

User Manual

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1 Basic Structure of Polysun, User Help

1.1 Getting Started

Welcome to Polysun!

This user manual provides technical background information and an overview of the main instructions to be followed to correctly operate this program. Additional useful information can be found in the Polysun videos; clicking on the title of the video you will be guided directly to our  YouTube channel. For further information do not hesitate to contact your distributor.

If you are working with Polysun for the first time we recommend you to use the provided wizard which will guide you through the creation of a project from the selection of the location and a suitable system to the entry of consumer values all the way to the first simulation. Results available in different output formats are shown automatically. Further relevant information can be found in the chapter describing the Results menu. Finally the project may be further developed and edited in the Polysun main window.

Your Vela Solaris-Team wish you success in the use of Polysun!

1.1.1 Introduction to Polysun

Polysun is a software that enables users to effectively simulate solar-thermal, photovoltaic and geothermal systems. This manual provides users with extensive operating instructions that will allow them to profitably take advantage of the wide range of functions provided by Polysun. In the following pages of this handbook you will find detailed descriptions of the single components as well as comprehensive information on the models on which they are based. Technical issues on the use of Polysun are dealt with in greater detail in a separate document (this can be obtained directly from the software by pressing the F1 button).

Tip: for quick user reference most functions, buttons, etc have been fitted with exhaustive tool-tips. Simply place and rest the pointer on the required item to view a short description of the relevant item.

1.1.2 Management of Projects, Templates and System Diagrams

In Polysun the **project** defines the indications on the location and on the consumers of the solar energy system. It also contains diverse system diagrams. The project can be started from the menu Project – New Project or by means of the Project Wizard. You can save a project with the function Project – Save Project.

The **system diagram** defines all of the components and connections of the solar energy system. A system diagram can be created in the System Diagram – Create New System Diagram menu (at the Designer level), by means of the Wizard or, if a template is

visualized, with Add Template to Project. It is possible to simulate each system diagram individually and to visualize the results. The system diagram is always included in a project and can be only saved together with it. Normally different system diagrams are considered in order to make comparison and optimize the project.

Polysun makes available a series of pre-defined **templates**. The template defines (as the system diagram) a solar energy system. The templates can be inserted into the project.

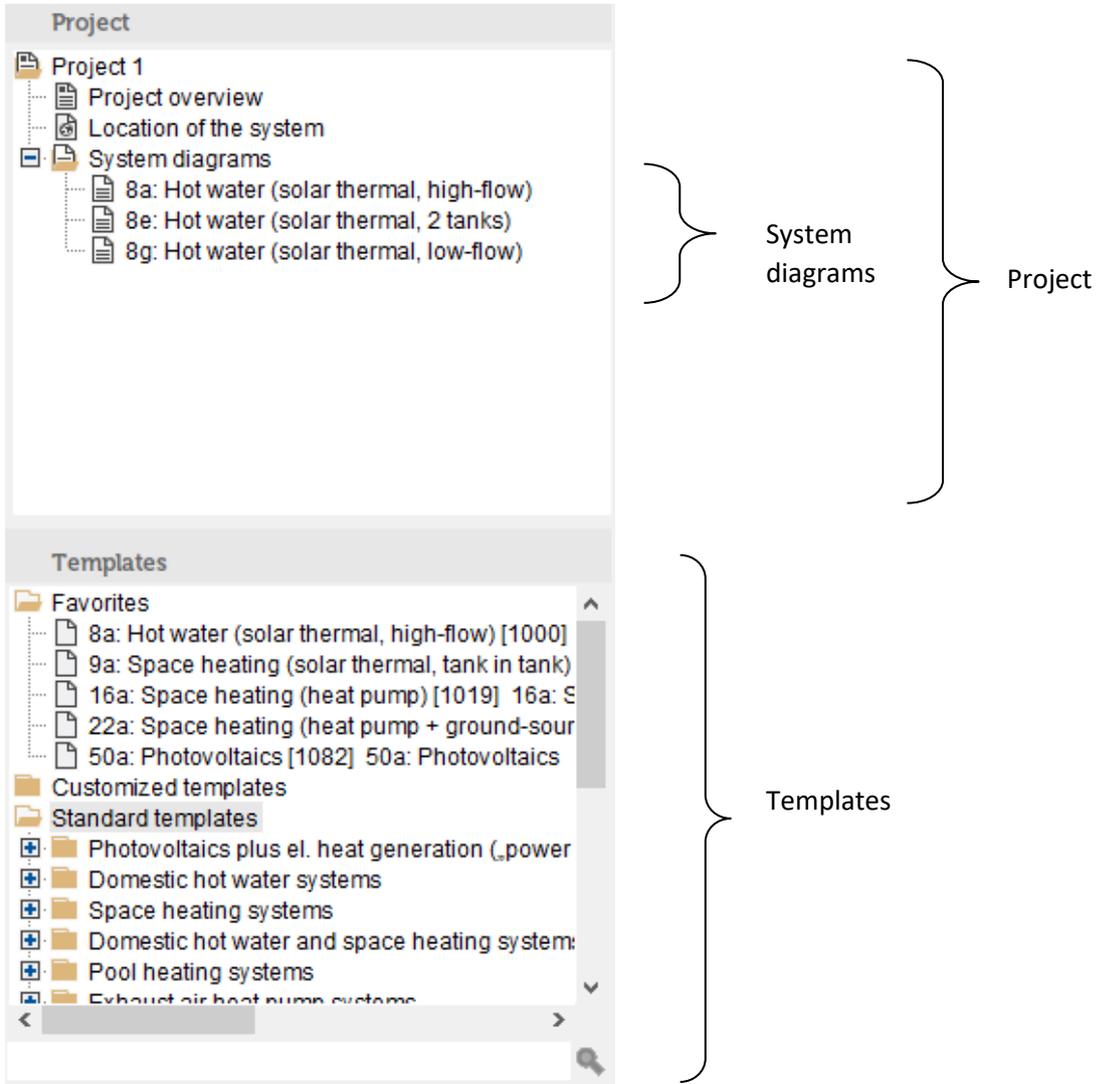


Fig. 1: project-tree and templates

1.2 Polysun Menu Bar

The Polysun menu bar shows the following main menus: Project, System Diagram, Results, Catalogs, Options and ?; these are described in greater detail in the following pages.

1.2.1 Project

A project includes all data required for a simulation. A project can be created, for example, for a house for which the user defines a location and the relevant consumer values creating, however, multiple system diagrams.

For further information check chapter 1.4 “Wizard”.

1.2.1.1 New Project

First step towards the creation of a project with no assistance from the Wizard. Name project and confirm with OK.

This command can be selected either from the Project menu or right-clicking the name of an existing project. In the latter case the existing project will be closed. If the project has not yet been saved Polysun will prompt the user to save the existing project.

1.2.1.2 Open Project

This command allows the user to open Polysun projects in *.pse format.

This command can be selected either from the Project menu or right-clicking the name of a running project. In the latter case the running project will be closed. If the project has not yet been saved Polysun will prompt the user to save the running project.

The software does not allow two projects to be opened at the same time. However the user will be able to run two different Polysun installations in parallel on the same PC by naming the relevant installation directories with different names. In this way the user will be able to work on two projects at the same time.

1.2.1.3 Close Project

This command can be selected either from the Project menu or right-clicking on the project's name.

Before unsaved Polysun projects are closed Polysun prompts the user to save the project.

1.2.1.4 Save Project/Save Project as

This command can be selected either from the Project menu or right-clicking on the project's name.

This command allows the user to save Polysun projects as *.pse file.

1.2.1.5 Rename Project

This command can be selected either from the Project menu or right-clicking on the project's name.

Rename project and confirm with OK.

1.2.1.6 Load Photograph of Property

Here the user can upload an external photograph available in *.jpg, *.gif or *.png format. The picture will then appear in the Project overview and in the PDF-Reports.

1.2.1.7 Print

The selected page will be shown as a PDF file (see chapter Print).

1.2.1.8 Close

This command allows the user to close Polysun.

1.2.2 System Diagram

A system diagram is a system scheme which can be simulated through the settings available in the dialogue boxes of the single components associated with other project data such as location and consumer. A project may include any number of system diagrams.

1.2.2.1 Create New System Diagram

This function (available only in the Designer version) allows the user to create an altogether new system diagram starting from a completely empty page. For further details see chapter Working with Designer.

1.2.2.2 Add Template to Project

To add a template to a project select the desired template (highlight in pink) directly from the template collection shown in the bottom left corner. After naming the system diagram and confirming with OK the template becomes a new system diagram, i.e. is linked to other specific data projects.

1.2.2.3 Rename System Diagram

To do so select the system diagram (highlight in pink) that is to be re-named. Then two options are provided:

- a) Click on “Rename system diagram” in the System diagram menu;
- b) Right-click on system diagram name and select “Rename system diagram”.

In both cases enter new name and confirm with OK.

1.2.2.4 Copy System Diagram

To do so select the system diagram (highlight in pink) that is to be copied. Then two options are provided:

- a) Click on “Copy system diagram” in the System diagram menu;
- b) Right-click on system diagram name and select “Copy system diagram”

In both cases enter name of copy and confirm with OK.

Tip: if two systems only differing in one or two settings are to be compared to one another you may want to create first a new system diagram, copy it and finally only change the desired settings in the copy. Simulation results can be thus compared meaningfully being ensured that all remaining settings are equal.

1.2.2.5 Delete System Diagram

To do so select the system diagram (highlight in pink) that is to be deleted. Then two options are provided:

- a) Click on “Delete system diagram” in the System diagram menu;
- b) Right-click on system diagram name and select “Delete system diagram”

In both cases confirm with Yes.

1.2.2.6 System Diagram as Reference

A system diagram should be set as a reference if two system diagrams are to be compared to one another in a diagram. Proceed as follows:

- Select and copy a system diagram.
 - Make changes in the component dialogue boxes of the new system diagram.
 - Set a system diagram as a reference. To do so select the system diagram (highlight in pink) that is to be set as a reference. Then two options are provided:
 - Click on “System diagram as reference” in the System diagram menu
 - Right-click on system diagram name and select “System diagram as reference”
- In the Result menu call-up the Result overview for the original blue-marked system diagram. The system diagram is simulated.
- Simulate the reference system diagram. Confirm the related message with OK.
- The Result overview will be displayed together with two data sheets. Some of the callable diagrams show both systems in comparison with one another.

Tip: it is always advisable that the more energetically unfavourable system diagram be set as a reference.

The reference system diagram may be restored to a normal system diagram either by clicking again on System diagram as reference or selecting a different system diagram as a reference. In a project only one system diagram may be set as a reference at the same time.

1.2.2.7 Comment on the System Diagram

Here the user will be able to enter and confirm with OK a comment on the system diagram. This comment will be shown on the Project overview page and in the PDF-Reports.

1.2.2.8 Save System Diagram

The image of the system diagram referring to the selected (highlighted in pink) system diagram can be saved as a *.png file.

1.2.2.9 Print System Diagram

The system diagram referring to the selected (highlighted in pink) system diagram can be shown as a PDF file. (see chapter Print).

1.2.2.10 Zoom System Diagram

The system diagram of the selected (highlighted in pink) system diagram may be zoomed in or out. You may want to zoom in on the system diagram in case of systems consisting of a large number of components as basic settings will not allow them to be completely shown on screen.

Tip: hold the Ctrl button pressed and roll the mouse wheel to zoom in or out.

1.2.3 Results

Simulation results will be shown for the currently selected system diagram. Results may be called-up either from the Results menu or clicking the  button (Display selection of results) located on the upper part of the window.

Further information on the meaning of the single values can be found in the User manual in the Simulation results chapter.

Attention: for the results to be displayed a system diagram must always be selected (highlighted in pink). The user will then be able to call-up the desired view from the Results menu. If since the last simulation data were edited or a dialogue box was opened and data were confirmed with OK the software will repeat the simulation process for the system diagram. If no data were edited or newly confirmed the results will be displayed directly.

If the system was incorrectly defined error messages will be displayed either during or after the simulation. The message Energy demand not met indicates that the calculated energy demand is not met in a considerable number of steps, i.e. the system cannot often rely on the amount of energy required to meet the calculated demand. A detailed analysis of component results will cue the user in on the possible source of error. In most cases components turn out to have incorrect settings. Tip: review settings in the templates and compare them with your settings. For further details see the User manual in the chapter “Controllers”.

The results may be displayed in different formats. Depending on the different user levels not all tables and graphs are available.

The following applies for all result display formats: Click the  button (Print) to display a PDF file (see chapter Print). Click the  button (Export results) to save results as a *.txt file.

Tip: selecting the heading of the respective data sheet (the data sheet title will be framed in red) and pressing the Ctrl and C buttons results will be copied to the clipboard; from there they may be later entered in a different program such as Microsoft Excel.

1.2.3.1 Results Overview

The results overview enables the user to get a first idea whether or not the system was correctly defined. Only the most significant results are displayed; annual values are presented in a tabular format. The values appearing in the selected lines are displayed down below as a bar graph.

The result overview takes on a particular meaning if two systems appearing in a diagram are to be compared with one another. To this end set a system diagram as reference.

1.2.3.2 System Results

Here the monthly values referring to the entire system and the single current and fluid loops are displayed both in tabular format and as a bar graph. This display provides the user with an excellent overview of the most significant values.

1.2.3.3 Component Results

Here the monthly values referring to the single components are displayed both in tabular format and as a bar graph (always the values included in the lines selected within the table). This view proves very useful in analysing the functionality of the different components and searching possible sources of error.

1.2.3.4 Tabular Evaluation

This comprehensive table (available only in the Designer version) displays the hourly values of all components.

Tip: clicking on the  button (Display selection window) a folder for the single components will be displayed. Double-click on the desired components. Finally select a value and confirm with OK. The table shows the corresponding columns.

1.2.3.5 Graphical Evaluation

This function enables a detailed and customised graphical evaluation of simulation results to be displayed. Proceed as follows:

- Select week or month.
- Click button „Add curve“.
- A window showing the folder tree for the single components is displayed. Double-click on the desired components. Finally select a value and confirm with OK.
- A curve showing the hourly values referring to the components selected for the indicated period is displayed.
- Further curves can be added for data comparison purposes.
- Selected curves (highlighted in pink) may be deleted with button “Delete curve”.

Shift Curves and Optimize Scaling

Using the  and  buttons, curves can be shifted, and the scaling can be optimized, respectively. Tip: vertically improve scaling if curves run over the lower edge of the graph.

Week or Month

The shorter the selected period, the more precise will be the graphical representation of hourly values. The software is unable to display a detailed annual curve as the graph does not have enough pixels to display all values.

Tip: zoom in on the graph to gain even more insightful data. To do so hold the left mouse-button pressed and draw a square over a portion of the curve from the top left corner to the bottom right corner and release the mouse button.

Units and Axes

The graph has two vertical axes. This allows curves with up to two different units to be meaningfully compared with one another. The respective reference axis may be changed by clicking  in the Axis column.

Colours and Lines

The user will be able to customise the graph choosing from a wide range of colours and lines. Colours and lines can be edited with a simple click.

Save Graph

Clicking the  button (Save graph) the selected graph can be saved as a *.png file.

1.2.3.6 Fluid Overview

The folder tree displayed by selecting this view shows which heat transfer fluid flows through which loop and the components the relevant loops consist of.

The fluid can be changed with the  button (Change heat transfer fluid).

1.2.3.7 PDF Reports

Different PDF reports differing in level of detail are available depending on user level (see chapter [Print](#)).

These reports provide an ideal tool to present results to customers. Reports should be created only when the user is satisfied with simulation results and has already reviewed them in the other available output formats.

1.2.4 Catalogs

Polysun provides for all system components separate catalogs (databases) in which products are listed in tabular format together with the relevant specific data. Catalogs include both anonymous component examples as well as products available on the market for which an indication of the manufacturer or the testing institute is provided.

1.2.4.1 View Catalog Entries

Catalogs can be viewed either directly from the Catalogs menu or through the component dialogue box. The  symbol refers to catalogs: double-clicking on the product name appearing next to the symbol will open the related catalog.

Many catalogs are hierarchically sorted; i.e. they contain sub-catalogs marked with the  symbol.

Tip: pausing with the mouse on a given column tool tips will be displayed providing useful information on the respective values. Column width can be adjusted using the mouse in the header.

Depending on the different user level not all catalogs are available.

1.2.4.2 Use Catalog Entries

Catalog entries may be only used by means of the respective component dialogue boxes. Should a product be replaced with another in a system diagram the relevant component of the existing system diagram should be double-clicked in the working area. A dialogue box will open. Proceed then as follows:

- The  symbol refers to the existing catalogs. Double-click the product name appearing next to it to open the corresponding catalog.
- Select the desired product. The selected line is highlighted in pink.
- Confirm with Accept.
- The catalog shuts down and the selected product is displayed in the dialogue box. Adjust further settings if required.
- Confirm settings with OK. The dialogue box shuts down.

Tip: the desired catalog entries can be found more rapidly using a filter. Clicking the blue header the values appearing in the relevant columns are sorted alphabetically and numerically. This makes catalog reading easier. Attention: the sorting process will take a few seconds to complete in case of particularly large catalogs (e.g. location catalog).

1.2.4.3 Create Catalog Entries

The creation of new catalog entries will essentially require the amendment of existing catalogs. Tip: it will be helpful to search for and amend an entry that is closest to the one you wish to create.

- Select an existing entry. The selected line is highlighted in pink.
- Copy the selected line with the  button (Copy selected line).
- Enter a name for the new catalog entry. Confirm with OK.
- Enable the copied line to be edited by pressing the  button (Edit selected line). The relevant line should appear in red.
- Make changes directly in the relevant fields and confirm either with the Enter button or with Accept.

Polysun Video



[New catalog entries](#)

1.2.4.4 Delete Catalog Entries

The user will be able to delete only catalog entries he/she previously defined. To do so proceed as follows:

- Select an entry you previously created. The selected line will be highlighted in pink.
- Click the  button (Delete selected line).
- Answer the “Should the selected line be deleted?” question with Yes.

1.2.5 Options and Help

1.2.5.1 Settings

Project

Here the user will be able to decide whether (after it is started) Polysun should automatically open the wizard, the latest project or a standard project. A standard project can be selected by clicking on the  button.

Simulation

Should the reference system diagram be simulated upon confirmation, without confirmation or never be simulated?

The preliminary simulation ensures that on simulation start (January 1st) a realistic situation is provided; the system has already been run in and it was not only put into operation at the turn of the year.

Reports

PDF-Reports will show the entered company name, e-mail address and telephone number as well as name and address of license holder. Clicking the  button you may

select your own company logo that will likewise appear in the PDF-Reports. In case of relocation the license holder's address can be changed collecting the license again (see paragraph Add license).

Display

A variety of settings can be adjusted here including the automatic search for updates, the display of Tool Tips, language, units and currency.

1.2.5.2 Add License

Should a license be added or renewed, e.g. after your Polysun subscription has been renewed, user-ID and e-mail address should be entered here like when the license was first released. Review your information for accuracy on the ensuing page. It is important that the entered information is correct as it will appear on all reports and your license will be registered using such information. Collect your license again and edit your information if you have relocated or changed your e-mail address.

A working Internet connection is required to collect the license. Ensure that the same network cards are always activated (possibly not a wireless network-card) when collecting your license and operating Polysun.

1.2.5.3 Subscription / Upgrade

If your Polysun subscription has expired or your wish to upgrade your Polysun (e.g. from Professional to Designer) here, you will be able to order all required products. Do not hesitate to contact your distributor any time. When your subscription has been renewed you can renew your license under Add license.

1.2.5.4 Support and Help

This chapter covers the '?' menu.

1.2.5.5 User Manual

The user manual provides you with technical background information and essential support in the use of Polysun.

1.2.5.6 Support Website

This link takes you to the website of Vela Solaris where you will be able to find an answer to the most frequently asked questions on Polysun (FAQ Frequently Asked Questions).

1.2.5.7 Support Request

Should you not find an answer to your questions in this Guide, in the User manual or in the FAQ your distributor will be delighted to help you find a solution. In this dialogue box you can read your distributor's contact information as well as your user number (User-ID); you should provide this information for each request.

Click the  button (Create support file) to create a support file to assist your distributor in finding out a solution to your problem. After clicking the button a message shows you the directory path where the file was stored.

1.2.5.8 Info

Here you will find information on the copyright and the different Polysun partners. Your information is stored under License. Should you forget your user-ID you will be able to read it here anytime.

1.3 Polysun Main Window (Graphical User Interface)

Polysun's graphical user interface is essentially divided into three parts: on the top left are the project data, on the bottom left is the template collection; the working area is on the right-hand side. The parting lines between the above areas can be easily moved using your mouse so that the main window can be adjusted to fit the needs of all users.

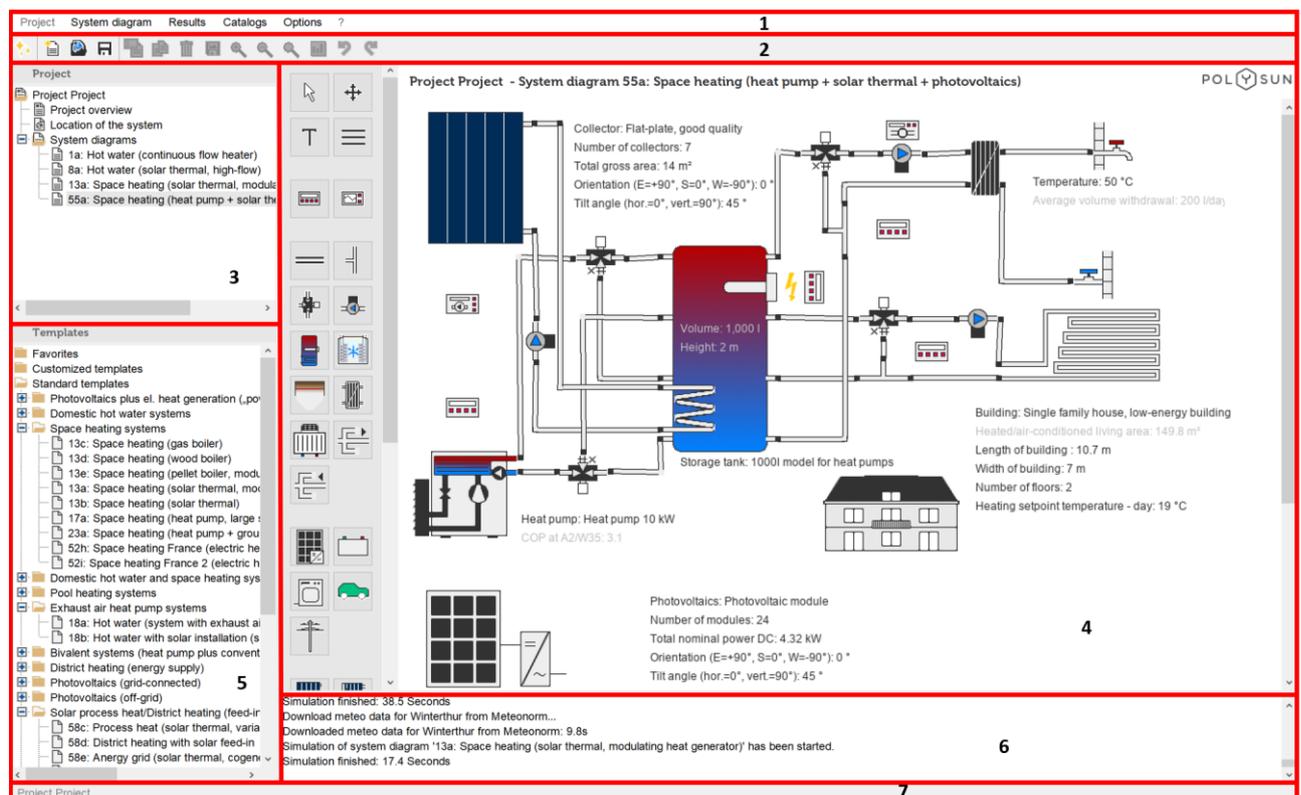


Fig. 2: Polysun Graphical User Interface

1. Menu bar
2. Toolbar
3. Project data (folder tree)

4. Working area
5. Template collection
6. Console (status window)
7. Status bar

1.3.1 Project Data

1.3.1.1 Project Overview

Photograph of Property

Right-clicking on the field in the top left corner you will call-up the “Load photograph of property” command. Confirm with the left mouse-button to upload external photographs available in *.jpg, *.gif or *.png format. To delete a picture from the project overview right-click on it and select “Remove photograph”.

Comments on the Project

Here you will be able to enter comments that are of some interest for the relevant project.

System Diagrams

This field contains a list of the system diagrams you already created. Selecting a system diagram (highlighted in blue) the comments you entered on the system diagram appear in the field on the bottom right. These can be edited from the System diagram menu (Comment on the system diagram).

1.3.1.2 Location

Location

A location may be either selected from the database or found on “openstreetmaps.com”. This will require an active Internet connection.

Weather Data

By clicking on “from location”, the weather data referring to the selected location will be calculated according to Meteotest.

By clicking on “from file“, the data of a file will be extracted together with hourly values saved in the application folder of the Polysun installation. For further information please open the catalog “Profile”.

Tip: by typing in the first letter of the desired location name in the location selection list the software will automatically go to the first location name starting with the typed in letter. Typing then the remaining letters of the name the software will search for the location name that comes closest to the entered sequence.

Horizon

Use the slide controls to display a graphical representation of the position of the sun for the selected location for every hour and day of the year. The yellow curve represents the solar ecliptic on the selected day. The red line is the horizon that can be drawn in the chart by clicking the graph or entering the exact horizon points. Tip: multiple values

(separated by a semi-colon) may be added from the clipboard directly to the table using the Ctrl-C buttons.

1.3.1.3 System Diagrams

Here a list is displayed of all project system diagrams. The system diagram currently selected (highlighted in pink) will be displayed in the working area.

For further details on how to create system diagrams see chapter System diagram (Polysun menu bar).

1.3.2 Templates

Polysun's template collection is shown in the main window's bottom left portion. Depending on the user level not all templates are available.

A template is a system scheme that becomes a system diagram and may be therefore simulated only after being copied to a project.

Templates are divided into three main groups (Vela Solaris, Special, Companies), consecutively numbered and sorted by category. Dragging your mouse over the list you will get a preview of the available system schemes. Templates may be directly selected off the list and copied to a project. Clicking them and confirming the related message (see also chapter System diagram, paragraph Add template to project).

Tip: use the wizard to make your search for the desired template easier.

1.3.3 Working Area

The working area takes up the largest part of the main window. The working area includes the Project overview, the location page as well as the system schemes of templates and system diagrams.

1.3.3.1 System Schemes

A system scheme displays all components of a system. In Polysun all components of a system diagram may be clicked on:

- Select a component by simply clicking on it; four dots appear around the component to confirm the selection (see also Working with Designer);
- Double-click to open the respective component dialogue box.

Attention: only components with a system diagram may be opened. Clicking on a template the user will be asked whether the template should be added to the project.

1.3.3.2 Component/Controller Dialogue Boxes

Dialogue boxes are the input windows displayed when the components of a system diagram are double-clicked. Dialogue boxes allow the user to:

- Adjust component-related settings;
- Open catalogs and possibly use other catalog entries or create new catalog entries for the respective components. The  symbol refers to a catalog. Double-click on the catalog entry appearing next to it to open the relevant catalog.
- Open a dropdown-menu. The  symbol refers to a dropdown-menu: click on the name appearing next to it to open the corresponding selection.

Double-click on a control to open a modified dialogue box. The above mentioned editing functions are available. A special time profile can also be loaded. To this end the availability times profile should be activated. Double-click on the profile name to open a catalog menu

In the User manual you will find comprehensive instructions on how to select the right settings in the different component dialogue boxes.

1.3.3.3 Speed Buttons

The following buttons appearing (from left to right) at the top of the window can be used as “quick links“ to call-up, the different features from the menu:

-  Wizard
-  New project
-  Save project
-  Open project
-  Copy system diagram
-  Rename system diagram
-  Save schematic system diagram
-  Delete system diagram
-  Zoom schematic system diagram
-  Preliminary simulation

1.3.3.4 Status Window

All simulation procedures are logged in the field appearing under the working area. The command Copy message area in the Options menu allows messages to be copied. The command Delete message areas in the Options menu allows all messages to be deleted.

1.3.3.5 Status Line

The status line is shown on the lower end of the window.

As soon as the project is saved the file name is displayed on the left-hand side in black characters. After a change has been made the characters turn grey to show that the current project was not yet saved.

If a system diagram was simulated the energy demand on the system is shown in black characters on the right-hand side. After a change has been made the characters turn grey to show that the value is no longer up-to-date and should be simulated again.

1.3.3.6 Polysun Component Symbol Bar (Designer Only)

In the Designer version a vertical bar showing the symbols of all system components is displayed on the left-hand side of the working area. Dragging the mouse over the different symbols the respective component names will be shown.

Components can be placed in the working area as follows:

- Click on the desired component.
- Click on the design area in the working area. The desired component will be placed in the working area.
- Double-clicking on the component previously placed in the working area a dialogue box opens and the components can be edited.

For further details on how to create a system diagram see chapter Working with Designer.

1.4 Wizard

In Polysun the project can be started by means of the Wizard. The Wizard is a helpful and user-friendly tool, which assists the user to size the system according to the requirements step by step. The procedure is straight-forward, you need to go from one tab to another filling in the required parameters.

The Wizard opens automatically after starting Polysun or it can be chosen by clicking on the Wizard icon (first button on the left of the icon bar).

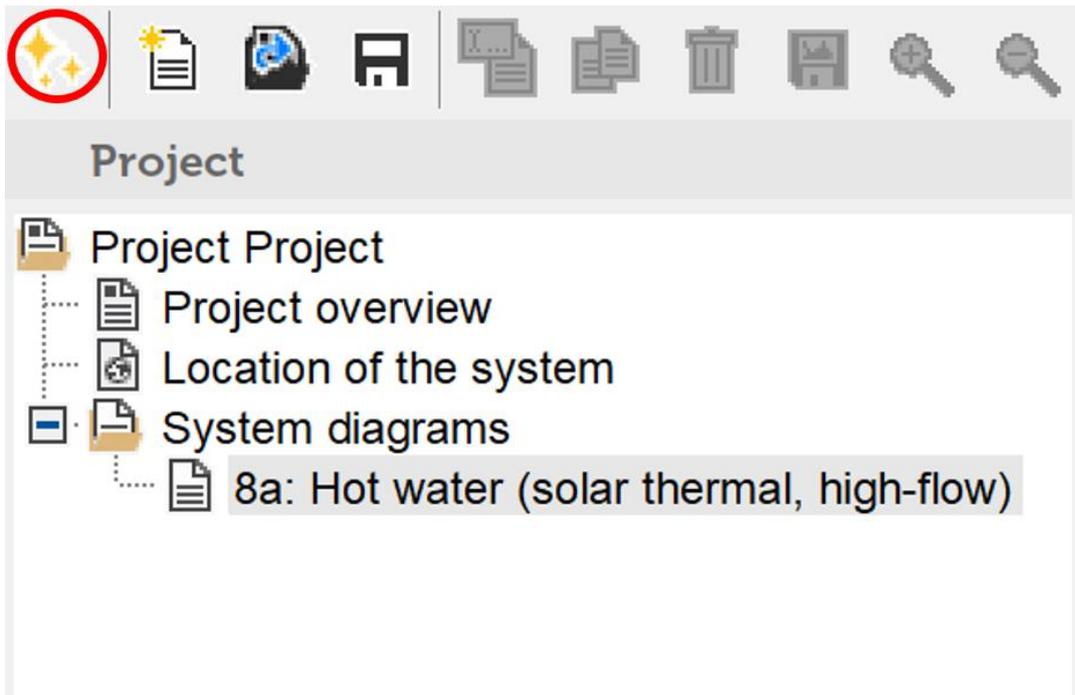


Fig. 3: Wizard icon

First choose a name for the project. A brief description of the project may be added. Next you will have to select the 'Location' of the system. The location can be chosen from the database or from the map. However, not all of the locations can be found on the map by entering the name in the field of the 'Search' option. In this case you would have to look for them manually on the map. Hint: if the message "No coverage" (Warning 191/24) appears, then it refers only to the natural horizon, the weather data are still interpolated and the location can be simulated.

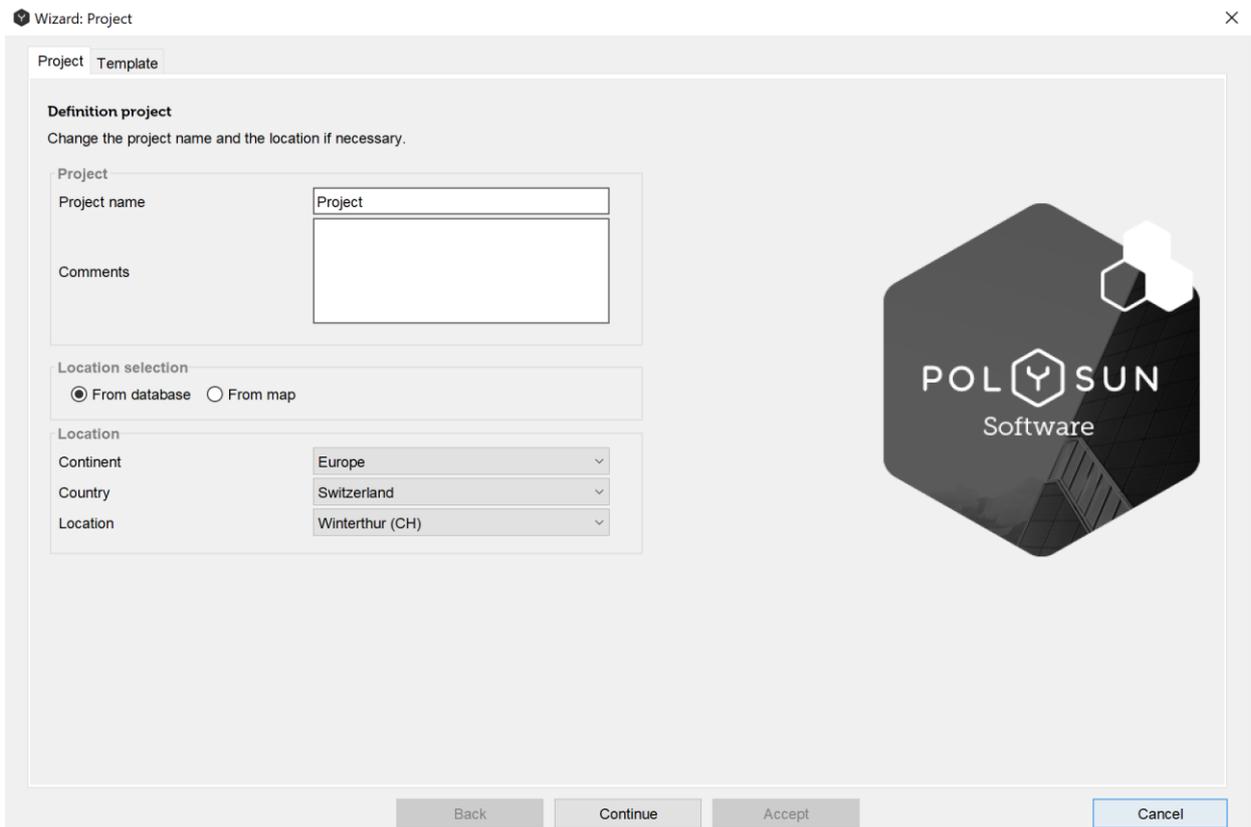


Fig. 4: project definition in Wizard

When the 'Location' has been defined, click on the 'Continue' button to proceed to the next step.

In the next dialog window you can choose a corresponding template by choosing the required energy providers, energy consumers/loads and system specification.

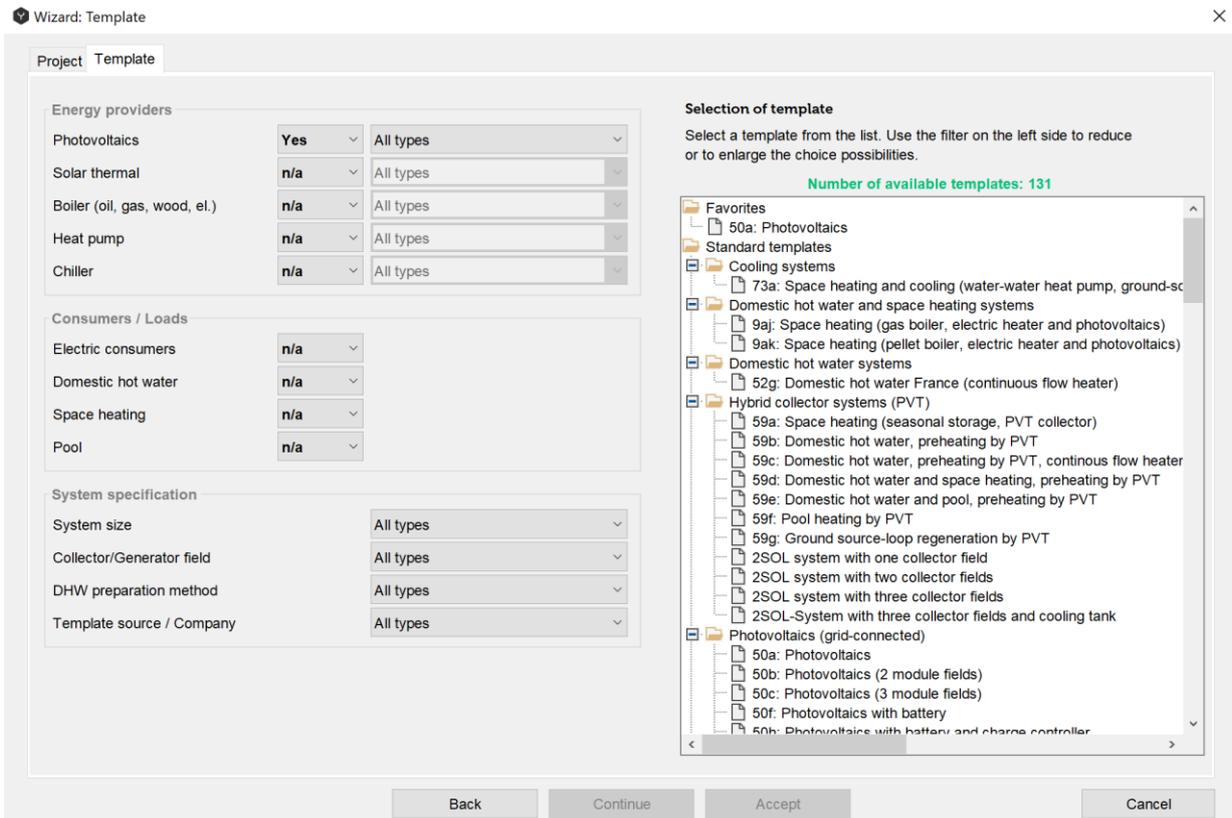


Fig. 5: selection of the template

In the drop-down menus you can first choose which energy providers your project should contain. Here you can choose one or more types of technologies (for example solar thermal and a heat pump).

'Yes' means this energy provider must be in the system.

'No' means this energy provider must not be in the system.

'N/a' (not applicable) means that this type of energy provider is not a criterion for the selection of the system (the list will show systems with and without this component).

Wizard: Template

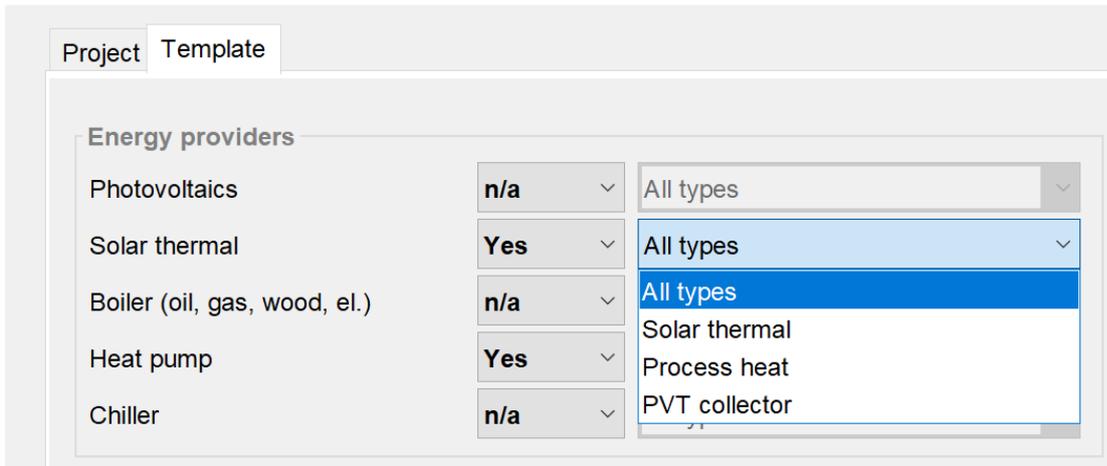


Fig. 6: definition of the energy providers

Next you may define the type of energy provider or providers, which were chosen previously. The following types of energy providers are available:

Table 1. Types of energy providers

ENERGY PROVIDERS	TYPES
PHOTOVOLTAICS	- Photovoltaics - PVT Collector
SOLAR THERMAL	- Solar thermal - Process heat - PVT Collector
BOILER (OIL, GAS, WOOD, EL.)	- Boiler (furnace) - Continuous flow heater
HEAT PUMP	- Air-water heat pump - Ground water loop+heat pump - Ground-source loop+heat pump - HP system module
CHILLER	- Compression - Adsorption - Absorption - Passive

In order to have a greater choice of templates, both boiler and heat pump can be chosen as a possible option (setting “n/a”), because the boiler can be later on substituted by an air-to-water heat pump without having to modify the system.

The following consumers/loads are available:

- Electric consumers
- Domestic hot water
- Space heating
- Pool

As a next step, system specification shall be defined as follows:

Table 2. Types of system specifications

SYSTEM SPECIFICATION	TYPES
SYSTEM SIZE	- Residential system - Commercial system
COLLECTOR/GENERATOR FIELD	- Single field - Several fields
DHW PREPARATION METHOD	- Potable water tank - Fresh water station - Immersed coil or tank
TEMPLATE SOURCE/COMPANY	- All standard templates - All company templates

Then the templates will be shown on the right side of the dialog window filtered in accordance to the defined parameters. The pre-view of the template will be displayed, when you hover the mouse cursor over the template line. You can choose the most appropriate template by double-clicking it.

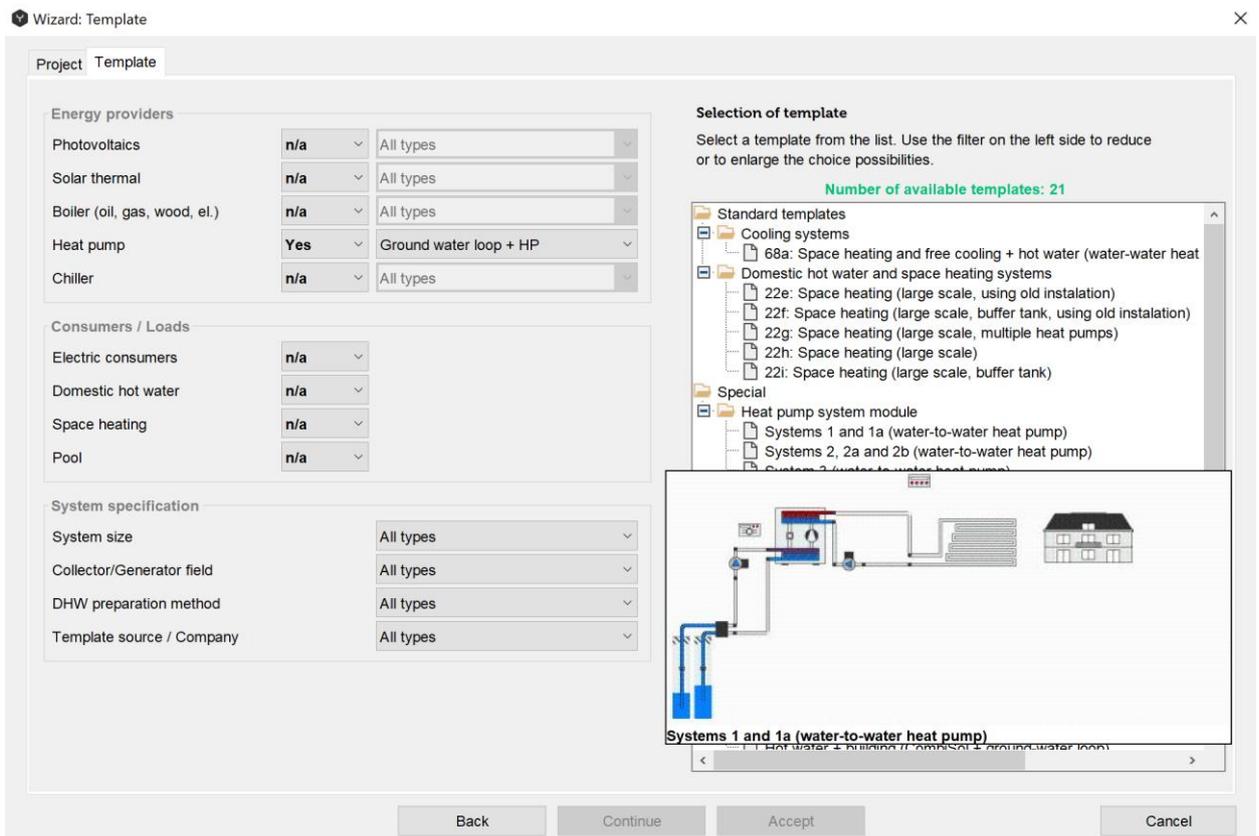


Fig. 7: displaying the templates

Solar Thermal System Wizard

In this chapter it will be explained how to use the Wizard in order to design a solar thermal system. Other types of systems, such as systems with PV modules or a heat pump, are described in the chapters concerning these particular components.

When a template is chosen, the Wizard will open the new tabs, which are relevant for this particular type of technology.

The next tab for solar thermal systems is defining the hot water demand.

Wizard: Hot water

Project Template **Hot water** Building Solar Heat generator

Hot water demand
You have selected a system with hot water. Now define the energy demand.

Domestic hot water

Computation base: Hot water demand

Number of persons: 4

Temperature [°C]: 50

Is the annual demand known?: Yes No

Daily hot water demand [l]: 200

Absences: Never

Back Continue Accept Cancel

Fig. 8: definition of the hot water demand for solar thermal systems

First, as a computation base can be chosen either hot water demand or end energy demand.

For the hot water demand the following parameters have to be specified:

- Number of persons to estimate the hot water demand. However, it is not necessary to state the number of persons, the daily hot water demand can be written directly in the tab-sheet, more detailed settings (e.g. daily profile) can be done later on;
- Required temperature for the hot water withdrawal. If this temperature is not reached, then a deficit will be calculated;
- Hot water demand can be estimated with a daily hot water demand or withdrawal energy for the whole year (in this case a hot water profile can be chosen from the catalog);
- Time of absences (during which there is no hot water withdrawal) can be chosen from the catalog.

For the specific end energy demand the following parameters have to be specified:

- Length and width of the building;
- Number of floors;
- Total heated/air-conditioned living area;
- Specific end energy demand is the end energy consumed by the user (for domestic hot water);
- Required temperature for the hot water withdrawal. If this temperature is not reached, then a deficit will be calculated;

When all parameters have been specified, press the 'Continue' button to proceed to the next tab-sheet.

In the next step of the Wizard, you can parametrize the building model.
The space heating can be estimated using the following parameters:

Table 3. Parameters of the building model

COMPUTATION BASE	DESCRIPTION
HEATING ENERGY DEMAND	<p>Total energy demand excluding DHW is a total energy demand of the building (without domestic hot water). If the fuel consumption is taken into account, it has to be multiplied by the boiler efficiency value (ca. 0.7)</p> <p>Energy losses transmission + ventilation are the total energy losses of the building through building envelope as well as ventilation/infiltration losses. This value is always bigger than the annual energy demand and may vary depending on the building type and climate. As a rule of thumb and for temperature climate zones, this value is usually 2-8 times bigger than the annual energy demand.</p> <p>Heating set point temperature is a comfort temperature set point which is generally between 19 and 22°C (66-72°F).</p>
FUEL CONSUMPTION	<p>Energy source shall be chosen, such as oil, gas, pellets, firewood, electricity.</p> <p>Annual consumption is a total energy heating demand of the building.</p> <p>Type of the heat generator: presumed efficiency for the new generator 85% presumed efficiency for the old generator 60%</p> <p>Heating set point temperature is a comfort temperature set point which is generally between 19 and 22°C (66-72°F).</p>
HEATING LOAD	<p>Maximum power demand is a heating demand at minimum ambient temperature.</p> <p>Heating set point temperature is a comfort temperature set point which is generally between 19 and 22°C (66-72°F).</p>
MONTHLY ENERGY DEMAND/LOSSES	<p>Heating energy demand excluding DHW is monthly heating energy demand Q_h of the building (excluding domestic hot water).</p> <p>Energy losses transmission + ventilation are monthly energy losses of the building through building envelope as well as ventilation/infiltration losses. This value is always bigger than the respective monthly energy demand and may vary depending on the building type and climate. As a rule of thumb and for temperature climate zones, this value is usually 2-8 times bigger than the respective monthly energy demand.</p>
BUILDING DIMENSIONS	<p>Building type can be chosen from the catalog.</p>

Heating set point temperature is a comfort temperature set point which is generally between 19 and 22°C (66-72°F).

The next step in the Wizard is dimensioning of the solar thermal system.

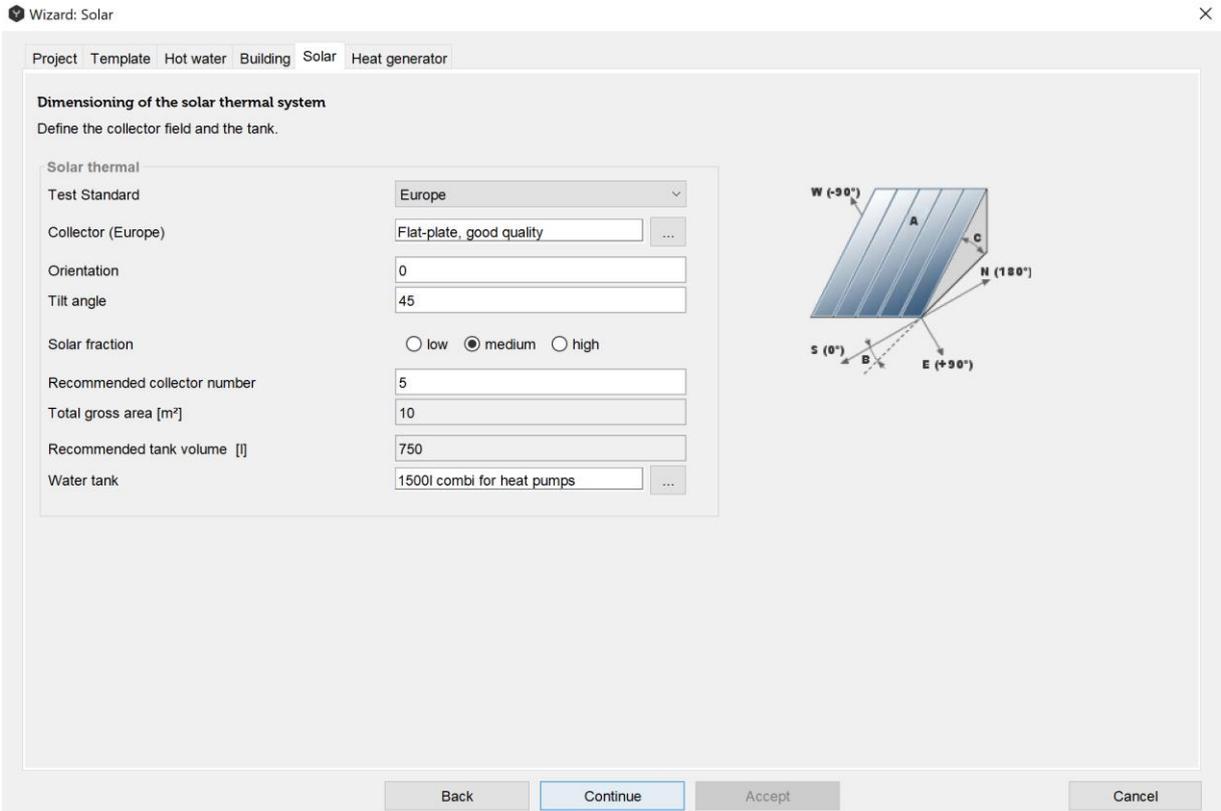


Fig. 9: Solar thermal systems design in Wizard

Table 4. Parameters of the solar thermal systems

PARAMETER	DESCRIPTION
TEST STANDARD	The collector standard can be chosen from the drop-down menu, such as: Europe, North America, China.
COLLECTOR ORIENTATION	The solar collector can be chosen from the catalog. Deviation angle from south (South is 0°, East is +90°, West is -90°, North is +/-180°).
TILT ANGLE	Angle between the collector tilt plane and the horizontal plane. A facade collector has a tilt angle of 90°. Advice: an ideal tilt angle for hot water systems corresponds approximately to the latitude of the location. In case of solar space heating systems the tilt angle should be steeper than the latitude. In order to chose the optimum tilt angle, the user can start from the latitude – 10% and then add tilt angles +/- 5-10° in order to make a comparison. The optimum tilt angle depends largely upon the seasonal climate of the location and consumption values of the system.
SOLAR FRACTION	Help to dimension the solar system. The ideal collector size and tank volume are defined according to the location, demand (number of persons live in the

	house) and collector orientation. According to the choice (low, medium or high) Polysun suggests different system sizes.
RECOMMENDED COLLECTOR NUMBER	Number of collectors per collector field. Polysun suggests collector number according to the selected location, template and loads, but it can be overwritten according to the system requirements.
TOTAL GROSS AREA	Total area of all modules. Largest projected area of collector field without fixing items and without hydraulic connections.
RECOMMENDED TANK VOLUME	The recommended tank volume for small-scale systems is 50-100 liter per square meter, respectively 2 gallon per square foot, for optimal oriented collector field. Tank size recommendation is not automatically simulated – only the selected tank in the next field will be simulated.
WATER TANK	Water tank can be chosen from the catalog. If a system with two tanks is selected, the Wizard will assist the user only dimensioning the solar tank, the back-up tank must be set manually by the user after having completed the work with the Wizard.

In the next tab of the Wizard the auxiliary heat generator can be dimensioned.

 Wizard: Heat generator

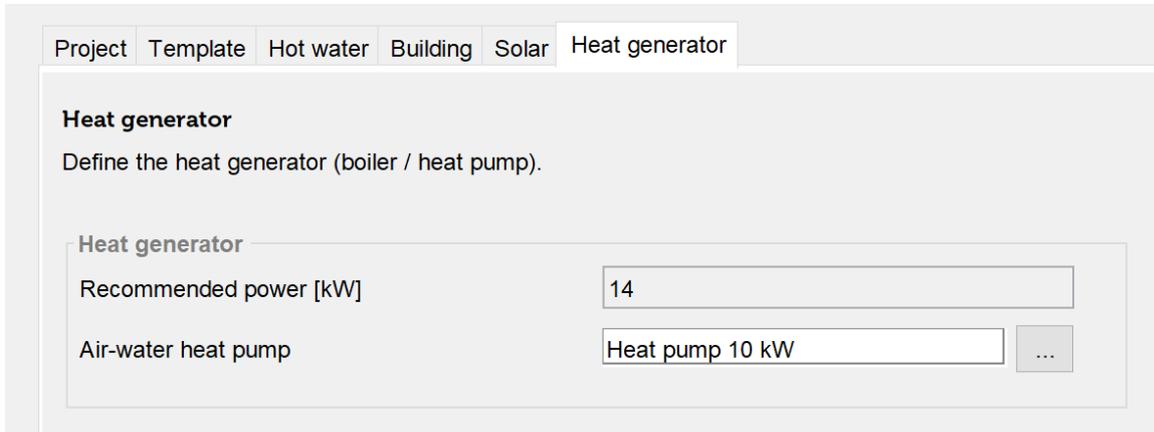


Fig. 10: dimensioning of the heat generator

First, the recommended power of the generator is given, which stands for an ideal design (it is not valid for flow-heater though). The necessary boiler power depends upon the hot water volume availability and the users habits.

Second, the boiler can be chosen from the catalog. The selected boiler will be simulated.

Clicking on the button “Accept” the settings are confirmed and the first simulation will be carried out automatically. The results can be checked and the system can be optimized manually in the Graphical User Interface.

Validation of the Photovoltaic Design

The Wizard includes a tab-sheet named PV validation. Polysun will check all parameters of the PV modules and the inverter for their compatibility. A green check sign symbolizes compatibility and a yellow exclamation mark a conflict between photovoltaic field and inverter. The following parameters of the inverter are checked:

- Minimum and maximum input voltage: describes the possible power range of the inverter on the DC side.
- Minimum and maximum MPP voltage: describes the possible working range of the MPP tracker.
- Maximum input current.
- Maximum system voltage.
- Minimum and maximum string fuse value.
- Maximum phase imbalance.

1.5 Weather Data

One of the first steps of the project design is the selection of the weather data. Polysun provides reliable yield forecasts for more than 8400 locations worldwide, but also allows reading meteo data from a file, calculating of hourly meteo data from external monthly values and obtaining the meteo data from the location through the internet from the Meteonorm webservice.

Polysun Video



[Meteorological data](#)

1.5.1 Location

The weather data dialog window can be easily accessed in the 'Geographical Location' in the project folder in the upper left side.

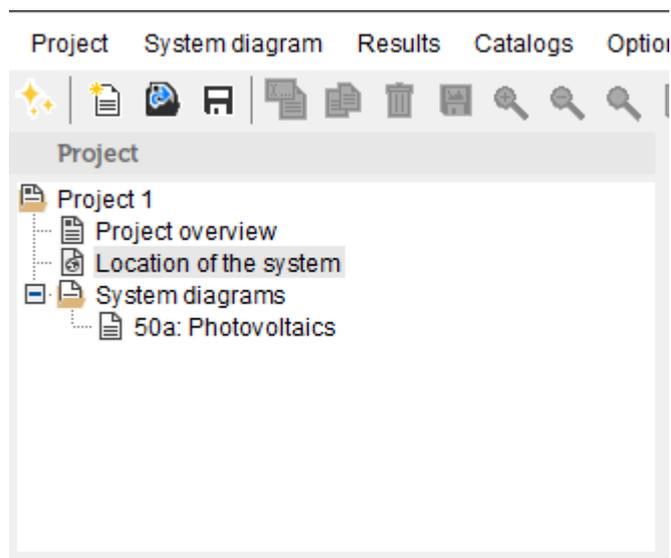


Fig. 11: defining the location of the system

A suitable geographical location can be chosen either 'from map' or 'from database'. In order to define the location from the database the following parameters shall be specified: continent, country and location of the system.

The map of the world is available at a resolution of 3 km. However, not all of the locations can be found on the map by entering the name in the field of the 'Search' option. In this case you would have to look for them manually on the map, the weather data will be interpolated.

The location of the system includes the continent, country and the city. You can also decide whether to apply 'daylight saving time option' or ignore it.

There are five options available for weather data: 'from location (according to Meteororm version 7.2)', 'from location (according to Meteororm version 6)', 'Profile', 'External monthly values' and 'Webservice'.

Project 1 - Site data POLYSUN

Location of the system

From database From map

Open map Daylight saving time ignore Site description Clear

Latitude [°]	Longitude [°]	Elevation [m]	Time zone [h]	Standard outdoor temperat...
47.23	8.82	417	1	0

Weather data

From location (according to Meteororm 7.2)
 Profile
 Webservice
 From location (1 h, according to Meteororm 6)
 From location (1 min, according to Meteororm 6)
 External monthly values

Horizon

East Azimuth [°] West

Fig. 12: location of the system

The option 'import weather data from Meteororm Vers. 6' can be chosen in order to calculate weather data for the given location by embedded Meteororm procedure.

For Meteororm version 6 the underlying measured weather data date from 1986 - 2005: the irradiance parameters date from 1986 - 2005, the other parameters from 1996 – 2005.

The option 'import weather data from Meteororm Vers. 7.2' can be chosen in order to use embedded weather profiles available for more than 7500 locations. For this option, the location has to be chosen from the drop-down list and not from the map.

The option 'Meteororm version 7.2' is recommended since it provides the more up-to-date data. The option 'Meteororm version 6' is kept for backwards compatibility reasons.

If the location has to be chosen specifically from the map, then the “webservice” option is recommended as it provides the most up-to-date data. However, in order to use “webservice” the internet-connection has to be provided.

For Meteonorm version 7.2 the irradiance parameters date from 1991 – 2010, for some countries from 1996 – 2015, all other parameters date from 2000 – 2009.

For more detailed information see www.meteonorm.com.

Besides the meteo data included in Polysun, many other sources are available. Thus, the option ‘Profile’ allows to import the meteo data from the file (with .CSV extension “Comma Separated Values”). In this case, the on-site measurements can be used. The software requires the following hourly weather data:

- Gh Global radiation [Wh/m²]
- Dh Diffuse radiation [Wh/m²]
- Lh Long wave irradiation [Wh/m²]
- Tamb Ambient temperature [°C]
- Vwnd Wind [m/s]
- Hrel Humidity [%]

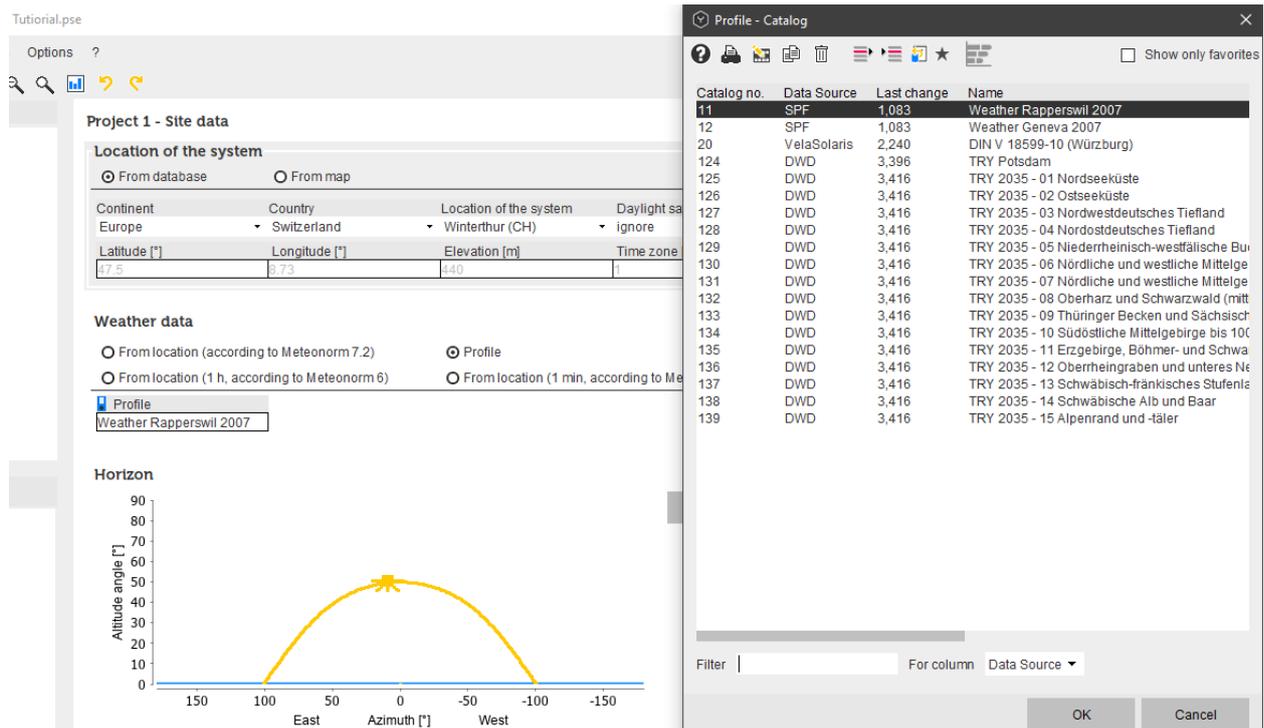


Fig. 13: selecting weather data from profile

It is possible to use one of the profiles available in the catalog. Please note, that importing the weather data from a file you need to select the same location under ‘Location of the system’ since the sun path is defined from location of the system.

You can also copy one of the available Meteorological data profiles with chosen name, open it and insert the available measured weather data in the corresponding column.

The option 'External monthly values' allows doing manual changes in the available monthly values. In this case the hourly meteo data is calculated from monthly values by embedded Meteonorm procedure.

Project 1 - Site data POLYSUN

Location of the system

From database From map

Continent	Country	Location of the system	Daylight saving time	Site description
Europe	Switzerland	Winterthur (CH)	ignore	<input type="text" value="Clear"/>
Latitude [°]	Longitude [°]	Elevation [m]	Time zone [h]	Standard outdoor temperat...
47.5	8.73	440		-12

Weather data

From location (according to Meteonorm 7.2) Profile Webservice
 From location (1 h, according to Meteonorm 6) From location (1 min, according to Meteonorm 6) External monthly values

User-defined weather data (Monthly values) ✕

Initial values are based on internal weather data for the chosen location.

Name	Unit	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
Global irradiation	kWh/m²	27.7	45.9	84.5	116	155	161	171	144	100	58.5	29
Outdoor temperature	°C	0.5	1.8	6	9.1	22.5	17.7	18.3	18.7	14.1	9.9	4.1
Wind speed	m/s	2.2	2.4	2.2	1.3	2	1.9	2	1.7	1.8	1.8	1.8

Background colour for user-defined values

Fig. 14: external monthly values of weather data

Polysun gives an opportunity to use newest weather data from Meteonorm 'Webservice'. This weather data is dynamic and changes according to the Meteonorm website. First you can choose the 'Webservice' option and then switch to the system diagram. In a matter of 10-15 seconds the console (Polysun log) will show that the weather data has been successfully downloaded.

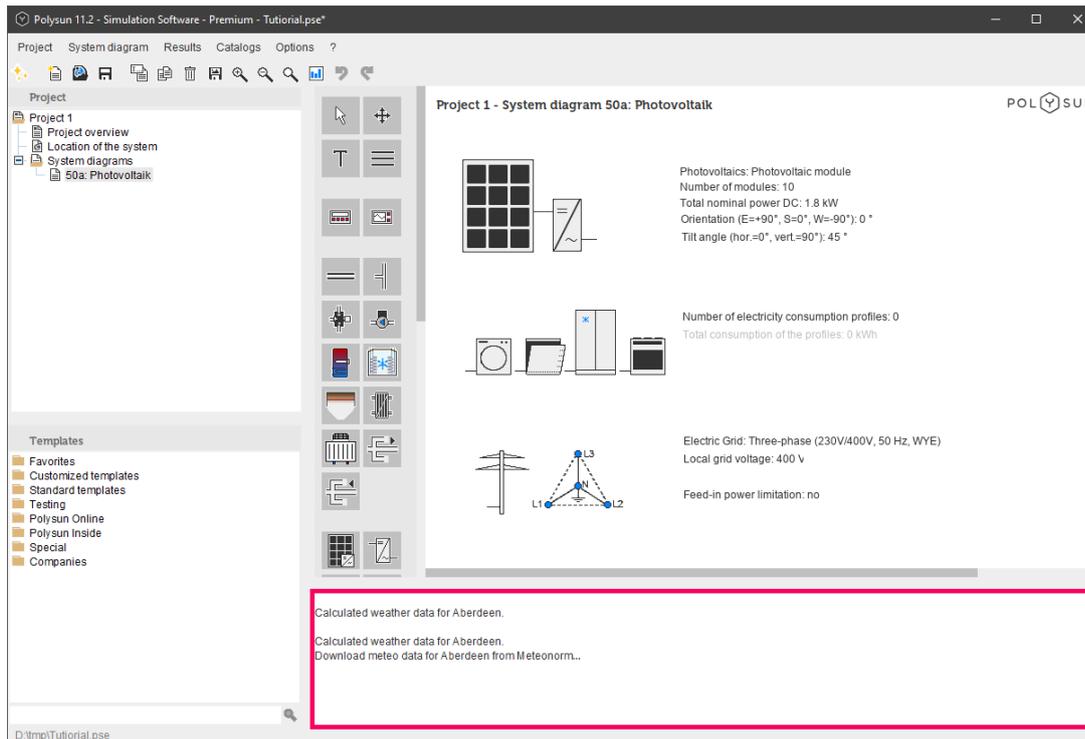


Fig. 15: Polysun log

1.5.2 Horizon and Shading

In order to make a precise calculation of the energy yield of a solar energy system, any possible shadow creating objects, such as adjacent houses, trees, mountains, etc. shall be taken into account. Shading obstacles have even bigger influence on the solar array's performance in winter months because of the low sun elevation. The shortest day of the year in the Northern Hemisphere, December 21st, can be used for shading calculation as a worst-case scenario.

The horizon profile as well as nearby obstruction and shadings can be simulated in the 'Horizon editor', which allows you to take into account the surrounding topography. The objects are taken into account based on distance and height. The dimensions of the objects are then reflected on the horizon line, allowing greater precision in site data entry and yield calculation.

In order to define the horizon, you can click on the location of the system, selecting the project location. The 'Horizon editor' can be opened by clicking on "Edit". The Horizon editor is divided into four parts. In the upper left part, there is a horizon line, which is indicated with the red line and the sun path, which is indicated with the yellow line. The sun path can be displayed throughout the year on a daily basis or during one day on an hourly basis by moving the sliding bars on the right side. If you go on the lower left part, there are obstructions and mutual shadings. In the 'Obstruction' tab you can enter a building or an object which is located near your PV module or solar collector. You can start by importing the profile of the horizon of the selected location. In order to do that we can click on the Meteonorm button and the horizon of the chosen location will be indicated with a red line. Then you can define the new object in the 'Obstruction' tab by indicating the distance to the object, the height of the object and the Azimuth angle to the left side of the object. In the 'Mutual Shading' tab Polysun offers a possibility for mutual sheds optimization. In this tool, you can define the location and the disposition of the PV module or solar collector area. The mutual shading depends on the shed orientation towards the

southern direction (a), the distance between the rows (d), tilt angle (α) and the height of the solar collector or a PV module (w), which cause the shading.

Then you can click on the button 'Add to Horizon' and the object and the mutual shadings will be added in the horizon line. The Horizon profile can also be adjusted manually by inserting azimuth and elevation angles in the bottom right part of the 'Horizon editor'. In order to delete all changes in the horizon profile, you can click the Reset button.

The Horizon profile can be also imported by a *.hor file from other tools and sources.

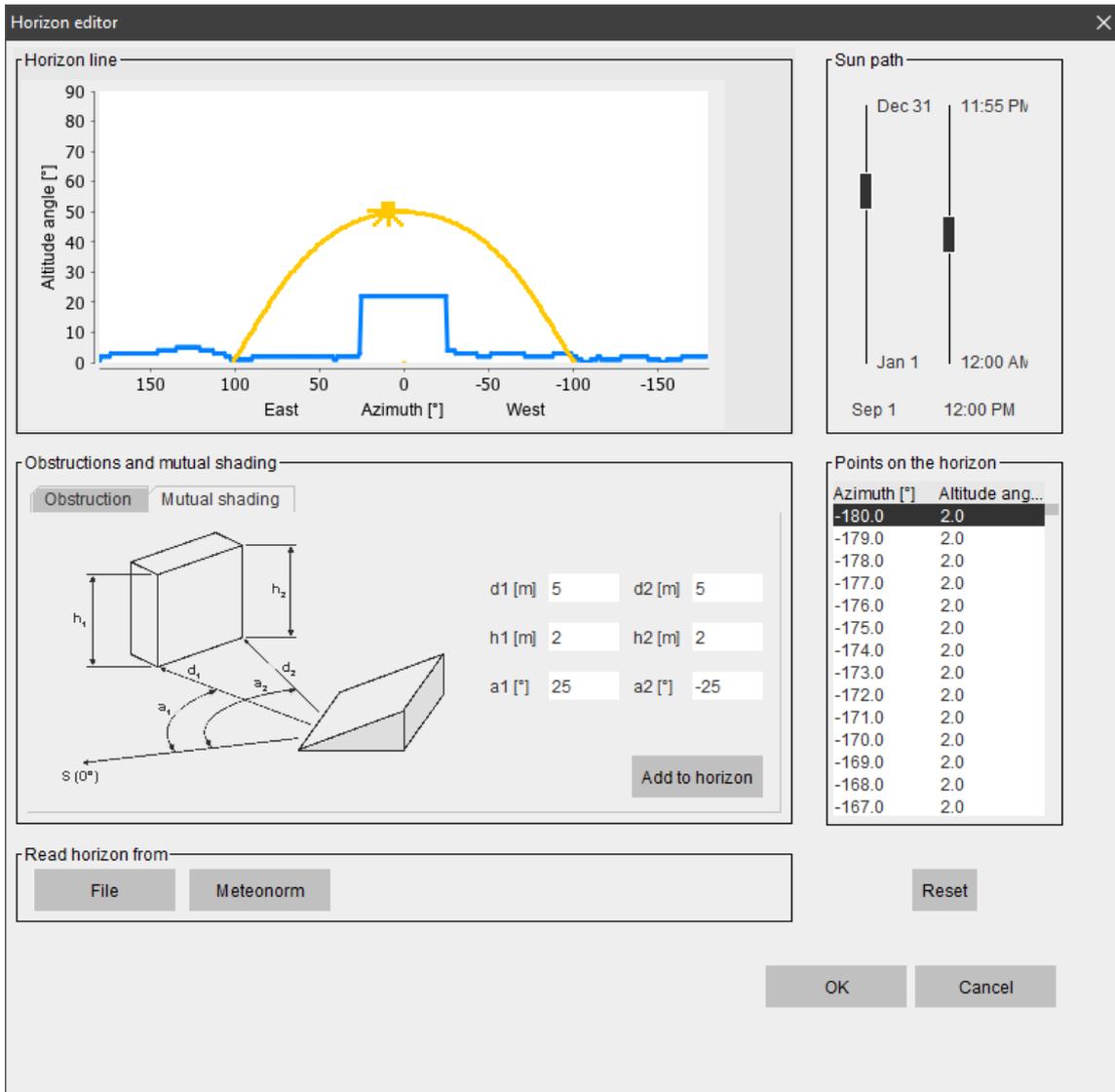


Fig. 16: defining the horizon and shadings in the horizon editor

Polysun Video

 [Nearby and row-to-row shading](#)

1.6 User Levels

Polysun Simulation software is available in two user levels: Designer and Standard.

Standard level of Polysun is a design and sales tool for daily use, super-easy to handle, generate professional sales reports with own company logo and address in an efficient and reliable way, allows to create a sales quote in a matter of minutes. Standard level of Polysun includes intuitive wizard-guided use and access to an extensive selection of manufacturer specific hydronic schemes and products. Standard level of Polysun is perfect for salespersons and installers.

Designer level gives the maximum flexibility for the design and sales of renewable energy systems of any size, allows exact modelling of hydraulics thanks to modularity of systems, templates for large-scale systems, process heat, district heating. Enhanced modularity and precision in the design of hydronic systems. Advanced inverter layout and shading simulation tool for Polysun PV. All features of Polysun Standard are included. Designer level of Polysun is a perfect tool for system designers, energy consultants, and development engineers for the comprehensive assessment of the system.

In the full version of Polysun all kinds of renewable energy technology are available, such as solar thermal, photovoltaics and heat pumps. Full version of Polysun allows combination of different technologies in one hybrid system. The possibility to design cooling systems is only included in the full version.

Besides the full version, the following modules of Polysun software are available:

Polysun Solar Thermal Simulation includes: Domestic hot water preparation, space and pool heating systems, worldwide weather data, huge hydronic template selection, updated collector catalogs (flat plate, tube, concentrating and unglazed collectors).

Polysun Heat Pump Simulation includes: Ground-source and ground-water loops, water-to-water and air-to-water heat pumps. Updated catalogs with certified heat pumps. Precise calculation of COP.

Polysun Photovoltaic Simulation includes: Updated module and inverter catalogs, worldwide weather data, shading simulation tool, state of the art inverter layout assistant.

It is also possible to combine two or three different modules with each other, in order to increase modularity and availability of the designed renewable energy system and therefore create an efficient and reliable solution for the customer.

1.7 Working with the Designer

The Designer version allows system schemes of existing system diagrams to be edited and enables the user to create altogether new system schemes.

1.7.1 Edit System Schemes

To do so the user should start from an existing template that he/she will add to the project as a system diagram (see Add template to project). The user can then delete components of the system diagram, add new components, connect components to one another and untie existing connections.

1.7.2 Add New Components

- Click the desired component in the component symbol bar.
- Click on the design area in the working area. The desired component will be placed in the working area.
- Double-click on the component you previously placed in the working area; a dialogue box opens and components can then be edited.

1.7.3 Select Components

Select a component by simply clicking on it; four dots appear around the component to confirm the selection. To select multiple components keep the Shift button pressed; select all components using the Ctrl-A buttons.

1.7.4 Move or Rotate Components

A previously selected component can be moved on the design area dragging it while holding the left mouse-button pressed. Keep the Ctrl button pressed to move the selected elements using the arrow buttons. Right-click on an element to display additional functions to adjust or rotate it.

1.7.5 Delete Components

- Select a component by simply clicking on it; four dots appear around the component to confirm the selection;
- Right-click on the selected component;
- Select Delete from the selection window – the component will be deleted.

1.7.6 Connect Components

- Click on the square connection of a component. The connection will be marked in red.
- Click on the connection of a different component. The two components will be connected.

Tip: if connecting two components that can only be joined by means of a pipe Polysun automatically displays the required pipe. This allows the user to design large systems in a time-saving and efficient manner. – To add a curve click on a given point of a pipe while holding the left mouse-button pressed.

1.7.7 Untie Connections

Double-click on existing connections (black dots) to untie them.

1.7.8 Create System Scheme from Scratch

The command Create new system diagram in the system diagram menu enables the user to create a system diagram from scratch starting with an empty page. Components can be added and connected as described above.

Tip: it is advisable to begin by editing existing system diagrams and reviewing default settings. The user should proceed step by step and carry out frequent simulations to better understand how changes are made.

1.7.9 Particular Features of Given Components

- Tank: if you wish to place a new tank you can choose between “Define a new tank” and “Choose a tank from the catalog”. This last option involves the selection of an existing tank from the catalog. Choosing “Define a new tank” a new window opens in which the tank can be configured. First the basic structure of the tank is defined. After confirming with OK the tank is displayed on the design area. Finally the tank can be further edited by double-clicking on it (see Polysun dialogue boxes and catalogs).
- Deleting a tank the temperature sensors are also deleted. When a new tank is placed the temperature sensors should be reset in the relevant controllers, i.e. the entries should be redefined.
- Controllers: when placing a controller the user should select the most suitable one. Here too it is advisable to take a cue from the default settings of the templates.
- Heat generator: boiler or heat pump, with or without integrated pump. Please ensure a flow-rate generator is available in the relevant loop.

Read by all means the comprehensive instructions on single components and controllers provided in the User manual.

Polysun Video



[Advanced Polysun example](#)

1.8 Updater

Polysun is regularly updated. Updates do not only refer to catalog data but also to software functionalities that are constantly extended. It is therefore advisable to always keep your Polysun updated to the latest version.

Users are entitled to free updates if they first picked-up their license or their latest subscription expired less than twelve months before. If your license has expired, you will be informed by an appropriate message. Renew your subscription or contact your distributor.

Choosing Look for updates in the first line (after Polysun has been started) under Display in the settings of the Options menu Polysun automatically checks for updates on the server. All you need is a working Internet connection.

If an update is available a message is displayed to inform the user. Proceed as follows:

- Download the update and close Polysun.
- Start the downloaded Polysun installer.
- Follow the instructions of the Polysun installer.
- If you have more than one Polysun installation, make sure the correct installation path is selected.

For further questions, please do not hesitate to contact your distributor.

2 Photovoltaics and Electric Components

Contrary to solar-thermal energy photovoltaics enable sunlight to be directly converted into electrical power. The so-called "photovoltaic effect" is brought about by means of a variety of semi-conducting materials including silicon, gallium arsenide, cadmium telluride or copper indium diselenide. As soon as sunlight hits solar cells made from these materials electrons immediately stream from the negative to the positive pole causing a continuous current to be generated. The process is practically wear-free; no emissions or sounds are generated and no moving parts are involved in the process. The photovoltaic effect was discovered in 1839 by French physicist A.E. Becquerel.

A solar-cell has a typical voltage of 0.6 V and a maximum short-circuit current of over 3 A. As such a voltage is too low to run any appliance solar-cells are typically wired in series to form a solar module (typically 36 cells). As we speak extensive researches are conducted worldwide to develop new effective production processes and new types of solar-cells. Today the main trend in solar-cell-manufacture is towards Silicon solar-cells with the largest market-share being held by mono-crystalline solar-cells. A close second to these is the poly-crystalline technology followed by amorphous cells. New technologies such as CIS and CaTe-cells are also available on the market.

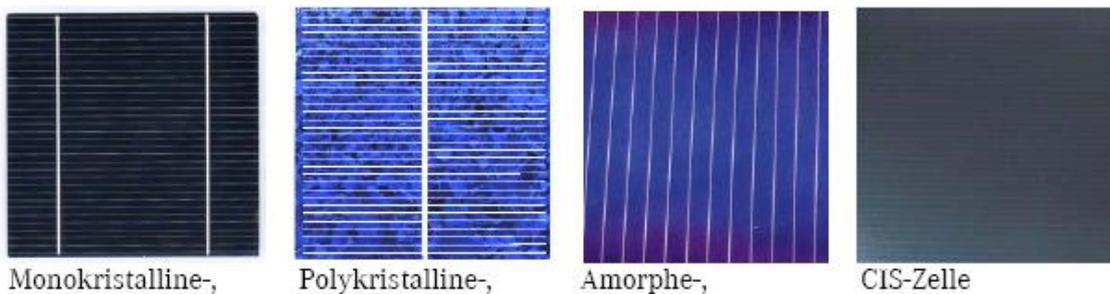


Fig. 17: different types of solar cells

A major factor for solar-cells is their efficiency; this refers to the ratio between the irradiance received by solar-cells and the amount of electrical power generated.

Table 5. Efficiency of different types of solar-cells

	Typical efficiency	Max. recorded efficiency	Max. in-lab recorded efficiency
Mono-crystalline	15-18%	22.7%	24%
Poly-crystalline	13- 16%	18%	18.6%
Amorphous silicon	5- 7%	10.2%	12.7%
Cadmium telluride (CdTe)	7- 8.5%	13%	16%
Copper indium diselenide (CIS)	9- 11%	13%	18.8%

Solar-modules are typically defined in terms of their efficiency and their nominal power output at STC. The nominal power output at STC refers to the amount of electrical power a module is able to generate with an irradiance of 1000 W/m², a module-temperature of 25°C and an AirMass of 1. Such conditions are seldom met in normal operation, if ever, only on sunny spring days. For most of the year cells operate in substantially less favourable light and temperature conditions, i.e. a solar module's yield will be lower than the indicated STC value. Solar modules are wired in series and in parallel; multiple modules wired in series are called a "string". In grid-connected systems the generated

power is sent to an inverter that converts the collected direct current (DC) into alternating current (AC) and feeds it in the public power-supply system. Grid connection systems use a variety of inverters. If a central inverter, for example, is used all solar modules will be wired to the inverter by means of a terminal box. In string inverters the terminal box is replaced and each string is converted into alternating current.

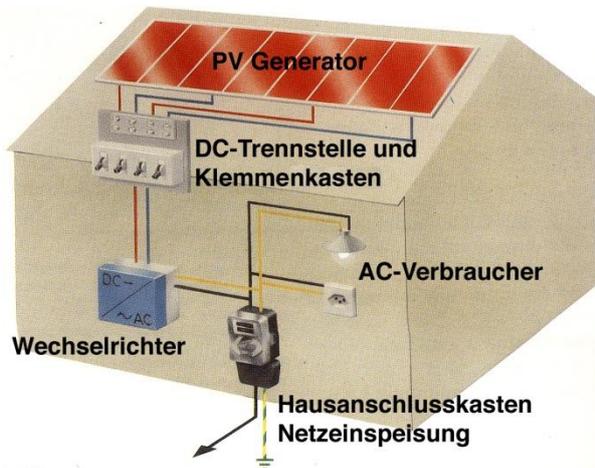


Fig. 18: functional chart of a grid-connected PV system (Source: Leitfaden Photovoltaische Anlagen; Deutsche Gesellschaft für Sonnenenergie, 2007)

A PV system with an installed power of 1 kWp (about 8m² solar module surface) placed on a south-facing roof on the Swiss Plateau is able to generate about 900 kWh electrical power a year. In the south of Switzerland and in more elevated locations (over 1000 metres a.s.l.) a higher solar irradiance results in substantially greater outputs. In a four year period a solar system is able to generate as much current as its was required to manufacture it. (Source: N. Jungbluth et. al.; Life Cycle Assessment of Photovoltaics; Update of the ecoinvent Database, 2007). Solar energy systems have a life-span in the range of 25 to 30 years, i.e. they can generate about 6 to 7 times the electrical power that was required to manufacture them. At the end of their life-span most components of solar-energy systems (solar-cells, glass, aluminum components).

Polysun's PV module allows users to figure out the amount of electrical power their systems are likely to generate. An extensive database provides users with a wide variety of solar-modules and inverters they will be able to use to define their PV fields.

2.1 PV Modules

Polysun makes it possible to set up PV fields having each an inverter and the desired number of series or parallel-wired modules. Each PV field has a specific orientation and tilt angle as well as a field-specific assembly system.

So that different orientations and pitches may be combined each system diagram enables multiple PV fields to be defined within it. Alternatively after a module has been chosen an assistant providing an overview of the suitable inverters may be called-up by simply pressing the Wizard button.

2.1.1 Parameters PV Modules

The definition of a solar-module requires, as a key parameter, that a suitable PV field is retrieved from the solar-module database or independently set-up as well as that an appropriate number of modules is determined. As an option the DC nominal power and the solar module surface may be entered based on which Polysun will automatically calculate the required number of modules.

Additionally module orientation (South is 0°, East is +90°, West is -90°) and tilt angle (floor is 0°, façade is 90°) may also be defined.

Polysun also enables users to work out the yield of sun-tracking PV systems (single or two-axis solar trackers). We proceed on the assumption that the system is set-up to track the position of the sun (and not the clearest spot) and that the tracker is able to follow the entire course of the sun and not just a limited angle. For a graphical representation of this principle see chapter 2.1.2 "Tracking".

2.1.1.1 Parameter Reference Value for the Area

The power of the photovoltaic generator field can be determined through the number of modules, total nominal power or total gross area.

The number of modules is the number of PV modules of the module type selected. The total nominal power is defined as the performance of the PV modules measured in kW without deducting cable or inverter losses. The total gross area is the area of the generator field in square meters.

2.1.1.2 Temperature Effect and Rear Ventilation

The amount of energy generated by solar-modules depends both on irradiance and module temperature. Energy production increases approximately linearly with irradiance. The influence of temperature is smaller and is dependent on the type of cell-technology. A temperature increase of 10°C will cause, for example, the energy production of crystalline cells to be cut back by about 4 to 5%. Amorphous cells are practically immune to temperature swings.

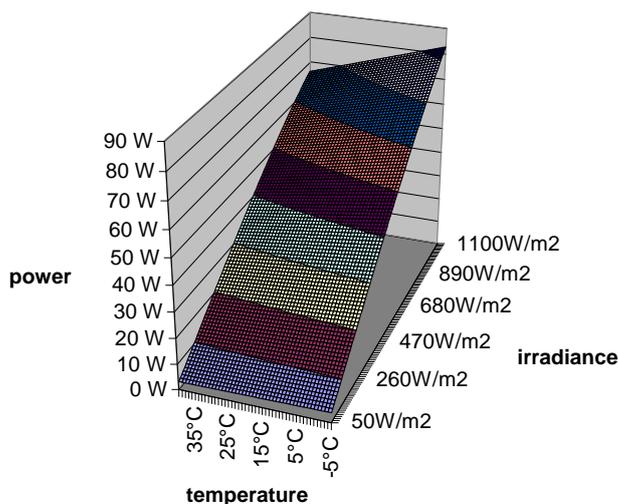


Fig. 19: influence of irradiance and temperature on a crystalline module (Source: R. Kröni et.al.; Final Report PV P+D, DIS 47456 / 87538 , February 2005; Energy Rating of Solar Modules)

In view of such temperature sensitivity an appropriate rear ventilation will result in a considerably higher yield. The software allows different types of ventilation to be set up as a parameter:

- Poor: for example a roof-integrated system with a very poor rear ventilation. With an irradiance of 1000 W/m² the module temperature will lie at about 40°C over the air temperature.
- Medium: for example a roof-mounted system with a rear ventilation of about 10 to 20cm. With an irradiance of 1000 W/m² the module temperature will lie at about 30°C over the air temperature.
- Good: a free-standing system with a ground clearance in excess of 20cm. With an irradiance of 1000 W/m² the module temperature will lie at about 20°C over the air temperature.

2.1.1.3 Degradation and Soiling

PV fields are subject to degradation and soiling. Researches have shown that soiling rapidly increases in the early weeks after installation or cleaning to eventually settle to a level in the range of 2 to 6% (Source: H. Becker, W. Vassen, W. Hermann: „Reduced Output of Solar Generators due to Pollution“. Proc. 14th EU PV Conf., Barcelona, 1997). The soiling rate matches the percentage reduction in the system's DC yield.

The degradation of solar modules as well as that of system as a whole is assumed to be a linear process. Degradation-induced yield decreases amount to an average 0.2%/year (Source: Leitfaden Photovoltaische Anlagen; Deutsche Gesellschaft für Sonnenenergie, Landesverband Berlin Brandenburg e.V.; DGS Berlin 2005.).

2.1.1.4 Results

The yield of a solar system can be calculated by means of the H.G. Beyer model. (Source: Beyer, H.G., Betcke, J., Drews, A., Heinemann, D., Lorenz, E., Heilscher, G., Bofinger, S., 19th European Photovoltaic Solar Energy Conference & Exhibition, Paris 7.6.-11.6.2004. Identification of a General Model for the MPP Performance of PV-Modules for the Application in a Procedure for the Performance Check of Grid Connected Systems). This model relies on the following inputs:

- 3 efficiency readings for the module at different irradiance conditions.
- 3 efficiency readings for the inverter with different loads
- The installed power
- The module's temperature coefficient

Such interpolation nodes enable an efficiency curve to be identified for the module and the inverter. These curves, the installed power and the temperature coefficients allow the yield to be calculated depending on the irradiance and module temperature.

Model temperature can be calculated from ambient temperature, irradiance and gamma parameter for rear ventilation:

Module temperature = ambient temperature + gamma x irradiance/1000 W/m²

The following factors may be inferred from the resulting yield:

- Soiling (default value 2%, it can be defined in the PV field)
- Degradation (default value 0.2%, it can be defined in the PV field)
- Standard deduction for piping lossess, module mismatch and module derating: 4% + 4% x inverter load

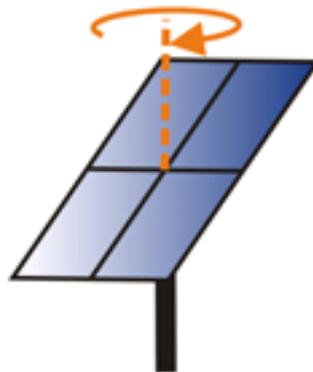
2.1.2 Tracking

Tracking systems enable collectors to yield an increased heat output. The use of solar tracking systems can be more or less worthwhile depending on use and location. The closer to the equator and the larger the system and the more the use of tracking systems will be worth your while. As these locations can enjoy a higher annual irradiance start-up costs for tracking systems will be accordingly lower.

The collector characteristic dialogue box gives the user the opportunity to choose from three different types of tracking devices.

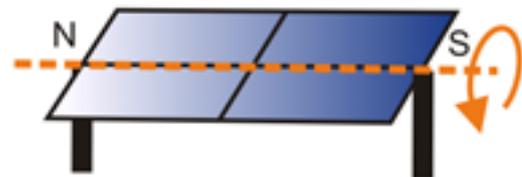
- One-axis azimuth tracker

The tracker causes the collector to rotate about the vertical axis.



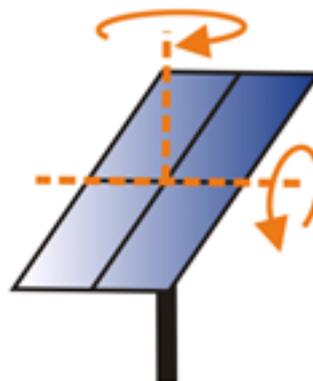
- One-axis zenith tracker

The tracker causes the collector to rotate about the horizontal axis.



- Two-axis tracker

The tracker causes the collector to rotate both about the horizontal and the vertical axis.



Simulations with sun-tracking collectors involve the calculation of computationally intensive IAM-factors. This heavily affects simulation times that may be considerably longer.

2.2 Inverters

2.2.1 Automatic Inverter Layout

Polysun provides users with a useful inverter configuration tool, the “Inverter assistant”. The “Inverter assistant” can be started both via the provided assistants (photovoltaics page) and by means of the photovoltaic or PVT components (double-click on the relevant component and subsequent single click on the assistant symbol)

The inverter assistant provides the user with a list of possible configurations (hereafter called “Configuration system diagrams”).

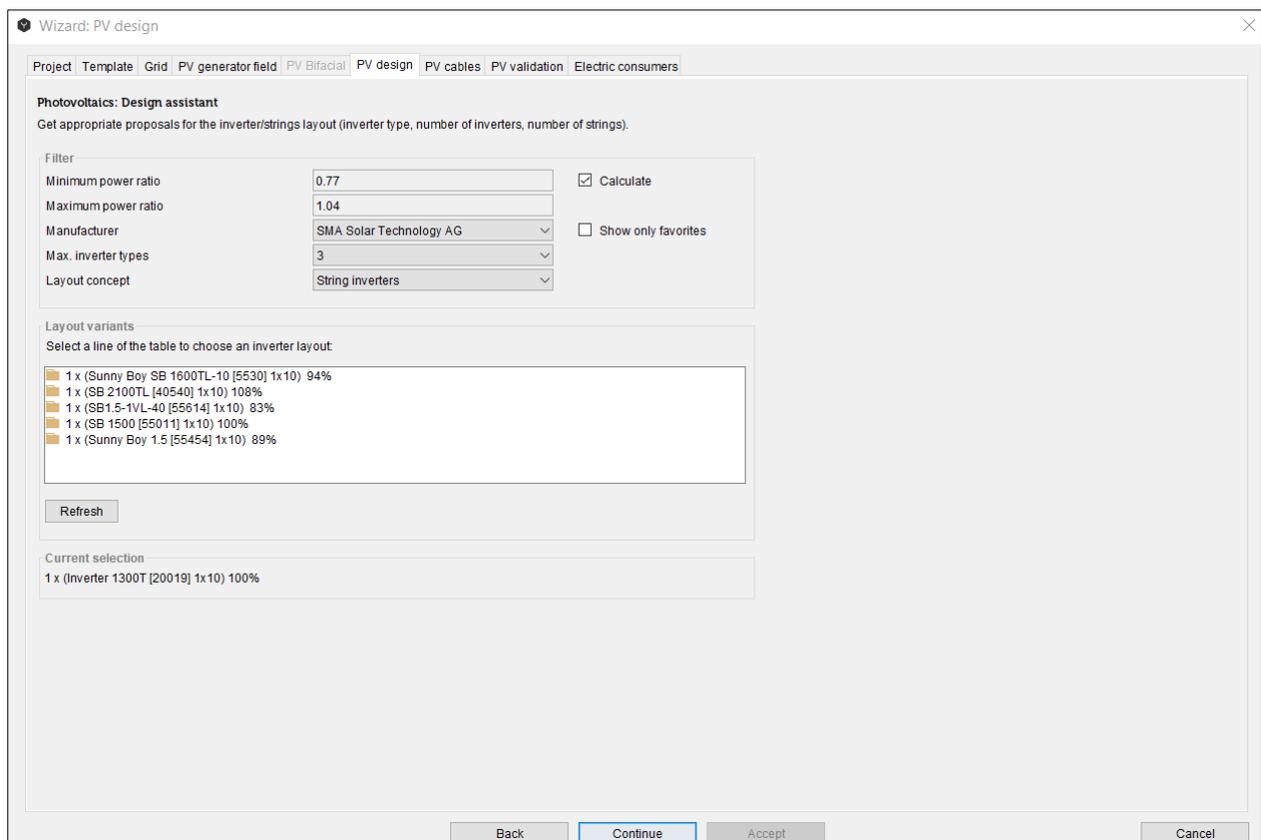


Fig. 20: inverter configuration

Starting Situation:

The following data are given in the calculation of configuration system diagrams:

- Location
- Type of module
- Number of modules

Additionally the following values will also be considered in the calculation of the max. DC power (and partially also for the calculation of the min. and max. module temperature and therefore the max. MPP voltage and the max. DC current): orientation, , tilt angle, level of soiling, degradation, wind percentage and rear ventilation.

Configuration Result – Configuration System Diagrams:

Configuration system diagrams are characterised through the following data:

- Type of inverter
- Number of inverters
- Number of MPP trackers employed
- Number of strings (per inverter or MPP tracker)

Number of MPP Trackers Employed:

In case multi-string inverters are used Polysun attempts to reach the full or partial allocation of all MPP-controlled inputs. The configuration programme assumes here that strings were allocated uniformly.

Additionally the following data will also be displayed in the inverter assistant: inverter manufacturer, number of modules per string and power ratio.

Power Ratio:

The term “power ratio“ refers in Polysun to the ratio between generator output at standard test conditions (STC) and the inverter’s maximum DC output.

Electrical Limit Values:

Configuration system diagrams are essentially selected based on the relevant electrical limit values. Polysun basically only reproduces combinations that comply with the limit values specified below (occasionally subject to particular operation and weather conditions). Voltage and current peaks can be calculated by means of the temperature coefficients included in the catalog.

Table 6. Electrical limits for the selection of the layout variants

Nr.	Component	Limit value	Mode	Weather conditions
1	Inverter	Max. DC output		Max. irradiance
2	Inverter	Max. DC voltage	Idling	Min. air temperature
3	Inverter	Min. MPP voltage	MPP	Max. air temperature
4	Inverter	Max. MPP voltage	MPP	Min. module temperature
5	Inverter	Max. DC current	MPP	Max. module temperature
6	Module	Max. system voltage	Idling	Min. air temperature
7	Mains	Max. phase imbalance		

Module Temperature Calculation:

Polysun enables module temperature to be calculated by the user. The following data are considered in the calculation: air temperature, irradiance, module gamma, wind percentage and rear ventilation.

If PVT collectors are used a fixed minimum (10°C) and maximum temperature (80°C) are assumed for inverter configuration purposes.

Phase Imbalance:

The configuration system diagrams provided by the configuration assistant comply with the requirement for a maximum phase imbalance of 4.2 kVA.

Thin-Film Modules – Galvanic Separation:

Thin-film modules should only be operated with a transformer or galvanic separation. This applies to all inverter configurations.

Filters/Tolerances:

Configuration system diagrams are eventually filtered, i.e. only given tolerance values will be allowed.

Filters/Tolerances Inverter Assistant:

The following fixed-sized filters will be used in the inverter assistant:

$0.75 \leq \text{power ratio} \leq 1.25$.

Additionally a fixed tolerance of 10% is given for the maximum input power. A tolerance of 0% applies to all remaining maximum values.

There isn't any guarantee that the automatic inverter layout wizard will find every solution suggested by a manufacturer tool. According to the conditions very detailed intermediate results could occur which then require limitations due to limited resources (memory, simulation time etc.). In those cases the user should design the inverter manually (chapter 2.2.2).

2.2.2 Manual Inverter Layout

'Automatic' or 'Manual' inverter layout shall be chosen in the dialog window by clicking on the photovoltaic component in the system diagram.

It is a common practice to start the project with a Wizard design and then adapt the automatic design version to the required conditions. If the system shall be slightly changed, manual design is also preferable.

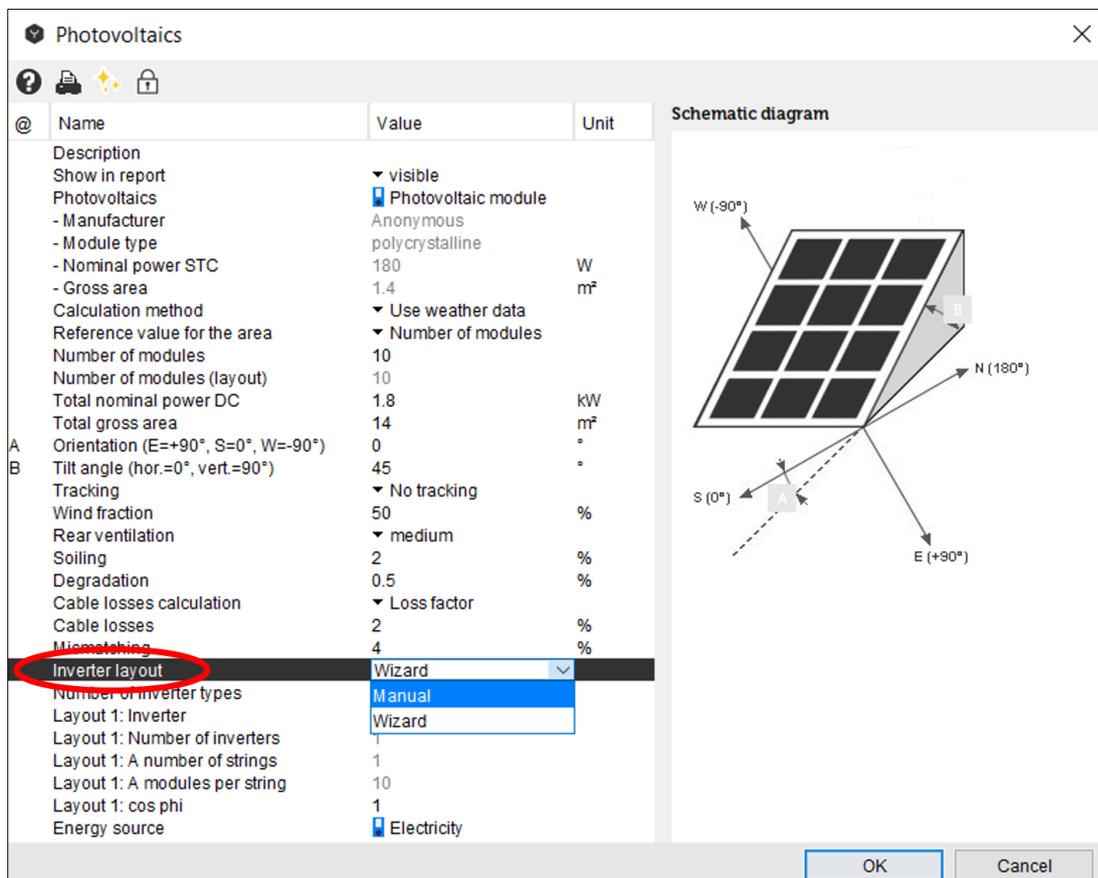


Fig. 21: manual inverter layout

With a manual inverter design the following parameters can be changed:

Table 7. List of parameters for the manual inverter design

PARAMETERS	DESCRIPTION
NUMBER OF INVERTER TYPES	Defines the number of inverter layouts (sub-layouts) in the combined layout. Up to 3 sub-layouts are possible. Each inverter layout (sub-layout) is defined by the inverter type, the number of inverters, the number of strings and the number of modules per each tracker.
LAYOUT: INVERTER	Selection of the inverter from the catalog.
LAYOUT: NUMBER OF INVERTERS	Number of parallel connected inverters.
LAYOUT: NUMBER OF STRINGS	Number of strings in parallel per inverter. The maximum current of the PV generator should not exceed the maximum input current of the inverter, otherwise premature aging of the inverter will take place.
LAYOUT: NUMBER OF THE MODULES PER STRING	Number of modules in series.
LAYOUT: ORIENTATION	The azimuth angle ($0^\circ = \text{South}$, $+90^\circ = \text{East}$, $-90^\circ = \text{West}$, $\pm 180^\circ = \text{North}$) allows to define a different value per each tracker input. Optimal orientation depends on the local weather and climate conditions, however generally taken if possible in the direct south direction.
LAYOUT: TILT ANGLE	Fixed angle at which PV modules are mounted from the horizontal plane, allows to define a different value per each tracker input. Tilt angle shall be chosen in order to maximize the exposure of the PV panel to the direct sunlight.
COS ϕ	Sets the $\cos \phi$ (ratio between real power and apparent power called power factor) to a constant value. The default value is $\cos \phi = 1$ which means no reactive power. The usable power is only a real power. The grid operator may demand to set up certain power factor $\cos \phi$ in order to avoid high additional load, which cannot be used to supply electrical devices.
ENERGY SOURCE	Energy source used as reference to calculate the economical and ecological results
GRID WIRING	Defines how single phase inverters are connected to the grid if there is more than one option. Refers to split-phase and high leg delta grids only. Options for split-phase grid: <ol style="list-style-type: none"> 'Split' or line to neutral (120V) 'Default' or line-to-line (240V) Options for high-leg delta grid:

1. 'Split' or line to neutral (120V)
 2. 'High-leg' high leg to neutral (208 V)
 3. 'Default' or line-to-line (240V)
- The default value is 'default'.

If the layout is changed manually in the photovoltaic component dialog window, it shall be checked afterwards through the Wizard for validity.

Manual inverter design is often used for inverters with multiple MPP trackers (multistring concept). Multistring inverters are simulated as one device with multiple, independent DC inputs and one AC output. Polysun supports up to 10 MPP-inputs. It is possible to manually define different sub-layouts for each MPPT-input available for the specific inverter type. The automatic layout algorithm always uses all the available tracker inputs. In the manual layout mode, you can set individual orientations and tilt angles for each tracker input by overriding the settings of the component. The PV-array pro MPPT input shall be homogeneous. Currently the multistring inverters can be simulated with only one module type.

2.3 External Grid

Polysun lets you define the external grid. You can select your preferred grid from a list. Additionally, you can define a feed-in power limitation, the maximum phase imbalance and a grid profile.

2.3.1 Grid Type Parameter

The Grid type parameter lets you select the external grid. The external grids you can select are defined by the number of phases, the nominal voltage in Volts and the nominal frequency in Hertz. The nominal voltage is equivalent to the local grid voltage.

2.3.2 Local Grid Voltage Parameter

The local grid voltage has to be in conformity with the specifications provided by the local grid operator.

2.3.3 Profile Parameter

The Profile parameter defines a grid profile. This enables you to take temporary feed-in limitations and blackouts into account. You can also import your own grid profile as a .csv file.

This parameter is important to simulate systems that bridge periods of blackouts and temporary feed-in limitations mandated by law.

2.3.4 Feed-in Power Limitation Parameter

The feed-in power limitation describes the relation between installed power and the power fed into the electric grid. You can select whether the feed-in power limitation is calculated before or after consumption.

The “before consumption” limitation type does not take battery charging and self-consumption into account, the “after consumption” limitation type does that.

2.4 Electric Consumers

In the component Electric consumers and internal grid, the electrical consumption may be specified by means of suitable consumption profiles. Multiple consumption profiles may be selected and respectively added to a specific time step.

Consumption profiles may be scaled to an annual value. The value “0” resets the annual consumption to the original profile value.

If no electrical consumption is available, the number of consumption profiles may be set to “0”.

In Polysun, profiles feature regular time steps. Two different time steps are supported:

- Each hour
- Each 15 minutes

The electrical consumption for a given time step is specified in kWh.

As the software supports 15-minute profiles, smart-meter measurements may be easily used in Polysun.

A wide range of pre-defined profiles are available for use in Polysun.

User-defined profiles may also be added, including, for example, any available reference profiles.

If the simulation of a given system requires that a special profile be used, this may be created, for example, using the Load Profiles Generator programme.¹ This software generates profiles based on a so-called “desire model”, allowing the creation of a wide range of profiles.

2.4.1 Electricity Consumption Profiles

The component internal grid and electric consumers calculates and displays different values for self-consumption. The corresponding tooltips (hover over the corresponding line with your mouse for two seconds) show the definition of the values and the calculation behind it. In the component results, self-consumption and total consumption are individualized under electric consumers and internal grid as follows:

¹ <http://www.loadprofilegenerator.de/>

- **Degree of self-sufficiency** ($R_{aut} = E_{ss}/E_{cs}$): The degree of self-sufficiency corresponds to the relation between self-sufficiency and total consumption.
- **Self-consumption fraction** ($R_{ocs} = E_{ocs}/E_{acp}$): The self-consumption fraction equals the relation between self-consumption and self-production.
- **Self-consumption** ($E_{ocs} = \min(E_{acp}, E_{cs} + E_{bchPV} + E_{bchCG})$): The self-consumption equals the share of the own power generation that is used to cover consumption.
- **Self-sufficiency** ($E_{ss} = \min(E_{cs}, E_{acp} + E_{bdisPV} + E_{bdisCG})$): The self-sufficiency equals the share of the consumption that is covered by the own production.
- **Direct consumption fraction** ($R_{dcs} = E_{dcs}/E_{cs}$): Equals the percentage of the power generated that is consumed directly afterwards.
- **Direct consumption** ($E_{dcs} = \min(E_{cs}, E_{acp})$): Equals the own power generated measured in kWh that is consumed directly afterwards.
- **Feed-in ratio** ($R_{ocsp} = 1 - (E_{ocs}/E_{acp})$): Is the share of power generated that is not consumed directly afterwards and fed into the external power grid.
- **To external grid** ($E_{teg} = E_{acp} - E_{cs} - E_{bch}$): Is the power fed into the external power grid.
- **From external grid** ($E_{feg} = E_{cs} - E_{acp} - E_{bdis}$): Is the electric energy withdrawn from the external power grid.
- **Own AC production** (E_{acp}): self-generated AC current.
- **Electricity consumption of the profiles** (E_{pcs}): Sum of the electricity consumption of the hourly profiles.
- **Electricity consumption** ($E_{cs} = E_{pcs} + E_{thcs}$): Sum of the electricity consumption from profiles and thermal components.

A collection of 1 min resolved consumption profiles that can be imported into Polysun is available for download [here](#).

Polysun Video



[Import of electrical consumption profiles](#)

2.4.2 Electric Consumption of Thermal Components

In addition to the default load profiles, the software also allows for the electrical consumption of thermal components to be taken into account. To this end, the feature Thermal components with electrical consumption may be enabled by the user in the component Electric consumers and internal grid. This feature will only be displayed if thermal components are available in the system.

The following thermal components will be included in the electrical consumption if the feature is enabled:

Table 8. List of thermal components

Component	Value
Heat pump	Eaux
B/W or W/W heat pump	Eaux
Pump	Epar
Internal heat generator (electric)	Eaux
Recooler	Fan speed

2.5 Batteries

Accumulators (commonly referred to as batteries, as is done in this document) are used to store electrical energy. Polysun supports lithium, lead and redox-flow technologies. In a PV system, batteries are used for self-consumption optimization purposes as well as in self-sustaining, off-grid applications. Furthermore, they can be coupled with intelligent operational strategies to balance out negative effects on the grid. Additionally, they are often used to enable an uninterruptible power supply (UPS) or for load peak shaving.

2.5.1 Performance “PerMod” simulation model

Polysun’s default battery computation model is based on the open source Performance model “PerMod” for the simulation of battery systems by (Weniger & Tjaden). A full documentation including Matlab source code is available at <http://pvspeicher.htw-berlin.de/permod>.

This subsection briefly describes the simulation model and the simplifications that were made compared to the original model, in order to allow a parameterization of PV battery systems using measurements based on the [BVES Efficiency Guideline](#).

2.5.1.1 Computation model

Instead of assuming constant efficiencies like many battery system models, PerMod computes the power losses of the individual components as a quadratic function of the power input or output, respectively. Fig. 2.5.1 depicts the efficiencies and power losses as functions of the normalized power output while charging for two exemplary PV storage systems.

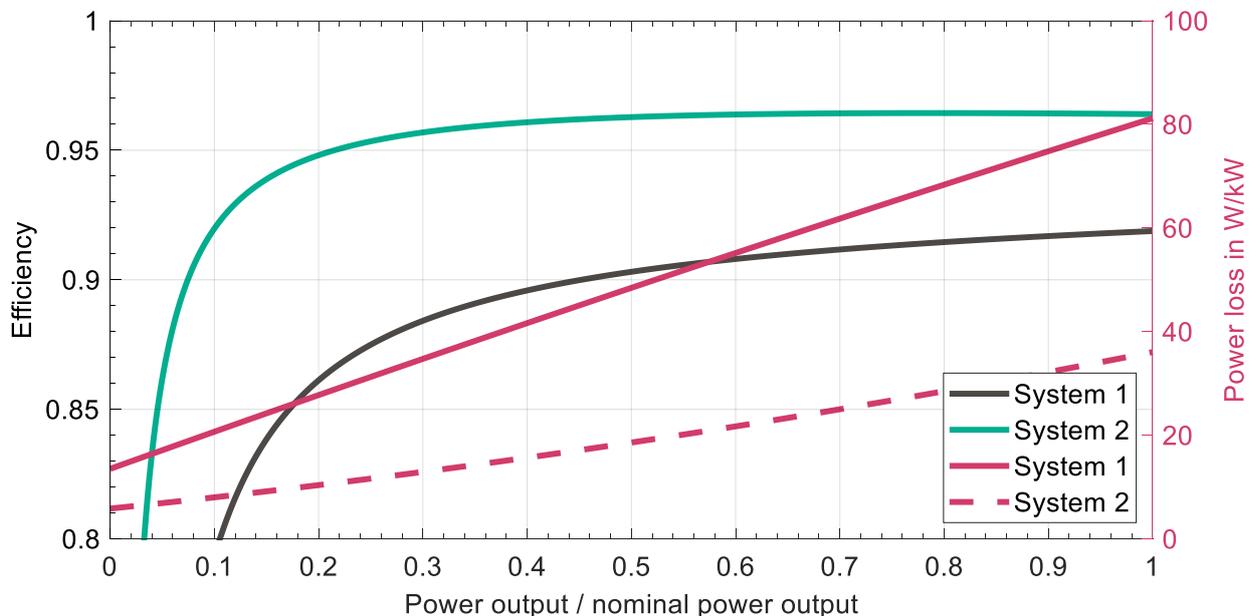


Fig. 2.5.1: The efficiencies and power losses of two AC coupled PV battery systems while charging (AC2BAT). [Data extracted and curve fitted from (Weniger, Maier, et. Al.: Stromspeicher Inspektion 2018)].

The power loss curve can be adequately fitted as

$$a \cdot p^2 + b \cdot p + c$$

with the specific power $p = (\text{power output} / \text{nominal power output})$ and the fitted parameters a, b and c . The efficiency $\eta(p)$ is equal to

$$\eta(p) = 1 - \frac{p_{\text{loss}}}{p}$$

where p_{loss} is the power loss in W/kW. On PV storage systems' data sheets that comply with the BVES efficiency guideline, curves are depicted for the applicable energy conversion paths illustrated in Fig. 2.5.2.

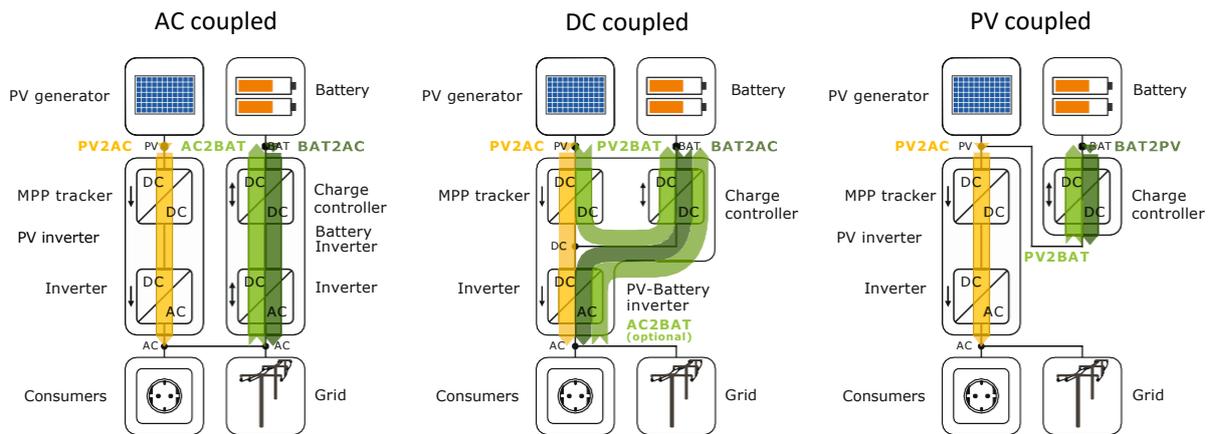


Fig. 2.5.2: Various PV battery system configurations and their energy conversion paths (source: HTW Berlin).

Once extracted (e.g., by using a curve fitting tool), the power loss coefficients can be entered into Polysun's PV inverter and battery inverter catalogues, respectively (see Fig. 2.5.3). If only one conversion path is specified in the catalogue entry (as is the case for most entries in Fig. 2.5.3), Polysun assumes that the power loss function is the same for the unspecified path.

Hint: It must be noted that the efficiency of an inverter depends not only on power, but also on voltage. Since PerMod only regards the power as an input to the efficiency function, an inverter may have different polynomials depending on the system it is used in. For example, an inverter may be more efficient when combined with a battery that has a higher DC voltage, due to the lower voltage difference between the battery and the inverter's intermediate circuit. For this reason, it may be necessary to have multiple catalogue entries for the same inverter; each with different loss coefficients. In this case, the battery that the coefficients were determined for shall be specified in the respective catalogue entry's name.

OffGridOperation	BackupOperation	Bat2AcA	Bat2AcB	Bat2AcC	Ac2BatA	Ac2BatB	Ac2BatC	Charging effi...	Discharging ef
-	-	-31.733	93.5532	10.8561	-4.4122	72.075	13.5181	-	-
no	no	1,458.58521	157.7915	25	-	-	-	-	-
no	no	243.51323	55.66851	14	-	-	-	-	-
yes	yes	47.30503	26.69696	10	-	-	-	-	-
no	no	1,064.61572	116.39778	14	-	-	-	-	-
no	no	223.33725	61.7445	25	-	-	-	-	-
no	no	1,588.17603	164.65199	25	-	-	-	-	-
no	no	364.6463	78.89575	25	-	-	-	-	-
no	no	2,010.03528	185.23351	25	-	-	-	-	-
no	no	3,573.396	246.978	25	-	-	-	-	-
no	no	3,281.81689	236.68726	25	-	-	-	-	-
no	no	2,100.36279	189.34979	25	-	-	-	-	-
no	no	3,573.396	246.978	25	-	-	-	-	-
no	no	5,834.34082	315.58301	25	-	-	-	-	-
no	no	223.33725	61.7445	25	-	-	-	-	-
no	no	364.6463	78.89575	25	-	-	-	-	-
no	no	2,191.6189	167.00552	14	-	-	-	-	-

Fig. 2.5.3: Battery inverter catalogue with the power loss coefficients.

2.5.1.2 PerMod Simplifications

The [HTW PerMod simulation tool](#) (version 1.0) was conceptualized for the simulation of PV storage systems based on laboratory measurements. Due to the limited availability of the data that are needed to parameterize the model, its use is currently mostly limited to research institutes, universities and PV battery system manufacturers. Furthermore, the original model is intended for simulations that comprise of fixed time steps of 1 s. Since Polysun’s user-base is not limited to those with access to such data, and because Polysun allows variable time step sizes of between 1 s and 1 h, various simplifications were made in the Polysun implementation of PerMod – with the purpose of allowing an easier parameterization and simulations with variable time step sizes. Table 2.5.1 summarizes the simplifications made in Polysun and provides a reason for each simplification. An extensive knowledge of the original [HTW PerMod simulation tool](#) is assumed.

Table 2.5.1. Summary of the Polysun PerMod simplifications and the reasons thereof.

Simplification	Reason
Polysun specifies E_{BAT} as $(E_{BAT_charge} + E_{BAT_discharge}) / 2$	Easier parameterization
The battery conversion losses are regarded a constant	Easier parameterization
No charging power limitation in constant voltage (CV) or constant power (CP) mode.	Easier parameterization
Static control deviation not as a function of power, but as constants (for charging/discharging)	Easier parameterization
No dynamic control deviation	Variable time step sizes
Standby losses are assumed to be the same in fully charged and empty state	Easier parameterization
Input data resolutions and time step sizes above 1 s are possible	Variable time step sizes

When comparing the [HTW PerMod simulation tool](#) with the simplified Polysun implementation, the following conclusions can be drawn:

- The simplified model with 1 s resolved data leads to a slight over-estimation of all of the system's performance indicators (see Table 2.5.2) by roughly 1 to 5 percentage points.
- After the model simplifications, reductions in the simulation's temporal resolution barely lead to further errors in the results (focus: SPI).
- A 15 min resolution causes a noticeable increase in the SSR.
- The simplified model with resolutions up to 1 min produces acceptable results.
- The results of the 15 min resolved simulation are tolerable, but not very accurate.

Table 2.5.2. Comparison of the performance indicators between an ideal system, the original PerMod model and Polysun simplifications with various temporal resolutions.

Results	Ideal 1 s	Original 1 s	Simplified 1 s	Simplified 10 s	Simplified 1 min	Simplified 15 min
Self-Consumption ratio / %	52.3	54.9	56.4	56.4	56.5	57.2
Self-Sufficiency ratio / %	55	49.5	51.8	51.8	52	55.8
AC system use degree / %	100	75.2	79.8	79.8	79.8	80.9
System use degree / %	100	89.5	90.6	90.7	90.7	90.8
System Performance Index / %	100	86.9	90.2	90.2	90.4	90.6

Differences to resp. left column	Ideal 1 s	Original 1 s	Simplified 1 s	Simplified 10 s	Simplified 1 min	Simplified 15 min
Self-Consumption ratio / %	▲0.0	▲2.6	▲1.5	▲0.0	▲0.1	▲0.7
Self-Sufficiency ratio / %	▲0.0	▼5.5	▲2.3	▲0.0	▲0.2	▲3.8
AC system use degree / %	▲0.0	▼24.8	▲4.6	▲0.0	▲0.0	▲1.1
System use degree / %	▲0.0	▼10.5	▲1.1	▲0.1	▲0.0	▲0.1
System Performance Index / %	▲0.0	▼13.1	▲3.3	▲0.0	▲0.2	▲0.2

Differences to Original	Ideal 1 s	Original 1 s	Simplified 1 s	Simplified 10 s	Simplified 1 min	Simplified 15 min
Self-Consumption ratio / %	▼2.6	▲0.0	▲1.5	▲1.5	▲1.6	▲2.3
Self-Sufficiency ratio / %	▲5.5	▲0.0	▲2.3	▲2.3	▲2.5	▲6.3
AC system use degree / %	▲24.8	▲0.0	▲4.6	▲4.6	▲4.6	▲5.7
System use degree / %	▲10.5	▲0.0	▲1.1	▲1.2	▲1.2	▲1.3
System Performance Index / %	▲13.1	▲0.0	▲3.3	▲3.3	▲3.5	▲3.7

Hint: When running detailed simulations of battery systems, we recommend a simulation time step size and an input data resolution of 1 min or below. Lower temporal resolutions result in an averaging of the charging/discharging power, which in turn leads to a less accurate modelling of peak cut-offs. In all Polysun editions, using a highly resolved load profile increases the temporal resolution of the overall simulation. In the Polysun Research/Premium editions, it is possible to set the maximum time step size using the “Time step” plugin controller.

2.5.1.3 Default values

Since the BVES efficiency guideline was not been fully established at the time of implementing the simulation model in Polysun, many PV battery system manufacturers have not yet released data sheets that conform with the standard. Furthermore, the

minimum data sheet requirements of the BVES Efficiency Guideline 2.0 do not guarantee enough parametrization data for Polysun's implementation of PerMod. Therefore, Polysun relies mainly on laboratory measurements provided by research institutes and battery manufacturers for parametrization of the catalogue entries.

To not disadvantage innovative manufacturers who have already released standards-based data sheets, or system designers who rely on a transparent market, Polysun assumes default parametrization data for any system that has no BVES conformant data provided. These data are taken from the respective least efficient systems of the German [Electricity storage inspection 2018](#). They have been extracted from the publication using image data acquisition and curve fitting software.

2.5.2 Lead Batteries/KiBa Model (KiBaM)

Hint: The KiBa model is still available for backwards compatibility. However, it has been deprecated and its use is no longer recommended, due to its inaccuracy and lack of comparability compared to PerMod. Furthermore, KiBaM is not applicable to lithium ion batteries. It can be enabled in the advanced settings.

In the KiBaM, batteries are assumed to be a two-tank electrical energy storage device, the first containing readily available electrical energy, the second containing slower chemical energy which is converted into electrical energy at a limited rate.

The model implemented in Polysun is that suggested by Vrettos & Papathanassiou (Operating policy and optimal sizing of a high penetration RES-BESS system for small isolated grids, 2011) which describes energies and performances. Voltage variations are not displayed. The paper (Vrettos, Witzig, Kurmann, Koch, & Andersson, 2013) directly addresses how the model is implemented in Polysun.

According to Vrettos & Papathanassiou (Operating policy and optimal sizing of a high penetration RES-BESS system for small isolated grids, 2011), we work at a constant battery voltage. The available and the chemically bound energy at the end of a time step are given by:

$$E_{1,t+1} = E_{1,t} e^{-k\Delta t} + \frac{(E_{0,t} \cdot k \cdot c - P) \cdot (1 - e^{-k\Delta t})}{k} - \frac{P \cdot c \cdot (k \cdot \Delta t - 1 + e^{-k\Delta t})}{k}$$

$$E_{2,t+1} = E_{2,t} e^{-k\Delta t} + E_{0,t}(1 - c) \cdot (1 - e^{-k\Delta t}) - \frac{P \cdot (1 - c) \cdot (k \cdot \Delta t - 1 + e^{-k\Delta t})}{k}$$

$$E_{0,t} = E_{1,t} + E_{2,t}$$

where Δt is the time step duration in hours, $E_{1,t}$, $E_{2,t}$ and $E_{0,t}$ are the available, chemically bound and total electrical energy stored in the battery. P is the charge/discharge power. $c = E_{1,t}/E_{2,t}$ is the capacity ratio parameter. k is the rate constant parameter that corresponds to the rate at which chemically bound energy becomes available for output. Conventionally, in this battery model P is positive during discharging and negative during charging.

The KiBaM also models the maximum charge ($P_{ch,max}$) and discharge ($P_{dis,max}$) power as a function of the stored energy:

$$P_{\text{dis,max}} = \frac{k \cdot E_{1,t} \cdot e^{-k \cdot \Delta t} + E_{0,t} \cdot k \cdot c \cdot (1 - e^{-k \cdot \Delta t})}{1 - e^{-k \cdot \Delta t} + c \cdot (k \cdot \Delta t - 1 + e^{-k \cdot \Delta t})}$$

$$P_{\text{ch,max}} = \frac{-k \cdot c \cdot E_{\text{max}} + k \cdot E_{1,t} e^{-k \cdot \Delta t} + E_{0,t} \cdot k \cdot c \cdot (1 - e^{-k \cdot \Delta t})}{1 - e^{-k \cdot \Delta t} + c \cdot (k \cdot \Delta t - 1 + e^{-k \cdot \Delta t})}$$

where E_{max} is the nominal battery capacity. With this notation, the State of Charge (SOC) is defined as:

$$\text{SOC}_t = \frac{E_{0,t}}{E_{\text{max}}}$$

In Polysun, batteries are connected to the AC side and are equipped with their own inverter. Inverters are depicted by means of simple efficiencies.

The self-discharge of batteries is depicted as a linear decrease in charge.

New battery models can also be added to the catalog. If the c and k parameters are not available, they may be calculated from three discharge curves, each with a constant power load. The calculation may be performed using the Battery Parameter Finder programme².

2.5.3 Battery Lifetime Estimation

The ROI (Return of Investment) of batteries depends on their lifetime, which on the one hand depends on the battery's wear and tear (cycle life), and on the other hand depends on time (calendar life). The cycle life can be estimated based on the number of charge/discharge cycles, which are counted (e.g., using the "Rainflow Cycle" counting method). The calendar life as well as the relationship between the depth of cycle (depth of discharge) DoD and the number of cycles to failure C_F is often presented in the battery's datasheet (see Fig. 2.5.4).

2

<http://www.umass.edu/windenergy/research.topics.tools.software.kibam.php>

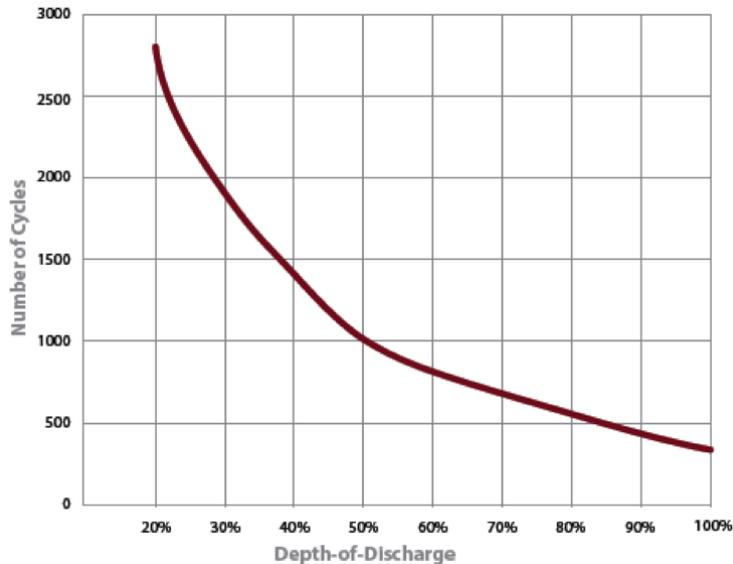


Fig. 2.5.4: typical curve showing the relationship between the number of cycles and discharge depth as indicated in a battery datasheet

In Polysun, the relationship between the number of cycles to failure and the depth of discharge is modelled via one of two functions:

- (i) As a double exponential function (suitable for lead batteries)

$$C_F = \alpha_1 + \alpha_2 \cdot e^{-\alpha_3 \cdot \text{DoD}} + \alpha_4 \cdot e^{-\alpha_5 \cdot \text{DoD}}$$

- (ii) As a Wohler curve (suitable for lithium ion batteries)

$$C_F = \alpha_1 \cdot \text{DoD}^{-\alpha_2}$$

The parameters α_1 to α_5 can be directly provided by the battery manufacturer or obtained via non-linear regression on empirical lifetime test data as shown in the datasheet charts³. All parameters are optional. However, no lifetime estimation can be made if they are not available. If only the parameters α_1 and α_5 are given, the Wohler curve is modelled. Otherwise, the double exponential function is used.

To compute the cycle life in Polysun, 20 histogram bins of equal size are used, each tallying the number of cycles of the respective DoD range R_i . M_i denotes the annual number of cycles with the range R_i . $C_{FL,i}$ denotes the respective number of cycles to failure of a range R_i . With each battery cycle, $1/C_{FL,i}$ of the battery's lifetime is exhausted. Therefore, the cumulative annual damage D is determined by:

$$D = \sum_i \frac{M_i}{C_{FL,i}}$$

For instance, if at the end of the annual simulation, $D = 0.5$, the battery is half-way through its cycle lifetime. In other words, the battery will need to be replaced every two years. Since a battery's lifetime is drastically affected by deep discharge cycles, only part of the available capacity is used for daily cycling. The battery is never discharged deeper than

³ For example, using Excel, Matlab or an online tool such as zunuzun.com

SOC_{min} . A $SOC \geq SOC_{min}$ constraint applies. The SOC_{min} value is type-specific and can be obtained from the manufacturer's data sheet.

Simulation results for the batteries show both the total number of cycles run and the deep cycles. In the battery properties dialogue box, a deep cycle threshold defines what may be classified as "deep discharge".

The total life L_{tot} of the battery is equal to the minimum of the calendar life L_{cal} and the cycle life L_{cyc} :

$$L_{tot} = \min(L_{cal}, L_{cyc})$$

If no calendar life is given in the respective battery catalog entry, the following values are assumed: 20 years for lithium ion-, vanadium redox flow- and NiCd batteries, and 10 years for lead and NiMH batteries.

2.5.4 Controller

In Polysun, batteries are equipped with an automatic controller as a standard. If necessary, the battery may also be controlled by means of the available programmable controller.

The controller works based on a calculation of the system's net power $P_n(t) = \text{generated power} - \text{consumed power}$.

Automatic controllers work on this basic principle: the battery is charged when enough self-generated power is available and discharged as soon as a power deficit occurs. It is never charged from the grid, unless under one of the following conditions:

- The battery's state of charge falls below an *SOE_H2* threshold (-0.05 by default). In this case, boost charging occurs with 0.25 times the nominal charging power, until the battery reaches its minimum state of charge. A common cause of this case is a high self-discharge or high peripheral consumption in combination with long periods without charging.
- The battery peripherals' or battery inverter's AC consumption is not met by the electricity production.
- The battery's stationary control deviation is not met by the electricity production.

Description of an automatic controller:

1. When the system generates an amount of power in excess of what is consumed ($P_n(t) > 0$) the following charge pattern applies:
 - a. Charge battery with maximum possible, available power as long as it can be charged.

$$P_{ch}(t) = \min[P_{nt}, P_{ch,max}]$$
 - b. Feed remaining power into the grid.

$$P_{tegt} = P_{nt} - P_{cht}$$
2. When the system consumes more power than it generates ($P_n(t) < 0$) the following discharge pattern applies:
 - a. Discharge battery to maximum possible extent as long as it can be discharged.

$$P_{dis}(t) = \min[|P_{nt}|, P_{dis,max}]$$
 - b. Draw the remaining power from the grid.

$$P_{fegt} = P_{nt} + P_{dist}$$

The battery offers two inputs for the programmable controller:

Table 2.5.3. Input parameters for the programmable controller

Input	Description	Value
Control mode	Shows how the battery is controlled	0: automatic controller (default value) 1: controlled battery power is used
Controlled power	Battery power may be set.	> 0: the battery is charged, value in W <= 0: the battery is discharged, value in W

Template 50h provides an example of explicit battery control.

2.5.5 PV-Performance Ratio Parameter (Self-Consumption Optimisation)

The PV-performance ratio input parameter appearing in the battery properties dialogue box may be used for self-consumption optimisation purposes. This value refers to the ratio between current and nominal PV performance. In Germany, for example, feed-in amounts in excess of 70% of the nominal PV-performance are associated with lower feed-in tariffs. The purpose of this controller is to pull down midday-peak electricity demand. The PV-performance ratio parameter is used to define a threshold value which, in turn, defines the time from which the battery is to be charged.

If the threshold value is set to 0%, the battery will always be charged. If the threshold value is set to 70%, the battery will only start charging from 70% of the nominal PV-performance.

In template 50h, the same pattern is implemented with a progressive controller which also takes SOC into account. To this end, the photovoltaic component provides the user with the PV-performance ratio output parameter.

Polysun Video



[PV array with battery rack](#)

2.6 E-Mobility

E-mobility refers to full electric or hybrid vehicles, powered by batteries or hydrogen fuel cells that convert hydrogen into electricity. Nowadays many countries set a goal to increase the number of electric vehicles, in order to integrate the environmental and economic strategies. E-mobility in turn aims to meet the emission requirements and market demand at affordable costs. The e-mobility market has a big growth potential and therefore it was included in Polysun. Polysun allows the user to add an e-mobility component in the PV system and calculate the self-consumption, among other things.

There are different options, how e-mobility projects can be created. The recommended solution for e-mobility though would be to start the project and choose an appropriate template from the list in the bottom left of the graphical user interface (main window).

There are currently three templates available:

56e: Space heating + domestic hot water + electric vehicle (PV + heat pump with a smart SG-Ready controller)

50s: Electric vehicle charged by photovoltaic energy

50t: Electric vehicle with programmable charge controller

50u: Electric vehicle (bidirectional) with programmable charge controller

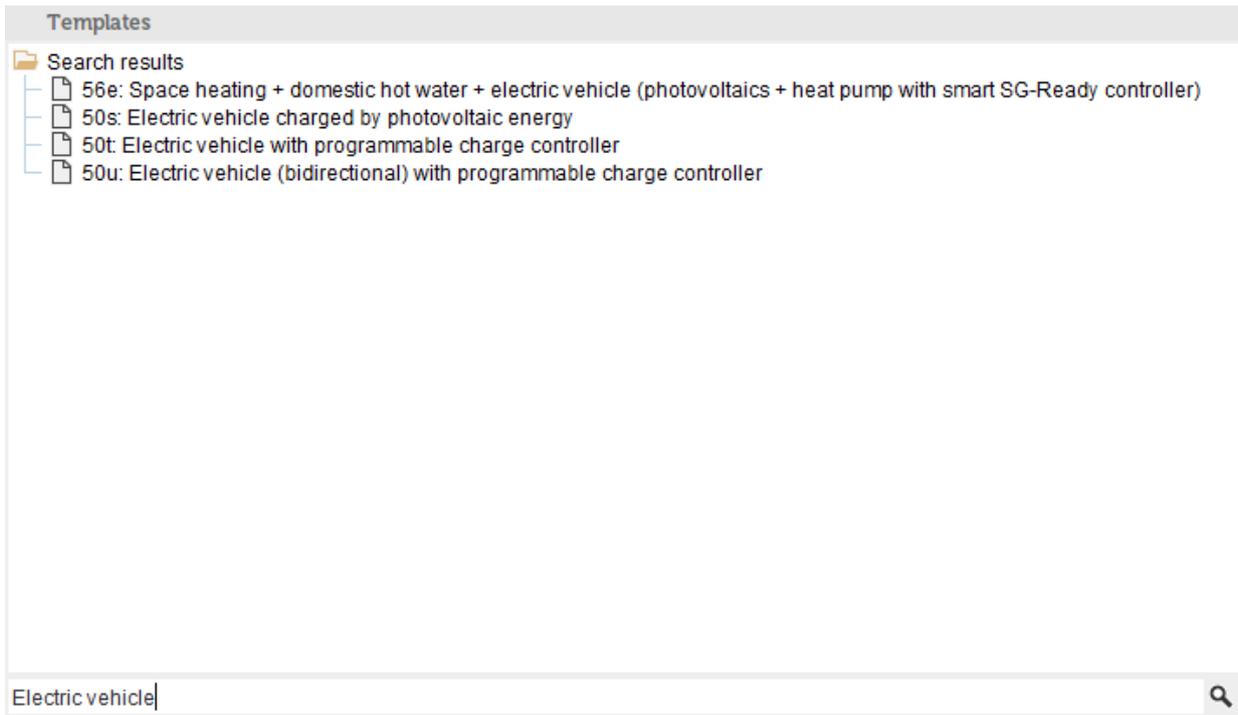


Fig. 23: templates for e-mobility systems

The main difference is that the system diagram in the template 50s can be used for charging the battery of the electric vehicle only from the PV system. Template 50t can be used to charge the battery and other electric consumers from the photovoltaic field as well as from the electricity grid as a backup source. Energy supply is managed using the programmable charge controller with defined logic, which is described later in this chapter. Finally, template 50u allows discharging of the electric vehicle, as long as the state of charge is above 50 %. Template 56e is for the demonstration of sector-coupled systems with intelligent controllers.

You can choose the most appropriate template by double-clicking on it.

As soon as the template is chosen, it could be adjusted in accordance to the project requirements. The system includes a PV module field, inverter, electrical consumers, electricity grid and the e-mobility component which has not been added as an electric consumer, but as a battery. In the dialog window of the e-mobility component the following parameters can be set:

Parameters	Description
Type	AC is an electric storage for stand-alone or hybrid PV-Systems
Electric vehicle	The most popular electric vehicles on the market can be chosen from catalog. It is also possible to add the self-defined vehicle.
Charging station	The appropriate charging station can be chosen from the catalog based on the nominal power and producer. It can be defined in the catalog, how long the battery will be loaded in order to optimize self-consumption.
Mobility profile	The mobility profile is defined on the hourly or weekly basis. The mobility profile can be opened by clicking on the "Mobility profile" or on the symbol

	<p>"Edit profile". In the matrix the user can define when the electric vehicle is driven and when it is at the charging station. The horizontal axis represents the hours of the day, the vertical axis the days of the week. The charging time shall be defined as well as the time on the road and kilometers driven with electric vehicle for every day during the week. Furthermore, it can be specified at which times the charging station allows discharging.</p>
<p>Performance ratio for battery charging</p>	<p>Is a user-defined relation between the instantaneous PV power and the total nominal power of all generator fields. The aim is to avoid to feed-in midday production peaks into the external grid. 0% means that the battery can be charged at any time; 100% means that the battery will never be charged.</p>
<p>Deep cycle threshold</p>	<p>Defines the cycle depth of a deep discharge. The value relates to the discharge range of the battery. 100% is the discharge of the battery up to the minimum battery capacity.</p>

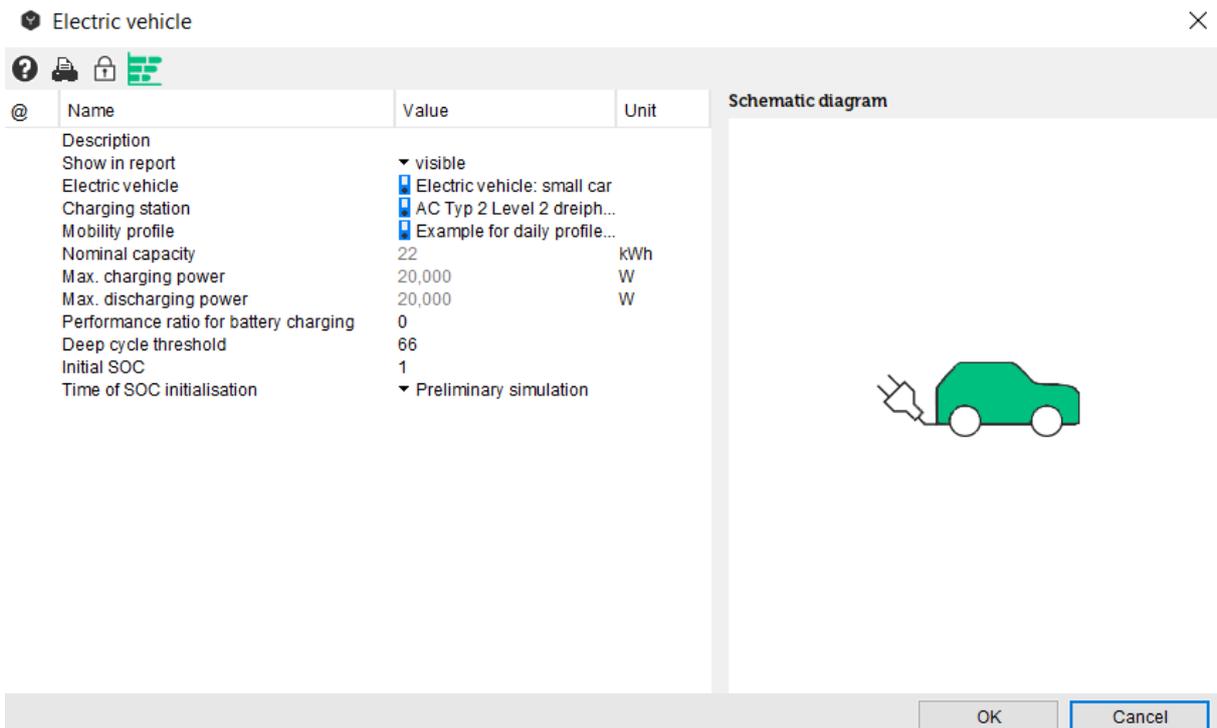


Fig. 24: dialog window for e-mobility component

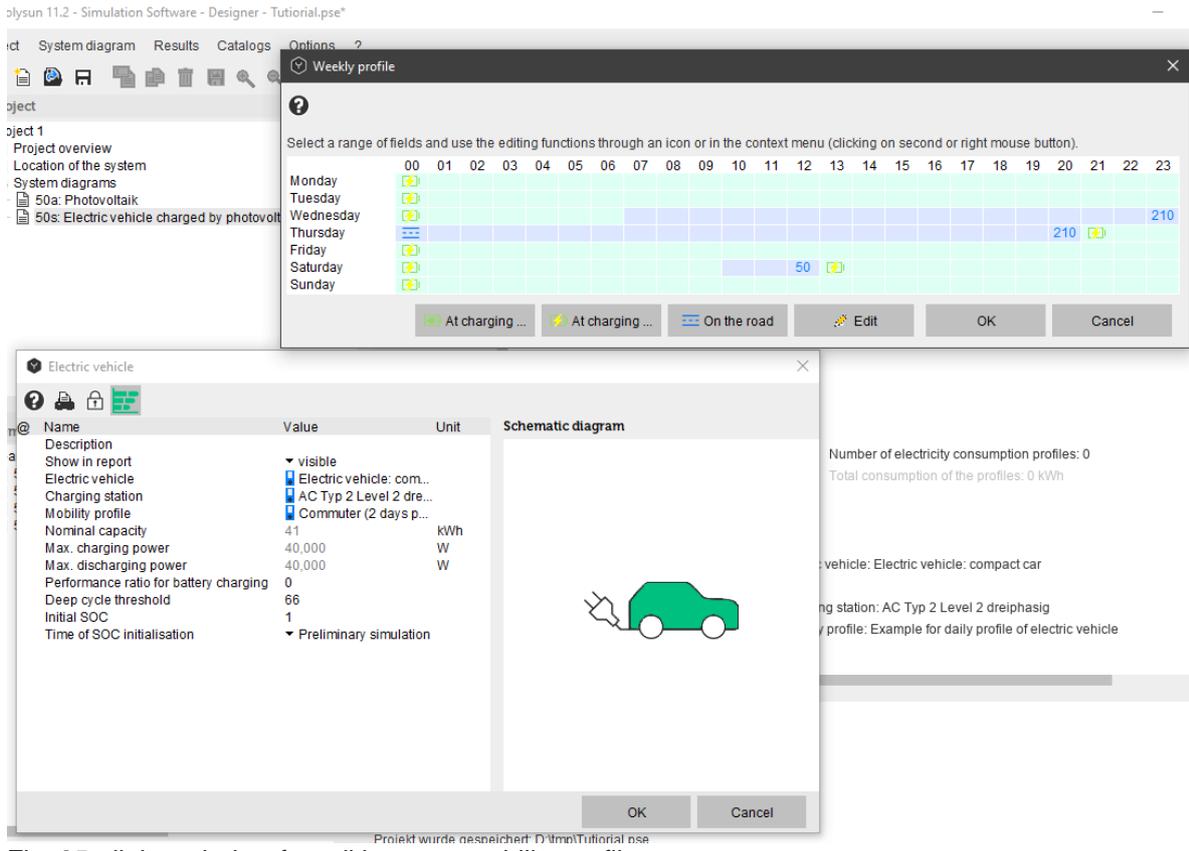


Fig. 25: dialog window for editing an e-mobility profile

If two or more electric vehicles are added, the programmable charge controller has to be set for each vehicle separately, especially when the charging profiles of the electric vehicles are different. The order for charging the vehicles will be the same as the e-mobility elements have been added to the system diagram.

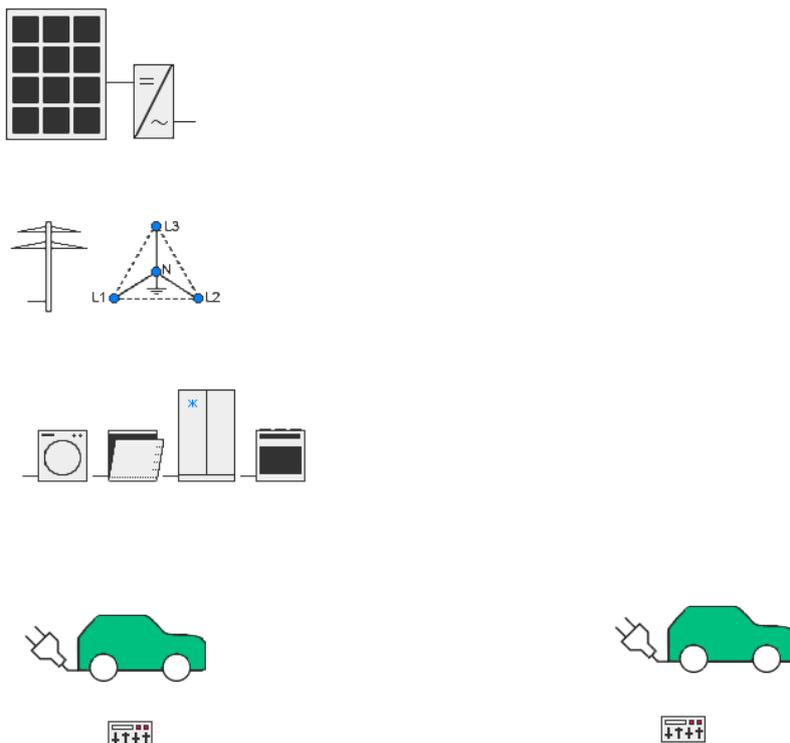


Fig. 26: system diagram with two electric vehicles

Electricity from the PV system can be used for household electric consumers and/or for electric vehicles. If the e-mobility is the only electric consumer in the given system then the number of electricity profiles for the household has to be set to 0.

If the system includes domestic appliances as well as E-Mobility, the loading order is as follows:

- 1st priority: electric vehicle, if there is any demand
- 2nd priority: domestic appliances (electricity consumption profile)
- 3rd priority: battery
- 4th priority: the surplus of electricity is supplied to the electricity grid

The pre-defined order can be changed using a programmable charge controller.

In addition to the control mode and the controlled battery power (see table 2.5.3 in section 2.5.3), the electric vehicle offers a third controller output, "Status charging station". By setting the charging station status to 1, it can be forced to allow discharging. When set to 0 (default), the e-mobility profile specifies whether discharging is allowed or not.

In the template 50t the charging logic is implemented in the programmable controller in the following way:

Operational state	Conditions
1 Electric vehicle is charged from PV	If the energy available from the PV system is more than 100 kWh AND Electric vehicle is under operating conditions AND Battery state of charge is more than 0.95
2 Electric vehicle is charged from the grid	If the energy available from the PV system is less than 100 kWh AND Electric vehicle is under operating conditions AND Battery state of charge is less or equal 0.80
3 End case	Is always true. This operational state is used to find the gaps in the defined logic if there are any. If none of the abovementioned conditions are true, then the operational condition "end case" is applied.

Simulation and evaluation

The main simulation results are given in the component results, where the average monthly and annual values, as well as maximum and minimum values for each individual component are shown. Separate tabs are provided for each electric vehicle. The priority for the charging, when not defined otherwise, is given as follows: "E-Mobil 1" has the first priority, "E-Mobil 2" the second, and further in kind. The tab can be renamed by the user in the dialog window.

System diagram 50: Electric vehicle with programmable charge controller - Component results

		Electric Grid	Electric consumers 1	Electric vehicle 1	Electric vehicle 2	Photovoltaics	Weather data									
Name	Symb...	Unit	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Battery charge	Ebch	kWh	1,581.8	122.2	115.5	136.2	139.3	139.8	144.9	145.5	145.5	132.6	127.5	115	117.9	
Battery charge grid	EbchG	kWh	832	82.9	63.6	55.9	58.9	66.4	60.8	58.6	63.2	64.3	77.3	87.1	93	
Battery charge PV	EbchPV	kWh	749.9	39.3	51.8	80.2	80.5	73.4	84.2	87	82.2	68.3	50.2	27.9	24.9	
Battery SOC (state of charge)	Bsoc	%	83.4	84.6	83.9	82	82.4	83.2	82.7	82.4	83.1	83.7	83.6	84.3	84.7	
Available battery capacity	Cb	kWh	18.3	18.6	18.5	18	18.1	18.3	18.2	18.1	18.3	18.4	18.4	18.5	18.6	
Control mode		%	38.6	30.4	34.9	40.5	44.1	45.2	47.1	44.8	43	41	35.1	29.8	27.5	
Minimum value		%	0	0	0	0	0	0	0	0	0	0	0	0	0	
Maximum value		%	100	100	100	100	100	100	100	100	100	100	100	100	100	
Cycle count			364	33	28	31	30	31	30	31	31	30	31	30	28	
Driven distance electric vehicle		km	7,102	603	545	603	584	603	584	603	603	584	603	584	603	
Profile distance electric vehicle		km	7,300	620	560	620	600	620	600	620	620	600	620	600	620	

Fig. 27: component results for e-mobility system

The component results show the monthly and yearly values of battery charge needed to drive the electric vehicle with the given profile (battery charge), the portion which was supplied from the photovoltaic system (battery charge PV) and the rest of the energy supplied from the electricity grid (battery charge grid). The detailed description for each row in the table can be found in tool-tips.

The different values can be displayed in the graphical evaluation. The graphic shows, which part of total energy demand (black) is covered by PV (green) and at what extent the backup energy from the grid is needed for the second vehicle in the given project.

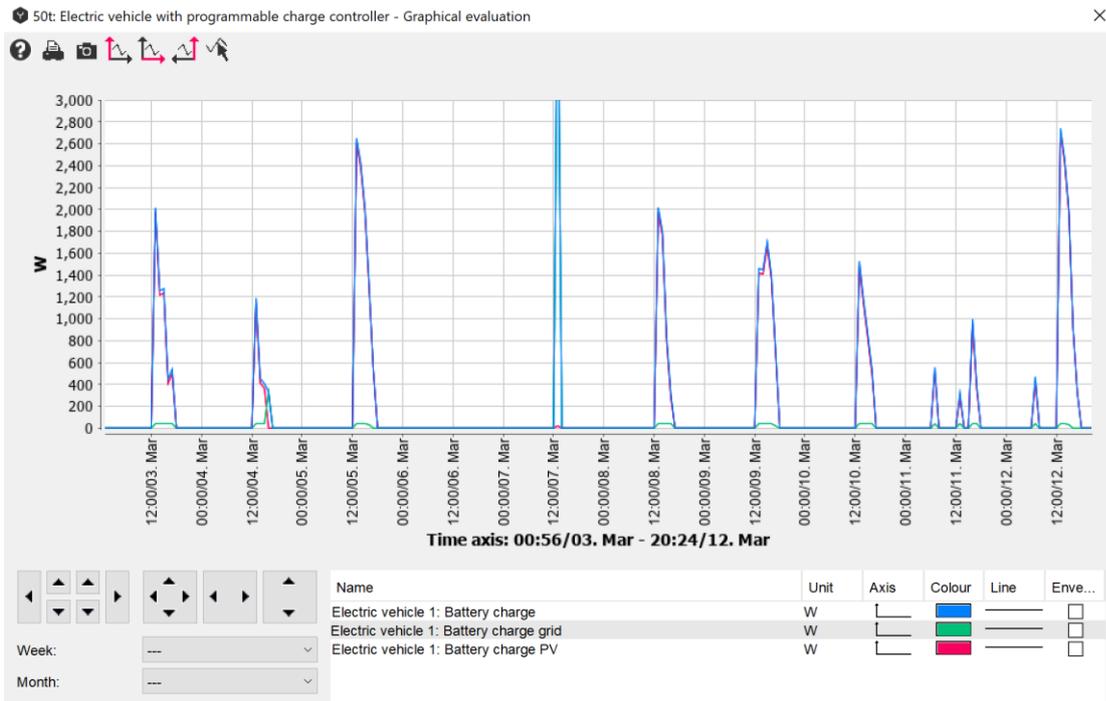


Fig. 28: graphical evaluation for the energy consumption of the second electric vehicle

The detailed simulation analysis shows instant energy available from the PV system as well as the state of charge of the battery in percentage and in kWh and the distance run in the certain time-step. The distance shown is not cumulative. The total distance per hour given in the mobility profile.

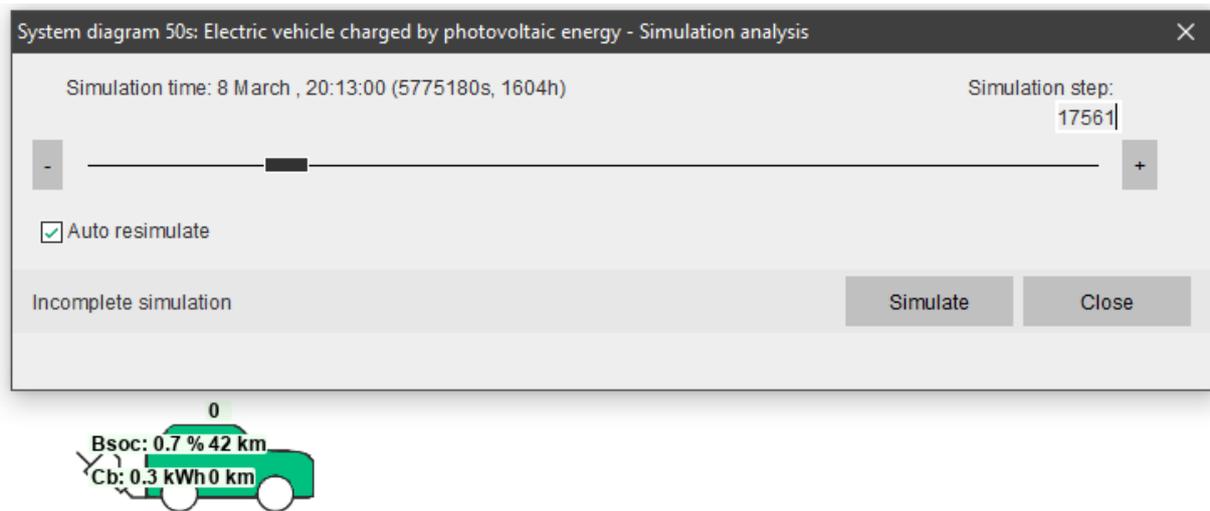


Fig. 29: simulation analysis for e-mobility system diagram

2.7 Generators

The generator component produces electricity. The energy stored in a fuel is converted into electrical power.

The generator component can be viewed as a special case of a cogenerator, however, it does not produce any usable heat. Polysun takes advantage of this comparability. Thus, you can refer to the documentation for the cogenerator in chapter 5.3 when referring to a generator. The only exception is the heat-specific functionality, of course.

Because of their proximity to cogenerators, generators in Polysun have fluid connections. The generator does not use them, however, they need to be part of a circuit.

Polysun can simulate generators with fixed power and with power modulation. To implement a generator with fixed power, the maximum and minimum power parameters need to be equal, meaning having the same value. For dynamic generators the values for maximum and minimum power parameters have to be different. Polysun calculates the start-up phase of a Diesel generator as a time-lag of eight to ten seconds.

2.8 Systems

2.8.1 Grid-Connected PV Systems

The project can be started from the menu Project – New project or by means of the Wizard.

In the Wizard first the location has to be defined either from the map or from the database. After the location has been defined, in the next step you can choose the criteria for the PV grid-connected system and the corresponding system template.

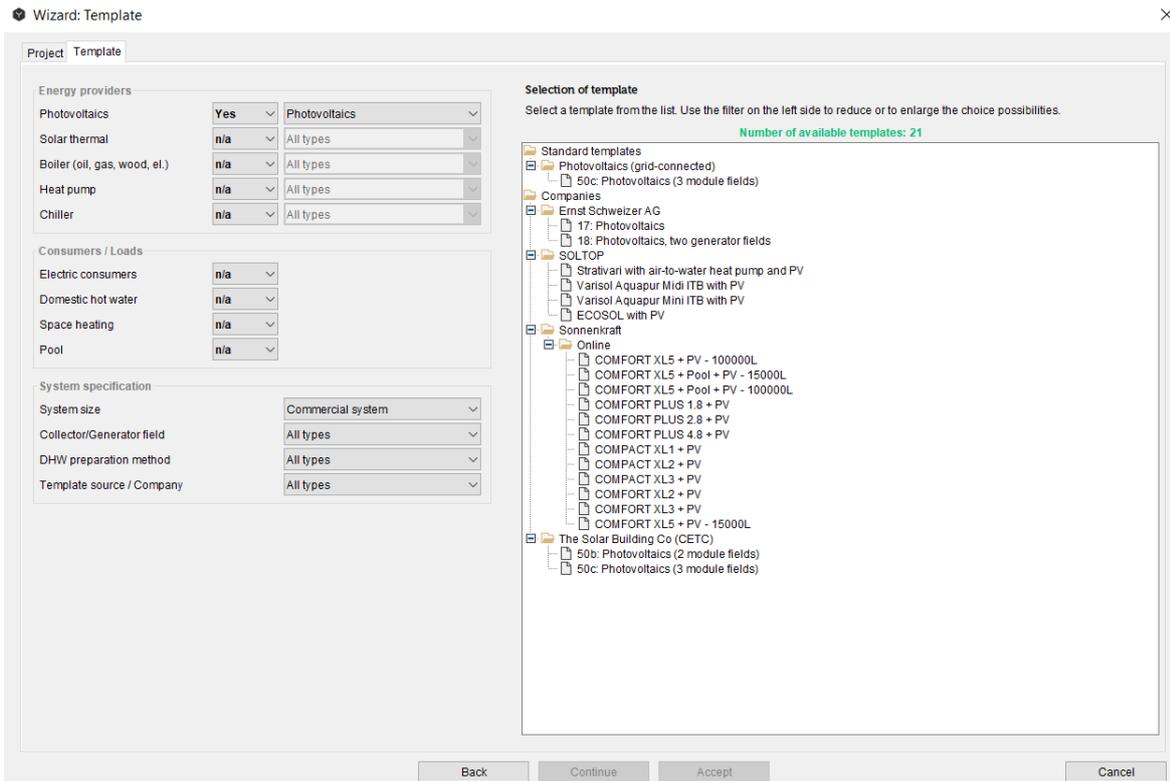


Fig. 30: choosing a PV system template

In the drop-down menus, you can first choose in the upper left side of the dialog window what kind of energy providers you would like to have in your project. Here you can choose one or more types of providers.

‘Yes’ means this energy provider must be in the system.

‘No’ means this energy provider must not be in the system.

‘N/a’ (not applicable) means that this type of energy provider is not a criterion for the selection of the system (the list will show systems with and without this component).

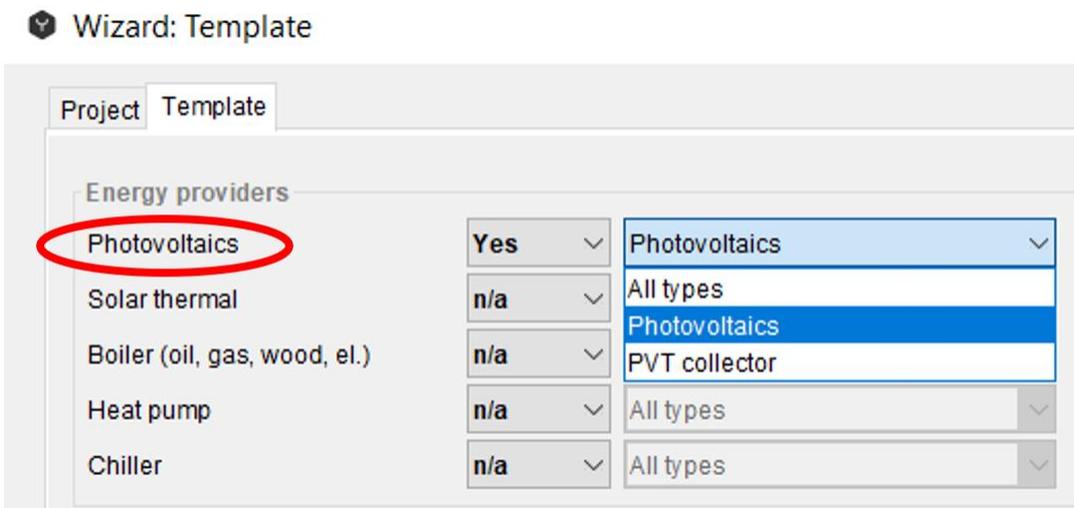


Fig. 31: choosing photovoltaics as an energy provider

Next you will have to define the type of energy consumers/loads available for your project:

As a next step, the system specification can be defined as follows:

Table 10. Photovoltaic systems specification

SYSTEM SPECIFICATION	TYPES
SYSTEM SIZE	- Residential system - Commercial system
COLLECTOR/GENERATOR FIELD	- Single field - Several fields
TEMPLATE SOURCE/COMPANY	- All standard templates - All company templates

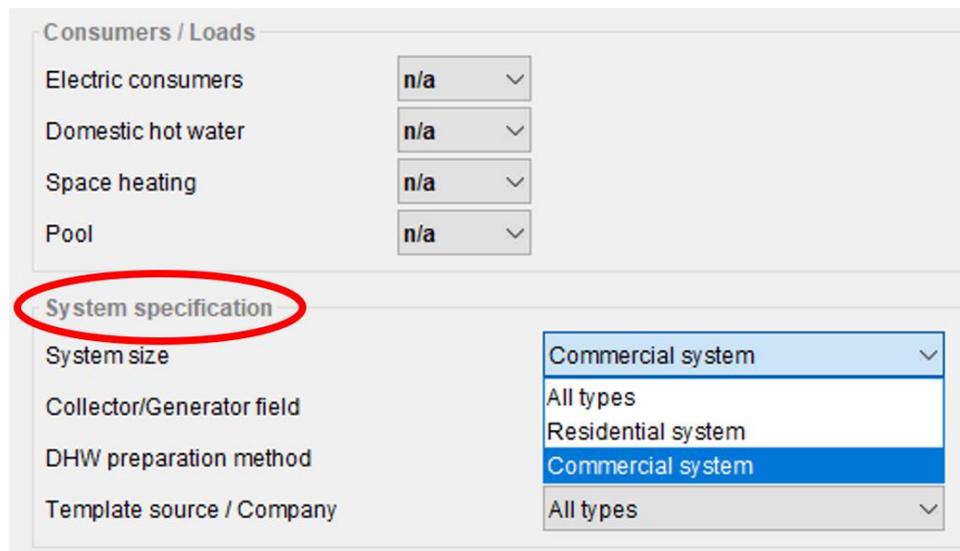


Fig. 32: choosing system specification

Then the templates will be shown on the right side of the dialog window filtered in accordance to the defined parameters. The pre-view of the template is available, when you hover the mouse cursor over the template name. You can choose the most appropriate template by double-clicking on it. If there aren't any templates which meet all the requirements of your system, then you can choose the closest one and change it accordingly.

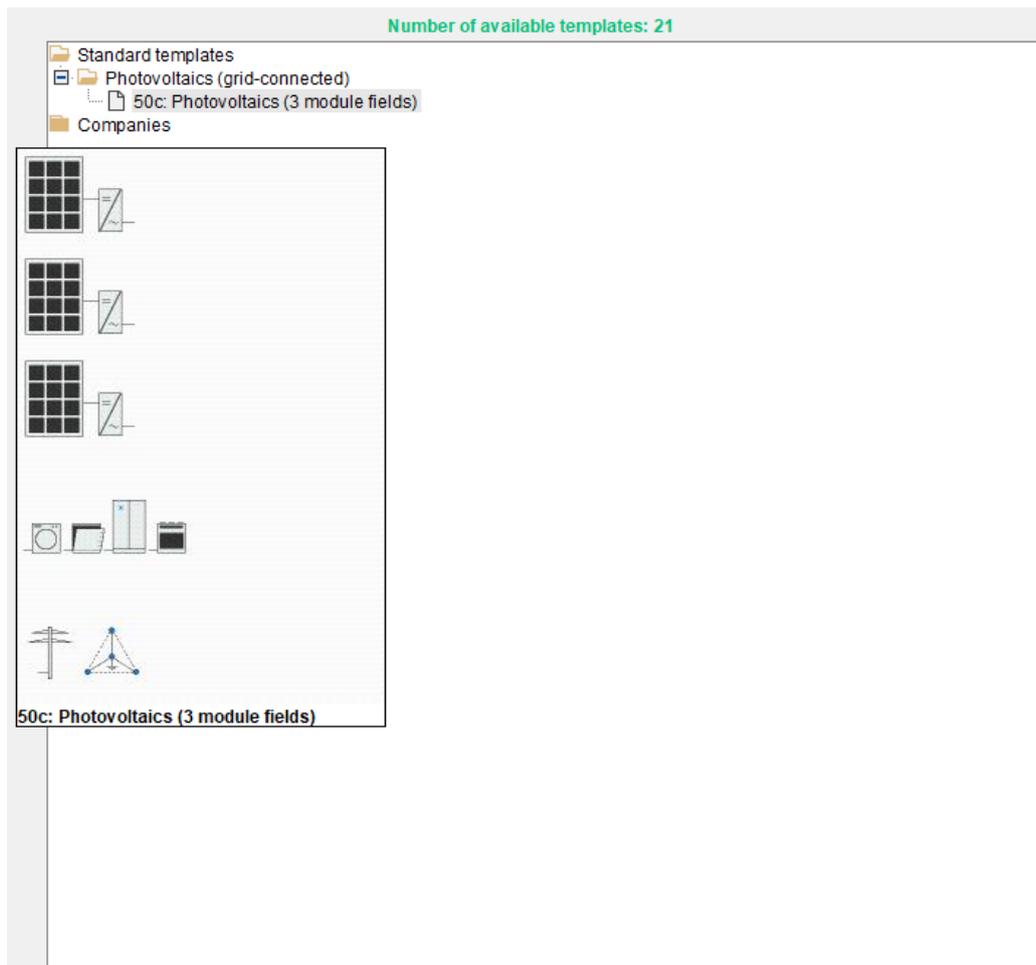


Fig. 33: selection of the template

When the template is chosen, in the next step the appropriate grid configuration, nominal voltage and nominal frequency can be defined from the catalog.

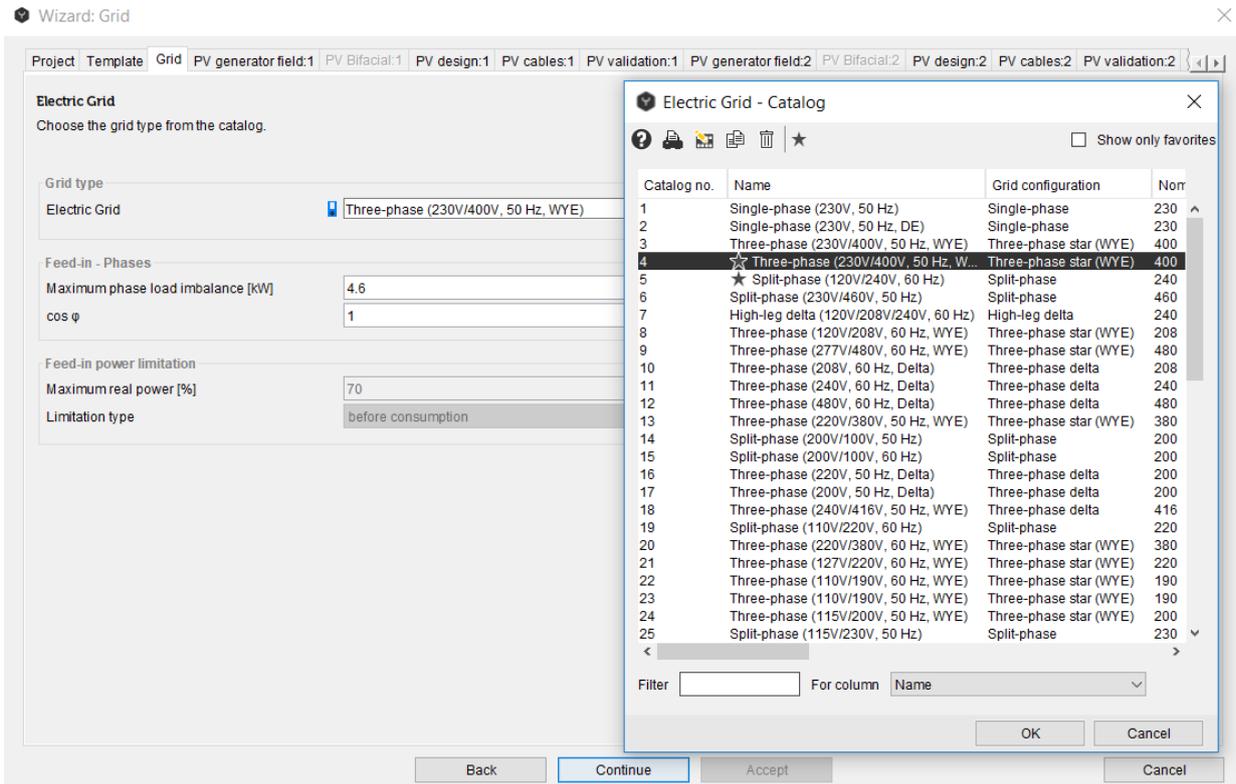


Fig. 34: selection of the electrical grid from the catalog

Then the 'Maximum phase-load imbalance' according to the local parameters as well as 'cos φ ' shall be determined. The maximum phase-load imbalance is important for 1-phase and 2-phase inverters, when the load must be balanced.

'Cos φ ' is the ratio between real power and apparent power (called also power factor) to a constant value. The default value is $\cos \varphi = 1$ which means no reactive power. The usable power is an active power. A certain degree of reactive power cannot be avoided in AC grids. The grid operator may demand to set $\cos \varphi$ between 0.95 and 1 in order to avoid high additional load, which cannot be used to power electrical devices. Reactive power leads also to greater conduction losses.

'Maximum real power' is a limitation of active power related to the peak power. The photovoltaic power station may feed into the grid not more real power than the indicated peak power fraction. The purpose of the power limitation is to avoid feed in high midday peaks.

'Limitation type' can be "before consumption" and "after consumption". "Before consumption" means limitation of the inverter power independently from self-consumption or battery charging. "After consumption" means limitation of the inverter power taking into account self-consumption or battery charging. In this case the charge controller has to be used for power limitation.

If the 'Unlimited' option is ticked, then it is not important for the system.

In the next step of the Wizard the PV Generator can be specified. You can find more detailed information about photovoltaic modules and their parameters in the section 2.1. and 2.1.1 of this User Guide.

The module type can be chosen from the catalog.

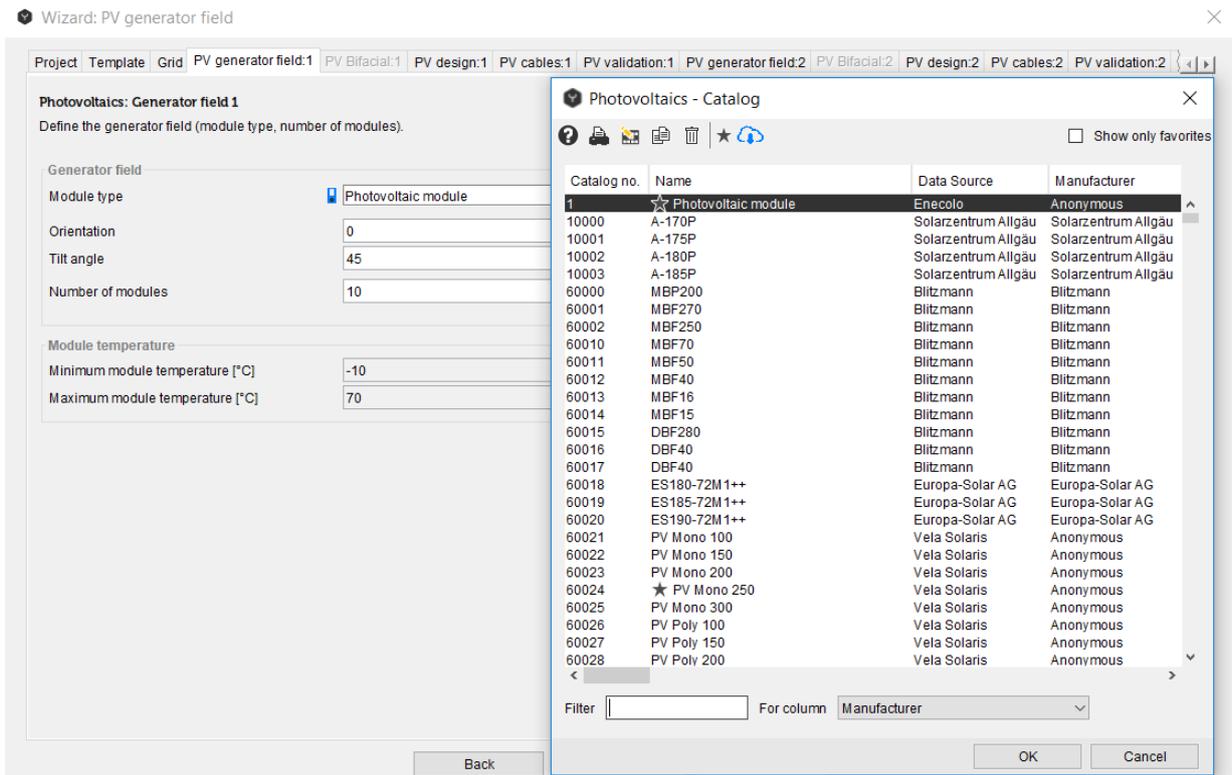


Fig. 35: selection of the PV module from the catalog

The important parameters for PV module disposition are as follows:

- Orientation: horizontal or vertical
- Tilt angle
- Roof width [m]
- Roof depth [m]
- Number of modules, which can be inserted manually or be calculated automatically for a complete roof occupation.

Maximum and minimum module temperature are important parameters for the inverter layout. They can be inserted manually or calculated automatically using the embedded Polysun algorithm.

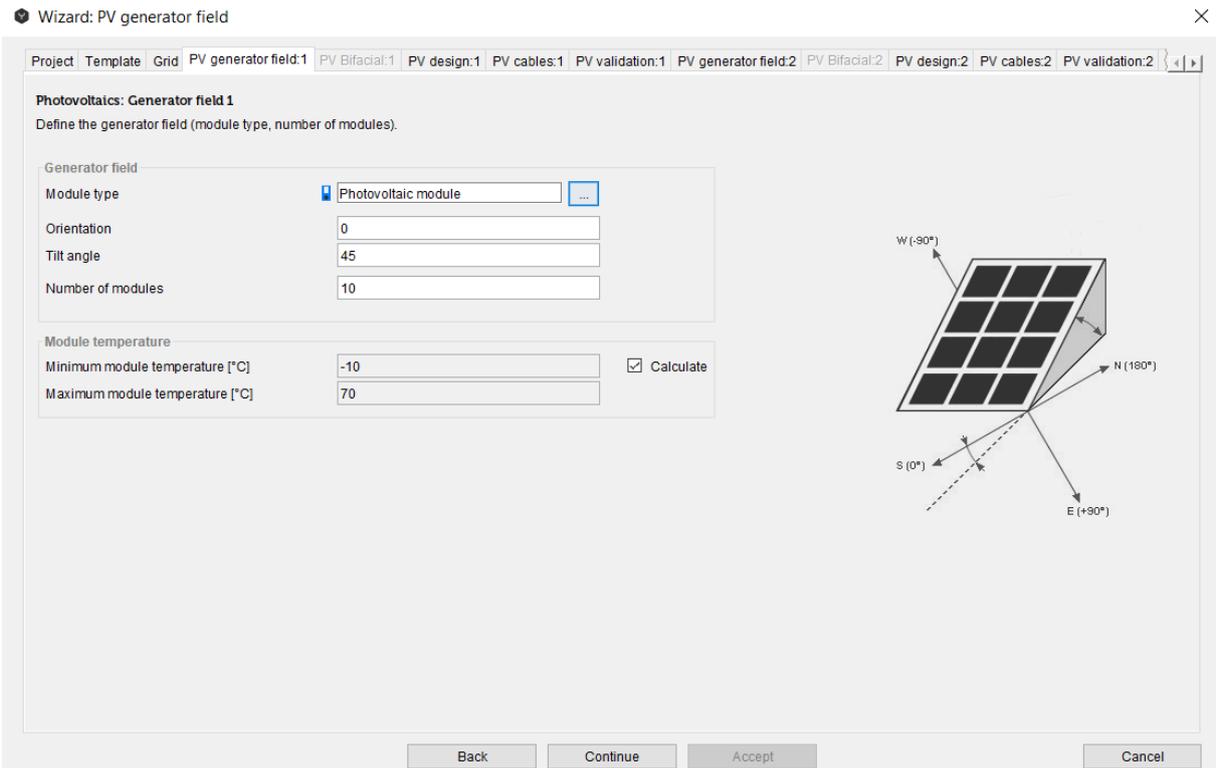


Fig. 36: defining the photovoltaic generator field

The next step in the Wizard is the inverter layout. In this section Polysun gives a number of suggestions of the inverter/string layout based on the system requirements. Inverters are described in detail in chapter 2.2.

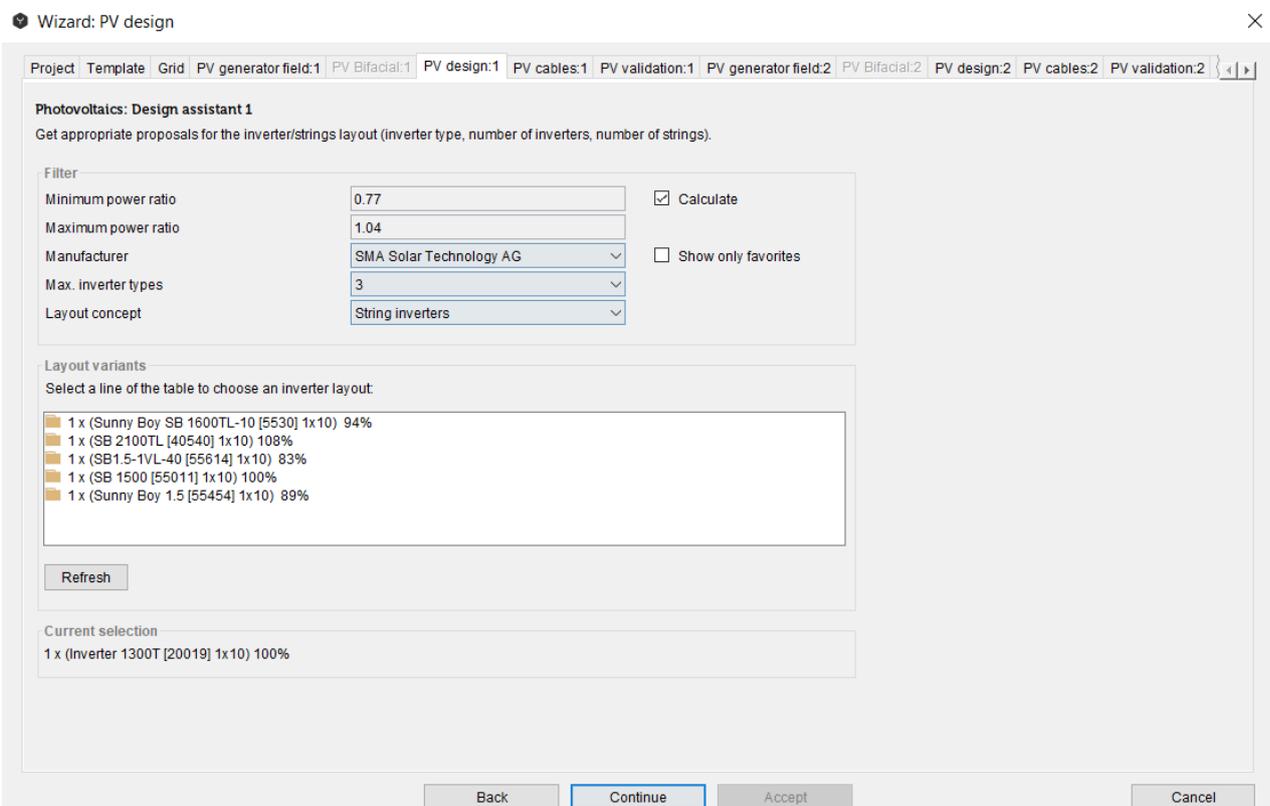


Fig. 37: selection of the inverter design in Wizard

Table 11. Filtering the layout variants

FILTER

<p>MINIMUM POWER RATIO MAXIMUM POWER RATIO</p>	<p>The layout results are filtered according to the power ratio (min-max power ratio. The value will be ignored if no results are found within the range. In Polysun it is the ration between maximum DC power and total nominal power of the generation field (number of module per inverter times nominal power Pmpp of the module). A bigger ration means that the inverter is overdimensioned. The optimal value depends on the orientation, tilt angle, region and reactive power.</p>
<p>MANUFACTURER</p>	<p>Producer or distributor of the inverter can be chosen from the drop-down list.</p>
<p>MAXIMUM INVERTER TYPES</p>	<p>Polysun can calculate combined layouts with up to three different inverter types.</p>
<p>LAYOUT CONCEPT</p>	<p>One of the following concepts can be chosen:</p> <ul style="list-style-type: none"> • Microinverters – 1 inverter pro module • String inverters – 1 string per MPP-tracker • Central inverters – at least 2 parallel strings per MPP-tracker • Uniform – 1 type per layout variant • Mixed – allow mixing different inverter types in one layout variant. The combination of different concepts is not allowed.

After all the filters have been chosen, Polysun shows layout variants. The power ratio is indicated by the percentage, e.g. [100%]. A click on the arrows or double click on a line opens the tree with the layout details.

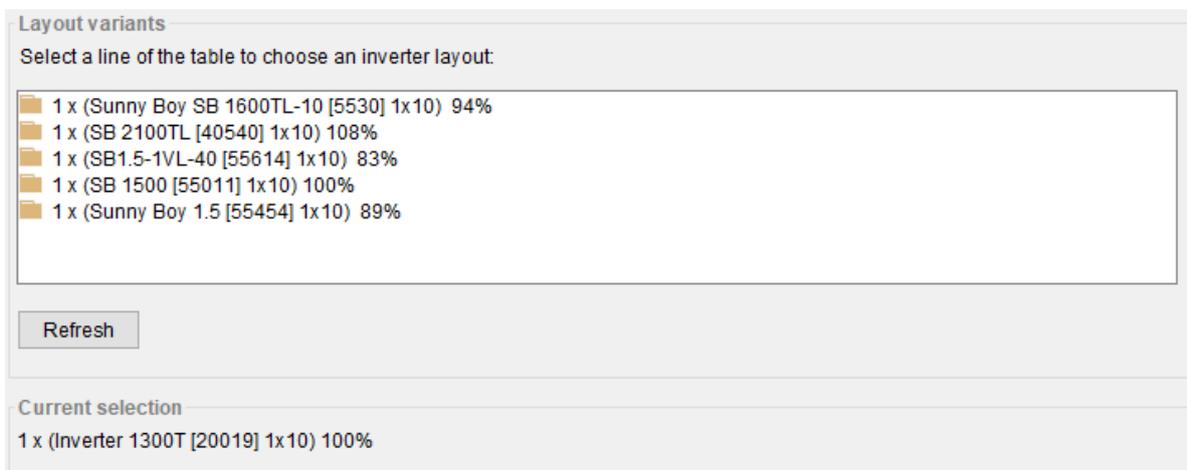


Fig. 38: inverter layout variants

Sorting configuration of inverter layouts is used from the 'Settings' under the tab 'Advanced 2'. This feature of Polysun is described in detail in the sub-chapter 2.8.1.

In the next step the cable losses are defined by the simple loss factor or detailed cable sections.

'Loss factor' defines DC cable losses at nominal power. The effective loss factor depends on the input power. Polysun calculates the loss factor in order to reach this value at nominal power. Total losses are much smaller than the loss factor, because the system rarely operates at a nominal power and therefore the loss factor is not constant.

In the 'Detailed cable sections' the cable sections which contribute to the calculation of the cable losses can be specified manually.

The cable section parameters, which shall be specified are:

- **Cable type** with an appropriate conductor diameter can be chosen from the catalog;
- **Current feed** defines how Polysun will compute the current through this cable section:
 - String – DC current of a single module or string;
 - N Strings – DC current of a specific number of strings (for example if this cable section is used for a part of the strings only);
 - Inverter DC – total DC current of all strings together, at inverter input;
 - Inverter AC – AC current at inverter output.
- **N strings** – number of strings for the current calculation. Only applicable if the current feed is set to N strings;
- **Length** (back and forth) for unit:
 - per string (current feed "string");
 - per inverter (current feed "N Strings", "Inverter DC")
 - per inverter and phase ("Inverter AC");
- **Quantity** defines how Polysun should compute the total length of the cable section:
 - Calculate number of units automatically from number of strings and/or number of inverters;
 - Number - enter a number of units manually.
- **Number** of units of the specified length
- **Total length** of the cable section, as it is inserted in the cable loss calculation.

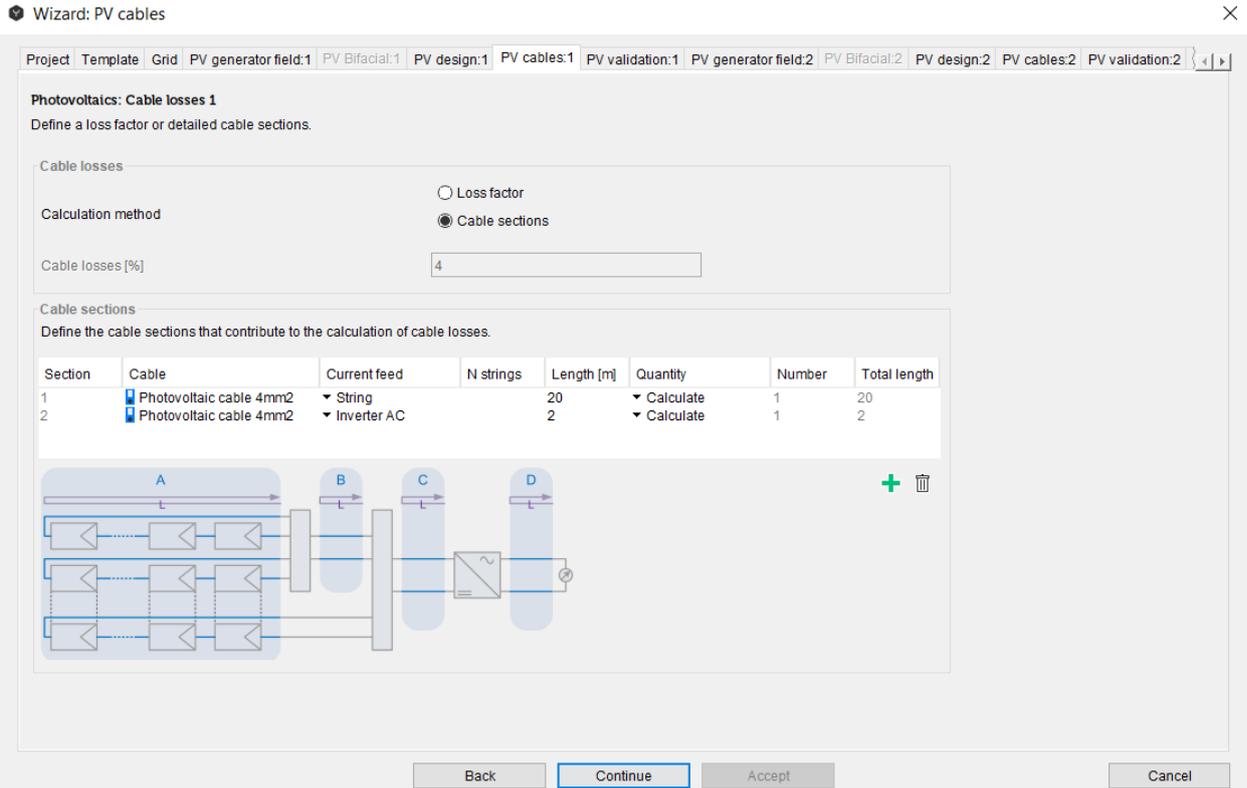


Fig. 39: cable losses calculation

The next step in the Wizard is the validation of the electrical limits of the inverter/strings layout. Validation can show an OK (green tick), error (red cross) or warning (yellow triangle) for each component in the system.

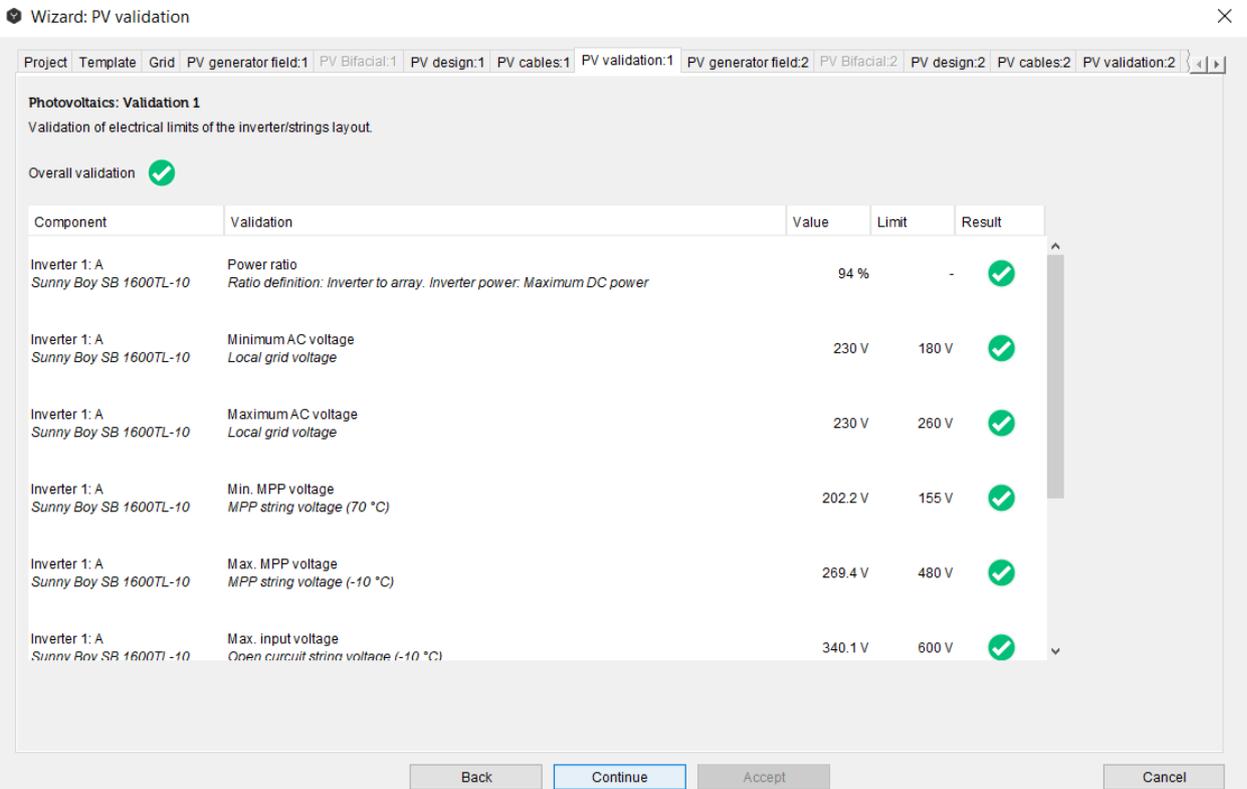


Fig. 40: validation of the electrical limits of the inverter/string layout

In the next step of the Wizard first the number of electricity consumption profiles shall be chosen as well as the consumption profile types from the catalog.

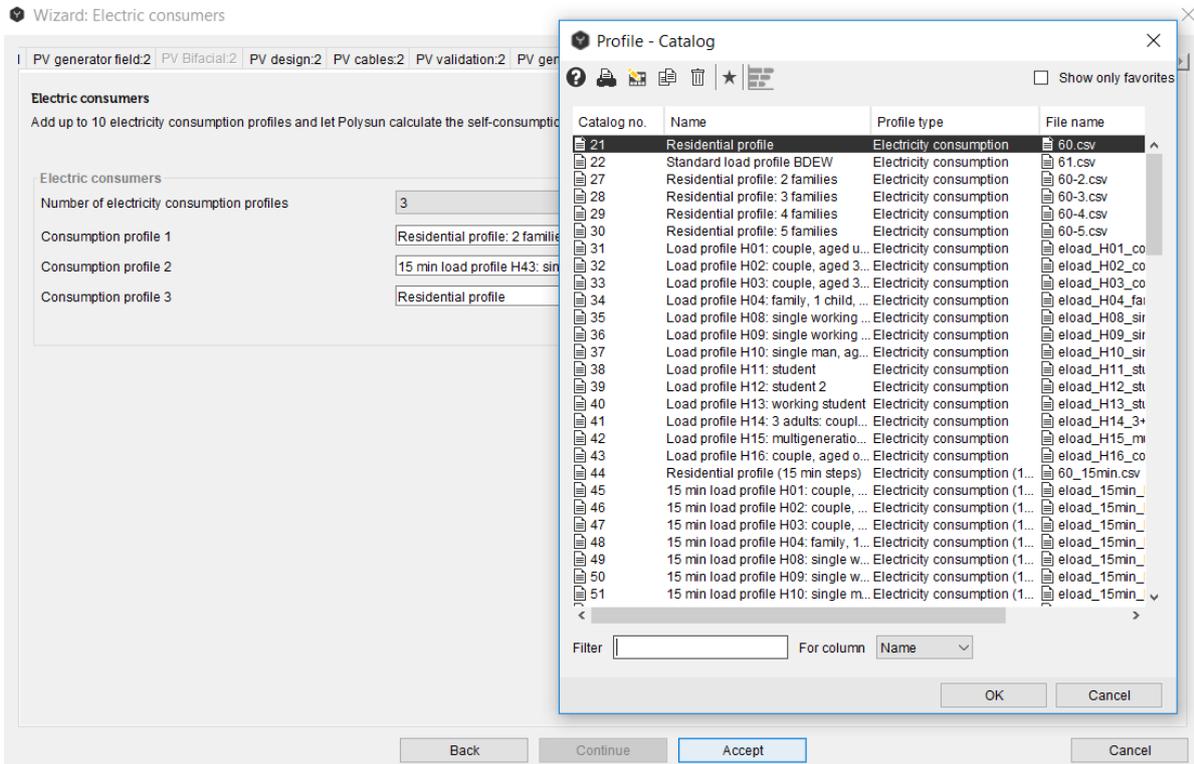


Fig. 41: adding the electricity consumption profiles

The annual consumption can be changed manually and the profile will be scaled up/down according to this number. After simulation Polysun shows the main system output parameters in the Results overview.

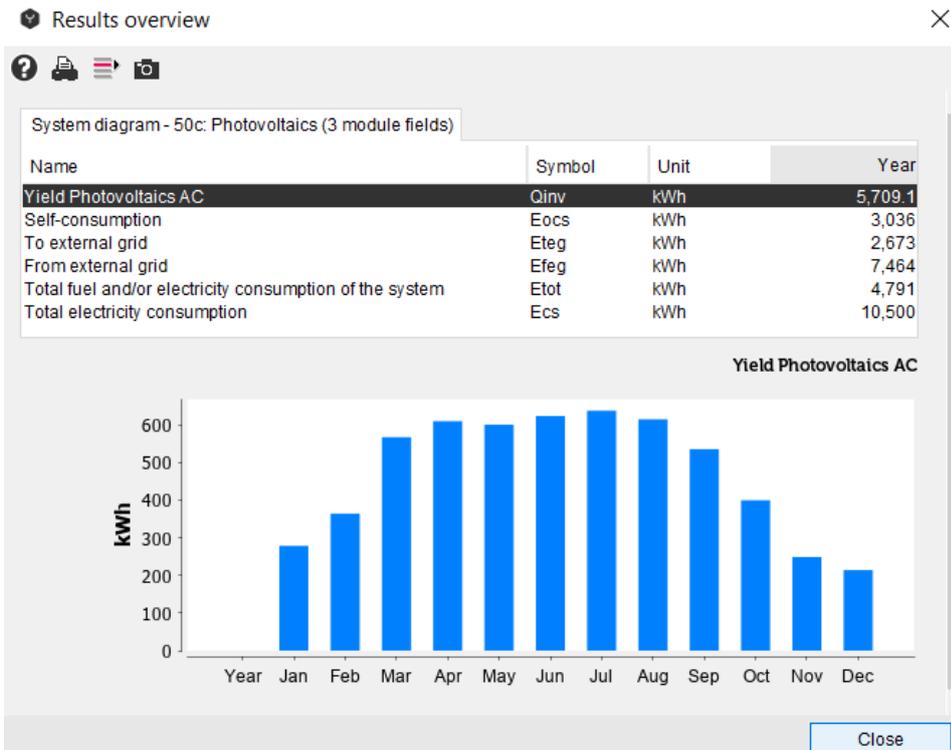


Fig. 42: simulation results overview

The more detailed results can be found in the Results → Component results.

System diagram 50c: Photovoltaics (3 module fields) - Component results

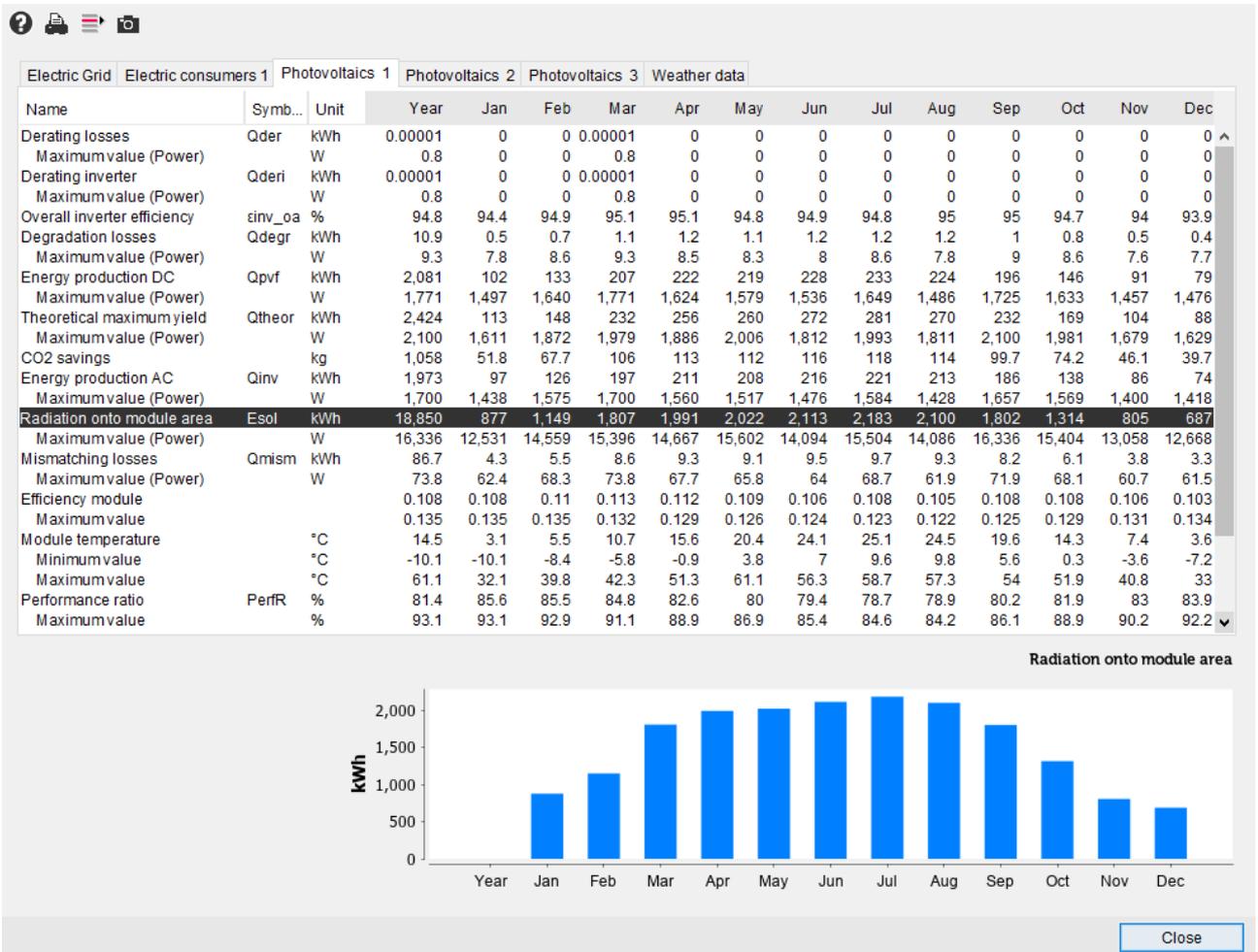
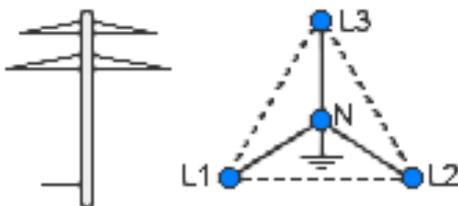


Fig. 43: detailed simulation component results

The main components of the grid-connected PV system in the system diagram are:

Electrical Grid



The electrical energy produced by the PV field is fed into the public electricity grid when 'Feed-in' is activated in the dialog window by clicking on the corresponding component.

Electric Grid
✕

? 🖨️ 🔒

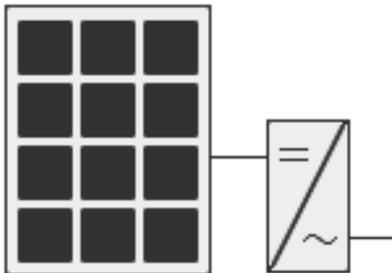
@	Name	Value	Unit	
	Description			<div style="border: 1px solid #ccc; padding: 5px;"> Schematic diagram </div>
	Show in report	▼ visible		
	Electric Grid	<input checked="" type="checkbox"/> Three-phase (230V/...		
	- Grid configuration	Three-phase star (WYE)		
	- Nominal voltage	400	V	
	- Nominal frequency	50	Hz	
	Local grid voltage	400	V	
	Voltage between outer lines	400	V	
	Star voltage	230.9	V	
	Check phase load imbalance	▼ Per phase		
	Maximum phase load imbalance	4.6	kW	
	Feed-in	▼ yes		
	Use profile	▼ no		
	Feed-in power limitation	▼ no		
	Anti-blackout	▼ yes		

OK

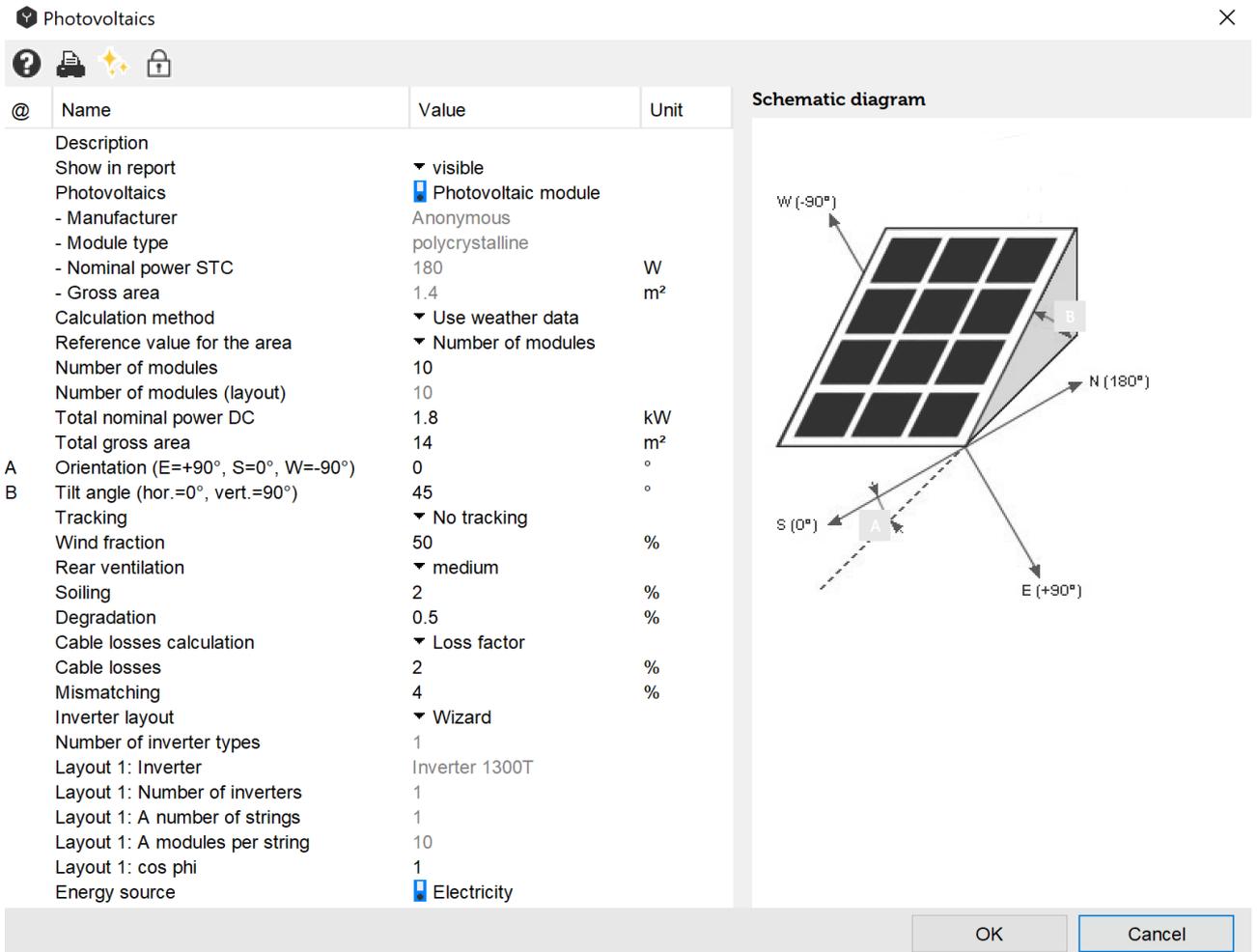
Cancel

Fig. 44: description of the electric grid

Photovoltaic component: inverter and PV module field



All parameters defined with the Wizard can be changed manually in the photovoltaic component. After all the changes have been entered, the validation through the Wizard must be carried out to ensure validity of the system.



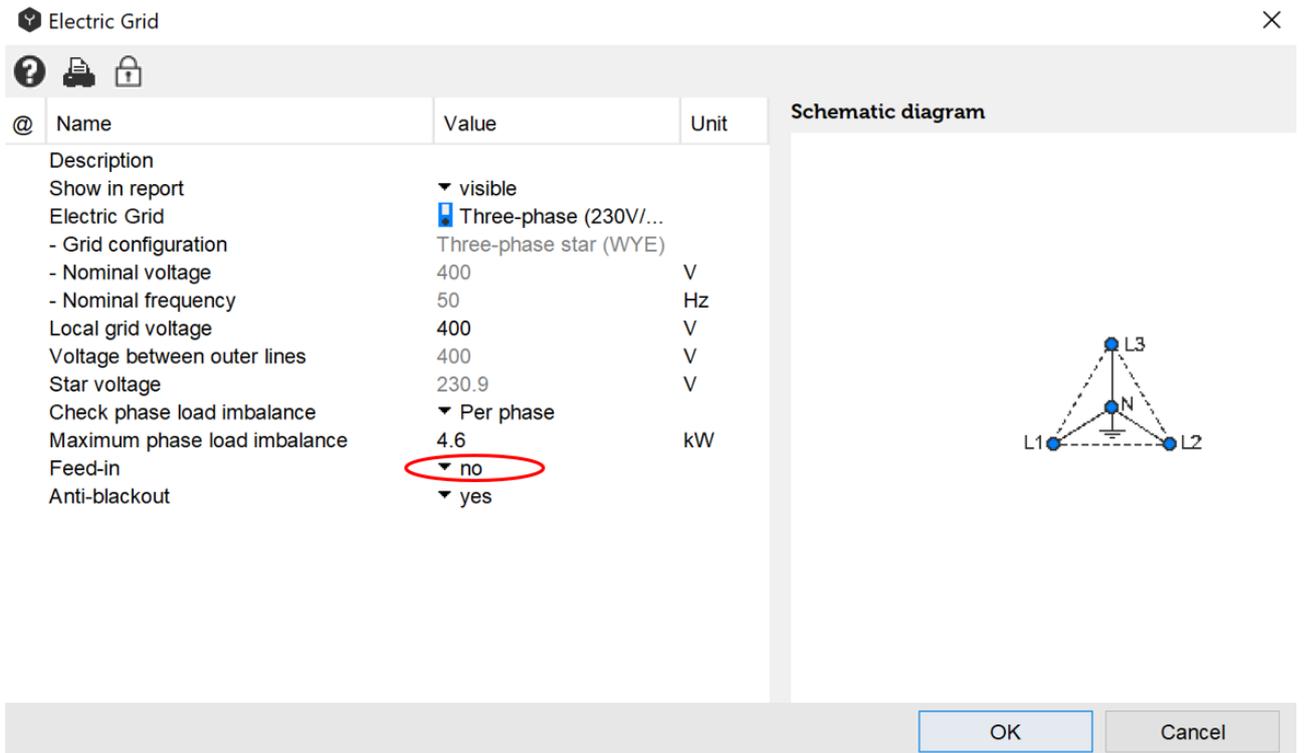


Fig. 46: disconnecting the photovoltaic system from electrical grid

The battery is another important system component for off-grid systems, which is described in detail in chapter 2.5.

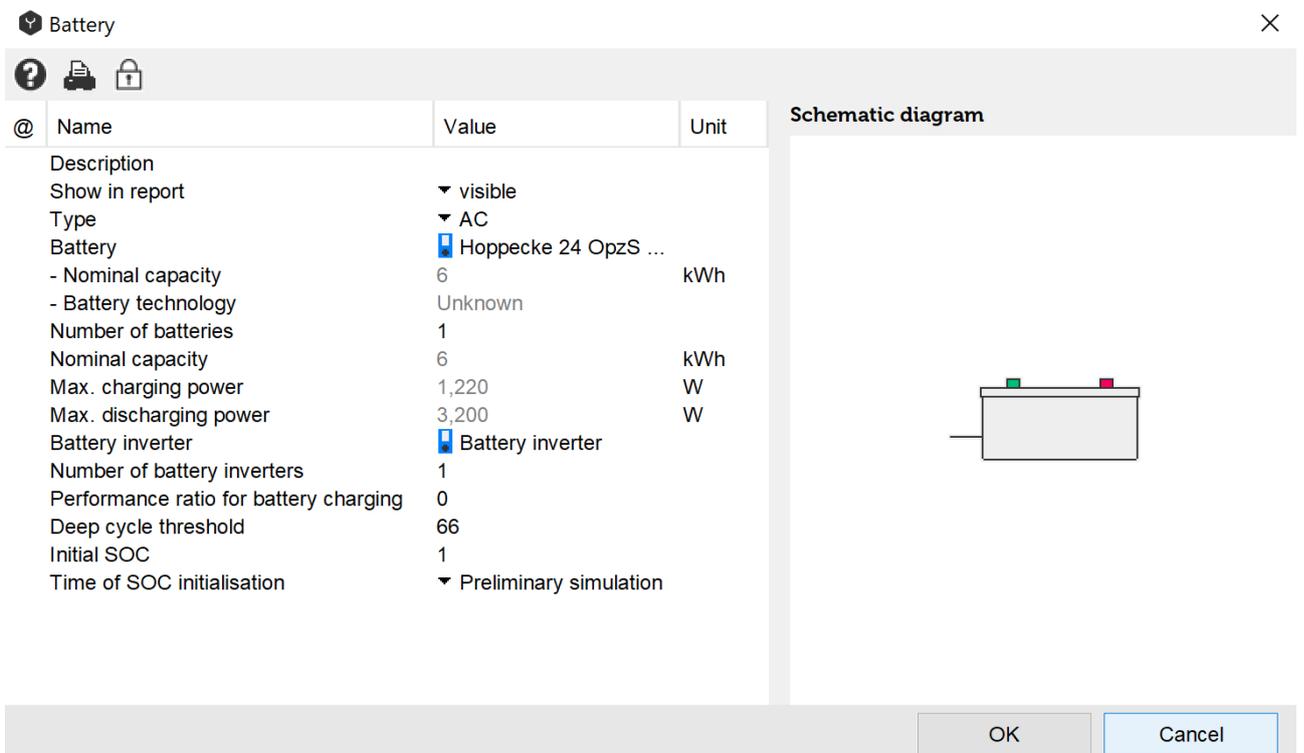


Fig. 47: battery component dialog window

2.8.3 Sorting of Inverter Layouts

This feature allows the user to configure the sorting of inverter layouts according to specific requirements. This feature can be found in the 'Settings' under the tab 'Advanced 2'. First, the criteria must be chosen for calculating the inverter layout, which are as follows:

Table 12. Inverter layout concepts

CONCEPT	DESCRIPTION
MICROINVERTERS	1 inverter per module
STRING INVERTERS	1 string per MPP-tracker. No parallel strings are allowed.
CENTRAL INVERTERS	At least 2 parallel strings per MPP-tracker.
MIXED UNIFORM	Allow mixing different inverter types in one layout variant. 1 type per layout variant (microinverters, string inverters, central inverters). Do not allow the combination of different concepts.

Second, the sorting criteria must be chosen. The sorting criteria are taken into account sequentially in the ascending order from 1 to 4. The following criteria are available:

- Number of combinations, ascending;
- Total number of inverters, ascending;
- Total number of strings, ascending;
- MPP voltage, descending;
- Relative MPP voltage, descending;
- Nominal voltage deviation, ascending;
- Power ratio deviation, ascending.

The most important parameters are:

- 1) Number of combinations, ascending;
- 2) MPP voltage, descending;
- 3) Total number of inverters, ascending

If there are too many results available after sorting, only the first 20 results are presented to the user.

Polysun Video



[Simulation of east-west module fields](#)

3 Solar Thermal and Conventional Heating Systems

The above mentioned irradiation values naturally cannot be entirely utilized by a collector. There are various factors which contribute to cause one part of the energy not to be transmitted to the heat transfer fluid.

- The partial reflection on the cover glass (approx. 8%), except for uncovered collectors
- The partial absorption by the collector, depending on the coating: minus 4-10 %
- The incomplete cooling of the absorber, the so-called factor F' : minus 3-10 %
- The emission of heat by thermal radiation, depending on the coating and the temperature
- The loss of heat by means of thermal conduction and convection, losses depending on temperature

The efficiency of a collector greatly depends on the difference between the average temperature of the collector and the external temperature. If this difference is substantial (i.e. 80°C), there are great losses because of thermal radiation and convection. In case of small temperature differences, the efficiency can reach up to approx. 90%. When the

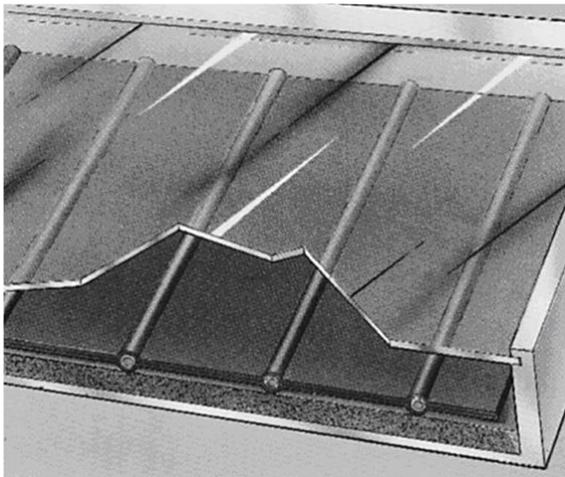


Fig. 48: schematic drawing of a glazed flat-plate collector. The heat transfer fluid flows through the thin longitudinal pipes.

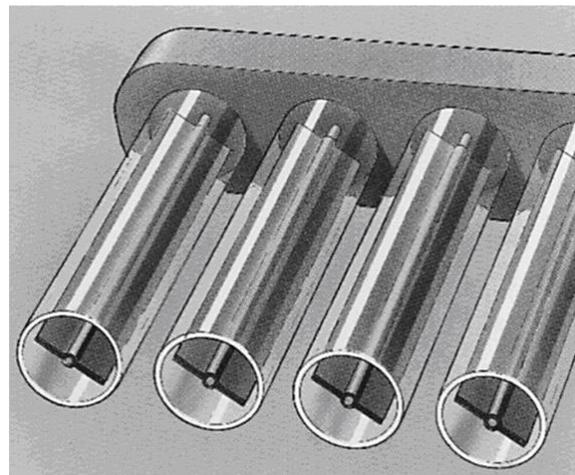


Fig. 49: schematic drawing of a vacuum tube collector. The heat transfer fluid flows through the thin longitudinal pipes.

temperature of the collector, due to cold fluid, is less than the surrounding ambient temperature, an efficiency could result even "greater than 100%". In this case the heat transfer fluid becomes heated not only by the sun, but also by the heat from the surrounding environment.

There are three different types of collectors. The most suitable one depends on user needs.

Unglazed collectors: uncovered flat-plate collector type. Unglazed collectors are ideal for heating pools and for certain uses of pre-heating hot water. In regions where strong winds prevail, there are greater convective losses. On the other hand unglazed collectors are low in cost and don't cause reflection (something which in glass-covered collectors often cause complaints).

Glass-covered flat-plate collectors (illustration on the left): are the most widely used collectors. They are suitable for pre-heating water, for the production of hot water and for space heating. They are a somewhat more expensive than uncovered collectors. Thanks to their good thermal insulation they are suitable for integration in facades.

(Vacuum) tube collectors (illustration on the right): are especially ideal for the production of hot water or where external temperatures are generally low (or when a considerable part of solar irradiation takes place in winter). This is based on the idea that the absorber in a vacuum tube only loses energy for thermal radiation. In addition, the reflective behaviour of light and the geometry of the tube in glass contributes to making the obliquely falling light arrive more efficiently to the absorber compared to what happens in flat-plate collectors. Overall, tube collectors are the most expensive though, and for certain uses are not always as suitable as flat-plate collectors.

3.1 Solar Thermal Collectors

Together with thermal properties, geometric and optical properties also contribute to establishing the efficiency of collectors. On one hand, in the presence of low angles of incidence (when the surface of the collector is irradiated “obliquely”) the irradiated surfaces become smaller. On the other hand, the cover glass reflects light much more intensely the lower the angle of reflection. This property dependent on angle is called IAM (Incident Angle Modifier).

It is possible that the efficiency curve of a collector can be higher than that of another which due to its reflective properties shows a lower annual yield. As a consequence the IAM is equally important for the description of a collector as well as its efficiency.

In a flat-plate collector, depending on size, it is of little importance that the angle is traced on the longitudinal axis or the transversal axis (longitudinally or transversally), as long as the glass does not have an unusual structure or the collector is not too elongated in shape.

The physical phenomenon of reflection and partial shade is well understood. It can be described by means of the Ambrosetti function $K(\theta) = 1 - (\tan(\theta/2))^a$ with a single parameter. In respect to this reflectant properties are often defined at an angle of 50° . At this angle it is possible to experimentally define efficiency with great precision and evaluate the angular effect reasonably well. The IAM values between the longitudinal and transversal orientation are approximated with the function $K(\theta, \varphi) = K(\theta, 0^\circ) * \cos^2(\varphi) + K(\theta, 90^\circ) * \sin^2(\varphi)$.

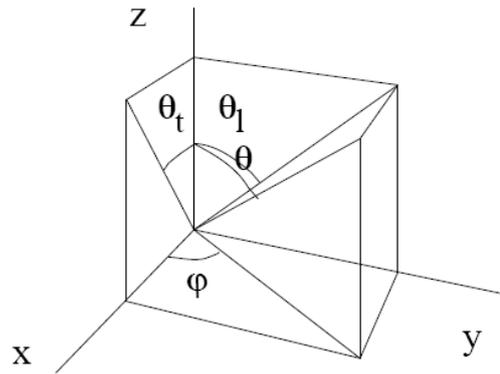


Fig. 50: definition of sphere coordinates

In tube collectors the two IAM values are different. Due to the reflective properties of the glass tube, in the transversal direction, the irradiation of energy diminishes less intensely in respect to what we should expect in the presence of the perspective reduction of the collector's surface. Beginning at a certain point though, the IAM drops drastically, due to the reciprocal shadowing of the tubes.

The longitudinal direction can also be calculated by the Ambrosetti function and with a point of measurement at 50° inclination from the norm. For the transverse direction, given the geometry of the collector, more measurement points are necessary and are interpolated with the help of a cubic spline. The conditions for the scope of the spline, (first and second derivation), are correspondent to a reflection on the axis Z $\theta=0^\circ$. All of the values between the longitudinal axis and transversal axis are approximated by the well-known McIntire function. However, there is also the possibility to insert IAM tables obtained by measurement or simulation.

3.1.1 Collector Model according to European Standards (EN)

The efficiency of a collector is represented by the so-called "efficiency curve". The difference in temperature (between the average collector temperature T_m and the outdoor temperature T_a) is divided by the total irradiated energy G_k : $x = (T_m - T_a) / G_k$

A normal glass-covered flat-plate collector therefore has the following curve:

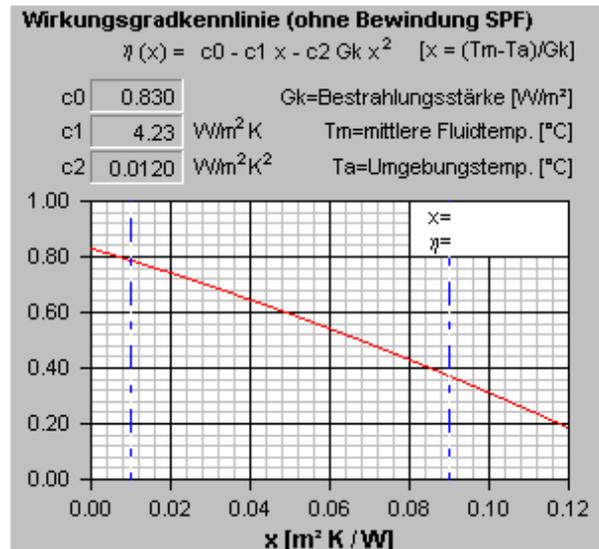


Fig. 51: efficiency curve of a glass-covered flat-plate collector. The higher the temperature of the collector, the lower the efficiency. The intensity of irradiation is $G_k = 800 \text{ W/m}^2$

The trend of the curve can be described by means of a polynomial of the second order, clearly determined by means of three parameters, c_0 , c_1 and c_2 (or by means of η_0 , a_1 , a_2 ; values measured at a wind velocity of 2-4 m/s):

$$\eta(x) = c_0 - c_1 \cdot x - c_2 \cdot G_k \cdot x^2$$

c_0 is the efficiency rate achieved when the average temperature of the collector and the outdoor temperature are equal. This value should be as high as possible. c_1 and c_2 are a combination of different loss factors. In a well insulated collector, these values should be as low as possible.

The operation of a solar energy system requires a certain compromise. On one hand you need a collector to work at the highest efficiency level, on the other the generated hot water should have a temperature of 50°-60°C. This means inevitably having the collector operate at these temperatures.

This explains why solar energy is often used for the pre-heating of water in large buildings. When cold water is heated from 10°C to 30°C, the collector works at a high level of efficiency. In terms of energy demand, it is of little importance that the water is heated from 10 to 30°C or from 30 to 50°C. Therefore the efficiency rate of collectors is quite high in pre-heating. These kinds of systems can be profitable already after a few years.

As briefly outlined, there are three main collector categories. They are distinguished among other specifications by their efficiency rate curves.

- Glass-covered flat-plate collectors: $c_0 = 0.75\text{-}0.85$, $c_1 = 3\text{-}6 \text{ W/m}^2/\text{K}$
- Tube collectors: $c_0 = 0.65\text{-}0.80$, $c_1 = 1\text{-}2 \text{ W/m}^2/\text{K}$
- Unglazed (uncovered) collectors: $c_0 = 0.90\text{-}0.95$, $c_1 = 10 \text{ W/m}^2/\text{K}$

The illustration shows the most efficient models of these three types of collectors:

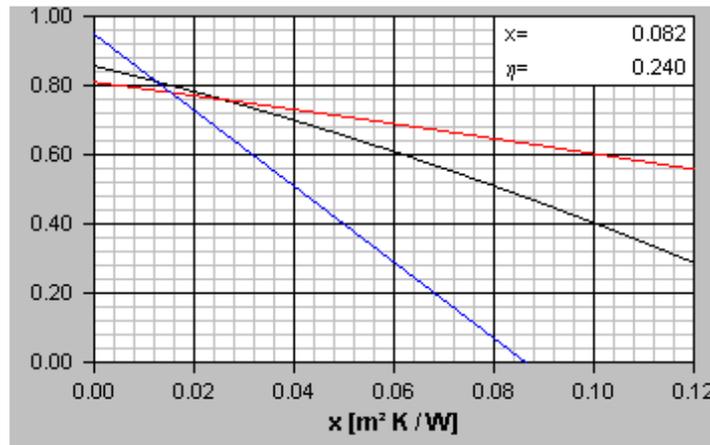


Fig. 52: efficiency rate curve of different collector types: unglazed flat-plate collector (steepest curve), glass-covered flat-plate collector, tube collector (flat curve).

A value of $x = 0.10 \text{ m}^2 \text{ K/W}$ corresponds at an irradiance of 800 W/m^2 to a temperature difference of $T_m - T_a = 80^\circ\text{C}$. At these operating conditions, the indicated tube collector still has an efficiency rate of 60%, the covered collector 40%, while the unglazed collector is no longer able to produce energy at these temperatures.

3.1.1.1 Numeric Model for Non-Covered Collectors

In accordance with the standards for measurement (EN 12975) non-covered collectors are given an additional parameter. The efficiency function curve has the following form:

$$\eta = \eta_0 * (1 - b_u * u) - \frac{(b_1 + b_2 * u) * (t_m - t_a)}{G''}$$

The coefficients η_0 , b_u , b_1 and b_2 are calculated by means of the adaption of the curve. G'' is the total irradiance which is determined on the basis of the following equation:

$$G'' = G_k + \left(\frac{\varepsilon}{\alpha}\right)(E_L - \sigma T_a^4)$$

E_L is the measurement of the intensity of long-wave irradiance onto the collector area and T_a is the outdoor temperature. For ε/α the value is fixed at 0.85, if the supplier has not given other indications.

3.1.1.2 Input Parameters

The decisive parameters that describe the efficiency of a collector, include in addition to the **absorber area A**, **efficiency rate parameters** c_0 , c_1 and c_2 and the **IAM values** $KCH1$ and $KCH2$, the **specific heat capacity** of the collector. The latter measures the “thermal inertia” of the collector: if a collector has great heat capacity it lasts longer, up until a certain quantity of solar irradiation has heated up the collector. On the other hand the collector still passes heat to the fluid when the sun is covered by a cloud. A collector with little heat capacity reacts more quickly to the variations of irradiation intensity.

In many cases the orientation of the collector is established on the basis of the pitch and the orientation of the roof. Here one can ask if the collector should be oriented east or west (if south is not possible) or if it should be integrated into the facade. With flat roofs, orientation and tilt angle can be chosen freely. The question to ask in these cases is ‘With which angle is it possible to obtain the maximum annual efficiency?’ There is no single answer. The optimum orientation and tilt angle could be different according to water consumption, the size of the tank, the climate and many other conditions.

For the choice of orientation, Polysun makes available the following dialogue window:

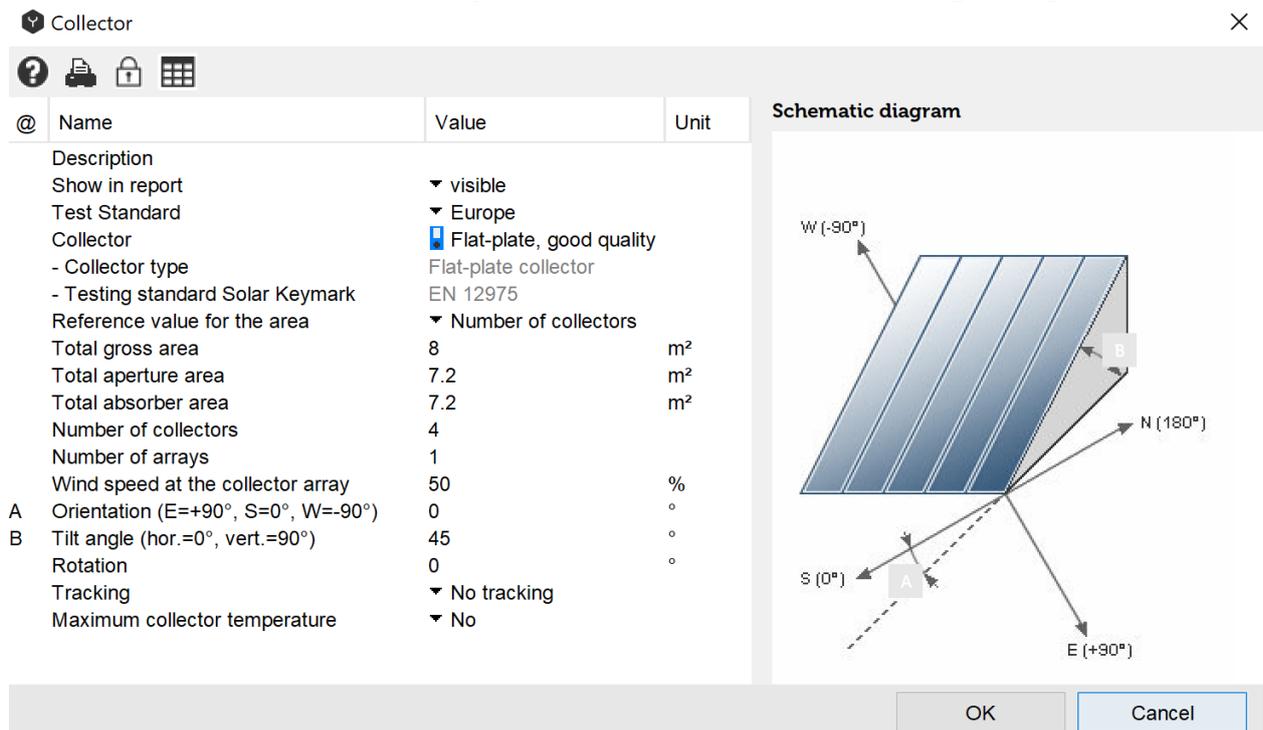


Fig. 53: dialogue window for defining collector orientation. Tilt angle and orientation can be optimized for single months or for the entire year. Tube collectors can be arranged vertically or horizontally.

3.1.1.3 Collector Data Entry in Polysun according to European Standards

Table 13. Collector data entry in Polysun in accordance with European standards

Collector type:	Chapter 4.1 describes two different models to calculate the efficiency value of the collector. For the input “flat-plate or tube collector” the standard model will apply whilst for unglazed collectors the “uncovered collector” model will apply.
Eta0 laminar ⁽¹⁾ ; bu:	“Eta0 laminar” is the efficiency value of a collector operating at outdoor temperature and in laminar flow conditions. Values of Eta0 laminar up to and of a2 refer to the aperture area of the collector and are determined at a radiation intensity of 800W/m2. “bu” is the wind reduction coefficient for uncovered collectors.
Eta0 turbulent:	The efficiency value of a collector operating at outdoor temperature and in turbulent flow conditions.
A1 (without wind) ⁽²⁾ ; A1 b1:	A1 coefficient for flat-plate and tube collectors measured with no wind or b1 in uncovered collector models.

A1 (with wind) ; b2:	A1 coefficient for flat-plate and tube collectors measured in normal ventilation conditions or b2 for uncovered collector models.
A2 ; epsilon/alpha (3):	A2 coefficient for flat-plate and tube collectors or epsilon/alpha or uncovered collector models.
Dynamic heating capacity (4):	Value computed pursuant to EN 12975-2, section 6.1.6.2
Nsis-Axis:	The orientation (tubes at a 90° horizontal or vertical elevation) for tube collectors. Mostly irrelevant in case of flat-plate collectors.
IAM model:	The "Ambrosetti Model" (described in chapter 1.3) is used to interpolate different flat-plate collectors. Tube collectors are interpolated by means of a cubic spline.
Angle factors (5):	IAM data are read over a table. Azimuth φ and elevation θ are described in chapter 1.3.
Volume:	Measured value of fluid volume in the collector including the manifold tubes.
Internal diameter:	Internal diameter of heat transfer pipes in the collector. C in figure n. 17.
Single pipe length (6):	The length of a single heat transfer pipe in the collector. A in figure n. 17.
Parallel piping:	Number of parallel pipings in the collector. 5 in figure n. 17.
Pipe roughness:	Roughness factor relating to the inner side.
Linear form factor:	The form factor of a pipe ranges based on bend radius between 1-1.5. The factor for rectilinear pipes is 1.
Friction factor:	The friction factor refers to pressure drops in branchings, valves, etc. If not measured it will be set on zero.
Test flow rate (7):	Fluid flow rate during a test. In l/h and collector.

(1): In the event that no indications are available about $\eta_{0 \text{ laminar}}$, $\eta_{0 \text{ turbulent}} = \eta_{0 \text{ laminar}}$ will apply.

(2): Pursuant to new provisions the a_1 with wind coefficient is detected at a wind speed of 3 m/s. The efficiency parameter c_1 may be worked out as follows:

$$c_1 = a_{1 \text{ without wind}} + \frac{(a_{1 \text{ with wind}} - a_{1 \text{ without wind}})}{(3 \text{ m/s})} \cdot v_{\text{wind}} \cdot \text{windportion}$$

If a_1 without wind is not expressly indicated, select a_1 without wind 10% lower than a_1 with wind for flat-plate collectors and 5% lower for tube collectors.

(3): Fix $\epsilon/\alpha = 0.85$ in case this was not otherwise pre-set by the manufacturer.

(4): Directive EN 12975-2 establishes two different procedures for the calculation of dynamic heat capacity; in appendix J3 a measured value and in section 6.1.2.1 a calculated value. The calculated value is typically much lower than the measured value. Collector geometry is not taken into consideration. Notwithstanding the high reliability of the measured value the calculated value is actually used in Polysun.

(5): Angle factor tables may not yet be entered directly by the user. In the creation of a given collector a collector with similar IAM values should be copied.

(6): In case no measurable or obvious indication is given enter the width or length of the absorber.

(7): Test flow rate, maximum flow rate, maximum pressure and maximum temperature do not currently affect the calculation.

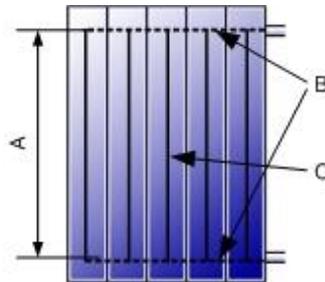


Fig. 54: collector model (A: length of single pipe, B: manifold pipes, C: single pipe)

3.1.2 Collector Model according to American Standards (ASHRAE)

Collectors complying with the ASHRAE 96-1980 and 93-1986 standards are modelled analogously to collectors complying with European standards. An overview of the main differences is provided below.

The following applies to the efficiency:

$$\eta(x) = \eta_0 + a_1 \cdot \frac{P}{I} + a_2 \cdot \frac{P^2}{I}$$

where

$$P = T_i - T_a$$

T_i = temperature of the fluid flowing through the collector

T_a = ambient temperature

I = irradiance on collector surface

The values measured for η_0 , a_1 and a_2 refer to the gross-surface. The relevant standard does not require absorber surface to be measured and so this is equalled to the aperture area. The a_1 value is recorded in the absence of wind; in case of wind blowing at 3m/s a_1 is to be multiplied by a 1.05 factor for tube collectors, 1.1 for glazed flat-plate collectors and 1.2 for unglazed flat-plate collectors. The influence that wind has on the collector is calculated like provided in the above chapter for European standards. Glazed and unglazed collectors can otherwise be calculated by means of the same model.

Should no indication be available for the mcp heat capacity the relevant field can be left blank; the standard value 10000 J/K will thus be used for the simulation .

The pressure loss can be deduced from three recorded interpolation nodes. Should no indication be available in this respect the relevant fields can be left blank; the following standard values will then be used for the simulation: 72, 180, 288 [l/h] for volume currents, 262, 885, 1784 [Pa] for pressure losses.

3.1.3 PVT Collectors

This type of collector consists of a combination of a solar-thermal collector and a PV module. Possible parameter alterations are identical to the components described in greater detail above. This combined-system only differs from the individual solutions in its operating features. For further details see the relevant chapter.

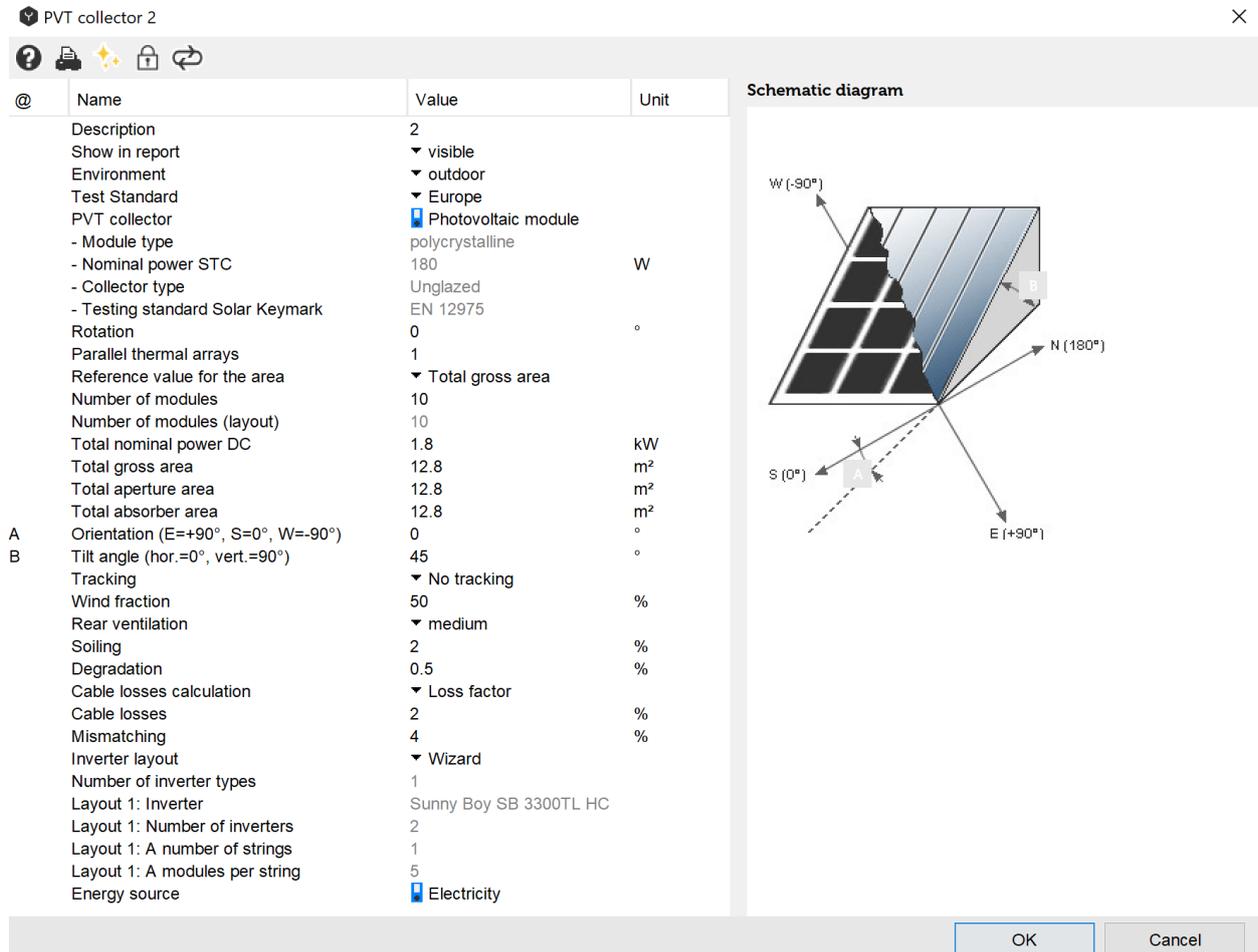


Fig. 55: PVT collector dialogue box

3.2 Hot Water Tanks

3.2.1 Tank Types

With the aim of having an efficient system, in addition to the collector the thermal tank is of great importance. The choice of tank is decisive, from the moment that energy from the sun is not available and that occasional meteorological conditions occur for which the collector, for one or two days does not supply thermal energy. Three categories may be identified:

- Domestic hot water tanks (dimensions: twice the daily demand = 80-100 l per person)
- Tanks for hot water and space heating (dimensions: 100 l per MWh of heating demand)
- Seasonal tanks as tanks for several months (water storage tank, terrestrial seasonal thermal accumulator, etc.)

An average single family house with four people calls for tank dimensions of 300-500 l (domestic hot water only), 800-1500 l (with space heating) and over 30,000 l (seasonal tank). Combined forms also exist, in which the domestic hot water tank is integrated in a larger tank (the so-called combined tank).

3.2.2 Physical Aspects in the Optimization of the Hot Water Tank

The quantity of energy Q [J] necessary for a heat transfer fluid of the mass m [kg] with a heat capacity c_p [J/kg/K] to heat a temperature ΔT [K] is calculated as:

$$Q = m * c_p * \Delta T$$

Nevertheless the distribution of heat in the tank is to be taken into consideration: normally the water is stratified at different temperatures. At the top, where the hot water is withdrawn, the layer with the hottest water is found (less dense water) and at the bottom there is the coldest layer (denser water). This stratification is desirable and for this reason the generation of the least possible turbulence is sought during the transfer of heat to the tank and the withdrawal of water.

Defining the dimensions of a tank is an exercise in proportion, in which various contrasting aspects are weighed out:

- A large tank has a great capacity
- A large tank needs a lot of energy to be “charged up”
- The higher the temperature, the greater the quantity of stored energy.
- The higher the temperature, the greater the tank losses

Usually it is sought to keep ready the quantity of water for daily consumption at the right temperature (or a few degrees higher) and to keep the rest of the tank temperature lower. This way the (cover of) hot water is always guaranteed and the losses from the tank are minimal. In the summer season though the tank can become overcharged, but having sufficient quantities of solar energy at this time allows acceptance of higher tank losses. The interesting fact is that the demand can be covered even in periods of bad weather. Since the water tank can be heated up to 95°C (also to 100°C) and the water reaches the desired temperature only when it is withdrawn and mixed with cold water, one can continue for several days.

3.2.3 Sizing the Combined Tank

The combined tank is used when one wants to produce domestic hot water and space heating from a single solar energy system. Since the heating circuit and that of drinking water should not be united for hygienic reasons, the domestic hot water boiler tank is integrated into the main tank with the combined hot water tank. This has three main advantages:

- The surface area of the tank can be kept small (only the surfaces of the main tank), in this way heat losses are minimal.
- The domestic hot water tank, which normally requires higher temperatures than the space heating tank, can be placed in the warmer upper part of the main tank.
- A higher consumption of hot water doesn't cause turbulence in the main tank. This way the stratification is better maintained.

The principal of a combined tank resembles that of a continuous flow heater. The domestic hot water, in a system of separate pipes, passes through the main tank where it is heated. Because this heat exchange needs to be as efficient as possible, the interior tank should have thin walls and be made of a material with high thermal conductivity.

The internal tank is located preferably in the upper half of the main tank (5-10 cm below the top cover). Its size should correspond to approximately double that of daily consumption.

The heat losses at the connections (see following paragraph) can be indicated in the second part of the dialogue window. The values proposed by Polysun are equivalent to well insulated s-bending connections.

With the Polysun Designer one can create a new tank with a great variety of possibilities.

Tank choice

Please configurate the storage tank:

Tank name

Connections

Left cap Right cap

Left top Right top

Left center top Right center top

Left center bottom Right center bottom

Left bottom Right bottom

Coil heat exchanger

Left top Right top

Left center Right center

Left bottom Right bottom

Stratifier lances

Left Right

Center left Center right

Internal heater

Top

Center

Bottom

Jacket heat exchan...

Internal tank

Top Tank Coil Pipe Empty

Center Tank Coil Pipe Empty

Bottom Tank Coil Pipe Empty

OK Cancel

Fig. 56: selection for defining a new tank

With the selection of a new tank a new catalog entry is created. In creating a new tank the standard components for the internal elements are established (coil heat exchanger, stratifier lances, auxiliary heating, etc.) The choice of internal elements are set in the tank catalog, where it is possible to eventually create new specifications in the catalog for the internal elements.

The following figure shows some exemplary possibilities:

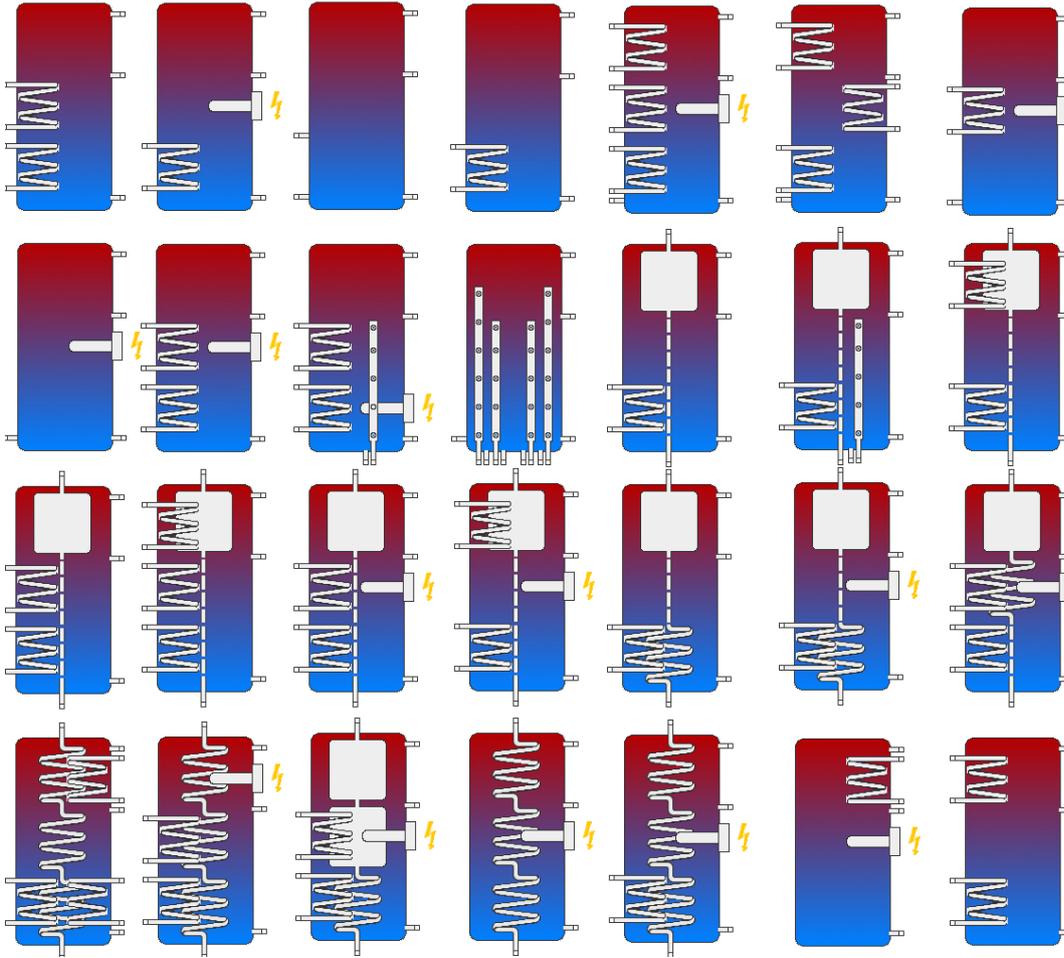


Fig. 57: various tanks

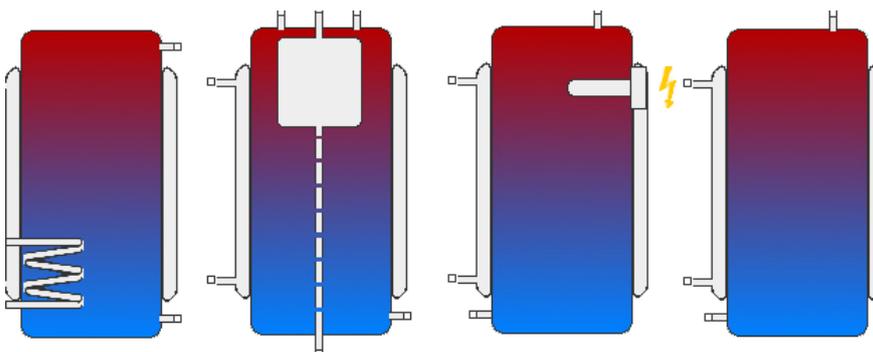


Fig. 58: tanks with coil heat exchangers

3.2.4 Tank Model and Relative Dimensions

For measurement, the height of the cylindrical part of the storage tank, the bulge height and the volume are important. By means of these three values the diameter is obtained.

With the height of the tank we don't mean the total height, including the thermal insulation, but only that of the cylinder.

The interior of the tank is subdivided into twelve isothermal layers. The fluid contained by the bulge is always added to the lower and higher layer, for which the relative volumes are greater in respect to those layers from two to eleven. For the difference in density, the hot layers spread towards the top, the cold ones towards the bottom. In the border area there is heat transmission by means of conduction. A convective mix is ignored.

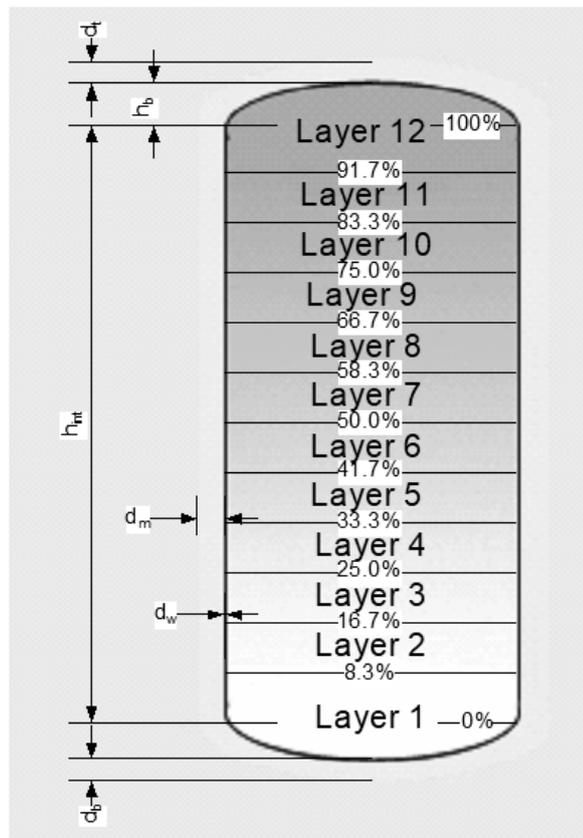


Fig. 59: measures and tank layers (d_m = thickness of insulation, d_t = thickness of insulation at the top of the tank, d_b = thickness of insulation at the bottom of the tank, d_w = thickness of the walls, h_{int} = height, h_b = bulge height)

The internal components of the tank shown are not correctly positioned from a graphic point of view. The determinant indications regarding the positioning are those in percentage in the tank catalog.

A tank has a maximum of ten connecting pieces available. The positioning in percentage is always measured from the lower part of the cylinder. (Note: not from the bottom of the tank). Likewise the connecting pieces are numbered from the bottom left towards the top and again from the bottom right towards the top.

The simulation does not allow unconnected open flanges. The incoming fluids have to be able to leave the tank by means of other connecting pieces.

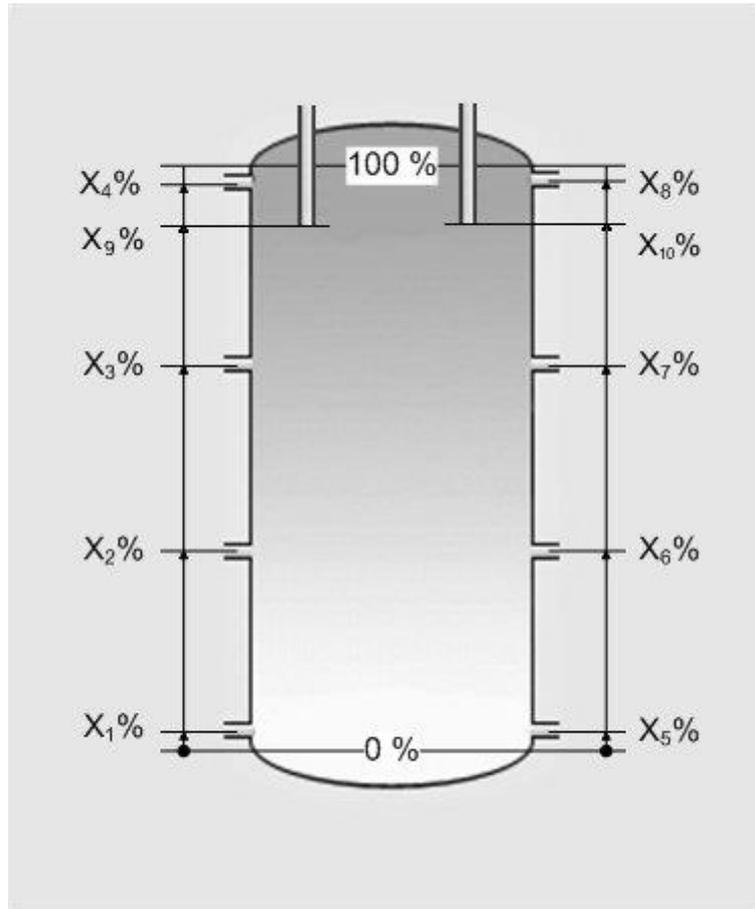


Fig. 60: positions of connecting pieces

A tank has up to six coil heat exchangers available. Three coil heat exchangers can be connected to the left internal tank wall and three to the right wall of the tank. This system diagram is illustrated in figure 20. The height of the coil heat exchangers is indicated in millimeters in the catalog “Coil heat exchangers”, its position in the tank is indicated in percentage from the top edge of the coil to the lower part of the cylinder.

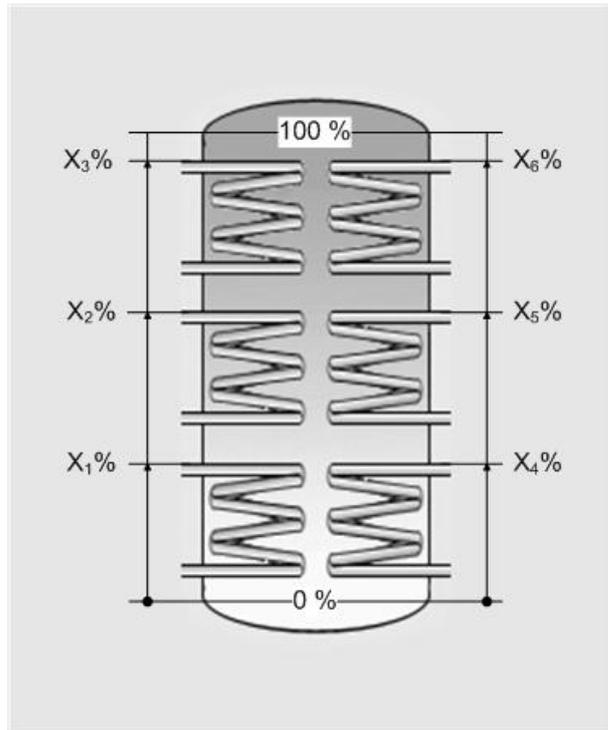


Fig. 61: arrangement of coil heat exchangers

The three internal elements “tank”, “tube” and “coil heat exchanger” are defined as shown in figure 21. Furthermore they have available positions from one to three, that can be substituted by choice with the three objects.

The volume of an internal tank is defined in function of the relative surface and the relative positioning. The height of the internal tank is calculated on the basis of the indications of its position

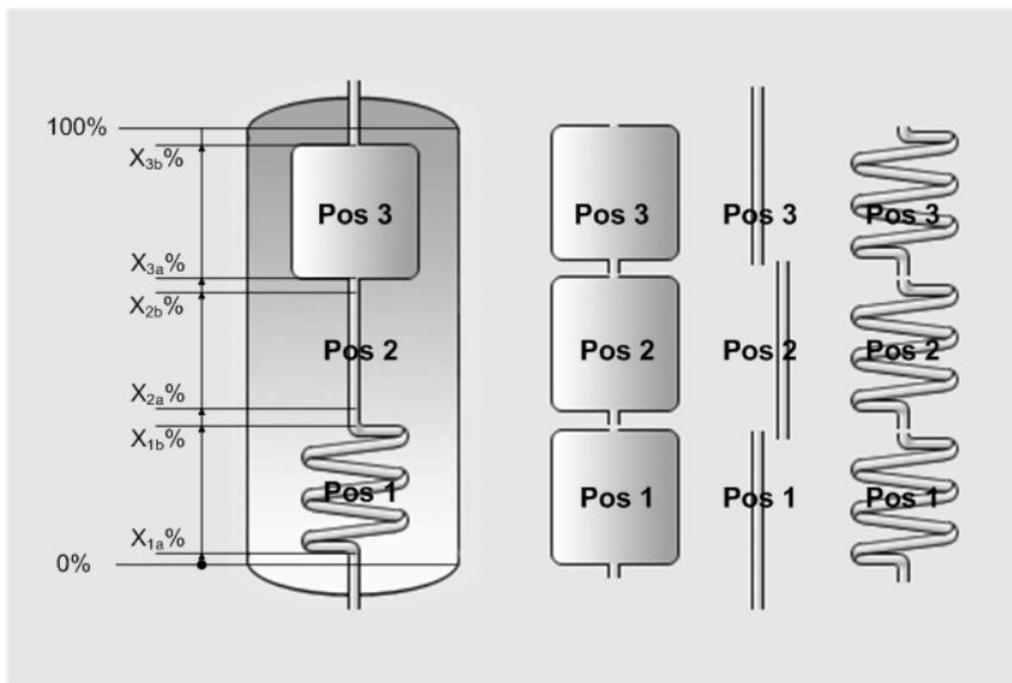


Fig. 62: positioning of internal elements

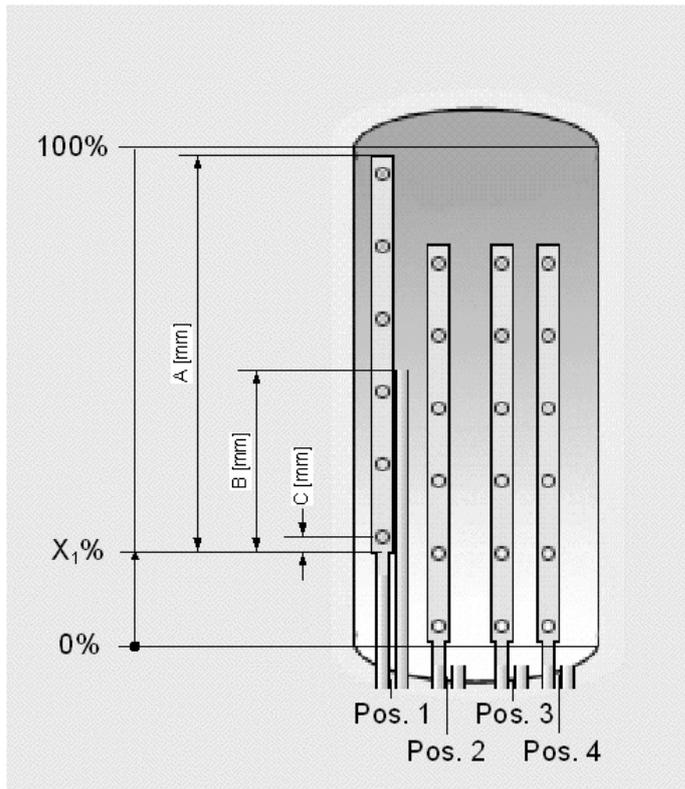


Fig. 63: measures and arrangement of stratifier lances (A= length, B=return, C=lower inlet)

It is possible to have up to four stratifier lances, arranged and numbered from left to right. In the tank catalog only the position is defined, the measurement is indicated in the “stratifier lances” catalog.

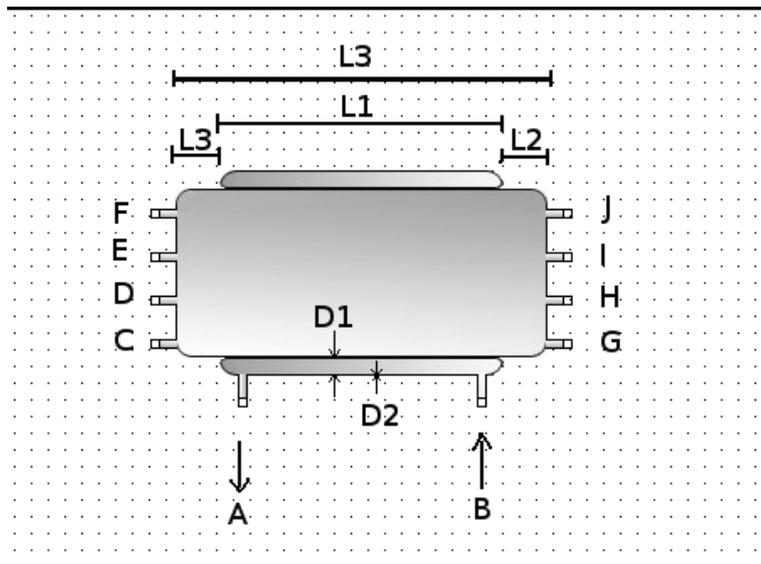


Fig. 64: measures and arrangement of horizontal tank with coat heat exchanger (A = fluid outlet, B = fluid inlet, C = port 1, D = port 2, E = port 3, F = port 4, G = port 5, H = port 6, I = port 7, J = port 8, L1 = length of the heat exchanger $L4 - (L4 * (100 - L2) / 100) + (L4 * (100 - L3) / 100)$, L2 = position of the heat exchanger's bottom edge in % of the total height of the tank, L3 = position of the heat exchanger's top edge in % of the total height of the tank, L4 = tank height, D1 = thickness of the coat heat exchanger, D2 = thickness of the heat exchanger's walls)

3.2.5 Thermal Insulation and Losses at Connections

The design of seasonal tanks depends strictly on the possibility of thermal insulation and the way in which the heat lost from the tank can return to become useful for heating the space (for example when the tank is in the centre of the house). Relative to losses, a large tank is more convenient than a small one because the relationship between surface and volume (even in proportion) is lower when the tank is large.

Normally thermal insulation with a thickness of 15-30 cm is used (with a heat conductivity coefficient of $\lambda = 0.04 \text{ W/m/K}$). The top cover can be thicker because hotter water is found there. The bottom cover, on the contrary, can be much thinner. In certain cases it is actually worth the trouble to omit the thermal insulation on the lower side. This way the environmental heat helps to warm the cold water.

In the course of planning, these various aspects need to be taken into consideration. Also the particular characteristics of heat input (from the collector and auxiliary heating) and from heat output (consumption of hot water and heating) are determining factors.

The illustration of the dialogue window for the definition of relevant parameters of the tank in Polysun follows:

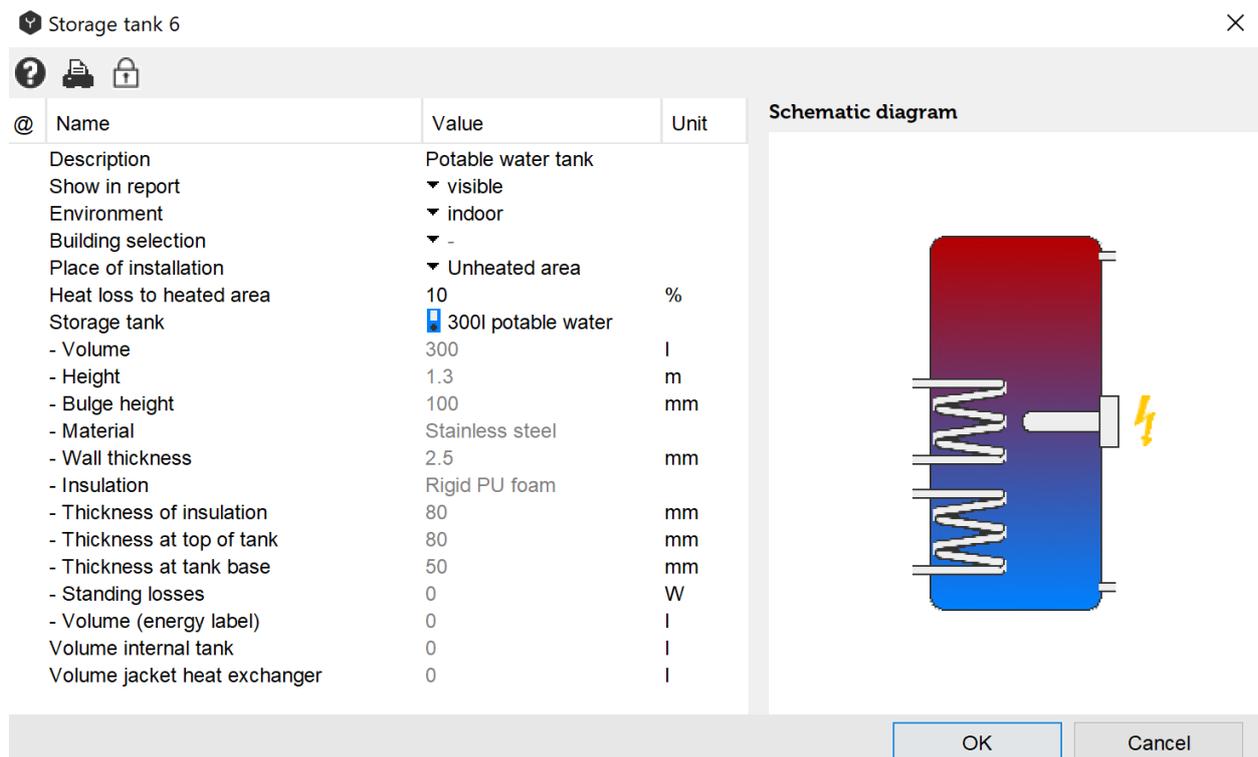


Fig. 65: tank dialogue

To modify the properties of the tank (for example the volume), you can open the tank catalog by double clicking on the catalog symbol in tank. At this point it is possible to select another tank or to copy and adapt the one in use (at the Professional and the Designer level).

With “connection losses” we mean that the pipes from and to the tank can be the source of considerable losses. For example in the hot water connection pipe (in stasis) the hot

water continually rises, it cools and descends again in the tank. This can cause considerable heat losses. Regarding this, two solutions exist:

S-bending the pipes and insulating the connections: right at the output of the tank a downward curving piece is installed. Here the water cools, but remains at this point in the pipe, impeding further exchange of hot water. If and how to curve and insulate well the connection can be chosen in the tank catalog. For the simulation, losses at the connections are determined, that are defined in the flanges (connections) catalog.

The extent of losses also depend on the temperature of the storage tank room. This can be indicated locally in the project. The indicated values are valid for S-bent and well insulated connections. Without these measures the losses at the connections are 10 times higher.

3.2.6 Charging the Tank

To transfer the heat from the collector to the tank in the most efficient manner, different methods are employed:

- **Internal heat exchanger:** the fluid is pumped through a coil that is found inside the tank. The pipe in the form of a spiral should have a wall that is quite thin with a large (external) surface (for example thermal fins) and made of material with a good thermal conductivity (for example copper). The heat is transmitted by means of a (free unilateral) convection to the fluid in the tank.
- **Coat heat exchanger:** The fluid flows around the tank through the coat heat exchanger encasing the tank. The heat is transferred to the fluid in the tank through (one-sided free) convection.
- **External heat exchanger:** the fluids of the collector and that of the tank are conducted one near the other in a counterflow plate heat exchanger and exchange heat by means of thin fins, which separate the two liquids. This is an efficient model of heat exchange in which, depending on the capacity of the exchanger and the ratio of temperature and flow, up to 99% of the thermal energy can be transmitted from one liquid to another. Normally on the tank side of the heat exchanger a circulation pump is also found. After the heat exchange, the fluid is released to the tank by means of one of the following system diagrams:
 - **Direct introduction:** the heat transfer fluid is withdrawn and introduced directly into the tank.
 - **Introduction by means of a stratifier lance:** inside the tank there is a vertical tube with about a dozen apertures covered externally by movable caps, similar to a flute. The fluid rises inside the tube until its density is greater in respect to that present in the corresponding point in the tank, and then flows out. The fluid is therefore “deposited” exactly at the point in which it has the same temperature as the tank’s liquid. This way an optimum stratification is guaranteed in the tank. Polysun doesn’t yet contain stratifier lances with internal heat exchangers, whose simulation is carried out by means of an external plate heat exchanger, as indicated in figure 25. A fixed flow rate must be selected in the pump, in order to have a balanced flow capacity ($m_1 \cdot cp_1 = m_2 \cdot cp_2$).

There are also cases in which two exchangers are employed, one at top and one at bottom of the tank. Depending on the solar irradiation and the temperature inside the

tank, the energy is used for pre-heating (only the lower exchanger) or for the production of domestic hot water (both exchangers).

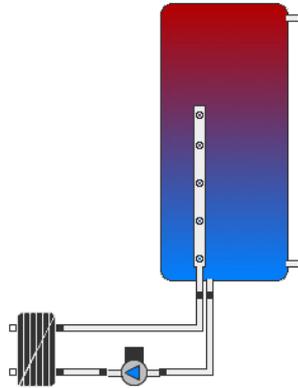


Fig. 66: plate heat exchanger and stratifier lance

3.2.7 Withdrawal of Water from the Tank

There are two ways to withdraw heat from the tank:

- **Direct withdrawal** from the tank: the hot water is taken directly from the tank and is brought together with cold water to the desired temperature by means of a mixing valve (if the temperature of the highest layer in the tank is too high).
- **Internal heat exchanger:** the heat is withdrawn from the tank by means of a coil heat exchanger. The hot water is brought together with cold water to the desired temperature by means of a mixing valve.
- **External heat exchanger:** The heat is withdrawn from the tank by means of a plate heat exchanger. The control of the flow indexes must be regulated in such a way that the produced hot water has the desired temperature.

Deciding whether to choose a heat exchanger or direct drain depends on the conception of the circuits. There are systems in which the collector loop and the tank are operated with water, in some only the collector loop is operated with a mix of water-glycol and in others the collector loop and the tank are operated with a mix of water-glycol. To make this kind of choice it is useful to take the following into consideration:

3.3 Boilers

In most cases, solar energy systems are used as support to conventional systems for the heating of hot water. During the summer auxiliary heating is most often inactive, while during the winter it forms the main contribution to heating.

Electric auxiliary heating is often used to lighten the work load of the boiler in summer. Normally, by installing a solar energy system, the use of auxiliary electric heating is canceled. As electrical energy is more expensive compared to oil or gas, the use of night-time electrical power, which is the most economical, can be convenient (this can be defined in the detailed dialogue of the controller). In Polysun, auxiliary electrical heating is carried out as an internal element of the tank, while gas or oil auxiliary heating is in the form of a separate component.

The design of auxiliary heating, that is the height at which the inlet and the return are installed, where the temperature sensors are placed and at which temperature the heating is activated or turned off, plays an important part in the efficiency of a solar power system. If for example in the afternoon solar energy will be produced, there is no need to keep the boiler on until noon. In real systems, but also in the simulation of Polysun, it is possible to establish the precise times at which auxiliary heating (in case of need) comes into operation. The auxiliary heating is programmed on the basis of the orientation of the collectors. It makes sense to introduce auxiliary heating only if after the irradiation of the collector, the level of required heat has not been reached in the tank. According to the consumption profile it could also be useful, directly before a peak in use, to make available the quantity of necessary heat in conditions when the sun hasn't provided sufficient energy. This way the tank losses are reduced to the minimum and a good possibility to find favourable working conditions (low tank temperatures) is given to the sun.

In Polysun, as in real heating systems, it is possible to define the operating times. Controllers are used for this purpose (see below).

The quantity of heated energy is defined as the product of the "heated volume" multiplied by the difference in temperature of hot and cold water (multiplied by the capacity of the fluid). The volume is given from the contents of the entire tank and the layer in which the electrical immersion heater and the temperature sensors are found.

In defining the project, on the page "Consumer", the daily energy consumption ("Hot water: daily demand") is indicated. If you want to be sure that the supply of hot water is guaranteed in unfavourable conditions, you have to make certain that, as in the example, the quantity of heated energy and daily use are approximately equal. In most cases you can choose lower quantities of heated energy (for example electrical immersion heater in layer 10). This way the sun is given greater possibility to supply the necessary energy during the day.

The control of auxiliary heating can be carried out by means of two temperature sensors, which can be freely placed above the electrical immersion heater. It is possible to choose the on/off temperature in different ways, but the switch-on temperature must be lower than the switch-off temperature. The desired hot water temperature adopted in the example is 50°C. The switch-off temperature should always be a few degrees above this so that even after a few hours the tank temperature doesn't drop too much. Finally, electrical energy is used only if an external temperature of at least 17°C is registered (i.e. in summer). This way great losses from the boiler are avoided for brief periods of operation.

Another frequent disposition is the use of a boiler for a temperature increase in the return (return shunt). In the case where a non modulating boiler is utilized, one must make sure that the boiler volume is large enough so that the fluid in the boiler doesn't overheat (Polysun would at this point choose a very short time step, which would influence negatively on the simulation times).

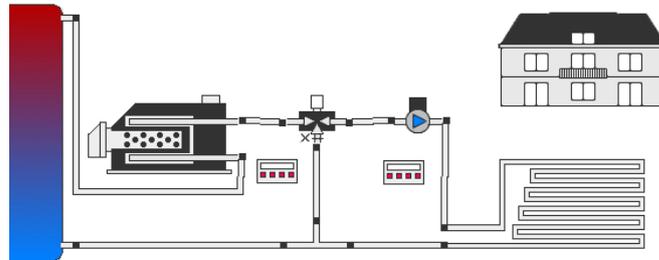


Fig. 67: return shunt

Fuel and CO₂ Savings

The use of the solar energy system enables to reduce both fuel demand and CO₂ emissions. Polysun calculates savings based on a calorific value table and the annual average efficiency of the heat generator. Double-clicking the heat generator and subsequently on the "Fuel" folder you will enter the fuel catalog. The catalog provides the user with a wide selection of fuels, stating the heating value and the CO₂ emissions of each fuel. A selection of fuels is already available, the user can create user-defined entries as required.

Fuel and CO₂ savings may be found under "Boiler" in the "Components results". The values are calculated according to the following formulas:

$$\text{CO}_2 \text{ savings solar thermal} = \text{energy savings solar thermal} * \text{CO}_2 \text{ emissions of fuel}$$

$$\text{Fuel savings solar thermal} = \frac{\text{energy savings solar thermal}}{\text{heating value of fuel}}$$

$$\text{Energy savings solar thermal} = \text{fuel savings solar thermal} * \text{heating value of fuel}$$

$$\text{Energy savings solar thermal} = \frac{Q_{\text{sol}}}{\text{Nominal efficiency of boiler}}$$

The data included in the fuel catalog (CO₂ emissions and heating values) come from the ecoinvent centre (Schweizer Zentrum für Ökoinventare).

3.4 General System Components

3.4.1 Cold Water

In the dialog window of the 'Cold water' the calculation method of the cold-water supply can be opened by clicking on the tap image in the system diagram. The cold-water temperature influences the energy demand for domestic hot water. By decreasing the cold-water temperature, the difference between set point of hot water and cold water inlet increases, which leads to a larger energy demand.

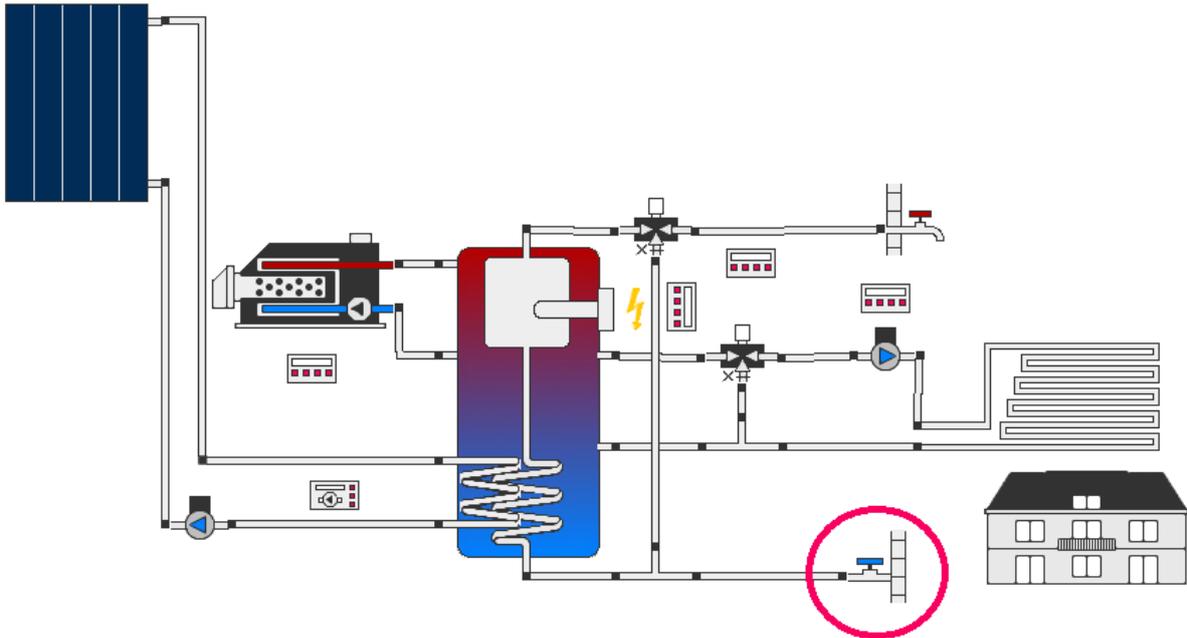


Fig. 68: cold water element on the system diagram

There are three methods available, such as 'Automatic', 'Catalog' and 'From file'.

'Automatic' calculation method of the cold water supply depends on the location chosen in the 'Location of the system' in project settings. Distribution of the cold water supply is calculated by the embedded Polysun procedure and depends on the weather data for the given location.

'Catalog' method allows choosing the appropriate cold water supply profile from the catalog.

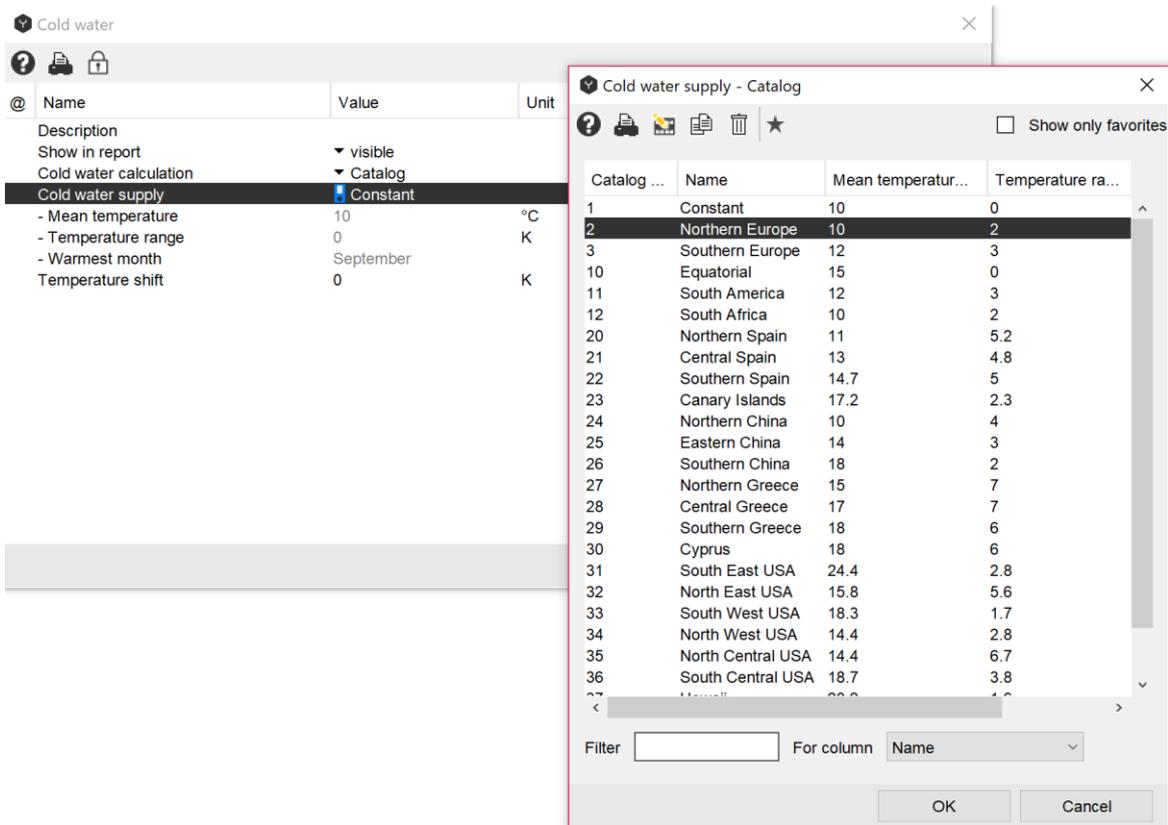


Fig. 69: selection of the cold water supply from the catalog

The main parameters, which are defined in the catalog are: the mean temperature [°C], temperature range [K] and warmest month.

The mean temperature – cold water mean temperature in a year.

Temperature range – differences between the mean temperature and the highest temperature and the highest temperature during the year.

Warmest month – month with the highest cold water temperature.

According to these parameters monthly values are calculated for the whole year.

It is also possible to change the values of the parameters if the suitable ones were not available. In order to do that, you can simply copy any line from the catalog with a new name assigned and then you can introduce any changes in the given line by clicking on the 'pencil'.

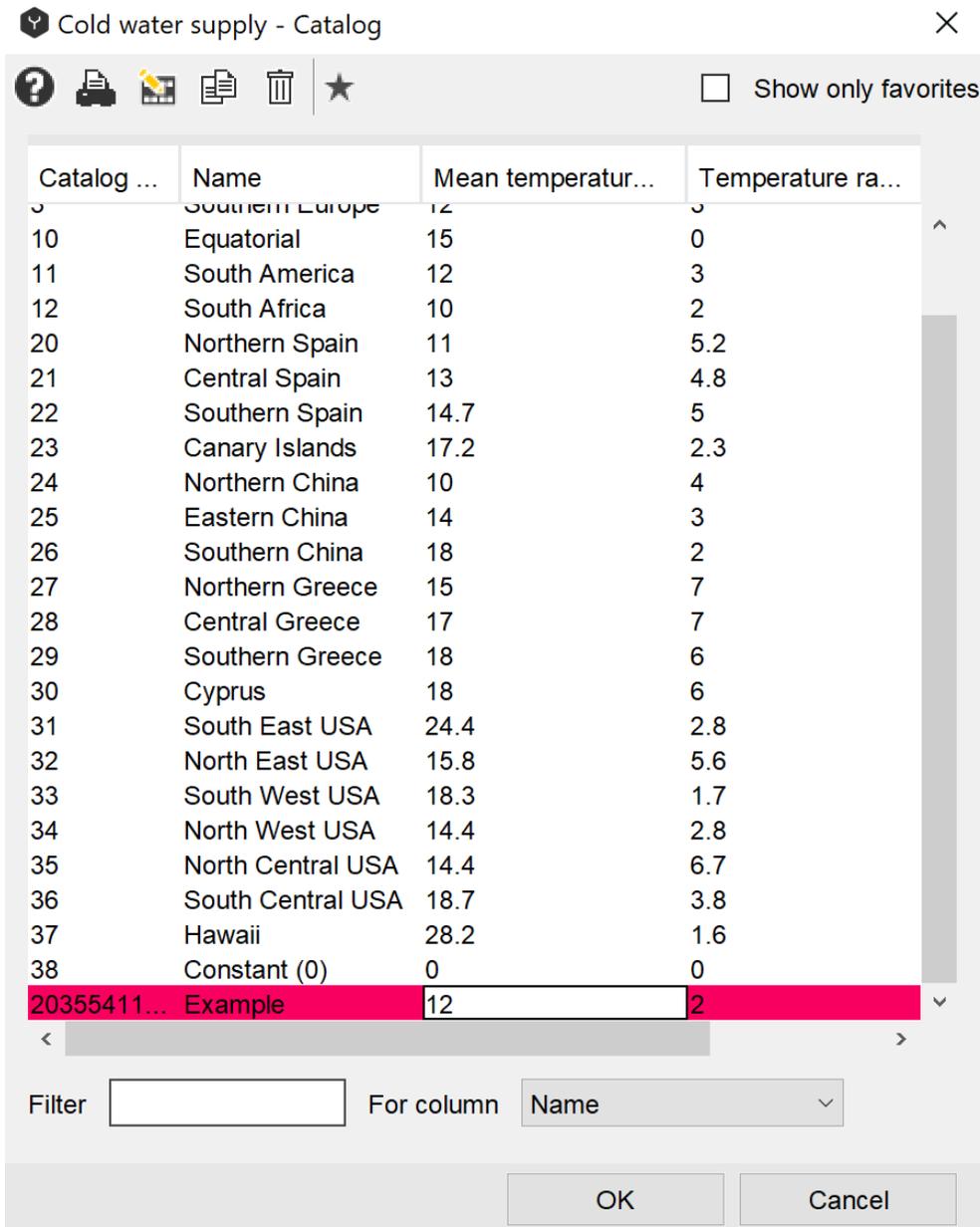


Fig. 70: editing cold water supply in the catalog

The third method 'From file' gives an opportunity to add available measured data from a file. In order to do that you can also first make a copy of the catalog with a new name, then click on the pencil and then open the *.csv file in the catalog.

The possibility of using the cold water temperature from a file makes Polysun flexible enough to use it also as inlet temperature for district heating systems, outlet (warm) temperature will be in this case the hot water demand.

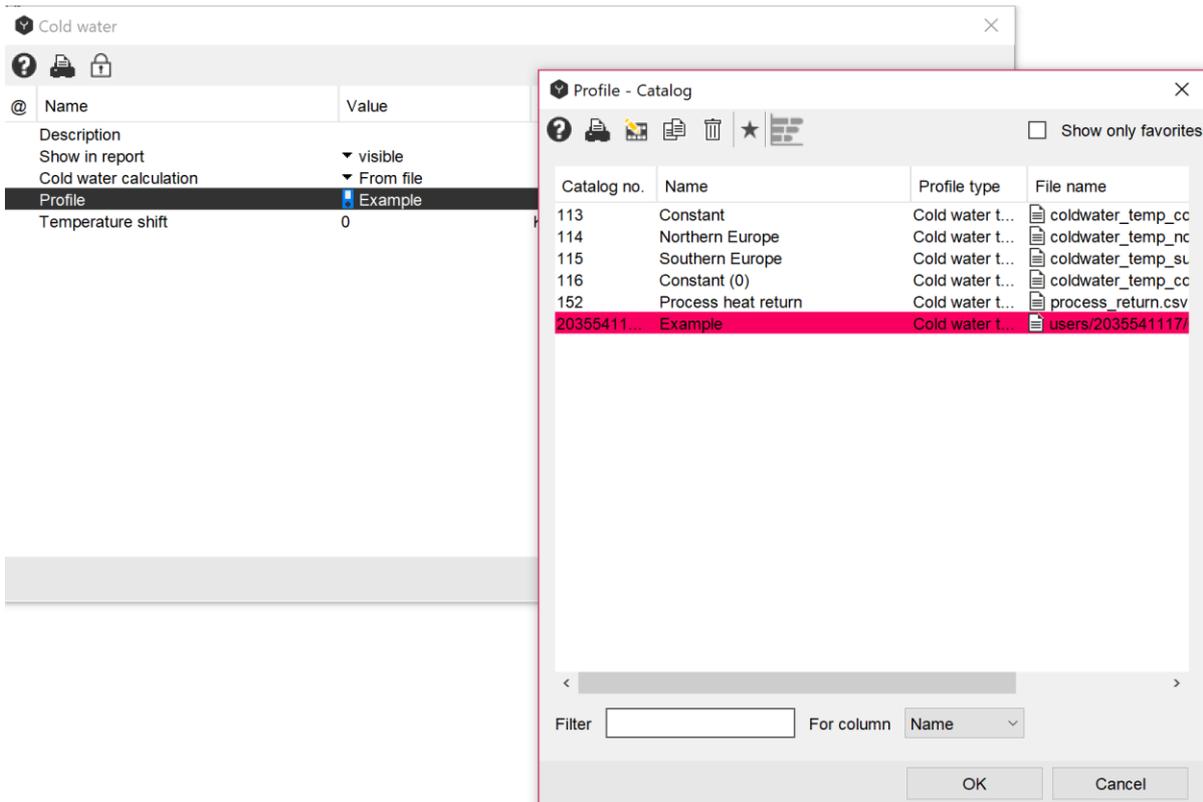


Fig. 71: selection of the cold water supply from file

In the spreadsheet file the temperatures for the cold water supply are given with a 6 minute time step size. This file can be changed with measured data and saved under the new name.

	A	B	C
1	# Cold water temperature		
2	#Time [s]	Temperature [°C]	
3	0	9	
4	3600	9	
5	7200	9	
6	10800	9	
7	14400	9	
8	18000	9	
9	21600	9	
10	25200	9	
11	28800	9	
12	32400	9	
13	36000	9	
14	39600	9	
15	43200	9	
16	46800	9	
17	50400	9	
18	54000	9	

Fig. 72: cold water supply temperature in 60-minutes-steps in the spreadsheet file

In order to choose the changed profile, you may click once again on the profile in the catalog and then choose 'Select File'.

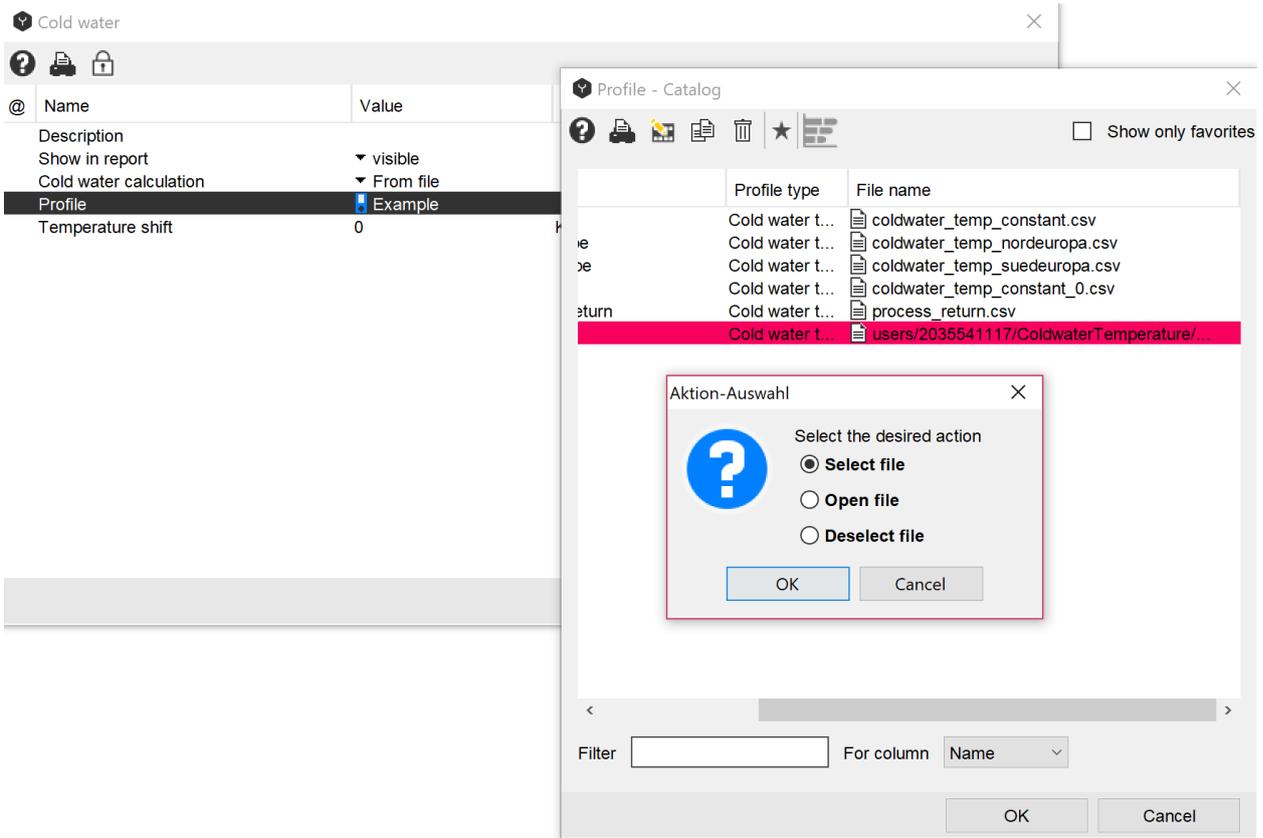


Fig. 73: selection of the previously edited profile

The cold water distribution can be found in the Component results – Cold water tab.

An example for the profile “Northern Europe” is shown below.

Storage tank Combined tank Internal heater [3]				Storage tank Combined tank Internal tank [1]				Weather data							
Boiler	Building	Cold water	Collector	Heating/Cooling element		Hot water demand		Storage tank	Combined tank	Storage tank	Combined tank	Coil heat exchanger [1]			
Name	Symbol	Unit	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Temperature		°C	10	9	8.3	8	8.3	9	10	11	11.7	12	11.7	11	10
Minimum value		°C	8	9	8.3	8	8.3	9	10	11	11.7	12	11.7	11	10
Maximum value		°C	12	9	8.3	8	8.3	9	10	11	11.7	12	11.7	11	10

Fig. 74: cold water distribution in the component results

3.4.2 Plate Heat Exchangers

Polysun makes available some types of systems with internal heat exchangers and others with external heat exchangers. The transfer rate of the exchanger is higher when the surface area of transfer is larger (that means the overall surface area of the heat exchanger), the thinner the walls of the tubes and the greater the conductivity of the material of which the heat exchanger tube is made of. Finally the fluid velocity in the tube is important, which depends on the flow rate. The number of “parallel heat exchanger coils” indicates how many exchangers are used in parallel (for example arranged one in another).

In an external heat exchanger a “fixed entry height” or a “variable entry height” (of a stratifier lance) may be chosen. It is possible to define the lowest position or the highest position of the stratifier lance. Curiously the optimum height of the stratifier lance is not the highest layer, but at about $\frac{3}{4}$ of the tank height. It results that in the upper part of the tank there is no “perfect” stratification, but heat losses are not as high at the top cover. The stratifier lance should reach at least the level for daily consumption requirements.

The product of the thermal transmission coefficient k [W/m²/K] multiplied by the transfer surface A [m²] gives the thermal transfer rate of the heat exchanger, which results in the order of thousands of W/K. The parameter Δt indicates that which is (or should be) the difference in hot water temperature between the collector and the tank, in order to transfer to the tank by means of the exchanger the power density of 500 W/m². This parameter depends on the transfer rate and the surface area of the collector.

The volumetric flow rate on the collector side can be determined by means of the flow rate. The volumetric flow rate on the tank side is determined by the fact that the capacity flow rate (= flow rate multiplied by the heat capacity of the fluid) is the same on both sides of the heat exchanger. If a glycol mix is being used in the collector loop, but only water in the tank, the two volumetric flow rates are not the same.

Heat Exchanger in the Consumption Loop

The use of the heat exchanger in the consumption loop doesn't only regard the fact that heat needs to be transferred in the most efficient way possible, but also that the desired water temperature needs to be reached. For this reason pump regulation in respect to the tank of the heat exchanger is provided for, in such a way that the user can directly obtain water at the desired temperature.

The temperature that needs to be found in the upper part of the tank in order to obtain the desired water temperature is indicated in the lowest line of the dialogue under “minimum tank temperature required”. It depends on the temperature of hot-cold water, transfer rate and nominal flow rate. The nominal flow rate indicates the maximum quantity of hot water received per unit of time. The corresponding “withdrawal power” is indicated, too.

3.4.3 Pumps

The pump model used by Polysun is based on the pump curve that regulates the flow rate foreseen in the circuit. In one circuit only a single pump can be employed. When not in operation, the pump blocks the flow.

The pumps can be subdivided into various types, according to which mechanism defines the flow rate.

- The flow rate is established by means of circuit pressure drop. The flow rate is calculated in correspondence to the pump curve that regulates the flow rate in the circuit.
- Fixed flow rate: the flow in the circuit is regulated by a pre-established flow rate.
- Controlled flow rate: a controller manages the pump flow rate.

Solar energy systems in which the collector is installed on the roof and the tank is installed in the basement require a circulation pump. Otherwise, due to the force of gravity, the heated fluid would remain above in the collector and the cold fluid below in the tank. The systems in which the collector is mounted below the tank can do without a pump. Such natural circulation (thermosiphon) systems require only a non return valve. In addition to saving on a pump, that is also tied to costs for electrical energy, such systems also present an inherent physical regulation, that in the presence of more intense solar irradiation allows the fluid to circulate more rapidly.

Often the collector is found above the tank, therefore forced circulation of the fluid is indispensable. The operation of the pump can therefore require considerable energy consumption. If a solar energy system works for 2000-3000 hours per year (in one year there are 8760 hours) the absorption of energy by the pump can in itself represent a certain percentage of the solar energy obtained. In well-planned large systems the consumption of energy by the pump is nevertheless lower than one percent of the obtained solar energy.

The specific flow rate is a measurement adapted to the definition of flow rate as directly linked to the maximum increase in temperature (heating of fluid by means of the collector). For example heating the fluid from 20 to 60°C is possible in the presence of full irradiation, high external temperatures and a low flow rate. At higher flow rates there is a corresponding lower temperature increase. The two techniques are respectively referred to as "Low-Flow" (10-20 l/m²/h) and "High-Flow" (30-40 l/m²/h).

The efficiency of the pump depends on among other things, the loss of pressure in the collector loop and on the collector area, but with these, pump efficiency increases linearly much less. A part of the heat lost by the pump (25-90%) is passed to the fluid and goes in favour of the thermal balance of the solar energy system. Still, this gain of energy is valued with scepticism because the consumed electrical energy is expensive and produced in an ecologically sustainable manner.

3.4.4 Expansion Vessels

Polysun enables users to design membrane expansion vessels according to EN 12828. It is assumed that a system simulation has been completed. Then open the “Solar loop pump” dialogue box and click on the design wizard icon ✨ (in the upper portion of the box). The tool is intended for solar loops only.

Now, a new dialogue box opens prompting the user to enter various information. Hoovering with the mouse over an input field, a help text is shown explaining the meaning of the relevant entry. All values shown as “derived values” are directly imported from the Polysun simulation and are essentially based on pipe size, collectors and controller settings. All derived values must be checked for plausibility. Click on the “Import” button to import all modified values. All changes in the “Solar loop pump” dialogue box must be confirmed by pressing “OK”. Now, you can make other changes and start the simulation. The dimensioning of membrane expansion vessels does not affect the simulation and its results. The values calculated for the membrane expansion vessel are, then, displayed in the professional report under the section dedicated to the relevant pump.

Calculation Basis for Membrane Expansion Vessels in Polysun

Minimum operating pressure (p_0): $p_0 = p_{st} + d_{pp} + d_p$

Final pressure (p_e): $p_e = p_{sv} - 0.5\text{bar}$ for $p_{sv} \leq 5$ bar

$p_e = p_{sv} - 0.1\text{bar}$ for $p_{sv} > 5$ bar

Nominal capacity (V_n): $V_n = (V_e + V_V + V_k) * \frac{p_e+1}{p_e-p_0}$ where:

Collector capacity (V_k): Calculation through Polysun

Expansion volume (V_e): $V_e = \frac{n}{100} * V_A$ where:

Degree of expansion (n): depending on the fluid in the loop

System volume (V_A): $V_A = \sum \text{Kollektorvolumen, Rohrleitungen etc.}$ $V_A = \sum \text{collector volume, pipes, etc.}$

Water header (V_V): $V_V = 0.005 * V_A$ for $V_n > 15$ l with $V_V \geq 3$ l

$V_V = 0.2 * V_A$ for $V_n \leq 15$ l

3.4.5 Pipes and Heat Transfer Media

3.4.5.1 Pipes

The pipes are the links between the various components of the solar energy system. Their role is primarily to transport the heat transfer fluid among these components with a minimum of heat loss. Thin pipes have the advantage of having low volume, requiring little fluid and the heated fluid is rapidly transferred from the collector to the tank. On the

other hand they also cause great pressure loss, compared to pipes with a greater diameter, which causes an elevated power absorption by the circulation pump. In Polysun it is possible to separately define inlet and return pipes. It is therefore possible, to better insulate the (hotter) inlet or size the return pipes thicker to reduce the pressure loss.

To define the thickness of the pipes the following aspects are to be considered:

- Pipes with a large diameter have a **large surface area** and therefore greater heat loss
- Pipes with a large internal diameter allow for a **higher flow rate**
- In thicker pipes the fluid flow is **laminar**, something which slows the transverse heat transfer in the fluid and causes lower heat losses
- Thicker pipes (equal in length) have a greater volume, which presupposes a greater quantity of heat transfer fluid in the collector loop and makes the system inert.

In light of these considerations it can be deduced that the diameter of the pipe needs to be rather small and is substantially established by means of the criteria of suitable pressure loss.

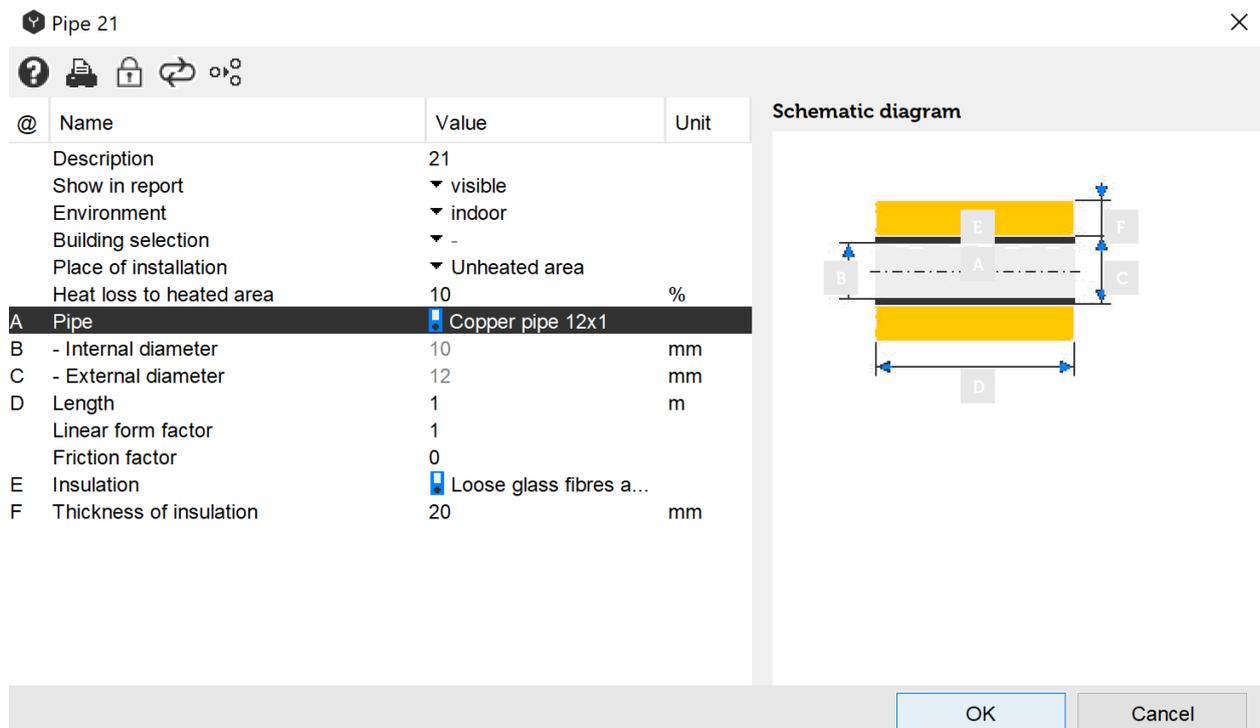


Fig. 75: pipe dialogue

The diameter and thickness of the pipe walls are given by means of a catalog of commercially used pipes (copper and steel). In copper pipes the specification 22 x 1 indicates an external diameter of 22 mm and a wall thickness of 1 mm. In gas pipes the internal diameter is indicated in inches (1 inch = 2.54 cm).

3.4.5.1.1 Thermal Insulation of Pipes

The thermal insulation of piping is very important. During the transfer of heat to the tank one doesn't want to lose the level of collector efficiency attained with much effort. With the use of thermal insulation with some centimeters of thickness acceptable heat losses can be sustained.

The connecting pipes are to be insulated as much as possible starting from the collector outflow. The thickness of the insulation can be regulated by the following dialogue (double click on pipe):

The thickness of thermal insulation can be freely defined, as well as the relative thermal conductivity. Likewise determinant for the efficiency of the piping is the conductivity and the heat capacity of the used metal pipes. The total length of the piping can be indicated separately in the respective fields. In the simulation it is important to also consider details such as the length of indoor piping, in respect to the length of outdoor piping. In this regard two separate pipes are established (at the Designer level) where the insulation thickness and length can be inserted separately.

3.4.5.1.2 Pipe Dimensions

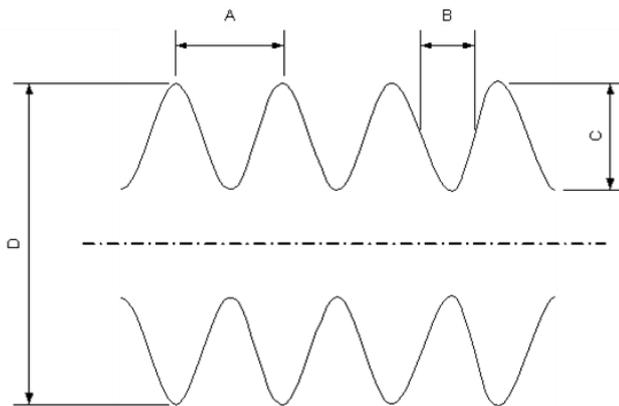


Fig. 76: dimensions of a ribbed pipe (D = diameter, A = rib period, B = rib width, C = corrected depth)

3.4.5.2 Heat Transfer Fluids

The climatic conditions in central Europe make it necessary for solar energy systems to be resistant to temperatures below zero. This, for example, impedes the production of necessary hot water directly in the collector. When water freezes inside the collector, it destroys the collector by means of its expansion. The water of the hydro network furthermore has the disadvantage that it tends to calcify the collector over time.

In order for the heat transfer fluid to be suitable for the above-mentioned needs, water is mixed with a certain quantity of glycol. In many cases ethylene glycol is used as an anti-freeze (for example Antifrogen L) or propylene glycol (e.g. Antifrogen N). From the moment the fluid circulates in a closed circuit, the danger of calcification is contained. For the mixing proportions the following various points of view are to be considered:

- The heat capacity of the fluid diminishes with an increased concentration of glycol
- Viscosity increases with higher percentages of glycol (problems with pressure loss)

- The freezing point drops with an increase in the percentage of glycol
- The boiling point increases with higher percentages of glycol
- Different possible chemical processes must be kept in mind, especially in passing through different metals
- The heat resistance of the fluid is to be considered

Freezing fluid is no longer a problem starting from a certain concentration as it no longer freezes as ice (crystalline), but rather in a grainy gelatinous form. Explosive effects are no longer evident. Beginning with a volumetric percentage of 33% (propylene glycol), or 38% (ethylene glycol), the fore-mentioned results take effect.

In Polysun the concentration of glycol can be defined. The corresponding physical properties for a temperature of 50°C are indicated.

3.4.5.3 Heat Transfer Media (Mix of Fluids)

- **Danger of freezing in winter:** if we consider that the external temperature can reach below zero, an anti-freeze product would be used (normally glycol). The higher the quantity of glycol, the lower the thermal capacity of the fluid. Ethylene glycol is normally used at a concentration of 33% (propylene glycol at 38%). In this way the fluid only freezes “like gelatin” without causing explosive effects inside the collector.
- **Calcification of the system:** for this condition there are two aspects to consider: if pipes with a small internal diameter are used inside the collector, calcification may obstruct the collector over time. Calcification may become a problem also in the tank. The situation is further aggravated if water is brought to temperatures above 60°C.
- **Sterility of the tank:** if domestic hot water is ready for use in the tank, there is a possible risk of legionella bacteria. This can be avoided by periodically heating the tank to above 65°C. In domestic hot water systems with an annual degree of coverage above 50%, sterility in summer is guaranteed by the temperature of the season.

For the choice of the system, cost considerations naturally also come into play. External heat exchangers are normally more expensive than internal ones, they require an auxiliary pump, but have greater transfer efficiency than internal heat exchangers. External heat exchangers are used above all in large systems, where the higher expense is compensated by greater efficiency.

3.4.6 Three-Way Valves

Three-way valves play a crucial role when it comes to the analysis of fluid loops. Three-way valves share the inflowing fluid-flow in a fixed proportion. The position of the mixing valve is adjusted by the controller. Based on the situation in the schematic system diagram the three-way valve alternatively distributes inflowing fluid-flows or brings together two separate fluid flows. The adjusted output is marked with x. If the signal of the controller is logically one the x output will be completely open. Both situations are schematically outlined in the following graph:

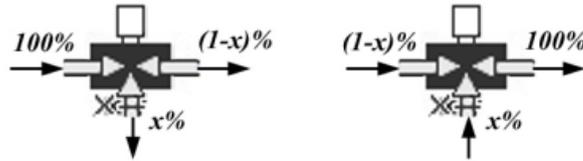


Fig. 77: three-way valves

3.5 Thermal Consumers

3.5.1 Domestic Hot Water

In a home, the consumption of hot water varies considerably according to the habits or the preferences of its inhabitants. For this reason the level of coverage by a solar energy system depends on the consumer’s profile. In principle there is rarely a need for the water temperature to be higher than 50°C, except for the kitchen area, where sometimes the temperature requested is up to 55°C.

If the system is not set up optimally, according to the consumer’s profile, unfortunate consequences may occur: if, for example, a lot of water is consumed in the evening, the tank temperature drops and, if too low levels are reached, auxiliary energy is introduced. In cases in which during the night auxiliary heating works too little, there is a lack of necessary hot water in the morning.

The following parameters relative to domestic hot water can be inserted. The user can define different consumption profiles for daily, weekly, and monthly values.

Hot water demand
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@ Name	Value	Unit	Schematic diagram
Description			
Show in report	▼ visible		
Loop description			
Use consumption profile	▼ No		
Daily profile	<input checked="" type="checkbox"/> BDH/BSW withdraw...		
Nominal flow rate automatic	▼ Yes		
Temperature	45	°C	
January	200	l/day	
February	200	l/day	
March	200	l/day	
April	200	l/day	
May	200	l/day	
June	200	l/day	
July	200	l/day	
August	200	l/day	
September	200	l/day	
October	200	l/day	
November	200	l/day	
December	200	l/day	
Average volume withdrawal	200	l/day	
Annual demand ca	2,971	kWh	
Enable hot water circulation	▼ No		
Absences	<input checked="" type="checkbox"/> Never		
Load profile automatic	▼ No		
Load profile	▼ M (5.845 kWh/d)		

OK
Cancel

Fig. 78: domestic hot water dialogue

In many domestic environments the consumption of summertime hot water doesn't quite equal that of winter, depending on whether one wants to enjoy a nice hot bath in winter or a refreshing shower in summer. Such variations, that are verified over the course of the year, can be taken into consideration in the monthly consumption values.

The temperature of cold water in pipes varies according to region, on the average it is approximately 10°C.

Demand Profile and Absence Periods

The hot water consumption dialogue box allows users to choose between "Profile" and consumption-specific "Monthly values". As a standard six different VDI 6002 profiles are available for hot water. Each single profile can be individually adjusted to the required yearly demand.

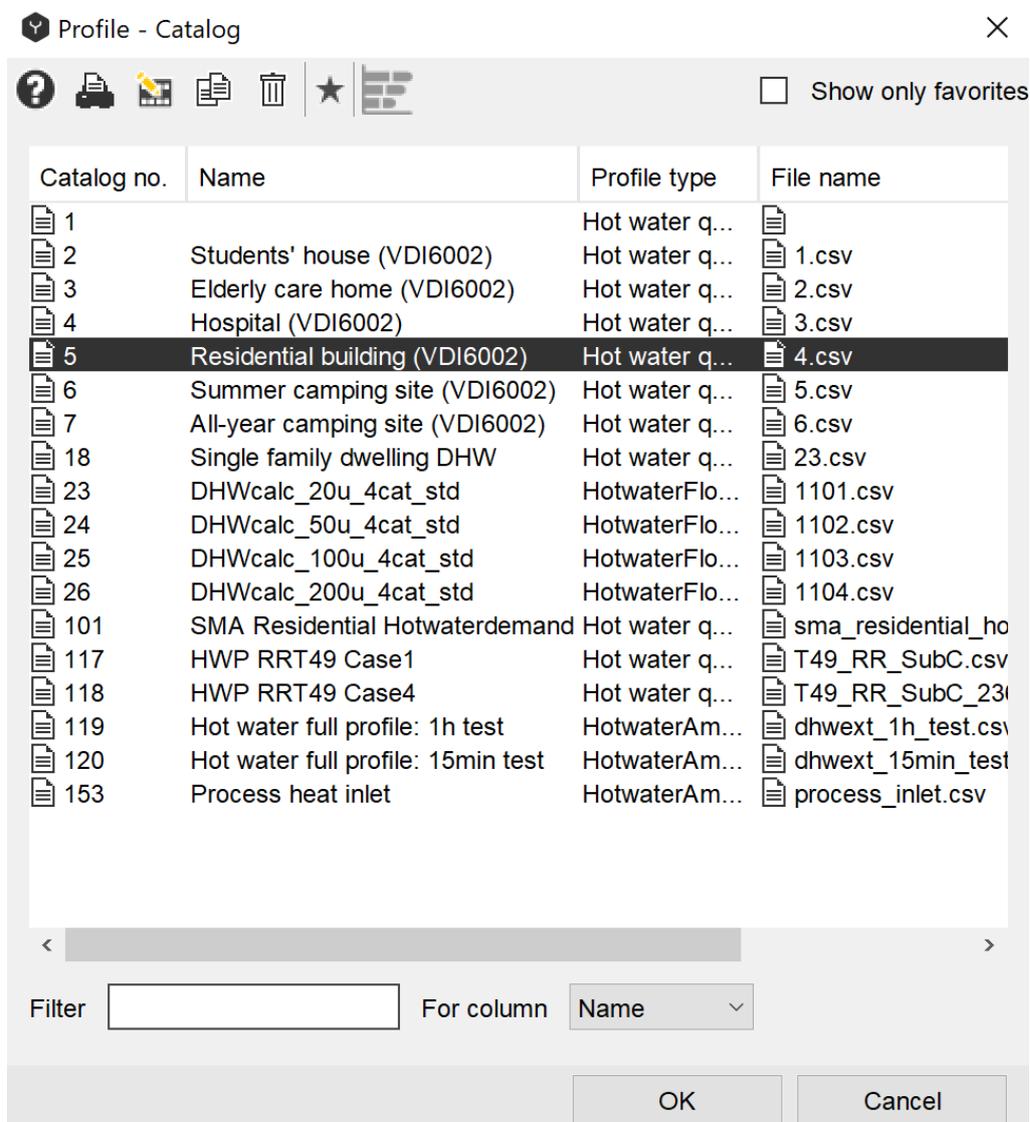


Fig. 79: profile dialogue box

The single files are stored in the "Profiles" folder in Polysun's installation path. No existing profile file should be changed; Polysun runs a check before each use to ensure no file was manipulated. The software offers the opportunity to tailor profiles to one's individual

needs. The file consists of two columns: the first column defines the time in seconds (from 0 to 31536000) when a change in hot water withdrawal takes place; the second column defines the corresponding hot water requirement (in litres) from this time on.

To best set-up a profile in Polysun the use of spread sheets like, for example, Excel is recommended.

Below is an extract of a profile:

```
...
18000;4.6
21600;4.6
25200;16
28800;16
...
```

This extract says that starting from second 18000 a water amount of 4.6 litres will be tapped; the same amount will then be tapped one hour later.

Remarks

- The software enables the user to create profiles with precision down to the second.
- All you need to do is copy a line in the profile catalog, accordingly rename the file and select the correct profile type.

Energy requirements may be further differentiated by defining any absence periods (e.g. holidays) for hot water consumption (if a profile is not in use) and building model. During the defined period:

- No hot water is tapped.
- No ventilation is switched on in the building, the temperature is set to the night mode and no internal heat gain is added.

Absence periods (Period catalog) may consist of multiple switching times. As soon as one of these periods sets in results also apply to the combination.

Ex.: the first period defines August as an absence period; the second defines all week-ends as an absence period. As a result all week-ends and August are regarded as absence periods.

August on:



Week-end on:



Result:



A start and end-date are defined for each period. The time running between the start and end-date is regarded as an absence period. Should the start-date be set to a later point than the end-date the absence period will extend over the end of the year.

Ex.: the start-date is set to November 1st; the end-date is set to the end of February. As a result the period between the beginning of the simulation and the end of February and from November 1st to the end of the simulation is regarded as an absence period.

November to February:



A weekly repetition can be set for each day of the week. The repetition will be run between the start and end-date. The cut-in time corresponds to the start-time; the cut-off time corresponds to the end-time on the selected week-day.

Ex.: the start-time is set to February 1st 8:00 a.m., the end-time is set to March 31st 8:00 p.m. 20:00. The repetition is set on Wednesday. As a result in February and March each Wednesday the time between 8:00 a.m. and 8:00 p.m. is regarded as an absence period.

February 1st 8:00 a.m to March 31st 8:00 p.m., Wednesday:



Hot Water Demand Profile Types

Table 14. Hot water demand profile types

Profile type	Columns	Remark
Hot water amount [l]	Time [s]; Amount of water [l]	
HotwaterFlowrate [l/h]	Flow in l/h; Time stamp in mins	HotwaterFlowrate profile in the DHW-format (external format)
Hot water amount, temperature and flow rate („Full hot water profile“)	Time [s]; Amount of water [l]; Temperature [°C]; nominal flow rate [l/h]	When the amount of water for a time step is used up, the flow rate will be zero. In case the flow rate is too little, the full amount of water will not be drawn.

In all profiles the time steps can be chosen individually and do not have to be regular. For example, a profile may include time steps of twelve minutes each during the day and only two hot water profile intervals for the night.

3.5.2 Building

Besides hot water for bathroom and kitchen use, there is also space heating demand which has to be covered by the designed system.

All modern heating systems enable the desired type of control to be set manually. The system's energy consumption varies according to the selected setting.

For example with an outdoor temperature -10 °C the inlet temperature should be 45 °C. The temperature level of the transfer fluid running back through the system is 15 °C lower than at the tank outflow. The closer the outdoor temperature lies to the limit temperature; the lower is the difference between inlet and return temperature.

The building icon represents either heated area (living area to be heated, walls included) or unheated area (such as garages, basements, cellar, where the thermal equipment can be installed) or both areas. This allows the actual consumption to be scaled with greater precision.

Unheated area can be activated in the building dialog window as it is shown in the Fig. 83. The temperature of the unheated area can be set as a constant value or as a temperature range between the highest and lowest temperature during the year. The month with the highest outdoor temperature shall be indicated considering the location of the project.

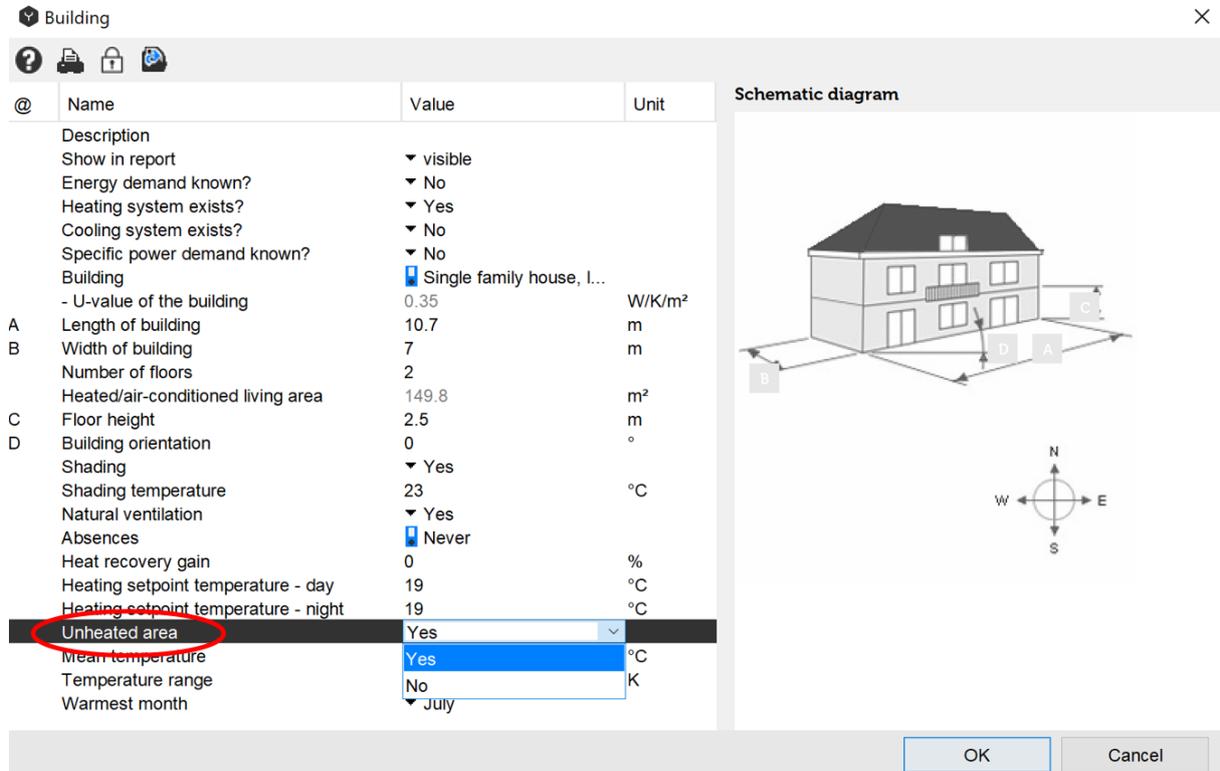


Fig. 80: selection of the unheated area in the building dialog window

Heated area

Based on complexity of the model there are two types of models in Polysun: dynamic and simplified.

Dynamic models

The building's dynamic thermal demand integrated in the simulation algorithm can be inferred from the compliance with the heating/cooling energy balance equation (displayed here in a simplified form).

$$HG - HL = MCp \frac{\Delta T}{\Delta t}$$

HG = HeatGain

HL = HeatLoss

MCp = thermal capacity

ΔT = Temperature variation per time step in the building

Δt = Time step

The equation takes into account both passive heat gains from the sun as well as the amount of heat generated by people living in the building, the air exchange rate, the type of lighting as well as any electrical appliances. A **Window-To-Wall-Ratio** enables the influence of the employed glazing to be also taken into account. Depending on the type of window this reflects on the SHGC value (**Solar Heat Gain Coefficient**)

As a result the energy yield is composed as follows:

$$HG = G * SHGC * WWR + HG_{people} + HG_{light} + HG_{equipment} + G_{sys} \quad [W]$$

G : Total solar irradiation on the wall [W]

$SHGC$: Solar Heat Gain Coefficient, value varying depending on the type of the window [-]

WWR : Window to Wall area ratio [-]

HG_{people} : Heat gain dissipated by people living in the building [W]

HG_{light} : Heat gain dissipated through lightings [W]

$HG_{equipment}$: Heat gain dissipated by electrical equipments etc. [W]

G_{sys} : Heat gain/Heat removal through Heating/Cooling system (in cooling session it is a minus value) [W]

$$HL = HL_{transmission} + HL_{ventilation} + HL_{inf\ infiltration} \quad [W]$$

$$HL_{transmission} = UA(T_{in} - T_{out}) \quad [W]$$

Where U is overall heat transfer coefficient of the building, A is total surface area of the building' envelope, T_{in} is the indoor temperature and T_{out} is outdoor temperature.

$$HL_{ventilation} = (\dot{V} \rho C_p)_{freshair} * (T_{in} - T_{out}) \quad [W]$$

Where \dot{V} , ρ , and C_p are volumetric flow rate, density, and specific heat capacity of the fresh air delivered through ventilation system into the building interior respectively.

$$\dot{V}_{freshair} = \frac{V * ACH_{ventilation}}{3600} \quad [m^3/s]$$

V : Building total ventilated volume [m³]

$ACH_{ventilation}$: Number of air changes through ventilation system [1/hr]

$$HL_{inf\ infiltration} = (\dot{V} \rho C_p)_{inf\ infiltration} * (T_{in} - T_{out})$$

$$\dot{V}_{inf\ infiltration} = \frac{V * ACH_{inf\ infiltration}}{3600}$$

$ACH_{infiltration}$: Number of air changes through infiltration

* In cooling session $HL_{transmission}$, $HL_{ventilation}$, and $HL_{infiltration}$ are minus values.

For the specification of the controlled ventilation the air exchange rate indicates how often per hour the overall air amount is exchanged. The amount of heat that can be recovered by means of an air-air heat exchanger typically amounts to about 50% and can be likewise entered in Polysun (Parameter: Efficiency heat recovery). Additionally automated shading is taken into account (e.g. by means of shades or awnings): should the outdoor temperature rise above the entered Shading temperature the irradiance will be reduced by 90%.

The Polysun specific building template can likewise be extensively and individually adjusted. Should no specific heating loads be known the building will be defined based on editable basic dimensions as well as by means of a variety of building types included in the catalogue (with reference to a variety of international standard house types). However, it shall be taken into account, that if any parameters of the building from the catalogue are changed (e.g. the size of the windows), then the U-value shall be changed accordingly. The U-value is given for the whole building, including the doors and windows. The advantage presented by this template lies in the greater individualization opportunities given in the layout of the building structure as well as in the opportunity to accommodate multiple heating loops within the same building.

The energy deficit warning will appear at the end of simulation, when there is not enough energy for heating for more than 6 hours.

Alternatively a building may be defined based either on a known heating energy demand or the annual fuel consumption (so called simple building model) by choosing "Energy demand known" as "Yes". In this case one of the simplified models will be used.

Simplified models

1. Quasi-dynamic model takes into account dynamic building characteristics (e.g. solar gains), even though the static demand values are predetermined by the User before starting the simulation.
2. Well-known degree-hour model. More information about this model can be found in the book John A. Duffie, William A. Beckman, 2006, Solar Engineering of Thermal Processes 3rd Edition, Hoboken, New Jersey, John Wiley & Sons Inc.
3. Hourly energy demand model. The aim of this model is to read and process hourly building heating and/or cooling demand import.

There are 4 possibilities to define the heating demand for simplified models:

- 1) Annual energy demand is a total annual heating energy demand of the building (without domestic hot water). The total energy loss of the building through the building envelope as well as ventilation/infiltration losses. This value is always bigger than the total annual energy demand and may vary depending on the building type and climate.
- 2) Fuel consumption of the heat generation multiplied by its efficiency (presumed efficiency for the new generator is 85%, for the old generator is 60%).
- 3) Maximum power demand has 2 calculation options:
 - a. Given, that heat generator works with the maximum power certain period (table value).
 - b. Given, that the maximum losses at the lowest ambient temperature are

known, the UA-value (building characteristics) can be calculated and then annual losses and demand of the building.

- 4) Monthly annual demand has the same approach as annual energy demand, but with monthly distribution of heating energy demand and losses available.

One more important issue is the location of thermal component in respect to the building. There are 3 available locations for thermal components: outdoor, heated and unheated areas. The storage tank, for example, can be installed either indoor or outdoor. In Polysun it is possible to make a project with more than 1 building, therefore, if indoor option is chosen, the building must be defined, where the tank shall be located. Then in the chosen building heated or unheated area shall be selected. In the case, when the tank is installed in the unheated area, the percentage of the heat losses to the heated area can be defined.

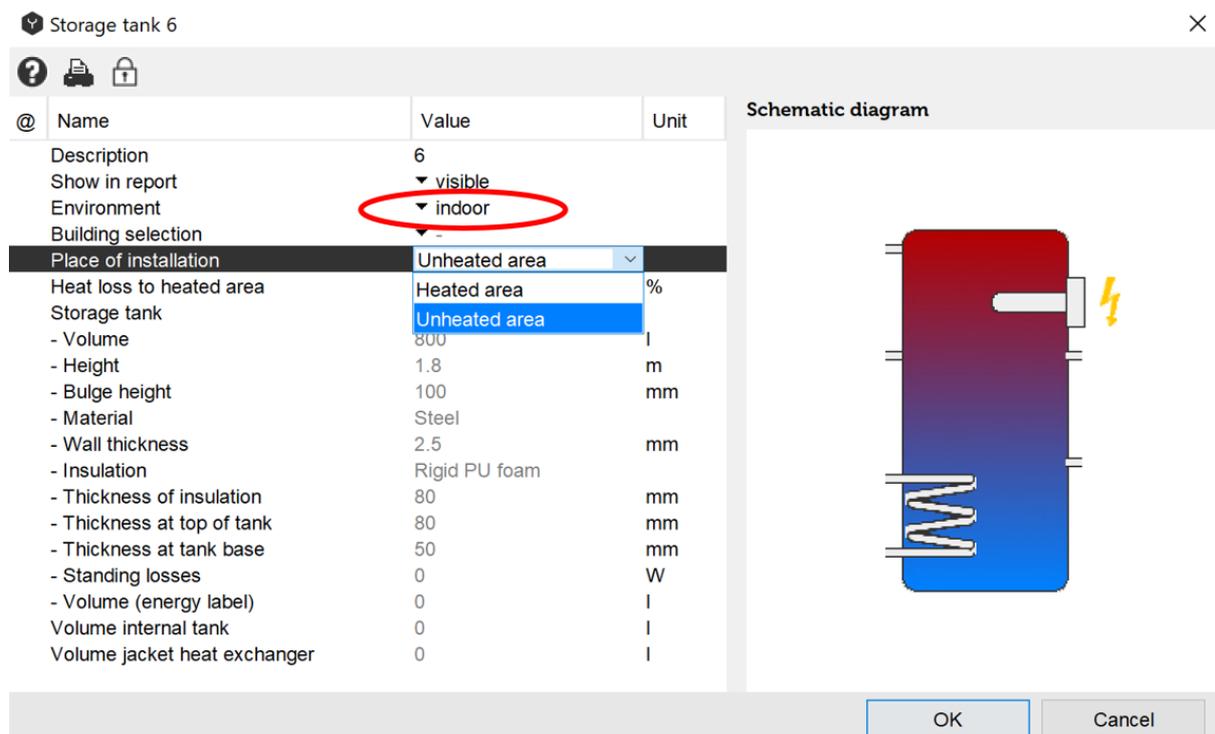


Fig. 81: selection among the 3 possible locations, where the thermal component can be installed: outdoor, in the heated area or unheated area

For the components, which are placed in the heated area, heat losses are added to the heating balance of the building. A thermal balance is the net amount of all gains and losses. The graphic bellow shows how heat losses from thermal components influence the heating balance of the building depending on the temperature at which heat losses occur.

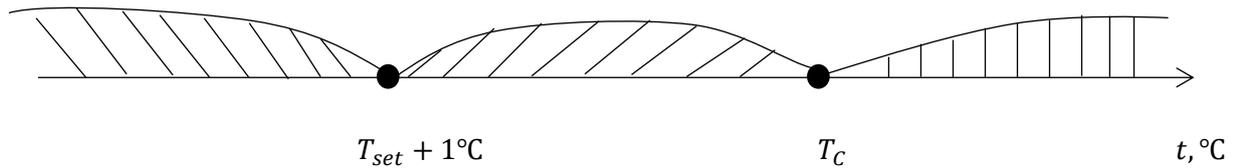


Fig. 82: graphical representation of the heat losses in the heating balance of the building depending on the temperature

The heat losses to the unheated area are calculated using the following approach:

- 1) If the indoor temperature is lower than the set point temperature $T_{set} + 1^{\circ}\text{C}$, then the losses cover a part of heating demand (so called recoverable losses Q_R);
- 2) If the indoor temperature is higher than the set point temperature $T_{set} + 1^{\circ}\text{C}$, but lower than cooling set point temperature T_C , then the losses cannot be utilized in the building (so called non-recoverable losses Q_{NR});
- 3) Moreover if the indoor temperature is higher than the cooling set point temperature, then the losses lead to even more overheating of the building and therefore contribute to the cooling demand Q_{CD} .

There is one more important application of unheated area. It can be chosen as a source for exhaust-air heat pumps. In more detail the exhaust-air heat pumps are described in the chapter 4.1.3.

Heat pump
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@	Name	Value	Unit
	Description		
	Show in report	▼ visible	
	Environment	▼ indoor	
	Building selection	▼ -	
	Place of installation	▼ Unheated area	
	Heat loss to heated area	10	%
	Loop description		
	Heat generator	▼ Heat pump	
	Heat pump	Heat pump 5 kW (in...	
	- Heating power at A2/W35	4	kW
	- Electrical power at A2/W35	1.2	kW
	- DeltaT at A7/W35	9.5	K
	COP at A2/W35	3.3	
	Temperature over-pressure failure	65	°C
	Heat source	▼ Ambient air	

Schematic diagram

OK

Cancel

Fig. 83: example of the heat pump installed in the unheated area (e.g. cellar)

Hourly energy demand. This model works with hourly energy demand input. It allows accurate modeling of the heating/cooling system by specifying energy demand in the building along with an optional set-point temperature for each hour.

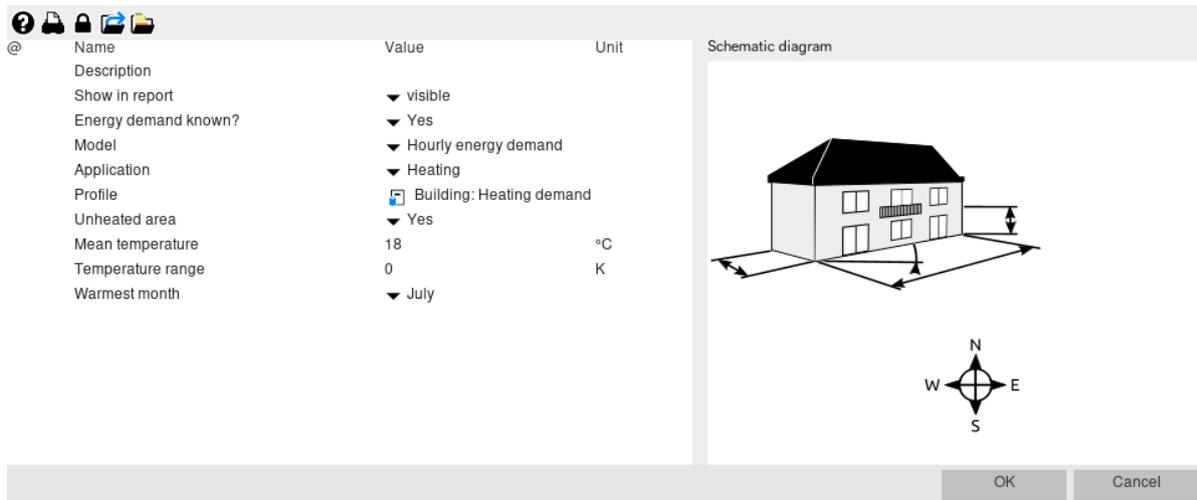


Fig. 84: selection of hourly energy demand model in Polysun GUI.

The hourly demand profile can be selected from the Profile catalog (“Thermal power demand”).

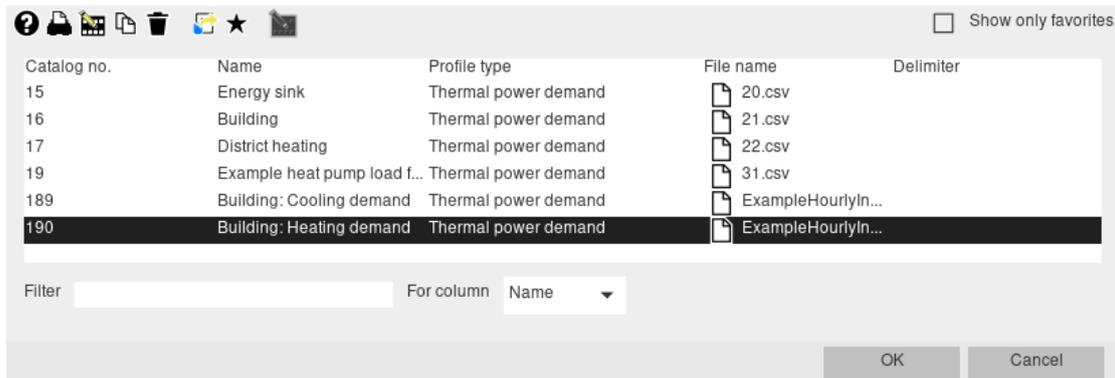


Fig. 85: “Thermal power demand” profile catalog.

Depending on the number of columns in the CSV file, the profile may be interpreted differently:

- Profile with 3 columns – Time, power and a set-point temperature: The variable set-point temperature is read from the profile.
- Profile with 2 columns – Time and power: A constant set-point temperature can be set in the building’s configuration table.
- Profile with 4 columns (designed for the energy sink/source) – Time, inlet temperature, outlet temperature and power: Only the power column is used. The inlet and outlet temperature columns are ignored by the building model. A constant set-point temperature can be set in the building’s configuration table.

The power column is the heating or/and cooling demand of the building in W. A variable set-point temperature in the building can be specified for each hour in °C. It may be useful to define a variable set-point temperature, since it can depend on the season or time of day. Please note that heating demand values should be positive (plus) and cooling demand values should be negative (minus). In contrast to the energy sink/source, the building cannot read profiles with both positive and negative values.

The hourly energy demand model can be used as an „interface“ to another simulation software. This simulation software should allow generation of building energy demand with hourly time resolution. In this case the building can be first simulated in details in the building simulation software (e.g. Energy Plus, IDA ICE etc.) and then “imported” to Polysun, where energy supply system can be designed and sized. This “interface” allows importing both the whole building and different thermal zones of the building.

3.5.3 Swimming Pool

The swimming pool module is created as a component with two connections. The fresh water supply is taken into consideration, which can be inserted as a parameter. The physical models also include evaporation values, heat losses to the environment, convection, thermal emission and irradiation. The parameters used for the swimming pool are geometric measures (length, width, depth) also as the U-value between pool and soil.

The operating periods are indicated by the date (day of the month) and by the hour of opening (hour of the day). Also with “cover” and “gap losses cover” the user can indicate if and how the pool is covered at times of non-use.

Double-clicking on a swimming-pool out of the catalog you will be able to select either an indoor swimming-pool or an open-air pool. For open-air pools room temperature, relative humidity of air and the recovery of heat evaporation are not taken into account. On the other hand wind portion and swimming-pool absorption have no influence on the indoor swimming-pool. The level of absorption of global radiation by the swimming-pool ranges based on colour, depth and covering between 60% and 90% (Duffie and Beckman 60%). The reflection of light on the water surface amounts to 8% and is already taken into account.

Definitions of Fundamental Parameters

A_{surf} = area of the pool surface in m^2

T_{pool} = water temperature inside the pool in $^{\circ}C$

T_{amb} = ambient temperature in the air outside the pool in $^{\circ}C$

v_{wind} = wind speed in m/s

Heat Transfer to Soil Surrounding the Pool

$$\dot{Q}_H = u \cdot A_{walls} \cdot (T_{pool} - T_{soil})$$

A_{walls} = total wall and floor area in m^2

u = u - value in $W/(m^2K)$

$$T_{soil}(t) = \frac{\Delta t}{\tau} \cdot T_{soil}(t - \Delta t) + \left(1 - \frac{\Delta t}{\tau}\right) \cdot T_{amb}(t)$$

with a temporal constant of $\tau = 7$ days.

This corresponds to the formula $x(t) = 1 - e^{-t/\tau}$.

Heat Losses due to Evaporation from the Water Surface

Formula according to Transsolar (TRNSYS TYPE 144):

$$\dot{Q}_{Evap} = A_{surf} \cdot c_0 \cdot (c_1 + c_2 \sqrt{v_{wind}}) \cdot (\hat{P}_{pool} - \rho \cdot \hat{P}_{amb})$$

$$\hat{P}_{poolamb} = k_0 + k_1 \cdot T_{poolamb} + k_2 \cdot T_{poolamb}^2 + k_3 \cdot T_{poolamb}^3$$

ρ = relative humidity in kg/kg

with the fit parameters [Auer96]

$$c_0 = 1.01325 \times 10^5 \text{ Pa/atm}$$

$$c_1 = 42.39 \text{ m/s}$$

$$c_2 = 56.52 \sqrt{\text{m/s}}$$

$$k_0 = 4.82 \times 10^{-6} \text{ atm}$$

$$k_1 = 7.11 \times 10^{-7} \text{ atm/K}$$

$$k_2 = -3.52 \times 10^{-9} \text{ atm/K}^2$$

$$k_3 = 7.22 \times 10^{-10} \text{ atm/K}^3$$

The following illustration shows the influence of the wind and relative air humidity on the area related evaporation heat \dot{Q}_{Evap}/A_{surf} .

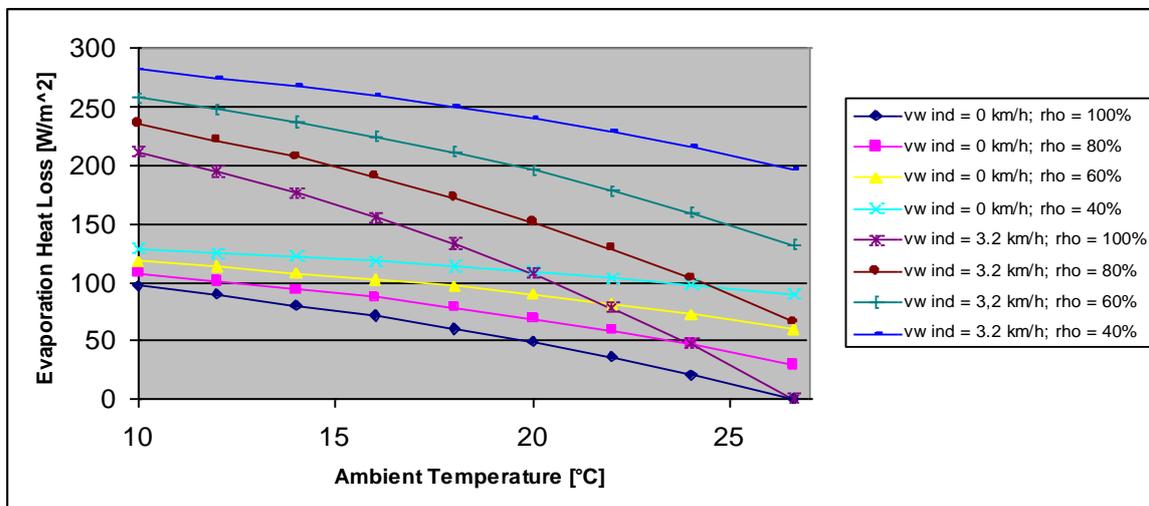


Fig. 86: influence of wind and relative air humidity

Heat Losses due to Thermal Emission

$$\dot{Q}_S = A_{surf} \cdot \varepsilon \cdot \sigma \cdot ((273.15 + T_{Pool})^4 - (273.15 + T_{Sky})^4)$$

$$\varepsilon = 0.9$$

$$\sigma = \text{Stefan Boltzman constant} = 5.67 \times 10^{-8}$$

Heat Gains by Means of Direct Solar Irradiation

$$\dot{Q}_S = L_{up} - L + G_h \cdot (1 - \rho)$$

Heat Losses due to Convection

$$\dot{Q}_{conv} = A_{surf} \cdot (b_1 + b_2 \cdot v_{wind}) \cdot (T_{pool} - T_{amb}) \cdot \left(1 - \eta_{cover} + \eta_{cover} \cdot \frac{u_{cover}}{b_1} \right)$$

$$b_1 = 3.1 \text{ W} / (\text{m}^2 \text{ K}) = \text{heat transfer, no wind}$$

$$b_2 = 4.1 \text{ Ws} / (\text{mK}) = \text{correction term for finite wind speed}$$

$$u_{cover} = u - \text{value of the cover in } \text{W} / (\text{m}^2 \text{ K})$$

$$\eta_{cover} = \text{percentage of covered pool surface}$$

Heat Losses due to Exchange of Pool Water (Fresh Water Supply)

$$\dot{Q}_F = \dot{V} \cdot d \cdot c \cdot (T_{Pool} - T_{Fresh})$$

$$\dot{V} = \text{fresh water supply in } \text{l/h}$$

Normally: 2% of pool volume per day or 50 l a day per swimmer.

$$d = \text{water density} = 1 \text{ kg/l}$$

$$c = \text{specific heat capacity of water} = 1.16 \text{ Wh} / (\text{kgK})$$

3.5.4 Heat Sink/Source

A simplified representation of a heating load may be achieved by means of the components "Heat sink" and/or "Heating modules" (radiators, floor heating, fan, etc.). The former are defined by means of fixed inlet, temperature gradients, flow rate and power range. The specified power levels can be freely edited from user levels Professional and above. The use of a heat sink is especially recommended for the representation of process-heat processes as power input and output can be freely defined. The modelling of the heating module may be inferred from its specific emission characteristics as well as its power and flow ratio and inlet and return temperature. The values provided here enable a simulation to be carried out without the building-specific data defined in the consumer dialogue box. As a consequence, however, seasonal dynamics from the consumer side are no longer recorded.

Polysun Video



[How to use a heat sink/source for process heat](#)

3.6 Systems

3.6.1 Standard Templates

3.6.1.1 Choice of the Right Template

A good practice is to start the design of a system based on the standard template suggested by Polysun. Standard templates are located in the bottom left of the graphical user interface (main window).



Fig. 87: standard templates

There are many templates dedicated to solar thermal systems. In the standard templates tree they are saved in several folders and depending on the type of the load they are shown as follows:

- Domestic hot water systems
- Space heating systems
- Domestic hot water and space heating systems
- Solar pool heating systems
- Exhaust air heat pumps systems
- Bivalent systems (heat pump plus conventional heat generation)
- District heating (energy supply)
- Solar process heat/District heating (feed-in)
- Hybrid collector systems (PVT)
- Cooling systems
- Ice storage systems
- Cogeneration/Fuel cell system

Solar thermal systems can be also used in combination with other technologies, e.g. with photovoltaic modules or a heat pump. Therefore, if you are looking for a combined system, they can be also found in other folders.

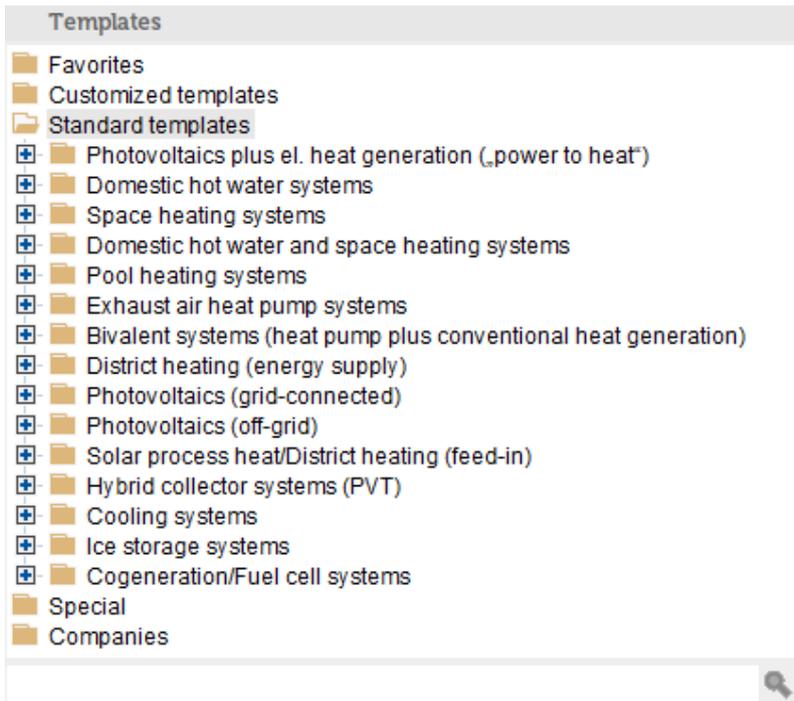


Fig. 88: standard templates-tree

The standard template must have maximum correspondence to the technical specification of the real system, which has to be designed. You can see the pre-view of the templates, when you hover the mouse cursor over the template name. This visualization will help you to understand the main features of the suggested system in the given template. The most important parameters that have to be taken into account in order to choose a proper template are as follows:

- 1) the type of the system (stand-alone, district-heating, process heat);
- 2) demand (domestic hot water and/or heating and/or pool);
- 3) energy generating (solar collector, PVT, heat pump) and energy storing (buffer store, combi-store, ice-store) elements of the system.

3.6.1.2 Adapting a Template

As soon as the template is chosen, it shall be adjusted in accordance to the project requirements. There are two possible cases:

- 1) The chosen template has the same or very similar configuration to the real system;
- 2) the chosen template includes only some parts which correspond to the real system.

In the first case, the hydraulic configuration of the template shall be adjusted to the real system, thus some components as well as controllers can be added or deleted. All the components of the system have to be carefully checked for compliance with the technical specification of the real system. For example, type/model of the boiler, solar collector, etc.

The settings of the building and the building type must be checked. For example:

- type of the building, which influences building losses;
- size of the building, which determines the heating area;
- size and type of the windows, which determine solar gains.

Domestic hot water and heating systems must also be checked. For example, the following parameters shall be considered:

- required temperature and the flow-rate of the water;
- the required volume of the hot water;
- the temperature of the cold water shall be set according to the location in the cold water tap component. More detailed information about the cold water can be found in the chapter 3.4.1.;

The system with a pool might require different switching times for the three-way valve, which is connected to the pool loop.

When the parameters of the main system components have been checked, the next step is to size the equipment in accordance to the given load. At this design stage the rules of thumb might be very helpful, such as:

- 1) Storage tank shall be approximately 50/100 l per square meter of the flat-plate solar collector;
- 2) Flat-plate heat exchanger shall be in the range of 0.05 to 0.08 m² per square meter of the flat-plate solar collector;

Please note, that the volume heated up by the auxiliary heater shall be big enough to satisfy the DHW demand entirely.

If it is required, new controllers shall be added and set up. The easiest way to set up a new controller is to find a similar technical configuration in another template, copy controller to the designed system and make changes according to the given technical specifications.

After you have completed all the above steps, the first simulation can be run.

In the second case, the task is more difficult: to build a complex new system, which would work right away. Therefore, it is recommended to build the system step by step using the hydraulic components (collector loop, auxiliary heater loop, heating loop), starting from the one available in the template and gradually adding the rest. In order to make the first loop work, a load is required (DHW, space heating, pool). Therefore, one of the loads shall be added to the first loop. After that, the controlling strategy can be set up and then the simulation can be run in order to check if this part of the system works. The components shall be added one after another, until the planned system has been designed. Using the suggested procedure, it will be easier to detect problem zones, which might block the simulation (e.g. missing controlling inputs, too complex hydraulics, etc.).

The main aim is to design all hydraulic connections and set up all the controllers. It makes sense to start from the part of the template, which corresponds to the real system (e.g. solar collector loop).

Once the final hydraulic layout of the system has been designed, you can size the system according to the recommendations of the first case.

3.6.1.3 System Optimization and Analysis of Results

As soon as all abovementioned steps have been implemented, the simulation can be started in order to size all components correctly and to optimize the controlling strategy. First, the analysis of the results has to be done. The most important parameters of the solar thermal system are: solar fraction (a ratio of the generated solar energy to the total generated energy) and the ratio of the solar energy yield (Q_{sol}) to the available energy onto collector aperture area (E_{sol}). Using the key figures, the effectiveness of the solar energy utilisation and the level of the auxiliary energy consumption can be estimated. If the energy requirements are not met, the size of the equipment has to be checked (size of the collector field and/or storage tank and/or auxiliary heaters) and the controlling strategy. Be aware, that the controlling strategy has to be optimized depending on the system location (climate data), type of load (temperature of the DHW, type of the space heating system (floor heating or radiator)) and energy goals (e.g. solar fraction). The following controller settings must be checked, since not always the default settings are suitable for specific projects:

- availability times of auxiliary heater/s;
- sensor positions.

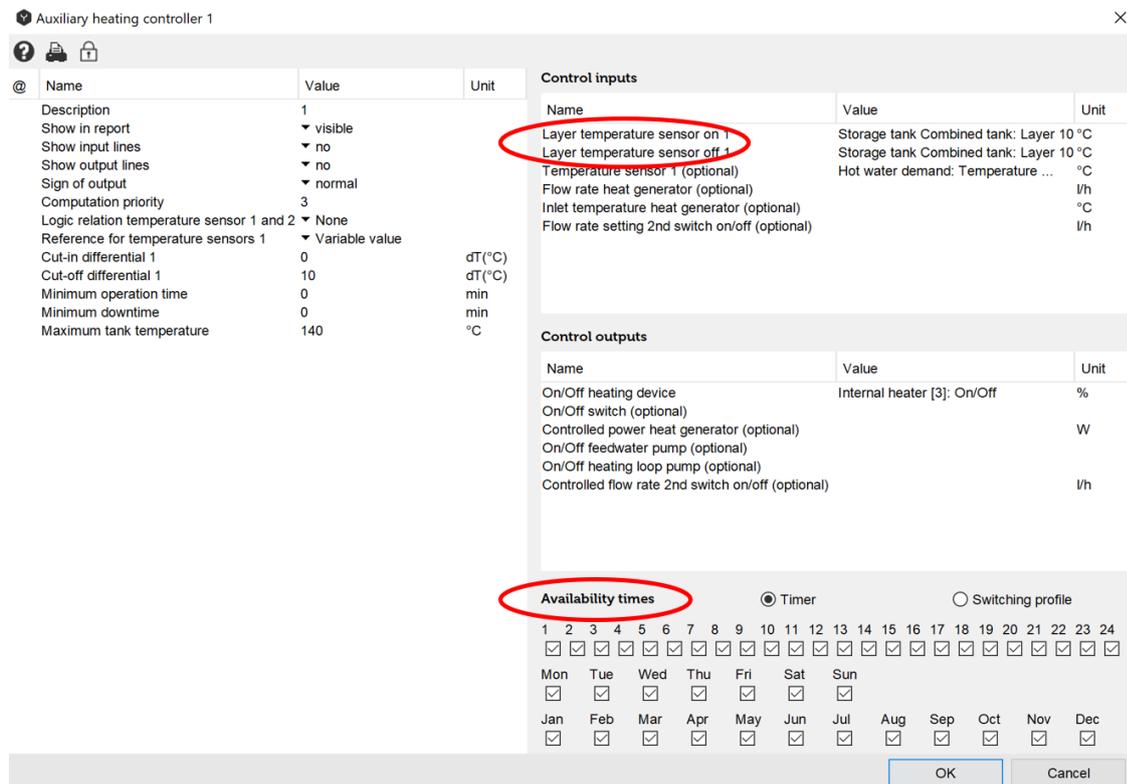


Fig. 89: controller settings

If the system works well and the energy demand is covered, you can try to increase the solar fraction and collector efficiency by reducing auxiliary energy (e.g. reducing the availability of the auxiliary heater and auxiliary energy volume in the storage tank). Another factor that should be considered during the system analysis is the stagnation temperature of the solar collector. It can be checked in the solar collector component results for each individual case. There are two important outputs: stagnation time and maximum temperature of the collector field.

System diagram 9a: Space heating (solar thermal, tank in tank) - Component results

Storage tank Combined tank Internal heater [3]			Storage tank Combined tank Internal tank [1]			Weather data									
Boiler	Building	Cold water	Collector	Heating/Cooling element	Hot water demand	Storage tank	Combined tank	Storage tank	Combined tank	Storage tank	Combined tank	Coil heat exchanger [1]			
Name	Symbol	Unit	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	D
Collector field yield	Qsol	kWh	4,330	226	327	474	426	446	426	454	428	400	297	224	2
On/Off		%	52.1	37.5	44.2	50.8	57.8	63.6	68.3	64	61.2	53.3	46.4	40.3	3
Collector aperture area		m²	12.6	12.6	12.6	12.6	12.6	12.6	12.6	12.6	12.6	12.6	12.6	12.6	1
Direct irradiation after IAM		kWh	8,982	398	560	940	989	803	978	977	1,082	891	633	359	3
Minimum value (Power)		W	0	0	0	0	0	0	0	0	0	0	0	0	
Maximum value (Power)		W	12,661	10,157	10,666	12,103	12,616	10,075	11,943	11,995	11,410	12,661	10,859	10,492	9,7
Collector field yield relating t...		kWh	344	17.9	25.9	37.7	33.8	35.4	33.8	36	33.9	31.8	23.6	17.8	
Collector field yield relating t...		kWh	309	16.1	23.3	33.9	30.4	31.8	30.5	32.4	30.6	28.6	21.2	16	1
Maximum temperature		°C	220	220	220	220	220	220	220	220	220	220	220	220	2
Diffuse irradiation after IAM		kWh	6,834	266	399	545	683	926	803	881	716	646	466	297	2
Minimum value (Power)		W	0	0	0	0	0	0	0	0	0	0	0	0	
Maximum value (Power)		W	5,350	2,830	3,666	4,420	4,806	5,118	5,350	5,330	4,782	4,892	3,891	3,048	2,3
Irradiation onto collector		kWh/m²	1,255	52.7	76.1	118	133	137	141	147	143	122	87.2	52	
Minimum value (Power)		W/m²	0	0	0	0	0	0	0	0	0	0	0	0	
Maximum value (Power)		W/m²	1,147	902	936	1,055	1,116	974	1,097	1,073	1,028	1,147	969	966	8
Temperature during operation		°C	55.2	37.1	41.9	51	64.1	66.1	70	66.6	73.2	65.8	56	39.6	3
Minimum value		°C	16.7	16.9	19.9	17.8	28.9	31.9	36.6	34.9	33.7	35.8	21.6	20.5	1
Maximum value		°C	104	65.6	67.8	102	102	102	102	104	103	101	98.5	69	6
Outflow temperature		°C	25	7.8	13.2	21.1	29.1	34.4	39.4	40	39.2	32	22.9	12.1	
Minimum value		°C	-9.9	-9.9	-8.1	-5.7	-1.3	4	6.7	8.5	8.7	5.4	-0.2	-3.9	-
Maximum value		°C	155	69.9	74.6	134	133	135	155	142	144	150	101	73.7	6
Global irradiation after IAM		kWh	15,816	664	959	1,486	1,672	1,728	1,781	1,858	1,797	1,536	1,099	656	5
Minimum value (Power)		W	0	0	0	0	0	0	0	0	0	0	0	0	
Maximum value (Power)		W	14,457	11,362	11,794	13,294	14,058	12,272	13,819	13,522	12,958	14,457	12,212	12,178	10,8
Days of stagnation		Day	1	0	0	0	0	0	1	0	0	0	0	0	
Stagnation time		%	0.02	0	0	0	0	0	0.2	0	0	0	0	0	

Fig. 90: stagnation temperature of the collector field in the components result overview

3.6.2 Tips and Tricks to Work with Designer

3.6.2.1 Adapting a Template

The easiest way to create a user-defined system scheme is to adapt a similar, existing template. Here, an advantage is that the controllers for the unchanged components are already configured. Below are some tips:

- **Replicability:** in order to always be able to revert to a functioning system diagram, always copy the system diagram and save the project after each process step. In addition, the simulation should be started and results should be checked so that any errors can be detected as early as possible.
- **Tank replacement:** Should changes be made to connections or internal components of the tank, a new tank is to be entered in the scheme. Following this, controllers should be checked and the relevant sensors be set on the new tank. If any component is removed from the scheme, the associated references in the controllers will be removed too – therefore, it is advisable to initially only remove pipe connections to the old tank and to remove the old tank from the scheme only after installing the new one and adjusting the controllers. This way, before the old tank is removed, you will still be able to identify in the controllers which in and outputs should be adjusted.

3.6.2.2 Designing a New System Scheme

If you do not wish to adapt an existing template, you may perform the following steps to design a completely new scheme altogether. Here too, we recommend the system diagrams are regularly copied as a backup. If the scheme to design is a complex one, it may make sense to first design a simplified version of it and gradually add more complex features on a functioning base.

1. Place all required components on the design area.
2. Connect components.
3. Start simulation. If the simulation is running, Polysun can calculate the designed scheme. Due to the missing controllers, the results are not yet significant (i.e. the calculation can be interrupted, it is enough to check whether or not the simulation is starting). If the simulation does not start, an error message referring to the cause will be displayed. For further information see the trouble shooting section.
4. Now, controllers can be added step by step. After adding each controller, it is always advisable to check whether the scheme is still functioning.
5. Check the results, e.g. with the aid of component results.

3.6.2.3 Controller Settings

- Where possible, use variable values, e.g. in the heat generator controller set the "Reference for temperature sensors 1" field on the left-hand side to "Variable value" and on the right-hand side, in the "Controller inputs" field, select the hot water demand temperature setting for "Temperature sensor 1". This allows hot water tapping temperature to be modified without the need for controllers to be adapted.
- Should the status of a mixing valve or the flow-rate of a pump be set through a controller, components must be set accordingly. Otherwise, the value pre-set in the components will be used.
Three-way valve: set "Branching model" option "Set value"
Pump: set "Flow-rate controlled" to "Flow-rate setting"

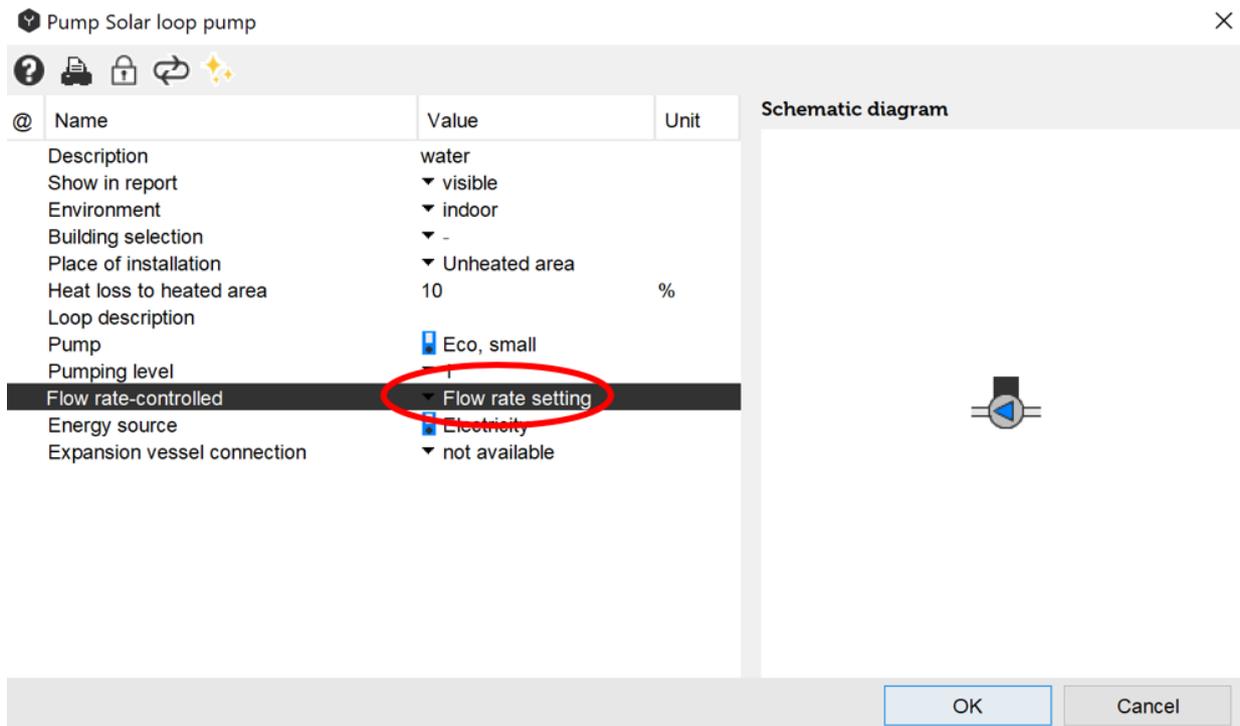


Fig. 91: pump settings

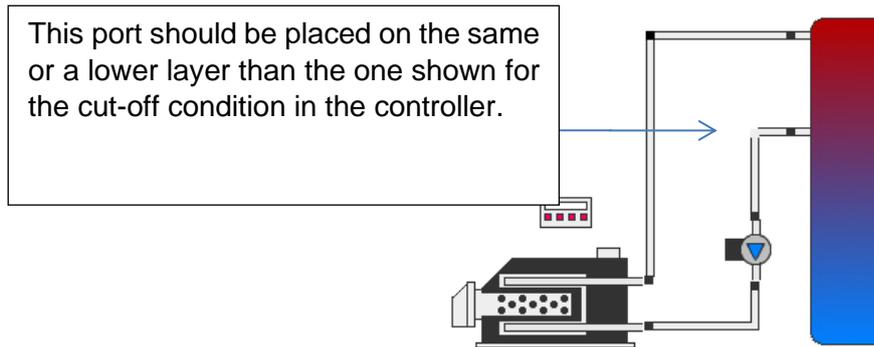
- If the parameters available for a controller are too few, an OR-operation of both controllers may be performed by means of two pumps arranged in parallel within the circuit, each with a controller.
- The indication of tank layers in the controllers is important and should be in line with ports and coil heat exchangers. At the same time, care should be taken to ensure that ports and coils are regularly distributed on the displayed tank image; however, for the simulation, the relevant heights are those listed in the tank catalog. In particular, tanks designed for water-pump systems have different port heights. It will be helpful to drag your mouse over the controller to see what height in the tank the sensors are pointing to.

Heat Generator Controller

If a heat generator is connected to the tank, the value for the cut-off condition in the “Heat generator controller” field must refer to the same or a higher layer than the one the return port is placed on.

Example of an incorrect controller setting:

The return port is at 60%. The boiler cuts in when layer 8 (58.3-66.7%) in the tank drops below 50°C. The cut-off condition is that temperature in layer 6 (41.7 – 50%) is 60°C. This is never reached as the boiler return lies at 60% (above layer 6) and therefore layer 6 cannot be effectively warmed up. Heating occurs on layer 8, where the return port is installed, and above. The heating continues until the maximum tank temperature configured in the controller is reached as the cut-off condition does not become effective. The correct setting for the cut-off condition is on layer 8 or higher.



3.6.2.4 Connection Multiplier

With the help of this component, hydraulic components or sets of components can be used several times for the simulation. For example, the multiplier can be incorporated in the inlet of a collector, so that all subsequent components can be multiplied by a chosen factor. In order for the system to work it is then necessary to install the antagonist, the outflow multiplier, in the return of the collector. This method can be used analogously at any point of a hydraulic loop.

3.6.2.5 Trouble-Shooting

3.6.2.5.1 System Scheme Is Not Running

If the simulation cannot start, an error message referring to the cause is displayed. Possible issues are:

- Open pipe connections (all connections, tank connections included, must be connected with pipes)
- Undetermined flow direction in a circuit, a pump or a three-way valve are missing. A circuit may also be over-determined, e.g. if two pumps are installed in series within the same circuit. The following components can determine flow direction:
 - Pump
 - Boiler/heat pump with internal pump
 - Cold + hot water connection
 - Three-way valve
- If an error message is displayed saying the circuit is too complex (Error n. 5070/21), the three-way valve should possibly be replaced with a T-piece.

3.6.2.5.2 Simulation Is Running Slowly

A long simulation time is suggestive of a failure during the simulation. If significant temperature differences are observed between two distinct calculation steps, Polysun

reduces the duration of the time step and calculates again, which causes simulation time to increase. Generally, complex and/or large systems have longer simulation times. In such case, an effective way to find errors is to switch-off controllers consecutively and observe in which case the simulation runs faster. To do so, disable all months in the availability times of the respective controller.

Availability times												⊙ Timer												○ Switching profile																																			
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24																																				
<input checked="" type="checkbox"/>																																																											
Mon	Tue	Wed	Thu	Fri	Sat	Sun																																																					
<input checked="" type="checkbox"/>																																																											
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec																																																
<input type="checkbox"/>																																																											

Fig. 92: example of the switched-off auxiliary heater in the controller settings

Possible causes include, for example, a controller that keeps switching on and off or an over-definition of flow direction in a circuit, for example, due to unnecessary three-way valves.

Avoid having two different flow directions in a pipe; particularly, in the case of pipes connected to a tank this may result in incorrect results. A better option is to use an additional port (port heights may be altered through the tank catalog, so, for example, also ports marked on the cap may be used as a connection further down).

Badly placed tank-ports or referencing a layer lying too high or too low in a controller may also be an issue. Temperature distribution in the tank may be suggestive of this problem. The individual tank layers can be seen in the component results, tabular and graphical evaluation.

3.6.2.5.3 Energy Demand Not Met

If at the end of the simulation this message is displayed, this may be due to a number of reasons including but not limited to:

- The tank is too small
- The tank cannot reach the required temperature
 - Availability times for auxiliary heating (boiler/heat pump/electric resistance heaters) are set too short in the controller.
 - The boiler is too small/heat pumps and possibly the borehole are too small
- In the controller, use “Variable value“ instead of fixed values, e.g. to refer to the hot water temperature setting.
- The mixing valve (for hot water and/or heating circuit) is set to a temperature that is too low. If required, configure a temperature shift to offset pipe losses.

Additional causes if the hot water demand is not met:

- For tank-in-tank systems: surface or volume of the inner tank are too small.

- The piping between the heat source and the tap is too long and this results in significant heat loss (circulation required)
- For fresh-water stations: pumps or plate heat-exchangers are too small.

Additional causes if the heating energy demand is not met (the desired temperature was not always reached in the building during the heating period):

- The night temperature set for the building is too low as compared to daytime temperature (the warm-up phase is too long)
- The number of convectors is too small (in the convector settings, set "Number of modules automatic" to "Yes")

Possible causes if the cooling demand is not met (= in the cooling period the building was above the desired temperature)

- The chiller is too small
- The number of fan-coils is too small (in the fan coil settings, set "Number of modules automatic" to "Yes")
- In the building settings, "Shading" and "Natural ventilation" were not set.

3.6.2.5.4 Limitations

- **Non-return check valve:** in Polysun, there are no non-return check valves. Indeed, non-return check valves are used for maintenance purposes, however, they are not relevant for the simulation. In addition, non-return check valves are installed to prevent an unwanted flow against the direction of the pump when the latter is switched off. In Polysun, pumps are ideal, i.e. when the pump is off nothing flows in or against the direction of the pump. Flow directions in the pipes are, thus, in any case clearly defined through pumps and three-way valves, which makes non-return check valves irrelevant for the simulation.
- **Multipliers:** as a general rule, only a couple of inflow/outflow multipliers should be used in a scheme.
- **Parallel tanks:** the connection of parallel tanks is not advisable. The use of a single, large tank provides in most cases good approximation and a more stable simulation. Tanks connected in series are also possible.
- **Flow rate producer / three-way valve:** exactly one flow rate producer should be available for each circuit. Serially connected pumps are not a possibility. If three-way valves are used in places for which a flow direction is already defined, this results in an over-definition for the flow-rate. Below are some examples:

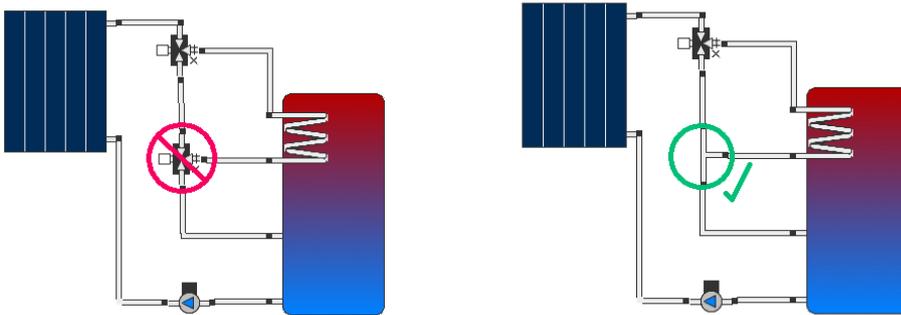


Fig. 93a: three-way valve examples – the lower valve is unnecessary as the upper valve and the coil determine where the fluid should be flowing through

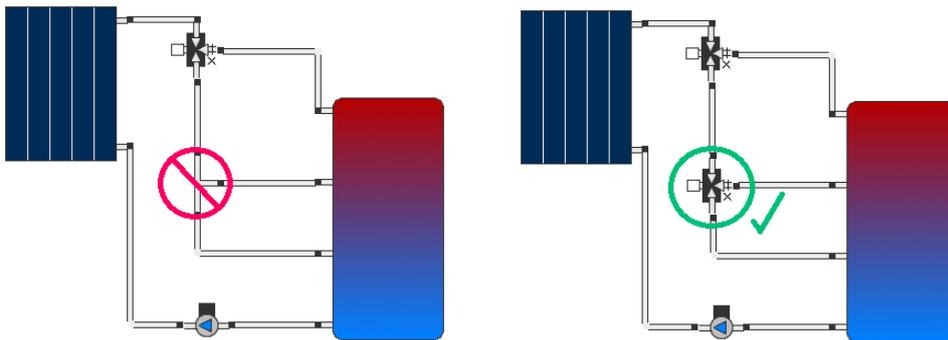


Fig. 93b: three-way valve examples – without a coil in the tank, the lower three-way valve is required to determine whether the fluid should flow out at the second port from the top.

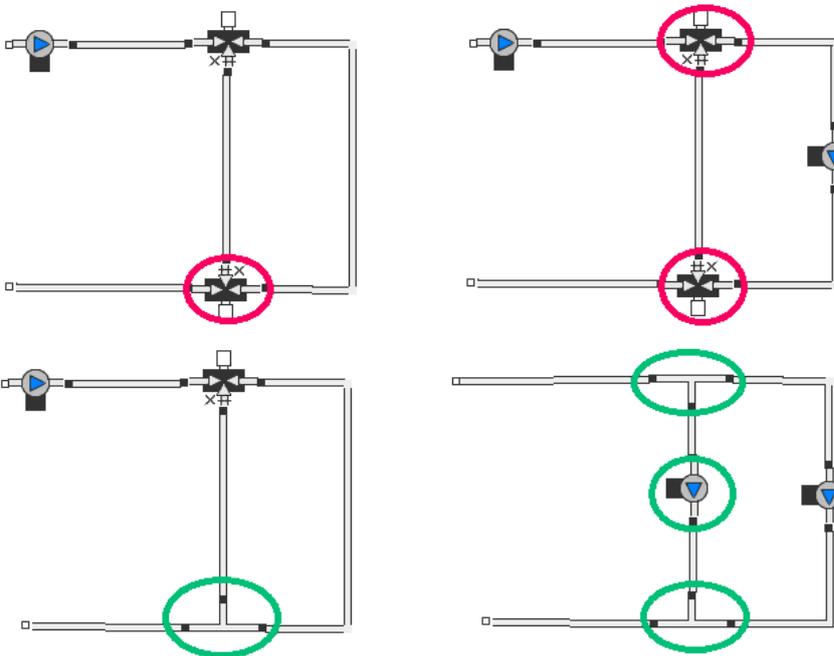


Fig. 93c: three-way valve examples – In the examples above there are too many flow-determining elements

3.6.2.6 Labels

The properties of a component may be illustrated by adding a label to the drawing area. Furthermore, additional information that the user has regarding the component may be added to the label.

Another feature allows you to modify values directly through the label. In the Designer version the most important labels for a component can be generated automatically in just

one click. Select the label symbol from the tool bar and click on the component for which you want to add the labels.

4 Heat Pumps and Geothermal Systems

4.1 Air-to-Water Heat Pumps

In the air-water heat pump catalog as well as in the water-water heat pump catalog there are two ways in which you can define the reference data for the heat pump. The first is to insert the reference points directly into the appropriate fields of the catalog (e.g. "Heating power at A20W35", "Electrical power at A20W35"). Alternatively the reference data can be read from a file by inserting the name of the reference file in the column „File name“. The file must be saved in the Polysun folder "profiles" (in Windows, the default path is C:\Users\Public\Polysun\profiles). The file is saved in "csv" format and is structured as follows (in Windows 7 the default path is "C:\Users\Public\Polysun\profiles"). The file is in "csv" format. File formats vary depending on the type of heat pump and are specified in the respective sub-chapters.

The file data substitute the data in the columns „Heating power at XX“ and „Electrical power at XX“ and will no longer need to be defined. The other columns will have to be filled in, particularly „DeltaT at A7/W35“.

Within the file you may indicate reference points for any evaporator and condenser temperature.

4.1.1 Standard Heat Pumps

The air-to-water heat pump is depicted in Polysun as a component equipped with two hydraulic connections. The model is based on the input values Heating power and Power consumption; such values were measured according to test standards EN 255 or EN 14511 on predefined sampling points (e.g. A2/W35). The electrical power absorbed by the heat-pump is calculated by linear interpolation of the sampling points. The thermal heating power is defined by linear interpolation of the corresponding quality grade of the sampling points.

Frosting and de-frosting behaviour are likewise taken into account through the norm and may be thus simulated in Polysun. This model only applies to intermittent heat pumps; variable-speed heat pumps are described in the chapter "Modulating air-to-water heat pump".

The results "Energy from/to system" and "End Energy" include the power of the heat pump and that of the internal heating element, in case the auxiliary heating was switched on. To calculate the COP (Coefficient of Performance), the power of the internal heating element is, however, to be deducted from the results. The result "COP", therefore, only applies to the compressor and not to the heating pump as a whole.

The absorbed power of compressor, internal circulation pump, fan as well as the supplied heat output are taken into account in the COP calculation.

Within a hydraulic scheme you will be able to switch from a boiler to a heat-pump by accordingly setting the selection of the heat generator.

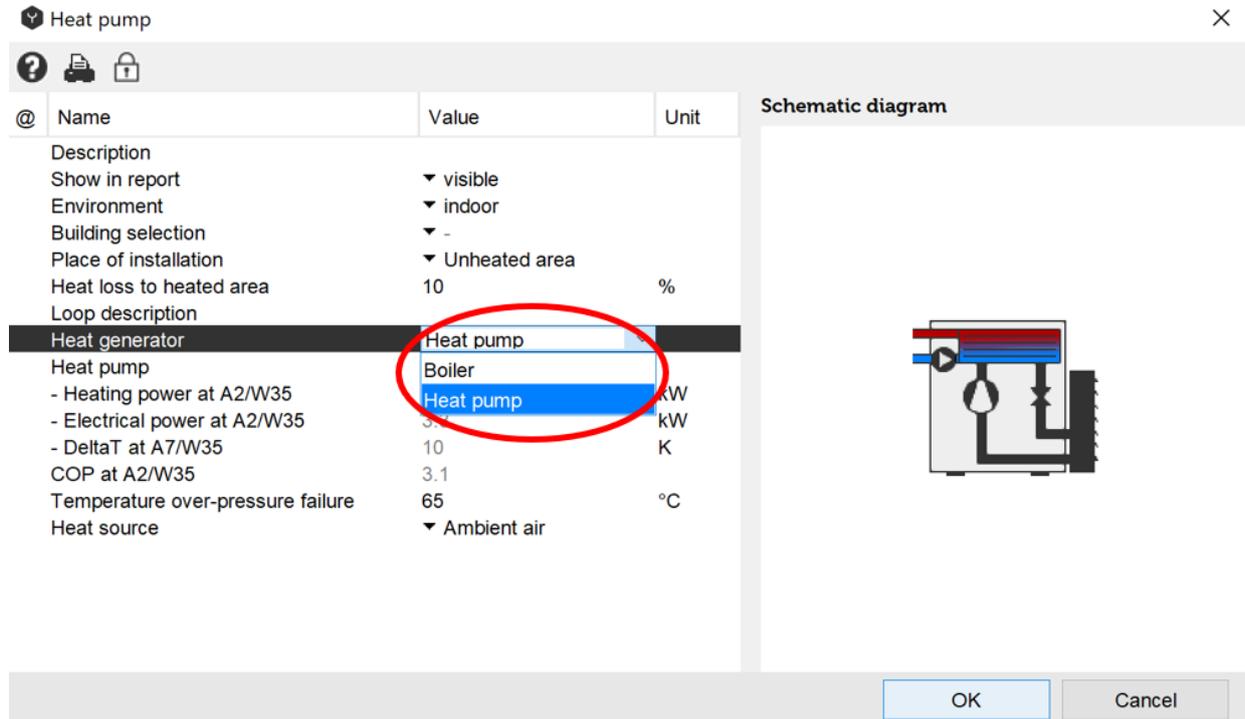


Fig. 94: selection of air-to-water heat pump

The heat-pump-specific operating times may be defined by means of the minimum operation times and minimum idle period that may be found in the heating controller.

Q is implemented from the measured values; this requires T_v . This is approximated through $TU = Q'/k * V - T_i$ (1) where $k = Q_{ref} / V_{ref} * 1/\Delta T_{ref}$ (2) and Q' from the previous time-step or on switching on the heat-pump $Q' = Q_{ref}$. This allows Polysun to calculate with Q' , V , T_i the outflow temperature.

All calculations are carried out with delta T_{ref} .

As a result: the calculation enables a correct calculation also for arbitrarily selected v .

Exceptions: for (1) and (2): the internal heat-exchanger is capable of transferring the overall power. The formulism will become inaccurate for $V \ll V_{ref}$.

Catalog Entries with Reference Points from a File

The file format for the definition of reference points in a profile file is as follows:

```
#Heat pump name;;;
#Evaporator[°C];Condenser[°C];Heating power[W];Electrical power [W]
20;35;20800;4100
10;35;18700;4100
...
...
```

4.1.2 Modulating Heat Pumps

The modulating air-water heat pump is integrated in Polysun as an extension to the air-water heat pump. Its working principle very closely follows the air-water heat pump model. Save as otherwise defined, the information provided for the air-water heat pump model also applies to the modulating air-water heat pump. Below is an overview of the different types of modulation available in Polysun (the type of modulation is available as a field in the air-water heat pump catalog):

Table 15. Types of modulation for the air/water heat pumps

Modulation	
None	Non-modulating heat pump, see chapter 5.5.2.
Based on outdoor temperature	A heat pump that adjusts its power level based on outdoor temperature so that the thermal power output remains constant over time. This kind of heat pump can be simulated with the model for basic air-water heat pumps (see chapter 5.5.2). In the process, reference points are entered whose modulation has already been taken into account, i.e. the thermal power is identical for all reference points, whilst the electrical power consumption varies.
Based on demand	The modulation takes place steplessly based on the desired thermal power output. For more details see the following sub-section.
Two-stage	The modulation takes place in two steps based on the desired thermal power output.

Different modes of operation can be set for on-demand and two-stage controlled heat pumps via the controller. All modes of operation are subordinated to the heat pump's "Status" controller value. If the latter is set to "0", the heat pump will be switched off in any case, regardless of the mode of operation. If the status is set to "1", the heat pump will at least run, in any case, at the lowest power level. In this way, the heat pump will not switch off if, for example, while running in the "Defined power level" operating mode a "0" is forwarded to it through "Desired power level". The heat pump must be switched off by through its status.

Should the mode of operation need to be controlled, the "Heat pump: status" should be set as an output in the programmable controller. For each operating status, a numerical value corresponding to a given mode of operation should be assigned to this output. In the following chart, these numerical values are shown in the "Controller value" column. Based on the respective mode of operation, additional information should be provided to the heat pump. Such information is to be entered via an additional output in the controller. Subsequently, for each operating status the controller will need to have been allocated by these additional outputs a value which, however, will only be taken into account if the mode of operation is appropriately set. The following chart lists the possible modes of operation.

Table 16. Modes of the heat pump operation

Description	Controller value	Additional controller outputs	Function description
Fixed maximum power	0	-	The heat pump runs at the maximum power level
Heat-driven operation mode	1	„Controlled power heat generator“	The heat pump delivers, as far as possible, the desired thermal power set via the “Controlled power heat generator” controller value. (default mode)
Electrically-driven operation mode	2	“Controlled power heat generator“	The heat pump draws, as far as possible, the available electrical power set via the “Controlled power heat generator” controller value.
Defined power level	3	“Controlled Power level“	The heat pump is run at the power level closest to the “Desired Power Level“.

In the event that the additional controller output is not configured in the mode of operation 1,2 or 3, the heat pump will be run at the maximum power level.

In the event that the mode of operation is not set through the controller, the heat pump will be run in the “Heat-driven“ operation mode as a standard.

In the event that the heat pump selected from the catalog does not provide any selectable power controller (field “Modulating“), the controller values shown in the above chart will not be taken into account. In this case, “Controller mode“, “Controlled power heat generator“ and “Controlled Power level“ may not be selected in the controller configuration menu.

In the typical case of power control being heat-driven, two configuration options are made available to the user. Two options are provided for setting the controller parameter. Similarly to the boiler model, the heat generator controller may be set to a constant inlet temperature for tank loading purposes. In so doing, the “control mode“ is implicitly set to “Heat-driven“. The controller in/outputs are set to the same settings as for a modulating boiler.

More complex control settings are performed through a programmable controller, whereby, with the aid of the HEATING CURVE function, i.e. by means of the heating curve, the current inlet temperature required for the heating loop and, as a result, with the aid of the MATCHFLOW function, also the required thermal power output are calculated. The desired thermal power output is then transferred to “Controlled power heat generator” via a controller output. When dealing with similarly controlled systems, special attention should be paid that heat pump size and the parameters of the HEATINGCURVE function (for a more accurate description see the “Programmable controller“ chapter) are appropriately matched to the building to be heated and its location. In the worst-case

scenario, should the heating curve not be appropriately configured, the heat pump will modulate to too low a power level and will be unable to match the energy demand as a result. If, on the contrary, the curve is set so that the heat pump constantly delivers more energy than required, instead of running non-stop at a lower power level and with a higher efficiency, this reverts back to the on-off operation. In this case, the potential of the power controller are not fully exploited.

In the event that the heat pump is also used for DHW preparation purposes, it should be ideally run at reduced power for this purpose. The “Defined power level“ operating mode may be used to this end.

4.1.2.1 Stepless modulating Air/Water-Heat pump

The model for stepless modulating air/water heat pumps was developed within the framework of a research project, “Implementierung der leistungsgeregelten Luft/Wasser-Wärmepumpen aus dem BFE-Projekt „Effiziente Air/Water-Heat pumps durch kontinuierliche Leistungsregelung in der Simulationssoftware Polysun“ [Implementation of power-controlled air/water heat pumps from the BFE-Project “Efficient air/water heat pumps through continuous power control” in the simulation software, Polysun”].

Like the other heat pump models available in Polysun, the model for stepless modulating air/water heat pumps, too, is based on an interpolation procedure. The family of curves is described by means of several measuring points that are saved in a text file. Reference points must be necessarily saved as a profile file. The format is:

```
#Heat pump name;;;
#Power level[0-1];Evaporator[°C];Condenser[°C];Heating power[W];Electrical power[W]
1;-20;30;5313;2310
1;-12;30;6745;2448.7
1;-2;30;8739;2553.3...
...
...
0.5;-20;50;2520;1602.034329
0.5;-12;50;3158.1;1683.788578
0.5;-2;50;3989.74;1687.274583
```

where “Evaporator“ corresponds to the outdoor temperature and ”Condenser“ to the inlet temperature. This input format makes it possible to process data in a clear, intelligible way using a spreadsheet program such as Microsoft Excel.

For results to be fairly accurate, a total of at least 140 reference points should be defined covering the expected operating range. For the simulation of home systems, reference points should be ideally spread out over an outdoor temperature range from -20°C to +20°C (= evaporator temperature) and an inlet temperature range from 30°C to 60°C (= condenser temperature). However, there is also a chance that in a given time step an operating point is needed for the simulation that lies outside the temperature range defined in the file. In this case, the data curve will programmatically flatten out, as is shown in the following chart in the form of dashed lines.

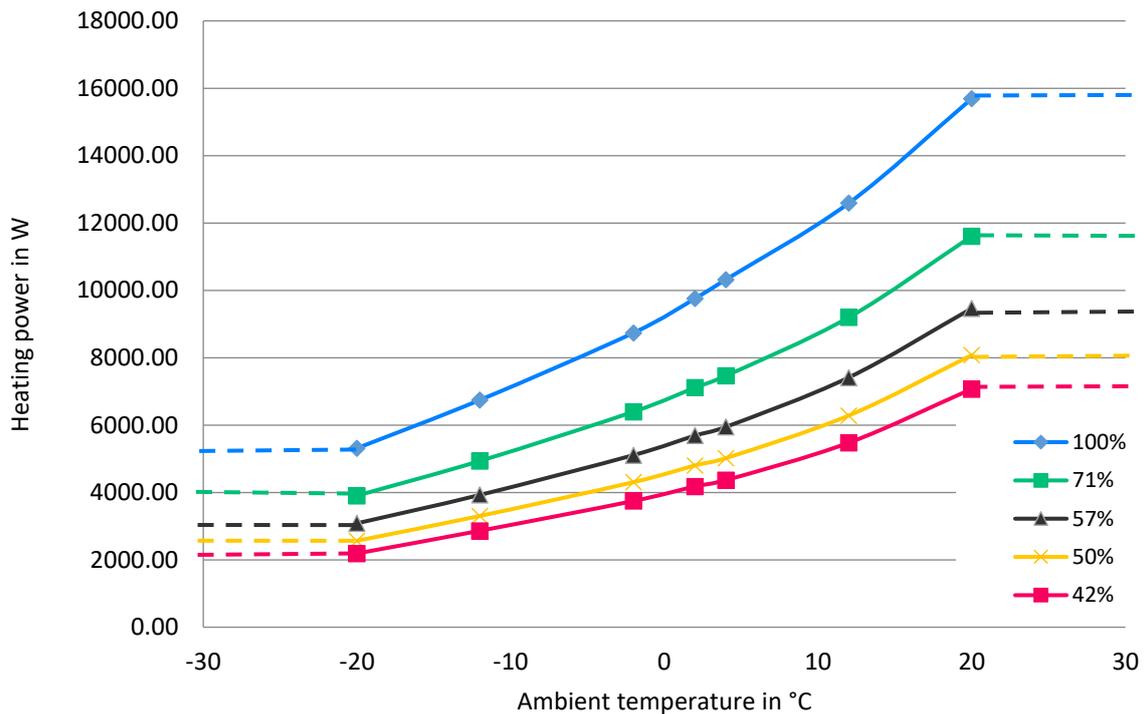


Fig. 95: outdoor-temperature heating-power data for different power levels. The dashed lines show the programmatic extension of data series.

The simulation requires that the electrical power absorbed by the heat pump as well as the thermal power output are calculated for each time step.

In the heat-driven operation mode, i.e. in the standard case, the required thermal power is calculated by a controller. The power is then transferred to the “Controlled power heat generator” of the Heat pump component via a controller output. Polysun provides the outdoor temperature for each time step. The last required input parameter is the inlet temperature at which the heat pump is currently operating. However, as this is only calculated when the system is simulated, the inlet temperature is extrapolated from the data collected in the latest time steps (similarly as for the non-modulating air/water heat pump model).

In a first step, using the known input parameters and the defined reference points, the power level is calculated by means of scattered data interpolation. If this turns out to be lower than the lowest power level specified in the reference points, it will be rounded off to the lowest power level. Then, in a second step, the current thermal power output and the currently absorbed electrical power are interpolated for the calculated power level and passed on to the overall system simulation.

The electrically driven operation mode runs in a way that is very similar to the heat-driven mode. For the determination of the power level, however, the electrical power consumption together with the outdoor and inlet temperature are used as interpolation points instead of the required thermal power.

If the required power level is sent directly by the controller, the interpolation step will no longer be required for the determination of the power level.

Schemes with and without DHW preparation respectively for a new building and an old renovated building are presented as an example in the scheme catalog under “Swiss

Systems“. As has been mentioned, the parameters for the HEATINGCURVE function need to be adjusted in the programmable controller. In the template, these parameters are set to the configured building and to the location Rapperswil SG.

4.1.2.2 Two-Stage Air/Water Heat Pumps

The two-stage heat pump model is implemented as an extension to the standard air/water and water/water heat pump model. In this model, the two-stage heat pump is presented as a device containing two units operating in parallel. For the pump to run at full power, both units need to be activated. If the power is reduced to 50%, only one unit is required to be running.

The heating power delivered at the current operating point is calculated by means of the existing model. The power is then reduced to 50% by decreasing both the heating power and the electrical power by 50%.

In the heat-driven operation mode, a check is made whether 50% of the power is sufficient to meet the required power demand. If this is the case, the heat pump is run at 50% of its capacity.

In the electrically-driven operation mode, the power is reduced to 50% as soon as the available electrical power drops below 90% of the electrical power absorbed by the heat pump when running at 100% capacity.

In the “Fixed power level“ operation mode, the power is reduced to 50% if the required power level is equal or lower than 50%.

In the database or in the profile file, reference points are entered for the full power; the format is the same as for a standard air/water heat pump.

4.1.3 Exhaust Air Heat Pumps

In order to improve the air heat pump efficiency, the source part of the heat pump can be placed in the unheated area of the building where the temperature is higher than the ambient temperature, such as cellar, storage room, garage, etc. In this case, you can open the heat pump dialog window, select the required building and choose the unheated area in the heat source drop-down menu.

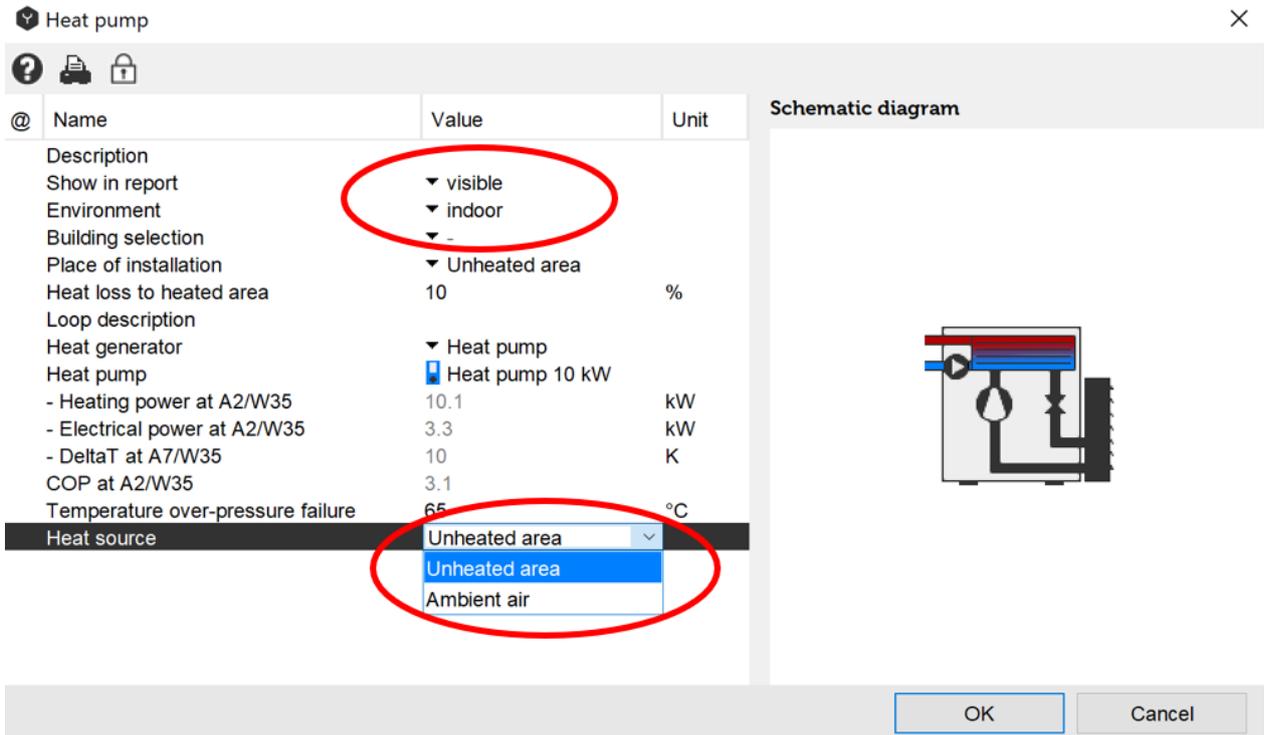


Fig. 96: selection of the unheated area in the heat pump dialog window

In the building dialog window, you may also define the temperature of the unheated area.

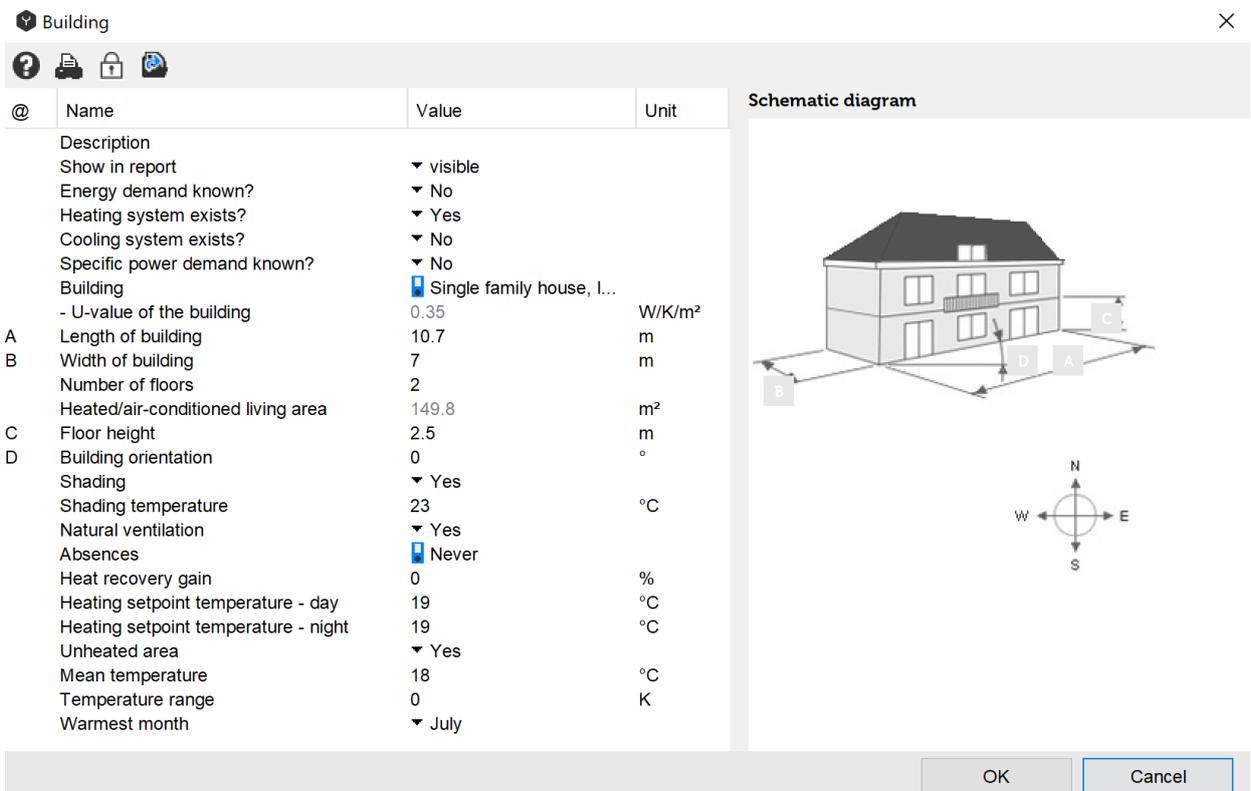


Fig. 97: definition of the mean temperature of the unheated area in the building dialog window

4.2 Water-to-Water Heat Pumps

A water-to-water or brine-to-water heat pump is a component fitted with four hydraulic connections. The calculations of heating power and absorbed power are based on a so-called “Scattered data interpolation”. This also enables unknown interpolation nodes to be omitted, which may result in less accurate results. As with air/water heat pumps start-up losses will not be considered for water/water heat pumps either. Besides the supplied amount of energy the calculated coefficient of performance takes into account only the amount of energy absorbed by the compressor.

When configuring a system care should always be taken to ensure that brine temperature at the heat-pump input (T_s) is always lower than the inlet temperature (T_v) in the heating loop.

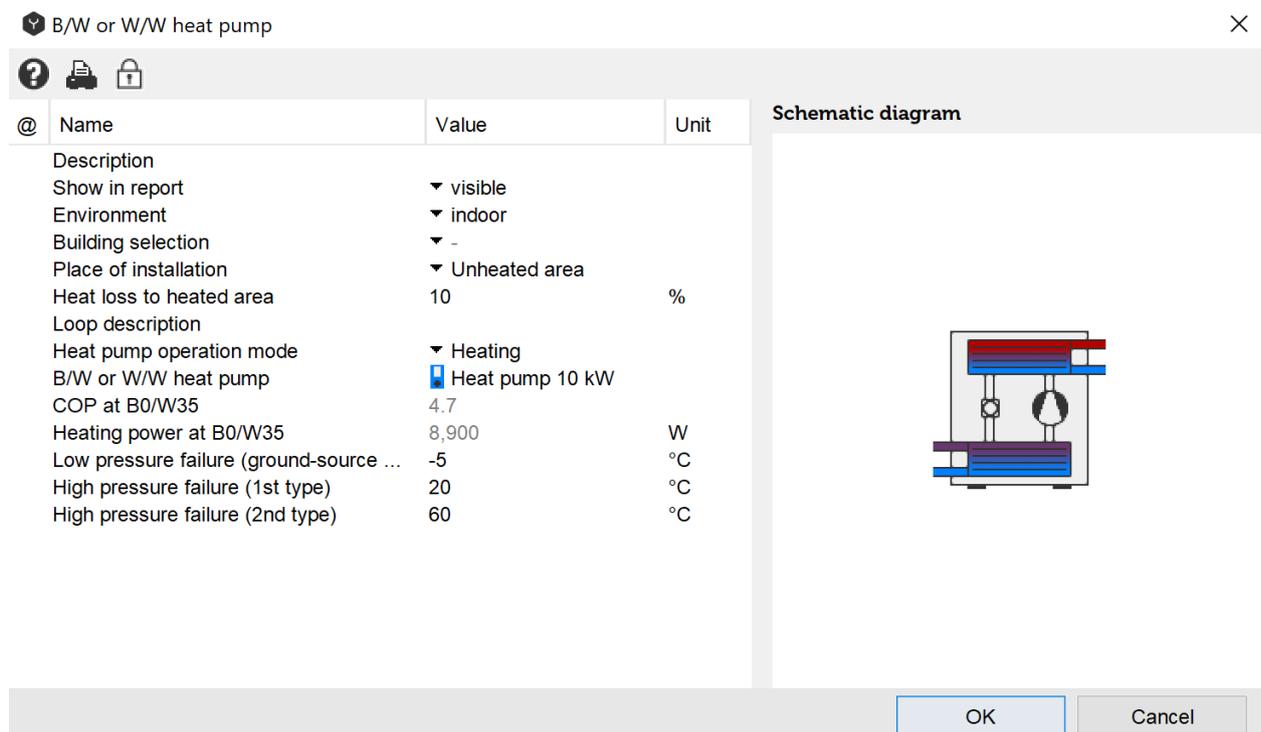


Fig. 98: water-to-water heat pump

A realistic heat pump control can be reproduced by means of the minimum operation time and the minimum idle time.

4.2.1 Catalog Data with Reference Points from a File

The data format for the definition of reference points in a profile file is as follows:

```
#Name der Heat pump;;;
#Evaporator[°C];Condenser[°C];Heating    power[W];Electrical    power[W];    Cooling
power[W]
-5;35;14800;3700;0
0;35;17200;3600;0...
...
```

Optionally, the cooling power may be also indicated. Where this is greater than 0, the internal losses of the heat pump will be taken into consideration in the simulation.

$$\text{Internal losses HP} = \text{cooling power} + \text{electrical power} - \text{heating power}$$

4.2.2 Two-Stage Water/Water Heat Pump

A two-stage water/water heat pump works on the same principle as a two-stage air/water heat pump (see **Error! Reference source not found.**).

Its operation is based on the standard water/water heat pump model. Two-stage operation is only considered in case of heating.

In the database or in the profile file, reference points are entered for the full power; the format is the same as for a standard water/water heat pump

4.3 Ground-Source Loops

Depending on output requirements and local conditions a ground-source loop can reach a depth in the range of 50 to over 100 metres. Three different types of ground-source loops (single-U, double-U and coaxial) are typically lowered into the borehole. The mathematical model that Polysun uses for ground-source loops was imported from the EWS programme.

Compatibility with the EWS programme makes it possible from user level Designer and above to enter EWS project files directly into Polysun. The strong model running in the background makes it likewise possible to set-up ground-source loop fields. These are characterised by indicating Eskilson's g function:

$$g = (r, t) \frac{\Delta T_{Erde}(r, t) 2\pi\lambda_{Erde}}{\dot{q}}$$

ΔT_{Erde} : *Temperaturabsenkung*

λ_{Erde} : *Wärmeleitfähigkeit*

\dot{q} : *spezifische Entzugsleistung*

This dimension-free step response reproduces the temperature behaviour within the ground-source loop environment with respect to the uninfluenced ground. Care should be taken that the g-function always only applies to a determined ratio between loop depth H and loop distance B. A wide range of ground-source loop arrangements is available in a separate catalog. The B/H ratio does not necessarily have to match the actual arrangement as an effective B/H ratio will be extrapolated in case of any deviations. So as to keep extrapolation inaccuracies to a minimum the closest possible ratio should always be used.

The model admits a maximum of up to 10 different earth layers each of which will affect the calculation of the ground-source loop as a whole. Multiple temperature nodes will be calculated for each earth layer according to a detailed physical model. The model also takes into account a possible energy rear feed, for example, for regeneration or free-cooling purposes.

To effectively simulate the degradation of the loop a "Annual withdrawn energy" and a "Loop pre-load time" may also be entered. In doing so the ground-source loop will be preloaded with a constant load over the given length of time. Should the ground-source loop behaviour be calculated in the long term, preliminary simulation duration may be

appropriately set (in menu under System diagram – Preliminary simulation). This preliminary simulation enables the whole of the system to be simulated so that the actually arising workload may be applied to the ground-source loop. If 50 years are to be simulated the value to be entered is 17885 (49 * 365), i.e. 49 years are pre-simulated before the standard annual simulation is carried out.

Soil heating defines the difference between the average annual temperature of air and soil surface. Typical values are as follows:

- Forest, shady location: 0 K
- Field, meadow: 0.8 K
- Average value: 1.5 K
- Urban location up to 2 K
- Snow-covered elevation: up to 4 K

The axial temperature gradient defines temperature increase with depth. Such gradient is defined as the soil's geothermal heat flow/heat conductance. A typical value is 0.03K/m (0.06W/m² / 2 W/mK).

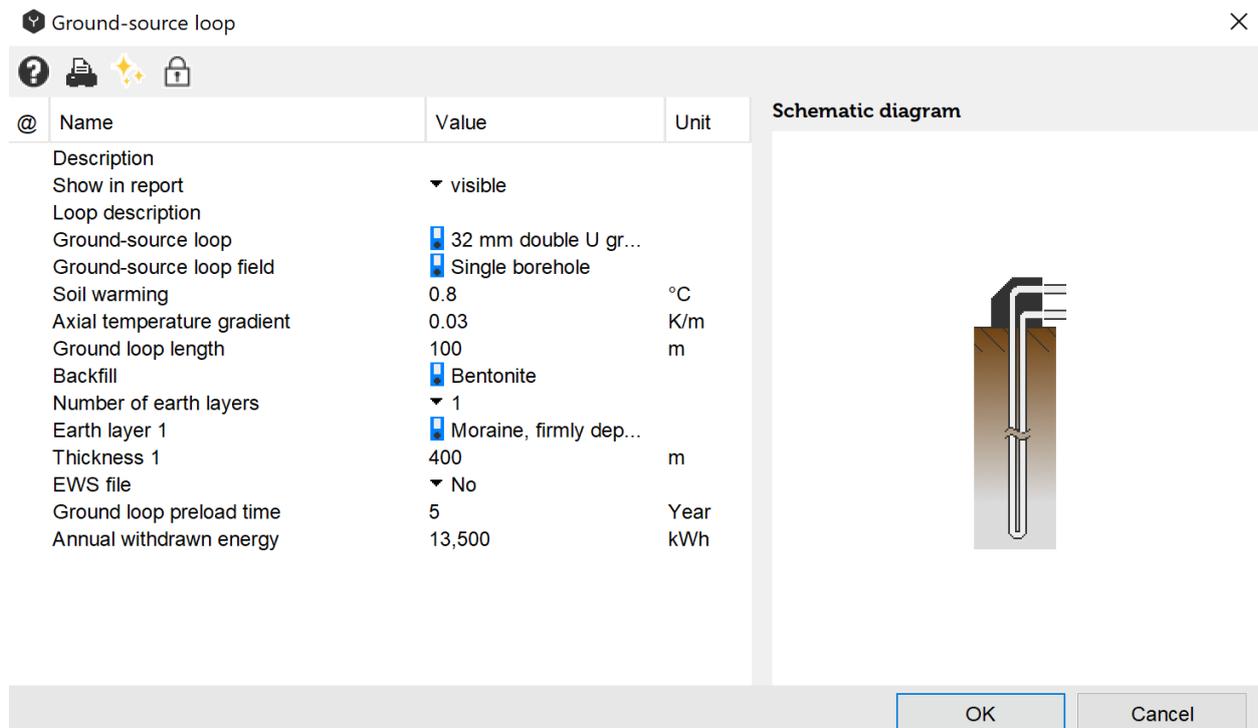


Fig. 99: ground-source loop

During the simulation Polysun calls up the relevant ground-source loop algorithm each 4 minutes producing thus consistently reliable end results.

For a detailed description of a ground-source loop see the publication issued by Hetag AG in 1997: <http://www.bfe.admin.ch/php/modules/enet/streamfile.php?file=00000005132.pdf&name=000000195115.pdf>

4.4 Ground-Water Loops

The software allows for a ground-water loop to be used in association with a heat pump. Here temperature is calculated depending on depth. The following assumptions were made in this respect:

Soil temperature $\theta(x,t)$ depending on depth x (into the soil) and time t varies under the influence of the seasonal course of the outdoor temperature according to the following formula:

$$\theta(x,t) = \theta_m - \theta_0 \cdot \exp\left(-x \cdot \sqrt{\frac{\pi}{a \cdot T}}\right) \cdot \cos\left(\frac{2\pi}{T}t - x \cdot \sqrt{\frac{\pi}{a \cdot T}}\right)$$

With a ground water depth of about 10-15 m and deeper it can be assumed with good accuracy that the ground water temperature remains constant over the year and matches the average annual outdoor temperature.

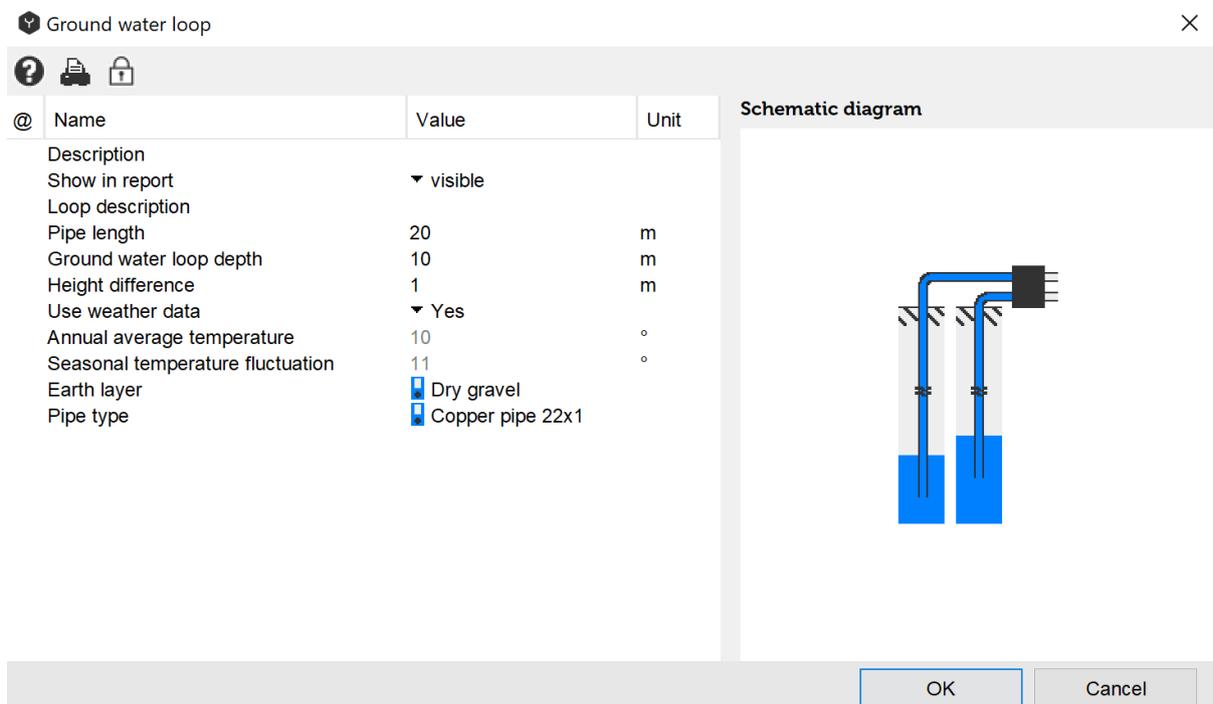


Fig. 100: ground-water loop

Static Pressure

Polysun enables users to correctly calculate both static and dynamic pressure. To correctly calculate the required height difference ΔH a distinction should be made whether or not the loop return line is immersed in the return water tank. A negative difference is also possible; this will result in the pump being relieved of pressure. The image below illustrates this correlation:

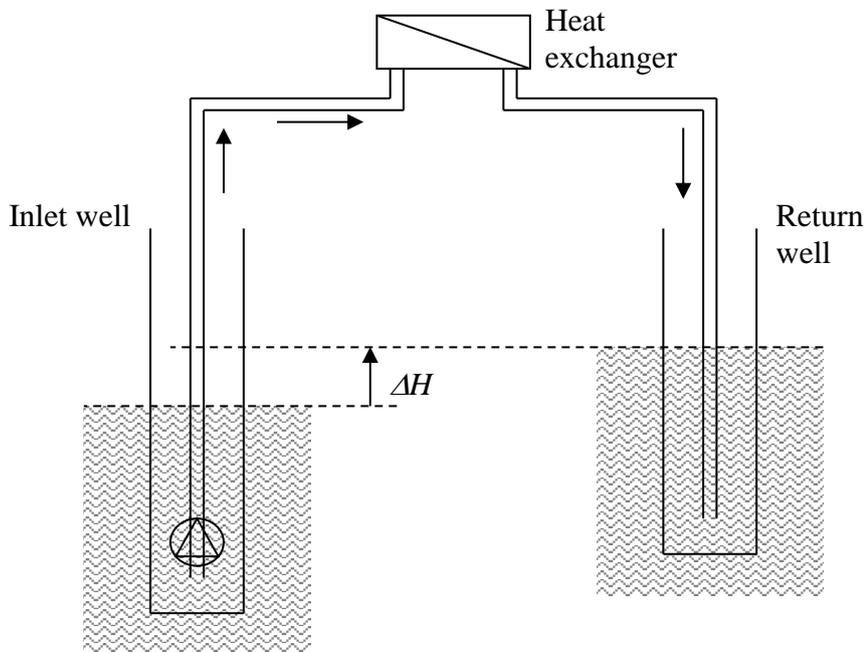


Fig. 101: schema of the ground-water loop

4.5 Systems

Heat pump systems consist of the heat source, the heat pump and the energy distribution system. The heat source can be chosen based on the system location with the maximum possible temperature, which will increase the heat pump coefficient of performance (COP). The COP is the ratio of heating or cooling energy output to the equivalent electrical energy input. The maximum COP can be achieved, if a ground-water source is available. Ground-source loops can be also an effective solution. Air-water heat pumps have the advantage, that they can be used almost everywhere and have low installation cost. Air-water heat pumps can be used mostly in bivalent systems for space heating and domestic hot water preparation. When the outside temperature is too low, an auxiliary source of energy is required. Air-water heat-pumps can be also installed in the unheated area of the building. A detailed description about exhaust air heat pumps can be found in the chapter 4.1.3.

Heat pump systems can be designed in Polysun either automatically using the Wizard as it is described in chapter 1.4 or manually using the correspondent components.

When making a design using the Wizard, in order to find a proper template for the system with a heat pump, a heat pump has to be chosen as an energy provider.

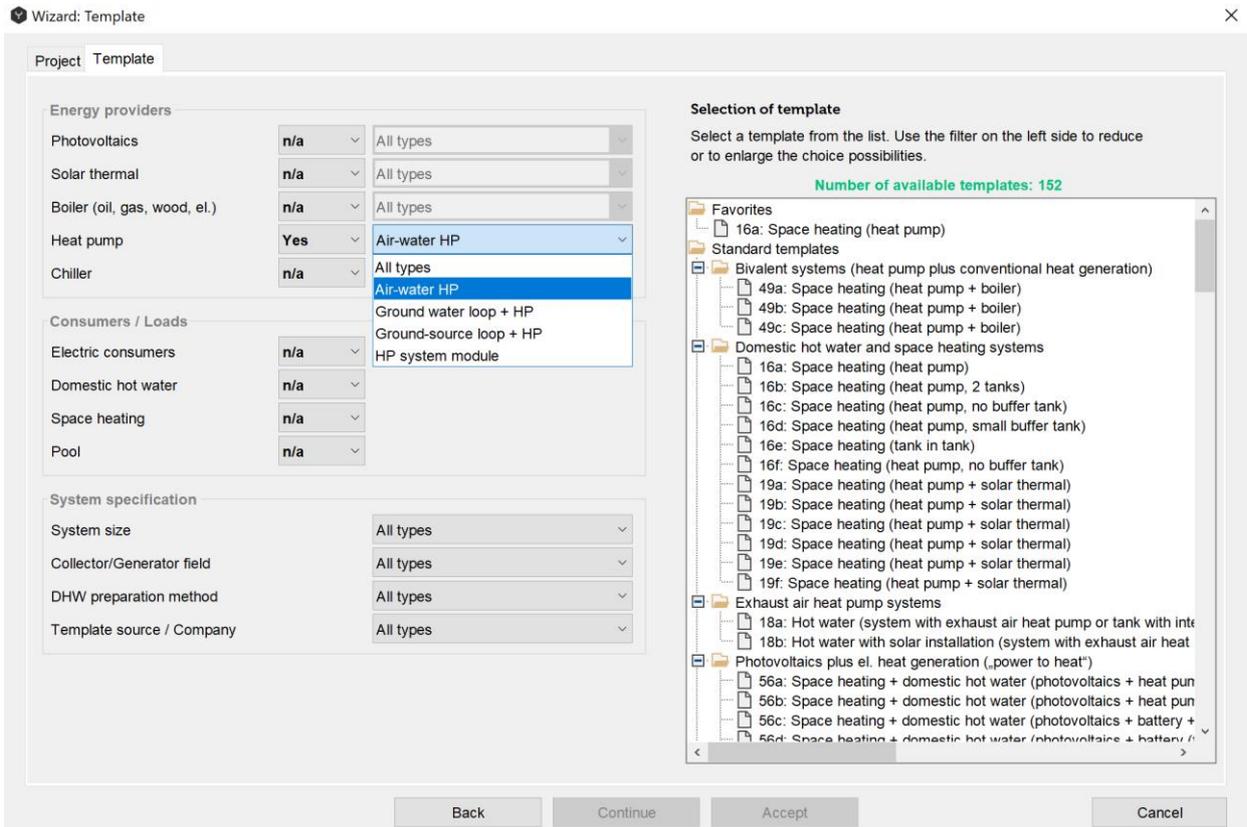


Fig. 102: selection of a template with heat pump

There are several types of the heat pumps, which can be chosen from the drop-down menu, such as:

Air-water heat pump extracts heat energy from the outside air.

Ground-water loop + HP extracts heat energy from a ground-water source.

Ground-source loop + HP extracts geothermal energy from the ground.

HP system module – systems designed according to the requirements and philosophy of FWS (www.fws.ch). FWS is a Trade Association for heat pumps in Switzerland, which unites the organizations and groups working for the promotion and dissemination of heat pumps.

Consumers, system specification and the proper template can be chosen according to the instructions and recommendations in the chapter 1.4 about the Wizard.

In the geothermal tab ground-source and ground-water loop parameters can be specified.

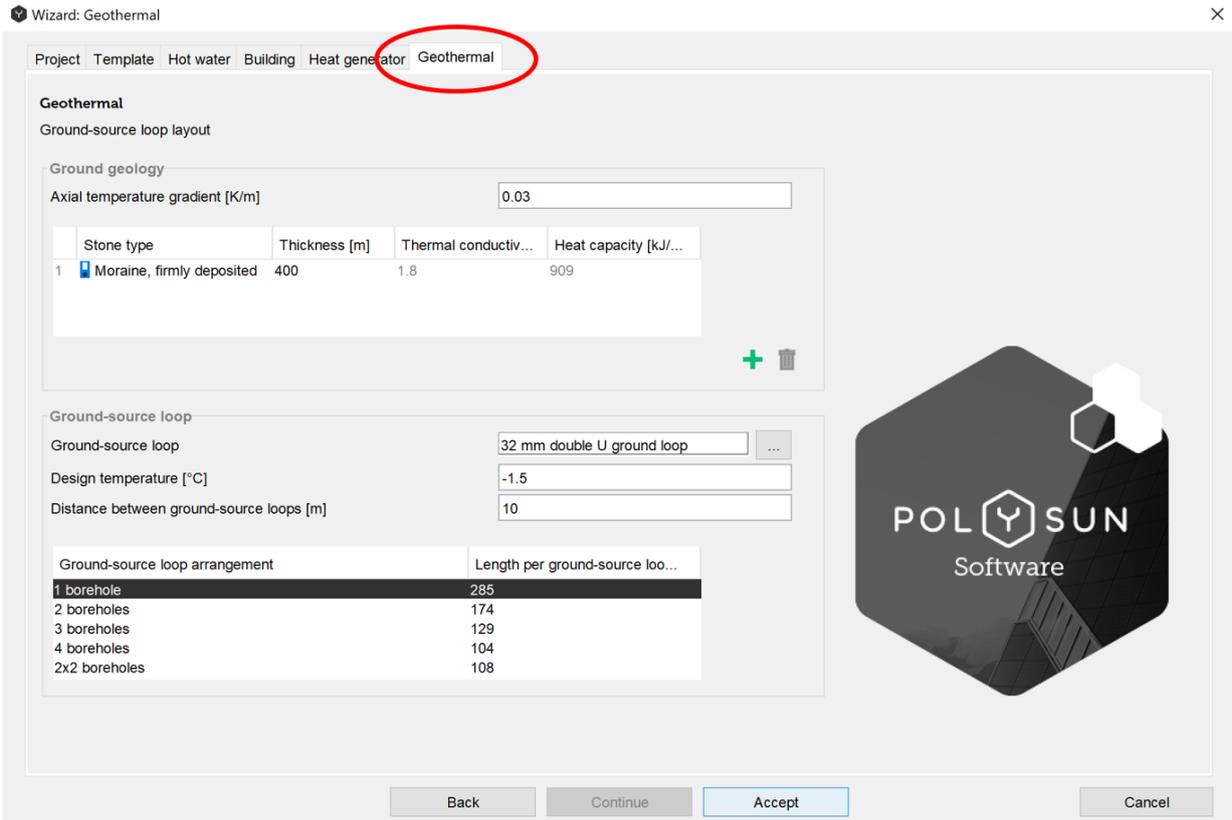


Fig. 103: ground-source loop layout definition in Wizard

An important parameter for ground-source loops is the axial temperature gradient in the undistributed soil. In the ground geology part the earth layers can be added and then chosen from the catalogue corresponding to the given location. The layers can be added and deleted using the buttons at the right bottom part of the dialog window.

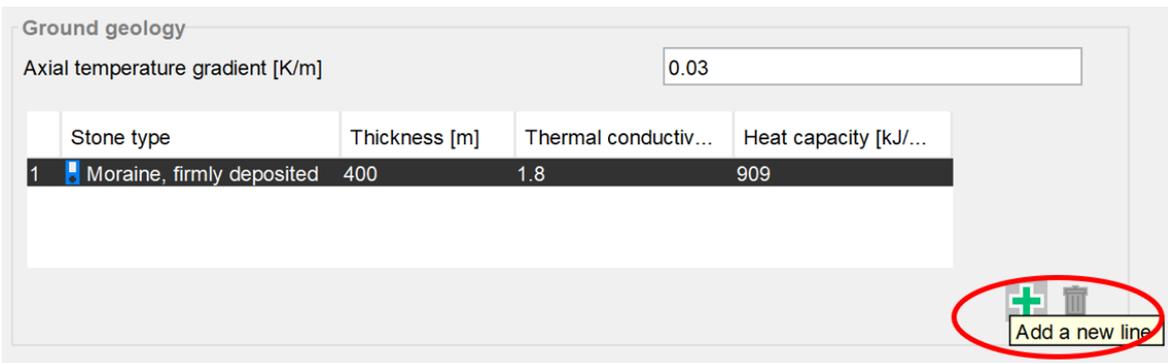


Fig. 104: ground geology dialog in Wizard

In the ground-source loop window, the loop can be chosen from the catalogue, design temperature and the distance between ground-source loops can be specified manually, the desired ground-source loop arrangement can be chosen from the table at the bottom of the window.

The design temperature is the average minimum temperature of the brine over 50 years. Over a time the heat extraction from the ground cools down the reservoirs, because it takes time to replace this energy naturally. In order to replace extracted energy, a solar thermal system can be added to the heat pump. Then the ground-source loop will use the surplus of heat produced by the solar system in summer and store it in the ground for further utilization by the heat pump and increase its COP. In such a way, the solar system

and the heat pump will complement each other and improve the overall efficiency. In order to evaluate the effect of the hybrid solar-geothermal system, preliminary simulation for a longer period (i.e. 10 years) can be run. If the ground has certain geological formation, such as rock or water-saturated soil, it can be used as a seasonal storage for solar thermal energy.

Photovoltaic systems can be also a perfect match to the heat pump, since they generate renewable electricity, which can be used by a heat pump.

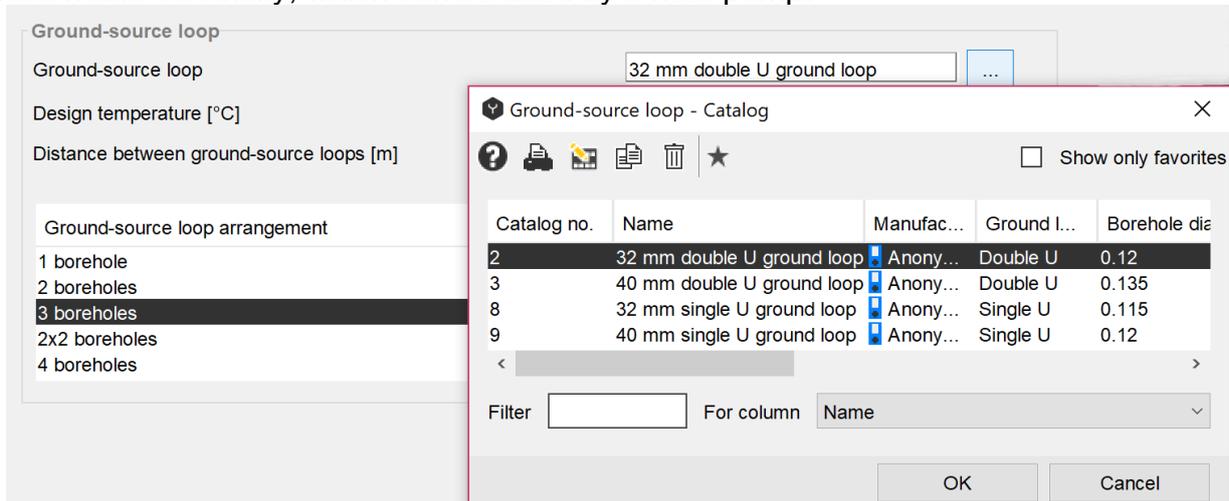


Fig. 105: selection of the ground-source loop from the catalog

For ground-source heat pumps the local geology has to be evaluated. There are different standards and regulations which are specific for different locations. In Polysun, the ground-source loop layout can be chosen in compliance with the SIA 384/6 standard in 'Options' → 'Settings' under the tap 'Wizard'. SIA 384/6 is an important valid regulation for the dimensioning of ground-source loops in Switzerland where it is obligatory to design geothermal systems according to this standard.

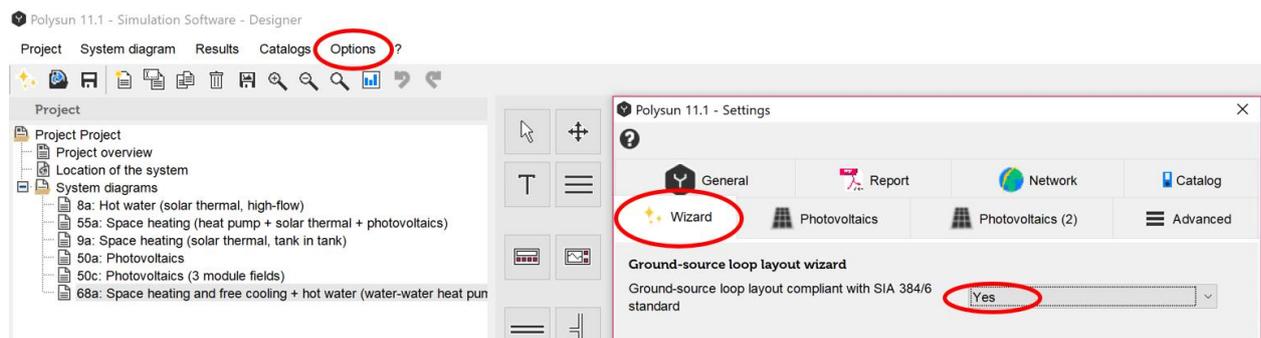


Fig. 106: choosing the ground-source loop layout in compliance with Swiss standard SIA 384/6

In Germany the guidelines VDI 4650 must be used. This standard can be activated in the 'Options' → 'Settings' under the tab 'Report'.

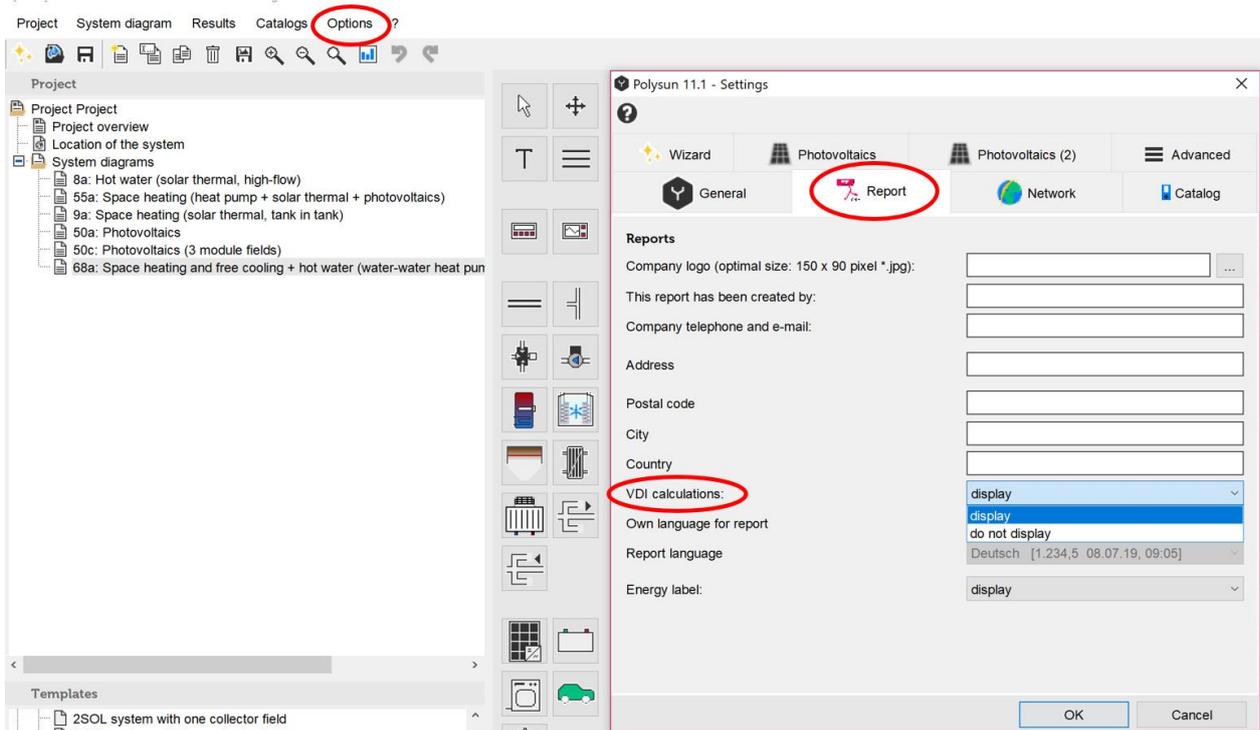


Fig. 107: choosing the ground-source loop layout in compliance with German regulations VDI 4650

Then after choosing 'Results' → 'Professional Report', additional values will be required for calculations according to the VDI 4650 (Monovalent systems with ground-source loop).

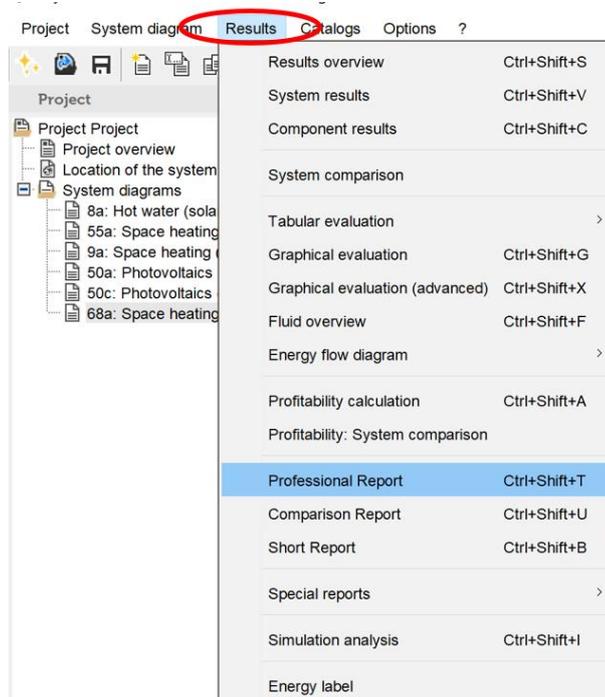


Fig. 108: choosing the professional report from the results drop-down list

System diagram 22a: Space heating (heat pump + ground-source loop) - Calculation SPF

Calculation of the seasonal performance factor according to VDI 4650
(Monovalent systems with ground-source loop)

Input values:	Values for VDI calculation:	Simulation results:
Inlet temperature space heating [°C]	40	40
Return temperature space heating [°C]	35	35
Minimum temperature of brine at heat pump inlet [°C]	2	-0.2
Power of heat-source pump [W]	5	6
Ratio of space heating energy demand to total energy demand	50	67

Seasonal performance factor:	Values for VDI calculation:	Simulation results:
Overall according to VDI	4.13	
Space heating according to VDI	4.34	
Domestic hot water according to VDI	3.94	
Overall according to time step simulation	3.83	

Show overall seasonal performance factor according to VDI in the results.

Don't show this window again (setting can be changed in the settings dialog).

Close

Fig. 109: additional values required for calculations according to the VDI 4650 (monovalent systems with ground-source loop)

The ground-source loop model in Polysun is a transient EWS model, which allows the detailed simulation of the hourly operation of the borehole heat exchanger and ground simulations. It allows predicting the operation of the designed ground-source loop. Therefore, an EWS file can be also imported and used for simulation in Polysun. It can be uploaded in the ground-source loop component dialog window.

Heat Pump Low-Pressure/High-Pressure Failure

Air-water heat pumps have two self-protection temperature limits, brine/water-water heat pumps have three. If the temperature drops below the low-pressure failure temperature (brine/water-water heat pumps only) or exceeds the high-pressure failure temperature (2nd type), the heat pump cuts off. As a rule, the connected pumps are regulated by the heat generator controller, for which reason they keep running in case of failure. If the failure occurs too frequently (see component results), this could be due to the fact that hot water demand may no longer be met.

Possible causes for the failure:

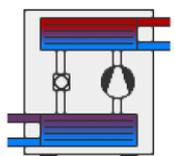
- Low-pressure failure: the heat source or the borehole are too small
- The heat pump is too large

- Flow rate on source or consumer side is too large
- The temperature in the tank is too high or the position of ports does not fit controller settings
- The configuration of safety temperatures in the heat pump settings (double click on the heat pump) is incorrect

B/W or W/W heat pump 4

@	Name	Value	Unit
	Description	4	
	Show in report	▼ visible	
	Environment	▼ indoor	
	Building selection	▼ -	
	Place of installation	▼ Unheated area	
	Heat loss to heated area	10	%
	Loop description		
	Heat pump operation mode	▼ Heating	
	B/W or W/W heat pump	Heat pump 10 kW	
	COP at B0/W35	4.7	
	Heating power at B0/W35	8,900	W
	Low pressure failure (ground-source ...	-5	°C
	High pressure failure (1st type)	20	°C
	High pressure failure (2nd type)	60	°C

Schematic diagram



OK Cancel

Fig. 110: brine/water-water heat pump settings

5 Other Components and Systems

5.1 Cooling Systems

Two types of cooling machine models are available in Polysun: Compression and heat-driven chillers. Respectively, typical cycles of such chillers are shown in Figure 111 and Figure 112. As can be seen, the main difference of the two machines is the replacement of the compressor used in the compression cycle by three main parts in the heat-driven cooling cycle meaning absorber, pump, and generator resulting in much lower electrical consumption of the later cycle compared to the other. Another advantage of a thermally-driven chiller is that a waste heat such as solar thermal energy can be used to drive the machine at moderate to high temperatures with very good matching between the solar irradiation availability and the cooling demand during summer time. However, heat-driven chiller has lower coefficient of performance than that of compression chiller.

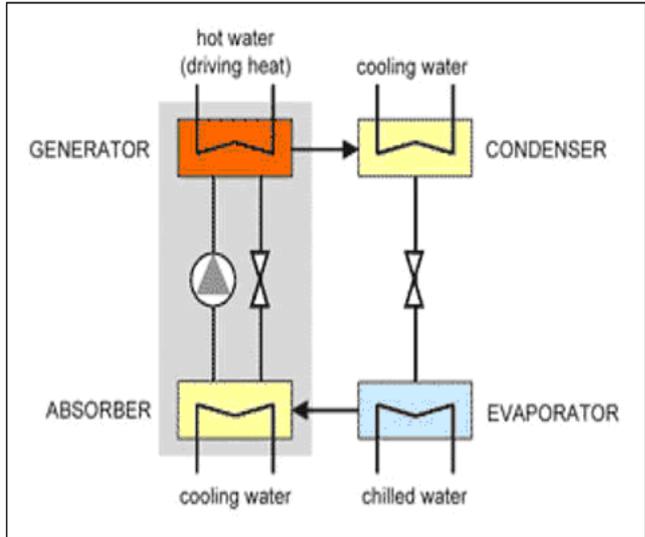
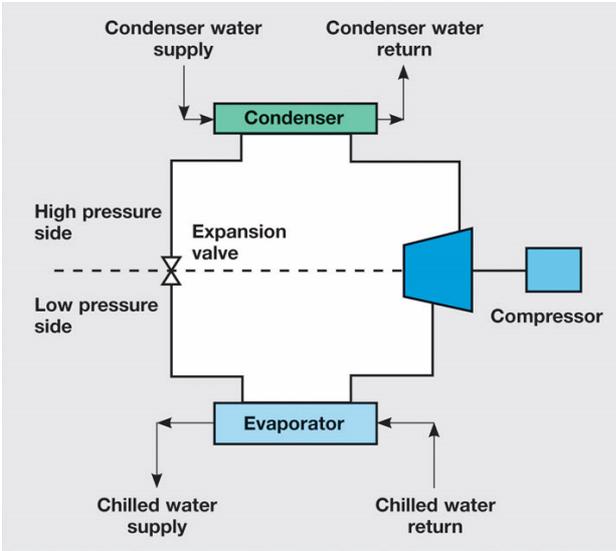


Fig. 111: Compression cooling cycle

Fig. 112: Heat-driven cooling cycle

5.1.1 Compression Cooling Model

The compression cooling can be provided through the current four port W/W heat pump component. The following figure shows that three operation modes can be chosen from the drop-down list.

Similar to the old heat pump model, cooling power output as well as electrical power consumption are calculated through linear interpolations of the measured points. Figure 113 illustrates an available template in Polysun by which heating, hot water, and cooling demand can be provided through heat pump operating in “Heating and Cooling” mode. The ground-source loop is used as low temperature heat source in heating mode and in cooling mode it is used as heat sink. The necessary pressure failure set points have been implemented for cooling mode as well.

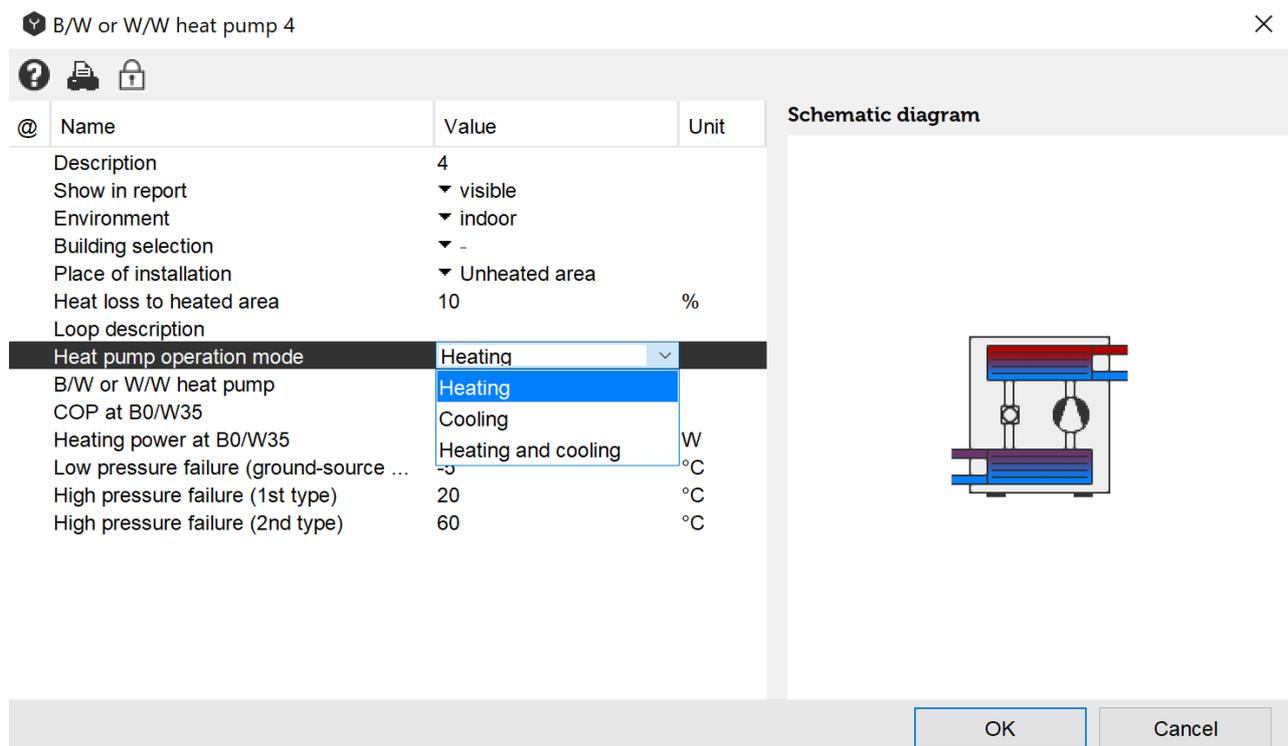


Fig. 113: W/W heat pump dialog window. New heat pump model can operate in three modes: Heating, Cooling, and Heating and Cooling.

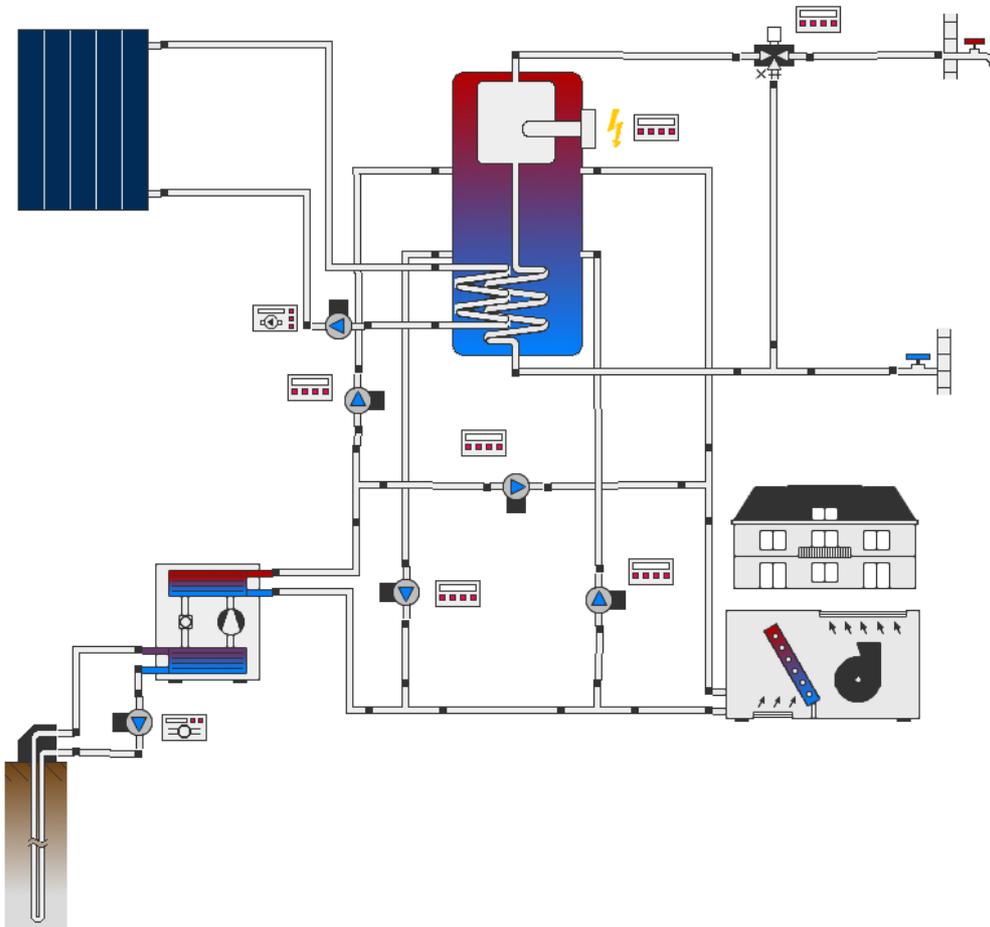


Fig. 114: heating, hot water, and cooling template using W/W heat pump as auxiliary energy source.

5.1.2 Heat-Driven Cooling Model

The heat-driven chiller model in Polysun is based on absorption chiller cycle. Several theoretical or empirical methods have been proposed so far by researchers to model and simulate absorption chiller cycle. An analytic solution of the governing equations of the single-effect closed-cycle absorption chiller has been suggested by Kim et al. [1] which is used in Polysun. The main advantage of this model is that it can enable a quick simulation of absorption system with minimal information on working fluids and operation condition. The model is based on the heat exchanger effectiveness definition, Dühring equation and thermodynamic principles of the main constitutive components. The absorption machine model has three pairs of connecting ports enabling heat exchange between heat source, heat sink, and cooling load fluid domains over the component. The icons of absorption chiller and recoler (a heat sink to reject the heat from the absorption chiller's condenser to the ambient through cooling water circulation) are shown in Figure 115.

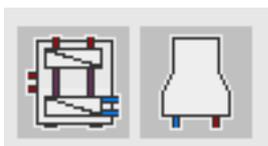


Fig. 115: heat-driven chiller (the left icon) and recoler (the right icon).

A number of different absorption cooling system configurations are possible to be simulated in Polysun. For an instance, a system is shown in Figure 116 in which solar thermal collector

field as well as the auxiliary gas boiler are used to provide heating demand during winter and to run the absorption chiller as heat sources during summer to compensate for cooling demand of the building. Domestic hot water demand is also provided through such a system all over the year. The type of re-cooler is wet in this layout which can be replaced by dry re-cooler, ground-loop, or pool. Two separated heat and hot water storage tanks are used in this system layout.

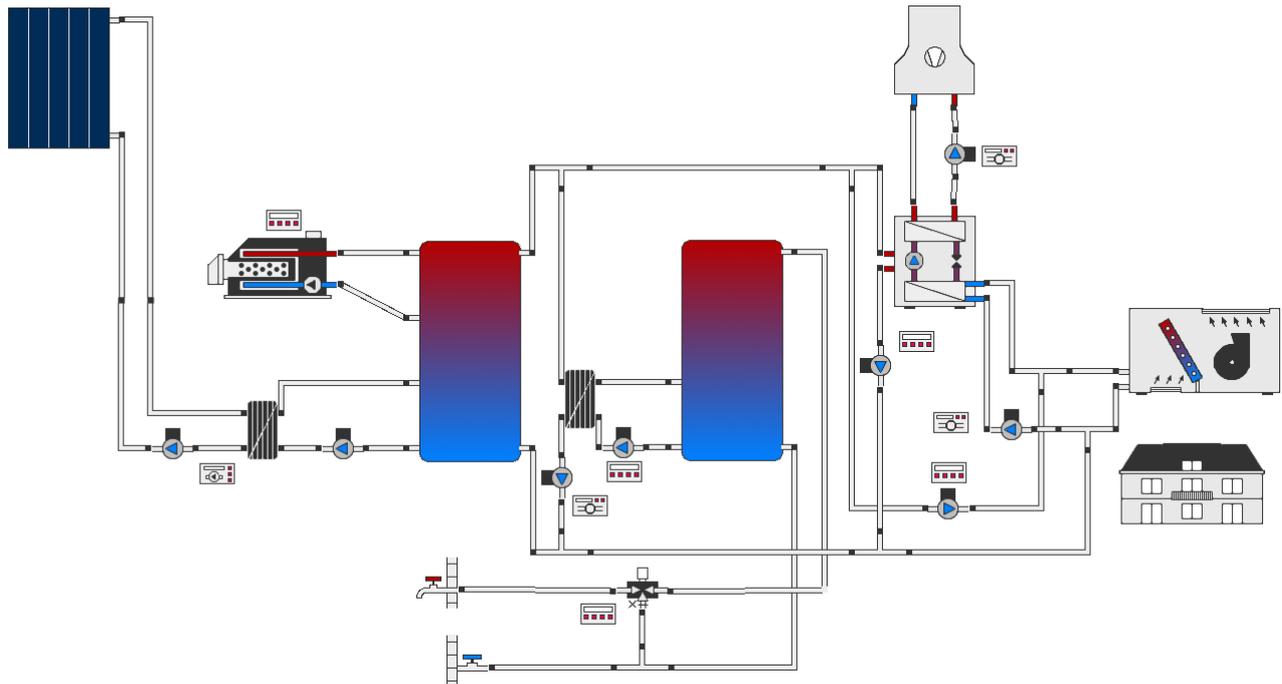


Fig. 116: solar-assisted absorption cooling system. The system also provides heating and hot water demands.

5.1.3 Ad- and Absorption Chillers

The notion of six port absorption chiller model is depicted in Figure 117. The chiller is connected to three fluid domains namely hot water circuit (left side red ports), cooling water circuit (upper side pink ports), and chilled water circuit (right side blue ports). The main varying inputs into the chiller model are inlet hot, cooling, and chilled water temperatures and flow rates. The constant parameters used in the model are absorber, condenser, evaporator, generator, and solution heat exchanger effectiveness values and also solution mass flow rate circulated inside the machine. These values are called from absorption chiller catalog. Therefore, if necessary, these constant parameters should be changed carefully in the catalog based on information obtained from the chiller manufacturers. Such a component is flexible to be connected to different kinds of heat source such as solar thermal, heat sink such as wet/dry re-coolers, pool, or ground-loop, and load such as fancoil, ceiling cooling etc.

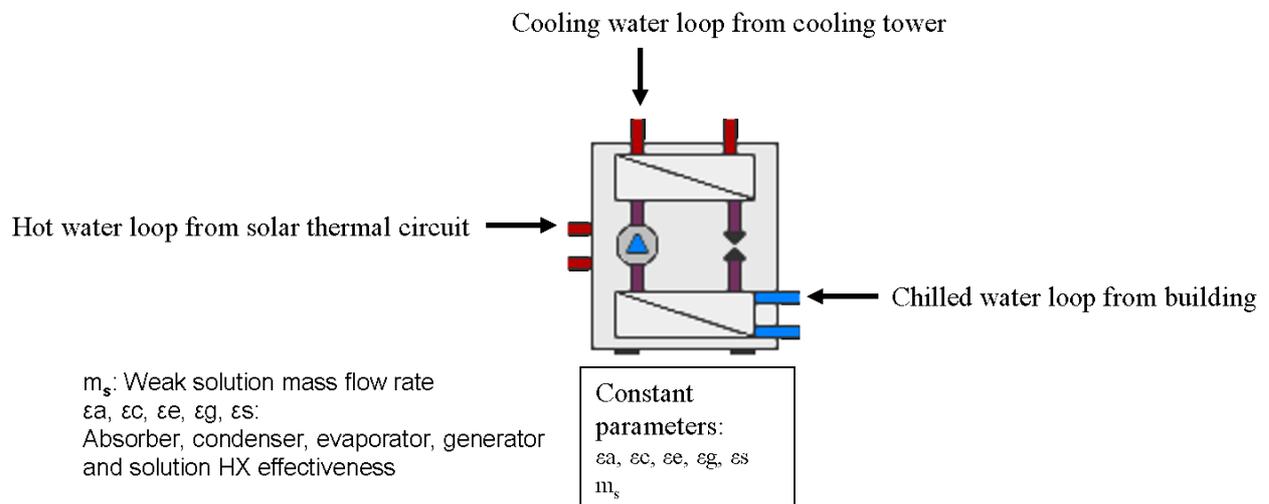


Fig. 117: six port absorption chiller model concept.

The dialog window of the absorption chiller is shown in Figure 118. As can be seen, different refrigerant/absorbent pairs i.e. Water/LiBr, Ammonia/Water, Water/LiCl, Water/ CaCl₂ can be defined in the catalog. Design water temperatures and flow rates are also possible to determine.

The four failure set point temperatures i.e. high and low heat sink temperature failure, high generator temperature failure, and low chilled water temperature failure have been implemented and can be set by user. These temperatures constrain the operation of the cooling machine to avoid abnormal condition e.g. crystallization phenomenon or very low performance of the chiller happens. As soon as one or more than one of these temperatures occurs during operation, machine will be switched off for a certain time span (Switch-off time) which can be defined by user. All mentioned controlling parameters are to be set according to the manufacturer technical advice.

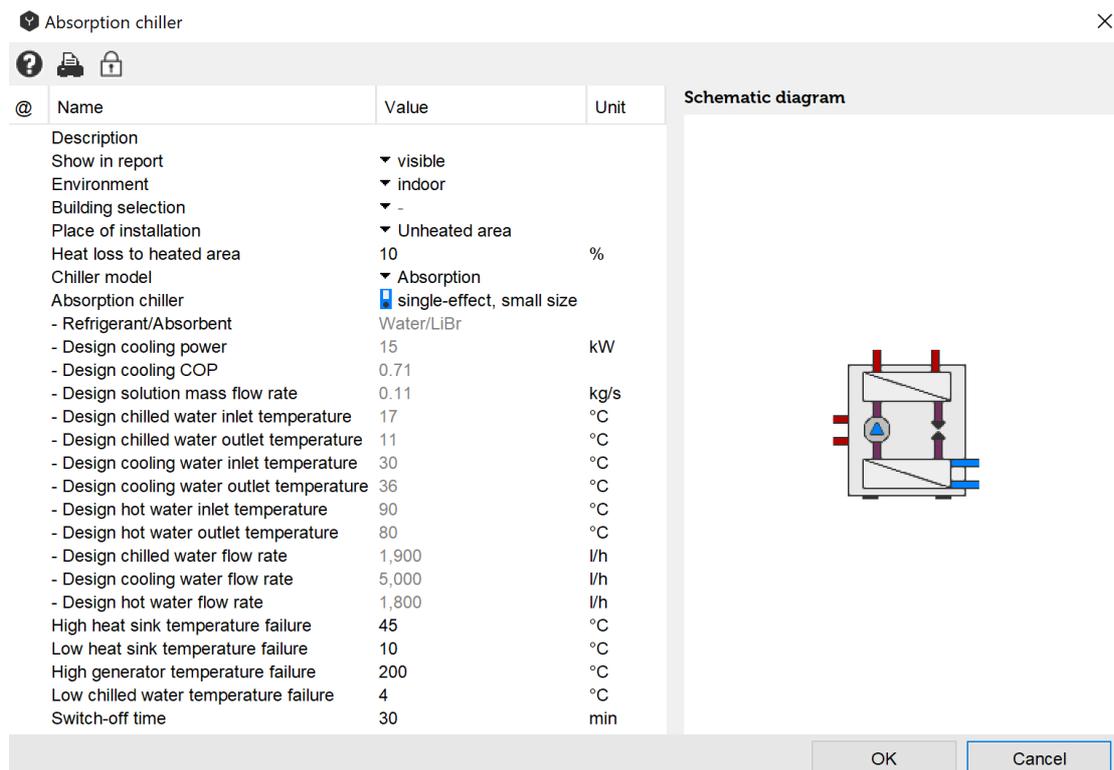


Fig. 118: absorption chiller dialog window

The typical flow chart of the power exchange calculation over the absorption chiller model as well as controlling criteria on the operation condition is shown in Figure 119. It is a magnificent fact that the proper controller(s) should be implemented on the chiller and the surrounding loops. The corresponding controlling strategies should be also set inside the controllers considering the cooling concept. It is always worth reading the available tool tips attributed to the properties inside the controllers.

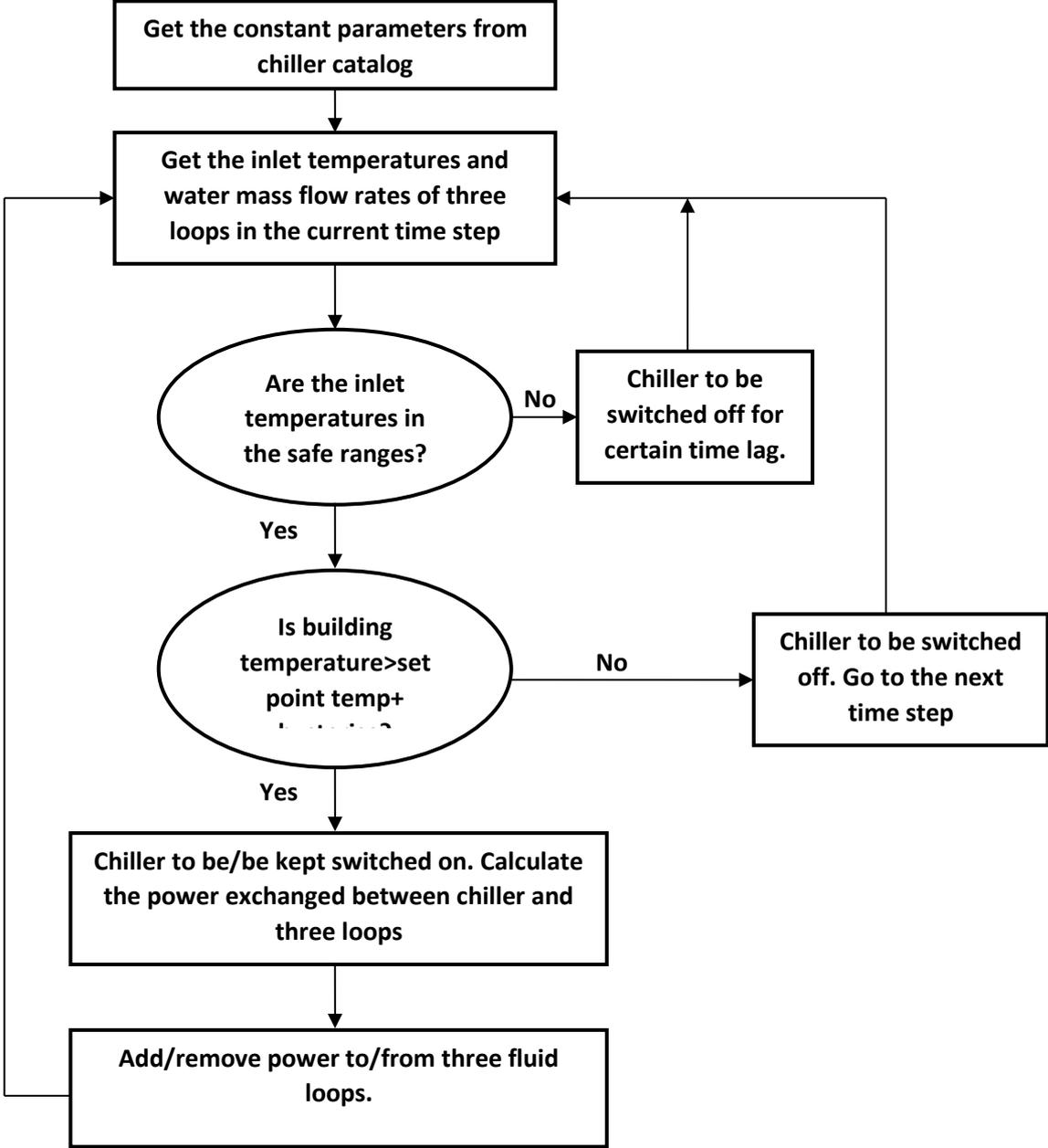


Fig. 119: the flow chart of absorption chiller operational procedure in Polysun.

5.1.4 Recoolers

As described above, different types of recoolers can be connected to the chiller component as heat sink. Figure 120 shows the dialog window of the “Wet recooler” or so called “Cooling tower” model. Cooling towers use the principle of evaporative or “wet-bulb” cooling in order to reject the heat from water. The main advantages over a conventional heat exchanger are:

- They can achieve water temperatures below the temperature of the air used to cool it.
- They are smaller and cheaper for the same cooling load.

The main disadvantage of cooling towers is their need for careful maintenance to minimize the risk of water fouling and water-borne organisms e.g. Legionnaire's disease.

There are two main types of cooling tower: **forced draught** and **natural draught**. However, their principles of operation are identical. The present model concerns the forced draught type.

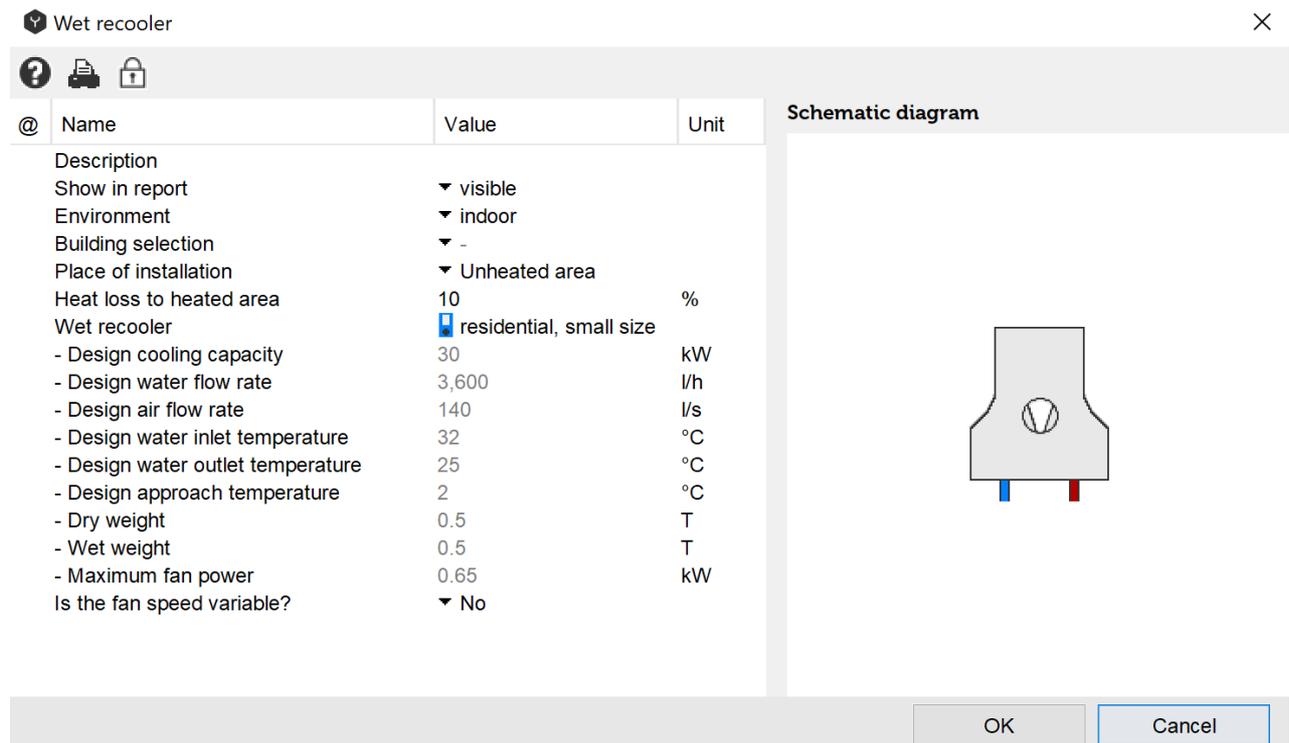


Fig. 120: the dialog window of the wet recooler.

The model is based on steady-state condition using energy balance, mass balance, and mass diffusion relations on the incremental volume. The associated differential equations are simplified by using effectiveness approach model and the **Merkel's assumptions** that is neglecting the effect of the water loss due to evaporation as [2]. The following assumptions are also made:

- Heat and mass transfer in the direction normal to flows only.
- Negligible heat and mass transfer through tower walls to the environment.
- Negligible heat transfer from the tower fans to the air or water streams.
- Uniform temperature throughout the water stream at any cross section.
- Uniform cross-sectional area of the tower.

To obtain accurate results, it is important to choose/implement an appropriate cooling tower according to the absorption chiller component size. As a rule of thumb, the cooling capacity of a cooling tower is almost twice as cooling capacity of the absorption chiller connected to it. Usually, cooling towers are rated based on their design cooling capacity, design water flow rate, design air flow rate, design water inlet/outlet temperatures, and also design approach temperature. The main two performance figures of a cooling tower are **approach temperature** and **thermal efficiency**:

Approach temperature: $\frac{\text{cooling water outlet temperature} - \text{inflow air wet-bulb temperature}}{\text{cooling water inlet temperature} - \text{cooling water outlet temperature}}$

Thermal efficiency: $\frac{\text{cooling water inlet temperature} - \text{inflow air wet bulb temperature}}{\text{cooling water outlet temperature} - \text{inflow air wet bulb temperature}} * 100 (\%)$

It can be observed that the thermal efficiency will increase as cooling water outlet temperature approaches the inflow air wet-bulb temperature. In another word, the smaller approach temperature also implies better thermal efficiency. Typical acceptable approach temperature is above 2.

As can be seen in figure 121, the variable fan speed is also possible to apply. This feature would bring the advantage of reducing the fan power consumption during the part load condition. The operation concept of the variable fan speed is depicted in Figure 121.

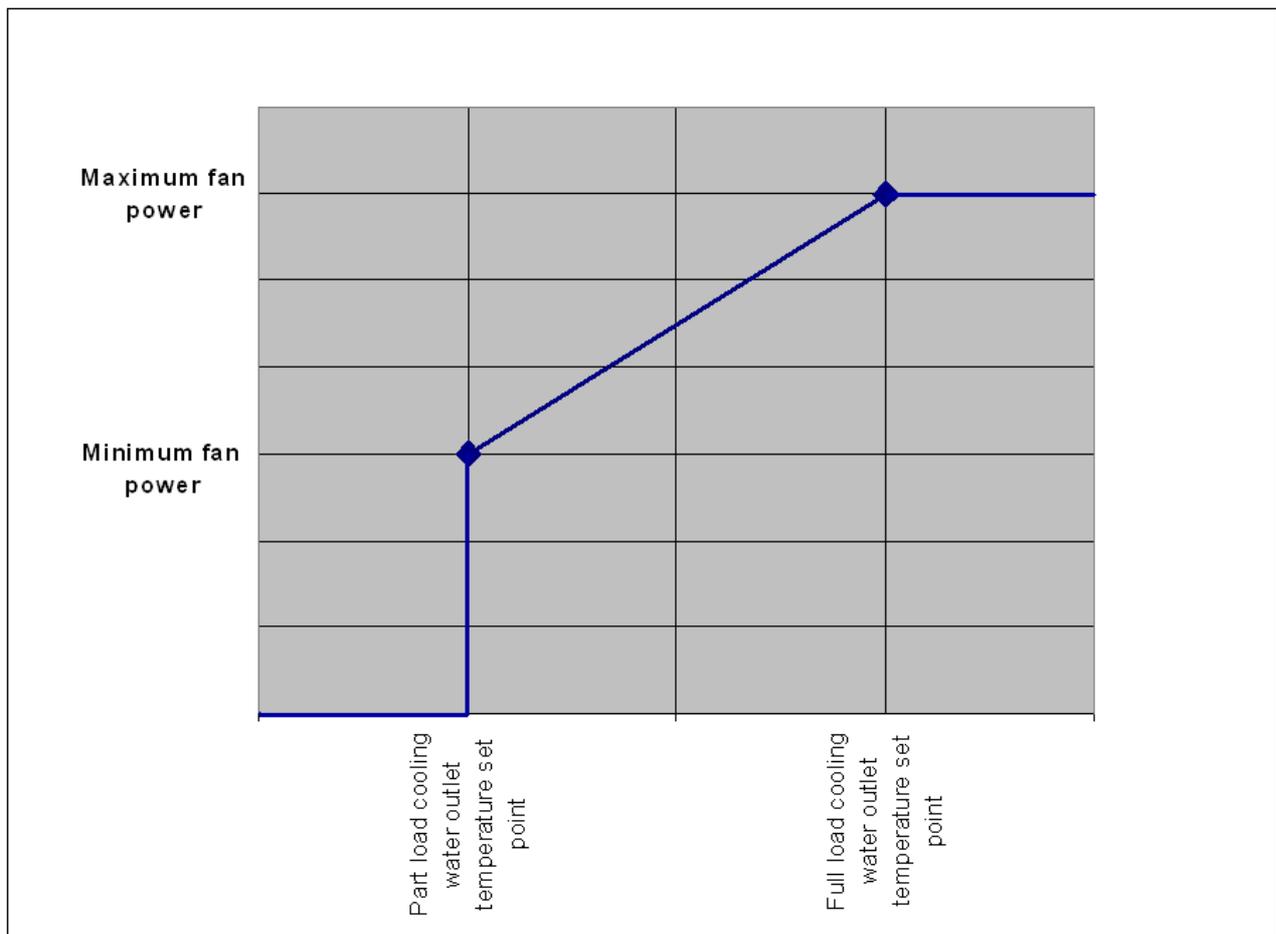


Fig. 121: the operation control curve of variable speed fan

5.1.5 Validation

The validation is always an important step in the modelling. A set of measured cooling powers of an existing absorption chiller machine were obtained. Comparison between such data and the corresponding results calculated by the implemented model is shown in Figure 122. The design figures of the real machine are listed in the following table:

Table 17. Technical parameters of the absorption chiller
Absorption chiller type

Single-effect, Refrigerant/Absorbent:
Water/LiBr

Design cooling power (kW)	35.14
Design COP	0.65
Design chilled water inlet/outlet temperatures (°C)	12.5/7
Design chilled water flow rate (l/hr)	5496.4
Design cooling water inlet temperature (°C)	31
Design cooling water flow rate (l/hr)	18351.7
Design hot water inlet temperature (°C)	88
Design hot water flow rate (l/hr)	8630.7

Figure 122 reveals a good agreement between measured and calculated powers, especially in the neighbourhood of design condition, at different hot water and cooling water inlet temperatures.

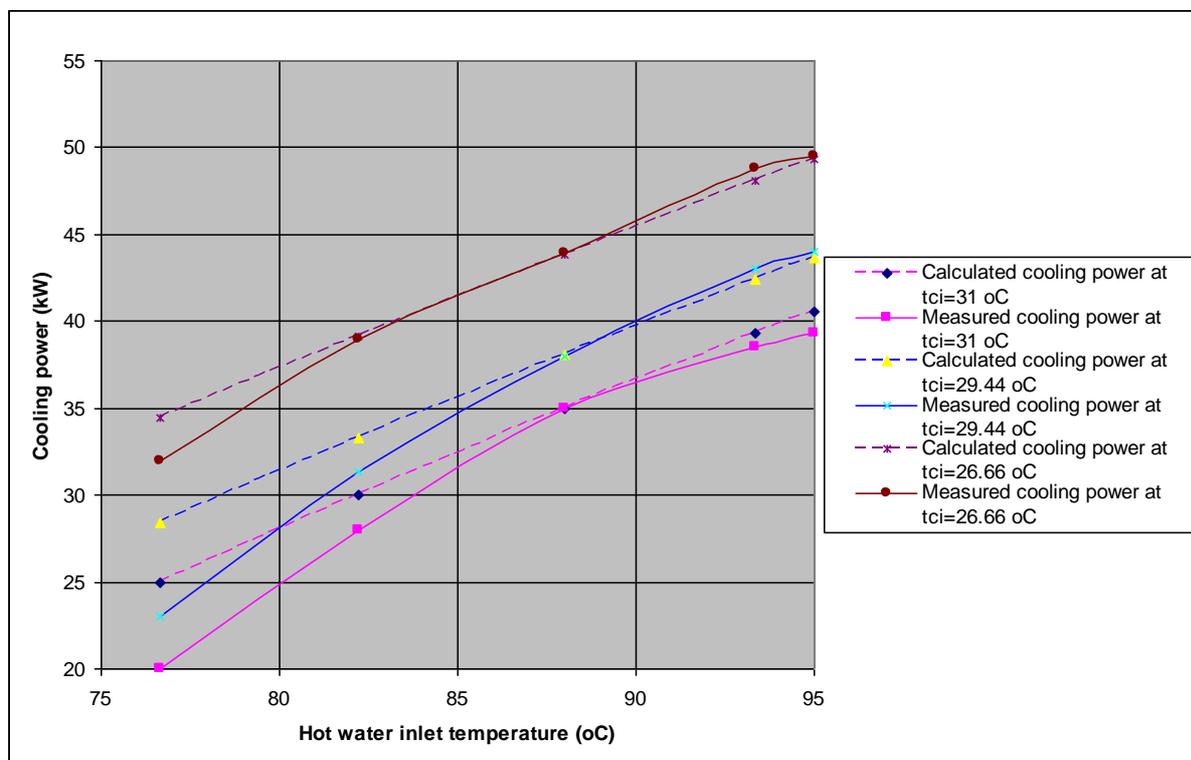


Fig. 122: characteristic curves of the absorption chiller. Comparison between measured data and calculated values. Cooling power versus hot water inlet temperature at different cooling water inlet temperatures (tci). Dashed lines: calculated values, solid lines: measured values.

5.2 Ice Storage Tanks

Polysun can simulate ice storages with the ice storage component. Ice storages use the phase transformation from the liquid to the frozen phase to increase the heat storage capacity per volume. The melting of ice at 0°C to water at 0°C takes roughly the same energy as the heating of 0°C water to 80°C.

5.2.1 Models

There are two different ice storage models available in Polysun. The “Coil Heat Exchanger Model” uses an empirical Enthalpy-Temperature-function. This function represents the decrease of the source temperature due to ice on the heat exchangers. While ice is growing, the heat transfer value of the heat exchanger decreases, forcing the system to go to lower temperatures in order to extract the same power from the ice storage. The function is fixed to a specific heat exchanger geometry and should be derived from measured performance data of the ice storage. Different functions for different geometries can be stored in the catalogue. As a default, the function for a Viessmann-Isocal ice storage is provided. The dimensions and the insulation of the storage tank can be parametrized as well as the material properties and the length of the heat exchanger coils.

The new model “Ice Storage Plate Heat Exchanger” was designed to simulate ice storages with plate heat exchangers. The heat exchanger material and geometry as well as the distance between heat exchangers in the ice storage can be parametrized. Therefore, the model can be used to test and simulate new ice storage configurations ad hoc without the need of providing experimental data. In addition, in comparison to the Coil Heat Exchanger Model, the Plate Heat Exchanger Model accounts for measurable differences in the heat transfer properties between icing and melting making it precise in reproducing both behaviors.

The ice storage is in a thermal exchange with its surroundings – the ground or the basement – and with the heat exchangers connected to it that link the ice storage to the other components. The connection to the ground is modeled with an earth layer that connects the ice storage to the temperature of the undisturbed earth. In addition, the location of the ice storage can be changed to cellar with a fixed surrounding temperature only in the Plate Heat Exchanger Model.

Polysun supports cylindrical and cuboid shapes of ice storages. For a realistic simulation, a sufficiently long preliminary simulation time should be set, for example 180 days.

For both models, a detailed technical documentation is available. For more information please contact info@velasolaris.com

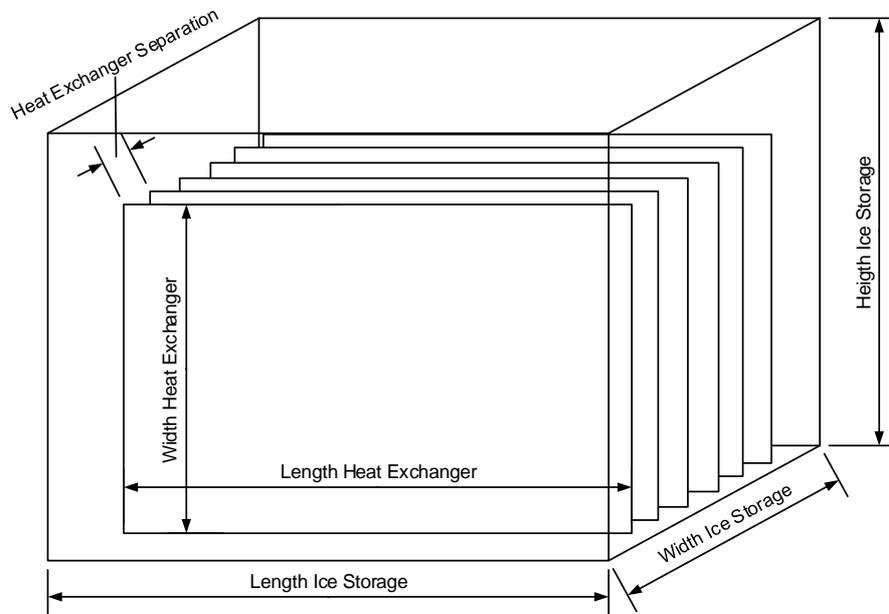


Fig. 123: configurable dimensions of the ice storage plate heat exchanger model

5.2.2 Model for the heat exchange with the ground

5.2.2.1 Parameters

The ground model is calculated with the following parameters (Calc indicates the parameter is calculated in the course of the routine):

Parameter	Description	Unit	Value
\bar{z}	Average depth of the ice storage under the surface	m	Calc
G_t	Geothermal gradient	K/m	0.03
ρ_{grd}	Density of the ground	kg/m^3	2'500
cp_{grd}	Thermal capacity of the ground	kJ/K	800
λ_{grd}	Thermal conductivity of the ground	W/mK	2
U_{tank}	Thermal conductivity of the storage tank	W/mK	Calc
U_{earth}	Thermal conductivity of the earth	W/mK	Calc
V	Capacity of the ice storage	m^3	10
Z_{boden}	Depth of the bottom of the ice storage	m	3.2
h_{tank}	Height of the ice storage	m	2.3
D_{tank}	Diameter of the ice storage	m	2.7
d_{grd}	Strength of the surrounding ground layer	m	0.5
$\bar{\theta}_e$	Average outside temperature	$^{\circ}C$	11
$\Delta\theta_e$	Amplitude of the monthly deviations of the outside temperature	$^{\circ}C$	9.3

λ_{wall}	Thermal conductivity of the ice storage wall	W/mK	1.33
$d_{\text{wall w}}$	Thickness of the ice storage wall to the sides	m	0.1
$d_{\text{wall b}}$	Thickness of the ice storage wall to the bottom	m	0.12

5.2.2.2 Implementation

The temperature of the undisturbed ground is calculated as a function of the depth in the ground and of time.

$$\zeta_{\text{grd}}(t, z) = \bar{\theta}_e - \Delta\theta_e \exp\left(-\frac{z}{\delta_{\text{grd}}}\right) \cos\left[2\pi\frac{(t - t_{\text{shift}})}{t_0} - \frac{z}{\delta_{\text{grd}}}\right] + G_t z$$

With the thermal penetration depth δ_{grd} as a measure for the degree to which the temperature in the depth lags behind the surface temperature. It is calculated as follows:

$$\delta_{\text{grd}} = \sqrt{\frac{t_0 \cdot 3600 [s/h] \cdot \lambda_{\text{grd}}}{\pi \cdot \rho_{\text{grd}} \cdot c_{p\text{grd}}}}$$

With z as the mean depth of the ice storage \bar{z} ($\bar{z} = z_{\text{boden}} - 0.5h_{\text{tank}}$) and the ground temperature around the ice storage assumed to be homogenous.

If the ground has a temperature that is different from that of the ice storage, a thermal flow will start. Thus, the temperature of the wall of the ice storage is calculated using this formula:

$$T_{\text{Wall}} = \int \frac{1}{m_{\text{grd}} c_{p\text{grd}}} \left(UA_{\text{earth}} (\zeta_{\text{grd}} - T_{\text{wall}}) - UA_{\text{tank}} (T_{\text{wall}} - T_{\text{ice}}) \right) dt$$

With UA_{earth} being the thermal transmission coefficient of the ground layer between the undisturbed earth and the ice storage wall. This is calculated according to this formula:

$$UA_{\text{earth}} = \frac{\lambda_{\text{grd}}}{d_{\text{grd}}} \times \left[\pi \left(\frac{D_{\text{tank}} + 2d_{\text{grd}}}{2} \right)^2 + \pi (D_{\text{tank}} + 2d_{\text{grd}}) (h_{\text{tank}} + d_{\text{grd}}) \right]$$

UA_{tank} being the thermal transmission coefficient of the ice storage casing and is calculated from the area of the wall or the ground respectively divided by the respective thermal resistance. The heat exchange between ice storage and ground in this model is limited to the lower, cylindrical part of the ice storage. Thermal gains or losses via the conical lid are not taken into calculation.

$$UA_{\text{tank}} = \frac{\left(\frac{D_{\text{tank}}}{2}\right)^2 \pi}{\frac{d_{\text{wall b}}}{\lambda_{\text{wall}}}} + \frac{D_{\text{tank}} \pi h_{\text{tank}}}{\frac{d_{\text{wall w}}}{\lambda_{\text{wall}}}}$$

m_{grd} is calculated taking the volume of the ground multiplied by its density – the volume being calculated via the external area of the ice storage and the thickness of the ground

layer.

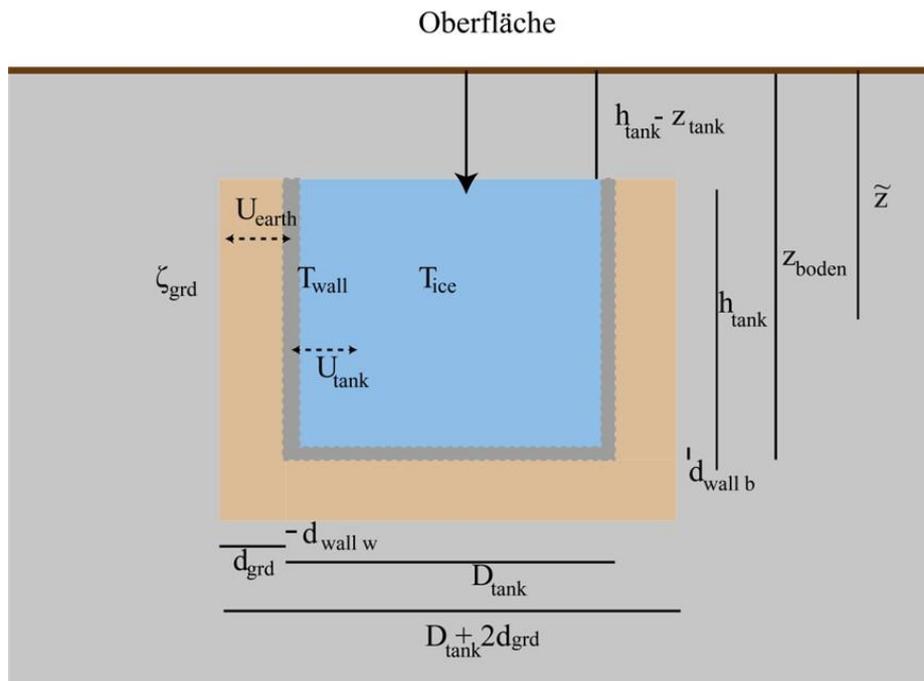


Fig. 124: schematic representation of the ice storage model

5.2.3 Coil Heat Exchanger Model

5.2.3.1 Parameters

The ice storage model using coil heat exchangers is calculated with the following parameters (Calc indicates the parameter is calculated in the course of the routine):

Parameter	Description	Unit	Value
m_{ice}	Mass of the ice storage	kg	Calc
m_{grd}	Mass of the ground surrounding the ice storage	kg	Calc
t_{shift}	Time distance between the time of the lowest temperature in the course of a year and January 1	h	319
t_0	Number of hours per year for scaling	h/a	8'760
$T_{\text{tabelle}}(H_{\text{ice}})$	Temperature equaling a given heat content H	$^{\circ}\text{C}$	
V	Capacity of the ice storage	m^3	10
f_{ice}	Initial part of the ice storage being frozen (0..1)	-	0
t_{init}	Initial temperature of the ice storage	$^{\circ}\text{C}$	15

5.2.3.2 Background

The ice storage model is a simple model for a water storage tank as heat exchanger that with temperatures around zero degrees can store or release thermal energy through the phase transition from liquid to solid or from solid to liquid, respectively.

The temperature of the ice storage depends on the heat flows to the wall and the heat flows because of the heat exchangers. The formation of ice on the heat exchangers is not explicitly determined but calculated via the heat content H.

The heat content H of the ice is calculated using

$$H_{\text{ice}} = \int \frac{1}{m_{\text{ice}}} \left(\sum_i (\dot{Q}_{2\text{ice}})_i + UA_{\text{tank}}(T_{\text{wall}} - T_{\text{ice}}) \right)$$

$(\dot{Q}_{2\text{ice}})_i$ are the heat flows through heat exchangers and m_{ice} the mass of liquid in the ice storage – volume times the density of water (1,000 kg / m³).

The temperature of the ice storage is subsequently read from an interpolated table containing different temperature values in dependence from the heat content H.

$$T_{\text{ice}} = T_{\text{table}}(H_{\text{ice}})$$

Through the access via the heat content, the thermal energy stored during the melting phase transition can be taken into account, as can the thermal energy released in the solidification phase transition.

The temperature of the ice can be calculated through linear interpolation in dependence from the heat content. The following value pairs between temperature (T) and heat content (E) are used as nodes:

Temperature in °C	Heat Content in J / kg
-10	-10·2'060
-3	-3·2'060
0	3.35·10 ⁵
10	10·4'182+3.35·10 ⁵

First, the heat content has to be initialized. For that, the initial temperature and the initial ice content are used. They are calculated according to

$$H_{init} = (1 - f_{ice}) 3.35e5 + \Theta(-f_{ice}) \times 4'182 t_{init}$$

with $\Theta(x)$ being the Heaviside function, which results in zero for a negative x and assumes the value one for $x \geq 0$. f_{ice} is the part of the ice storage that is initially frozen, and is handed over as a parameter.

T_{wall} is initialized with 4°C, the remaining parameters are given.

5.2.4 Plate Heat Exchanger Model

The advanced ice storage model implemented in the CTI project “Modul-Ice” extends the capabilities of Polysun to represent different kinds of ice storages. While the existing model relies on an empirical fitting function fixed to the specific kind of coil heat exchanger geometry used in Viessmann-IsoCal ice storages, the new model was designed to simulate any ice storage with plate heat exchangers. The heat exchanger material and geometry as well as the distance between heat exchangers in the ice storage can be parametrized.

5.2.4.1 Symbols and Nomenclature

$UA_{tot,i}$	overall heat transfer coefficient times surface area product of one heat exchanger temperature node, W/K
$UA_{in,i}$	internal heat transfer coefficient times surface area product of one heat exchanger temperature node, W/K
$UA_{wall,i}$	wall heat transfer coefficient times surface area product of one heat exchanger temperature node, W/K ³
$UA_{ice,i}$	ice heat transfer coefficient times surface area product of one heat exchanger temperature node, W/K
$UA_{out,i}$	external heat transfer coefficient times surface area product of one heat exchanger temperature node, W/K
Nu	Nusselt number, -
Re	Reynolds number, -
Pr	Prandtl number, -
d_h	hydraulic diameter, m

b	width flow cross section, m
A	area of one control volume, m^2
λ_{fluid}	heat conductivity fluid, $W/(Km)$
x_{wall}	wall thickness, m
β	coefficient of thermal expansion, m/K
ρ	density, kg/m^3
l_c	characteristic length, m
c_p	specific heat capacity, $J/(kgK)$
μ	dynamic viscosity, $kg/(ms)$
Ra	Rayleigh number, -
x_{ice}	ice thickness, m
Q_{hx}	heat exchanged between heat exchanger and storage, J
ΔH	enthalpy of fusion, J/kg

5.2.4.2 Model design

The Model is based on discrete control volumes with the corresponding heat transfer equations. The implemented version is a simplified version of the model described in Carbonell et al. (2016). In comparison to the original model, the number of control volumes used in the storage was fixed to 1. The general structure of the model is shown in Fig. . In the used modelling approach, apart from the chosen control volume geometry, the UA values of the heat transfer equations are the defining quantity. In the following section, the governing equations for the UA-values are presented. The energy transfer due to fluid flow in between the control volumes is computed according to Polysun's standard fluid flow interface.

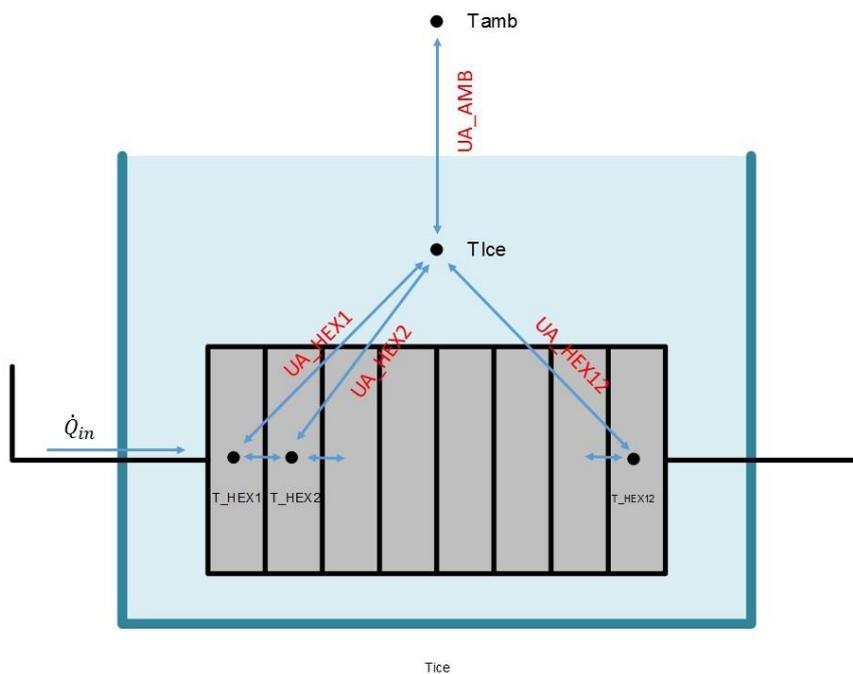


Fig. 125: temperature nodes and UA-values of the ice storage model

5.2.4.3 Losses to ambient

Two options for the location of the ice storage model are implemented, earth and basement. The earth model was completely inherited from the existing Isocal-Model of Polysun that is described in “Eisspeicher in Polysun, Roland Kurmann, Christian Winteler, 2017”. The basement option was added for conditions in which the temperature in the area surrounding the storage can be defined by a fixed value. The U-value of the storage tank casing and insulation is a direct input component of the model and has to be defined by the user.

5.2.4.4 Heat Exchanger model

The core elements of the model are the heat transfer values between the brine inside the heat exchangers and the water inside the storage UA_i . As they limit the maximal power that can be extracted from or injected to the storage, they have a large influence on the system simulation results. Sensible heating, sensible cooling as well as icing are treated individually as they all inflict different physical dynamics in the fluid on small scales that effect the overall heat balance. In all states, the UA-values are derived from general heat transfer correlations. In the following section the control volume number index i is omitted for simplicity reasons. All UA-values always represent the values associated to one control volume.

All UA-values are a combination of heat transfer area product between heat exchanger fluid and heat exchanger wall UA_{in} , through the wall UA_{wall} , through the ice UA_{ice} and from the wall or the ice layer to the storage water UA_{out}

$$UA_{tot} = \left(\frac{1}{UA_{in}} + \frac{1}{UA_{wall}} + \frac{1}{UA_{ice}} + \frac{1}{UA_{out}} \right)^{-1} \quad (1)$$

5.2.4.4.1 Plate Heat Exchanger

In the case of plate heat exchangers UA_{in} is calculated as follows. If the Reynolds number $Re < 70$.

$$Nu_{laminar} = 1.68 Re^{0.4} \left(Pr * \frac{d_h}{b} \right)^{0.4} \quad (2)$$

If $Re > 150$

$$Nu_{turbulent} = 0.2 Re^{0.67} Pr^{0.4} \quad (3)$$

If $70 < Re < 150$, a linear interpolation between $Nu_{laminar}$ and $Nu_{turbulent}$ is used.

The diameter d_h of the flow cross section in the calculation of the Reynolds number is reduced by a factor of two in the case of corrugated heat exchangers.

Based on the Nusselt numbers, the UA value can be computed as:

$$UA_{in} = 2A \cdot Nu \cdot \lambda_{fluid}/d_h \quad (4)$$

The factor of two indicates that the plate heat exchanger has both front sides in contact with the water.

Accordingly, UA_{wall} is calculated as:

$$UA_{in} = 2A \cdot \lambda_{wall}/x_{wall} \quad (5)$$

5.2.4.4.2 Sensible heating/cooling without ice

In the case of no ice on the heat exchanger $UA_{ice} = \infty$ and the equation of UA_{tot} reduces to

$$UA_{tot} = \left(\frac{1}{UA_{in}} + \frac{1}{UA_{wall}} + \frac{1}{UA_{out}} \right)^{-1} \quad (6)$$

In this case UA_{out} is calculated based on the Rayleigh number Ra .

$$Ra = 9.81\beta\rho^2(T_{storage} - T_{wall})l_c^3 c_p \mu \lambda_{tank,fluid} \quad (7)$$

$$Nu = 0.55 \cdot Ra^{0.33} \quad (8)$$

$$UA_{out} = 2A \cdot Nu \cdot \lambda_{tank,fluid}/l_c \quad (9)$$

5.2.4.4.3 Icing

Icing starts to build on the heat exchanger as soon as $T_{storage}$ reaches 0 °C and the brine temperature is below 0 °C (no supercooling is assumed). No simultaneous energy transfer to latent and sensible heating is modeled. When ice is present in the storage, the model distinguishes between a state where ice grows on the outer surface of the ice layer and a second state in which there is an inner layer of water in the liquid phase due to melting at a previous time. In case there is a liquid water layer assumed between heat exchanger and ice, during the next icing, this inner water layer is iced first and only the inner ice layer $x_{ice,inner}$ is considered for the calculation of the UA -value until it reaches the melted thickness. The following applies:

$$UA_{tot} = \left(\frac{1}{UA_{in}} + \frac{1}{UA_{wall}} + \frac{1}{UA_{ice}} \right)^{-1} \quad (10)$$

where

$$UA_{ice} = 2A \cdot \lambda_{ice}/x_{ice,inner} \quad (11)$$

If there is only a single layer of ice and ice grows at the outer surface, the UA_{ice} is calculated using the full thickness of the ice:

$$UA_{ice} = 2A \cdot \lambda_{ice}/x_{ice} \quad (12)$$

The thickness of the ice layer x_{ice} or $x_{ice,inner}$ are updated after each time step by the total energy transferred through the section of the heat exchanger $Q_{hx,i}$.

$$\Delta x_{ice,i} = \frac{Q_{hx,i}}{\Delta H \rho_{ice}} \cdot \frac{1}{2A} \quad (13)$$

5.2.4.4 Melting

During melting, UA_{tot} is calculated as

$$UA_{tot} = \left(\frac{1}{UA_{in}} + \frac{1}{UA_{wall}} + \frac{1}{UA_{out}} \right)^{-1} \quad (14)$$

Melting is modelled with two different phases. At first, when the thickness of the melted layer x_{melt} is smaller than 0.01 m, the UA_{out} is assumed to be dominated by conduction

$$UA_{out} = 2A \cdot \lambda_{water} / x_{melt} \quad (15)$$

For larger depths of the melted layer ($x_{melt} > 0.02$ m) convection is assumed to become relevant:

$$Ra = 9.81 \beta \rho^2 (T_{storage} - T_{wall}) l_c^3 c_p \mu \lambda_{tank,fluid} \quad (16)$$

$$Nu = 0.3 \cdot Ra^{0.208} \quad (17)$$

$$UA_{out} = 2A \cdot Nu \cdot \lambda_{tank,fluid} / l_c \quad (18)$$

In the transition a linear interpolation is used.

5.3 Cogenerators

Polysun also provides for the simulation of cogenerators. Cogenerators work on the cogeneration principle to simultaneously generate both heat and electricity. Cogenerators are mainly used in decentralised energy supply systems for single or multi-family houses as well as for industrial plants.

5.3.1 Power Modulation

A great number of cogenerators are non-modulating, on/off devices. As soon as a request is received from the controller, the cogenerator increases its output to a specific operating point, converting the fuel energy input into heat and electricity at a fixed ratio. In addition to these, cogenerator models also exist that can be operated within a given range by modulating their power output. Output modulation makes it possible to positively affect cycle behaviour and service life which, in turn, can have a positive impact on key factors such as maintenance intervals and economic viability.

In the catalog, the power range of the respective cogenerator may be defined by means of two reference points, the maximum and minimum operating point based on the fuel power input. The fuel power input, the thermal efficiency value as well as the electrical efficiency value are required for each reference point. Should it not be possible for the

cogenerator to be operated in modulating mode, matching minimum and maximum values should be entered.

Depending on the selected modulation, the model performs its calculations based on the fixed power data or interpolates between the two reference points as needed.

5.3.2 Operation

Basically, a cogenerator can be operated in two distinct modes: the heat-driven operation mode and the power driven operation mode. When operated in the heat-driven operation mode, the cogenerator strictly operates to meet the specified heating energy demand. The electrical energy output is either used to cover self-consumption needs or fed into the public grid. In the power-driven operation mode, the device is operated based on electricity demand. It must, however, be ensured that the heat output may be directly or indirectly decreased at any time by means of appropriate tank modules. Should this not be the case, the surplus heat must be dissipated by means of appropriate emergency cooling devices. This, however, negatively affects the system's overall efficiency and should, therefore, be avoided as far as possible. Thus, an interesting alternative is provided by combined operation, whereby priority is given to meeting the specified heating demand while simultaneously attempting to supply the most possible amount of electrical energy so that no excess heat is dissipated unused to the environment.

In Polysun, the cogenerator's operation mode may be defined by selecting the appropriate control mode. The programmable controller makes it possible to operate the cogenerator both according to heat and electricity demand or based on any combination of these.

5.3.3 Controller

The component "cogenerator" may be operated both through the heat generator controller as well as by means of the programmable controller. It should be noted that for the heat generator controller only (and directly) the heat-driven operation mode is available as a default setting. Alternatively, only the status or additionally the cogenerator's controlled output may be selected for the corresponding modulating operation. It should also be noted that a cogenerator may only be operated in controlled mode if the relevant reference points have been appropriately parameterized in the database; otherwise, despite the controlled operation having been selected, the cogenerator will not operate in modulating mode.

Next to the control mode, an additional output is available for the programmable controller that may alternatively be set to "1" (heat-driven operation mode) or "2" (power-driven operation mode). As in the preceding case, both the status and the controlled power output must be selected. The control mode allows the user to define whether the requested output is a thermal (1) or electrical (2) output. Accordingly, the model performs its calculations with thermal or electrical values from the database. The third available control mode is the "0" mode. If this is active, the cogenerator will operate in non-modulating mode, even if essentially it could also operate in modulating mode. This makes it possible to study the influence of modulation.

Table 18. Cogenerator settings in the programmable controller

Description	Control value	Additional controller outputs	Function description
Fixed maximum power	0	-	The cogenerator runs at the maximum power level
Heat-driven operation	1	“Controlled power heat generator“	The cogenerator delivers, as far as possible, the desired thermal power set via the “Controlled power heat generator“ controller value. (default mode)
Electrically-driven operation	2	“Controlled power heat generator“	The cogenerator supplies, as far as possible, the desired electrical power set via the “Controlled power heat generator“ controller value.

5.4 Air/Water Heat Exchangers

The air/water heat exchanger is a thermal component which allows transferring energy between the fluid in the loop and the ambient air. Heat transfer can go in both directions: from the fluid in the loop to the ambient air or from the ambient air to the fluid in the loop. Therefore, the ambient air can be a heat source or a heat sink. No additional settings are required to change heat flow direction through the heat exchanger. Depending on the temperature of the fluid entering the heat exchanger and the temperature of the ambient air, the component defines itself the direction of the heat transfer. The air/water heat exchanger can be used with different technologies: water-water heat pumps, compressor- and thermal-driven cooling machines.

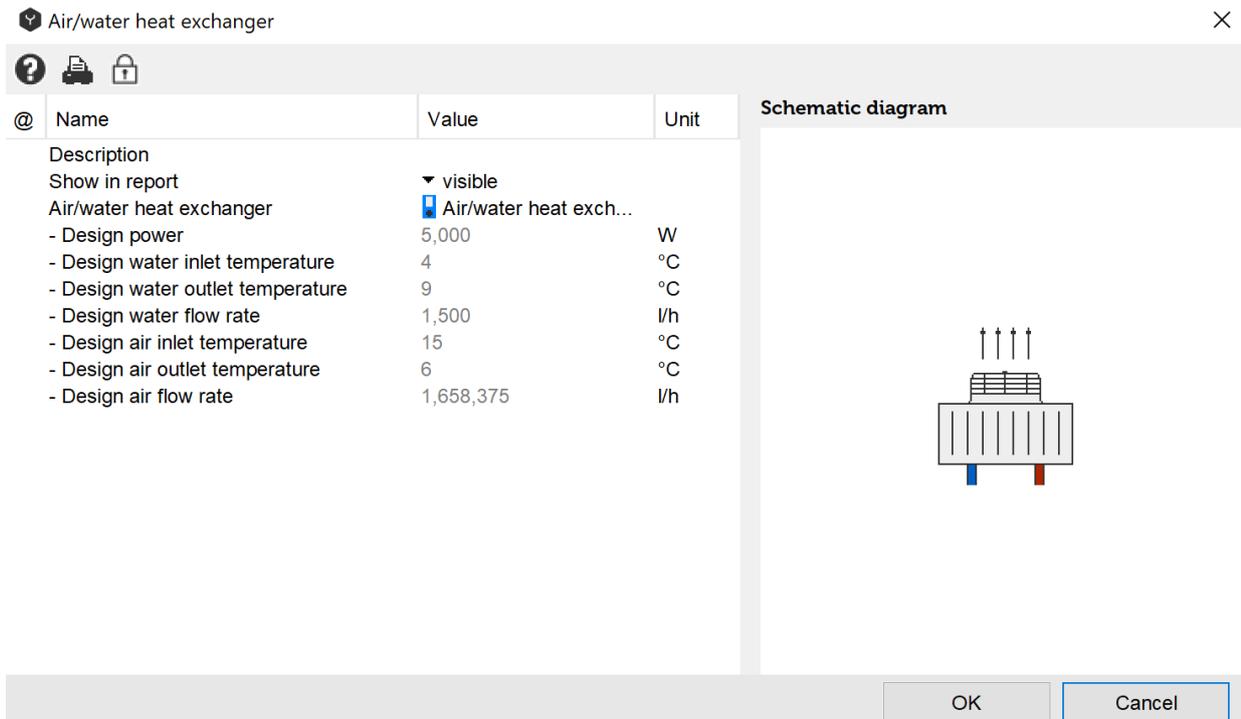


Fig. 126: dialog window of the air/water heat exchanger

The air/water heat exchanger is computed using the well-known “Number of Transfer Units (NTU) – Effectiveness” method. The method works as follows: based on design (nominal) values of the heat exchangers (transfer power capacity, temperature differences and flow rates at both sides) the UA-value is calculated => each time-step NTU, effectiveness and maximum theoretical transfer power capacity are defined => based on these values operational transfer power capacity is found=> having transfer power capacity outlet temperatures at both sides of the heat exchanger can be determined. The air/water heat exchanger is adiabatic. It means there is no heat transfer with ambient environment through the heat exchanger enclosure. The latent heat in the air is not considered in the model.

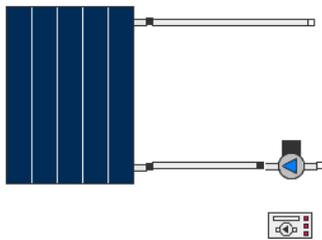
6 Controllers

6.1 Overview

Solar loop controller

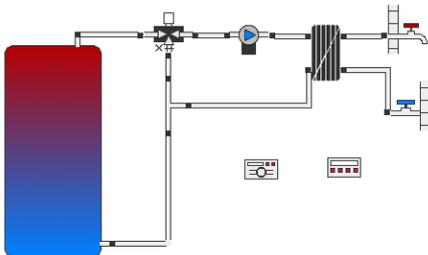
The solar loop can be controlled in 4 different ways:

1. Fixed flow rate
2. Specific flow rate per collector field (in l/h per m² of aperture area)
3. Matched Flow
4. Pressure drop according to the pump characteristics



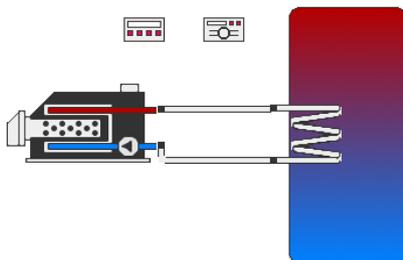
Variable speed pump controller

Controls the flow rate of the primary pump so that the secondary side reaches a certain temperature.



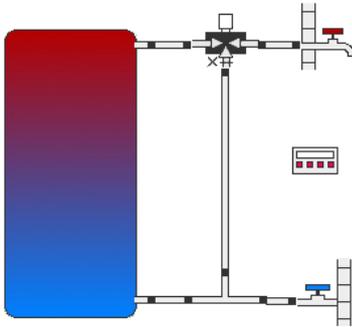
Auxiliary heating controller

Can be used for internal electric resistance heaters and external boilers. The two output signals are equal and digital. Therefore, in certain cases, the controller can also be used for pumps.



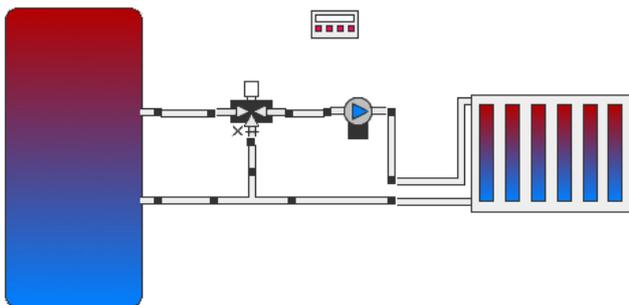
Mixing valve controller

Generates an analog output signal and mixes two inlet temperatures to reach the requested value. The hotter connection is connected horizontally on the left side of the 'x' symbol. The colder connection is connected vertically by the 'x' symbol.



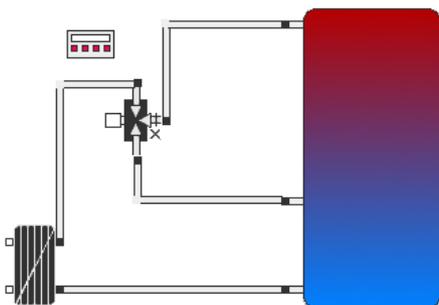
Heating circuit controller

Can be used to control the pump of the heating circuit.



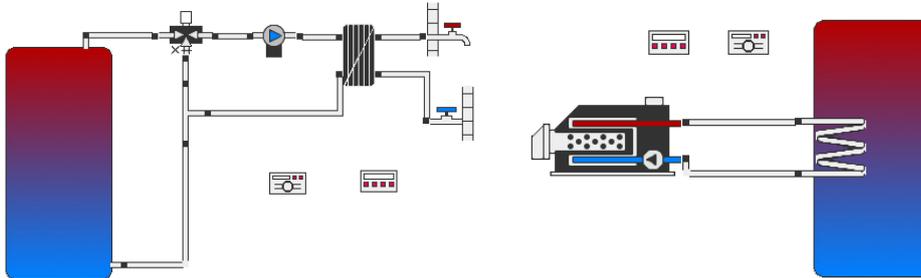
Temperature controller with AND/OR operation

Generates a digital output signal and is best applied to switching valves. One output signal is calculated based on two temperature levels, which can be set freely. It can also be used as a controller for heat generators and pumps. Various reference temperatures can be linked logically with AND/OR operations.



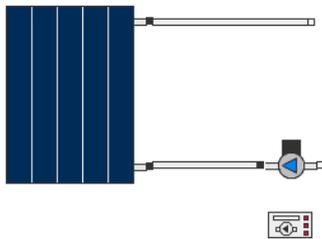
Flow rate controller

Measures a flow rate and passes it on as a pump setting. The flow rate controller provides a digital output signal and thus can also be used to turn a heat generator on and off.



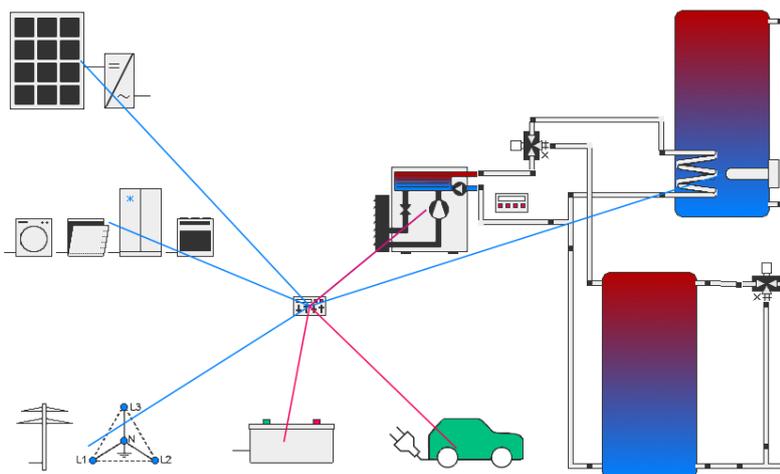
Irradiance controller

Provides a digital output signal based on different radiation intensity values.



Programmable controller

Freely programmable with spreadsheet-like functions. Dynamic control of any components (Polysun Designer and above).



Plugin controller

External implementation of the control logic (e.g. in Python, Java, Matlab, ...) via a plugin (Polysun Research or Premium).



6.1.1 Introduction

In this chapter we will provide an overview of the different controllers available in Polysun and their use and operation.

The following controllers are currently implemented in Polysun:

- Solar loop controller
- Variable speed pump controller
- Auxiliary heating controller
- Mixing valve controller
- Heating circuit controller
- Temperature controller with AND/OR Operation
- Flow rate controller
- Irradiance controller

Controller functions are basically editable at all user levels. Only the Designer level enables the user to individually integrate controllers within hydraulic schemes. Light level users will not be able to edit control outputs. Professional level users are able to edit the control parameters, but not the controller type.

Note:

Controllers employed in Polysun templates are defined as they are normally used in practice. The pre-defined parameter settings do not in any way claim to ensure enhanced solar yields.

6.1.2 Controller Selection

Adding a controller (Designer version) in the system diagram you will be prompted to enter the type of controller in a query dialog:

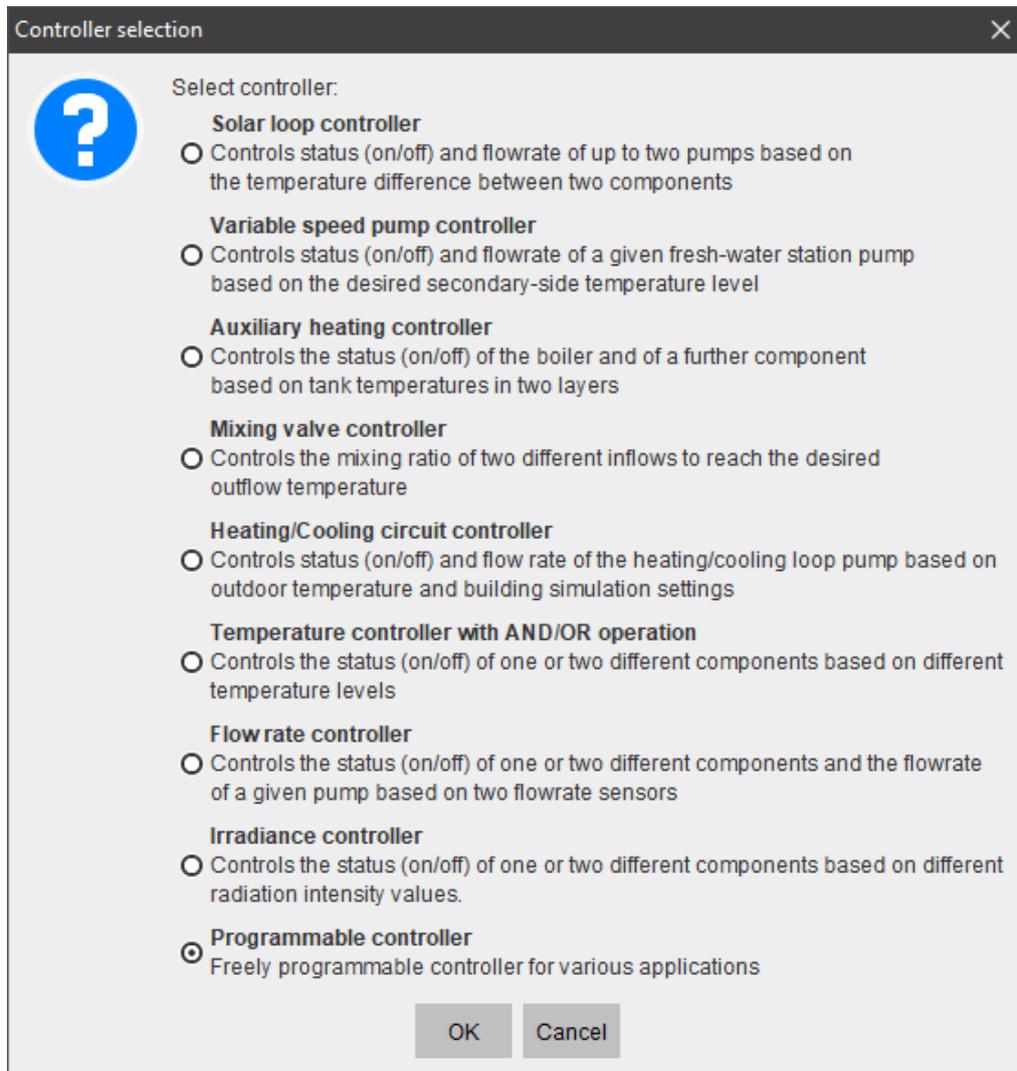


Fig. 127: controller selection

Choose a controller as required by means of the above controller overview. The controllers “temperature“ and “flow rate“ may be used in different applications. Once you’ve added the controller to the system, click on the controller component in the system diagram and define its features.

In the following chapters we will provide a detailed description of all controllers. The application of the individual controllers is shown in the above table.

In the definition of control features appropriate examples in the templates may be taken into consideration.

6.1.3 General Control Features

Controller “Description“

Entering figures or text in the field “Description“, these will appear after closing and re-opening the window in the title area of the controller:

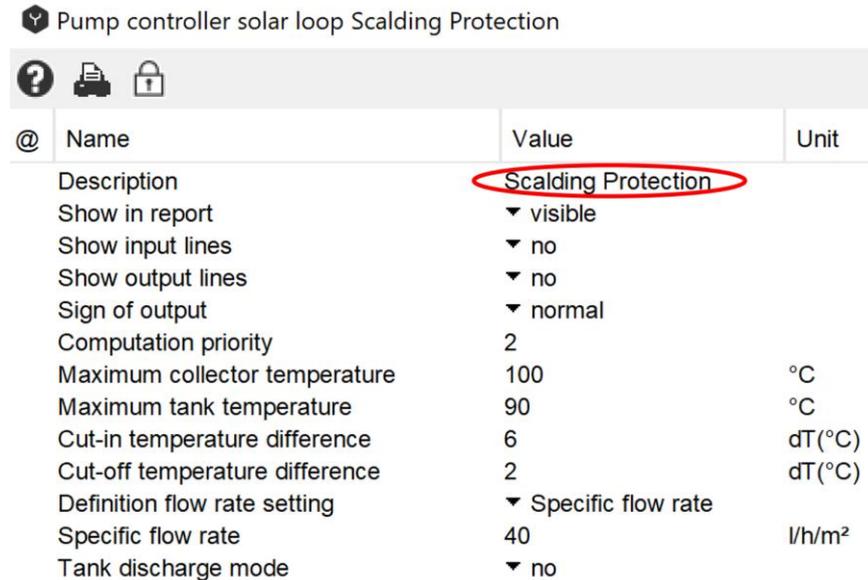


Fig. 128: scalding protection for mixing valve controller

Automatic Numbering of Polysun:

Adding multiple controllers in Polysun this latter will automatically assign each controller a consecutive number regardless of the fact that previously added controllers were later cancelled. Such consecutive numbers may be edited manually. A resetting of the consecutive numbering is, however, impossible. For each new system diagram the numbering will automatically start from "1".

Timer Controller

The “timer function“ may be used for all controllers, i.e the user will be able to define availability times in which the controller should be operating. This function enables to enter time, day and month in which the controller should be “active“ as required. In idle mode outputs are set to zero.

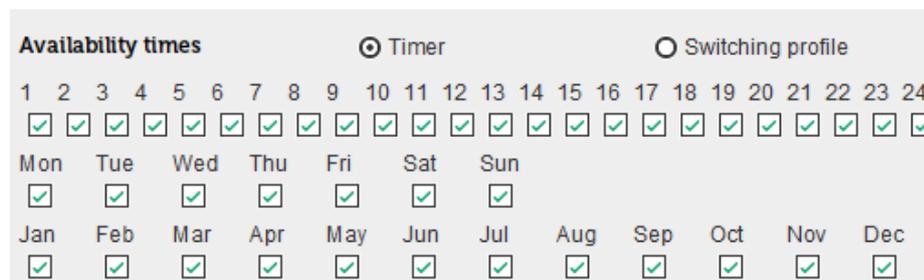


Fig. 129: timer controller

The definition of independent “week and month profiles“ is not possible.

Controller Outputs

Two parallel outputs are usually available. If two components need to be switched on and off in parallel this may be achieved by means of a special controller. In case of a number of parallel controlled components in excess of two the controller should be copied. An exception is provided by the mixing valve controller that only outputs an analogic signal.

“Energy Demand Not Covered”

A number of controllers (e.g.: temperature, flow rate) allow to set fixed and variable temperature settings. Sometimes after running a simulation the energy demand will be shown as “not covered”. This may happen if the temperature settings or flow rates defined within controllers and user profiles are not reached.

You may, for example, have set a mixing valve controller to “variable temperature setting: hot water demand” and entered in the hot water user profile a temperature of 50°C. If the controller was set so that the temperature setting for hot water may not be reached (e.g. due to temperature losses between mixing valve and tap) Polysun will show the report “Energy demand not covered” once the simulation is over. If this is the case check the state of the different temperature levels and compensate the temperatures in the controllers by means of “temperature shift”.

If a “Energy demand not covered” report is shown this does not mean that Polysun is making wrong calculations or that the hydraulic system is not correctly working but that information is only available on whether the entered temperature levels and flow rates were reached. The generated solar yields will be correct also if temperature levels and flow rates were not reached. In this case check the parameters entered in the controllers and the different values against the hourly results of the individual components.

Sign of Output

Output signals can be digital (0 or 1) or analogic (0...1). If the notation of the employed ratings matches the actual situation (e.g. higher temperature > lower temperature) the output signal will be 1 (“true”). This corresponds to the “normal” sign. If an “inverted” sign is used the output signal will be computed $1-x$. In the above example 0 (false) would be the output. Such convention applies to both output signals so long as both were duly defined. If the pump shown in the time window is disabled the output signal will be 0 also in case of inverted choice.

6.2 Solar Loop Controller

The solar loop controller is a two-channel controller that regulates the pump in the solar-loop.

The controller regulates the status and flow rate of up to two pumps based on the temperature difference of two distinct measured values.

The controller has 2 (plus 3 optional) analogic inputs.
 The controller has 1 (plus 3 optional) outputs (partially digital and partially analogic).

Block Diagram

The block diagram shows the employed measuring and controlling values.

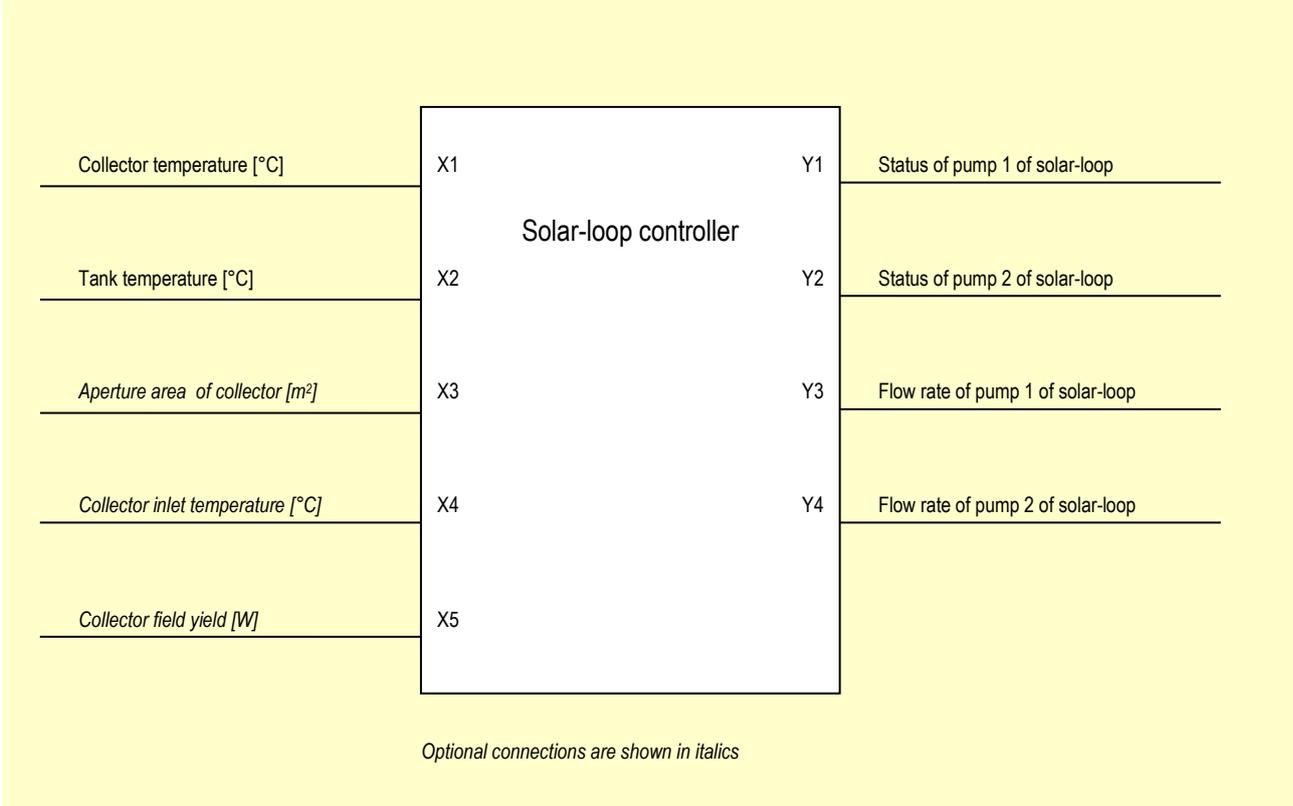


Fig. 130: block diagram: measuring values of solar loop

Controller Input Mask “Fixed Flow Rate“

Pump controller solar loop

Name	Value	Unit
Description		
Show in report	▼ visible	
Show input lines	▼ no	
Show output lines	▼ no	
Sign of output	▼ normal	
Computation priority	3	
Maximum collector temperature	100	°C
Maximum tank temperature	90	°C
Cut-in temperature difference	6	dT(°C)
Cut-off temperature difference	2	dT(°C)
Definition flow rate setting	▼ Fixed flow rate	
Fixed flow rate	60	l/h
Tank discharge mode	▼ no	

Name	Value	Unit
Collector temperature	Collector: Outflow temperature	°C
Tank temperature	Storage tank Combined tank: Layer 5	°C
Upper tank temperature (optional)		°C

Name	Value	Unit
On/Off pump 1	Pump Solar loop pump: On/Off	%
On/Off pump 2 (optional)		
Pumping capacity pump 1 (optional)	Pump Solar loop pump: Flow rate	l/h
Pumping capacity pump 2 (optional)		l/h

Availability times

Timer Switching profile

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>																		
Mon	Tue	Wed	Thu	Fri	Sat	Sun																	
<input checked="" type="checkbox"/>																							
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec												
<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>				

OK Cancel

Fig. 131: controller input mask “Fixed flow rate“

With this setting the solar pump cuts in as soon as the collector outflow temperature is 6 degrees higher than the temperature in the tank on layer 5. The flow rate is 60 l/h for the collector field as a whole.

Controller Input Mask “Specific Flow Rate”

Pump controller solar loop

Name	Value	Unit
Description		
Show in report	▼ visible	
Show input lines	▼ no	
Show output lines	▼ no	
Sign of output	▼ normal	
Computation priority	3	
Maximum collector temperature	100	°C
Maximum tank temperature	70	°C
Cut-in temperature difference	6	dT(°C)
Cut-off temperature difference	2	dT(°C)
Definition flow rate setting	▼ Specific flow rate	
Specific flow rate	15	l/h/m²
Tank discharge mode	▼ no	

Name	Value	Unit
Collector temperature	Collector: Outflow temperature	°C
Tank temperature	Storage tank Combined tank: Layer 5	°C
Collector aperture area (optional)	Collector: Collector aperture area	m²
Upper tank temperature (optional)		°C

Name	Value	Unit
On/Off pump 1	Pump Solar loop pump: On/Off	%
On/Off pump 2 (optional)		
Pumping capacity pump 1 (optional)	Pump Solar loop pump: Flow rate	l/h
Pumping capacity pump 2 (optional)		l/h

Availability times

Timer Switching profile

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>																		
Mon	Tue	Wed	Thu	Fri	Sat	Sun																	
<input checked="" type="checkbox"/>																							
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec												
<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>				

OK Cancel

Fig. 132: controller input mask “Specific flow rate“

With this setting the solar pump cuts in as soon as the collector outflow temperature is 6

degrees higher than the temperature in the tank on layer 5. The flow rate is 15 l/h/m² of collector field.

Controller Input Mask “Matched Flow”

Pump controller solar loop 2

Name	Value	Unit
Description		
Show in report	▼ visible	
Show input lines	▼ no	
Show output lines	▼ no	
Sign of output	▼ normal	
Computation priority	4	
Maximum collector temperature	100	°C
Maximum tank temperature	70	°C
Cut-in temperature difference	6	dT(°C)
Cut-off temperature difference	2	dT(°C)
Definition flow rate setting	▼ Matched flow (varia...	
Nominal temperature at collector outflow	60	°C
Min. flow rate	50	l/h
Max. flow rate	100	l/h
Tank discharge mode	▼ no	

Control inputs		
Name	Value	Unit
Collector temperature	Collector: Outflow temperature	°C
Tank temperature	Storage tank Combined tank: Layer 5	°C
Collector inlet temperature (optional)	Pipe 1: Temperature	°C
Collector field yield (optional)	Collector: Collector field yield	W
Upper tank temperature (optional)		°C

Control outputs		
Name	Value	Unit
On/Off pump 1	Pump Solar loop pump: On/Off	%
On/Off pump 2 (optional)		
Pumping capacity pump 1 (optional)	Pump Solar loop pump: Flow rate	l/h
Pumping capacity pump 2 (optional)		l/h

Availability times Timer Switching profile

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
<input checked="" type="checkbox"/>																							
Mon	Tue	Wed	Thu	Fri	Sat	Sun																	
<input checked="" type="checkbox"/>																							
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec												
<input checked="" type="checkbox"/>																							

OK Cancel

Fig. 133: controller input mask “Matched flow”

With this setting the solar pump cuts in as soon as the collector outflow temperature is 6 degrees higher than the temperature in the tank on layer 5. The flow rate ranges between 50 and 100 l/h for the collector field as a whole as an attempt is made to reach an output temperature of 60°C.

Input Values

6.2.1 Collector Temperature [°C]

The value refers to the point where the temperature of the collector is measured. Enter either the collector mean or outflow temperature.

6.2.2 Tank Temperature [°C]

The value refers to the point where the tank temperature is measured. Enter the relevant tank layer.

6.2.3 Aperture Area of Collector [m²] (Required in Case of Specific Flow

Rate)

The value refers to the aperture area of the selected collector. This value enables a pump to be controlled with a specific flow rate. (see the definition of flow rate setting in the control parameters)

6.2.4 Inlet Temperature of Collector [°C] (Required in Case of Matched Flow Operation)

The collector's inlet temperature is used to define the pump flow rate in "Matched flow" mode. To this end measure pipe temperature at collector's inlet.

6.2.5 Yield of Collector Field [W] (Required in Case of Matched Flow Operation)

The yield of the collector field is used to define the pump rate in "Matched flow" mode. Select the relevant collector field.

Description of Control Parameters

6.2.6 Description

The "description" value enables the user to assign controllers any name or number. Polysun assigns a consecutive number as a standard feature as different controllers are added chronologically in the hydraulic system.

6.2.7 Sign of Output

The term "Normal" means that digital output signals are controlled as intended in the switching logics. (Example: if $X1 > X2$ the output of pump 1 is positive) The term "Inverted" that output signals are multiplied -1. (Example: if $X1 > X2$ the output of pump 1 is equal to zero)

6.2.8 Maximum Temperature of Collector [°C]

If collector temperature $X1$ is higher than the entered maximum temperature the solar-loop pump cuts off.

6.2.9 Maximum Temperature of Tank [°C]

If tank temperature $X2$ is higher than the entered maximum temperature the solar-loop pump cuts off.

6.2.10 Cut-in Temperature Difference [K]

If the collector outflow temperature $X1$ is higher than tank temperature $X2$ by the entered value, the solar-loop pump cuts in. (Example: if $X1 > X2 + \text{value}$, the pump cuts in)

6.2.11 Cut-off Temperature Difference [K]

If the collector outflow temperature X1 is lower than tank temperature X2 plus the entered value, the solar-loop pump cuts off. (Example: if $X1 < X2 + \text{value}$, the pump cuts off)

6.2.12 Definition of Flow Rate Setting

- Specific flow rate
The controller regulates the pump according to the aperture area of the collector field by means of the value entered in the "Specific Flow rate". **The corresponding pumps should be set to "Flow rate setting"** (Double-click on pump to adjust the required settings).
- Fixed flow rate
Selecting a fixed flow rate the pump is controlled by means of the value entered in the "Fixed flow rate" field. The input value "Aperture area of collector" has no relevance and will be hidden. **The corresponding pumps should be set to "Flow rate setting"** (Double-click on pump to adjust the required settings).
- Matched Flow
In case of "matched flow" operation the flow rate of the pump will be defined by means of a preset flow rate range. In the process the flow rate will be set so as to allow the collector output temperature to be reached. **The corresponding pumps should be set to "Flow rate setting"** (Double-click on pump to adjust the required settings).

6.2.13 Definition of Flow Rate Value

- Specific flow rate [l/h/m²]
Value of the specific flow rate in [l/h/m²] aperture area of collector field.
- Fixed flow rate [l/h]
Value of the required fixed flow rate of collector field.
- Matched flow:
Value used to define the variable flow rate: collector outflow temperature [°C]; minimum flow rate [l/h], maximum flow rate [l/h].

Output Values

6.2.14 Status Pump 1

This digital output refers to the solar-loop pump to be controlled. Select the relevant pump from the list.

6.2.15 Status Pump 2 (Optional)

This digital output is activated just like the output of Status Pump 1. A second component (e.g. a further pump) may be controlled based on the same criteria as Status Pump 1. Select the relevant component from the list.

6.2.16 Flow Rate Pump 1 (Optional)

This analogic output controls the flow rate of pump 1. Select the relevant pump from the list. (the output is active only if the option "Flow rate setting" has been selected in the field "Flow rate-controlled" for the pump to be controlled; otherwise pump settings will have

priority over the analogic control outputs. Double click on the pump to change/check the settings)

6.2.17 Flow Rate Pump 2 (Optional)

This analogic output performs the same function as the flow rate output of pump 1. Select the relevant pump from the list.

Overview of Control-Dependencies

Table 19. Control-dependencies of the flow rate pump

Outputs	Parameter	Tip	Inputs	Function
Y1: Status Pump 1 Y1 = Y2 Y2: Status Pump 2	Fixed flow rate	Set pump to - Flow rate setting -	X1: Collector temperature	Y1=0 if X1 > maximum collector temperature [°C]
			X2: Tank temperature	Y1=0 if X2 > maximum tank temperature [°C]
			X1: Collector temperature	Y1=1 if X1 > X2 + cut-in temperature difference [K]
			X2: Tank temperature	Y1=0 if X1 < X2 + cut-off temperature difference [K]
Y3: Flow rate Pump 1 Y3 = Y4 Y4: Flow rate Pump 2	Specific flow rate	Set pump to - Flow rate setting – Flow rate dependent on X3 and the value of the specific flow rate	X1: Collector temperature	Y1=0 if X1 > maximum collector temperature [°C]
			X2: Tank temperature	Y1=0 if X2 > maximum tank temperature [°C]
			X1: Collector temperature	Y1=1 if X1 > X2 + cut-in temperature difference [K]
			X2: Tank temperature	Y1=0 if X1 < X2 + cut-off temperature difference [K]
			X3: Aperture area of collector	Y1=0 if X1 < X2 + cut-off temperature difference [K]
Y3: Flow rate Pump 1 Y3 = Y4 Y4: Flow rate Pump 2	Matched Flow	Set pump to - Flow rate setting – Flow rate within the entered range and adjusted to the defined collector output temperature	X1: Collector temperature	Y1=0 if X1 > maximum collector temperature [°C]
			X2: Tank temperature	Y1=0 if X2 > maximum tank temperature [°C]
			X1: Collector temperature	Y1=1 if X1 > X2 + cut-in temperature difference [K] Y1=0 if X1 < X2 + cut-off temperature difference [K]
			X2: Tank temperature	
			X4: Collector input temperature	
			X2: Yield of collector field	

6.3 Variable Speed Pump Controller

The variable-speed pump controller is a two-channel controller regulating status and flow rate of the pump of the fresh-water station.

The controller has 4 (plus 2 optional) analogic inputs.
 The controller has 2 digital and analogic outputs.

Block Diagram

The block diagram shows the employed measuring and controlling values

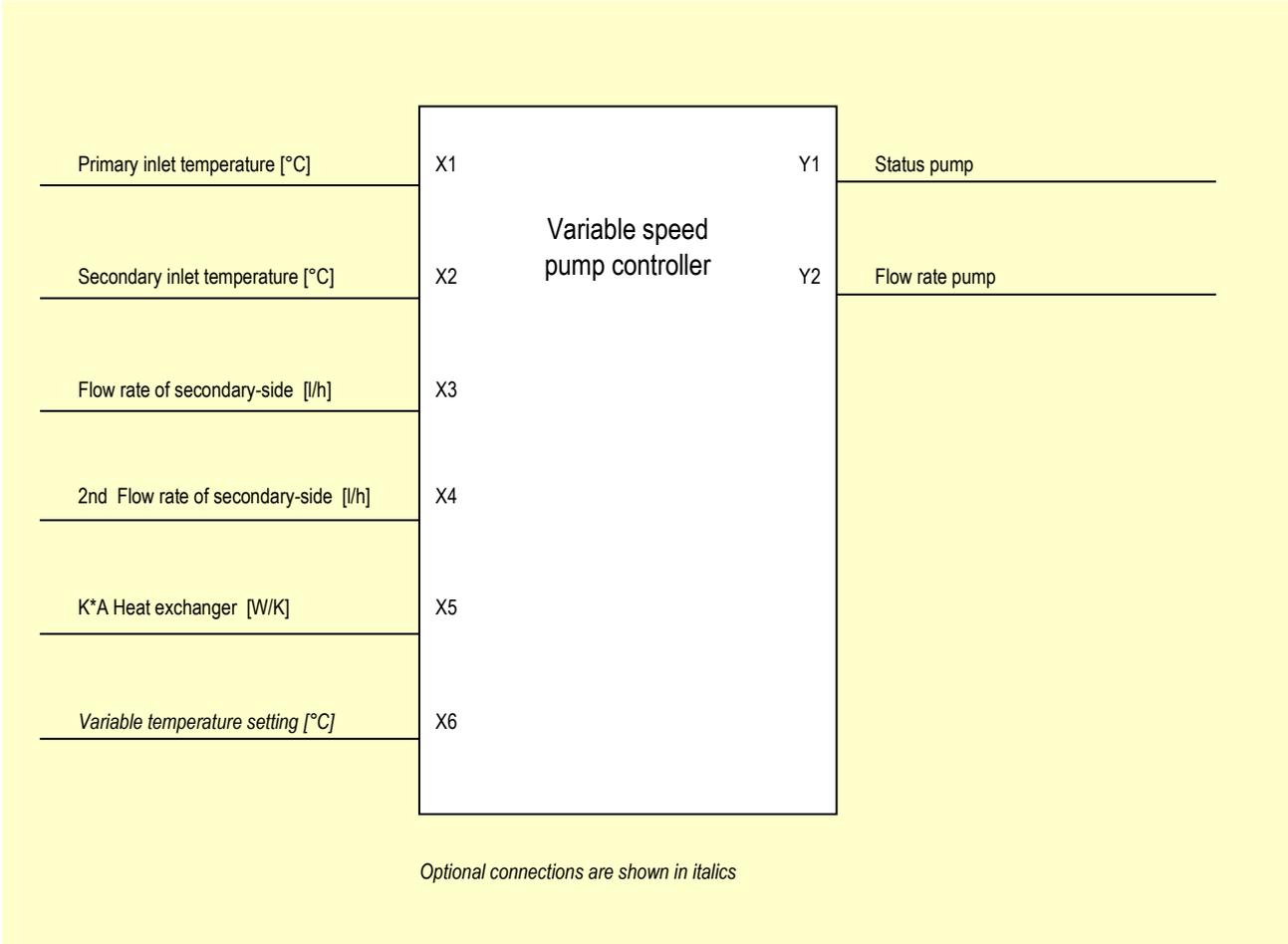


Fig. 134: block diagram: measuring values of variable speed pump controller

Controller Input Mask “Fixed Temperature Setting“

Variable speed pump controller FWM

Name	Value	Unit
Description	FWM	
Show in report	▼ visible	
Show input lines	▼ no	
Show output lines	▼ no	
Sign of output	▼ normal	
Computation priority	5	
Definition temperature setting	▼ Fixed value	
Fixed temperature setting	52	°C

Control inputs		
Name	Value	Unit
Input temperature supply	Storage tank Buffer tank: Top layer	°C
Input temperature demand	Pipe FWM primary cold: Temperature	°C
Flow rate secondary side	Hot water demand: Design flowrate	l/h
Second secondary-side flowrate (optional)		l/h
K*A heat exchanger	External heat exchanger: K*A he...	W/K

Control outputs		
Name	Value	Unit
On/Off pump	Pump FWM: On/Off	%
Pumping capacity	Pump FWM: Flow rate	l/h

Availability times Timer Switching profile

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
<input checked="" type="checkbox"/>																							
Mon	Tue	Wed	Thu	Fri	Sat	Sun																	
<input checked="" type="checkbox"/>																							
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec												
<input checked="" type="checkbox"/>																							

OK Cancel

Fig. 135: controller input mask “Fixed temperature setting“

With this setting the pump of the fresh-water station cuts in as soon as hot water is tapped. Pump speed is adjusted so that the output temperature on the secondary-side can reach 52°C. **Controller Input Mask ”Variable Temperature Setting“**

Variable speed pump controller FWM

Name	Value	Unit
Description	FWM	
Show in report	▼ visible	
Show input lines	▼ no	
Show output lines	▼ no	
Sign of output	▼ normal	
Computation priority	5	
Definition temperature setting	▼ Variable value	
Temperature shift	5	dT(°C)

Control inputs		
Name	Value	Unit
Input temperature supply	Storage tank Buffer tank: Top layer	°C
Input temperature demand	Pipe FWM primary cold: Temperature	°C
Flow rate secondary side	Hot water demand: Design flowrate	l/h
Second secondary-side flowrate (optional)		l/h
Variable temperature setting (optional)	Hot water demand: Temperature ...	°C
K*A heat exchanger	External heat exchanger: K*A he...	W/K

Control outputs		
Name	Value	Unit
On/Off pump	Pump FWM: On/Off	%
Pumping capacity	Pump FWM: Flow rate	l/h

Availability times Timer Switching profile

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
<input checked="" type="checkbox"/>																							
Mon	Tue	Wed	Thu	Fri	Sat	Sun																	
<input checked="" type="checkbox"/>																							
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec												
<input checked="" type="checkbox"/>																							

OK Cancel

Fig. 136: controller input mask “Variable temperature setting“

With this setting the pump of the fresh-water station cuts in as soon as hot water is tapped. Pump speed is adjusted so that the output temperature on the secondary-side is as high as the hot water demand temperature setting plus 5°C.

Input Values

6.3.1 Inlet Temperature of Primary Side [°C]

The value shows the point where the inlet temperature of the primary side is measured. Enter pipe temperature immediately before the plate heat exchanger or, e.g., the temperature of the tank connection.

6.3.2 Inlet Temperature of Secondary Side [°C]

The value shows the point where the inlet temperature of the secondary side is measured. Enter cold water temperature or pipe temperature immediately before the plate heat exchanger of secondary side.

6.3.3 Flow Rate of Secondary Side [l/h]

The value refers to the flow rate of the reference side. In fresh-water modules the value refers to the nominal flow rate of hot water withdrawal.

6.3.4 Second Flow Rate of Secondary Side [l/h]

As in flow rate of secondary-side a second flow rate may be entered. In case of the fresh-water station with circulation it is the circulation flow rate.

6.3.5 K*A Plate Heat Exchanger [W/K]

This value refers to the heat transfer properties and the heat transfer surface of the heat exchanger. Data are defined by the manufacturer.

6.3.6 Variable Temperature Setting [°C] (Optional)

The temperature that should be reached at the outflow of the plate heat exchanger, e.g. the temperature setting of the hot water demand.

Description of Control Parameters

6.3.7 Description

The “description“ value enables the user to assign controllers any name of number. Polysun assigns a consecutive number as a standard feature as different controllers are added chronologically in the hydraulic system.

6.3.8 Sign of Output

The term "Normal" means that digital output signals are controlled as intended in the switching logics. (Example: if $X3+X4>0$ the output of pump 1 is positive) The term "Inverted" that the digital output signals are multiplied -1.

6.3.9 Definition of Temperature Setting

- Fixed temperature setting
The components connected to the controller are adjusted so that the entered fixed temperature setting can be reached at the output of the plate heat exchanger on the secondary side.
- Variable temperature setting
The components connected to the controller are adjusted so that the entered variable temperature setting can be reached at the output of the plate heat exchanger on the secondary side allowing for the relevant temperature shift.

6.3.10 Definition of Temperature Shift

- For example. 5 [K]
The temperature shift value enables to adjust temperature drops in the plate heat exchanger and pipe cooling after the plate heat exchanger. If the value is positive the outflow temperature will be increased by this value. If the value is negative the outflow temperature will be decreased by this value.

Output Values

6.3.11 Pump Status [%]

This digital output refers to the pump to be controlled, e.g. the pump of the fresh-water station. Select the relevant pump from the list.

6.3.12 Pump Flow Rate [l/h]

This analogic output adjusts the pump flow rate so that the desired temperature level can be reached on the secondary side of the plate heat exchanger. In the process the plate heat exchanger shows a temperature drop from the primary to the secondary side. This temperature drop may be corrected through the temperature shift.

The output is active only if the option "Flow rate setting" has been selected in the field "Flow rate controlled" for the pump to be controlled; otherwise pump settings will have priority over the analogic control outputs. Double click on the pump to change/check the settings.

Select the relevant pump from the list.

Overview of Control-Dependencies

Table 20. Control-dependencies of the fixed and variable temperature settings

Outputs	Parameter	Tip	Inputs	Function
Y1: Pump Status Y2: Pump flow rate	Fixed temperature setting	Adjust pump to - Flow rate settings -	X1: Primary-side inlet temperature [°C]	Y1=0 if X3 + X4 = 0 Y1=1 if X3 + X4 > 0 Y2= f(X1, X2, X3 + X4, X5)
			X2: Secondary-side inlet temperature [°C]	
			X3: Secondary-side flow rate [l/h]	
			X4: Second flow rate of secondary-side [l/h]	
			X5: K*A Plate heat exchanger[W/K]	
Y1: Pump Status Y2: Pump flow rate	Variable temperature setting	Adjust pump to - Flow rate settings -	X1: Primary-side inlet temperature [°C]	Y1=0 if X3 + X4 = 0 Y1=1 if X3 + X4 > 0 Y2= f(X1, X2, X3 + X4, X5, X6)
			X2: Secondary-side inlet temperature [°C]	
			X3: Secondary-side flow rate [l/h]	
			X4: Second flow rate of secondary-side [l/h]	
			X5: Variable temperature setting [°C]	
			X6: K*A Plate heat exchanger [W/K]	

6.4 Auxiliary Heating Controller

The auxiliary heating controller is a two-channel controller that regulates status and flow rate of the boiler and the status of a further component based on tank temperatures in two layers.

The controller has 2 analogic inputs.
The controller has 1 (plus 1 optional) digital output.

A switch is turned on based on the temperature of a given point and turned back off based on the temperature of (another potential) point.

Block Diagram

The block diagram shows the employed measuring and controlling values

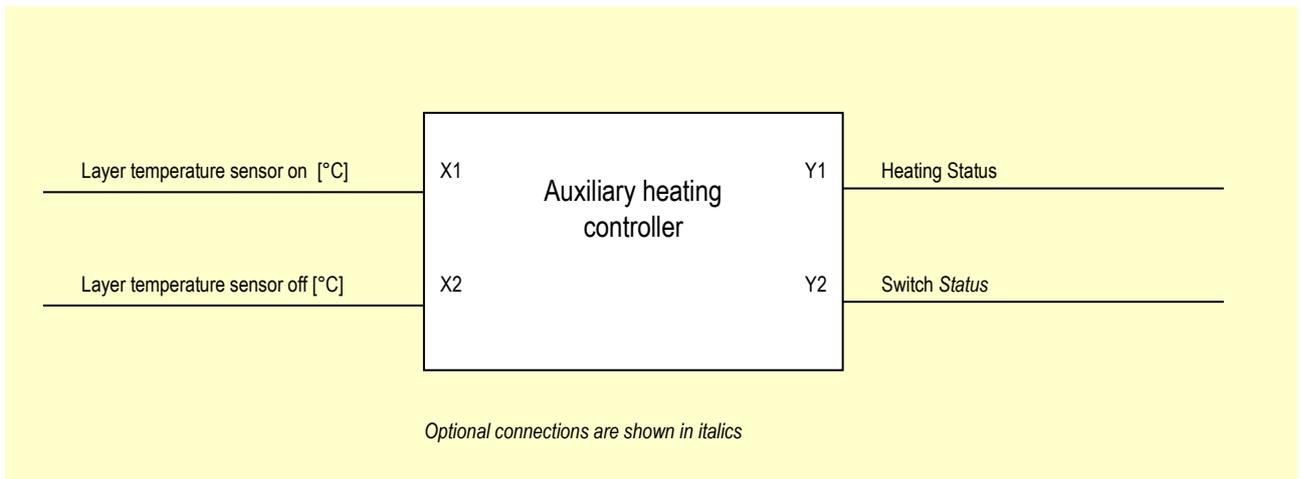


Fig. 137: block diagram: measuring values of auxiliary heating controller

Controller Input Mask

Auxiliary heating controller
✕

Name	Value	Unit
Description		
Show in report	▼ visible	
Show input lines	▼ no	
Show output lines	▼ no	
Sign of output	▼ normal	
Computation priority	3	
Logic relation temperature sensor 1 and 2	▼ None	
Reference for temperature sensors 1	▼ Fixed value	
Cut-in tank temperature 1	53	°C
Cut-off tank temperature 1	55	°C
Minimum operation time	0	min
Minimum downtime	0	min
Maximum tank temperature	140	°C

Control inputs

Name	Value	Unit
Layer temperature sensor on 1	Storage tank Combined tank: Layer 11	°C
Layer temperature sensor off 1	Storage tank Combined tank: Layer 8	°C
Flow rate heat generator (optional)		l/h
Inlet temperature heat generator (optional)		°C
Flow rate setting 2nd switch on/off (optional)		l/h

Control outputs

Name	Value	Unit
On/Off heating device	Internal heater [2]: On/Off	%
On/Off switch (optional)		
Controlled power heat generator (optional)		W
On/Off feedwater pump (optional)		
On/Off heating loop pump (optional)		
Controlled flow rate 2nd switch on/off (optional)		l/h

Availability times

Timer Switching profile

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>											
Mon	Tue	Wed	Thu	Fri	Sat	Sun																	
<input checked="" type="checkbox"/>																							
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec												
<input checked="" type="checkbox"/>																							

OK Cancel

Fig. 138: input mask auxiliary heating controller

With this setting the auxiliary heating cuts in as soon as layer temperature 11 in the tank drops below 53°C.

Input Values

6.4.1 Layer Temperature Sensor on [°C]

The value refers to the tank layer in which the temperature is measured to switch on the heating. Select the relevant tank layer.

6.4.2 Layer Temperature Sensor off [°C]

The value refers to the tank layer in which the temperature is measured to switch off the heating. Select the relevant tank layer.

Description of Control Parameters

6.4.3 Description

The “description” value enables the user to assign controllers any name or number. Polysun assigns a consecutive number as a standard feature as different controllers are added chronologically in the hydraulic system.

6.4.4 Sign of Output

The term “Normal” means that digital output signals are controlled as intended in the switching logics. (Example: if $X1 < \text{cut-in tank temperature}$ the output of pump 1 is positive) The term “Inverted” that output signals are multiplied -1.

6.4.5 Cut-in Tank Temperature [°C]

Enter the temperature at which the heating should be turned on.

6.4.6 Cut-off Tank Temperature [°C]

Enter the temperature at which the heating should be turned off.

Output Values

6.4.7 Heating Status

This digital output refers to the heating to be controlled. Select the relevant boiler from the list.

6.4.8 Switch Status (Optional)

This digital output enables, if required, to control one further component, for example a second heating, pump or a switching valve. Select the relevant component from the list. This will only allow you to control the status of a given component.

Overview of Control-Dependencies

Table 21. Control-dependencies

Outputs	Parameter	Tip	Inputs	Function
Y1: heating status Y1 = Y2 Y2: switch status	---	Adjust heating to: - Fixed power - controlled power - controlled temperature	X1: Layer temperature sensor on [°C] X2: Layer temperature sensor off [°C]	Y1=1 if X1 < Cut-in tank temperature [°C] Y1=0 if X2 > Cut-off tank temperature [°C]

6.5 Mixing Valve Controller

The mixing valve controller is a one-channel controller that regulates the mixing ratio of two different inflows so that the desired outflow temperature can be reached. Such outflow temperature may be specified through a constant or variable value. This analogic output enables to control a three-way valve and put in place this way a scalding protection.

The controller has 2 (plus 1 optional) analogic inputs.
The controller has 1 analogic output.

Remark: as during a simulation time step the mixing ratio remains constant its calculation should be based on temperatures that are as constant as possible. You can therefore beneficially use to this end the large volumes preceding the mixer and not the immediately adjacent pipes (for example temperature in tank layers or connections).

Block Diagram

The block diagram shows the employed measuring and controlling values

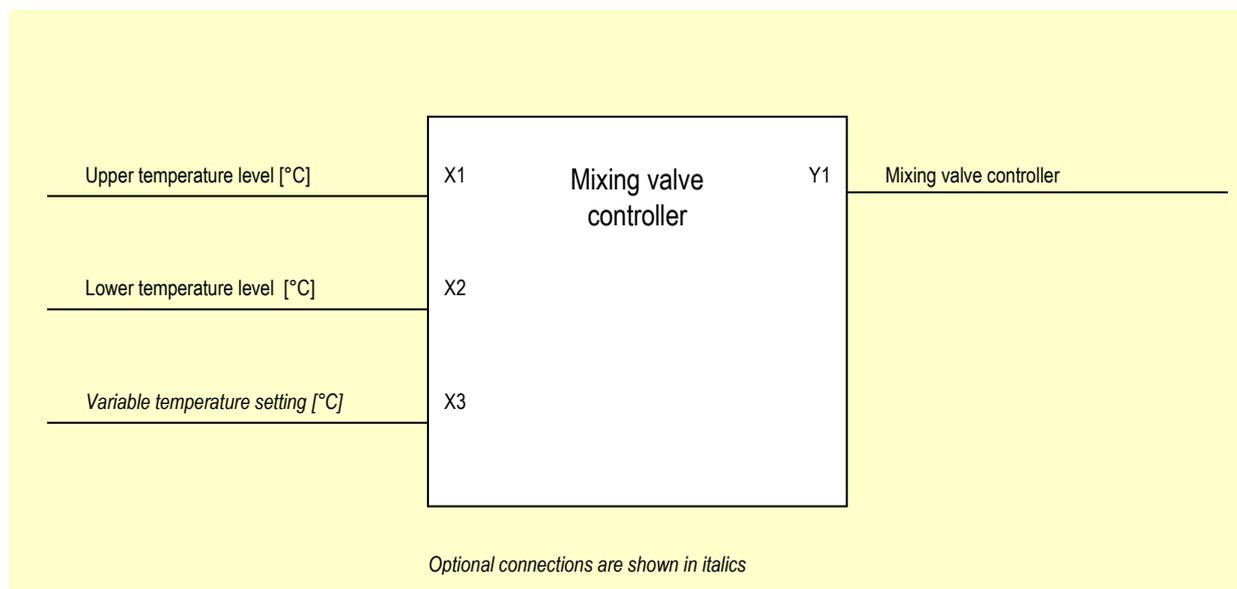


Fig. 139: block diagram: measuring and controlling values of mixing valve control

Definition of Mixing Valve

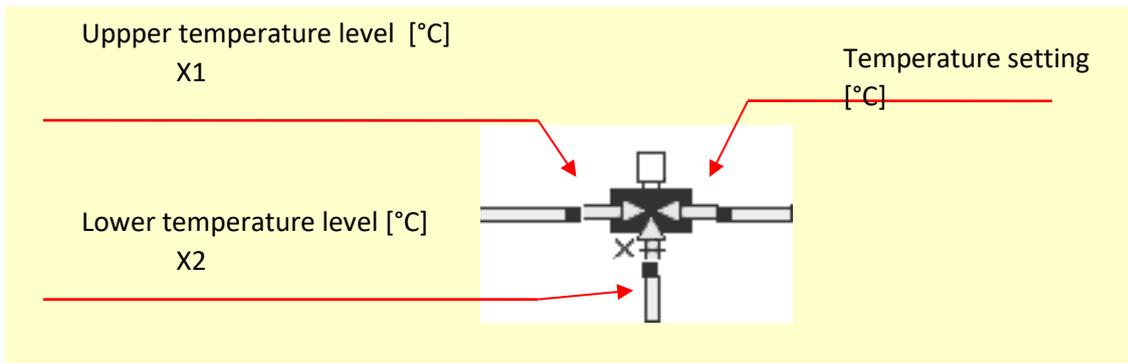


Fig. 140: definition of mixing valve

Controller Input Mask “Fixed Value“

Mixing valve controller

Name	Value	Unit
Description		
Show in report	▼ visible	
Show input lines	▼ no	
Show output lines	▼ no	
Sign of output	▼ normal	
Computation priority	1	
Definition temperature setting	▼ Fixed value	
Fixed temperature setting	52	°C

Control inputs		
Name	Value	Unit
Upper temperature level (optional)	Storage tank: Top layer	°C
Lower temperature level (optional)	Cold water: Temperature	°C

Control outputs		
Name	Value	Unit
Mixing valve (optional)	Three-way valve: Valve position	%

Availability times Timer Switching profile

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
<input checked="" type="checkbox"/>																							
Mon	Tue	Wed	Thu	Fri	Sat	Sun																	
<input checked="" type="checkbox"/>																							
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec												
<input checked="" type="checkbox"/>																							

OK Cancel

Fig. 141: controller input mask “Fixed value“

Controller Input Mask “Variable Value“

The screenshot shows the configuration window for a 'Mixing valve controller'. It is divided into several sections:

- Properties Table:**

@	Name	Value	Unit
	Description		
	Show in report	▼ visible	
	Show input lines	▼ no	
	Show output lines	▼ no	
	Sign of output	▼ normal	
	Computation priority	1	
	Definition temperature setting	▼ Variable value	
	Temperature shift	2	dT(°C)
- Control inputs Table:**

Name	Value	Unit
Upper temperature level (optional)	Storage tank: Top layer	°C
Lower temperature level (optional)	Cold water: Temperature	°C
Variable temperature setting (optional)	Hot water demand: Temperature ...	°C
- Control outputs Table:**

Name	Value	Unit
Mixing valve (optional)	Three-way valve: Valve position	%
- Availability times:**
 - Radio buttons: Timer, Switching profile
 - Grid of checkboxes for days 1-24, months (Jan-Dec), and days of the week (Mon-Sun).
- Buttons:** OK, Cancel

Fig. 142: controller input mask “Variable value“

With this setting the mixing will be performed based on the variable temperature setting “Hot water demand: temperature setting“ plus 2°K according to the selection of the temperature shift. The hot water temperature setting will be defined in the user profile of the project overview. The temperature shift will enable to compensate the temperature drop between mixing valve outflow and hot water tap.

Input Values

6.5.1 Upper Temperature Level [°C]

The value refers to the component in which the upper temperature level is measured. Select the relevant inlet pipe to the mixing valve or the **previous tank connection**.

6.5.2 Lower Temperature Level [°C]

The value refers to the component in which the lower temperature level is measured. Select the relevant pipe to the mixing valve on “Input X” (see figure “Definition of mixing valve“)

6.5.3 Variable Temperature Setting [°C] (Optional)

The value refers to the temperature setting to be achieved.

Description of Control Parameters

6.5.4 Description

The “description” value enables the user to assign controllers any name or number. Polysun assigns a consecutive number as a standard feature as different controllers are added chronologically in the hydraulic system.

6.5.5 Sign of Output

The term “Normal” means that digital output signals are controlled as intended in the switching logics. “Inverted” should not be used.

6.5.6 Definition of Temperature Setting

- Fixed value
The mixing valve will be regulated by means of the measured inlet temperatures so that the specified “Fixed value” temperature may be reached at the outflow of the mixing valve.
- Variable temperature setting
The mixing valve will be regulated by means of the measured inlet temperatures so that the specified “Variable value” temperature may be reached at the outflow of the mixing valve allowing for the temperature shift.

6.5.7 Definition of Temperature Shift

- E.g. 5 [K]
The temperature shift value enables to compensate the temperature drop between the outflow of the mixing valve and the hot water tap. If the value is positive the outflow temperature will be increased by this value. If the value is negative the outflow temperature will be reduced by such value.

Output Values

6.5.8 Mixing Valve Position

The output “Mixing valve” allows to define the position of the valve. The output regulates the branching ratio of inputs so that the specified temperature setting may be reached.

Overview of Control-Dependencies

Table 22. Control-dependencies of the mixing valve

Outputs	Parameter	Tip	Inputs	Function
Y1: Mixing valve status	Fixed value	Adjust mixing valve to - controlled value	X1: Upper temperature level [°C]	Y1=f(X1,X2) for the specified temperature setting
			X2: Lower temperature level [°C]	
Y1: Mixing valve status	Variable temperature setting	Adjust mixing valve to - controlled value	X1: Upper temperature level [°C]	Y1=f(X1,X2,X3) for the specified measured value of variable temperature setting plus temperature shift
			X2: Lower temperature level [°C]	
			X3: Variable temperature setting [°C]	

Valve Used as Switching Valve

The switching valve can be operated in the easiest possible manner through the temperature controller.

The mixing valve controller is not suitable for this use.

The switching valve should be connected so that the directions of flow match the figure.

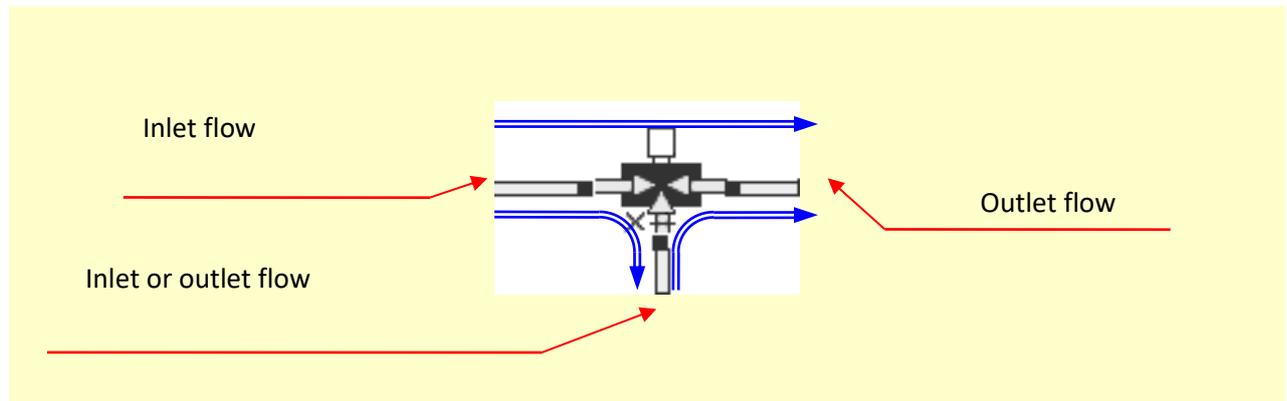


Fig. 143: valve used as switching valve

6.6 Heating Loop Controller

The heating controller regulates the status and flow rate of a pump based on building simulation settings. Optionally, the controller can also control a mixing valve.

The controller has 4 (plus 3 optional) analogic inputs.
 The controller has 2 (plus 2 optional) outputs, partially digital, partially analogic.

Heating loop cut-in and cut-off are based on thermostatic room temperature control. The inlet temperature is calculated based on the outdoor temperature which, in turn, is used as the temperature setting for the mixing valve.

Block Diagram

The block diagram shows the employed measuring and controlling values.

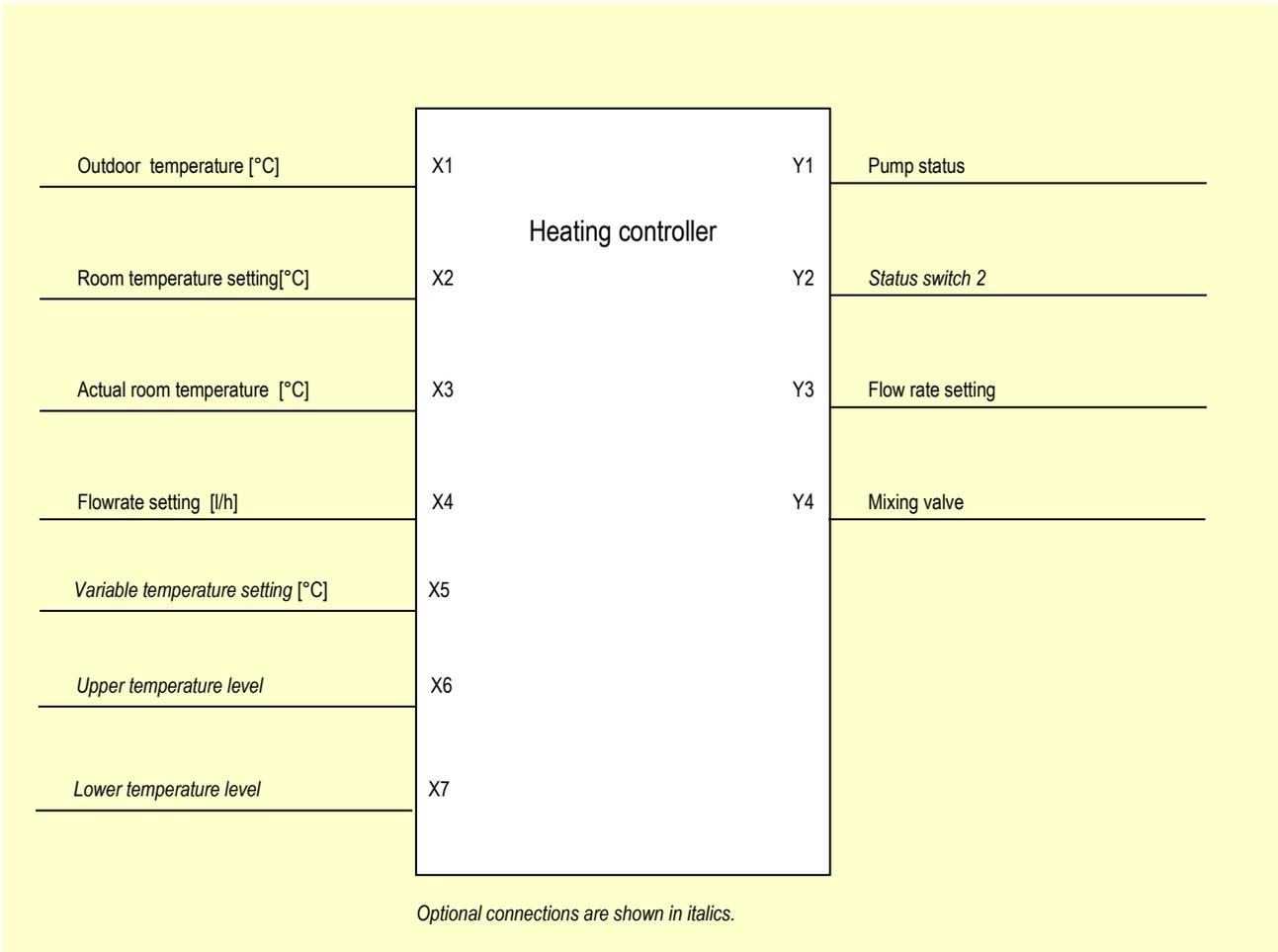


Fig. 144: block diagram: measuring and controlling values of heating controller

Controller Input Mask

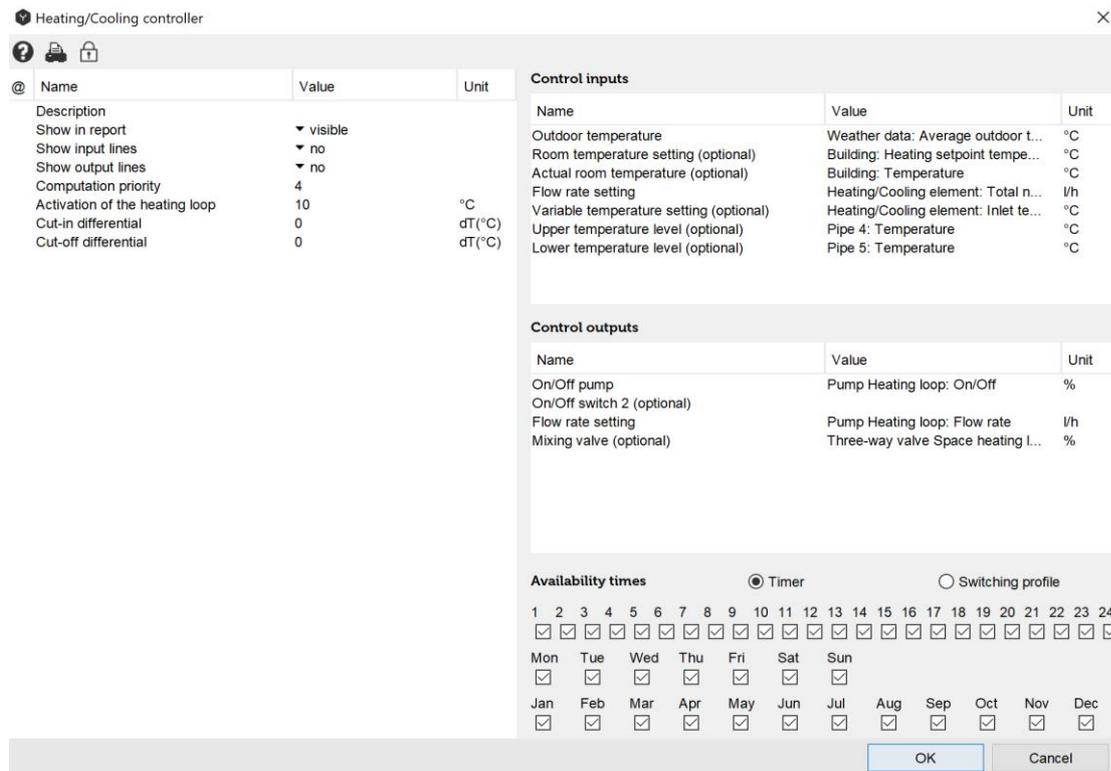


Fig. 145: controller input mask

Input Values

6.6.1 Outdoor Temperature [°C]

The value refers to the weather data being measured. Enter either the weather data outdoor temperature or the 24-h mean outdoor temperature.

6.6.2 Room Temperature Setting [°C]

The value shows how high the room temperature setting is when people are present.

6.6.3 Actual Room Temperature [°C]

The value shows how high the actual average room temperature is.

6.6.4 Flow Rate Settings [l/h]

The value shows the flow rate of the connected convectors. Enter the “Total design flow rate” for the convector. This will be calculated from the convector properties stored in the catalog and the number of existing convectors.

6.6.5 Variable Temperature Setting (Required for Mixing Valve)

Enter the inlet temperature setting for the convector. This value determines the maximum inlet temperature.

6.6.6 Upper Temperature Level (Required for Mixing Valve)

The value shows which components the upper temperature level for the mixing valve is being measured in. Select the appropriate inlet pipe to the mixing valve or **the appropriate port on the tank** (as shown in the Mixing Valve Controller section).

6.6.7 Lower Temperature Level (Required for Mixing Valve)

The value shows which components the lower temperature level for the mixing valve is being measured in. Select the appropriate pipe to the mixing valve on "Input X" (as shown in the Mixing Valve Controller section).

Description of Control Parameters

6.6.8 Description

The "description" value enables the user to assign the controller any name or number. Polysun assigns a consecutive number as a standard feature as different controllers are added chronologically in the hydraulic system

6.6.9 Sign of Output

The term "Normal" means that digital output signals are controlled as intended in the switching logics. The term "Inverted" means that the digital output signals are multiplied by -1.

6.6.10 Heating Loop Activation [°C]

If the outdoor temperature drops below the specified value, the inlet temperature is calculated by means of the outdoor temperature and the inlet temperature setting. If the outdoor temperature exceeds the specified value, the inlet temperature is set to a minimum value.

6.6.11 Cut-in Hysteresis

The pump in the heating circuit cuts in if the actual room temperature lies below the room temperature setting plus the cut-in hysteresis.

6.6.12 Cut-off Hysteresis

The pump in the heating circuit cuts off if the actual room temperature lies above the room temperature setting plus the cut-off hysteresis.

Output values

6.6.13 Status Pump 1

This digital output refers to the pump to be controlled within the heating loop. Select the relevant pump from the list.

6.6.14 Status Switch 2 (Optional)

This digital output is activated just like the Status Pump 1 output. This output enables to control an additional component. For the switching valve “logically one” means that the output “X” on the mixing valve is open. Select the relevant component from the list as required.

6.6.15 Flow Rate Setting

Here, the value indicated for “Flow rate” is transferred to the pump. To this end, select the flow rate of the relevant pump.

This output is only active if the option "Flow rate setting" has been selected in the field "Flow rate controlled" for the pump to be controlled; otherwise the pump settings will have priority over the analogue control outputs. Double click on the pump to check/change settings.

6.6.16 Mixing Valve (Optional)

The required inlet temperature is calculated and the position of the mixing valve is accordingly regulated based on the outdoor temperature and the inlet temperature of the convector. The calculated inlet temperature ranges from a maximum equal to the inlet temperature setting and a minimum equal to the room temperature setting plus 10°C.

Overview of Control-Dependencies

Table 23. Control-dependencies with or without mixing valve

Outputs	Parameter	Tip	Inputs	Function
Y1: Pump status Y1 = Y2 Y2: Status Switch 2	Without mixing valve	Adjust pump to - Flow rate setting	X1: outdoor temperature X2: room temperature setting X3: actual room temperature X4: Flow rate setting	Y1=0 if X3 > X2 + cut-off hysteresis [°C] Y1=1 if X3 < X2 + cut-in hysteresis [°C]
Y3: Flow rate setting				Y3 = flow rate setting X4

Y1: Pump status Y1 = Y2 Y2: Status Switch 2	With mixing valve	Adjust pump to - flow rate setting Adjust mixing valve to set value	X1: Outdoor temperature X2: Room temperature setting X3: Actual room temperature X4: Flow rate setting X5: Variable temperature setting X6: Upper temperature level X7: Lower temperature level	Y1=0 if X3 > X2 + cut-off hysteresis [°C] Y1=1 if X3 < X2 + cut-in hysteresis [°C]
---	-------------------	--	---	---

6.7 Temperature Controller with AND/OR Operation

The temperature controller regulates the status of up to two components based on one or two temperature differences. The controller may be used for different components including the switching valve (see chapter “Mixing valve controller”)

The controller has 1 (plus 3 optional) analogic inputs.
The controller has 1 (plus 1 optional) digital outputs.

The switch cuts-in or off based on the comparison of two or four different temperatures. The comparison may be carried out with a constant value; if several temperature sensors are used the different measured temperatures will be compared with one another.

Block Diagram

The block diagram shows the employed measuring and controlling values

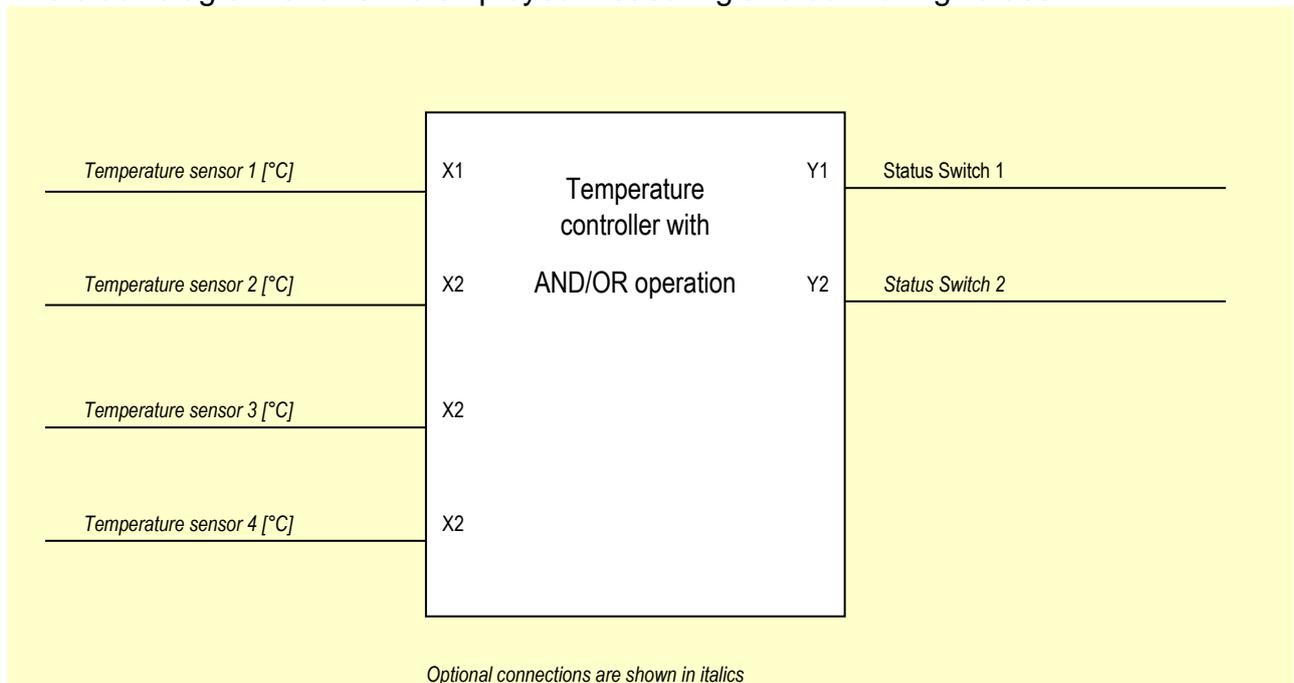


Fig. 146: block diagram: measuring and controlling values of temperature controller with AND/OR operation
Controller Input Mask without Logical Connection Once with “Fixed Value” and Once with “Variable Value”

Temperature controller with AND/OR operation

@	Name	Value	Unit
	Description		
	Show in report	▼ visible	
	Show input lines	▼ no	
	Show output lines	▼ no	
	Sign of output	▼ inverted	
	Computation priority	3	
	Logic relation temperature sensor 1 ...	▼ None	
	Reference for temperature sensor 1	▼ Fixed value	
	Fixed temperature setting 1	50	°C
	Apply differential	▼ yes	
	Cut-in differential	2	dT(°C)
	Cut-off differential	-2	dT(°C)

Control inputs		
Name	Value	Unit
Temperature sensor 1	Pipe solar inlet: Temperature	°C

Control outputs		
Name	Value	Unit
On/Off switch 1	Three-way valve Solar loop switc...	
On/Off switch 2 (optional)		

Availability times Timer Switching profile

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
<input checked="" type="checkbox"/>																							
Mon	Tue	Wed	Thu	Fri	Sat	Sun																	
<input checked="" type="checkbox"/>																							
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec												
<input checked="" type="checkbox"/>																							

OK Cancel

Fig. 147: controller input mask without logical connection once with "Fixed value" and once with "Variable value"

With this setting the output located on the three-way valve and marked with X opens as soon as the pipe's solar inlet temperature is higher than 50°C plus 2°.

Temperature controller with AND/OR operation

@	Name	Value	Unit
	Description		
	Show in report	▼ visible	
	Show input lines	▼ no	
	Show output lines	▼ no	
	Sign of output	▼ inverted	
	Computation priority	3	
	Logic relation temperature sensor 1 ...	▼ None	
	Reference for temperature sensor 1	▼ Variable value	
	Apply differential	▼ yes	
	Cut-in differential	2	dT(°C)
	Cut-off differential	-2	dT(°C)

Control inputs		
Name	Value	Unit
Temperature sensor 1	Pipe solar inlet: Temperature	°C
Temperature sensor 2 (optional)	Storage tank Buffer tank: Layer 8	°C

Control outputs		
Name	Value	Unit
On/Off switch 1	Three-way valve Solar loop switc...	
On/Off switch 2 (optional)		

Availability times Timer Switching profile

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
<input checked="" type="checkbox"/>																							
Mon	Tue	Wed	Thu	Fri	Sat	Sun																	
<input checked="" type="checkbox"/>																							
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec												
<input checked="" type="checkbox"/>																							

OK Cancel

Fig. 148: controller input mask without logical connection once with "Fixed value" and once with "Variable value"

With this setting the outflow located on the three-way valve and marked with X opens as soon as the pipe's solar inlet temperature is higher than the temperature on layer 8 plus 2°.

Controller Input Mask with Logical Connection Once with "Fixed Value" and Once with "Variable Value"

Name	Value	Unit
Description	Pool	
Show in report	▼ visible	
Show input lines	▼ no	
Show output lines	▼ no	
Sign of output	▼ normal	
Computation priority	5	
Logic relation temperature sensor 1 ...	▼ AND operation	
Reference for temperature sensor 1	▼ Variable value	
Reference for temperature sensor 3	▼ Fixed value	
Fixed temperature setting 2	70	°C
Apply differential	▼ yes	
Cut-in differential	6	dT(°C)
Cut-off differential	2	dT(°C)

Name	Value	Unit
Temperature sensor 1	Collector: Outflow temperature	°C
Temperature sensor 2 (optional)	Pool: Temperature	°C
Temperature sensor 3 (optional)	Storage tank Buffer tank: Layer 4	°C

Name	Value	Unit
On/Off switch 1	Three-way valve Solar loop mixin...	
On/Off switch 2 (optional)	Pump Pool: On/Off	%

Availability times Timer Switching profile

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
<input checked="" type="checkbox"/>																							
Mon	Tue	Wed	Thu	Fri	Sat	Sun																	
<input checked="" type="checkbox"/>																							
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec												
<input checked="" type="checkbox"/>																							

OK Cancel

Fig. 149: controller input mask with logical connection "Fixed value" and "Variable value"

With this setting the swimming-pool pump is activated only if the temperature measured by Temperature sensor 1 (Collector: outflow temperature) is higher than the temperature measured by Temperature sensor 2 (Pool: temperature) AND the temperature measured by Temperature sensor 3 (Tank: Layer 4) is higher than the reference for Temperature sensor 3: Fixed value = 70°C. As the swimming-pool is only used from May through to September the timer will be set accordingly.

Input Values

6.7.1 Temperature Sensor 1 [°C]

The value refers to the point where the temperature should be measured. Enter a component from the list.

6.7.2 Temperature Sensor 2 [°C] (Optional)

The value refers to the point where the reference temperature for temperature sensor 1 should be measured. Enter a component from the list.

6.7.3 Temperature Sensor 3 [°C] (Optional)

In case of AND / OR operation an additional switching conditions may be defined. Analogous to Temperature sensor 1.

6.7.4 Temperature Sensor 4 [°C] (Optional)

The value refers to the point where the reference temperature for temperature sensor 3 should be measured. Enter a component from the list.

Description of Control-Parameters

6.7.5 Description

The “description” value enables the user to assign controllers any name of number. Polysun assigns a consecutive number as a standard feature as different controllers are added chronologically in the hydraulic system

6.7.6 Sign of the Output

The term “Normal“ means that digital output signals are controlled as intended in the switching logics. (Example: if $X1 > \text{Fixed value}$ or if $X1 > X2$ the output Status Switch 1 is positive). The term “Inverted” means that the digital output signals are multiplied by -1. (Example: if $X1 > X2$ the output Switch 1 is equal to zero). **In case of inverted selection hysteresis may not be used.**

6.7.7 Logical Connection Temperature Sensor 1 and 3

- None
The output is activated based on the requirements existing amongst “Temperature sensor 1, Reference temperature, Temperature sensor 2 or Fixed temperature setting 1”.
- AND-Operation
The requirements existing between “Temperature sensor 1, 2, Fixed temperature setting 1“, **AND** “Temperature sensor 3, 4, Fixed temperature setting 2“ must be met.
- OR-Operation
The requirements existing between “Temperature sensor 1, 2, Fixed temperature setting 1“, **OR** “Temperature sensor 3, 4, Fixed temperature setting 2“ must be met.

6.7.8 Definition of Temperature Setting

- Fixed value
If the temperature measured by Temperature sensor 1 or 3 drops below the specified Fixed temperature setting 1 or 2, the controller output switches to "on".
- Variable value
If the temperature measured by Temperature sensor 1 or 3 exceeds the temperature measured by Temperature sensor 2 or 4, the controller output switches to "on".

6.7.9 Use of Hysteresis

If hysteresis is used the following applies

- Cut-in hysteresis [K]
If the temperature measured by Temperature sensor 1 or 3 exceeds the reference temperature by the specified temperature hysteresis, the controller output switches to "on".
- Cut-off hysteresis [K]
If the temperature measured by Temperature sensor 1 or 3 drops below the reference value by the specified temperature hysteresis, the controller output switches to "off".

Output Values

6.7.10 Status Switch 1

This digital output refers to the component to be controlled within the system. Select the relevant component from the list.

6.7.11 Status Switch 2 (Optional)

This digital output is activated just like the Status Switch 1 output. Select the relevant component from the list.

Overview of Control-Dependencies

Table 24. Control-dependencies of the temperature controller with AND/OR operation

Outputs	Parameter	Tip	Inputs	Function
Y1: Status Switch 1 Y1 = Y2 Y2: Status Switch 2	No operation Fixed value	If hysteresis is applied alter cut-in and off temperatures	X1: Temperature sensor 1	Y1=0 if X1 < Fixed temperature setting 1 [°C]
				Y1=1 if X1 > Fixed temperature setting 1 [°C]
				Y1=1 if X1 > Fixed temperature setting 1 [°C] + Cut-in-Hyst. Y1=0 if X1 < Fixed temperature setting 1 [°C] + Cut-off-Hyst.
				Y1=0 if X1 < X2

Y1: Status Switch 1 Y1 = Y2 Y2: Status Switch 2	No operation Variable value	If hysteresis is applied alter cut-in and off temperatures	X1: Temperature sensor 1 X2: Temperature sensor 2	Y1=1 if X1 > X2	
				Y1=1 if X1 > X2 + Cut-in temperature difference [K] Y1=0 if X1 < X2 + Cut-off temperature difference [K]	
Y1: Status Switch 1 Y1 = Y2 Y2: Status Switch 2	AND-Operation	Both Temperature sensor 1 and 3 may be compared either with Fixed temperature settings 1 and 2 or with temperature sensors 2 and 4	X1: Temperature sensor 1 X2: Temperature sensor 2 X3: Temperature sensor 3 X4: Temperature sensor 4	Y1=0 if	X1 < X2 or X1 < Fixed temperature setting 1 [°C] AND X3 < X4 or X3 < Fixed temperature setting 2 [°C]
				Y1=1 if	X1 > X2 or X1 > Fixed temperature setting 1 [°C] AND X3 > X4 or X3 > Fixed temperature setting 2 [°C]
				Hysteresis analogous to "No Operation"	
Y1: Status Switch 1 Y1 = Y2 Y2: Status Switch 2	OR-Operation	Both Temperature sensor 1 and 3 may be compared either with Fixed temperature settings 1 and 2 or with temperature sensors 2 and 4	X1: Temperature sensor 1 X2: Temperature sensor 2 X3: Temperature sensor 3 X4: Temperature sensor 4	Y1=0 if	X1 < X2 or X1 < Fixed temperature setting 1 [°C] OR X3 < X4 or X3 < Fixed temperature setting 2 [°C]
				Y1=1 if	X1 > X2 or X1 > Fixed temperature setting 1 [°C] OR X3 > X4 or X3 > Fixed temperature setting 2 [°C]
				Hysteresis analogous to "No Operation"	

6.8 Flow Rate Controller

The flow rate controller is a two-channel controller that regulates the status of up to two components and the flow rate of one pump based on a flow rate sensor. The controller is mainly used as a controller for the fresh-water station.

The controller has 1 (plus 2 optional) analogic inputs.
The controller has 1 (plus 2 optional) outputs, partially digital, partially analogic.

Switch cut-in or off are based on the comparison of two different flow rates. The comparison may be made with a constant value or in respect of a variable flow rate of any component. Additionally a scaling factor referring to a flow rate setting may be output as an analogic signal.

Block Diagram

The block diagram shows the employed measuring and controlling values

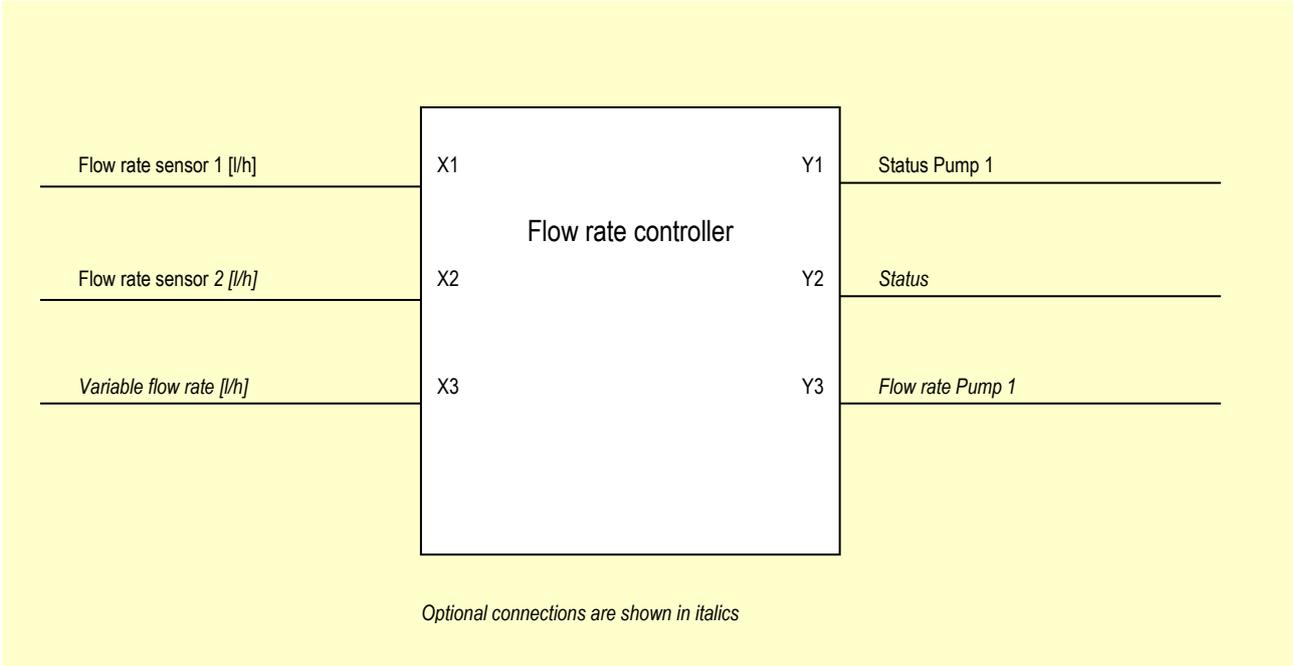


Fig. 150: block diagram: measuring and controlling values of flow rate controller

Controller Input Mask “Fixed Value”

Flow rate controller

@	Name	Value	Unit
	Description	▼ visible	
	Show in report	▼ no	
	Show input lines	▼ no	
	Show output lines	▼ no	
	Sign of output	▼ normal	
	Computation priority	7	
	Definition flow rate setting	▼ Fixed value	
	Fixed flow rate	10	l/h
	Scaling factor	1	

Control inputs		
Name	Value	Unit
Flow rate sensor 1	Hot water demand: Design flowrate	l/h
Flow rate sensor 2 (optional)		l/h

Control outputs		
Name	Value	Unit
On/Off pump 1	Pump Domestic hot water: On/Off	%
On/Off (optional)		
Pumping capacity pump 1 (optional)	Pump Domestic hot water: Flow rate	l/h

Availability times Timer Switching profile

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
<input checked="" type="checkbox"/>																							
Mon	Tue	Wed	Thu	Fri	Sat	Sun																	
<input checked="" type="checkbox"/>																							
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec												
<input checked="" type="checkbox"/>																							

OK Cancel

Fig. 151: flow rate controller input mask “Fixed value”

With this setting the hot water pump cuts in as soon as the flow rate of a tap is higher than 10 l/h. The tap flow rate will be referred to as the flow rate setting for the hot water pump.

Controller Input Mask “Variable Value”

Name	Value	Unit
Description	visible	
Show in report	no	
Show input lines	no	
Show output lines	normal	
Sign of output	7	
Computation priority	Variable value	
Definition flow rate setting	1	
Scaling factor	1	

Name	Value	Unit
Flow rate sensor 1	Hot water demand: Design flowrate	l/h
Flow rate sensor 2 (optional)		l/h
Variable flow rate	Pipe 13: Flow rate	l/h

Name	Value	Unit
On/Off pump 1	Pump Domestic hot water: On/Off	%
On/Off (optional)		
Pumping capacity pump 1 (optional)	Pump Domestic hot water: Flow rate	l/h

Availability times: Timer Switching profile

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
<input checked="" type="checkbox"/>																							
Mon	Tue	Wed	Thu	Fri	Sat	Sun																	
<input checked="" type="checkbox"/>																							
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec												
<input checked="" type="checkbox"/>																							

Fig. 152: flow rate controller input mask “Variable value”

With this setting the hot water pump cuts in as soon as the flow rate of the tap is higher than the flow rate of pipe 13. The tap flow rate will be referred to as the flow rate setting for the hot water pump.

Input Values

6.8.1 Flow Rate Sensor 1 [l/h]

The value refers to the point where the reference flow rate should be measured. Enter a component from the list. The value may be concurrently employed as output signal at the “Flow rate Pump 1” output. In this context the value is multiplied by the “Scaling factor”.

6.8.2 Flow Rate Sensor 2 [l/h]

An additional reference flow rate may be measured. Enter a component from the list. If 2 flow rate sensors are used their values are added. The added value may be concurrently employed as an output signal at the “Flow rate Pump 1” output. In this context the value is multiplied by the “Scaling factor”.

6.8.3 Variable Flow Rate [l/h] (Optional)

The value refers to the flow rate setting to be measured. The value serves as the reference value for flow rate sensor 1 or 1 + 2.

Description of Control-Parameters

6.8.4 Description

The “description” value enables the user to assign controllers any name or number. Polysun assigns a consecutive number as a standard feature as different controllers are added chronologically in the hydraulic system

6.8.5 Sign of Output

The term “Normal“ means that digital output signals are controlled as intended in the switching logics. (Example: if $X1 > \text{Fixed value}$ or if $X1 > X2$ the output of pump 1 is positive). The term “Inverted“ means that the digital output signals are multiplied by -1. (Example: if $X1 > X2$ the output Switch 1 is equal to zero).

6.8.6 Definition of Flow Rate Setting

- Fixed value
If the flow rate measured on the flow rate sensor exceeds the specified Fixed value the controller switches to “on”.
- Variable value
If the flow rate measured on the flow rate sensor exceeds the specified Variable value the controller switches to “on”.

6.8.7 Scaling Factor

The flow rate sensor value ($X1+X2$) is multiplied by the scaling factor and transferred via the “Flow rate Pump 1” as output signal to the relevant pump.

Output values

6.8.8 Status Pump 1

This digital output refers to the component to be controlled within the system. Select the relevant component from the list. (For the fresh-water station select the pump).

6.8.9 Status (Optional)

This digital output is activated just like the output of Status Pump 1. Select if required a component to be controlled from the list.

6.8.10 Flow Rate Pump 1 (Optional)

This option allows the pump to be speed-controlled. The flow rate setting is only active if the option "Flow rate setting" has been selected in the field "Flow rate controlled" for the pump to be controlled.

Overview of Control-Dependencies

Table 25. Control-dependencies of the flow rate controller

Outputs	Parameter	Tip	Inputs	Function
---------	-----------	-----	--------	----------

Y1: Status Pump 1 Y1 = Y2 Y2: Status	Fixed value	Pump:enter in the field "Flow rate controlled" the value "Flow rate setting"	X1: Flow rate sensor 1 X2: Flow rate sensor 2	Y1=0 if X1 + X2 < Fixed value [l/h] Y1=1 if X1 + X2 > Fixed value [l/h]
Y3: Flow rate Pump 1				Y3= (X1 + X2) * Scaling factor
Y1: Status Pump 1 Y1 = Y2 Y2: Status	Variable value	Pump:enter in the field "Flow rate controlled" the value "Flow rate setting"	X1: Flow rate sensor 1 X2: Flow rate sensor 2 X3: Variable flow rate setting	Y1=0 if X1 + X2 < X3 Y1=1 if X1 + X2 > X3
Y3: Flow rate Pump 1				Y3= (X1 + X2) * Scaling factor

6.9 Irradiance Controller

The irradiance controller is a one-channel controller that regulates up to two components based on irradiance values. The controller is mainly used as a solar loop controller.

The controller has 1 (plus 1 optional) analogic inputs.

The controller has 1 (plus 1 optional) digital outputs.

Block Diagram

The block diagram shows the employed measuring and controlling values

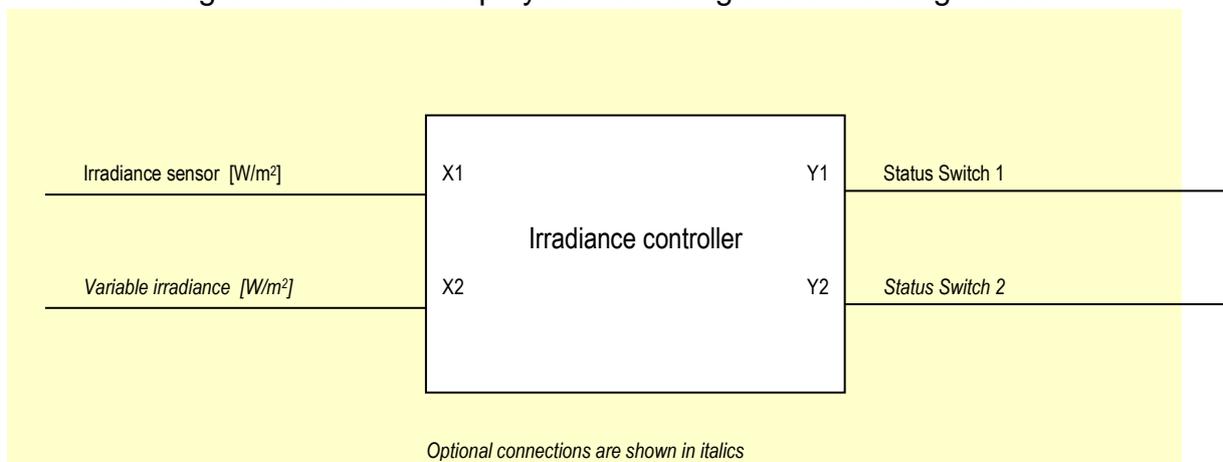


Fig. 153: block diagram: measuring and controlling values of irradiance controller

Controller Input Mask "Fixed Value"

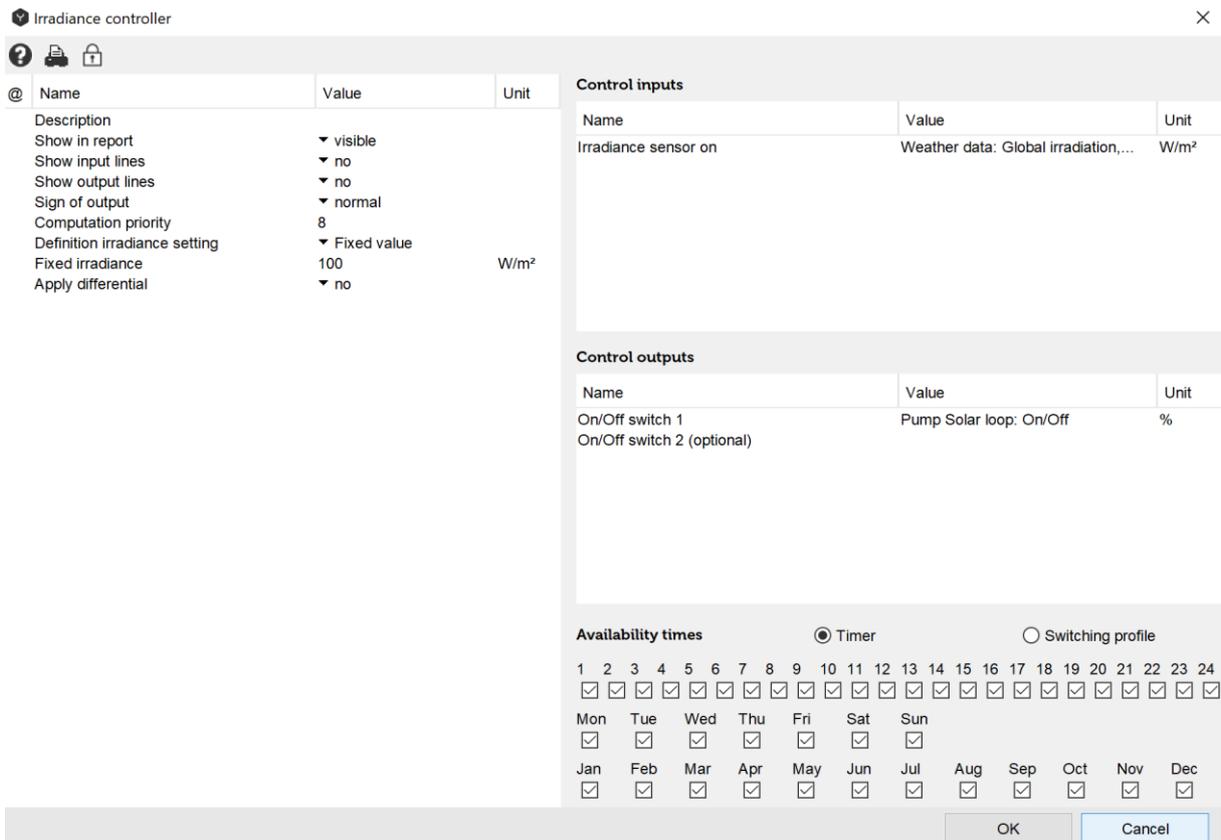


Fig. 154: irradiance controller input mask "Fixed value"

With this setting the pump cuts in as soon as the global irradiance is greater 100 W/m².

Controller Input Mask "Variable Value"

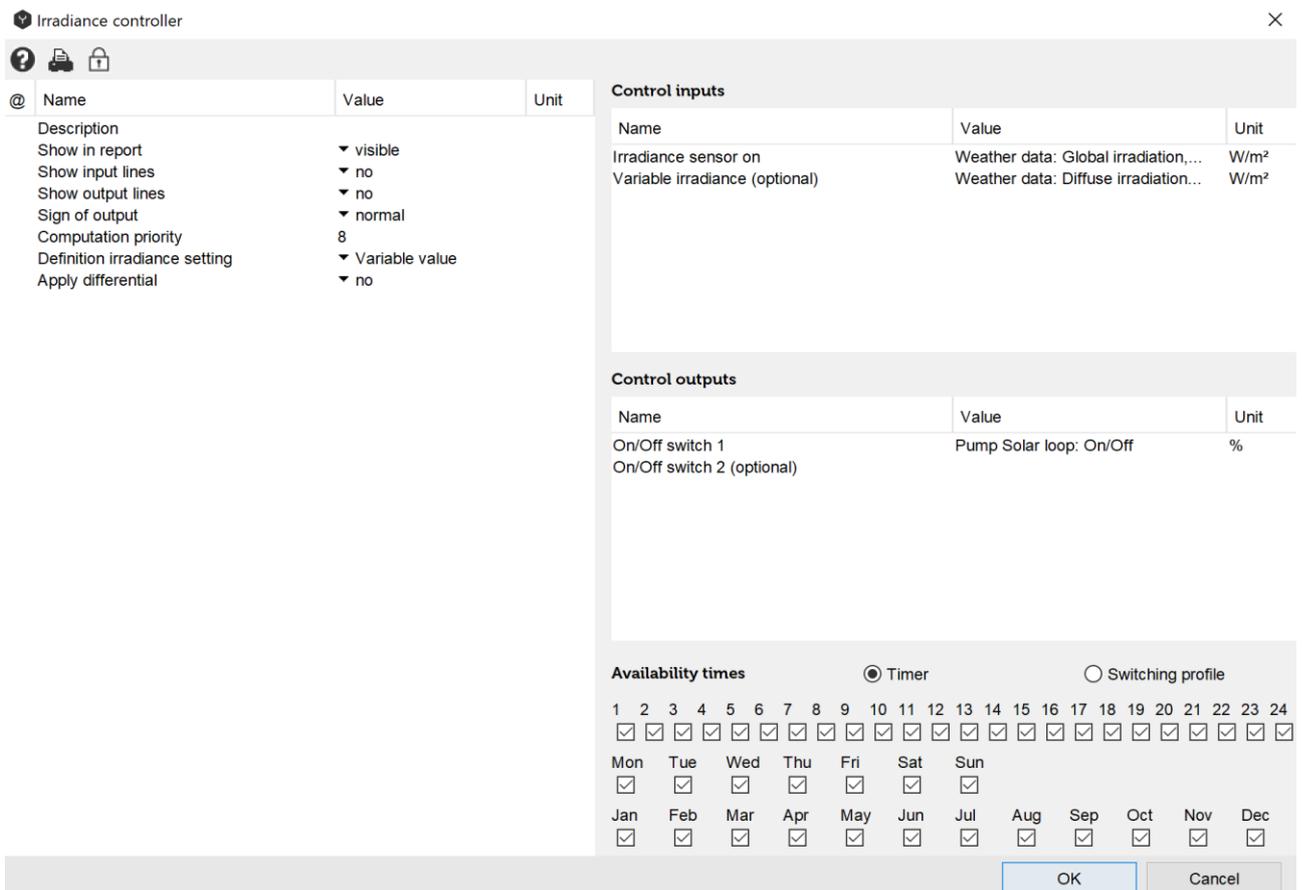


Fig. 155: irradiance controller input mask "Variable value"

With this setting the pump cuts is as soon as the global irradiance is greater than the diffuse irradiance.

Input Values

6.9.1 Irradiance Sensor [W/m²]

The value refers to which irradiance should be measured. A distinction can be made between "Global irradiance", "Diffuse irradiance" and "Long wavelength irradiance". Enter a component from the list.

6.9.2 Variable Irradiance [W/m²] (Optional)

The value refers to the diffuse irradiance setting to be measured. A distinction can be made between "Global irradiance", "Diffuse irradiance" and "Long wavelength irradiance". Enter a component from the list.

Description of Parameters

6.9.3 Description

The “description” value enables the user to assign controllers any name or number. Polysun assigns a consecutive number as a standard feature as different controllers are added chronologically in the hydraulic system

6.9.4 Sign of Output

The term “Normal” means that digital output signals are controlled as intended in the switching logics. (Example: if $X1 > \text{Fixed value}$ or if $X1 > X2$ the output of pump 1 is positive). The term “Inverted” means that the digital output signals are multiplied by -1. (Example: if $X1 > X2$ the output Switch 1 is equal to zero).

6.9.5 Definition of Irradiance Setting

- Fixed value
If the irradiance measured by the irradiance sensor exceeds the specified fixed value the controller output switches to “on”.
- Variable value
If the irradiance measured by the irradiance sensor exceeds the specified variable value the controller output switches to “on”.

6.9.6 Use of Hysteresis

If the hysteresis is used the following applies

- Cut-in hysteresis [W/m²]
If the irradiance measured by the irradiance sensor exceeds the reference value by the specified hysteresis the controller output switches to ”on “.
- Cut-off hysteresis [W/m²]
If the irradiance measured by the irradiance sensor drops below the reference value by the specified hysteresis the controller output switches to ”off“.

Output Values

6.9.7 Status Switch 1

This digital output refers to the component to be controlled within the system. Select the relevant component from the list. For the switching valve the ”On“ status means that the output located on the switching valve and marked with “X“ is ”open”.

6.9.8 Status Switch 2 (Optional)

This digital output works just like output Status Switch 1. Select if required the component to be controlled from the list.

Overview of Control-Dependencies

Table 26. Control-dependencies of the irradiance controller

Outputs	Parameter	Tip	Inputs	Function
---------	-----------	-----	--------	----------

Y1: Status Switch 1 Y1 = Y2 Y2: Status Switch 2	Fixed value	If hysteresis is applied cut-in and cut-off criteria vary	X1: Irradiance sensor	Y1=0 if $X1 < \text{Fixed value [W/m}^2\text{]}$ Y1=1 if $X1 > \text{Fixed value [W/m}^2\text{]}$
				Y1=1 if $X1 > \text{Fixed value} + \text{Cut-in hysteresis[K]}$ Y1=0 if $X1 < \text{Fixed value} + \text{Cut-off hysteresis [K]}$
Y1: Status Switch 1 Y1 = Y2 Y2: Status Switch 2	Variable value	If hysteresis is applied cut-in and cut-off criteria vary	X1: Irradiance sensor X2: Variable irradiance	Y1=0 if $X1 < X2 \text{ [W/m}^2\text{]}$ Y1=1 if $X1 > X2 \text{ [W/m}^2\text{]}$
				Y1=1 if $X1 > X2 + \text{Cut-in hysteresis [K]}$ Y1=0 if $X1 < X2 + \text{Cut-off hysteresis[K]}$

6.10 Programmable Controller

The programmable controller enables operating states to be freely defined according to controller inputs as well as controller initial values to be set for each operating state. This makes the controller suitable for the most diverse applications. The control logic is defined by means of formulas that are comparable to the calculation formulas used in spreadsheets such as, e.g. Excel.

For programmable controllers, the control logic is to be defined by the user, i.e., for standard applications such as, for example, a simple solar loop, the predefined controller "Solar Loop Pump Controller" will prove easier and faster to use; for special or more complex applications, the programmable controller provides the user with a much wider range of options to control the system component as desired.

6.10.1 Procedure

1. Create a **programmable controller** on the design area.
2. Define which **actuators** (elements) should be controlled.
Limit yourself to the fewest possible elements having also a logical relationship to one another such as, for example, all the elements of a given loop. Using multiple controllers is easier than to use fewer but more complex ones. Establish a connection between controller outputs and the elements to be controlled.
3. Define which **sensors** are needed for the controller. Establish a connection between controller inputs and the measuring points of the different elements.
4. Consider which **operating states** may come into play for the combination of elements. Only a single state can be active during operation. Create an appropriate state for each operating state. For a solar loop, the operating states could be, for example, as follows: "Downtime" (too little radiation or full tank), "Charge tank", "Cool down tank" (at night, if the tank gets too hot).
5. Use a formula to define the **conditions** required for a state to be activated.
6. Define for each state, which **initial values** should be assigned to the elements to be controlled.

6.10.2 Operators

Below we provide a description of the operators that can be used in the formulas.

Logical operations:

Table 27. Logical operations of the programmable controller

<	Returns the value 1 if the value to the left of the operator is smaller than the value to the right of the operator. Otherwise, the returned value is 0.
<=	Returns the value 1 if the value to the left of the operator is smaller than or equal to the value to the right of the operator. Otherwise, the returned value is 0.
>	Returns the value 1 if the value to the left of the operator is larger than the value to the right of the operator. Otherwise, the returned value is 0.
>=	Returns the value 1 if the value to the left of the operator is larger than or equal to the value to the right of the operator. Otherwise, the returned value is 0.
=	Returns the value 1 if the value to the left of the operator is equal to the value to the right of the operator. Otherwise, the returned value is 0.
<>	Returns the value 1 if the value to the left of the operator is not equal to the value to the right of the operator. Otherwise, the returned value is 0.
AND	Returns the value 1 if the value to the left and right of the operator is 1. Otherwise, the returned value is 0.
OR	Returns the value 1 if the value to the left or right of the operator is 1. Otherwise, the returned value is 0.
NOT	Returns the value 1 if the value to the right of the operator is 0. Otherwise, the returned value is 0.

Mathematical operations:

+	Returns a value which is the sum of the values to the left and right of the operator.
-	Returns a value which is the difference between the values to the left and right of the operator.
/	Returns a value which is the quotient of the values to the left and right of the operator.
*	Returns a value which is the product of the values to the left and right of the operator.
%	Returns a value which is the integer quotient of the values to the left and right of the operator.
^	Returns a value which is the power of the values to the left and right of the operator.

Expressions can be grouped and evaluated before others using brackets "(...)". The formulas are evaluated in the following order:

^	NOT
=	AND
+, -	OR
<, >, <=, >=, <>	
*, /, %	

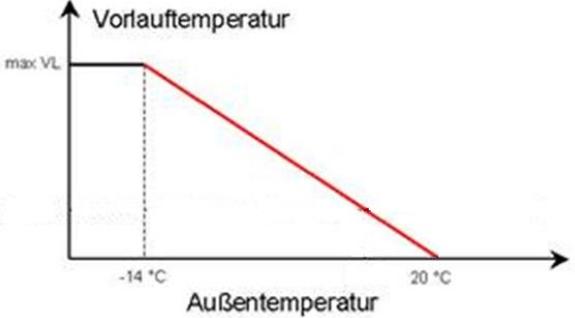
6.10.3 Functions

Below we provide a description of the predefined functions that can be used in the formulas.

Table 28. Functions, which can be used in formulas

SQR	Square For example, SQR(4) returns the value 16.
SIN	Sine in radians For example, SIN(1.571) returns the value 1.
COS	Cosine , see also SIN
TAN	Tangent , see also SIN
SINH	Hyperbolic sine , see also SIN
COSH	Hyperbolic cosine , see also SIN
ATAN	Arctangent , see also SIN
COTAN	Cotangent , see also SIN
EXP	Exponential function For example, EXP(1) returns the value 2.718.
LN	Natural logarithm For example, LN(4) returns the value 1.386.
LOG	Decadic logarithm For example, LOG(10) returns the value 1.
SQRT	Square root For example, SQRT(4) returns the value 2.
ABS	Absolute value For example, ABS(-4) returns the value 4.
SIGN	Sign , returns -1 for negative, 1 for positive and 0 for 0 For example, SIGN (-4) returns the value -1.
TRUNC	Integer part For example, TRUNC(-3.7) returns the value -3.
CEIL	Round up to the next higher integer For example, CEIL(-3.7) returns the value -3.
FLOOR	Round down to the next lower integer For example, FLOOR(-3.7) returns the value -4.
RND	Integer random number The upper limit of the random number should be specified as an argument.
RANDOM	Random number with decimal places The lower limit of the random number should be specified as an argument.
MIN	Minimum value For example, MIN(2, 3) returns the value 2.
MAX	Maximum value For example, MAX(2, 3) returns the value 3.
IF	If (condition, return value for condition complied with, return value for condition non complied with). If the condition is complied with, the first return value will be returned as a result, otherwise the second. Operations too may be used as a return value; depending on the condition, only the appropriate return value will be evaluated. Several IF functions may be nested in one another. For example, IF(1>2, 3, 4) returns the value 4.
SUM	Sum of any number of arguments. For example, SUM(1, 2, 3) returns the value 6.
MATCHFLOW ($T_i, Q, T_a, C_p, \dot{V}_{min}, \dot{V}_{max}$)	Regulation of a flow-rate in l/to the desired temperature MATCHFLOW(T_i Inlet temperature in °C, for example to the collector,

	<p>Q Power in W, for example power of the collector, T_a Outlet temperature in °C, for example the desired target temperature, C_p Heat capacity in J/(l*K), for example, the heat capacity of the fluid, \dot{V}_{min} \dot{V}min. flow-rate in l/h, for example the lower limit of the pump, \dot{V}_{max} max. flow-rate in l/h, for example the upper limit of the pump)</p> $\dot{V} = \frac{\dot{Q}}{C_p * (T_a - T_l)} * 3600$
<p>MATCHPOWER $(T_i, \dot{V}, T_a, C_p, \dot{Q}_{min}, \dot{Q}_{max})$</p>	<p>Regulation of a flow-rate in W to the desired temperature MATCHPOWER(T_i Inlet temperature in °C, for example to the boiler \dot{V} Flow-rate in l/h, for example, flow-rate of the boiler pump, T_a Outlet temperature in °C, for example the desired target temperature, C_p Heat capacity in J/(l*K), for example, the heat capacity of the fluid, \dot{Q}_{min} min. power in W, for example the lower limit of the boiler pump, \dot{Q}_{max} max. power in W, for example, the upper limit of the boiler pump)</p> $\dot{Q} = (T_a - T_i) * C_p * \dot{V} / 3600$ <p>If $\dot{Q}_{min} / \dot{Q}_{max} = 0$ the values will not be taken into account; otherwise, the result \dot{Q} will be restricted to these minimum/maximum values before being returned.</p>
<p>MATCHRATE (T_u, T_l, T_o)</p>	<p>Regulation of a mixing ratio to the desired temperature MATCHRATE(T_u Upper level temperature in °C, for example hot water inlet to mixing valve, T_l Lower level temperature in °C, for example cold water inlet to mixing valve, T_o Outlet temperature in °C, for example the desired target temperature)</p> $p = \frac{T_u - T_o}{T_u - T_l}$
<p>MEANVALUE (a, b)</p>	<p>Arithmetic mean value of two values MEANVALUE (a value 1, for example a temperature value from the latest time step Value 2, for example a temperature value from the current time step)</p> $m = \frac{a + b}{2}$
<p>HEATINGCURVE$(T_{soll}, T_{a_norm}, a, T_a)$</p>	<p>Regulation of temperature based on the heating curve (function HEATINGCURVE)</p>

	 <p>The function adopts 4 parameters: T_{soll}: nominal inlet temperature heating elements (= max VL in the chart) [°C] T_{a_norm}: design outdoor temperature (for the T_{soll} gilt (= -14°C in the chart)[°C] a: heating curve gradient T_a: current outdoor temperature [°C] The point (= 20°C in the chart) where the curve meets the x-axis is determined from the remaining parameters.</p>
<p>PVPROG ($t, P_{pv}, P_{ld}, p_{gfl}, P_{gsl}, t_{fpast}, t_{fhor}, \Delta t_{freq}, \Delta t_f$)</p>	<p>Forecast-based battery control with measurement-based PV- and consumption forecasts.</p> <p>PVPROG(t current simulation time in s, P_{pv} PV production AC (before curtailment) in W, P_{ld} electricity consumption in W, p_{gfl} Feed-in limit normalised to the installed nominal PV capacity (0 to deactivate dynamic feed-in limitation through the battery), P_{gsl} grid supply limit for the electricity consumption in W (0 to deactivate grid supply limitation), t_{fpast} time frame in h in which the weather situation is incorporated into the PV forecasts, t_{fhor} forecast horizon of the PV and load forecasts in h, Δt_{freq} frequency of the forecast updates in min [1 (recommended) or 15 (for a faster simulation but with a slightly reduced control accuracy and therefore with decreased system performance) – The recommended value is used without warning for unexpected inputs, Δt_f temporal resolution of the PV- and load forecasts [1 or 15 (recommended)] - The recommended value is used without warning for unexpected inputs)</p>

6.10.4 Variables

In the formulas, different variables are available to access controller inputs or outputs or other statuses of the simulation.

Table 29. Variables available to access controller inputs and outputs

I1 I2 ... I16	Current value of a controller input Value of the controller input in the current time step of the simulation. Only variables that are linked to sensors are allowed for use.
PI1 PI2 ... PI16	Latest value of a controller input Value of the controller input from the latest time step of the simulation. Only variables that are linked to sensors are allowed for use.
O1 O2 ... O16	Current value of a controller output Value of the controller output in the current time step of the simulation. Only variables that are linked to actuators are allowed for use.
PO1 PO2 ... PO16	Latest value of a controller output Value of the controller output from the latest time step of the simulation. Only variables that are linked to actuators are allowed for use.
H1 H2 ... H8	Current value of an auxiliary variable (constant, formula or time delay) Value of the auxiliary variable in the current time step of the simulation. Only previously defined variables are allowed for use.
PH1 PH2 ... PH8	Latest value of an auxiliary variable (constant, formula or time delay) Value of the auxiliary variable from the latest time step of the simulation. Only previously defined variables are allowed for use.
S	Number of the active status (operating status) in the current time step of the simulation. The variable may include values ranging from 1 to the number of defined states (max. 16).
PS	Number of the active status (operating status) from the latest time step of the simulation. The variable may include values ranging from 1 to the number of defined statuses (max. 16).
TS	Current time step in seconds since the start of the simulation (January 1 st 00:00)
PTS	Last time step in seconds since the start of the simulation (January 1 st 00:00)
TC	Signal of the time switch from this controller. Returns the value 1 if the time switch is on, 0 if the time switch is off.
PI	Constant π

All numbers included in the formulas should use the “point“ as a decimal separator (regardless of the “Language and Region” setting in Polysun). The symbol “E“ may be used as an exponent, for example 1234.6 or 1.2346E3

Controller inputs may be used for the following variables. For the variables from I1 to I16 or from PI1 to PI16, the value is returned in the following basic unit (regardless of the “Units” setting in Polysun):

Table 30. Basic units of measure for the variables from I1 to I16 or from PI1 to PI16

Temperature	°C
Area	m ²
Power	W
Specific power	W/m ²
Thermal conductivity	W/K
Heat capacity	J/(l*K)
Flow-rate	l/h

Controller outputs may be used for the following variables. For the variables from O1 to O16 or from PO1 to PO16, the value is returned in the following basic unit (regardless of the “Units” setting in Polysun):

Table 31. Basic units of measure for the variables from O1 to O16 or from PO1 to PO16

Status	Without unit, on/off signal, value 0 or 1
Percentage	Without unit, analogue control signal, value from 0 to 1
Leistung	W
Flow-rate	l/h

6.10.5 Status

A “status” is a possible operating status of the group of elements to be controlled. For a heat pump equipped with a switching valve for tank charging, the operating statuses could be the following: “Charge tank for space heating”, “Charge tank for domestic hot water”. For each status, the user can use a formula to define when this is active. Only one status can be active at a time.

6.10.6 Auxiliary Variables

Auxiliary variables can be used in three different ways.

Constant

The auxiliary variable may be used as a constant with a unit. The entered value is converted to the basic unit and may be used in the formulas for states or outputs through the variables from H1 to H16 or from PH1 to PH16. So, for example, a cut-in temperature may be comfortably entered in the unit system (°C or F) that can be set in the Polysun settings without the need for the value to be searched for and adapted in the formulas.

Formula

Entering a formula, the user can calculate an intermediate result that may be used in the formulas for states or outputs through the variables from H1 to H16 or from PH1 to PH16. So, for example, you may calculate an intermediate result that can be re-used in several formulas.

Time-Delay

With a time-delay, signals may be delayed or extended. There are four different types of delay that are listed below. With a formula, the user can define when the delay should

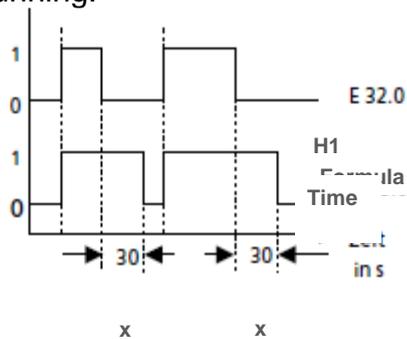
start (result of the formula = 1). With the variables from H1 to H16 or from PH1 to PH16, the user can check in the formulas for states or outputs whether the time function has run out (1 = running, 0 = run out).

So, for example, a pump can be switched on with a delay after the switch-on condition is fulfilled in order to avoid it being turned on and off too frequently.

As the length of time steps is variable, the entered time delays may be not exactly complied with. Time functions may only start or run out when a time step is running.

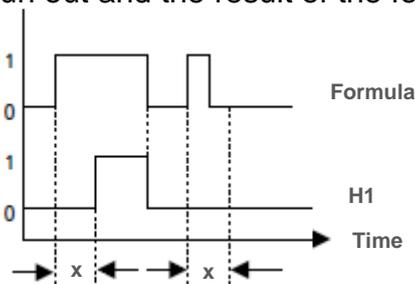
- SA Start of a time as a cut-off delay.

If the result of the formula changes to "0", the entered time runs out. If the result of the formula changes again to "1", the time is restored to the initial value. A query returns the state "1" as long as the result of the formula = "1" or the time is running.

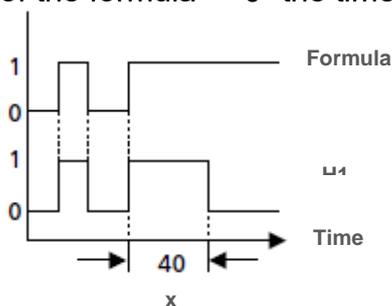


- SE Start of a time as a cut-in delay.

The time starts when the edge of the result of the formula is rising. If the result of the formula = "0" the time is set to "0". Queries return "1" only when the time has run out and the result of the formula is still pending.

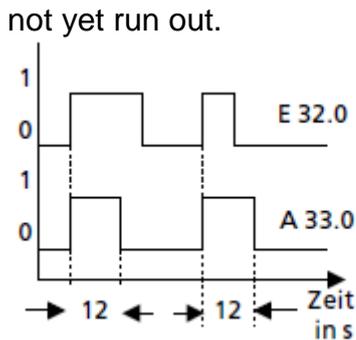


- SI Start of a time as an impulse. The time starts when the edge of the result of the formula is rising. Queries return "1" as long as the time is running. If the result of the formula = "0" the time is likewise set to "0" and the query returns "0".



- SV Start of a time as an extended impulse.

The time starts when the edge of the result of the formula is rising. A result of the formula = "0" does not affect the time. Queries return "1" as long as the time has



6.10.7 Processing Sequence

In the Polysun simulation, a year is calculated from January 1st,00:00 to December 31st, 24:00, possibly with an advance that can be selected for the system diagram. The time steps for the simulation have a variable length ranging from one second to max. 4 minutes (during the day) or 12 minutes (at night). For each time step, controllers are processed first, then all elements.

In each time step of the simulation, variables or formulas for the controller are processed in the following order:

1. Evaluation of time step and time-switch and allocation to variables TS and TC.
2. Reading of controller inputs and allocation to variables from I1 to I16 or from P11 to P116.
3. Processing of auxiliary variables, starting with the first auxiliary variables and allocation to variables from H1 to H16 or from PH1 to PH16.
4. Evaluation of the conditions of the state, starting with the first state. The evaluation is interrupted at the first active state. The number of this state is then allocated to the S variables or the previous number is allocated to the PS variable.
5. Processing of the controller outputs of the active state, starting with the first controller output. Allocation to the variables from O1 to O16 or from PO1 to PO16.

This processing sequence reveals that only variables of the current values which were already processed in the sequence may be read. So, for example, in the formulas for auxiliary variable 3, variables H1 and H2 can be read, not variable H3, H4, etc.; likewise in the formulas for the state, only PS variables can be read, but not S variables and, for example, in the formula for controller output 2 the variable O1 can be read, but not variables O2, O3 and so on.

6.10.8 Comments

Within formulas you will be able to insert comments at any point by positioning them between two hash symbols („#“),

e.g.: $I1 > I2 + 6$ #Start-up hysteresis# AND $I2 < 70$ #Maximum tank temperature#

6.10.9 PVPROG Function

The increasing share of power produced through PV in the grid leads to higher gradients, and especially around noon, to higher peaks of the grid feed-in. This in turn results in a

higher strain on the distribution grids. Batteries can make a positive contribution to this problem. The common practice of systems that are laid out for high degrees of self-consumption, in which all surpluses are stored immediately, however, hardly reduces any feed-in peaks. For this reason, PV battery systems are increasingly only subsidised if the feed-in power is limited to a certain percentage of the installed nominal PV capacity. Using PV- and load forecasts, the period in which the battery is charged can be shifted towards noon so that the grid feed-in is limited through the battery system. With this method, curtailment losses can be significantly reduced.

In Fig. 163 (left), the battery is charged as soon as the PV power exceeds the load. When the battery is full, the feed-in power increases abruptly. All PV surpluses that exceed the feed-in limit are curtailed. By including locally generated, measurement based PV- and load forecasts the PVprog algorithm determines a dynamic feed-in limit above which the battery is charged (Fig. 163, right). By temporally shifting the battery charge to noon, a reduction of the curtailment losses as well as a high degree of self-consumption can be achieved. The algorithm is freely available and can moreover be used commercially, too.

Source: <https://pvspeicher.htw-berlin.de/pvprog>

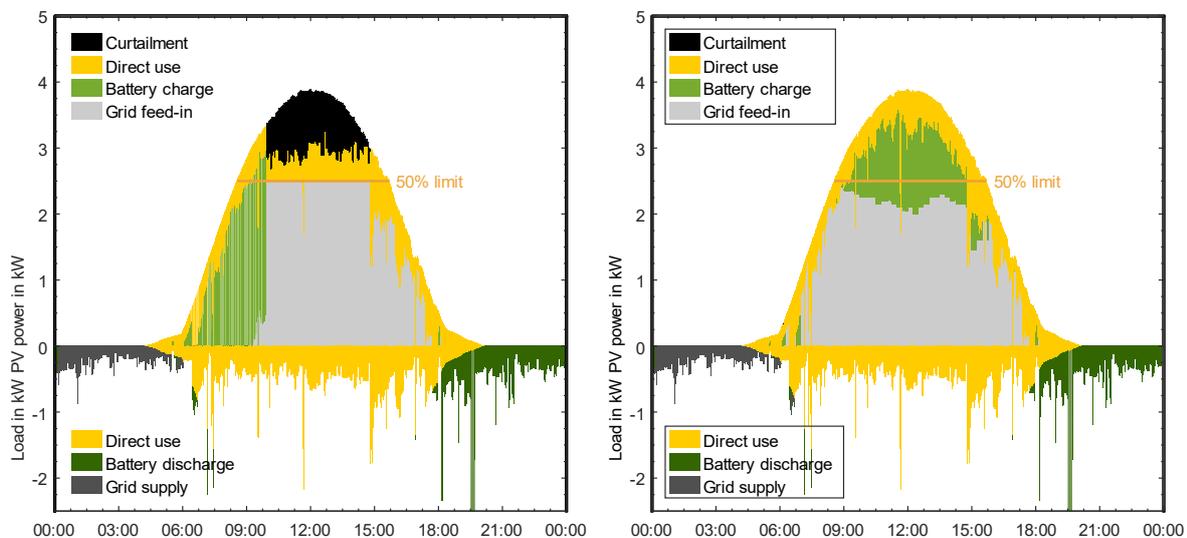


Fig. 156: Power flows in a household with early battery charging (left) and with forecast-based battery charging (right) with a feed-in limit of 50 % of the nominal PV capacity.

Functionality

To achieve PV production and consumption forecasts with sufficient accuracy and without having to rely on an external communication infrastructure, the PVprog algorithm implements a so-called adaptive day persistence forecast. For the PV forecasts, the historical generation and an estimation of the theoretical historical power with a clear sky are used. The quotient of the respective energies within the selected persistence time frame is computed and used as a scaling factor for the theoretical clear-sky power within the forecast horizon. At every optimisation interval (normally every 15 min), the PV forecast is updated (see Fig. 164).

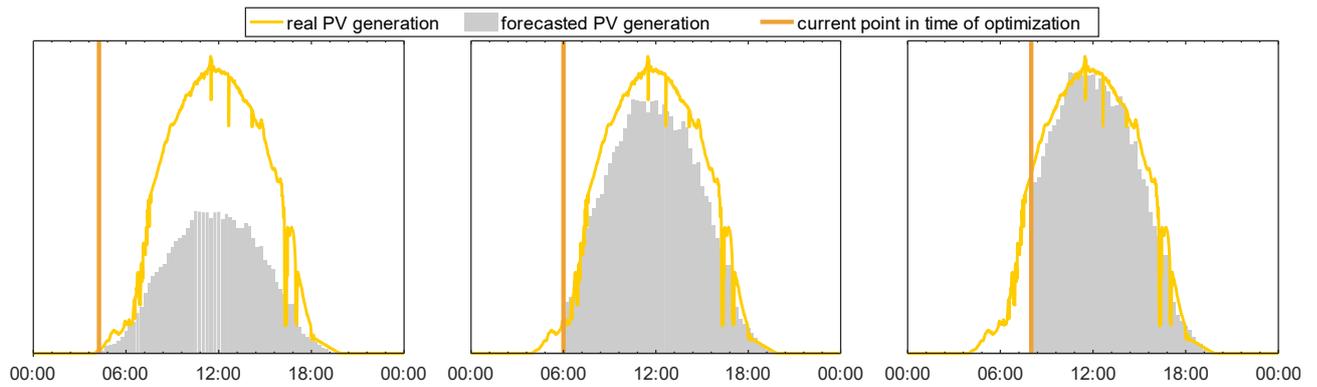


Fig. 157: Dynamic adjustments of the PV persistence forecasts in the course of the day.

A day persistence is also created for the load forecasts and variably weighted with the mean of the last 15 min over the forecast horizon. Thus, the short-term forecast is adjusted dynamically according to temporary load peaks, while the forecast over the whole forecast horizon contains has approximately the same energy amount as the load of the previous day. The dynamic adjustment of the load is depicted in Fig. 165 for a selected time frame.

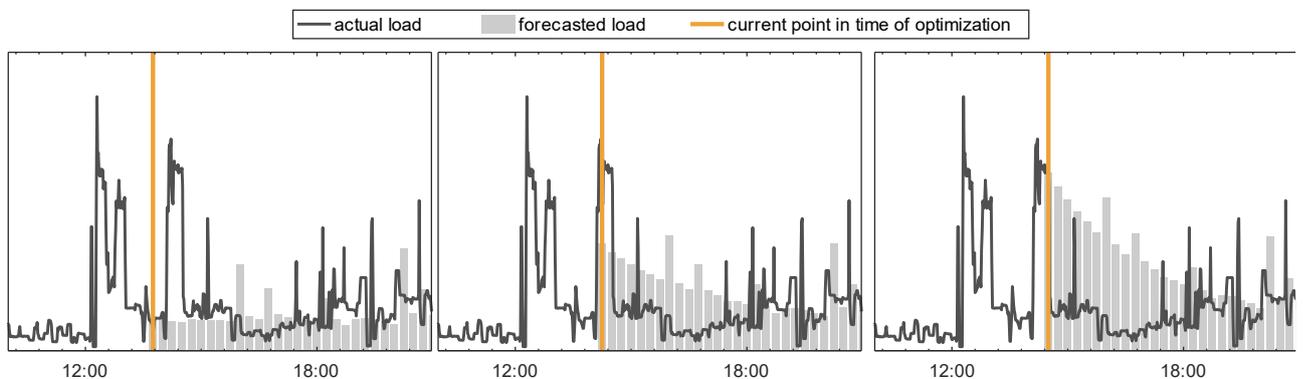


Fig. 158: Dynamic adjustment of the load forecasts in the course of the day.

The battery charge optimisation is performed in an iterative manner. A virtual feed-in limit is set depending on the battery's state of charge and is gradually reduced until the energy above the limit is enough to charge the battery as much as possible. This limit is adjusted for the updated forecast at every point in time of optimisation (see Fig. 166). Using the same method, the PVprog algorithm can control discharging of the battery to cut off as many load peaks as possible.

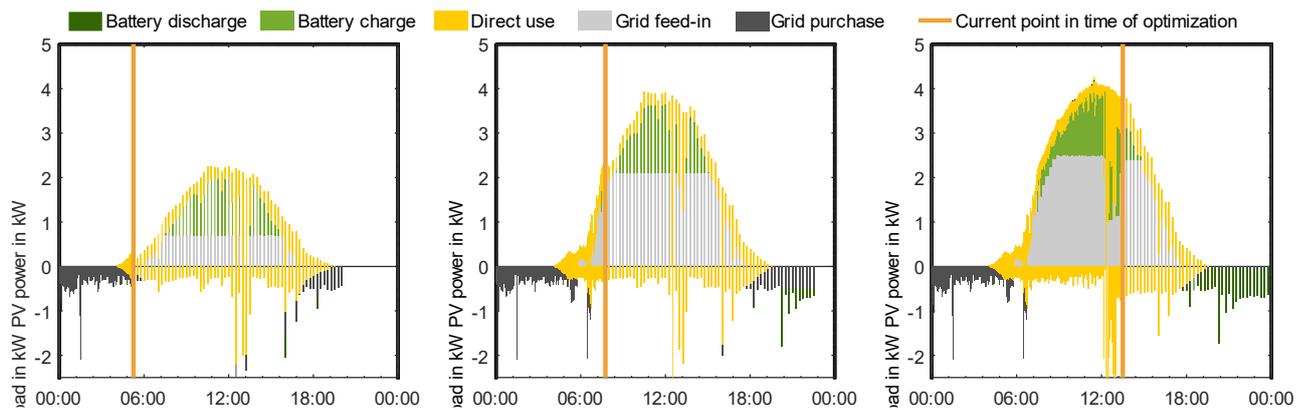


Fig. 159: Dynamic adjustment of the battery charge and discharge roadmap in the course of the day.

To achieve the set feed-in limit, the set battery power is continuously adjusted by the difference between the forecasts and the actual measurements. By continually adjusting the battery charge and discharge plan, updated PV and load forecasts can be incorporated and differences of the state of charge between the corrected roadmap and the original roadmap can be balanced.

Usage in Polysun

To perform forecast based battery control in Polysun, the PV power (AC before curtailment) and the load must be passed to the sensors of the programmable controller. The feed-in limit can be passed via a sensor or per manual input. A manual input of 0 disables the feed-in and load limitation, respectively. So that no problems arise when generating the forecasts, the variable "TS" (current time step in seconds since the beginning of the simulation) should be passed as a parameter. More than one call of the function in the same simulation time step have no influence on the result; the result of the first call is always returned. For this reason, it is not possible to call two instances of the function in the same time step with different input arguments – except for the frequency of forecast updates and the temporal resolution of the forecasts. Each of these arguments has two possibilities: 1 min and 15 min. A forecast update frequency of 1 min is recommended. The simulation work load can be reduced by setting it to 15 min (resulting in faster simulations). However, this results in a less accurate control and leads to a slightly decreased system performance. Therefore, setting the forecast update frequency to 15 min should only be done for rough system dimensioning in which multiple variants need to be simulated. The fine tuning and final evaluation should always be done with the forecast frequency set to 1 min.

On the contrary, a value of 15 min is recommended for the forecast resolution, to reach a high degree of self-sufficiency. Should for some reason the feed-in or load limitation not be achieved as desired (to be expected only in the rarest cases), the forecast resolution can be set to 1 min. It must be kept in mind that the forecast resolution cannot be set to a lower time value than the update frequency. If an unexpected value is input for one of the two arguments, the respective recommended value is used (for technical reasons, no warning is issued).

For the persistence time frame that is looked back into for the PV forecast generation, 3 hours are recommended to achieve stable results. A low time frame leads to a faster adjustment of the virtual feed-in limits. It can, however, also lead to too intense

fluctuations of the battery's set charging power. With a larger frame, the fluctuations of the feed-in and load limitations are decreased. But a too large time frame leads to sluggishness of the control algorithm. From experience, a forecast horizon of 15 h can be recommended for the PV feed-in limitation and 24 h is a good value for load limitation. Persistence time frames and forecast horizons outside of the interval [0 h, 24 h] are corrected to the upper or lower boundaries without further warning, respectively.

Two instances of the PVPROG function can be called to limit the grid feed-in and load supply simultaneously (see standard template 50q). This is possible because charging and discharging of the battery never occur at the same time. This can, however, lead to a decrease in system performance compared to a system with only one of the two limitations, because forecast errors can have a negative influence on the available battery capacity. In individual use cases, a combination may be desirable. To achieve optimal results, the use of weather and load data with a temporal resolution of 1 min (maximum: 15 min) should be used. So that the PV forecasts are completely initialised at the beginning of the simulation, a pre-simulation of 10 days should be performed.

6.11 Plugin Controller

The plugin controller is a controller that can be extended through plugins. Controller plugins can be programmed by the users themselves using the Java programming language. This enables users to program complex controllers. Redirections or forwarding to other programming environments such as Matlab are possible, for example to use existing controllers for Polysun. The interface to the plugin controllers is the Java interface IPluginController.

6.11.1 Introduction

Plugin controllers enable the user to create controllers for Polysun. This way, complex and powerful controllers can be developed. These controllers can either be developed from scratch or external controller plugins can be added to a Polysun installation.

A Polysun installation comes with several plugin controllers, see the following chapters.

In practice, plugin controllers behave similar to "traditional controllers". The difference is that anyone able to program in Java, is able to develop and pass on a plugin controller.

6.11.2 Difference to the Programmable Controller and Advantages of the Plugin Controller

Plugin controllers are used for the programming of controllers just like the "Programmable controller". However, the programming of plugin controllers is done through the programming languages Java, Python or Matlab. Thus, complex controllers can be programmed. Program loops or libraries can be used. The full scale of these programming languages is at your disposal.

Additionally, you have the possibility to program redirections or forwarding to existing controllers, for example like how it was done for Matlab or Python.

6.11.3 Uses of Plugin Controllers

Plugin controllers are added to your system diagram just like “traditional” controllers through the controller selection. In the plugin controller selection, all existing plugin controllers are on display.

Projects containing a plugin controller need the plugin containing the controller in order to run or to be edited. Plugins are stored as .jar-files and can be added to the plugins folder in the data path of Polysun. As a default for Windows this would be C:\Users\Public\Polysun\plugins, as a default for MacOS, it would be /Programs/Polysun/plugins. Plugins added are available after Polysun is started anew.

You can test it using the demo plugin controller contained in the plugin DemoPlugin.jar. This is found in the Polysun folder and can be copied from the folder plugins/examples to the folder plugins. This controller is available once Polysun is started anew.

If a plugin controller is missing, an error message is shown. Editing or running a simulation is not possible if the plugin is missing. You have to add the missing plugin controller.

Polysun has a number of plugin controllers included.

Project examples can be found in the folder plugins/examples.

Currently, plugin controllers are not automatically added to projects the way profiles are. Users have to pass on plugins manually.

6.11.4 Flow Rate Plugin Controller

The flow rate plugin controller behaves like the existing flow rate controller. It is a mere copy. This controller is offered as part of the source code and as open source software, check the folder plugins/PolysunPluginDevelopmentKit.zip.

6.11.5 „Fixed Time Step“ Plugin Controller

This controller prescribes the simulation a regular, fixed time step.

For every point in time that is a multiple of the fixed time step, the simulation will execute a time step. Polysun can execute more time steps if necessary for the simulation. For example, for the fixed time step of 180s, the simulation will execute the time steps 0s, 180s, 360s, 540s, 720s, 0 means no fixed time steps, the default time steps of Polysun (240s during the day and 720s at night) are used. In other words, 0 stands for “normal time steps”.

6.11.6 Matlab Plugin Controller

The Matlab controller is a plugin controller passing on the commands from Polysun to a Matlab function. The plugin will set the name of the function in Matlab. This function has to be in the path of Matlab or in the start folder. The Matlab function must have the following function arguments:

```
function [ controlSignals, logValues, timepoints ] = control( simulationTime, status, sensors, sensorsUsed, properties, propertiesStr, preRun, controlSignalsUsed, numLogValues, stage, fixedTimestep, verboseLevel, parameters)
```

The Matlab function given in the Matlab controller is retrieved in every time step from Polysun and has to calculate the controller outputs for Polysun based on the input parameters in every time step.

The configuration and examples of the Matlab controller are stored in the Polysun folder `plugins/com.velasolaris.plugin.controller.matlab.matconsolectl.MatlabPluginController` after the first command, for example

```
C:\Users\Public\Polysun\plugins\com.velasolaris.plugin.controller.matlab.matconsolectl.MatlabPluginController.
```

The file `config.properties` contains the basic configuration of the MatLab controller. If MatLab is not found, the path to the MatLab program file in `matctl.matlabLocation` must be set, for example

```
matctl.matlabLocation=C:\\Program Files\\MATLAB\\R2017a\\bin\\matlab.exe
```

The correct usage of “\” is technically necessary, i. e. double and a single one in front of “.”. The start directory can also be set the first time Matlab is started using the parameter `matctl.matlabStartingDirectory`. The names of most other parameters make them self-explanatory or generally do not have to be altered.

The function arguments of the control function are documented in `control.m`. The Matlab function `controlFlowrate.m` implements a flow rate controller. It behaves the same way as the “traditional” Polysun flow rate controller.

This controller is offered in source code and is open source software, check the folder `plugins/PolysunPluginDevelopmentKit.zip`.

If Matlab was not started already, it will be started. Breakpoints in Matlab are supported.

The Matlab controller uses the library `MatConsoleCtl` for its internal communication.

In the chapter “Speed comparison”, Matlab will be compared to the other command giving types.

6.11.7 RPC Plugin Controller (Python)

The RPC controller is a plugin controller that passes commands from Polysun through a Remote Procedure Call (RPC) on to a RPC server. In the controller, the name of the function and the URL of the server are set, for example “`controlFlowrate`” and `http://localhost:2102/control`. The function in the RPC server must contain the following function arguments:

control(simulationTime, status, sensors, sensorsUsed, properties, propertiesStr, preRun, controlSignalsUsed, numLogValues, stage, fixedTimestep, verboseLevel, parameters)

=> controlSignals, logValues, timepoints

The RPC function entered into the controller is retrieved in every time step from Polysun and has to calculate the output commands for Polysun based on the input parameters in every time step.

Three types of RPC are supported: JSON-RPC stream (optimized for speed), JSON-RPC and XML-RPC. Both JSON-RPC and XML-RPC are supported by many systems, for example by the programming language Python.

In Python (<https://python.org>), JSON-RPC is supported through additional modules and XML-RPC by default. In the RPC controller folder (plugins/com.velasolaris.plugin.controller.rpc.SimpleRpcPluginController) you will find both a XML and a JSON-RPC server and an optimized JSON-RPC stream server for Python. The controller functions are found in controlFunctions.py.

How to start the function server:

```
python controlJsonRpcStreamServer.py
```

```
python controlJsonRpcServer.py
```

```
python controlXmlRpcServer.py
```

```
python controlRpcServer.py
```

You can also use pypy (<http://pypy.org>), which uses a just-in-time (JIT) compiler making it faster:

```
pypy controlJsonRpcStreamServer.py
```

```
pypy controlJsonRpcServer.py
```

```
pypy controlXmlRpcServer.py
```

```
pypy controlRpcServer.py
```

Polysun offers the possibility to automatically start a RPC function server. For a successful start of a RPC server, the parameters have to be set right. Should the automatic start of the RPC server fail, please refer to the Polysun log file in the Polysun folder, for example C:\Users\Public\Polysun\data.log. Analyzing existing problems is only possible with a minimum degree of technical knowledge.

The different command giving types are compared with one another in the chapter “Speed comparison”.

Additional information is documented in the script files.

This controller is offered as a source code and is open source software, check the folder plugins/PolysunPluginDevelopmentKit.zip.

6.11.8 Programming of Plugin Controllers

You can program plugin controllers yourself using the programming language Java. Preconditions to programming are knowledge of the Java programming language and a Java programming environment.

As an introduction, the interface `IPluginController` defines a controller and `ControllerPlugin` a plugin.

Plugin controllers have to meet (implement) the Java interface `IPluginController`. The most important method is `control()`. This method is called on in every time step and calculates the controller output signals from the sensor signals. The signature is

```
control(int simulationTime, boolean status, float[] sensors, float[] controlSignals, float[] logValues, boolean preRun, Map<String, Object> parameters).
```

The values for the set controller inputs are provided in the sensors array in every time step. Based on these values, the plugin controller calculates the controlling commands (`controlSignals` array) for the controller inputs.

The files necessary for the development of plugin controllers are available as a zipped archive in the folder `plugins/PolysunPluginDevelopmentKit.zip`. Further information can be found in the `README.txt` files.

A plugin controller is defined by the interface `ControllerPlugin`. A plugin has to have a class that is implemented by this interface. In order for the plugin to be found, it has to be “registered”. In order for this to happen, the full name of the class of the plugin programmed (including packages) has to be set in the file

`META-INF\`

`services\com.velasolaris.plugin.controller.spi.ControllerPlugin`. For the plugin demo, this content is contained in this file

`com.velasolaris.plugin.controller.DemoControllerPlugin`. The compiled Java classes (`.class`) with the `META-INF` folder can then be packed into a Java archive (`.jar`-file) and subsequently added to the class path of Polysun. It is best if the plugins are added to the folder `plugins` of the directory. A plugin jar file is best created with an Ant script, please refer to `build.xml` of the demo plugin.

Normally plugin-jar-files will not be reloaded executing Polysun, but this can be helpful during the development. Setting the command

```
Plugin.ReloadAlways=1
```

in the file `user.ini` (eg. in `C:\Users\Public\Polysun`) which contains the Polysun user settings, the plugins will be reloaded executing the plugin controller dialogue.

In order to program a new plugin controller it is best to make a copy of the demo plugin and to adapt the relevant files. We recommend to check new controllers with a JUnit test. The `DemoFlowratePluginControllerTest` is an example of a JUnit test.

6.11.9 Speed Comparison

Plugin commands are possible through numerous ways. Programming languages like Matlab, Python or Java can be especially suitable for some determined tasks.

The simulation time is dependent on the type of commands. In order to compare the speeds, the different types of command giving were compared. The template “16c: Space heating (heat pump, no buffer tank)” was used, always with the same flow rate control logics (see Polysun project “FlowratePluginControllerComparison.pse”).

Table 32. Simulation time and average execution time for different plugin controller types

System used for testing: Intel Core i7-6820HQ 2.7GHz, Windows 10 1607, Java 8, Matlab 2016a, pypy 5.4.1, Polysun 9.2 dev (r24000), plugins/examples/FlowratePluginControllerComparison.pse

Plugin controller type	Simulation time	Average execution time
FlowrateController	4 s	0 ms
Java FlowratePluginController	4 s	0 ms
MatlabPluginController	86 s	0.5 ms
JSON-RPC stream (Python)	14 s	0.06 ms
JSON-RPC (Python)	Abort (68s)	0.4 ms
XML-RPC (Python)	228 s	1.5 ms

Comparison of commands by different Remote Procedure Call (RPC) protocols with the different Python interpreters.

Table 33. Average execution time for different Python interpreters and RPC protocols

System used for testing: Intel Core i7-4500U CPU 1.80GHz, openSuse 13.2 Linux, Java 8, Polysun 9.2 dev (r24000), plugins/examples/FlowratePluginControllerComparison.pse

Python / RPC protocol	JSON-RPC stream	JSON-RPC	XML-RPC
RPC type	Own development	Standard	Standard
Communication protocol	TCP Socket	HTTP	HTTP
One TCP connection per	Simulation	Time step	Time step
PyPy 5.4.1	0.06 ms	0.5 ms	0.6 ms
Python 2.7	0.09 ms	0.7 ms	1.3 ms
Python 3.4	0.08 ms	0.9 ms	1.4 ms

Using JSON-RPC locally on fast systems under Windows leads to the error message "java.net.BindException: Address already in use: connect" (PSA-4571). Use the “JSON-RPC stream” protocol instead.

6.11.10 Possible Further Developments

Controller plugins currently have to be passed on in parallel with the projects. In the future, it could be possible to store plugins in the Polysun project files .pse, as it is already the case with profiles.

7 Simulation Results and Analysis

7.1 Abbreviations in Polysun Simulation Results

7.1.1 Solar Fractions

When viewing “Results for the system diagram” the different solar fractions SF_i (input oriented), SF_n (net) and SF_g (gross) are displayed. These refer to diverse limits of the system, see fig. 5. Only those solar fractions for the system diagrams that can be automatically calculated are displayed.

$$SF_i = \frac{\text{Solar energy to storage tank}}{\text{Solar energy to storage tank} + \text{Auxiliary energy to storage tank}} = \frac{S_{sol}}{S_{sol} + S_{aux}}$$

$$SF_n = \frac{\text{Solar energy to the system}}{\text{Solar energy to the system} + \text{Auxiliary energy to the system}} = \frac{Q_{sol}}{Q_{sol} + Q_{aux}}$$

$$SF_g = \frac{\text{Irradiation onto collector area}}{\text{Irradiation onto collector area} + \text{Auxiliary energy}} = \frac{E_{sol}}{E_{sol} + E_{aux}}$$

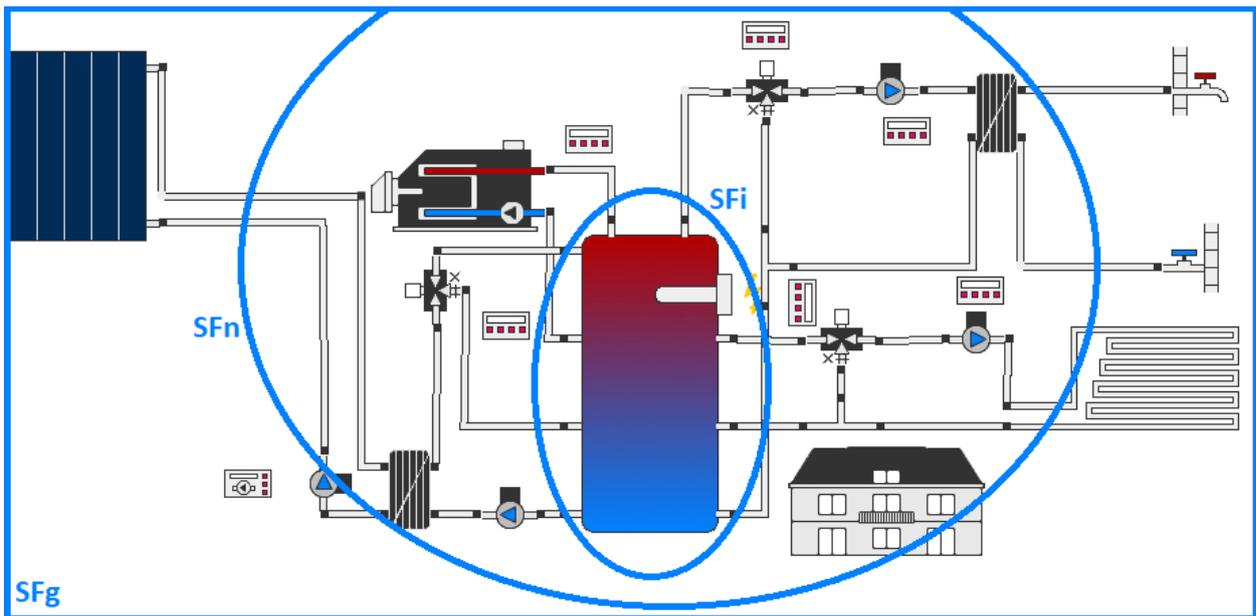


Fig. 160: limits for the calculation of solar fractions

For the purpose of the analysis of the system’s behaviour it is sometimes required that the solar fraction for hot water and heating are specified separately. This is only possible for special system configurations where the heat for heating and hot water are run and stored separately. In systems equipped with return flow bypass or with a tank used as a hydraulic compensator choosing whether in the consumer the heat was generated at some point at an earlier time-interval through the solar collectors or the auxiliary heating is not possible.

Polysun employs just like Polysun 3 an approximate calculation method that may be applied in all situations. The separate specification of solar fraction for hot water and

heating is based on the weighting of the overall solar fraction with the heat demand over a defined time interval.

$$S_{Fn}^{Heiz} = \frac{\sum_i S_{Fn}^i \cdot Q_{Heiz}^i}{\sum_i Q_{Heiz}^i}$$

$$S_{Fn}^{WW} = \frac{\sum_i S_{Fn}^i \cdot Q_{WW}^i}{\sum_i Q_{WW}^i}$$

In this context Polysun uses for the calculation a variable time-interval ranging from two days to two weeks. The output result will be simply a yearly value as monthly values would not be meaningful.

Interpretation example: During the summer months the heat demand from the heating system is very low and the solar fraction is therefore relevant only for the hot water.

Discussion: If compared with the direct calculation (separate buffer tanks) the solar fractions achieved by means of the above formula are much closer. The separated solar fractions of further consumers (like e.g. swimming pool or solar cooling system) may be defined in analogous manner.

Recommendation: Use reference systems! The specification of separate solar fractions has no significance for design or customer service purposes. A much more crucial role will be played by the use of the reference systems offered as a standard in Polysun. This will enable to elicit the influence of single system components and to optimize the heating system. See paragraph 2.2 on page 8.

7.1.2 Denominations and Representation of the Results

The abbreviations for the energy balances are always based on the same model. Therefore “QparS” means the heat energy transferred from the pump to the solar loop.

“Q” stands for the energy transferred to the system, or rather to the hydraulic system, “par” for parasitic energy and “S” for the circuit, in this case, the solar loop. If the last index is missing, here S, it is meant the transferred heat energy to all loops by all available pumps.

The meaning of the various letters of the alphabet and the positions are explained in the table below.

Heat loss to interior space “Qint” means the losses of all the components present indoors, also including the chemical energy losses in boilers with less than 100% efficiency.

“Qdem” is the energy demand, calculated by Polysun, that should be possibly covered. In the case when the “Quse” (the effective energy consumption) is lower than the “Qdem”, the energy demand can’t be covered and the corresponding warning appears. The causes are sought primarily in the installation height of the connections in the boiler or of

controller settings. The availability of hot water and building heating shown in the component results indicate what percentage of energy demand is covered. In case of the collector, “Esol” is referring to the solar irradiation onto the aperture area of the collector. “Eaux” means the chemical energy (highest value of heat of combustion) of combustible fuel.

Table 34. Denomination and representation of the results

Letter position	Letter	Definition
1	E	End energy (fuel and electrical power consumption)
	Q	Energy to the system or energy withdrawn from the system
	S	Energy to the tank or energy withdrawn from the tank
2. to 4.	sol	Solar energy (example: Q_{sol} = Energy supplied from collector to
	out	Energy withdrawn
	use	Energy consumption (amount of energy actually consumed for domestic hot water, swimming pool, building and heat sink)
	dem	Energy demand (theoretically calculated value referring to the amount of energy required, for example, to heat the cold water of the cold water piping to the desired hot water temperature)
	aux	Auxiliary energy (energy of heat generators or electrical air-conditioning devices, for example Q_{aux} = energy supplied from
	par	Auxiliary or parasitic energy (pumps and fans)
	int	Energy to indoor room (all components placed indoors, for example Q_{int} = heat loss to indoor room)
	ext	Energy to surroundings (all components placed outdoors, for example Q_{ext} = heat loss to surroundings)
	def	Energy deficit (difference between energy demand and energy consumption)
	xfr	Transferred energy
	ventil	Energy in ventilation of building
trans	Energy transmission in building	
5	S	Solar
	A	Auxiliary
	X	Heat transmission
	U	User
	M	Midex (solar and auxiliary) Total of all loops

7.2 Results Overview and System Comparison

An overview of primarily used results is given. By selecting a result, the respective graph with monthly values is displayed at the bottom of the window.

7.2.1 Reference System Diagram

Polysun allows the use of reference system diagrams for the analysis and enhancement of solar energy systems. To this end a system diagram may be specially labelled within the project tree (right mouse click – „System diagram as reference...“).

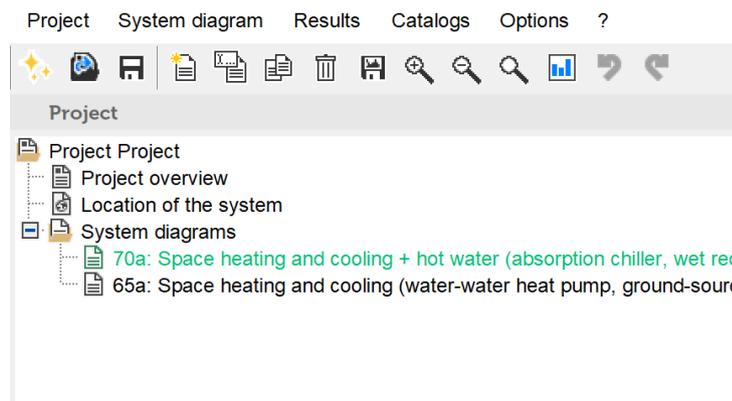


Fig. 161: project-tree with reference system diagram

Important values like, e.g. Solar savings (Fractional solar savings, F_{ss}) may only be calculated with the aid of the definition of a reference system. Solar savings are defined as follows:

$$F_{ss} = 1 - \frac{(E_{aux} - E_{par})_{sol}}{(E_{aux} - E_{par})_{ref}}$$

where E_{aux} refers to the Auxiliary energy and E_{par} refers to the Parasitic energy of the respective system („sol“ = solar energy system, „ref“ = reference system)

Example: In a solar energy system, system diagrams with and without solar input are required to be compared. To this end a model is applied as a system diagram in the project. Copy the system diagram (right mouse click – „Copy system diagram...“) and alter it so that the pump in the solar loop is not running. This system diagram will then be set as a reference (right mouse click – „System diagram as reference...“). Once the simulation results from both system diagrams are available the solar savings F_{SS} will be shown in the results.

Discussion: For customer service purposes and more in particular in a retrofitting situation the existing heating system too may be recreated in detail and set as a reference. This will enable to figure out the expected solar savings with a new solar energy system.

Tip: In the Options – Settings – Simulation menu you will be able to select when Polysun should calculate the reference system:

- „Simulate reference upon confirmation“: the user should confirm the start of the reference simulation
- „Simulate reference without confirmation“: the reference simulation will be restarted immediately after the simulation of a system diagram
- „ Do not simulate reference“: the reference simulation will not be automatically simulated and the user must start the simulation manually

7.2.2 System Comparison

For the technical evaluation and performance analysis of different system diagrams in one project the user can choose “System comparison” from the drop-down list of the Polysun menu bar Results. This feature allows the user to see how a change in the system design influences the system performance. In addition, it allows the fast examination of the system behavior with different system designs. An example of the results window is shown below.

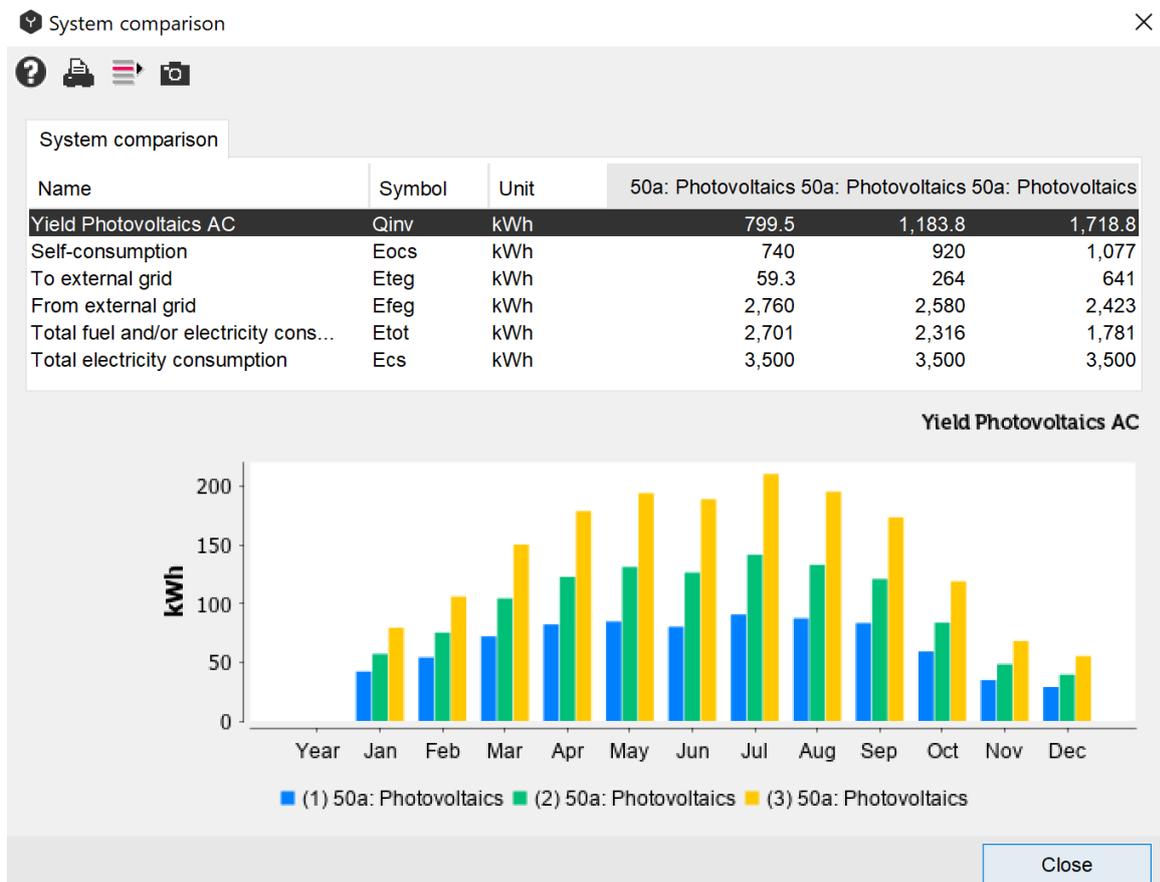


Fig. 162: system results comparison dialog window

The results comparison shows main performance indicators for a given technology of the active systems in the project in tabular and graphical form. By left clicking on the correspondent parameter the values over the year will be displayed graphically. The system comparison can be printed out in a separate pdf-document by clicking on the “Print” button on the top of the window.

7.2.3 Total CO₂ Emissions and CO₂ Savings

The CO₂ (equivalent) emissions are estimated for any component which consumes electricity or a fuel. Life-cycle emissions of components such as PV, batteries, or electric vehicles, are neglected. For fuel consumers (e.g., boilers, generators, co-generators), the emissions are estimated as follows:

$$\text{emissions} = \text{specific emissions} \cdot \text{fuel consumption}$$

whereby the specific emissions are defined in the “Energy Source” catalog. For electrical consumers, the emissions are:

$$\text{emissions} = \text{specific emissions} \cdot E_{\text{fromGrid}}$$

where E_{fromGrid} is the electrical energy purchased from the grid.

To estimate the total CO₂ emissions of a system, Polysun requires it to have an electric grid and electric consumers, so that own consumption and feed-in limitations can be considered. Given these conditions, Polysun displays the system’s total emissions in the results overview. Additionally, if a reference system is defined, the CO₂ savings compared with the reference system are shown.

7.3 System Results

The results of the various loops are listed in this window. In the overview there are the solar fractions as well as the respective energies and how they are determined.

Table 35. Results of the various loops

Description	Abbrev	Meaning
Energy consumption	Quse	Amount of energy actually consumed by a consumer unit. This includes energy consumption for domestic hot water, swimming pool, building heating and cooling as well as heat sink, provided the latter is a consumer unit. All values are added to a total amount (positive values).
Energy demand	Qdem	Amount of energy required by consumer units to ensure that the required comfort conditions are met. This includes energy demand for domestic hot water, building heating and cooling as well as heat sink, provided the latter is a consumer unit. All values are added to a total amount (positive values).
Energy supplied from heat generators to system (inclusive of air-conditioning devices)	Qaux	Amount of energy supplied from electrical and fuel-operated heat generators and electrical air-conditioning devices to fluid.

Fuel and power consumption by heat generators and air-conditioning devices	Eaux	Amount of fuel and electrical power required by heat generators and electrical air-conditioning devices.
Overall fuel and electrical power consumption	Etot	Amount of fuel and electrical power required by heat generators, electrical air-conditioning devices, pumps, fans, etc.

7.4 Component Results

The results of each individual component are shown in average monthly and annual values, as well as maximum and minimum values. These latter values are useful above all for the pipes, in which the average temperature has less importance than the effective temperature at the time of flow. This visualization is possible at the Professional and the Designer level.

7.5 Tabular Evaluation

This is the display of all hourly values in the form of a chart. It is possible to select the series of data by clicking on the title, copying with “Ctrl-c” and inserting it in Excel. This visualization is possible at the Designer level.

7.6 Graphical Evaluation

The graphic tool of Polysun (Professional and Designer level) offers the possibility of having a visual analysis of the data. The following values can be represented, on the basis of hourly values, for any period of time (year, month, hour and intermediate periods):

- All temperatures
- All power values
- All flow rates
- All on-off statuses
- All Sfg solar fractions

The temporal scale can be freely selected by opening a box using the mouse. If it is necessary to display more than one scale (for example one for temperature and one for power value), these are visualized to the left and to the right of the graphic chart and one or the other can be dragged vertically and independently. If in addition you add one of the values without units “solar fraction” or “pump activity”, the temperature is spread from 0 – 100 and the corresponding value is represented in %.

The consumption values, such as hot water consumption, the heating energy demand and the night cool-off temperature are indicated with a negative sign.

Suggestions: The results are of average hourly values and might not be precisely represented over the course of an entire year. A year contains 8760 hours, a screen has many fewer pixels. Therefore in the visualization of the year the values become averages over more hours. This creates confusion above all regarding the temperature of the collector. Consequently a time frame as brief as possible is to be selected.

The values that change in the course of an hour are equally difficult to interpret. If the pump is activated for five minutes, the status will be indicated in the entire hour as 1, that

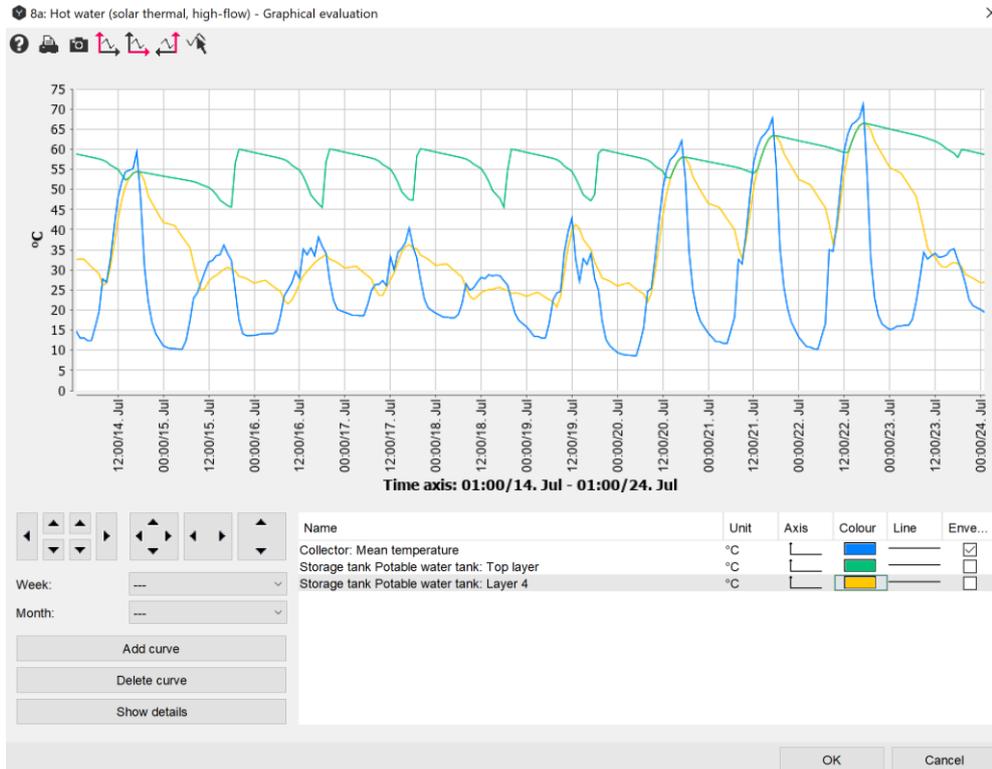


Fig.

163: graphical evaluation of simulation results

is, “on”. The effective operation time of the pump can only be evident in the visualization of the component results.

For an even more detailed analysis the user can switch between the graphical representation of the hourly values and the time-step values. Hourly values could not be precise enough for system evaluation purposes. Therefore, it was made possible to change to more detailed time-step-based graphical representation by clicking on the button “Show details”.

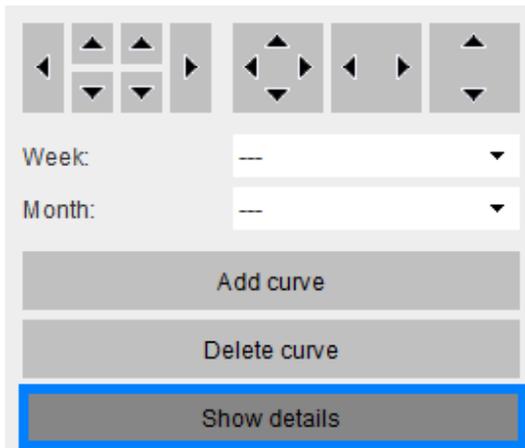


Fig. 164: switching to the time-step-based graphical representation

You can also zoom-in and zoom-out by choosing the certain area on the graphic with a pointer.

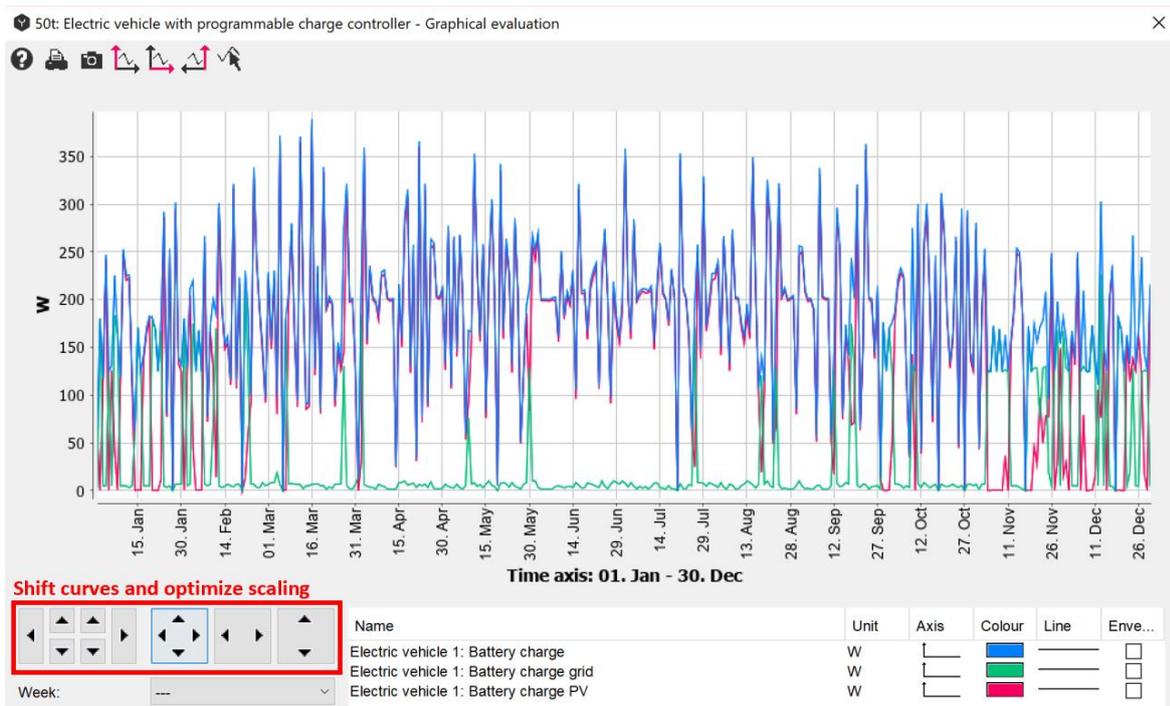


Fig. 165: graphical evaluation dialog window

By clicking on the buttons marked on the above-shown figure the user will be able to shift curves and optimize the scaling. Tip: the scaling can be vertically improved if curves run over the lower edge of the graph.

In order to see the minimum and maximum values of the certain parameter, the envelope curves can be ticked. This function can be applied only to hourly values.

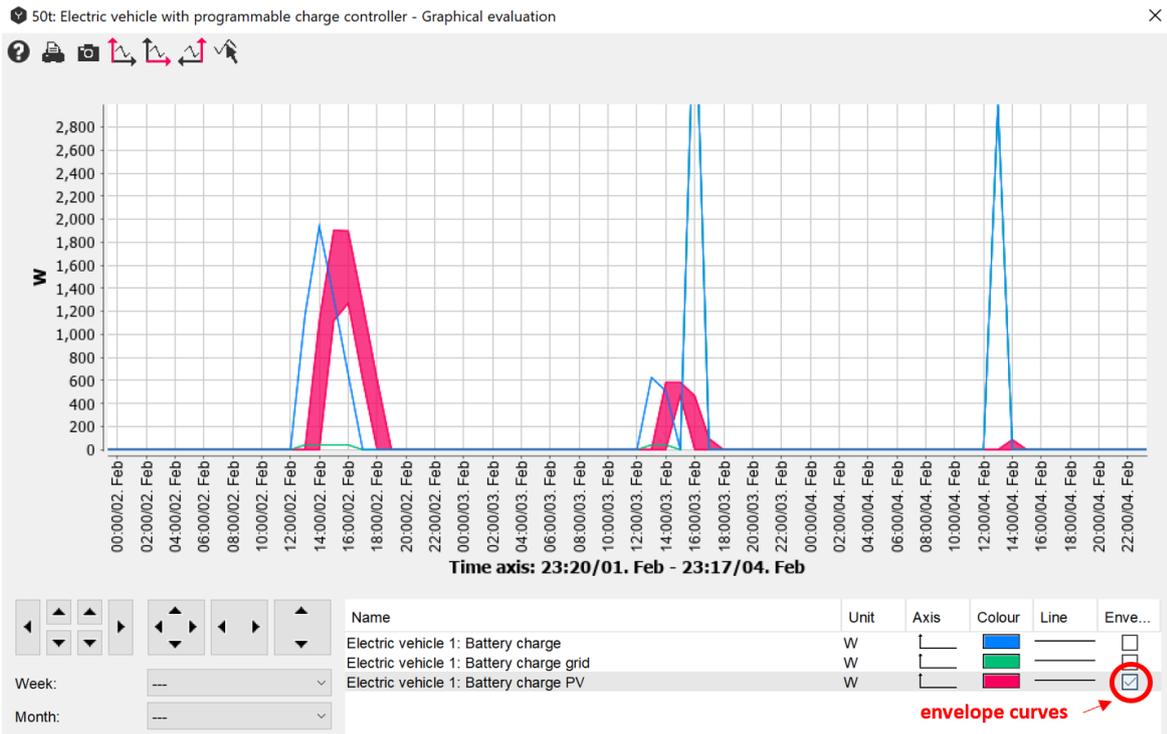


Fig. 166: envelope curves in the graphical evaluation

7.7 Fluid Overview

The various loops of the system with all of their respective components and fluids are listed. In this window the fluid can also be modified at any time. All you need to do is select a fluid and click on “Change heat transfer medium”.

Fluid Transport

Polysun was designed so as to allow users to create the desired system layout by means of the available components. The first step of the simulation foresees hence a careful analysis of the system layout. The process includes in the sequence the identification of fluid domains and subsequently the identification of fluid loops.

Definition: The term fluid refers to the fluid that circulates the different components and transports energy. As fluids often contain different substances Polysun includes a catalog of main fluid components showing the pure substances (like, for example, water, ethylenglycol, propylenglycol) as well as a fluid mixture catalog showing the fluids that are actually employed (like, for example, potable water, ethylene mixture, propylene mixture).

Definition: A fluid domain is a continuous hydraulic area permeated by a common fluid. A system typically consists of several different fluid domains. System components belonging to a defined fluid domain are circulated by the same fluid.

Definition: A fluid domain consists of one or more fluid loops. A fluid loop always includes a flow-rate producer. Results are given for fluid loops (not fluid domains).

Definition: A component is defined as a flow rate producer when fluid transport between component connections is determined through physical processes in the same components.

The following components are flow rate producers:

- Pump
- Boiler with inbuilt pump
- Hot water outlet (in which case a direct connection to the cold water outlet may be thought of to close the fluid loop).

Example: The system diagram 1f: hot water (2 collector fields, heating oil) should serve as an example for the analysis of the system topology. In this system there are three fluid domains (hot water, auxiliary heating, solar). The solar domain comprises two loops, each one activated by a pump. It is clear that there can be components that belong to two different loops (like the solar coil heat exchanger). On the contrary from the point of view of drinking water, there is only one loop, from the moment that there is only one flow rate producer (the hot water tap) and the three-way valve clearly sets at all times the mix ratio.

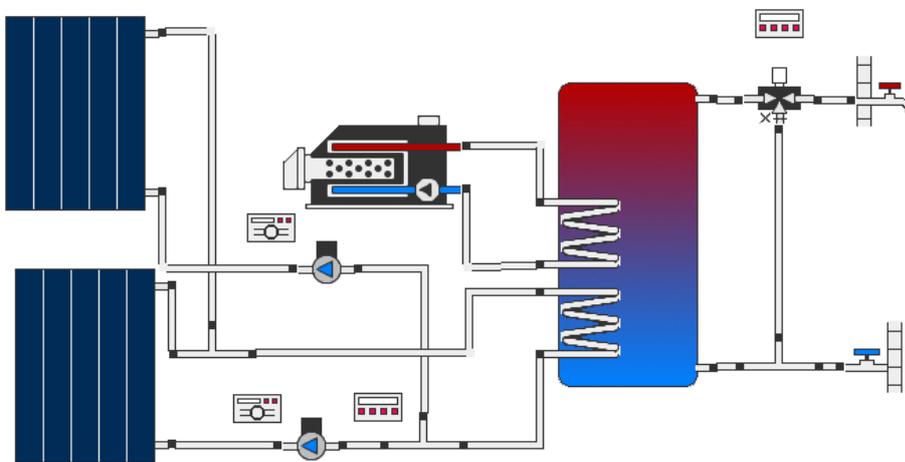


Fig. 167: example for fluid domain and fluid loop

The algorithm ensures that the fluid transport is determined for each section of the system in an unequivocal manner. In this way, for example, it prevents two pumps from working counter-productively in the same circuit.

7.8 Energy Flow Diagram

The energy flow diagram is a graphical representation of the energy balance of the designed system. It can be opened in the 'Results' tab or by the keyboard command Ctrl+Shift+E.

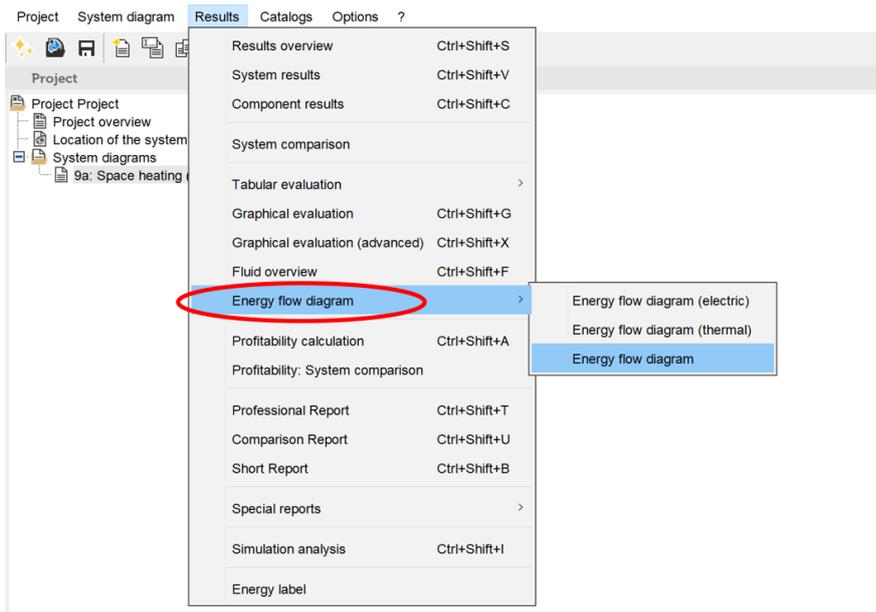


Fig. 168: selection of energy flow diagram

The energy flow diagram shows the energy inflows on the left hand side and its distribution on the right hand side. On the inflow side – heat generated to the system, e.g. from solar collector field. On the distribution side – demands and losses of the system. Both thermal energy and electrical energy are considered. For some hydraulic systems the energy flow diagram can not be displayed, e.g. borehole regeneration. The reason is that the energy flow balance can not always be calculated.

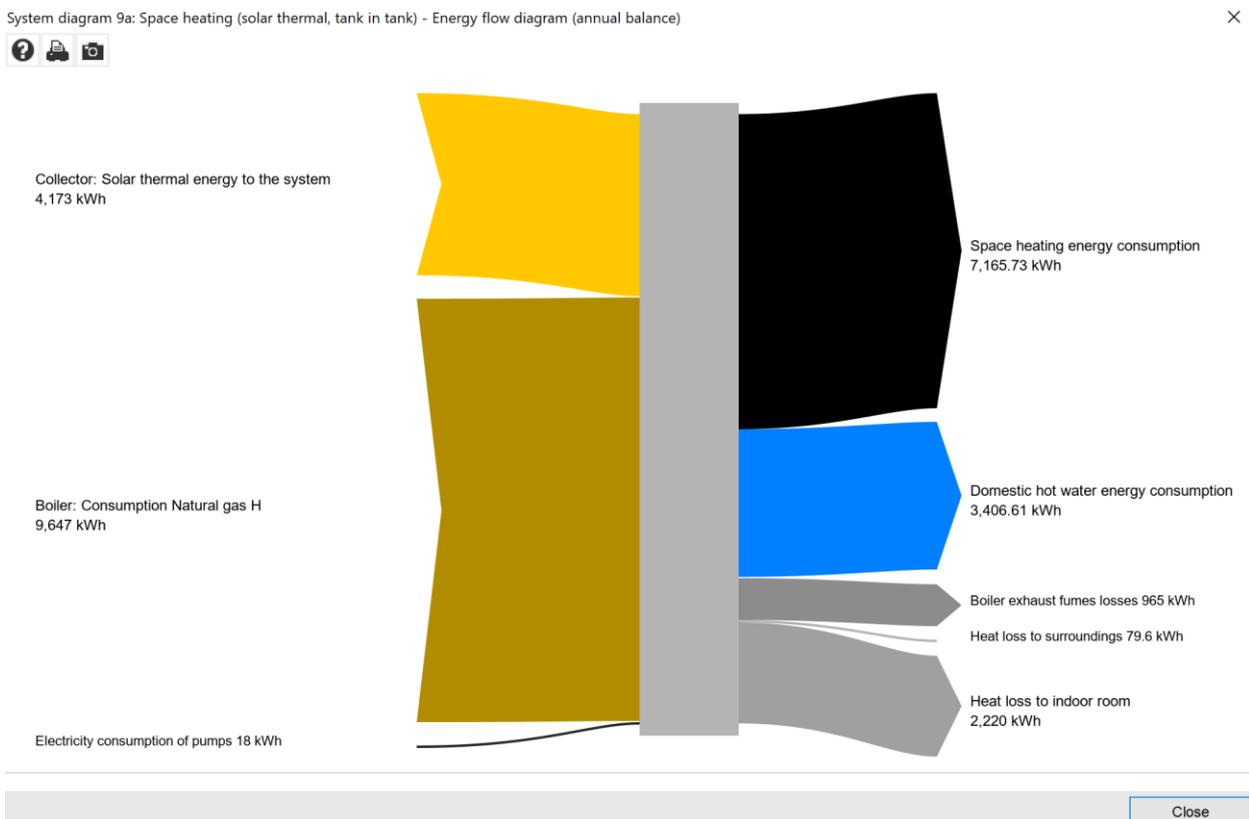


Fig. 169: example of the energy flow diagram

In order to view what each arrow on the diagram stands for, move the mouse over it to see the description.

The Energy Flow Diagram can be saved as an image or printed out using the buttons on the top left corner of the window.

7.9 Report

The different types of report – short report, professional report, comparative report and economic viability report – summarize all relevant results within a single document. The following example outlines the results shown in the report.

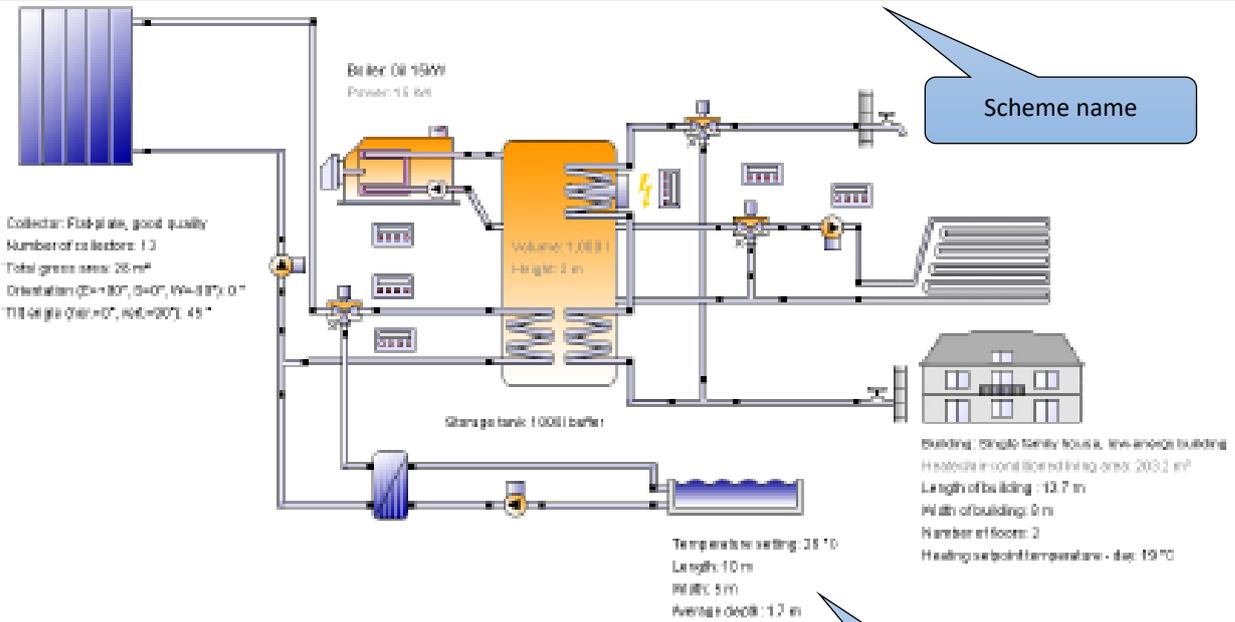
Professional Report

Company logo

Your Logo

Projekt

10a: Space heating + pool (solar thermal, high-flow)



Scheme name

Location of the system

Rapperswil SG
 Longitude: 8.82°
 Latitude: 47.23°
 Elevation: 417 m

Installation site

Scheme with system description

This report has been created by:

Lars Kunath
 Stadthausstrasse 125
 8400 Winterthur

Name and address of the planner

Total fuel and power consumption required for operation (heat generators, chillers, pumps, fans)

System overview (annual values)

Total fuel and/or electricity consumption of the system [E _{tot}]	13,847.5 kWh
Total energy consumption [Q _{use}]	18,573.6 kWh
System performance [(Q _{use} +E _{inv}) / (E _{aux} +E _{par})]	1.34
Primary energy factor	0.75
Comfort demand	Energy demand not met

Amount of actually consumed energy (consumers are domestic hot water, heating, cooling, swimming pool, process-heat and supply to a district heating network).

If the respective temperatures are exceeded by more than 5% for 5% of the time, the message "Energy demand not met" is shown. For a correct comparison between different systems the energy demand must always be met.

This enables an objective comparison between different systems. The higher the value, the better the result.

... correctness of the specifications and the results.

Professional Report

Your Logo

Aggregate of all collector fields

Percentage of total generated energy coming from solar sources. 47.6% of the energy need was met through solar energy. $[Q_{sol}/(Q_{sol}+Q_{aux})]$

Overview solar thermal energy (annual values)

Collector area	26 m ²
Solar fraction total	47.6%
Solar fraction hot water [SF _h Hw]	64 %
Solar fraction building [SF _b Bd]	15.8 %
Total annual field yield	9,941.2 kWh
Collector field yield relating to gross area	382.4 kWh/m ² /Year
Collector field yield relating to aperture area	424.8 kWh/m ² /Year
Max. fuel savings	1,169.6 l: [Heating oil]
Max. energy savings	11,695.5 kWh
Max. reduction in CO ₂ emissions	3,516.5 kg

An average 64% of the energy required for hot water was supplied by solar energy.

An average 15.8% of the energy required for heating was supplied by solar energy.

Annual amount of energy supplied by collectors to the system (loop).

Specific annual amount of energy supplied to the system (loop) per gross collector surface.

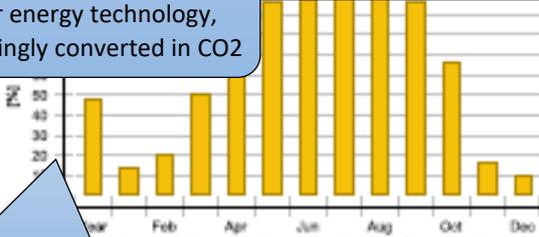
Specific annual amount of energy supplied to the system (loop) per effective collector area.

Annual fuel savings through use of solar energy technology converted in kWh. This value can be higher than the collector field yield as this also divided by boiler efficiency

Savings through the use of solar energy technology, accordingly converted in CO₂

Annual fuel savings through use of solar energy technology

Reduced yield through horizon and nearby shading are taking into account



Monthly breakdown of solar fraction

Average annual outdoor temperature (average in 24 hours)

Meteorological data overview

Average outdoor temperature	9.9 °C
Global irradiation, annual sum	1,103.4 kWh/m ²
Diffuse irradiation, annual sum	577.9 kWh/m ²

Total annual radiation on a horizontal surface, in a defined location, per square meter or foot

Percentage of global radiation scattered on clouds and mist particles. The value is equal to the global radiation minus direct radiation.

Component overview (annual values)

Boiler		Oil 15kW
Power	kW	15
Total efficiency	%	79.3
Energy from/to the system [Q _{aux}]	kWh	10,933.6
Fuel and electricity consumption [E _{aux}]	kWh	13,793.1
Fuel consumption of the back-up boiler [B _{aux}]	l	1,379.4
Energy savings solar thermal	kWh	11,695.5
CO ₂ savings solar thermal	kg	3,516.5
Fuel savings solar thermal	l	1,169.6

Denomination of boiler

Nominal power of boiler

Efficiency under different operating conditions over the year. $[Q_{aux}/E_{aux}]$

Energy supplied by boiler to the system (loop)

Energy savings for this boiler through the use of solar thermal technology, converted in kWh, CO₂ and liters of oil

Fuel and power consumption required for boiler operation. $[E_{aux}=Q_{aux}+Losses]$

Professional Report

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Collector	Flat-plate, good quality	
Data Source		SPF
Number of collectors		13
Number of arrays		1
Total gross area	m ²	26
Total aperture area	m ²	23.4
Total absorber area	m ²	23.4
Tilt angle (hor.=0°, vert.=90°)	°	45
Orientation (E=+90°, S=0°, W=-90°)	°	
Collector field yield [Qsol]	kWh	9,941.2
Irradiation onto collector area [Esol]	kWh/m ²	29,029
Collector efficiency [Qsol / Esol]	%	34.4
Direct irradiation after IAM	kWh/m ²	11,200
Diffuse irradiation after IAM	kWh/m ²	12,700
Building	Single family house, low	
Heated/air-conditioned living area	m ²	203.7
Heating setpoint temperature	°C	19
Heating energy demand excluding DHW [Qdem]	kWh	10,000
Specific heating energy demand excluding DHW [Qdem]	kWh/m ²	49
Solar gain through windows	kWh	10,000
Total energy losses	kWh	35,000
Heating/Cooling element	Floor heating	
Number of heating/cooling modules	-	1
Power per heating/cooling element under standard conditions	W	10,000
Nominal inlet temperature	°C	45
Nominal return temperature	°C	35
Net energy from/to heating/cooling modules	kWh	10,000
Hot water demand	Daily peaks	
Volume withdrawal/daily consumption	l/d	100
Temperature setting	°C	45
Energy demand [Qdem]	kWh	10,000
Pool	Outdoor pool	
Pool type		Outdoor pool
Length	m	10
Width	m	5
Average depth	m	1.5
Temperature setting	°C	25
Energy from/to the system [Quse]	kWh	10,000
External heat exchanger Pool	Small	
Transfer capacity	W/K	5,000

Collector testing center

Collector inclination with respect to the horizontal plane

Collector surface orientation. (0°=south, east=+90°, west=-90°, also implies for the southern hemisphere)

Energy supplied from collector field to the system (loop)

Annual global radiation on the aperture area

Annual global radiation on the aperture area, minus reflection losses (listed separately for direct and diffuse)

The heating energy demand is equal to annual amount of energy that is calculated to be supplied by radiators to the building (heated leaving space).

Total annual solar yield through glazed window surface, regardless of its use. (also in the summer time below the set shading point).

Total annual energy losses through building envelope and air exchange.

Total maximum power output is equal to the number of heating/cooling modules times the

Amount of energy supplied to the building by floor heating over the year.

Amount of energy actually required to bring the cold water to the desired temperature.

Unit of measurement for heat exchanger size (e.g. with a transmission power of 10 kW the temperature drop from supply to demand side is equal to 2 K).

Professional Report

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Pump Solar loop		Eco, medium
Circuit pressure drop	bar	2.035
Flow rate	l/h	938
Fuel and electricity consumption [Epar]	kWh	21.7

Average flow rate in operation

Pump Pool		Eco, large
Circuit pressure drop	bar	0.004
Flow rate	l/h	520
Fuel and electricity consumption [Epar]	kWh	18.1

Pump Heating loop		Eco, medium
Circuit pressure drop	bar	0.013
Flow rate	l/h	1,125.2
Fuel and electricity consumption [Epar]	kWh	14.7

Storage tank Buffer tank		1000l buffer
Volume	l	1,000
Height	m	2
Material		Steel
Insulation		Rigid PU foam
Thickness of insulation	mm	80
Heat loss [Qh]	kWh	730.9
Connection losses	kWh	776.1

Annual heat loss through walls

Annual heat loss through connections

Loop

Solar loop		
Fluid mixture		Propylene mixture
Fluid concentration	%	33.3
Fluid domains volume	l	66.8
Pressure on top of the circuit	bar	4

33% ethylene, the rest is water

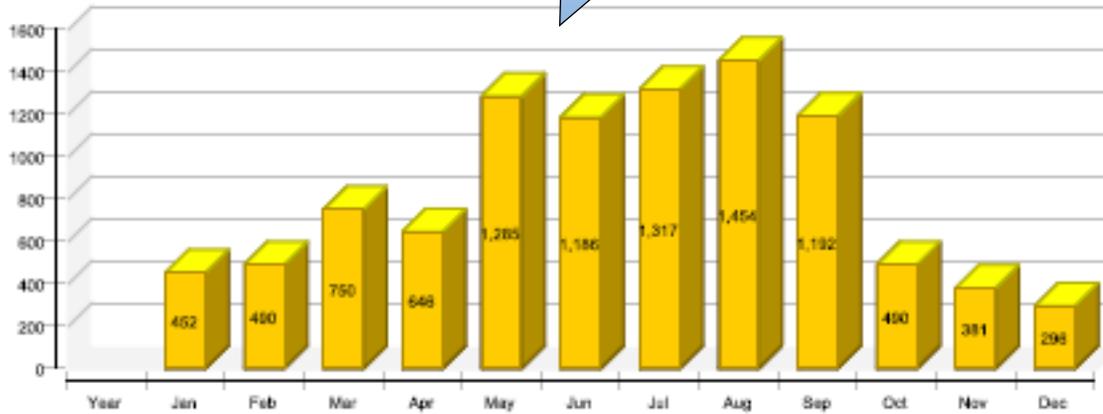
66.8 l of glycol are required to fill the solar loop

Pressure affects the evaporation point

Amount of energy supplied by collectors to the system (loop).

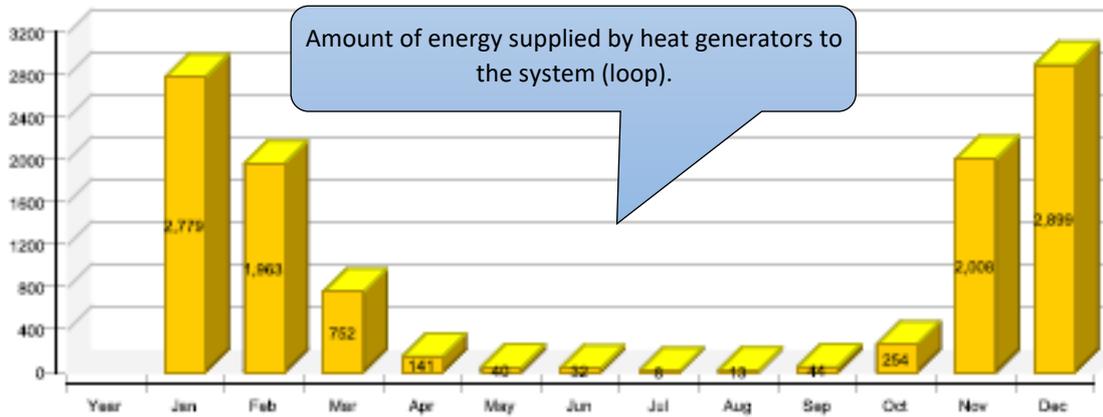
Solar thermal energy to the system [Qsol]

kWh



Heat generator energy to the system (solar thermal energy not included) [Qaux]

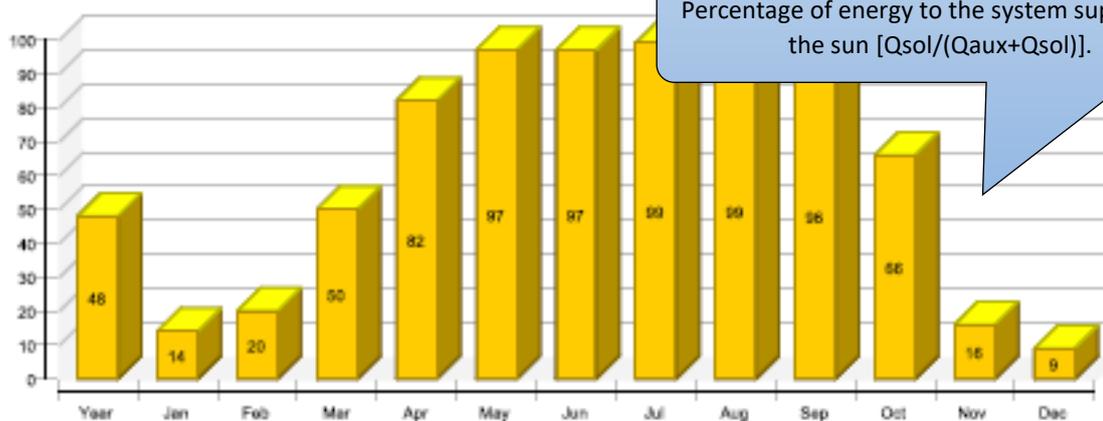
kWh



Amount of energy supplied by heat generators to the system (loop).

Solar fraction: fraction of solar energy to system [SFn]

%

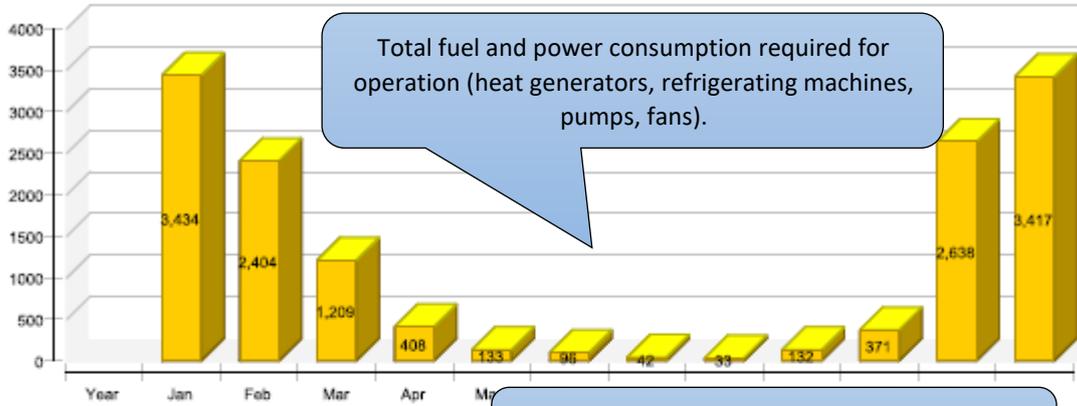


Percentage of energy to the system supplied by the sun $[Q_{sol}/(Q_{aux}+Q_{sol})]$.

Professional Report

Total fuel and/or electricity consumption of the system [Etot]

kWh



Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Solar thermal energy to the system [Qsol]	7163	305	387	572	581	835	822	1000	1000	1000	1000	1000
Heat generator energy to the system (solar thermal energy not included) [Qaux]	11226	2750	1907	938	298	77	56	2	2	2	2	2
Heat generator fuel and electricity consumption [Eaux]	14265	3430	2400	1206	406	127	90	35	27	127	370	2635
Solar fraction: fraction of solar energy to system [SF_{th}]	%	39	10	16.9	37.9	66.1	91.6	93.7	97	97	97	97
Total fuel and/or electricity consumption of the system [Etot]	kWh	14318	3434	2404	1209	408	133	96	42	33	132	371
Irradiation onto collector area [Esol]	kWh	17989	786	1028	1593	1782	2011	2011	2011	2011	2011	2011
Electricity consumption of pumps [Epar]	kWh	53.1	4.6	4	3.3	2.6	5.5	5.3	5.3	5.3	5.3	5.3
Total energy consumption [Quse]	kWh	16272	2923	2174	1314	677	699	68	68	68	68	68
Heat loss to indoor room (including heat generator losses) [Qint]	kWh	2886	282	250	248	229	225	216	222	224	218	227
Heat loss to surroundings (without collector losses) [Qext]	kWh	210	10	13	18	22	24	22	22	23	22	15

Total fuel and power consumption required for operation (heat generators, refrigerating machines, pumps, fans).

Amount of energy supplied by collectors to the system (loop).

Amount of energy supplied by heat generators to the system (loop).

Total fuel and power consumption required for operation, minus pumps and fans

Percentage of total generated sources coming from solar thermal sources. [Qsol/(Qsol+Qaux)]

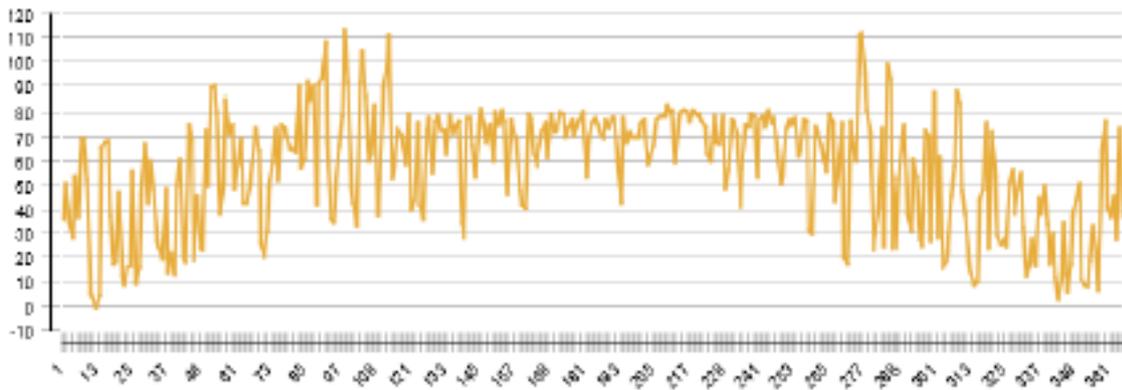
Total fuel and power consumption required for operation (heat generators, refrigerating machines, pumps and fans)

Annual irradiation onto the aperture area

Total heat losses from all components installed indoors and outdoors respectively (e.g. waste heat from pump, piping losses, etc. To a certain extent, heat losses prove advantageous to heating energy demand).

Here collector stagnation can be checked

Collector
Daily maximum temperature [°C]

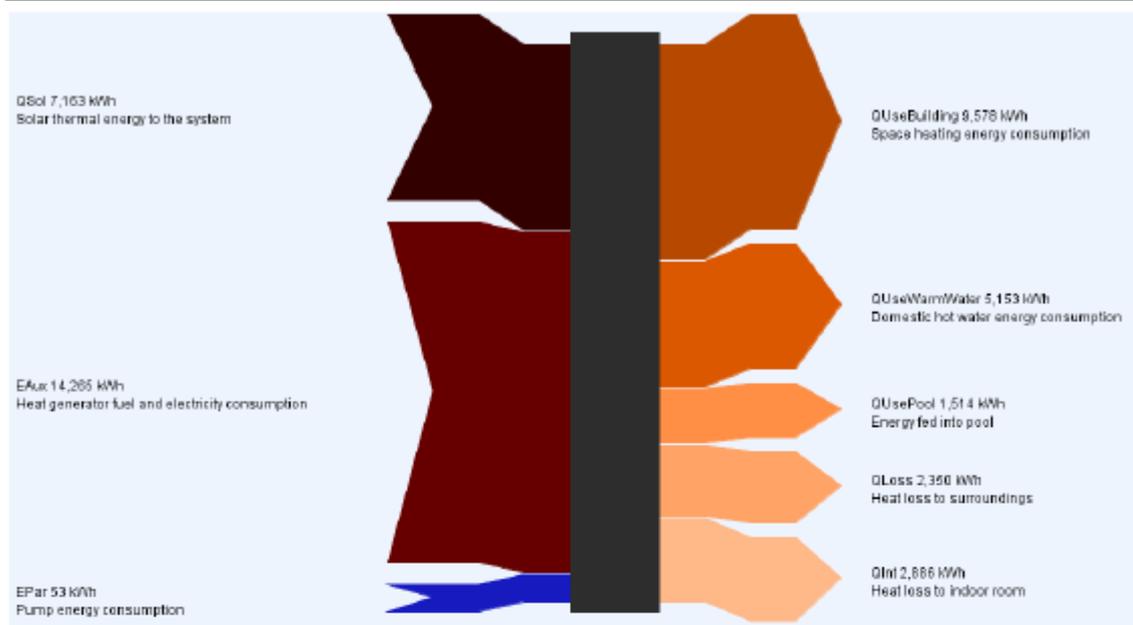


Pool
Temperature [°C] - Daily average



Professional Report

Energy flow diagram (annual balance)



7.10 Energy Label

Polysun can calculate the Energy label for one of your system diagrams according to the EU regulations 811/2013 and 812/2013.

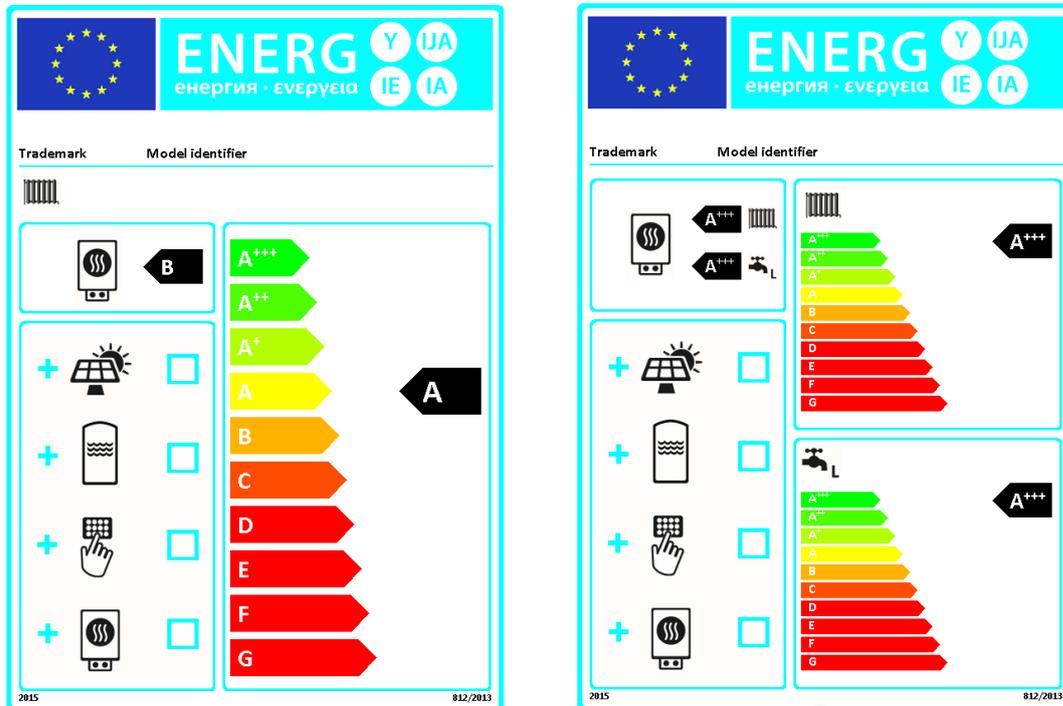


Fig. 170: example of the energy label

The Energy label can be calculated for systems with space heating and/or domestic hot water preparation. A separate energy efficiency class will be calculated for both space heating and domestic hot water preparation. The calculation results can be found in the attached data sheets.

You can instantly access the Energy label under “Results – Energy label”. This option also allows you, to save the label and the data sheets as an image file (*.png) and to enter additional parameters.

The Energy label can be part of both the short report and the professional report. The short report includes the Energy label, the professional report incorporates both the Energy label and the pertaining data sheets. Additionally, the section “System overview” will display the energy efficiency classes for domestic hot water preparation and space heating. You can choose whether you want the label displayed in the report or not under “Options – Settings – Report”.

7.10.1 Preconditions for the Calculation of the Energy Label

The Energy label can only be calculated for the some system types:

- (1) The main heat generator of the system needs to have a nominal power of less than 70 kW. This main heat generator may be a boiler, a heat pump, a cogenerator or an internal heat generator in a storage tank (electric resistance heater).
- (2) An Energy label can be calculated only for boilers fueled by oil, gas or electricity. It cannot be calculated for boilers using firewood or pellets as fuel.
- (3) The system may include an additional heat generator, provided it is a boiler or an internal heat generator in a storage tank. If the additional heat generator is a heat pump or a cogenerator, the Energy label cannot be calculated.
- (4) For systems that include more than two heat generators, no Energy label can be calculated.
- (5) The system may only include one collector field with solar thermal or PVT collectors. A system including a collector field must also include a storage tank.
- (6) The system may include no more than three storage tanks.
- (7) If the system is designed only for domestic hot water preparation and not for space heating, an Energy label can only be calculated if the storage tank volume is less than 500 liters.

7.10.2 Calculation of Energy Efficiency Classes

The following parameters enter into the calculation of the energy efficiency class for space heating:

- the energy efficiency of the heat generator used for space heating,
- class of the temperature control,
- energy efficiency of the additional heat generator, if applicable,
- data of collector and storage tank, if applicable.

The following parameters enter into the calculation of domestic hot water preparation:

- the load profile selected for hot water consumption,
- the energy efficiency of the heat generator used for domestic hot water preparation in the selected load profile,
- data of collector and storage tank, if applicable.

Data relating to the storage tank are only relevant if the system includes a collector field. Otherwise, they are not entered into the calculation.

7.10.3 Components

7.10.3.1 Heat Generator

The following data of the heat generator enter into the calculation:

- Nominal power,
- Space heating energy efficiency,
- Domestic hot water preparation energy efficiency.

The values for space heating and domestic hot water preparation efficiency are recorded values that should be part of the catalog. In the case that the catalog does not include these values (yet), Polysun will calculate approximations.

7.10.3.2 Domestic Hot Water Load Profile

According to the EU regulation, there are four load profiles relevant for the calculation of the Energy label:

Table 36. Load profile according to EU regulation

Load profile	Energy used for domestic hot water preparation
M	5.845 kWh/d
L	11.655 kWh/d
XL	19.07 kWh/d
XXL	24.53 kWh/d

The load profile can be determined in the “Hot water demand” dialogue. It can either be entered manually or calculated automatically using the yearly demand.

7.10.3.3 Temperature Control

According to the EU regulation, there are eight classes of temperature control:

Table 37. Classes of temperature control according to EU regulation

Class	Description	Correction factor
I	On/off room thermostat	1 %
II	Weather compensator control, for use with modulating heaters	2 %
III	Weather compensator control, for use with on/off output heaters	1.5 %
IV	TPI room thermostat, for use with on/off output heaters	2 %
V	Modulating room thermostat, for use with modulating heaters	3 %
VI	Weather compensator and room sensor, for use with modulating heaters	4 %
VII	Weather compensator and room sensor, for use with on/off output heaters	3.5 %
VIII	Multi-sensor room temperature control, for use with modulating heaters	5 %

The temperature control class can be set when the Label is shown using the “Additional Parameters” tab. Temperature controls in Germany, Austria and Switzerland usually fall in the class VI type, so this is set as the default setting.

7.10.3.4 Storage Tank

The following data of the storage tank enter into the calculation:

- Storage tank volume,
- Standing losses.

The storage tank volume is usually the nominal volume taken from the storage tank-catalog. If for purposes of Energy label calculations a deviating volume should be considered, it can be entered into the column “volume (energy label)” of the catalog.

The standing losses can be found in the storage tank-catalog in the column “Standing losses”. It is defined as the heat loss of the entire storage tank measured in Watts and for

45 degrees Kelvin of temperature difference between the mean temperature in the storage tank and the ambient temperature. This should be a recorded measurement. In the case that the catalog does not include this measurement (yet), Polysun will calculate an approximation of the standing loss based on the insulation of the storage tank.

7.10.3.5 Collector Field

The following data of the collector field are taken into account for the calculation:

- Total collector aperture area,
- Optical efficiency η_0 at $\Delta T (u_M - u_L) = 0$ K, u_M being mean absorber temperature, u_L being mean ambient temperature of the collectors in °C
- Heat transmission coefficient a_1 , based on the aperture area,
- Temperature-dependent heat transmission coefficient a_2 , based on the aperture area,
- Angle factor (IAM value) at 50 °.

Both the orientation and the tilt angle of the collector field are irrelevant.

7.10.4 Headline of the Energy Label

The headline used for the Energy label consists of the trademark and the model identifier of the system rated.

When the label is displayed, the trademark can be entered once the button “Additional parameters” is clicked on. The name used for the installation will be the one chosen for the system diagram.

7.11 Simulation Analysis

The Simulation Analysis can be opened in the 'Results' tab or by the keyboard command Ctrl+Shift+I.

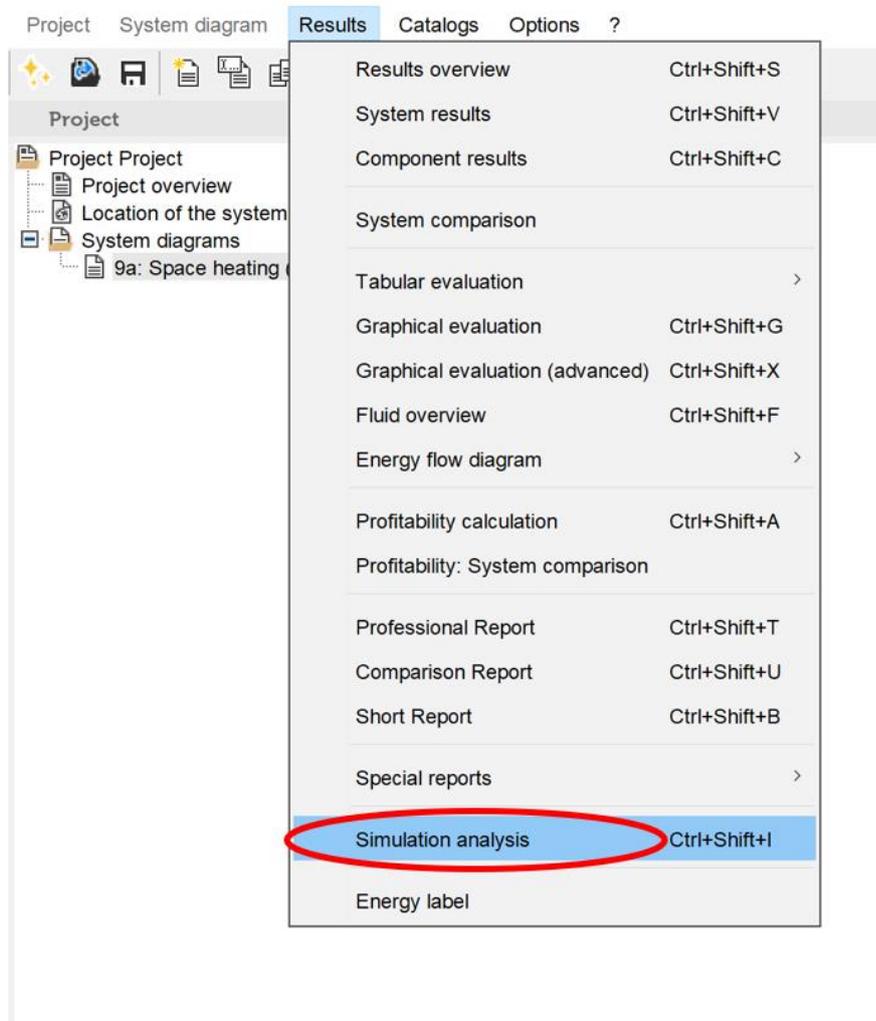


Fig. 171: selection of the simulation analysis

The simulation analysis allows to see the change in the main parameters for each system component based on the time steps during the year. For each system component, the main results are shown (e.g. storage tank – temperature in each layer, solar collector field – total radiation onto collector aperture area and outflow temperature). You can go through every time step by clicking “+”, or use the arrow keys to go through the time steps: arrow = 1 time step, control key + arrow = 10 time steps, shift key + arrow = 100 time steps.

On each step you can see also in the window the date, current time and the serial number of the simulation step.

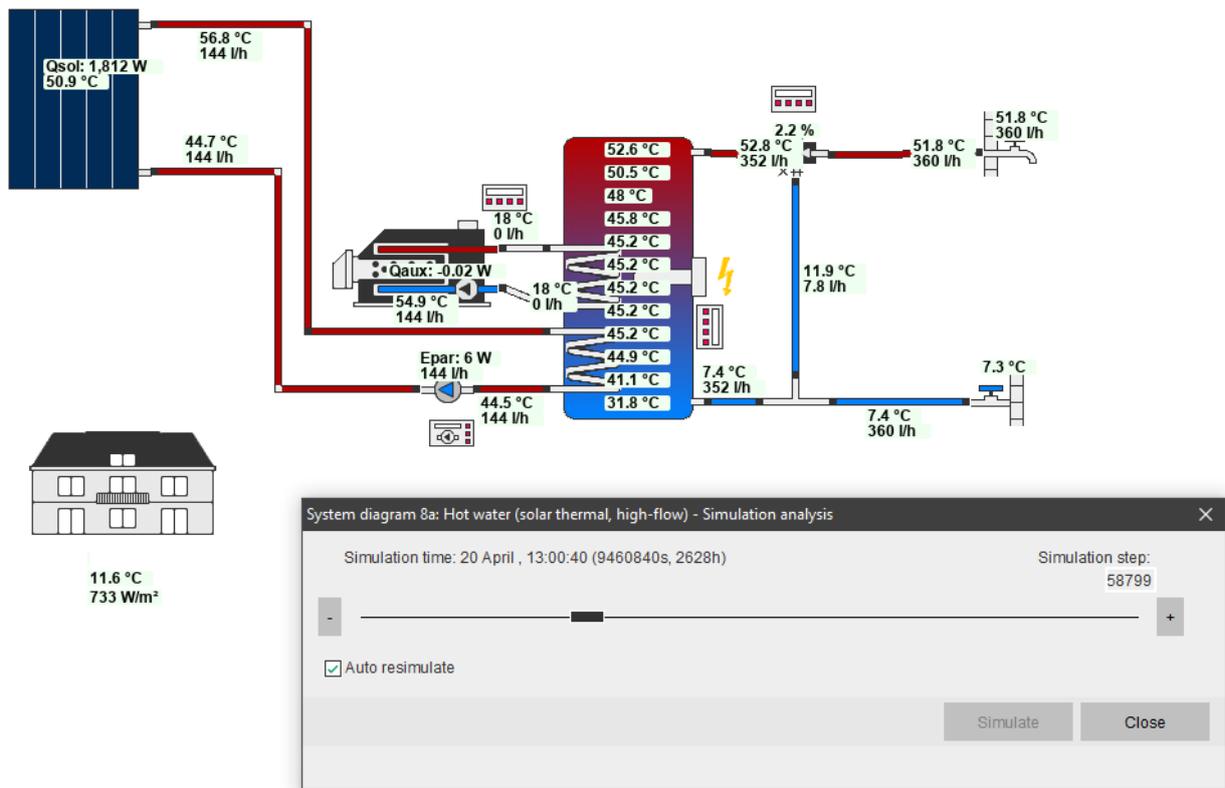


Fig. 172: example of the simulation analysis

The presence of flow in the pipes is indicated by red color for relatively hot water and by blue color for the relatively cold water.

Polysun Video



[Simulation analysis](#)

7.12 Log and Parametrize

The Parametrization feature allows to carry out several simulations of one system diagram with different input data simultaneously, without having to create a new system diagram or edit an existing one. It has two main advantages:

- 1) Parametrize input data which allows multiple simulation;
- 2) Necessary results output based on the time steps.

In order to use the Log and Parametrize feature, you need to open the menu “Options”, then choose “Settings” and under the tab-sheet “Advanced” enable the Log and Parametrize feature. Then you should define the folder where you would like to save the results.

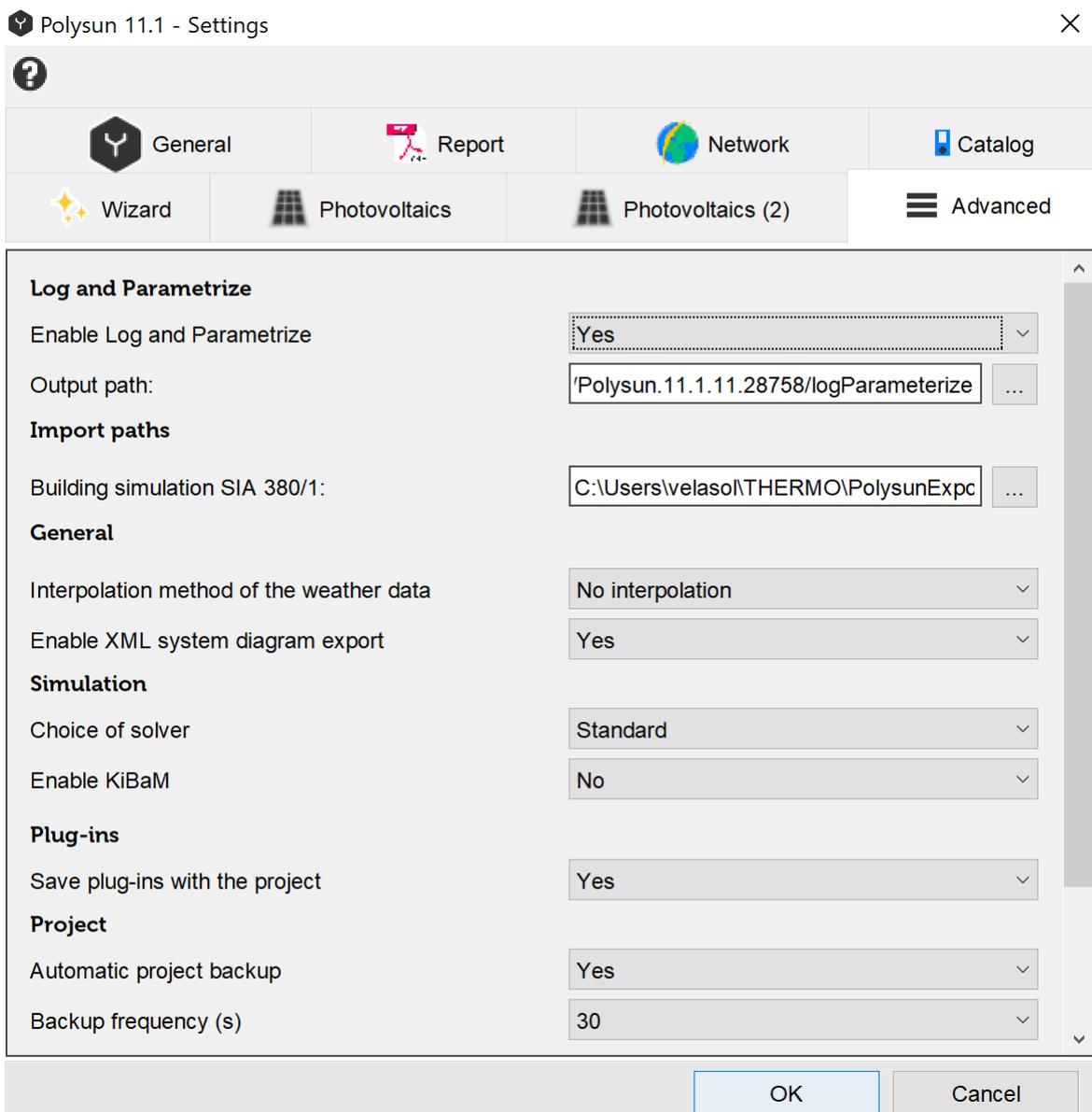


Fig. 173: enabling the Log and Parametrize function in Polysun

The 'Parametrizing Wizard' is divided into 4 parts: input data, output data, period and choice of output data presentation.

7.12.1 Parametrize

In the Input data the required combinations of the system configurations can be defined manually. For each input data several single values or a range of values can be defined. The single values are separated with a semicolon, e.g. 3;5. A range can be defined by [lowest value]:[difference between each value]:[highest value], e.g. 3:2:7. If several input data have been selected, all combinations of input data can be simulated.

Let's take as an example solar thermal system with different collector tilt angle (range between 30° and 60° with a step of 5°).



Fig. 174: example of the collector tilt angle parameter input as a range of values

Then the 'System diagram results' can be ticked in the fourth part of 'Parametrizing Wizard'.

Finally you can start your simulation by clicking on 'Start Multiple Simulation'.

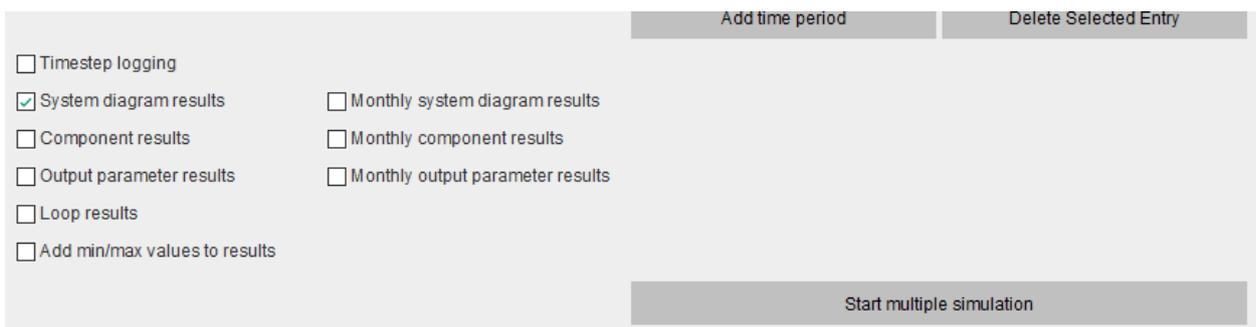


Fig. 175: settings of the parametrizing Wizard

When the simulation is completed, you can go to the folder defined previously and open the last saved folder with the simulation data for each time step 'VariantResultSummary'.

The results can be evaluated more precisely graphically.

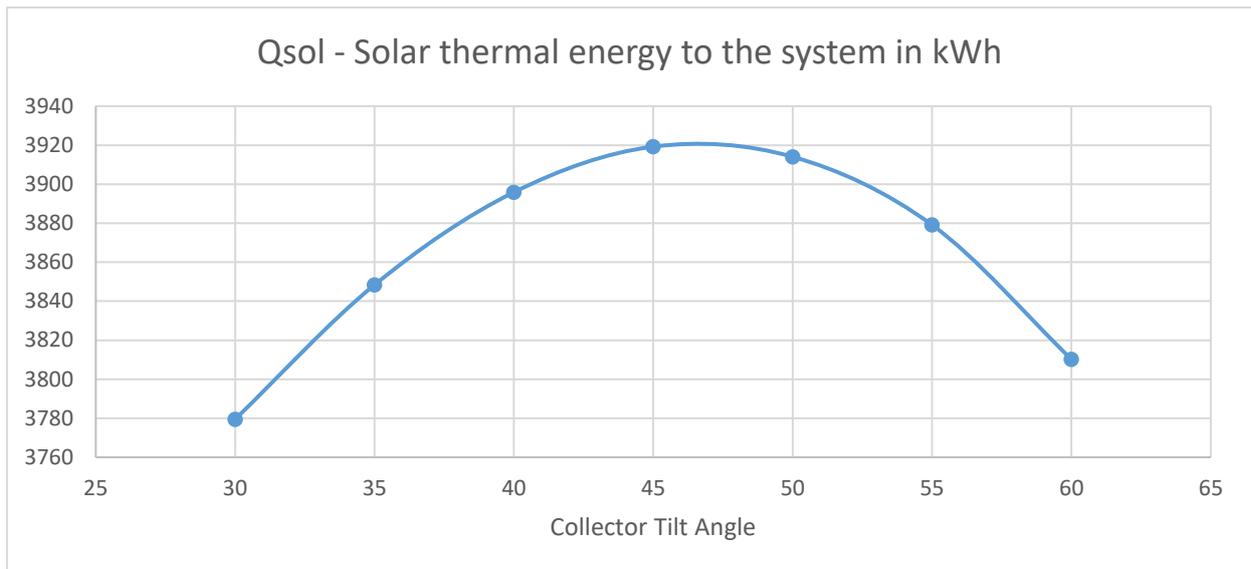


Fig. 176: example of the simulation results presented graphically

7.12.2 Log

The second option is to log defined parameters and time frames based on the time steps. It can be done for one or all system diagrams.

The required variables can be defined in the 'Output data' by clicking on 'Add output data'. The selected data is registered for every time step of the simulation in the log files.

As an example we can choose the following parameters for a solar thermal system:

- Average outdoor temperature (T_{amb});
- Outflow temperature of the collector;
- Layer 3 in the storage tank.

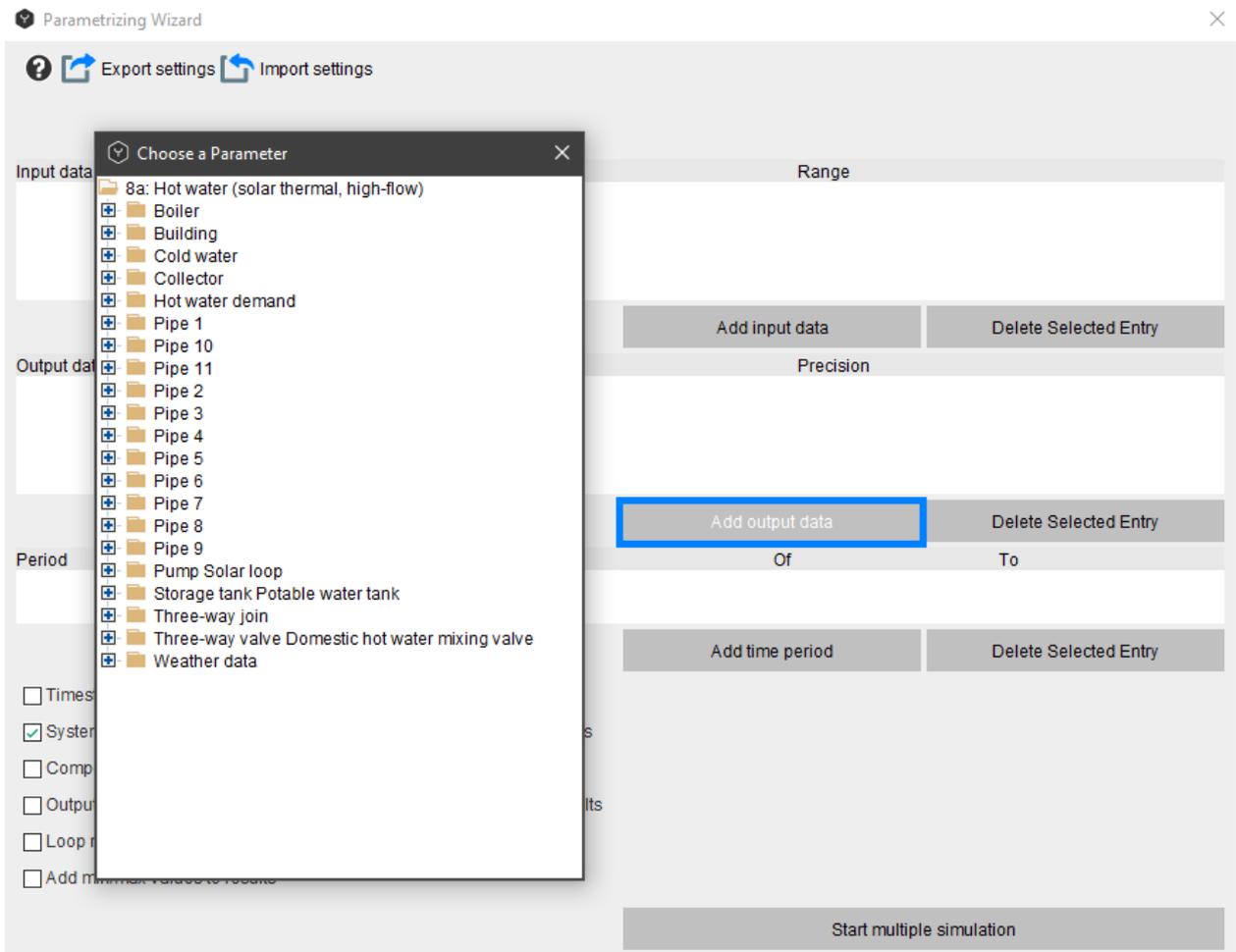


Fig. 177: definition of the log output parameters in the dialog window

Then the time period shall be defined in the “Period” tab, by clicking on “Add time period” and choosing the appropriate one. In the defined time period all simulation time steps are logged. As a default value May 1st of the current year is used.



Fig. 178: adding the log time period

The result file will contain all time step values (the smallest time step can be 1 second). This feature helps to do a more detailed simulation analysis and it can be compared with the measured data on the field. The results of the simulation are saved in the previously defined folder. Here all logged data files can be found. You can take the last folder and then do the detailed analysis of the available data. With the given data you can sketch a graph which will show how the chosen parameters change during the day.

Then you can start your simulation by clicking on the ‘Start Multiple Simulation’.

The logged data for the chosen parameters can be found in the pre-defined folder under the name ‘Timesteps_variation_1.csv’

In this file the data is given for the whole year for each time step period for the chosen parameters.

Weather data	Time step	Time since N	Day since Ne	Hour since be	Minute since	Second since	Date	Weather d:	Collector.Outflow	Storage tank
0	1	1.05E+07	120	23	0	0	02.05.00:00	9.598	9.701	65.511
0	30	1.05E+07	120	23	0	0	02.05.00:00	9.598	9.7	65.302
0	28	1.05E+07	120	23	0	30	02.05.00:00	9.598	9.674	64.927
0	10	1.05E+07	120	23	0	59	02.05.00:00	9.598	9.649	64.925
0	453	1.05E+07	120	23	1	8	02.05.00:01	9.598	9.641	64.873
0	533	1.05E+07	120	23	8	42	02.05.00:08	9.598	9.257	64.813
0	612	1.05E+07	120	23	17	35	02.05.00:17	9.598	8.939	64.745
0	703	1.05E+07	120	23	27	47	02.05.00:27	9.598	8.7	64.669
0	720	1.05E+07	120	23	39	29	02.05.00:39	9.598	8.536	64.593
0	510	1.05E+07	120	23	51	29	02.05.00:51	9.598	8.444	64.54
0	30	1.05E+07	121	0	0	0	02.05.01:00	10.03	8.409	64.537
0	30	1.05E+07	121	0	0	30	02.05.01:00	10.03	8.395	64.534
0	720	1.05E+07	121	0	0	59	02.05.01:01	10.03	8.367	64.461
0	720	1.05E+07	121	0	12	59	02.05.01:13	10.03	7.709	64.389
0	720	1.05E+07	121	0	25	0	02.05.01:25	10.03	7.367	64.319
0	720	1.05E+07	121	0	37	0	02.05.01:37	10.03	7.189	64.249
0	660	1.05E+07	121	0	48	59	02.05.01:49	10.03	7.096	64.187
0	30	1.05E+07	121	0	59	59	02.05.02:00	10.254	7.051	64.184
0	30	1.05E+07	121	1	0	30	02.05.02:00	10.254	7.034	64.181
0	720	1.05E+07	121	1	0	59	02.05.02:01	10.254	7	64.114
0	720	1.05E+07	121	1	13	0	02.05.02:13	10.254	6.209	64.048
0	720	1.05E+07	121	1	25	0	02.05.02:25	10.254	5.792	63.982
0	720	1.05E+07	121	1	36	59	02.05.02:37	10.254	5.571	63.918
0	660	1.05E+07	121	1	48	59	02.05.02:49	10.254	5.453	63.859

Fig. 179: example of the log data of the chosen parameters for each time step of the chosen year

In order to make a more detailed analysis a graph can be designed based on the given parameters.

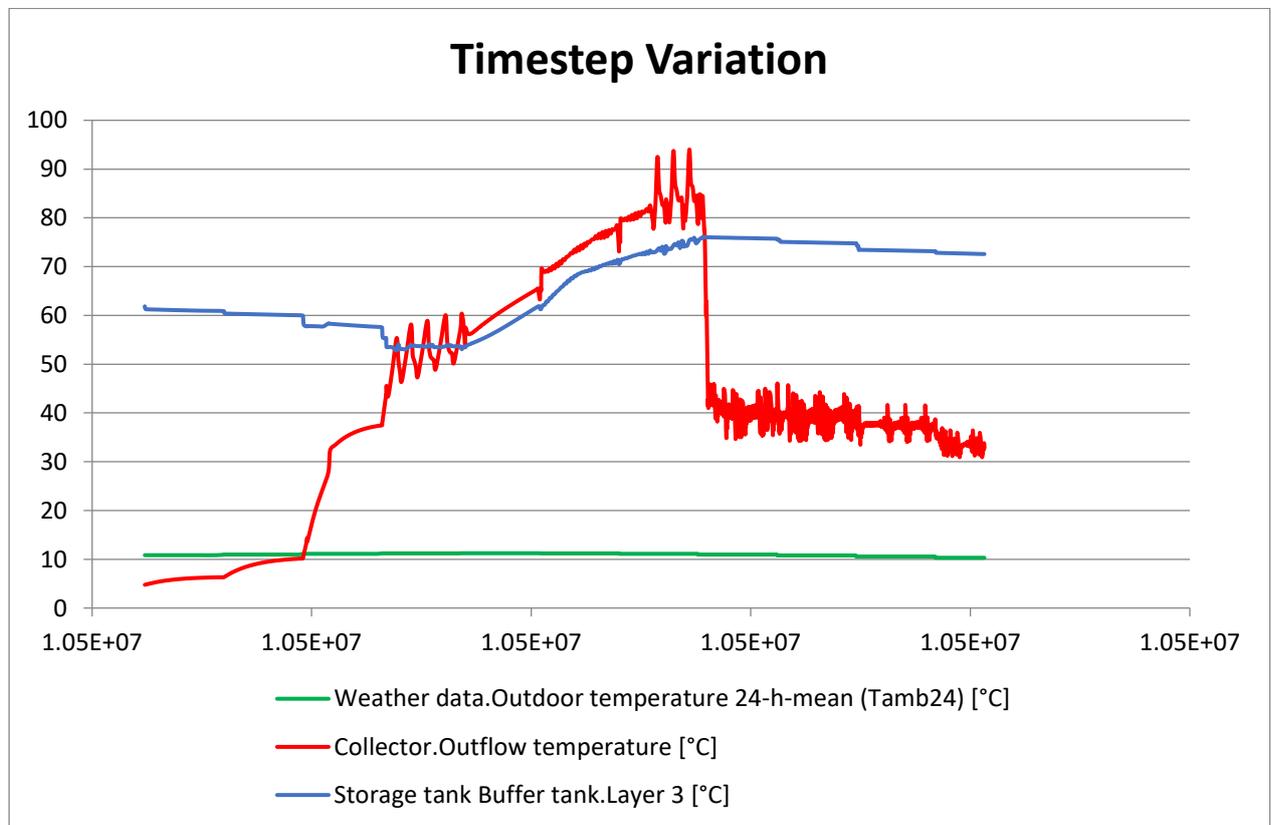


Fig. 180: graphical presentation of the logged data

In the last part of the 'Parametrizing Wizard' the presentation option of the output data can be defined. The following options are available:

Table 38. The data output format of the 'Parametrizing Wizard'

Data output format	Description
'Time step logging'	the results of the defined parameters in the 'Output data' for each time step during the defined 'Period'
'System diagram results' and 'Monthly diagram results'	the most important yearly or monthly values correspondingly for the given system. The same values are shown also in the 'System results'. The system diagram results are saved in log files VariantResultSummary.csv or Monthly_VariantResultSummary.csv correspondingly.
'Component results' and 'Monthly component results'	yearly and monthly values correspondingly for components of the system. The log data are saved in the separate files for each component.
'Output parameter results' and 'Monthly output parameter results'	simulation data for chosen parameters in the 'Output data' on the yearly and monthly basis correspondingly.
'Loop results'	yearly simulation data for the fluid loops of the existing system.
'Add min/max values to results'	allows adding minimum and maximum results to the chosen option of the output data.

Polysun Video



[Log and parametrize](#)

8 Profitability Calculation

The profitability calculation tool lets you determine different finance parameters for each option, it will also present them in a clearly laid-out way. These calculations let you do rough estimates as well as detailed analyses. In other words, the profitability calculation can be done in the very first phase of your project, or it can support the detailed analysis of an option. As default values for standard values are available and as they can be used automatically, a calculation can be done in a very short time period. The data defined manually would apply for one option only and can be saved for each option. The software will determine the full costs of the system, provided all the necessary entries are made. The internal benefit of the system (domestic hot water, heated or cooled rooms, electricity generated for self-use) is not monetarized. If there should be more expenditures than income during a period observed, the values calculated like the net present value will be negative and there will be no amortization. All calculations will be dynamic and will be presented that way. This ensures that the effects of changed raw data can be seen immediately in the results. The results of the profitability calculation will be shown in a separate report both as a table and as a graph.

Start the calculation of profitability with Ctrl + Alt + A or via Results Profitability calculation. Once the tool opens, you will find the input boxes on the left hand side, and the results of the different calculations on the right. Both sides can be faded in or out.

8.1 Input

The tool automatically copies the necessary energetic values of the planned option. As a norm, the software offers default values for the calculation of probability, which can be overwritten. The entries made will be saved as per option. An “OK” saves the entries and closes the window. “Close” will close the tool without saving the values entered.

8.1.1 Standard values

Default values offered in the tool can be overwritten and saved for each option. These default values come from different official norms and statistics. The values for the increase in energy prices come from the Swiss energy statistic of 2014, as calculated by the Swiss federal statistics office. The catalogue for the different components is from the Polysun data base. The entries made automatically for the components are the values for the components in the system planned.

8.1.2 Energy prices

Energy prices can be entered as a constant throughout the year or as a profile. For electricity prices, time periods for high and low rate tariffs can be entered and will be considered. The price per kilowatt is calculated for the maximum demand in the entire year.

The sale of thermal energy (heat/cold) will be considered under Miscellaneous and entered as an absolute amount for the entire period under consideration or for the entire year.

The different energy types will be inflated yearly by the individual energy price rises. These price rises will be considered for the purchase and the sale of energy.

8.1.3 Components

The components will be considered automatically according to your system chart and can be modified, changed or deleted. The component data can be amended by the individual price and the expected technical lifetime. The chapter names in the component list have no influence on the calculations and are meant to provide a better oversight only.

8.2 Formulas for calculation

8.2.1 Net present value (NPV)

Formulas:

One-off receipts:

Receipts year 0 = one-off subsidies + one-off tax relief + miscellaneous one-off receipts + loan

$$B_0 = B_{\text{For,e}} + B_{\text{div,e}} + B_k$$

Running receipts:

Yearly receipts = Energy sales * energy sales price * energy price increase + running subsidies + running miscellaneous receipts + thermal energy sales * energy price increase

$$B_j = E_{\text{teg}} * B_{\text{En}} * (1 + e_{\text{En}})^j + B_{\text{For,c}} + B_{\text{div,c}} + B_{\text{En,therm}} * (1 + e_{\text{En}})^j$$

One-off expenses:

Plant costs = Investment costs for construction

$$I_0 = \sum_{k=1}^{\text{Number comp.}} I_k$$

One-off expenses = Plant costs + loan repayment + miscellaneous one-off expenses

$$A_0 = I_0 + A_k + A_{\text{div},e}$$

Running expenses:

Replacement rate = Period under consideration / lifetime

$$i_{m,k} = \left\lfloor \frac{n_{\text{BP}} - 1}{n_{\text{tot},k}} \right\rfloor \quad 4$$

Replacement decision on whether a component must be replaced (0 = no, 1 = yes)

$$a_{k,j} = \begin{cases} 0, & (j - 1) \bmod n_{\text{tot},k} \neq 0 \\ 1, & (j - 1) \bmod n_{\text{tot},k} = 0 \end{cases} \quad 5$$

Replacement investment expenses per year = Investment * replacement decision * price change replacement

$$I_{m,j} = \sum_{k=1}^{\text{Number Comp.}} I_k * a_{k,j} * (1 + e_m)^j$$

Yearly expense = Maintenance costs + fees + replacement of components per year + energy bought * energy price * energy price increase + maximum energy demand * price per kilowatt * energy price increase + miscellaneous expenses

$$A_j = A_{\text{OM}} + A_G + I_{m,j} + (E_{\text{eaux}} + E_{\text{Par}}) * A_{\text{En}} * (1 + e_{\text{En}})^j + \max(E_{\text{teg}}) * A_P * (1 + e_{\text{En}})^j + A_{\text{div},c}$$

Remaining value:

Remaining value = Investment expenses * price change replacement * linear depreciation

$$W = \left(\sum_{k=1}^{\text{Number comp.}} I_k * (1 + e_m)^{i_{m,k} * n_{\text{tot},k}} * \frac{(i_{m,k} + 1) * n_{\text{tot},k} - n_{\text{BP}}}{n_{\text{tot},k}} \right)$$

Net present value:

$$\text{NPV} = B_0 - A_0 + W * (1 + i_i)^{-n_{\text{BP}}} * (1 + i_r)^{-n_{\text{BP}}} + \sum_{j=1}^{n_{\text{BP}}} ((B_j - A_j) * (1 + i_i)^{-j} - A_{\text{kr},j}) * (1 + i_r)^{-j}$$

The loan interest costs A_{kr} are not indexed with inflation. More information can be found in the chapter „Profitability terms“.

⁴ The rounding function (Floor function) rounds down to the closest integer number.

⁵ The mod function delivers the value after the decimal.

8.2.2 Internal rate of return (IRR)

For this, the NPV is set as zero. The formula is solved for i_r . The solution for i_r is found through iteration and equals the IRR.

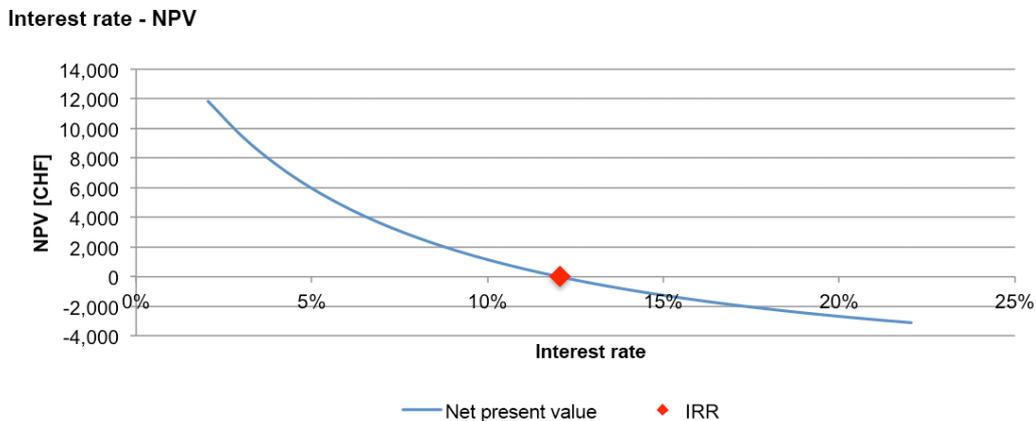


Fig. 181: diagram with the depicted IRR, which will lead to $NVP=0$

More information can be found in the chapter „Profitability terms“.

8.2.3 Payback period

The determination of the payback period is done in a cumulative way. Beginning with the year of the first payment, present values of the yearly net payments are added up, until the sum reaches zero or a positive amount for the first time. The point in time when the NPV is zero or positive for the first time is the payback period.

Depending on the settings the NPV can reach the value zero several times. If this situation occurs because of the entries made, the result will be presented with a remark pointing out that effect. In this case, the payback period is not unequivocal.

More information can be found in the chapter „Profitability terms“.

8.2.4 Annuities

Formulas:

$$AF = \frac{(1 + i_r)^{n_{BP}} * i_r}{(1 + i_r)^{n_{BP}} - 1}$$

Annuity = Capital value * annuity factor (AF)

$$A_A = NPV * AF$$

8.2.5 Energy production costs

Formula:

Energy production costs = discounted costs / discounted energy produced

$$G = \frac{A_0 - W * (1 + i_r)^{-n_{BP}}(1 + i_i)^{-n_{BP}} + \sum_{j=1}^{n_{BP}}(A_j * (1 + i_i)^{-j} + A_{kr,j}) * (1 + i_r)^{-j}}{\sum_{j=1}^{n_{BP}}(Q_{use,j} + Q_{inv,j} - Q_{Loss\ of\ energetic\ yield\ PV,j}) * (1 + i_r)^{-j}}$$

In calculating the share of the combined cost of energy production, the remaining value of the replacement investments is subtracted, interest costs on loans are considered under miscellaneous.

More information can be found in the chapter „Profitability terms“.

8.2.6 Credit costs

The credit costs (borrowing costs) mirror the interest costs of a loan at the nominal rate (inflation is not factored in). Depending on the payback, the total borrowing costs vary. For the payback of the loan, you can choose from three options:

Option 1: Type annuity with a constant payment. The sum of the payment equals the declining share of interest payments and the growing share of paybacks.

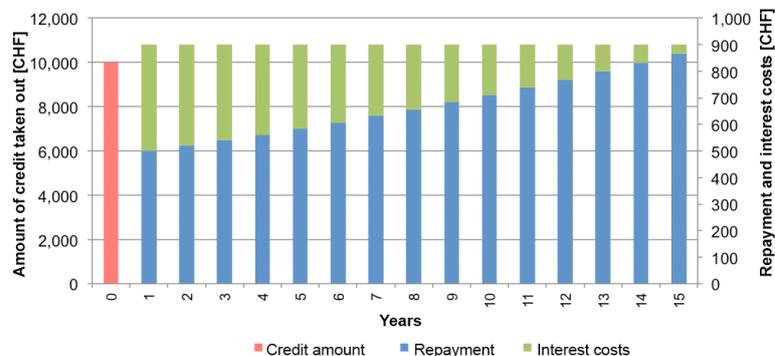


Fig. 182: repayment option with credit amount of 10,000 CHF, interest rate 4%, duration 15 years, annuity 899 CHF, total interest costs roughly 3,500 CHF

Formulas:

$$\text{Annuity} = \text{Credit sum} * \frac{(1 + \text{Credit interest rate})^{\text{Credit duration}} * \text{Credit interest rate}}{(1 + \text{Credit interest rate})^{\text{Credit duration}} - 1}$$

$$\text{Payback rate year 1 (T}_1\text{)} = \text{Annuity} - \text{Credit sum} * \text{Credit interest rate}$$

$$\text{Payback rate (T}_t\text{)} = T_1 * (1 + \text{Credit interest rate})^{\text{Credit duration} - 1}$$

$$\text{Yearly interest costs} = \text{Annuity} - T_t$$

Option 2: Constant partial amortization (payback) and decreasing interest payments

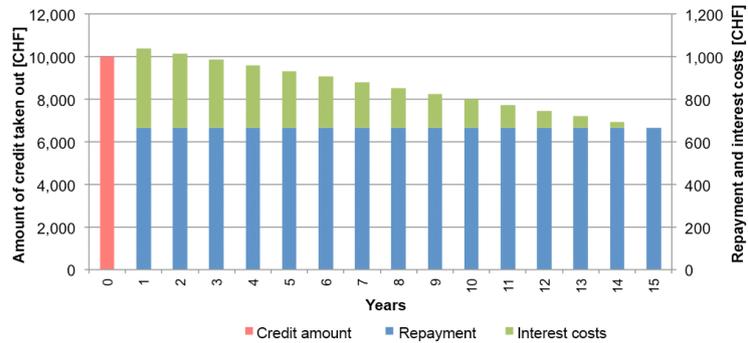


Fig. 183: repayment option with credit amount of 10,000 CHF, interest rate 4%, duration 15 years, total interest costs roughly 2,800 CHF

Formulas:

$$\text{Payback} = \frac{\text{Credit sum}}{\text{Credit duration}}$$

$$\text{Interest costs} = \text{Credit interest rate} * (\text{Credit sum} - \sum \text{interest payments})$$

Option 3: Fixed loan (bullet loan) with constant, yearly interest payments

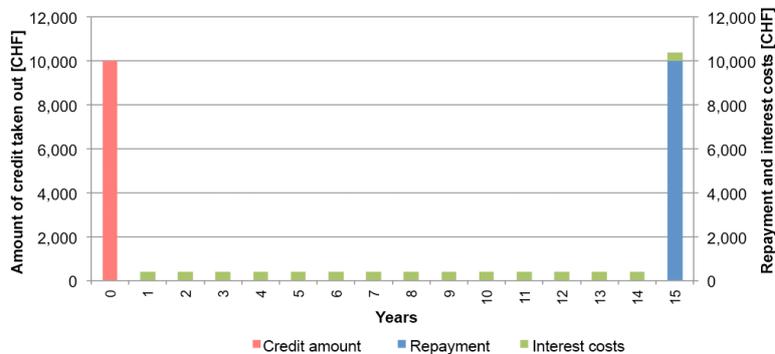


Fig. 184: repayment option with credit amount of 10,000 CHF, interest rate 4%, duration 15 years, total interest costs roughly 6,000 CHF

Formulas:

$$\text{Interest costs} = \text{Credit interest rate} * \text{Credit sum}$$

You should choose the option that resembles your own credit repayment conditions most. In general practice, the annuity option is quite common.

8.2.7 Replacement investments and technical life expectancy

The technical life expectancy's main purpose is to determine the costs for components having to be replaced for the period under observation, thus making the consideration of a life cycle analysis in the calculation possible. If, for example, one component has a life expectancy of half the period under observation, it is assumed that this component has to be replaced once during the period under observation. The investment costs for this component double accordingly. Is the (remaining) life expectancy in years longer than the (remaining) period under observation, a remaining value remains after the end of the period under observation, which is then deducted. The wear and tear of the components is assumed to be linear. Price changes taking place from the beginning of the period under observation until the time the component has to be replaced are considered with a factor. This factor is meant to reflect the learning curve for purchase prices and can be entered at will. It should be entered after talks with the constructors or picked from a trustworthy source. If the factor is positive, components are considered to increase in price over time and vice versa.

8.2.8 Automatised sensitivity analysis

The exactitude of the result of a profitability analysis is highly dependent on the reliability of the values entered. Small variations in these values can have huge effects on the result. It is thus recommended to conduct a sensitivity analysis with a view to the final result for those values entered with a large effect. This means the profitability calculation is done with the upper and the lower extreme value of this parameter, while the other parameters stay at their original value. The sensitivity analysis helps you to judge risks and possibilities of a project.

8.3 Results

In the input field, the results are divided in the chapters "Overview" and "Comprehensive". In the overview chapter, the most important results are presented as a table. For these results, Polysun also offers you charts which can be accessed by clicking on the respective line. In the "Comprehensive" chapter, these results are amended by further results.

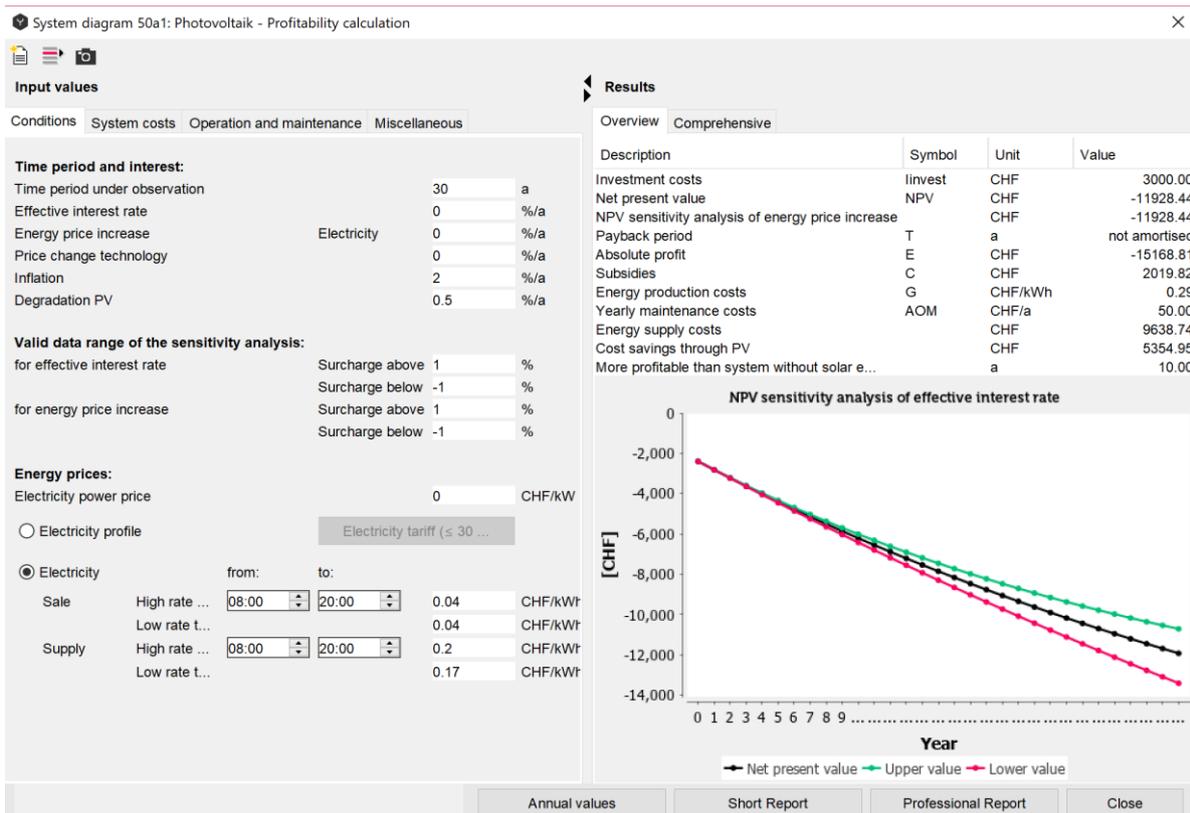


Fig. 185: overview of results with NPV sensitivity analysis, including the remaining value of the installation in the last year

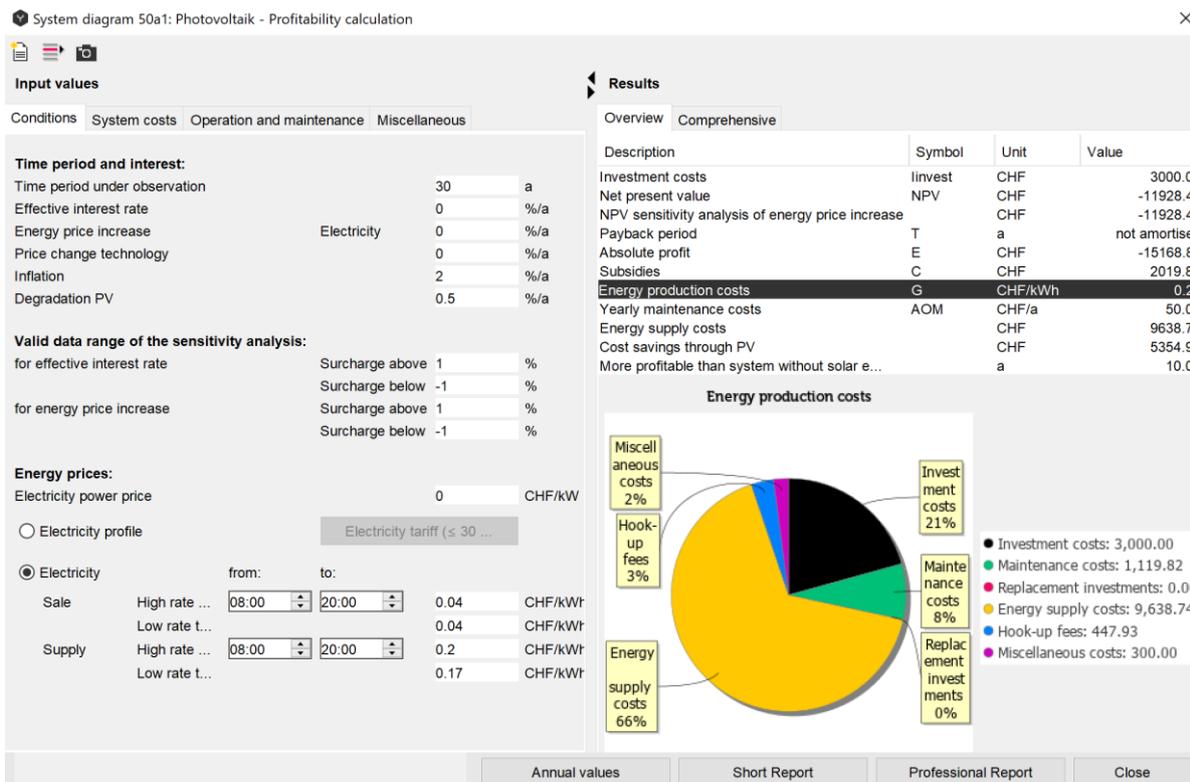


Fig. 186: graphic display of the components of the energy production costs

The overview of annual values is available in the bottom of the "Profitability calculation" dialog window as shown in the figure below.

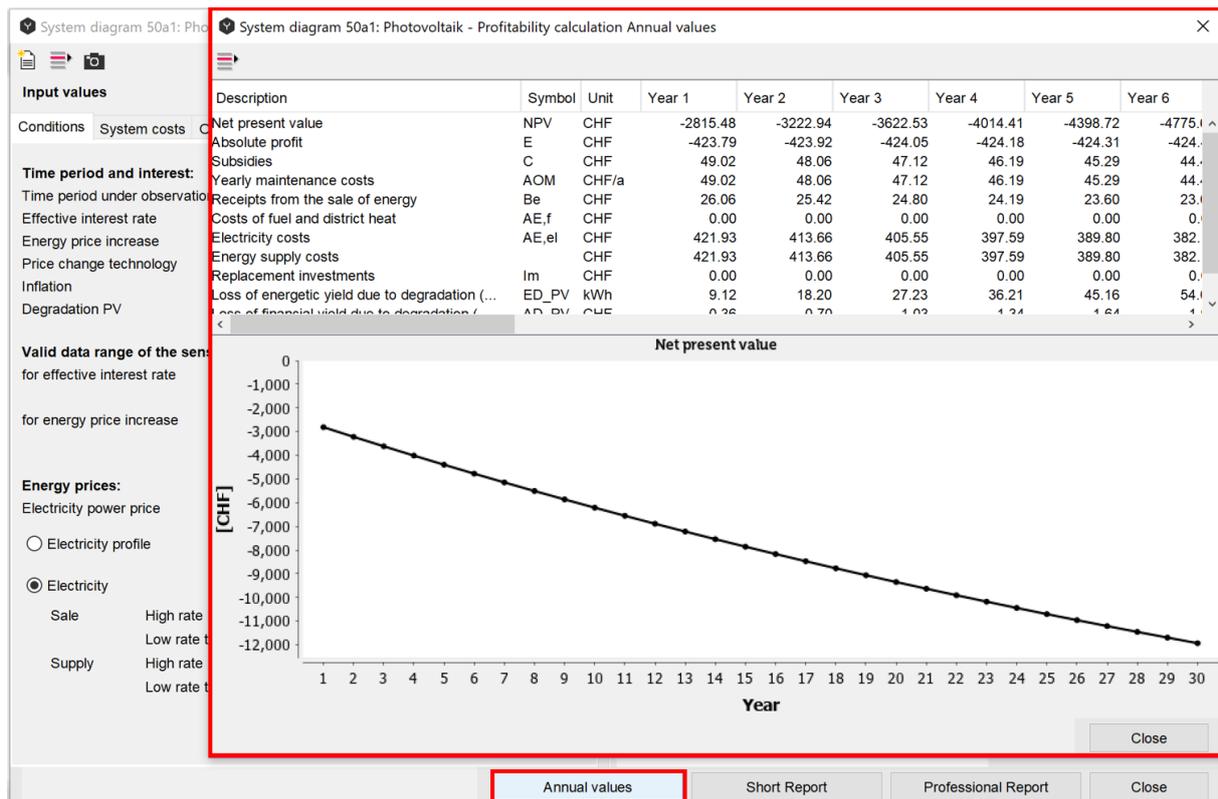


Fig. 187: overview of annual values of economic parameters

The overview shows the most important values and some additional parameters, which may be important for the economic feasibility estimation, such as:

- Receipts from the sale of energy;
- Cost of fuel and district heating;
- Electricity costs;
- Replacement investments;
- Loss of energy yield due to degradation (PV only);
- Loss of financial yield due to degradation (PV only);
- Annual cash flows;

For each parameter, the values for every year of operation as well as the graphical representation are shown under the comparison table.

Profitability: System Comparison

Polysun enables you to conduct both technical and economic analysis of energy projects. Implementation of the PV energy systems is often based on the economical evaluation. Profitability comparison feature in Polysun simplifies your decision-making. The economic comparison gives you an extensive overview about the main economic parameters over a year of the active designed system diagrams in the given project in comparison to the reference one. In order to assess the summary of the economic parameters in tabular and graphical form the “profitability comparison” can be found in the Polysun Results menu bar. The comparison table includes such parameters as investment cost, NPV, absolute profit, subsidies, energy production costs, yearly maintenance costs, energy supply costs, payback period comparison. The definition of the abovementioned parameters can be found in chapter 8.4. Based on the values given in the table, the

decision can be made which system is the most economically viable and therefore the most beneficial for the owner. The result window of the profitability comparison is shown in the figure below.

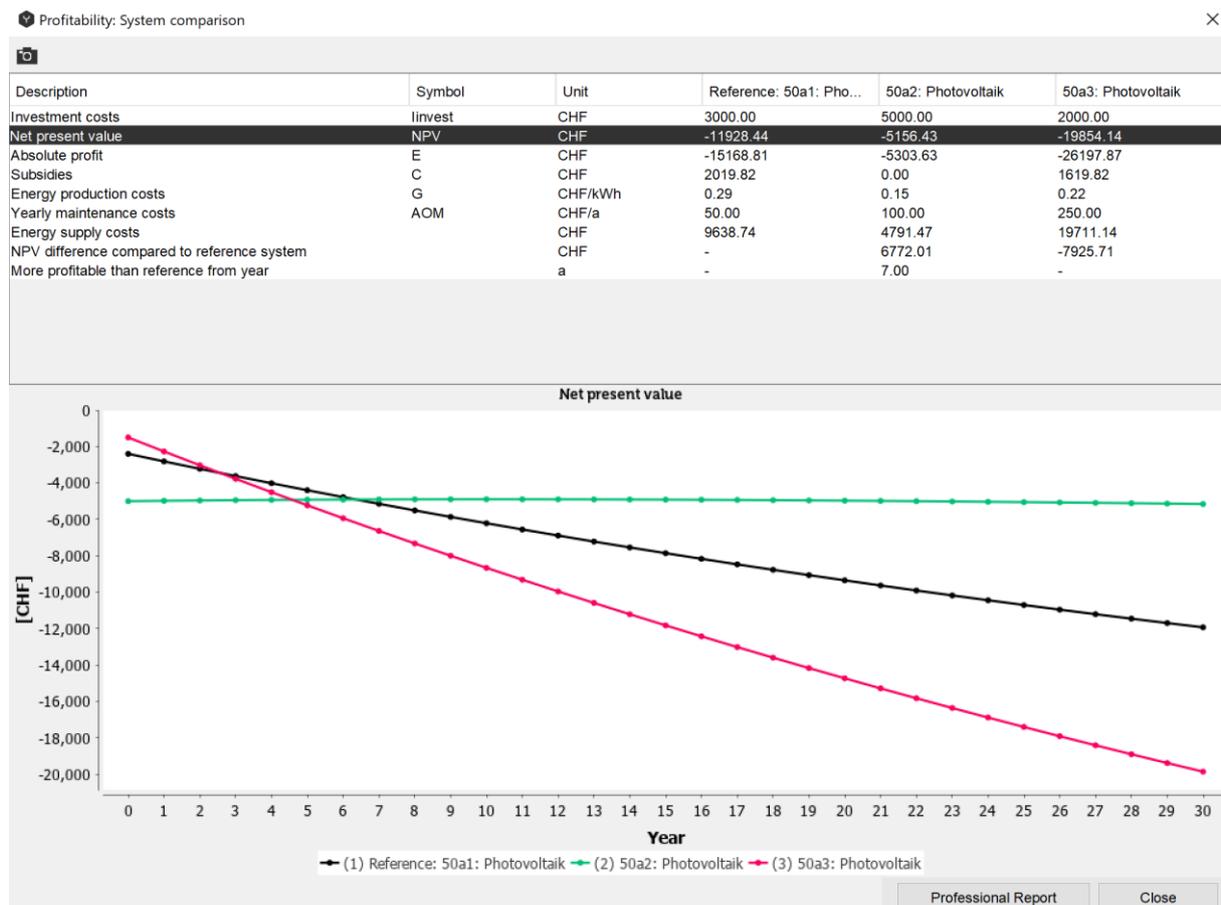


Fig. 188: profitability comparison result window with tabular and graphical representation of the economic parameters

By left-clicking on the correspondent parameter the values over the year will be visualized on the graph. The graph shows profitability comparison only for the chosen system diagrams.

In order to create a report containing comparison data, at least two system diagrams are required. Maximum 6 active system diagrams can be compared. The procedure is as follows:

1. Copy the variant you want to use for comparison (right-click on the variant in the project tree → copy system diagram) and make the desired modification in the copied variant. Alternatively, you can add another variant from the template database to the project tree (left-click on the template in the template folder).
2. Mark one system diagram as the reference (right-click on it in the project tree → set system diagram as a reference). If no reference system is set, the first system in the project will be used as a reference for comparison.
3. The system diagram can be activated or deactivated as well as set as a reference by right-clicking on it (Fig. XX). Another option is to choose the particular systems, which are to be compared in the dialog window. The correspondent dialog window

appears after choosing “Results” → “Profitability: system comparison” from the Polysun Menu Bar.

4. Select the original system diagram and start the report.

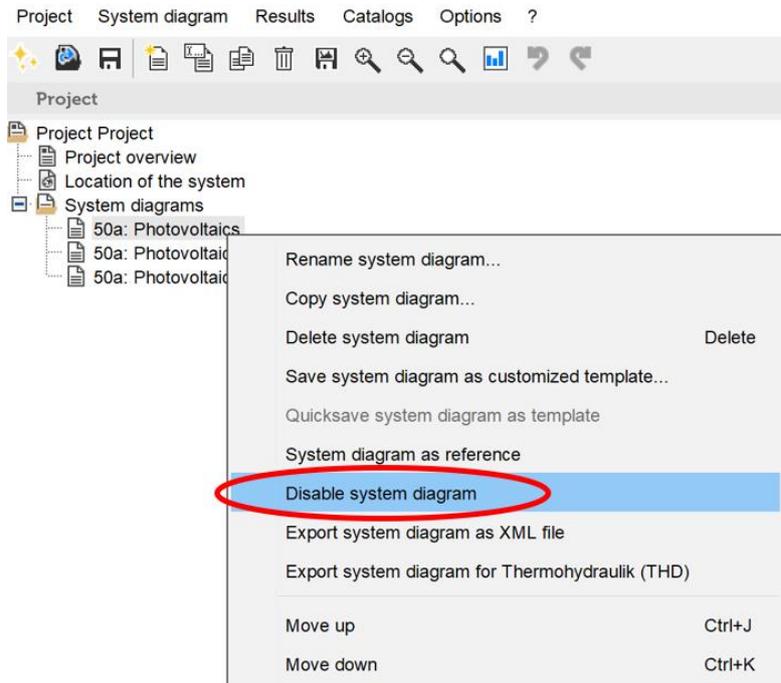


Fig. 189: enabling/disabling system diagram or setting it as a reference

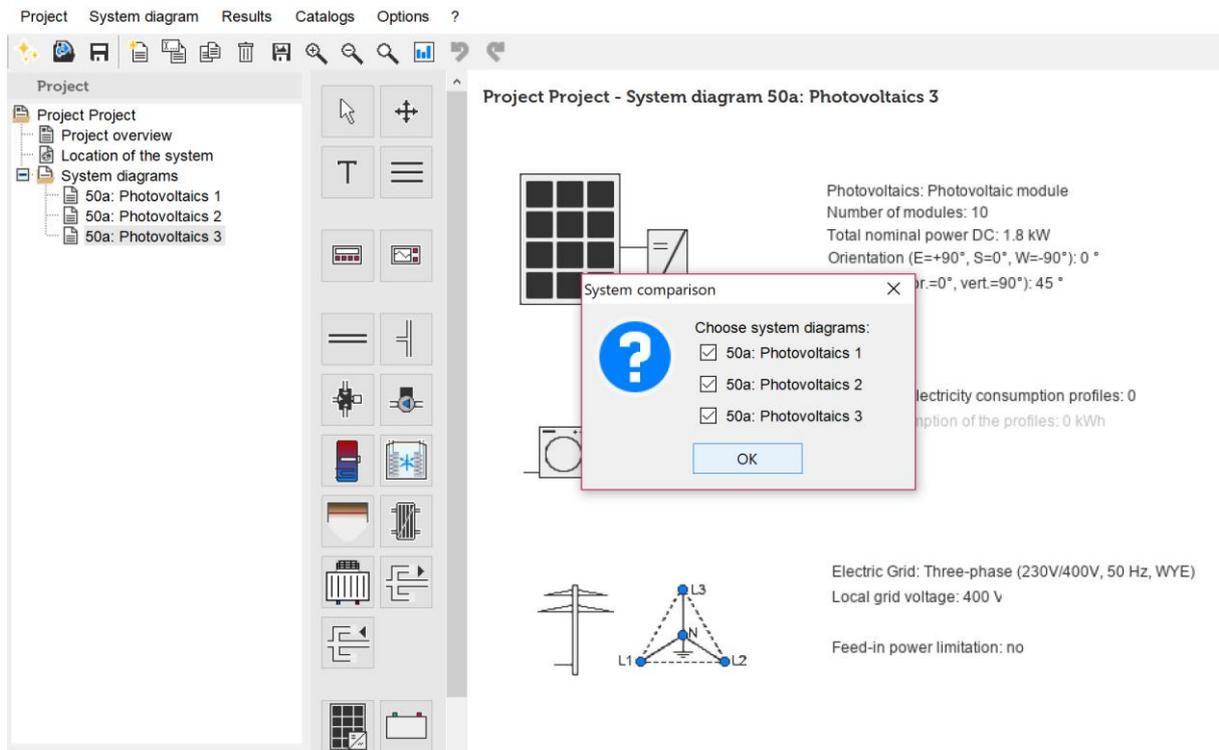


Fig. 190: selecting the variants to be compared

The profitability comparison professional report can be easily generated for by clicking on the correspondent tab in the bottom of the dialog window. System diagrams, result comparison table as well as graphs for such parameters as NPV, investment costs and energy supply are presented within a single document.

8.4 Profitability terms

8.4.1 Net present value (NPV)

The net present value is determined using the internationally renowned net present value method. It adds all incomes and expenditures of a facility, discounted by the interest rate. The cash flows of the individual years are discounted or written down to the present day with the internal rate of return (which is expressing the cost of capital). The result is the so-called present value of the payments. The net capital value expresses what would have to be paid today as a lump sum for the purchase and the upkeep of the facility for the period under observation, netted and without the cost of capital, and vice versa what the income would be as of today. This single amount is a possible form to express the profitability of a facility. It can be judged by its absolute height or compared with alternative investments.

8.4.2 Effective interest rate / Interest rate for cost of capital

The internal rate of return is used to make future cash flows, occurring at different times in the future, comparable when it comes to interest. Future income and expenses are discounted or written down using this internal rate of return to the present day. The internal rate of return expresses the cost of capital or, in projects with a net income surplus, the expected return on capital.

8.4.3 Internal rate of return (IRR)

The “internal interest rate”-method, internationally known as the method of effective interest or Internal Rate of Return (IRR), expresses the profitability of an investment as the mathematically correct determined yield of all cash flows of the investment in the period under observation. This yield can be compared in its absolute height or in comparison to alternative investments. As opposed to the net capital value method, which has a fixed interest rate (cost of capital rate) used to determine the net present value of all future cash flows, the IRR expresses the interest rate at which the net capital value equals zero. An IRR can sensibly only be calculated if during the period under observation the sum of all income is bigger than the sum of all expenses – only then one can talk of a return on capital.

The IRR makes it possible to calculate a (theoretical) average yearly return for an investment with changing and irregular incomes. If the IRR is negative, it means that the sum of the financial income is smaller than the capital invested.

8.4.4 Dynamic payback period

The payback period describes the amount of time it takes for an investment to pay itself off. A payback time can be calculated for investments, whose paybacks until a given point in time are larger as the sum invested, or equal that sum.

The simple payback period accumulates all paybacks from the time the investment was made nominally, until the (theoretical) balance is back to zero. The dynamic payback period used in the tool accumulates all paybacks from the time the investment was made as present values, until the net capital value is back to zero. In other words, the dynamic payback period expresses the time period an investment needs to reach the interest rate used in the calculation of the net values.

8.4.5 Inflation

Inflation describes the general and prolonged rise in the prices for goods, equalling at the same time the fall in the purchasing power of money. Inflation is usually expressed by yearly price changes of goods found in a hypothetical basket of goods. How can the expected future inflation incorporated in the cash flows of a simulation in Polysun?

If you expect continued low inflation, we urgently advise you not to inflate future costs and incomes for the following reasons:

The effects on prices of non-inflationary causes like supply and demand in case of energy prices, or the life-cycle-caused price changes in case of electrical apparatuses, are much stronger than the influence of inflation.

At low inflation rates, the economic subjects fall victim to the so-called money illusion. This means that inflation is so low and restricted to limited groups of goods that decisions are made based on nominal prices.

Long-term predictions of the future inflation rate of an economic area are only possible with a considerable amount of uncertainty.

As of 2016, the inflation rate is considered to remain low for the considerable future in the Swiss Franc- and Euro-Area. If expected inflation rates are high (multi-year average of above 5 % per year), it may make sense to inflate future prices and costs in the tool, as that will also mean that the money illusion of the economic subjects will be destroyed and the mechanisms of automatic indexing are starting to grip again. It is for this case that the tool offers the possibility to inflate future incomes and costs.

In the results (as in the reports), all values are shown nominally (including inflation). This might lead to some confusion. This is especially true if, for example, the same amount for yearly maintenance costs is entered manually, and the total for maintenance costs does not equal the multiple of the values entered: inflation is the reason for this deviation. Based on this change, however, it is possible to gauge the effect of inflation.

8.4.6 Cost of capital

The calculation of the economic advantageousness of investment projects is generally based on the total capital approach, as the economic performance of a facility is not dependent upon how it is financed. The capital cost rate or internal rate of return must therefore be a weighted, average interest rate derived from debt and own capital.⁶

If the economic advantageousness of a partially debt-financed investment is to be calculated, all income and costs related to the debt have to be considered (loan payout = income, loan payback = cost, interest payment = cost). The income and cost of a loan are considered by the tool if a loan is defined (interest rate, loan amount, duration). The net cash flows then only have to be funded by own capital. The internal rate of return would then have to equal the own capital cost rate or – in case of projects with a net surplus of income – the expected interest on own capital.

In case of a loan (like a bank loan), the tool automatically considers the payback and calculates the corresponding cash flows. In the year zero the payout of the loan is considered to be income and the subsequent payback as cost. Both add up to zero. The loan payback payments are shown in the charts depicting the cash flows. The payback and the interest on loans are not subject to inflation.

8.4.7 Energy production costs

The energy production costs mirror the cost for a usable, provided energy unit. In its calculation, the calculation method Levelized Cost of Energy (LCOE) is used. It determines the running costs per year under consideration, adds them up, discounts them with internal rate of return for the referenced point in time and adds the one-off costs. The discounted costs are then divided by the usable, provided energy units discounted for the referenced point in time. The LCOE is a common method used in the industry to calculate energy production costs. The formula can be used to calculate the production costs of all kinds of energy, be in thermal or electric.

As both the cost and the amount of energy produced during the period under observation are discounted to a referenced point in time, the comparability of energy production cost is given. The energy production costs provide comparable prices based on costs, not in dependence of feed-in tariffs. The value of the individual amounts of energy will not be determined separately, as it does not have to be.

8.4.8 Cost savings through PV

Energy yield from PV modules is calculated with the current electricity rates in order to see clearly how much does the electricity generated from photovoltaic modules would cost, if it were consumed from electricity grid. This number shows how much money the owner would have to pay without installing a PV system.

Cost savings through PV are calculated in a following way:

$$Q_{inv}(\text{hour}) - E_{teg}(\text{hour}) * \text{SupplyTariff}(\text{hour}) + E_{teg}(\text{hour}) * \text{FeedInTariff}(\text{hour})$$

⁶ Own capital also costs interest, namely the opportunity costs: the income foregone that could have been made if another, alternative investment had been made.

8.4.9 More profitable than reference from year

Payback period comparison for PV systems shows in which year the payback is reached in comparison to a reference system. In other words, in which year the system with renewable energy fraction becomes more profitable than the reference system. Dashes appear instead of a number of years, if the new system is less profitable in comparison with the reference one. On the example shown in the figure the system Nr. 3 (yellow line) is less profitable as the reference (red line), therefore the hyphen is shown. The system Nr. 2 (orange line) reaches payback in 9 years.

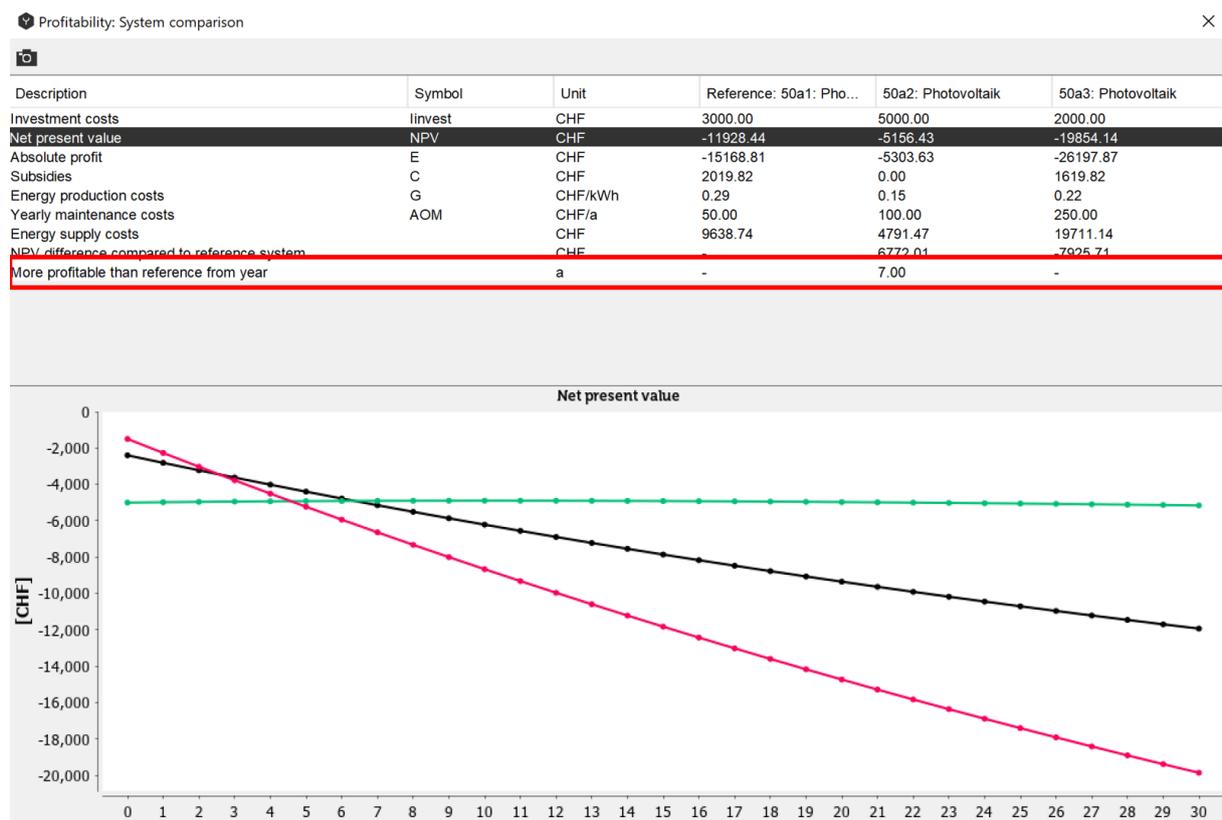


Fig. 191: profitability comparison of the selected systems in comparison to the reference

8.5 Useful hints for the calculation of profitability

8.5.1 Default standard values

Default values are provided for the period under observation, the internal rate of return, price changes when replacing components, inflation, degradation of photovoltaic cells and the parameters for the automatic sensitivity analysis. These values are used for each new project or variant. These default values are partially based on norms and research results and have been set by Vela Solaris.

8.5.2 Savings are not income

Savings compared to a different variant (for example, heating oil saved because a heat pump is used) must not be considered as income from an economic point of view. These savings reduce costs and the savings effect is shown when different variants are compared.

8.5.3 How are new variants compared to the old, existing facility?

When comparing different new facility variants with an existing facility, the existing facility is modeled in Polysun and the values for its profitability determined. This way, the results of the profitability of the existing facility can be compared to the new solutions. This puts you in a position to point out for the long term what difference it makes if the old facility is left in place or is replaced by a new one. For this it is important that the full costs of each variant are considered and the same basic assumptions are used.

8.5.4 Dealing with electric consumers

The energy used by the electric consumers (for example, a private household) are treated like energy costs for purposes of profitability. If two variants are compared, you need to take care that both variants have identical electric consumers.

8.5.5 How is it defined whether electricity produced through PV will be fed into the grid or consumed?

In the features of the electric consumers, you can define under „With electric consumption of the thermal components“ (yes/no-answer) whether the electricity produced through PV will be used for the facility (pick „yes“) or will be fed into the grid (pick „no“).

8.5.6 What does the use of an electrical battery cost per energy unit?

If you install a PV plant, you are sometimes faced with the question whether the installation of a battery would be useful, for example to save the solar energy of the day for use during the night. The influence of a battery on profitability can be calculated comparing two otherwise equal variants, one with and one without battery. If all other parameters of the variants considered are equal (except for the presence or absence of a battery), the difference in energy production costs will reflect the costs for the battery per energy unit.

Polysun Video



[Profitability calculation](#)

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