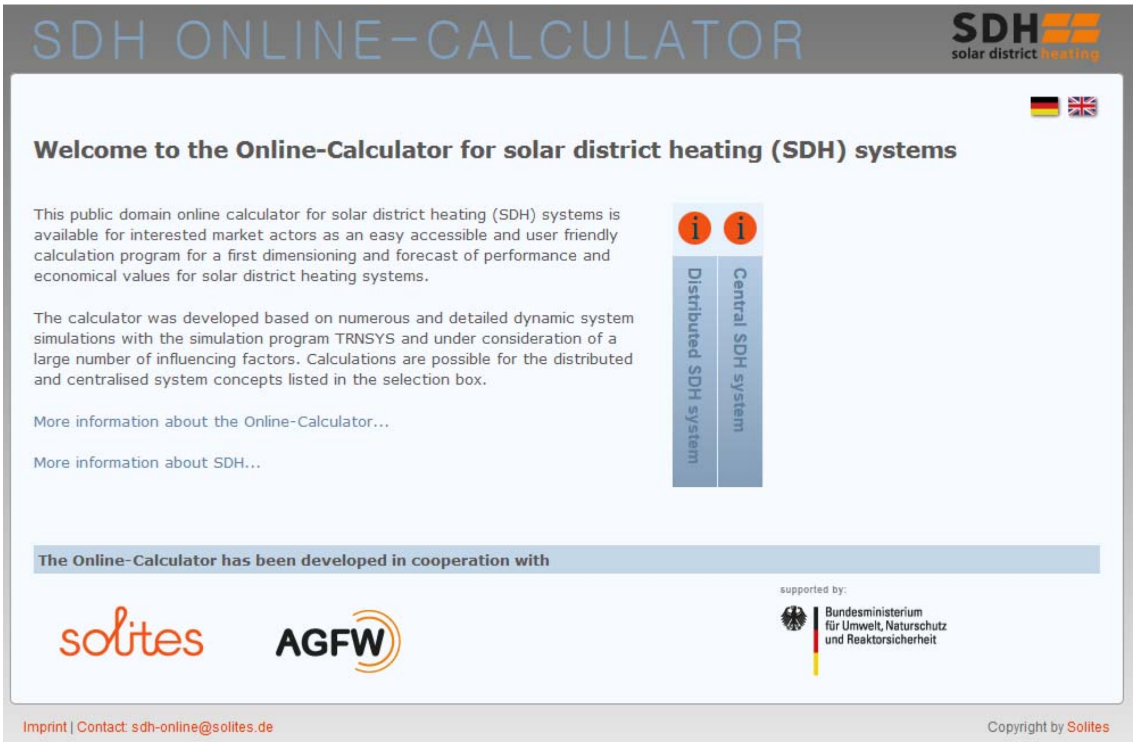
SDH ONLINE-CALCULATOR

CALCULATION PROGRAM FOR THE COST-BENEFIT ANALYSIS OF SOLAR DISTRICT HEATING SYSTEMS



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CONTENT

1. INTRODUCTION

The SDH Online Calculation Tool is based on dynamic system simulations with the simulation program TRNSYS [TRNSYS, 2012] and is a user-friendly first approach tool to get a first idea of dimensioning and economics of a solar district heating plant.
Two system configurations are available: central solar district heating plants with thermal storage and distributed solar district heating plants (decentralised feed-in).The results of the calculator are based on more than 100 000 TRNSYS simulation results. The performance values of the user-defined plant are obtained by a multi-linear interpolation between the outputs of the TRNSYS simulations. The economical and energy saving results are deduced from the calculated performance values.

The SDH Online Tool is available online at:

www.sdh-online.solites.de

Benefits and limits

- The tool is available online, user-friendly and fast.
- It enables the user to easily compare different dimensioning possibilities.
- It is specifically designed for Solar District Heating.
- Only the most basic choices can be made by the user.

2. DESCRIPTION OF SIMULATION MODELS

The tool has been developed based on extensive and detailed TRNSYS simulations, taking into account numerous parameters of influence. The calculation is possible at the moment for two types of system; with centralized or distributed feed-in of solar heat.

2.1. Procedure

One main requirement of the tool is the possibility to rapidly calculate different configurations for a system. Considering the current computing capacity needed for simulation programs, it is not possible to fulfill this requirement with a direct execution of dynamic simulations. Simplified static calculations on the other hand would fulfill the requirement of rapidity but would lead to high imprecision in the results due to the complexity of the system considered. To fulfill the requirements, a high number of dynamic system simulations have been performed for defined configurations and the results have been gathered in one database. In this way, the results are available and can be accessed in real time when a system configuration is chosen. For configurations which have not been simulated directly, results can be obtained by multi-linear interpolation between the results in the database. Thanks to this procedure, the high precision of dynamic system simulation can be coupled with the rapidity of a static calculation.

The underlying dynamic TRNSYS simulation models take into account a very high number of configuration parameters. In order to get results rapidly with the online calculation tool, these parameters have been divided between constant parameters and parameters depending on one or several constant parameters. Constant parameters with the highest influence on simulation results have been selected, and meaningful limit and step values have been defined. Finally, the systems have been simulated for each meaningful combination of these parameters values, and the results have been gathered in a database.

2.2. Locations

Three climates were simulated in Germany: Würzburg as favorable, Frankfurt as average climate and Hamburg as less favorable climate. Three more climates were simulated to cover most of Europe: Stockholm (SE), Milan (IT), and Barcelona (ES). The meteorological data from [Meteonorm, 2011] hase been used.

Tabelle 1: Standorte und Übersicht über Wetterdaten

Location	**Yearly meteorological data [Meteonorm, 2011]**		
	Average ambiant temperature [°C]	**Horizontal solar radiation [kWh/m²]**	**Heating degree days $G_{t20/15}$ [Kd]**
Würzburg (DE)	9,4	1090	3748
Frankfurt (DE)	9,6	1028	3653
Hamburg (DE)	8,8	952	3927
Stockholm (SE)	5,2	980	5252
Milan (IT)	11,7	1253	3035
Barcelona (ES)	15,3	1536	1727

2.3. Hydraulics

Two system concepts have been considered in the simulations; a distributed feed-in of solar heat into a district heating net and a centralized feed-in of solar heat in a district heating net with solar long-term heat storage. Both are described in the following section.

2.3.1. Distributed system

The following graph shows the hydraulic concept of a distributed solar district heating system. The solar collector field is connected via a heat exchanger but without additional components like buffer tanks or similar to the distribution network.

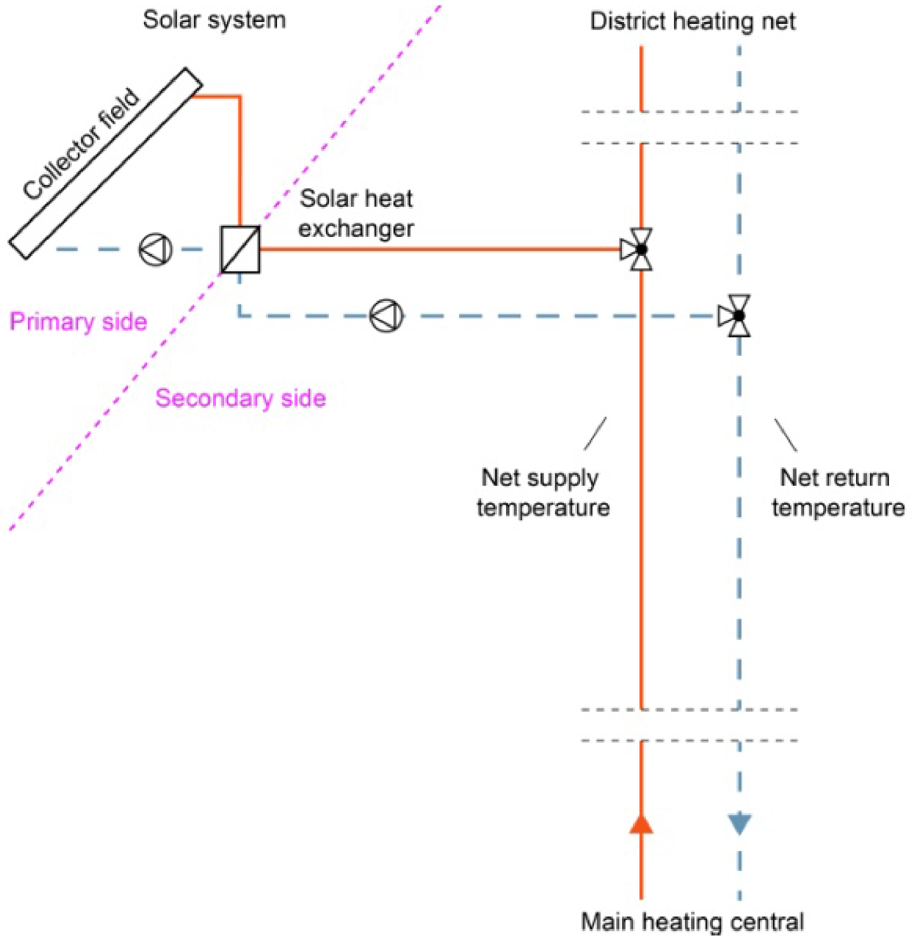

Figure 1: hydraulic concept of the distributed system

The distributed solar district heating system assumes that the produced solar heat is always fed into a distribution network which at any time can absorb the solar heat completely. Hence no self consumption is taken into account and the energy turnover in the distribution network is always big compared to the solar heat input.

The feed in occurs from the networks return line into the network forward line with user defined forward temperatures between 70 °C for a low temperature distribution network and 110 °C for a high temperature distribution network. To reach those feed in forward temperatures as often as possible both pumps around the solar heat exchanger are operated as matched-flow pumps.

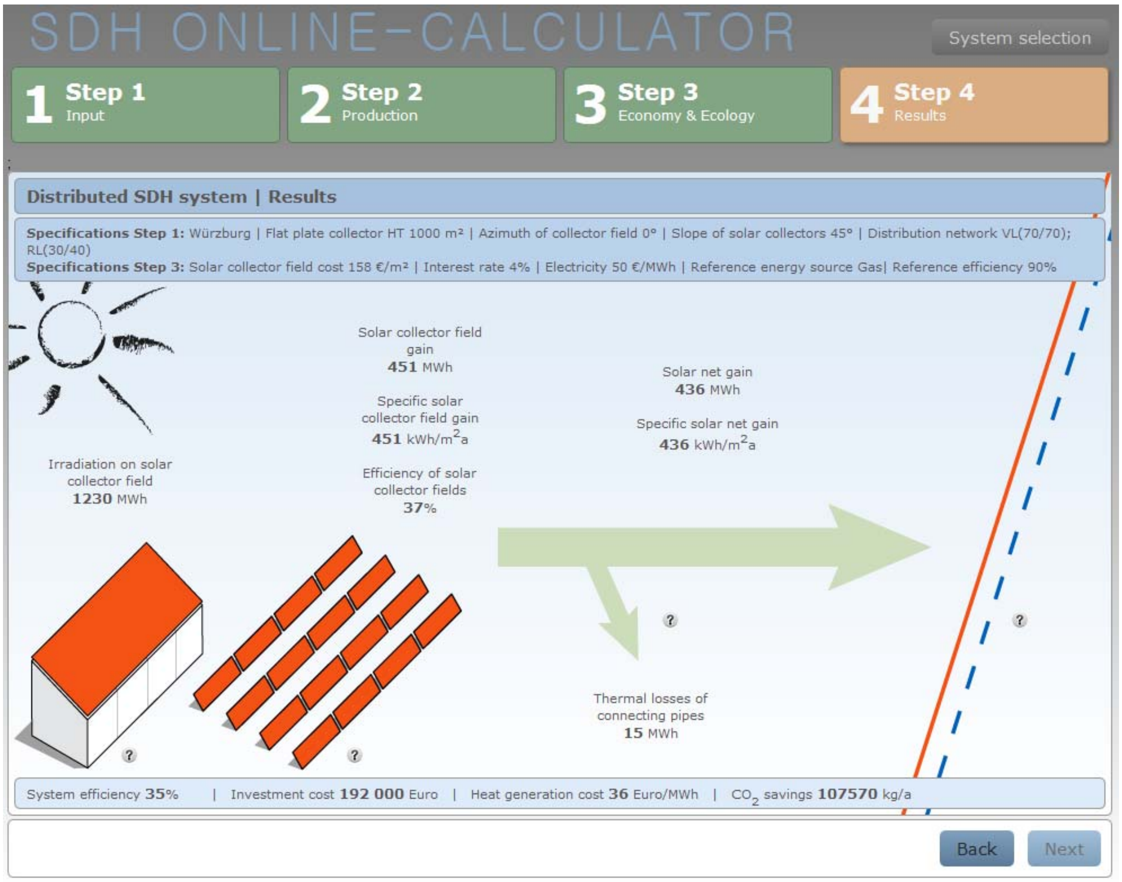

Figure 2: Results page of the online calculation tool for distributed feed-in of solar heat

Inputs:

- Collector area [m²], azimuth [°] and slope [°]
- Collector type [flat plate, flat plate high-temperature, evacuated tube, evacuated tube with CPC]
- Location and meteorological data
- Net operation temperatures
- Economical data (default data is available)

Outputs:

- Collector efficiency and yield
- Solar net losses
- Solar net gain
- Efficiency of the system
- Investment costs
- Heat production costs
- CO_2 savings

2.3.2. Centralized system

The central solar district heating system with ground buried tank thermal energy storage is composed of a large collector field feeding into a tank thermal energy storage situated at the main heating central of the district heating system. The pumps on the primary side and on the secondary side of the solar heat exchanger are matched-flow regulated.
When the solar plant produces heat when there is no heat demand, it is fed into the storage. Depending on the temperature in the storage and the temperature coming from the collectors the solar heat can either be fed in at the top or in the middle of the storage. In the time periods when the solar plant produces heat and heat demand occurs at the same time a direct pre-heating is possible, meaning the solar heat feeds directly into the main heating station and not by way of the storage. Also a simultaneous charging (in the middle) and discharging (from the top) of the storage is possible if e.g. the solar collectors deliver only low temperature heat due to bad weather conditions but at the same time the heat demand in the distribution network can be covered from the top part of the storage. An auxiliary heat source supplements the solar heating plant in order to cover the total heat demand.

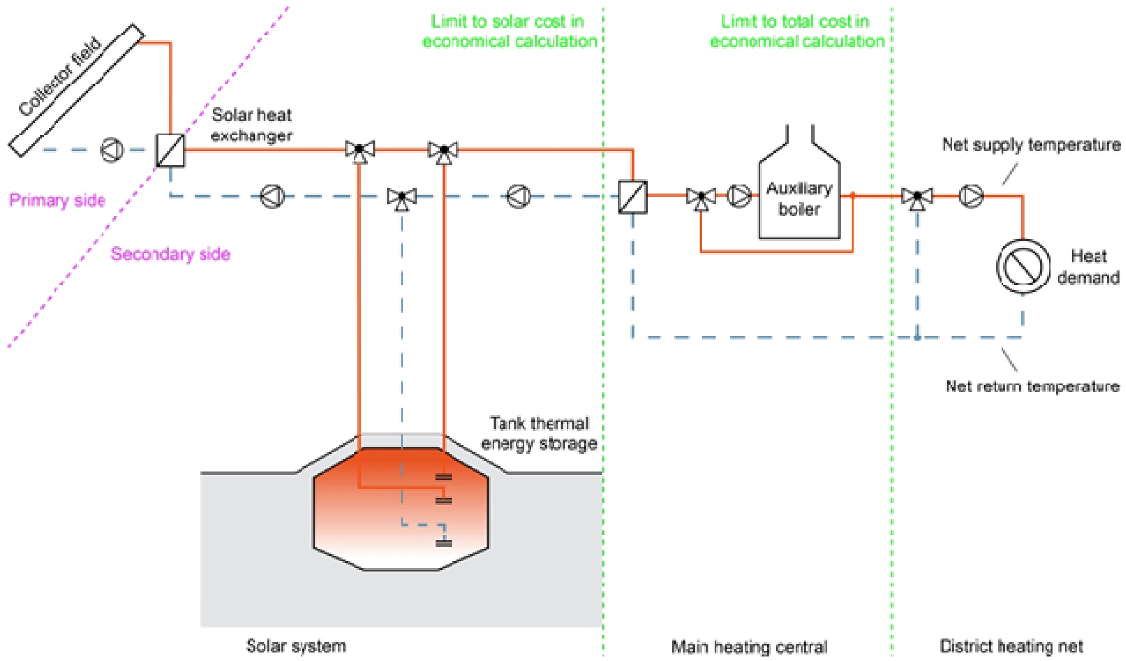

Figure 3: hydraulic concept of the centralized feed-in of solar heat in the heating plant of a district heating net

LOAD

The heat demand is obtained via TRNSYS simulation of average buildings connected by a distribution net, taking into account the hot water demand resulting from a DHWCalc [Jordan, Vajen, 2011] calculation. A reference heat demand file has been created for each location in order to take into account the variation of building's heat demand under different climate conditions. In the simulation model, a scaling factor is applied to the reference flow rates and operation temperatures according to the total heat demand and operation temperatures simulated. Figure 4 represents the monthly reference heat demand for Frankfurt, DE.

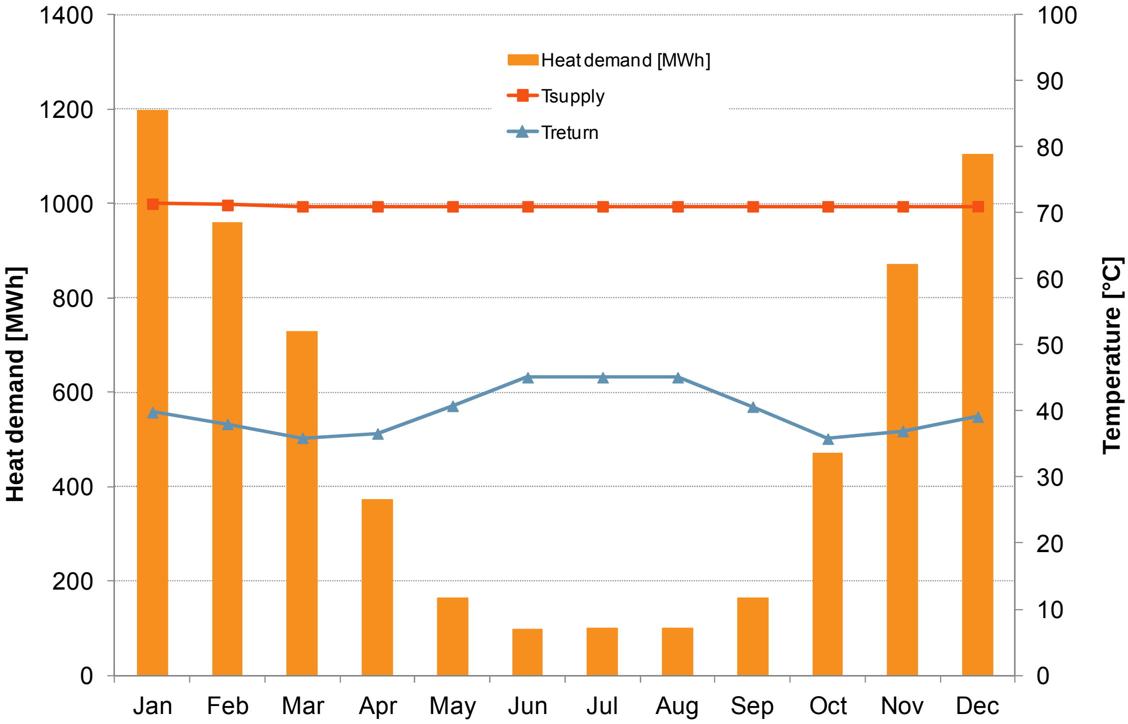

Figure 4: Monthly heat demand for a model net of 50 buildings in Frankfurt. Tsupply and Treturn are the supply and return temperatures of the district heating net in °C

A reference heat demand file has been produced for each location given in table 1.

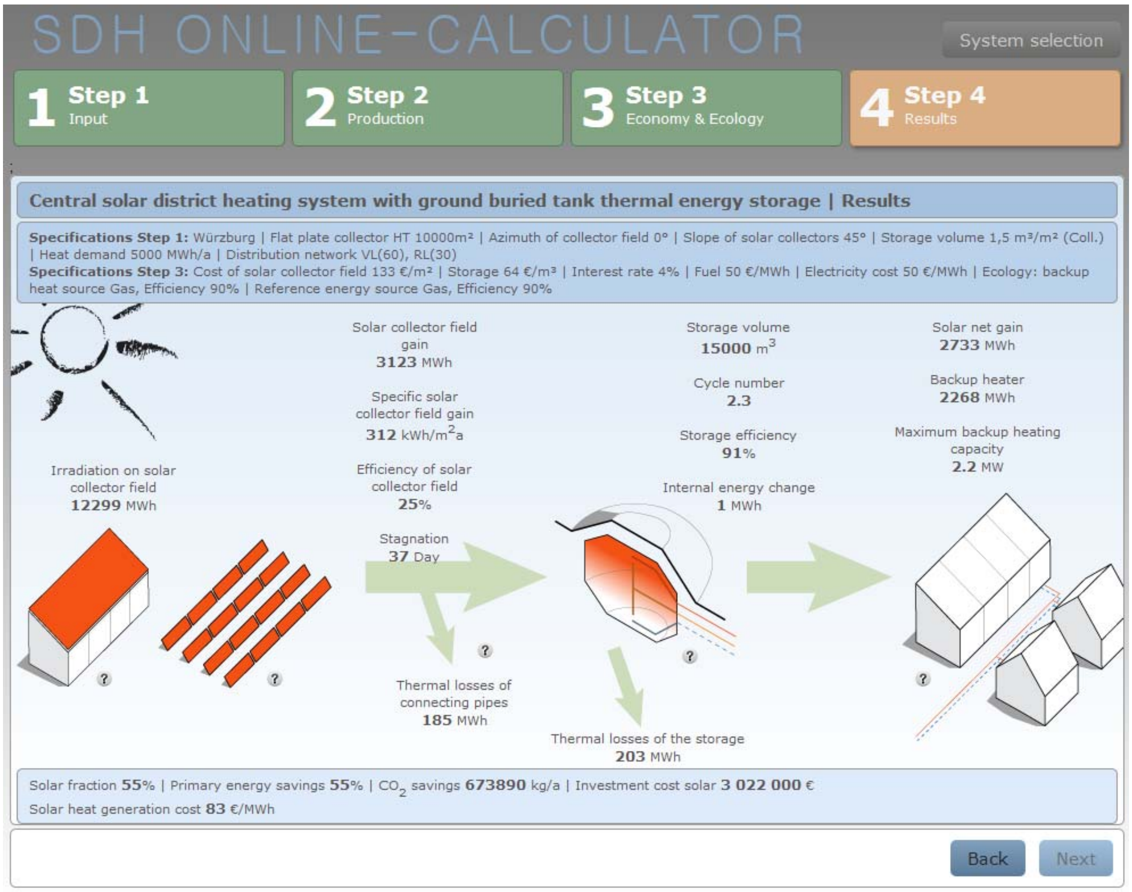

Figure 5: Results page of the online calculation tool for centralized feed-in of solar heat

In addition to the inputs for the distributed system, the following inputs are needed:

- Specific storage volume
- Heat demand of the district heating net

Additional outputs in comparison to the distributed system:

- Stagnation time of the collectors
- Storage efficiency
- Number of cycles of the storage
- Internal energy change of the storage
- Heat losses of the storage
- Solar fraction
- Backup heat demand
- Maximal backup power needed
- Primary energy and CO_2 emissions savings

2.4. Results

2.4.1. Technical characteristics

Besides the relevant energy gain values, following characteristics are being calculated to evaluate the system:

- Solar fraction:

$$F_{Sol} = \frac{Q_{Load} - Q_{Aux}}{Q_{\mathrm{Load}}} = \left(1 - \frac{Q_{Aux}}{Q_{Load}}\right)$$

Q_{Load}: Heat load from the district heating net
Q_{Aux}: Backup heat demand of the system

- Collector field efficiency

$$\eta_{Coll} = \frac{G_{Sol}}{Q_{Coll}}$$

G_{Sol}: Irradiation on the solar collector field
Q_{Coll}: Solar net gain

- Storage efficiency

$$\eta_{TES} = \frac{Q_{TES,out} + dQ_{TES}}{Q_{TES,in}}$$ (TES: Thermal Energy Storage)

$Q_{TES,in}$: heat fed in the thermal energy storage
$Q_{TES,out}$: heat loaded out of the thermal energy storage
dQ_{TES}: Internal energy change in the storage

- Number of cycles of the storage

$$N_{cyc} = \frac{Q_{TES,out}}{Q_{TES,\max}}$$

$Q_{TES,max}$: maximal capacity of the thermal heat storage

2.4.2. Economics

To calculate the economics of the system, a simplified calculation base on the German norm VDI 2067 has been implemented in the program. In this calculation, the main components are considered, the others are indirectly taken into account as percentaged additional charges. For the investment cost of the collector field, thermal energy storage and solar net, size dependant standard values have been implemented in the tool. These values allow the user to use the tool even if he doesn't have any cost data available. However, a cost specification by the user is possible. Moreover, it is possible to consider separate incentives for the collector field and the heat storage.

The additional charges considered on the total investment cost of the main components are:

- System installations 7 %
- Building/terrain 5 %
- Control system 3 %

Furthermore, 10% additional charges on the total investment cost is taken into account for the design of the centralized system and 5% for the distributed system.

The interest rate can be specified by the user, as well as the fuel cost for the backup heater (only for the centralized system) and the electricity cost. Other constant conditions defined for the economical calculation are summarized in Table 2.

Table 2: Conditions of the economical calculation

	Life time (years)	Maintenance (% of inv. cost)	Operation related cost (% of inv. cost)
Evacuated tube collectors	25[1]	0.50 %	0.50 %
Flat-plate collectors	25[1]	0.50 %	0.50 %
Heat storage	40	1.00 %	0.25 %
Solar net	40	1.00 %	0.00 %
System installations	15	1.50 %	0.75 %
Building	50	1.00 %	1.00 %
Control system	20	1.50 %	1.00 %

[1] See e.g. http://www.solar-district-heating.eu/ServicesTools/Plantdatabase.aspx or [Mauthner, Weiss 2013]

2.4.3. Environmental calculation

To evaluate the system on the environmental point of view, the $CO_{2\ equivalent}$ savings and the primary energy savings (only for the centralized system) are calculated in comparison to a reference system. The user must specify the fuel type and the efficiency of the reference and backup heat production. The values summarized in Table 3 are used for this calculation.

Table 3: Primary energy factors and $CO_{2\ equivalent}$ emission factors

	Primary energy factors	CO_2-eq. Emission factor in g/kWh_{el}
Biomass	0,2	7
Gas	1,1	222
Coal	1,1	369
Oil	1,1	283
Electricity	2,6	420
Solar thermal energy	0,0	0

The primary energy savings in comparison to a conventional reference system is calculated according to the following formula:

$$F_{Save,PE} = 1 - \frac{\sum_i \frac{Q_{Aux,i}}{\eta_{Aux,i}} * f_{PE,Aux,i} + \sum_i E_{el,i} * f_{PE,el}}{\sum_i \frac{Q_{Aux,ref,i}}{\eta_{Aux,ref,i}} * f_{PE,Aux,ref,i} + \sum_i E_{el,ref,i} * f_{PE,el}}$$

Q_{Aux}: Backup energy consumption of the system
$Q_{Aux,\ ref}$: Energy consumption of the reference system
E_{el}: Electricity for pumps
η: efficiency of the reference heater
f_{PE}: primary energy factor of the fuel

The calculation of the $CO_{2\ equivalent}$ savings is made according to the following formula:

$$F_{CO2-eq.} = \sum_i \frac{Q_{ref,i}}{\eta_{ref,i}} * f_{CO2-eq.,ref,i} - \sum_i \frac{Q_{Aux,i}}{\eta_{Aux,i}} * f_{CO2-eq.,Aux,i}$$

Q_{ref}: Energy consumption of the reference system
$F_{CO2\text{-}eq.}$: $CO_{2\ equivalent}$.emsission factor of the reference fuel

3. ACKNOWLEDGEMENT

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