WP5.D3: Design and simulation software

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SUMMARY

The target of the Work Package 5 of the NEGST project is the assessment of the potential of low to medium temperature solar collectors for advanced applications, specifically solar cooling and solar desalination.
In the first WP5 deliverable the state of the art of all cooling and desalination technologies which can be in theory used in combination with low to medium temperature solar thermal collectors was presented. The aim of this paper was to collect useful technical information for an initial selection of a limited number of systems to be deeply investigated in the following stages of the WP5. For this purpose a preliminary screening criterion, consisting of an energy comparison between the major technologies, was also introduced.
In addition the second WP5 deliverable supplies non-technical information in order to complete the background for the assessment of the suitability of the different collector types for solar cooling and solar desalination. In this paper other significant aspects, such like the level of interest in each technology, the barriers to its application, the cost-effectiveness, and the prospective of development are evaluated, based upon the opinions of researchers and manufacturers working in the field under investigation. For this purpose a questionnaire was prepared and circulated amongst the involved experts.
The current step is the development of a design software tool for dimensioning solar heating and cooling systems, which is offered as WP5.D3. This tool is essential to perform a number of feasibility studies aimed at identifying the potential areas for these applications, according to the targets of the WP5.D5 and the whole WP5.
In this paper an introduction to the methodology implemented in the software tool is presented together with a description of its main characteristics. In addition a brief explanation is given about the parameters required as input data and the corresponding items available as calculation outputs. Clearly among the last ones the main figures necessary for the development of the feasibility studies are included, such as the collector area corresponding to a certain primary energy saving and the associated annual solar fraction.
This information is presented so that the end user of the software tool can follow the calculation method step by step, thus being immediately able to run it. Easy use was one of the main issues, which was considered when developing this software tool.

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1. SOFTWARE TOOL FOR DIMENSIONING SOLAR COOLING SYSTEMS

Within the scope of the Work Package 5, the implementation of a calculation tool for dimensioning solar heating and cooling systems is a key step towards the assessment of the most suitable solar thermal technologies for the air-conditioning of buildings. In this framework a novel design and simulation software has been developed, trying to obtain the best trade off between simplicity and effectiveness for the objectives of WP5. As a result, an easy-to-use calculation tool, which can be especially operated to perform feasibility studies, has been made available. In effect, the identification of the potential areas for solar heating and cooling applications is the focus of the WP5 final deliverable.
In the following sections a brief description of the methodology implemented in the software tool and its main characteristics is introduced. Then a guide to the use of the tool is offered, by supplying a short explanation of each item present in both the input and the output section of the software.

1.1 Methodology implemented

The methodology implemented to perform the thermal analysis of the different solar cooling systems can be summarized in the following main steps:

- Calculation of both cooling and heating loads on monthly basis for the building located in the selected site. This issue is accomplished by multiplying the building area by the monthly values of the total thermal demand for both heating and cooling per unit of conditioned floor area, provided by the end user as input data.
- Calculation of the related primary energy consumption of the conventional cooling and heating system to be replaced by solar energy. An electrically driven vapour compression chiller, operating as a heat pump during the winter season, is assumed as the default reference system, being the most common system for the air-conditioning of the buildings in Europe. However, it is possible to refer to any other conventional system by setting to appropriate values the associated cooling and heating COP.
- Calculation of the thermal energy required by the solar system. This issue is achieved by dividing the monthly values of the building loads by the coefficient of performance of the thermally driven chiller.
- Assumption of a reasonable fraction of the primary energy consumption to be replaced by the solar energy.
- Evaluation of the requested collectors area to obtain the desired primary energy saving.

The last two steps are repeated for a wide range of values of primary energy to be saved.

PHIBAR f-Chart method (/Duf91/), applied to a general solar heating system, has been implemented to perform the thermal analysis of each solar assisted air-conditioning system under investigation.
Figure 1 shows the schematic of this type of solar thermal system, which can be used in principle for a wide range of thermal applications including space heating and air-conditioning.
In this system, solar energy is collected and stored in a liquid storage tank via a heat exchanger. In the closed-loop configuration, when required by the user, the heated liquid is pumped, through a second heat exchanger, from the storage to supply the thermal energy to the load. Alternatively, the fluid can be pumped directly to the user in an open-loop system.
For this kind of solar heating system, the thermal energy is delivered when the temperature is above a specified minimum useful temperature (T_{min}). The value of T_{min} depends on the type of application: for residential space heating, T_{min} is the indoor temperature of the building; for thermally driven air-conditioning applications, it depends on the particular installation. An auxiliary heater provides for supplying the thermal energy, when the solar input is not sufficient to meet the load.

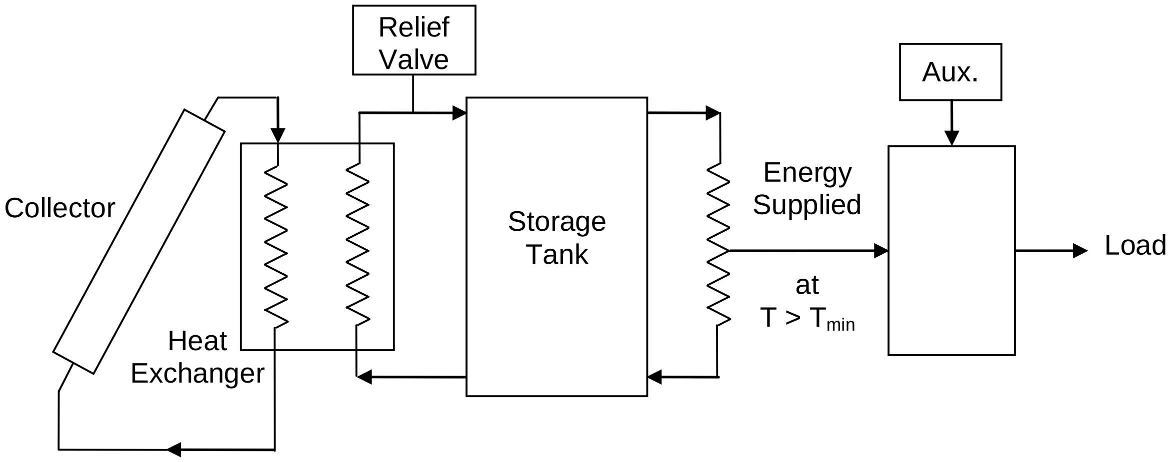


Figure 1: Schematic of a general closed-loop solar heating system (/Kle01/).

The calculation method adopted in this software is appropriate to analyse thermally driven chillers (in particular absorption cooling cycles), which are characterized by a minimum driving temperature under which they cannot operate correctly.

1.2 Main characteristics of the software tool

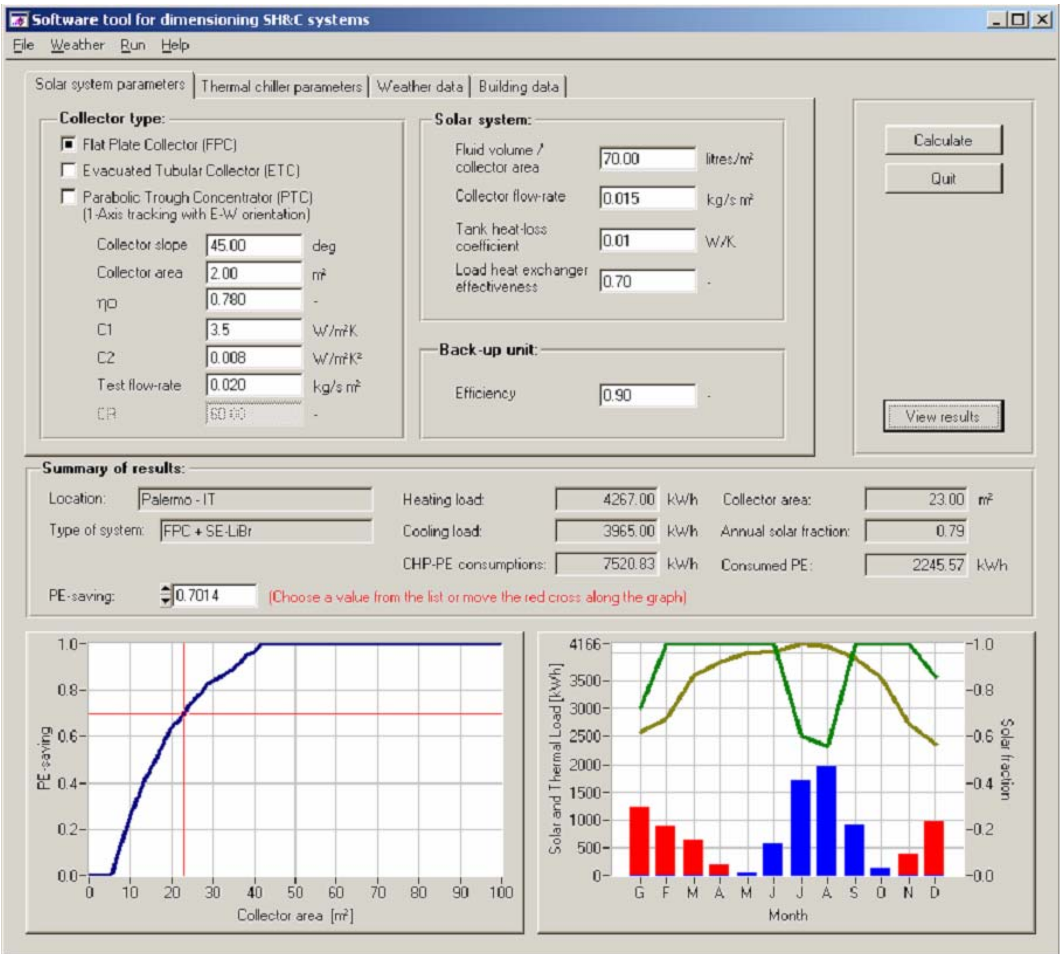


Figure 2: Graphical user interface of the design software tool.

Figure 2 shows the graphical user interface of the software tool, whose main characteristics are summarized below:

- Annual solar fraction for heating and cooling is calculated starting from monthly-based average meteorological data and building loads (to be provided as input data).
- Solar system is mainly characterized by the efficiency curve parameters of the solar collector, the efficiency of the back-up unit, the main features of both the solar tank and the heat exchanger. A wide range of solar collectors, going from flat-plate collectors to evacuated tubular collectors and concentrating collectors, can be taken into account.
- Thermal air-conditioning system is characterized by its cooling COP (and heating if reversible) and its driving temperature. This representation is specially intended for the analysis of single and double-effect H_2O/LiBr and NH_3/H_2O absorption chillers, but in practice any other cooling system, which can be schematized through these parameters, can be evaluated.
- The result is two plots:
  - o a curve reporting the variation of the primary energy saved with respect to the reference conventional system, as a function of the collector area.
  - o a chart showing the heating and cooling loads on a monthly basis (bars) as well as the solar fraction and solar radiation.

2. USER'S MANUAL

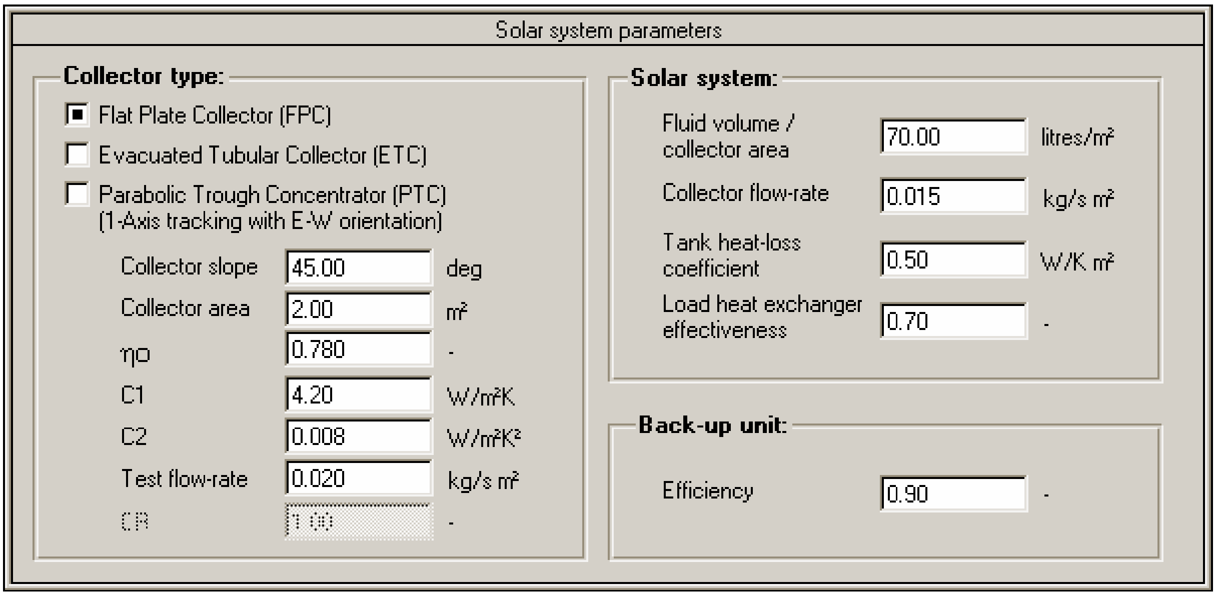
In the following paragraphs, a short description of each input and output section, along with an explanation of each parameter adopted for the thermal analysis, is provided.

2.1 Solar system parameters

Three types of solar collectors can be assessed by the present software:

- flat-plate collector (FPC);
- evacuated tubular collector (ETC);
- parabolic trough concentrator (PTC).

With regard to the last type of collector, in the present version of the software tool, only the PTC with East-West orientation for the axis tracking is considered. Each type of collector can be used in combination with any of the thermal chiller specified in the next paragraph. The collector is chosen from a list by clicking on the desired type.



Collector slope is the angle between the plane of the collector aperture and the horizontal.

Collector area is the area of collector panel that is used to determine the efficiency curve parameters.

ηo, C1, C2 are the efficiency curve parameters determined according to the standard EN12975.

Test flow-rate is the collector fluid flow rate per unit area used in the collector test.

CR (Concentration Ratio) is the ratio of the collector aperture area to the receiver area. This parameter is pertinent only to PTC collectors.

Fluid volume / collector area is the volume of the stored fluid per unit of collector area.

Collector flow-rate is the ratio between the total mass flow rate of the collector fluid through the collector array and the total collector area.

Tank heat-loss coefficient is the energy loss coefficient per unit of surface area for the solar storage tank. The default value of 0.5 W/m^2K is representative for tanks used in low temperature applications. Lower values are advisable for medium temperature applications.

Load heat exchanger effectiveness is the ratio of the current to maximum heat transfer rates in the heat exchanger between the solar storage tank and the load in a closed-loop system. For an open-loop system, this heat exchanger does not exist and this parameter must be set equal to 1.0.

Efficiency of back-up unit indicates the average efficiency of the auxiliary heating system.

2.2 Thermal chiller parameters

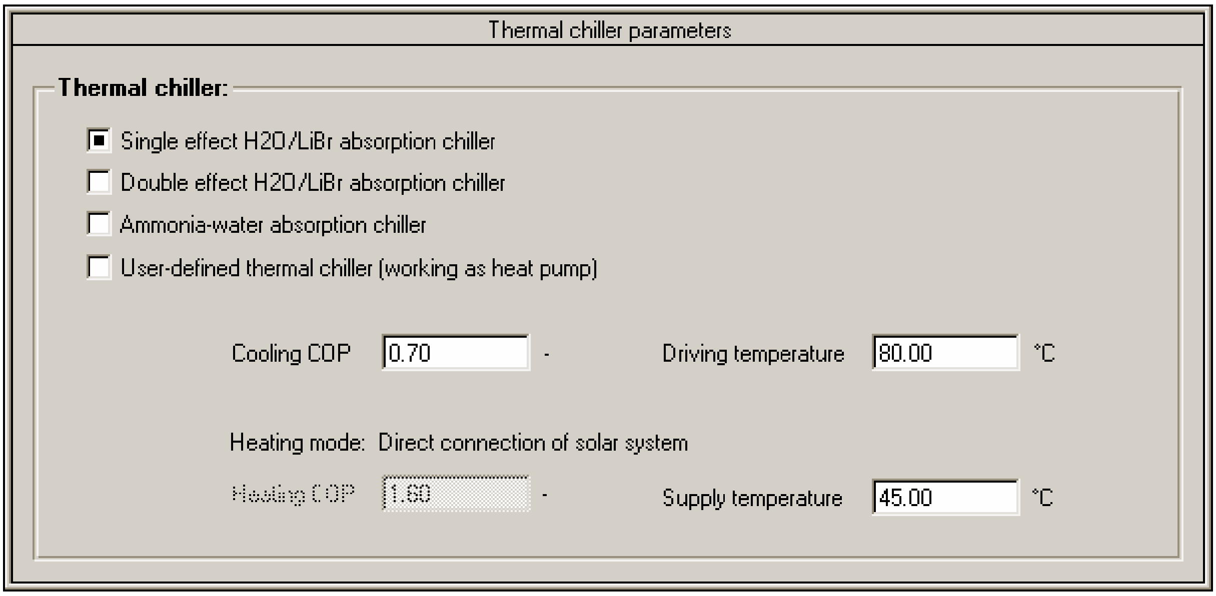
Three type of absorption chillers can be selected from the corresponding panel:

- single-effect cooling cycles using water/lithium bromide as working pair;
- double-effect cooling cycles using water/lithium bromide as working pair;
- advanced AHE cooling cycles using ammonia/water as working pair.

A fourth option ("User-defined thermal chiller") allows the user to analyse any other process (for example Thermo-Chemical Accumulator), which can be characterized via its cooling COP (and heating if reversible) and its driving temperature.

For each cooling cycle, typical values for the main parameters (COP and driving temperature) can be adopted on the basis of the information available in literature. These values, corresponding to average values, are considered constant for the whole conditioning period. In order to avoid an overestimation of the performance of the considered solar cooling system, the user has to pay particular attention to enter realistic values for COP and driving temperature. The current default values of COP correspond to the nominal values at design conditions, which can be achieved by implementing into the system an accurate control device.

Since the thermal analysis is performed on annual basis, for cooling cycles working only as refrigerator, the heat supplied by the solar field is directly used to meet the load during the winter season. This is accomplished by means of common low temperature heat distribution systems for space heating, assuming a suitable value for the supply temperature.



Cooling / Heating COP (Coefficient Of Performance) is the ratio of the thermal cooling output (or heating output for a chiller working as heat pump) to the driving heat input.

Driving temperature is the temperature at which the driving heat must be supplied to the working fluid.

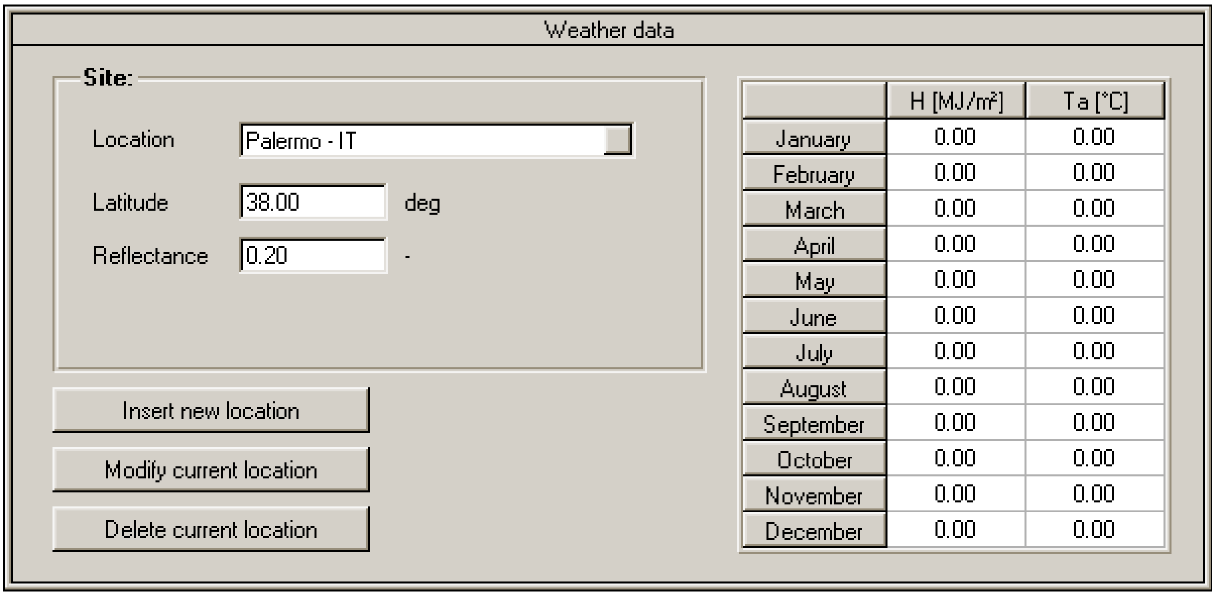
Supply temperature is the temperature at which the driving heat must be provided to a common low temperature heat distribution system for space heating.

2.3 Weather data

The software tool allows the user to manage a wide range of locations (up to 2000 sites) characterized by the following meteorological data: latitude of the site, monthly-average daily values of the solar radiation on horizontal plane and ambient temperature.

When the software is launched, a default Weather Archive (default.wdat) is loaded, it contains four locations (Palermo – IT, Lisbon – PT, Athens – GR and Rome – IT) inserted as samples of meteorological data to be processed. The user can insert new locations and modify or delete the existing ones. Furthermore, the user can create new Weather Archives (with the extension ".wdat") in which he can insert new locations.

Next, a short explanation of the parameters required to run the software and how the user can perform the operations on the previously described weather archives is given.



Location is the site where the system is located. It can be chosen from a list containing all the locations stored in the Weather Archive. Other Weather Archives can be loaded selecting “Load weather archive” from Weather menu. A new weather archive can be created from a copy of the original “default.wdat” file. Subsequently the user can modify this new archive according to the steps illustrated below.

Reflectance is the ground reflectance of the surrounding.

Insert new location allows the user to insert meteorological data for a new location. When clicking on this item, a dialog box appears in which it is possible to introduce the name of the new location, the latitude and the monthly-average daily values of the solar radiation on horizontal plane (H) and the ambient temperature (Ta). By clicking SAVE the new data can be inserted in the list of locations. This operation does not modify the Weather Archive. To save permanently the new location in the current or in a new Weather Archive “Save weather archive” or “Save as new weather archive” from the Weather menu must be selected.

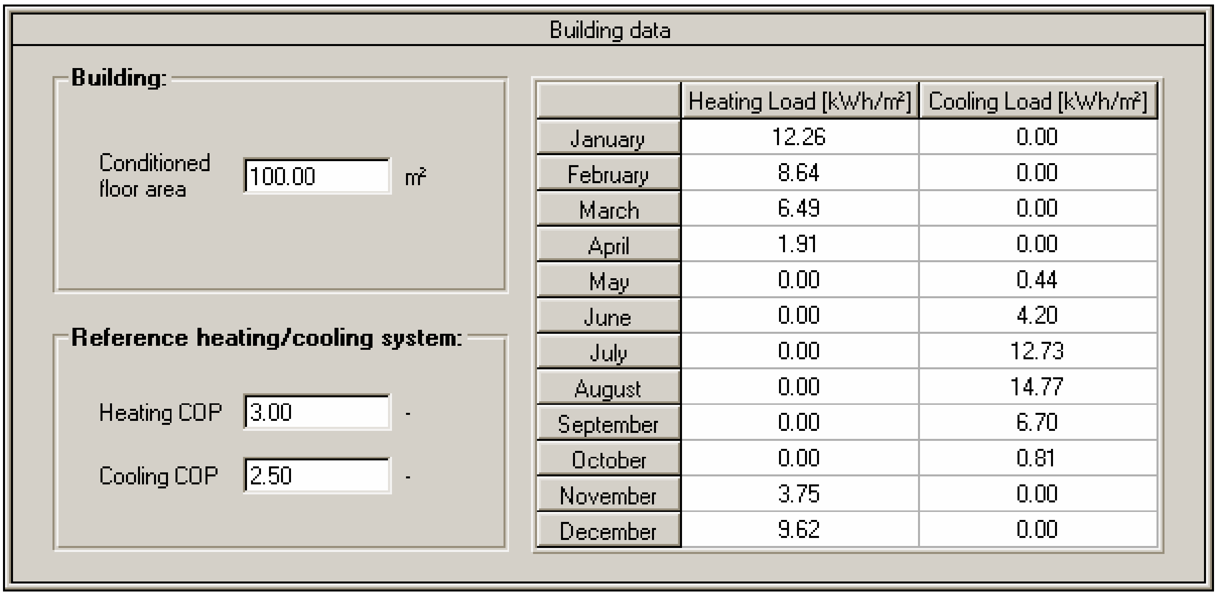
Modify current location allows the user to modify meteorological data for the current location. When clicking on this item, a dialog box appears in which the name of the location, its latitude and the monthly-average daily values of the solar radiation on horizontal plane (H) and the ambient temperature (Ta) are visualized. Changes can be made in these values and then saved by clicking on SAVE. This operation does not modify the Weather Archive. To save permanently the modification “Save weather archive” or “Save as new weather archive” from the Weather menu must be selected.

Delete current location allows the user to delete the current location. This operation does not modify permanently the Weather Archive too. To make permanently the deletion of the location “Save weather archive” or “Save as new weather archive” from the Weather menu must be selected.

2.4 Building data

In the present software tool the building is completely characterized by its total thermal energy demand for both heating and cooling, which must be entered on monthly-basis and per unit of

conditioned floor area. In order to evaluate the required loads for heating and cooling, different software tools (TRNSYS, EnergyPlus, etc.) are available in literature.
Moreover, in order to perform the thermal analysis according to the methodology initially described, the heating and cooling COP of a reference heating/cooling system have to be provided (the default values correspond to the average heating and cooling COP of an electrically driven vapour compression heat pump). This issue allows to evaluate the corresponding primary energy consumed by the heating and cooling machine assumed as the reference system.



	Heating Load [kWh/m²]	Cooling Load [kWh/m²]
January	12.26	0.00
February	8.64	0.00
March	6.49	0.00
April	1.91	0.00
May	0.00	0.44
June	0.00	4.20
July	0.00	12.73
August	0.00	14.77
September	0.00	6.70
October	0.00	0.81
November	3.75	0.00
December	9.62	0.00

Conditioned floor area is the effective building floor area to be conditioned.

Heating COP is the Coefficient Of Performance of the electrically driven vapour compression heat pump assumed as the reference heating system.

Cooling COP is the Coefficient Of Performance of the reference electrically driven vapour compression heat pump, when it works as cooling machine.

Heating / Cooling Load is the monthly total thermal energy demand for heating and cooling respectively, required by the building per unit of conditioned floor area. These values must be entered by the user as input data. The user can either introduce each single value manually or import the data from a common spreadsheet by selecting all the cells, by clicking the item located in the top-left corner of the table, and then copying the values in the table.

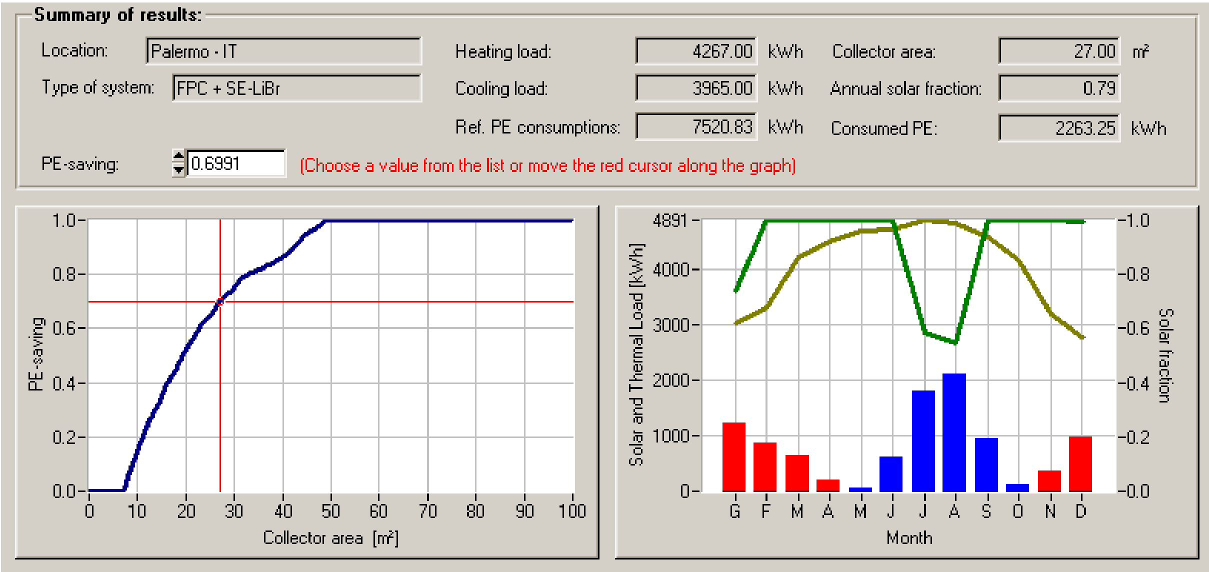
2.5 Description of the outputs

After the insertion of all the parameters needed for the thermal performance analysis, it is possible to start the calculation by clicking the <Calculate> item.
The results of the analysis are visualized in the bottom part of the main window. First there is a summary of the main output parameters, such like the total thermal energy required by the building for both heating and cooling, the primary energy consumptions of the reference system, the collector area needed to achieve the desired primary energy saving, the corresponding annual solar fraction and, finally, the consumed primary energy of the back-up unit.

In the left graph is plotted a curve that reports the variation of the primary energy saved, with respect to the reference conventional system, as a function of the collector area. A red cursor can be moved by the user allowing to select the desired percentage of primary energy to be saved. Alternatively the user can choose the desire PE-saving from the list positioned above the graph.

Additionally, in the right graph are plotted:

- the monthly-based total thermal load required by the solar system for both space heating and cooling;
- the total solar energy available on the collectors plane;
- the monthly solar fraction.



Clicking the <View result> item a dialog box appears, in which the results of the thermal analysis on a monthly basis are presented. The meaning of each column data is listed below.

Results of the analysis

	Solar radiation on tilted surface [kWh]	Building load for heating [kWh]	Building load for cooling [kWh]	Thermal load required to solar system [kWh]	Solar fraction [-]
January	3033.07	1226.00	0.00	1226.00	0.74
February	3295.98	864.00	0.00	864.00	1.00
March	4237.01	649.00	0.00	649.00	1.00
April	4504.20	191.00	0.00	191.00	1.00
May	4707.35	0.00	44.00	62.86	1.00
June	4710.56	0.00	420.00	600.00	1.00
July	4890.62	0.00	1273.00	1818.57	0.59
August	4846.70	0.00	1477.00	2110.00	0.55
September	4571.34	0.00	670.00	957.14	1.00
October	4169.79	0.00	81.00	115.71	1.00
November	3207.55	375.00	0.00	375.00	1.00
December	2777.52	962.00	0.00	962.00	0.99
Annual	**48951.69**	**4267.00**	**3965.00**	**9931.29**	**0.79**

Reference PE-consumption 7520.83 kWh
Collector area 27.00 m²
Consumed primary energy 2263.25 kWh
PE-saving 0.70 -
Ok

Solar radiation is the monthly total solar radiation incident on the collectors surface.

Building load for heating and cooling is the monthly total thermal energy demand of the building in winter and summer season respectively.

Thermal load is the monthly total thermal energy demand of the system at a temperature above the specified minimum useful temperature.

Solar fraction is the fraction of the load covered by the energy provided by the solar system. The remaining fraction must be supplied by an auxiliary source.

FINAL REMARKS

Considering the purposes for which this software tool has been developed, several simplifying hypotheses and approximations have been introduced when implementing the calculation methodology. Since no validation has been carried out so far, the authors do not guarantee that this first version of the software tool is free from errors and, therefore, they do not assume any responsibility concerning the precision of the results, which may be carried out from its use.

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