solarcombi+

Report on the methodology of the virtual case study

Edited by

Edo Wiemken, Björn Nienborg, Lotta Koch

ISE

Fraunhofer Institut
Solare Energiesysteme

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Identification of most promising markets and promotion of
standardised system configurations for the market entry of
small scale combined solar heating & cooling applications
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1 General approach

In work package 3, virtual case studies has been performed for selected applications (type of buildings and their use) and selected climate regions in Europe. Defined system configurations on solar assisted cooling are applied to these applications and regions, in order to identify the most promising system design for each case.

The project consortium of Solar Combi+ contains commercial partners, manufacturing or distributing small size chillers, which are in the focus of the project. It was thus suggestive to apply models for these chillers in the simulation calculations within the case study.

The chillers and their respective rated chilling capacities are briefly shown in Table 1 according to data sheets of the products.

Chiller model	Manufacturer / Industry partner	Rated chilling capacity	Rated chilled water temperature*
Solar 7	Rotartica	4.5 kW	7/12°C
ACS 08	SorTech	7.5 kW	15/18°C
ClimateWell 10	ClimateWell	10 kW	17/?°C
Suninverse	Sonnenklima	10 kW	15/18°C
Wegracal SE 15	EAW (Solution)	15 kW	11/17°C

Table 1 Chiller models to be applied in the Solar Combi+ virtual case study.

*Rated chilled water temperature as specified in the data sheets, corresponding to the chilling capacity. All of the chillers may provide chilled water at low temperatures < 9°C.

The different rated capacities of the chillers as well as their differing operation conditions demand for a particular approach in the determination of the heating and cooling loads, resulting from the selected applications. The reason will be explained in the following.

The system configurations, examined with respect to the capacity range in Solar Combi+ are supposed to be mainly solar cooling systems with a heat backup: when solar heat is not available, the cooling demand is covered by a fossil fuel driven heat support of the thermally driven chiller. A 'cold side' backup, consisting of an electrically driven compression chiller, is not expected to be common in small scale applications for economical reasons. As a consequence, the solar thermal coverage of the driving heat of the chiller has to be high on an annual base (usually > 70%), since with low fractions of solar thermal coverage the system will show no advantage in comparison with a conventional electrically driven solution with respect to primary energy savings. Thus, each of the different types of chiller with their different capacity fits to a different cooling demand or different size of building respectively.

In order to limit simulation work and to generalise the approach for an improved comparison of the results, the following was defined:

- Climatic representative European zones
- Basic Standard system configurations and control strategies.
- Types of building application
- For each of the climatic zones, a load file containing hourly values of one year of heating, cooling and domestic hot water demand for each of the applications.
- An appropriate scaling factor for the load files to make comparison between the different chiller sizes possible.
- Modifications of system components in frame of the case study:
    - type of collector
    - type of heat rejection
    - type of distribution of cold (fan coil and chilled ceiling)
    - size of storage
    - size of collector

In the following section 1.1 the boundary definitions for the virtual case study are described in detail. Furthermore the requirements on the output data and the limits of the virtual case study are described. In section 2 it is shown how the virtual cases have been implemented and in section 3 the possible evaluation data in view of work package 4 is described.

1.1 Definition of simulation boundaries

1.1.1 Selection of climatic zones

As the project SolarCombi+ focuses on combined systems for heating, cooling and domestic hot water demand, the selected regions demand for space heating in winter as well as for cooling in summer. An approach developed in the project ECOHEATCOOL was used to specify the appropriate zones. The following three climatic zones have been selected by European heat index and cooling index (EHI/ECI).

- ○ 100 / 100 – Strasbourg, France
- 🔴 85 / 115 – Toulouse, France
- 🟢 70 / 140 – Naples, Italy

Areas with similar EHI/ECI index (latent loads not considered):

- ● 100 / 100
- 🟢 70 / 140

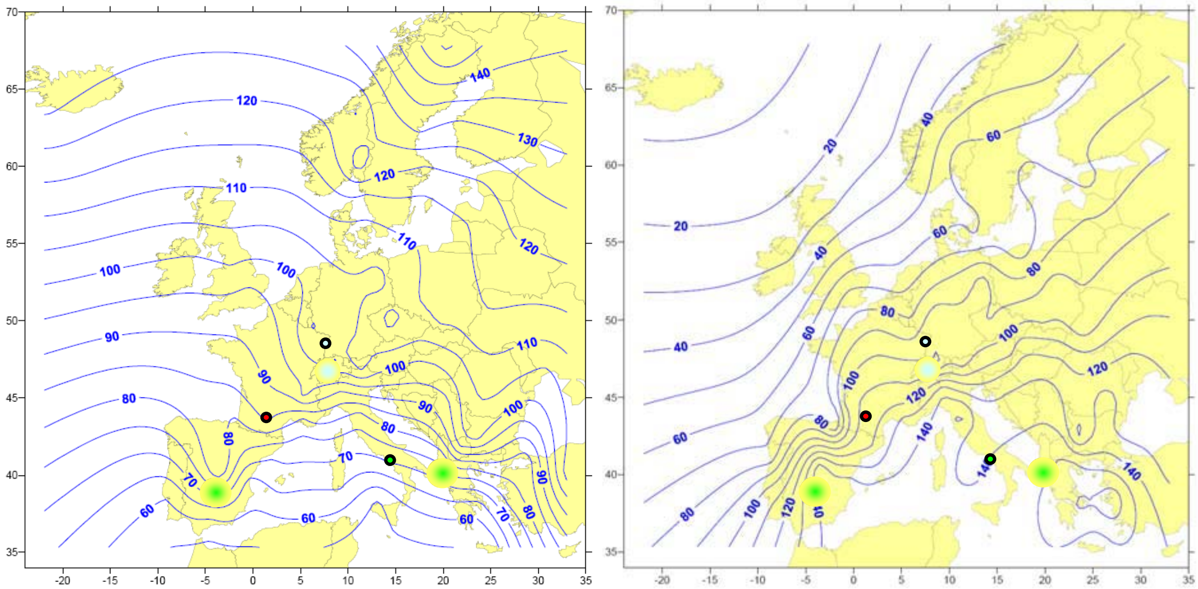


Figure 1: EcoHeatCool European Heat Index (EHI, left) European Cooling Index (ECI, right)

1.1.2 System Standard configuration

Two *Standard System Configurations* were selected according to experiences made with from realised installations and by considering approaches on solar combi systems as documented in Task 26 of the Solar Heating and Cooling Programme (SHC) of the International Energy Agency IEA. In order to fulfil the individual requirements and preferences of the participating industry partners two systems were selected. Each chiller has been simulated with one configuration.

Since the chilling capacity range considered in SolarCombi+ is relatively new, no comprehensive experience on small solar cooling systems is available so far. Thus, the systems expected to be installed in the near future may differ from the suggested schemes to a certain extent. Furthermore, a large variety of approaches for a reliable supply of hot water for space heating and domestic use exists, which is impossible to be studied in detail within this case study.

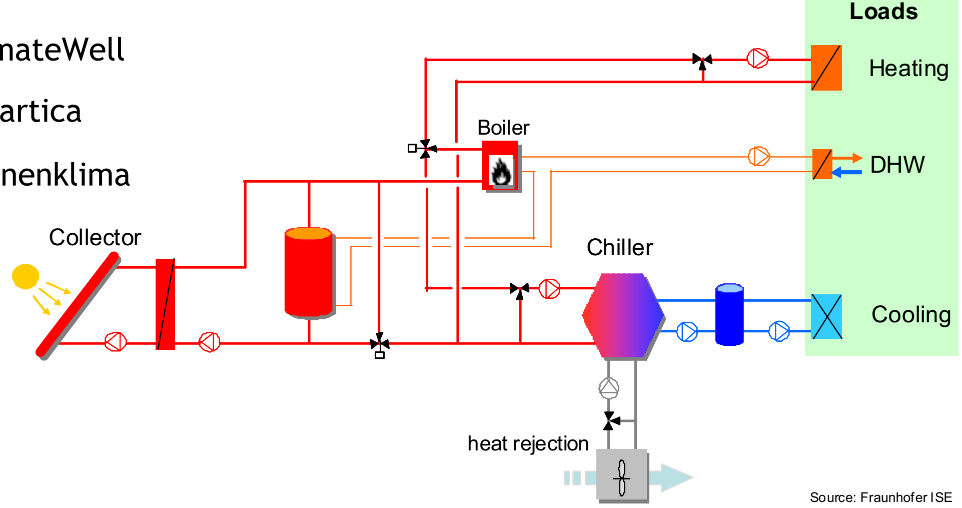
System configuration C1

Simulated for:

ClimateWell

Rotartica

Sonnenklima



Source: Fraunhofer ISE

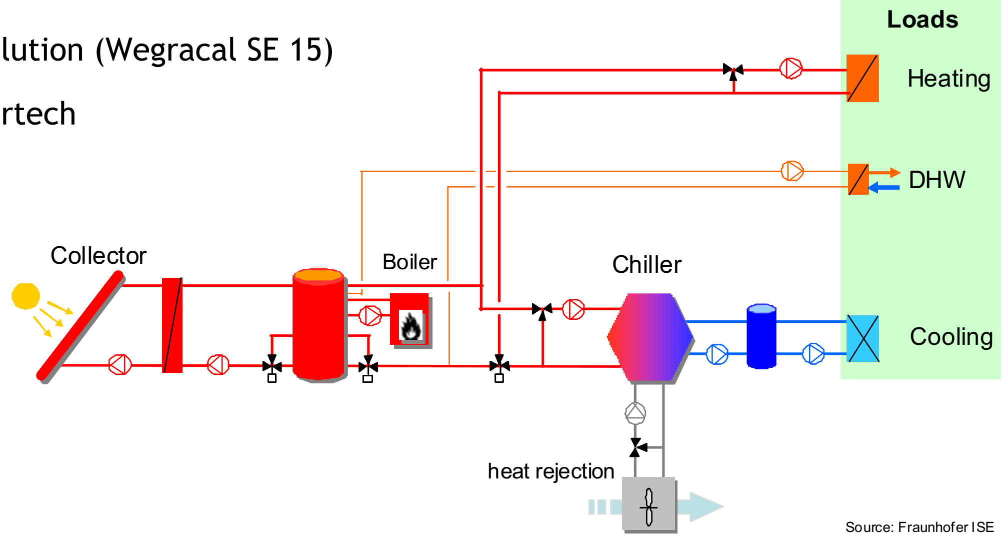
Figure 2: System configuration C1

System configuration E1

Simulated for:

Solution (Wegracal SE 15)

Sortech



Source: Fraunhofer ISE

Figure 3: System configuration E1

1.1.3 Building models

Three types of applications were defined:

I A small one-storied office building, ca. 310m² cooled floor area, based on a reference building for IEA Task 38; cold distribution by fan coils; all 3 locations

II Two-storied building, 140 m² cooled floor area, building standard 100kWh/m² in Zurich, Switzerland, based on IEA Task 32 reference buildings, cold distribution by fan coils and chilled ceilings; only 2 locations (Toulouse and Naples)

III Two-storied building, 140 m² cooled floor area, building standard 60kWh/m² in Zurich, Switzerland, based on IEA Task 32 reference buildings, cold distribution by fan coils and chilled ceilings; only 2 locations (Toulouse and Naples)

The building models were simulated separately, thus fixed load files were applied to the system simulation.

Figure 4: Two storied building, 140 m² from Task 32 reference buildings

1.1.4 Loadfiles and scaling

Due to the wide range of represented chilling capacities (4,5kW to 15kW nominal capacity) an adaption of the load file to the chiller was indispensable. Therefore a scaling factor has been introduced in order to fit the load files to the specific chiller. The scaling factor assures that the maximum cooling load of the load file can be met under certain reference temperatures, which depend on the system configuration

80-27-18 for wet cooling towers and active panel heating/cooling

80-35-18 for dry cooling towers and active panel heating/cooling

80-32-18 for hybrid cooling towers and active panel heating/cooling

For fan coil applications a lower chilled water temperature (12°C) will be selected.

The scaling factor is then calculated as follows

$$f_{scale} = \frac{Q_{chill,ref}}{Q_{coolingload,\max}}$$

and multiplied with the cooling and heating demand outputs of the load file.

The load data has been stored in a specific file format, which contains also site specific meteorological data. An example is given in table 2.

Hour of the year	Month	Day	Hour	T_{amb}	rH_{amb}	$T_{room,set}$	$rH_{room,set}$	$P_{heating,sensible}$	$P_{heating,latent}$	..
hh	mm	dd	hh	°C	%	°C	%	kW	kW	..

..	P	$P_{cooling,lat}$	T_{DHW}	G	G_{diffus}
..	kW	kW	°C	W/m^2	W/m^2

Table 2: Example of a load data file for one site and one application: the file contains hourly values of a representative year, combining heating and cooling for the application, as well as meteorological data (ambient temperature, humidity and radiation data). The DHW-demand has been listed in an own data file.

1.1.5 Variations of virtual case study

Collector

The simulations were carried out with two different collector types – a flat plate collector (Type 1) and an evacuated tube collector (Type 71) both with external IAM file. The IAM file for the flat plate collector was generic; the IAM values of the evacuated tube collector are based on measurements. The specific parameters are taken from the following collectors. The

Collector	Type	Tested flow rate (kg/hrm^2)	η_0	a1 (W/Km^2)	a2 (W/K^2m^2)
SolTop Cobra X	Flat plate	120	0.823	3.02	0.0125
Phönix CPC 14/21	Evacuated tube	30	0.601	0.767	0.0038

Table 3: Collector parameters used in virtual case study.

Heat rejection

Two options for heat rejection have been simulated:

Wet cooling tower (Trnsys standard Type 51) with parameters which fit the Axima EWK 036/06 cooling tower.

Hybrid cooling tower

For the hybrid cooler model a modular dry cooler model developed by Francesco Besana (EURAC) in combination with an equation type is used.

Cold distribution systems

In the residential buildings fan coil and active panel heating/cooling applications have been simulated. In the office buildings only fan coil application has been simulated as chilled ceilings are not common in office building.

For fan coil applications a chilled water temperature returning from the building of 12°C has been assumed, for chilled ceilings a higher temperature of 18°C.

Collector size

Five collector sizes of 2-5 m^2 per kW reference chilling power, calculated as seen above, have been simulated.

Storage size

Three storage sizes of 25, 50 and 75 Liter per 1 m^2 collector area have been simulated.

1.2 Requirements on the simulation results of the virtual case study

A set of *annual* and *monthly* results has been stored from each simulation run of the solar combi+ systems and of the respective reference systems. This data set has been defined with the aim to allow a post-processing in order to obtain a system evaluation with regard to the energetic, environmental and economic performance of the system. For this evaluation, the energy fluxes for heating, cooling and hot water as well as all relevant parasitic electricity demands and other media consumed such as water, are important. Thus, a system evaluation boundary has to be drawn around the complete system as shown for an example configuration in figure 5.

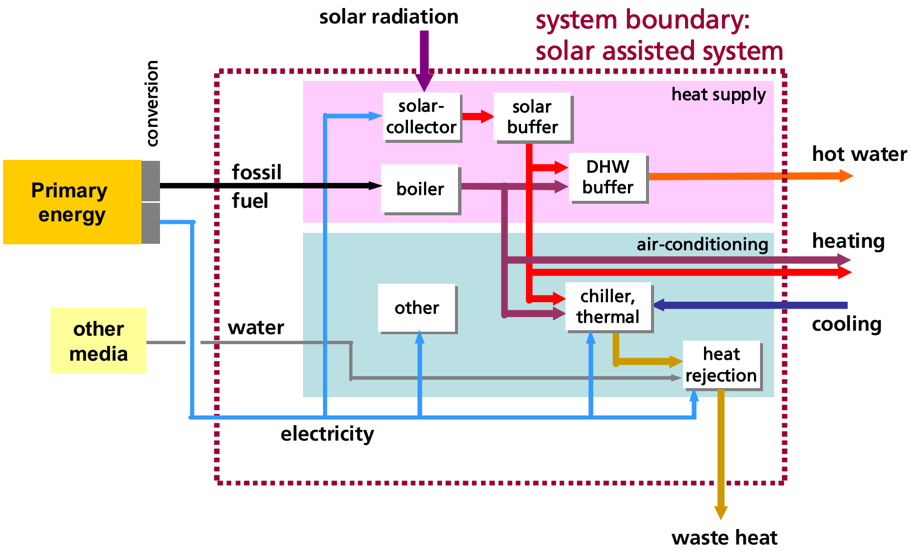
The outputs of the simulation form a database which contains all the figures required to calculate the performance figures defined below.

The following figures can be directly derived from the annual simulation results:

- the annual coefficient of performance (COP),
- gross collector yield,
- gross collector efficiency and
- solar fractions

Some values like costs for energy, water and the system, conversion factors, interests and expected life cycle should be specified by the end-user as they can differ for each country or solar system company. With these user-defined values the following values can be calculated:

- Primary energy savings
- Reduction of CO2-Emissions
- Costs of solar thermal investments (Solar system, installation)
- Investment costs for the thermally driven chiller (ab-/adsorption), heat rejection unit, installation, cold storage (if applicable)
- Costs for primary energy savings
- Costs for reduction of CO2
- Annual costs for SC+ and reference system



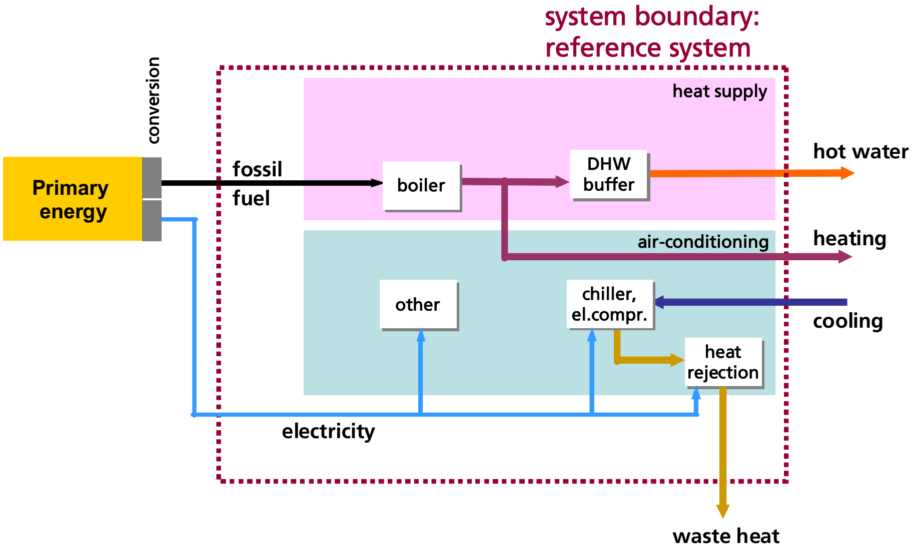


Figure 5 Top: system boundary for the evaluation of a solar combi+ system according to a configuration shown in figure 2 and 3, and for the corresponding reference system (bottom). All energy and media flow data crossing the boundary have been stored. In a post-processing phase, with appropriate conversion factors and economic data, primary energy savings, CO_2 savings, economic performance etc. may be assessed.

The performance and evaluation data, which will be calculated in a post-processing step are defined in section 3 "Evaluation".

1.3 Limits of chiller models and performance data

In the virtual case study of SolarCombi+, the simulation platform TRNSYS, version 16, was used for modelling and simulation.

With respect to the depth of simulation calculations, possible within the project, some limitations have to be outlined:

- The simulations underlie the common limitations of (standard) Trnsys models: e.g. the system inertia is mainly represented by the volume contained in storages and pipes. Thermal inertia of the components itself (collectors, pipes, chillers, etc.) is not taken into account by the models. Therefore it is not possible simulate the start, stop and transition phases in detail. Thus, the chillers will be simulated in quasi steady-state operation.
- The load files are computed separately to reduce simulation effort and to increase the stability of simulations. So no feedback from the system simulation to the building model and vice versa is possible. This has a number of consequences on the simulations:

  a) In principle, only solar thermally *assisted* cooling systems can be considered with this approach. In case the solar heat is not sufficient to cover the driving heat demand of the chiller, a back-up system is operated in order to ensure the set values in the building.

  b) The low cooling loads at the beginning and in the end of the cooling season result in clocking chiller operation. In reality the chiller would operate with a certain hysteresis which would result in a minimum operation time.

2 Description of initial TRNSYS decks

2.1 General remarks

In order to guarantee certain continuity in simulations carried out in international projects, the basic parameters for standard components of SolarCombi systems are adopted from those used in the simulations carried out in IEA Task 32. In this section the implementation of the virtual case study is described. There is a description of how the seasonal changing of the domestic hot water temperature dependant from the location has been realized and what was the basis for the DHW load file, how the electric power of the pumps have been determined, what is the needed input data and the calculated output data and how the two different system configuration are implemented exactly.

The Trnsys Decks are set up with Trnsys Version 16.01.0003

The simulation runs with time steps of 1.5 minutes, the tolerance for integration and convergence is set to 0.001.

The following non-standard Types are used in the decks:

Type 177 - Absorption Chiller with parameters for Sonnenklima suninverse by Jan Albers, TU Berlin

Types 215/216 – Absorption chiller ClimateWell 10 by ClimateWell

Type 231 – Absorption chiller Rotartica Solar 7 by Björn Nienborg, ISE

Type 290 – Adsorption chiller Sortech ACS08 by Björn Nienborg, ISE

Type 307 – Absorption chiller Wegracal SE 15 by Kai Witte, ISE

Type 340 - Multiport Storage Model by Harald Drück, ITW Stuttgart

Type 805 – DHW heat exchanger by Michel Haller, TU Graz

Type 878 – Modular dry cooling tower by Francesco Besana, EURAC

2.2 Domestic hot water (DHW) preparation

The basic DHW-load file provides 6-min values for the draw off volume flow in liters per hour. The file was generated by means of the program DHWcalc (http://www.uni-kassel.de/~solar) with the following assumptions:

4-person household

45 litres of hot water (45°C) are consumed per person and day

maximum draw off flow rate: 800 l/h

The hot water profile is scaled accordingly to the scaling of the building load file which depends on the available chilling capacity. Therefore the DHW data input in the Trnsys Deck is multiplied by the scaling factor "f_scale" (See section 1.1.4.).

Calculation of cold water temperature

The following function to calculate the value for cold water temperature as in ENV12977-2:2001 (Thermal solar systems and components - Custom built systems - Part 2: Test methods) was used:

$$t_{CW} = t_{avg} + \Delta t_{amp} \cdot \sin\left(360 \cdot \frac{(day - D_s)}{365}\right)$$

t_{CW}: effective cold water temperature

t_{avg}: yearly average cold water temperature

Δt_{amp}: average amplitude of seasonal variations

day: number of the day of the year

D_S: shift term

Location	t_{avg}	Δt_{amp}	D_S
Strasbourg	12.5	3.5	137
Toulouse	14	5	137
Naples	17	7	137

Table 4: Required parameters to determine effective cold water temperature for each location; estimated values deducted from reference values given in ENV 12977-2:2001

2.3 Determination of electric power consumption of chiller pumps

The overall electric performance of the solar cooling system is highly dependent on the electric power consumption. Therefore we determined the electric power consumption of the pumps in the three chiller circuits based on the required hydraulic power with a standardised approach.

The hydraulic power is defined as follows:

$$P_{hydr} = \Delta p_{total} \cdot \dot{V} \qquad [\mathrm{W}] \qquad (1)$$

with

Δp_{total}: total pressure drop in the hydraulic circuit [Pa]

V: volume flow rate in the hydraulic ciruit [m^3/h]

The total pressure drop is the sum of the single pressure drops of each circuit:

$$\Delta p_{hotwater} = \Delta p_{chiller,hotcircuit} + \Delta p_{pipes} + \Delta p_{storage} \qquad [\mathrm{Pa}] \qquad (2)$$

$\Delta p_{storage}$ is very small and therefore negligible.

$$\Delta p_{coolingwater} = \Delta p_{chiller,coolingcircuit} + \Delta p_{pipes} + \Delta p_{heatrejection} \qquad [\mathrm{Pa}] \qquad (3)$$

$$\Delta p_{chilledwatet} = \Delta p_{chiller,chilledcircuit} + \Delta p_{pipes} + \Delta p_{distributionsystem} \qquad [\mathrm{Pa}] \qquad (4)$$

The electric power of the pump is then defined as the quotient of the hydraulic power and the overall efficiency of the pump:

$$P_{el} = \frac{P_{hydr}}{\varepsilon_{Pump}} \qquad [\mathrm{W}] \qquad (5)$$

ε_{Pump}: Efficiency of pump [-]

The following assumptions were made for the calculation of the electricity consumption by the pumps:

- The hot and chilled water pumps are good "regular" pumps with an efficiency of 20%
- The cooling water pump is a highly efficient pump with an average efficiency of 45%

- The pressure drop in the pipes (and additional components such as valves, T-pieces, etc.) is the same for all system configurations.
- The pressure drop in a wet cooling tower is 400mbar for all systems.
- The pressure drop in a dry cooling tower is 150mbar for all systems.
- The pressure drop in the cold water distribution system is 300mbar for all systems.
- An uncertainty factor of 15% is added to all powers.

Resulting electric powers are rounded to 5 Watts.

Efficiency hot water pump	0.2	[-]
Efficiency cooling water pump	0.45	[-]
Efficiency chilled water pump	0.2	[-]
pressure drop in hot water pipes	100	[mbar]
pressure drop in cooling water pipes	300	[mbar]
pressure drop in chilled water pipes	200	[mbar]
pressure drop in wet cooling tower	400	[mbar]
pressure drop in dry cooling tower	150	[mbar]
pressure drop in chilled water distrib. system	300	[mbar]
uncertainty factor	0.15	[-]

Table 5: Efficiency of hot, cooling and chilled water pump and pressure drop in system parts.

$$P_{hydr} = \Delta p_{total} \cdot \dot{V} \qquad [W] \qquad\qquad P_{el} = \frac{P_{hydr}}{\varepsilon_{Pump}} \cdot \left(1 + f_{uncertain}\right) \qquad [W]$$

The resulting values are listed in appendix I.

2.4 Input data

There are two load files for each system; one providing a DHW-profile as 6-min values, the other providing the remaining relevant data as hourly values as described in section 1.1.4.

2.5 Output data

There is one printer (Type 25) in the deck which records the parameters which are varied during the parametric study (collector area and storage volume).

The simulation results necessary for the evaluation of the system configuration are printed by simulation summaries (Type 28b) which integrate the values over the entire year. There are four of these Types. Although the two different systems which will be simulated have partly different outputs, the structure of the output files is kept identical, so one evaluation tool can be used for all output files.

SummaryElectric: records the electricity consumption of the pumps, boiler, chiller and cooling tower fan.

PS1/2	solar circulation pumps	[Wh]
PB	boiler pump	[Wh]
PelBoiler	boiler	[Wh]
PDHW	DHW pump	[Wh]
PH	heating circuit pump	[Wh]
PC	hot water to chiller pump	[Wh]
PHR	heat rejection circuit pump	[Wh]
PCW	cold water circuit pump	[Wh]
PelChiller	chiller	[Wh]
PelCT	cooling tower fan	[Wh]

SummaryEnergy1: records energy quantities

Q_irr	total specific radiation on collector surface	[kWh/m²]
Q_coll	energy from collector	[kWh]
Q_aux_summer	auxiliary heat in summer	[kWh]
Q_aux_winter	auxiliary heat in winter	[kWh]
Q_aux_DHW	auxiliary heat for DHW	[kWh]
Q_aux_heat	auxiliary heat for heating	[kWh]
Q_aux_cool	auxiliary heat for cooling	[kWh]
Q_loss_store	total heat loss of storage	[kWh]
Q_solar_cool	solar heat for cooling	[kWh]
Q_loss_pipes	total heat loss of hot water pipes	[kWh]

SummaryEnergy2: records energy quantities

Q_cold	produced cold	[kWh]
Q_cold_aux	cold produced with auxiliary heat	[kWh]
Q_cold_solar	cold produced with solar heat	[kWh]
Q_cold_demand	cooling load	[kWh]
Q_heat_ demand	heating load	[kWh]
Q_DHW_demand	load for DHW preparation	[kWh]
Q_HR	heat rejected	[kWh]
Q_Chiller_tot	total driving heat to chiller	[kWh]
Q_DHW_summer	DHW load in summer (E1)	[kWh]
Q_solar	solar energy into system	[kWh]

SummaryRest&Ref: records other relevant values and those of the reference system

V_water	water consumption by wet cooling tower	[l]
solarcoolingtime	hours of solar cooling operation	[h]
auxcoolingtime	hours of cooling operation with auxiliary heat	[h]
coolingdemandtime	hours of cooling operation with auxiliary heat	[h]
PelrefChiller	electric power consumption of the reference compression chiller	[Wh]
PelrefBoiler	electric power consumption of the boiler in the reference system	[Wh]
stagnationtime	hours of stagnation in collector	[h]

From this data the information presented in section 3 "Evaluation" can be obtained via Microsoft Excel Macros.

2.6 Reference System

In order to determine the energy savings obtained by the solar system, a conventional reference system must be defined. This system consists of a hot water boiler to meet the heating and DHW demand and a compression chiller for cooling.

The boiler has the same capacity and electricity consumption (see below) as the boiler in the solar system.

The electric COP of the compression chiller (including dry heat rejection) depends on the temperature difference between ambient air and chilled water inlet. For a chilled ceiling system with 18°C return temperature it is 2.9 at 30°C ambient temperature.

$$COP = 3.62 - 0.06 \cdot (t_{amb} - t_{CW})$$

It is considered that the entire cooling demand is always met with the COP corresponding to the ambient temperature. The resulting electricity consumption is recorded by a simulation summary Type.

2.7 System C1

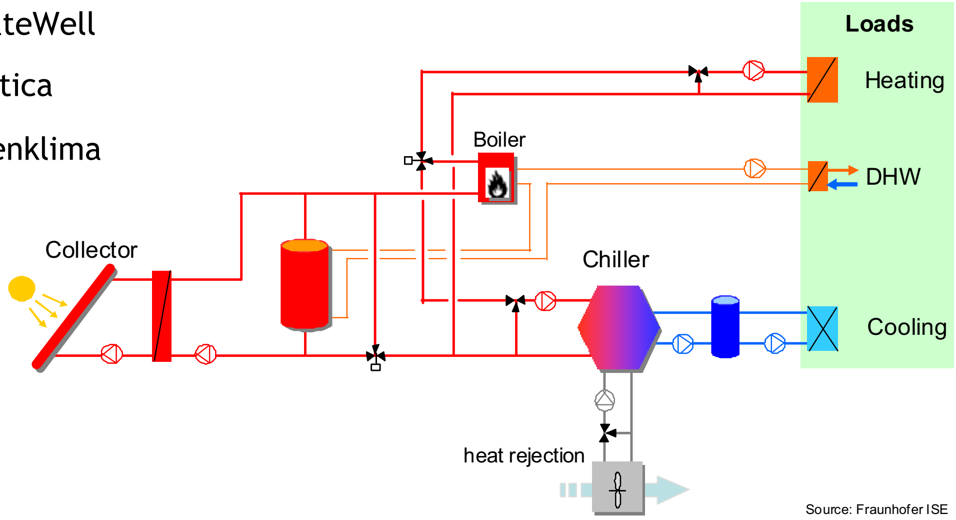
System configuration C1

Simulated for:

ClimateWell

Rotartica

Sonnenklima



Source: Fraunhofer ISE

Figure 6: System Scheme C1

Collector circuit

The collector circuit of this system is simulated using the standard collector type (Type 1/Type 71), pipes (Type 31) and variable flow pumps (Type 110).

The pumps PS1 and PS2 are switched on and off depending on the temperature difference between the outlet of the collector and the bottom of the heat storage (or, if $m_{Load}>0$, the outlet temperature of the T-piece in the return to the collector). The monitoring temperature is the maximum of either the temperature at the top of the storage or the temperature at the T-piece in the supply to the load.

Due to the intricate control of the solar storage (see below) using an iterative feedback controller in order to obtain a certain set temperature from the collector field leads to convergence problems. Therefore the flow rate is controlled according to the solar irradiation. If the irradiation is higher than 150 W/m² (540kJ/hm²) the pumps start operating at 20% of their maximum flow rate and reach the maximum flow rate at 800W/m².

The supply and return pipes of the collector circuit have a length of 20m each and are DN25.

Solar storage

The storage of the system is modelled by multi-port storage Type 340. Since the connections of this Type do not allow the circulation of the fluid in both directions, this peculiarity of system C1 must be realized externally. Two double ports are used to simulate this behaviour – one for circulation charging the storage from the solar system, the other for supplying energy to a load from the storage. Two flow diverters split the flow between storage and solar/load circuit respectively and two T-pieces join the flows from the storage and the solar/load circuit.

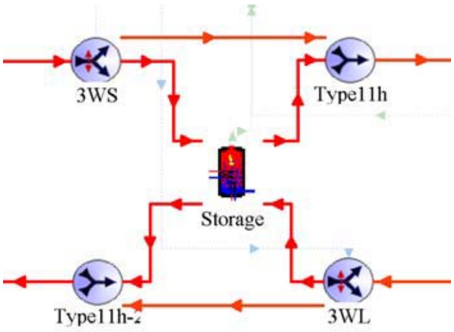


Figure 7: Sceenshot of storage in the TRNSYS-deck in system C1

The flow diverters are controlled by equation "StorageContr-3" as follows:

$$Sig_{3WS} = \begin{cases} 1 & if \quad \dot{m}_{Solar} \leq \dot{m}_{Load} \\ \dfrac{\dot{m}_{Load}}{\dot{m}_{Solar}} & if \quad \dot{m}_{Solar} > \dot{m}_{Load} \end{cases}$$

With:

$$\dot{m}_{SolartoLoad} = Sig_{3WS} \cdot \dot{m}_{Solar}$$
$$\dot{m}_{SolartoStorage} = (1 - Sig_{3WS}) \cdot \dot{m}_{Solar}$$

$$Sig_{3WL} = \begin{cases} 1 & if \quad \dot{m}_{Solar} \geq \dot{m}_{Load} \\ \dfrac{\dot{m}_{Solar}}{\dot{m}_{Load}} & if \quad \dot{m}_{Solar} < \dot{m}_{Load} \end{cases}$$

With:

$$\dot{m}_{LoadtoSolar} = Sig_{3WS} \cdot \dot{m}_{Solar}$$
$$\dot{m}_{LoadtoStorage} = (1 - Sig_{3WS}) \cdot \dot{m}_{Solar}$$

DHW-preparation

The heart of the DHW circuit is Type 805, a DHW heat exchanger programmed by Michel Haller from TU Graz, which was also used in Task 32. In this Type the primary side flow rate is calculated iteratively until the set point temperature on the secondary side at a given draw-off flow rate or the maximum flow rate on the primary side is reached. If the water from the storage is below 60°C the auxiliary boiler will heat it up to this temperature.

To increase the simulation stability there is no piping included in this circuit. Since the DHW-heat exchanger is usually located close to the storage, the losses are considered negligible.

Load circuit

The load circuit consists of the heating loop and the chiller loop. The 3-way-valve "H/C" switches between these two loops according to the heating or cooling demand. Simultaneous heating and cooling is not possible.

If the temperature from the solar system and/or the storage is not sufficient (set temperature for heating is 40°C, for cooling 80°C + 5°C Hysteresis) the boiler will be activated. In this case the "BoilerBypass" will close the loop in order to avoid heating up the storage or the solar circuit.

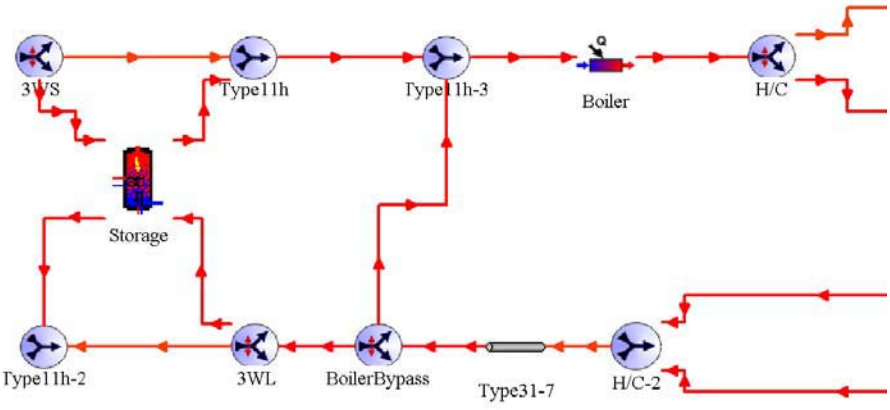


Figure 8: Screenshot of implementation of storage bypass in system C1.

Heating

In this Trnsys deck it is assumed that heating and cooling can be realized with active walls/ceilings/floors. This means that only sensible heating loads can be met and that heating is realized with low temperatures – in this case 40/30°C. The mass flow of the pump is controlled in order to obtain this temperature difference at any heating load. To assure that the supply temperature does not exceed 40°C a "HeatingBypass" is installed.

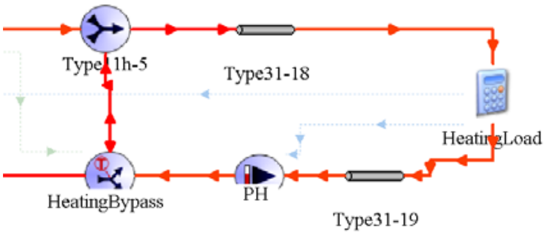


Figure 9: Screenshot of implementation of heating bypass in system C1.

The pipes (DN20) in the heating circuit have a length of 15 meters.

Cooling

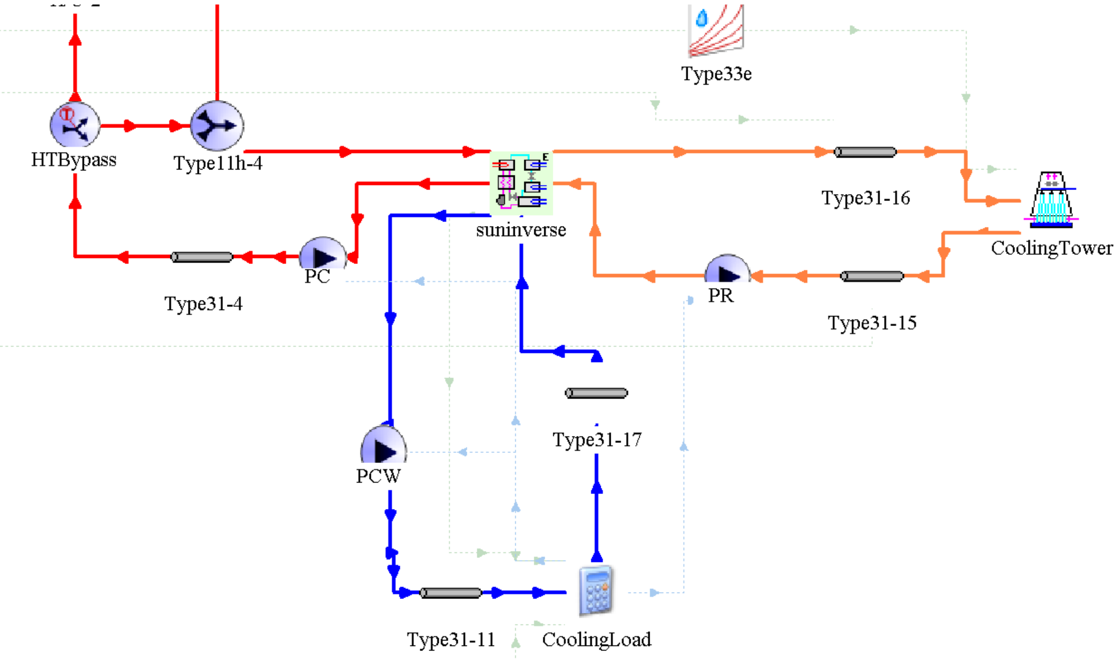


Figure 10: Screenshot of the integration of the suninverse chiller into the Trnsys Deck

In case there is a cooling demand the chiller is supplied with hot water from the solar system/storage if it can provide 80°C + 5°C (Hysteresis). Otherwise the boiler powers the chiller. Again a bypass is used to protect the chiller from excess temperature.

The chiller is connected with DN32 pipes congruently to its hot water connection (1 ¼”).

Heat rejection circuit

The control of the fan speed was realized with a characteristic equation for Suninverse[1] and Rotartica. For ClimateWell a simple on/off regulation was implemented.

Chilled water circuit

The cooling demand is coupled to the simulation under the assumption that the chilled water always returns from the building with 18°C (12° C with fan coils). The water enters the chiller at this temperature and is cooled down to the temperature necessary to meet the cooling load at the nominal mass flow.

This approach was selected to avoid very low temperatures in case the actual cooling capacity is higher than the required cooling rate or excessively high temperatures if the cooling demand can not be met.

Despite the control strategy described above for Suninverse and Rotartica it may occur that the actual cooling rate is higher than the demand. In reality (or in a simulation with a coupled building model) this would lead to a clocking chiller operation with the building acting as short time storage. This behaviour is implemented by an integrator. Excess cooling power is integrated until 1kWh is reached. Then the chiller is turned off and the cooling load is covered from this storage. The integrator works for excess cooling power only. If the cooling load is not met during some time, it is NOT integrated and therefore will not be covered at a later point in time.

Electricity Consumption

The consumption of electric energy of the system is calculated according to the agreements made during IEA SHC Task 26 [IEA-SHC 2002] and published in the Task 26 handbook [Weiss 2003].

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[1] *V. Clauß, A. Kühn, F. Ziegler (2007)*: A new control strategy for solar driven absorption chillers, Proceedings of the International Conference Solar Air Conditioning, 18.-19. October 2007, Tarragona, Spain

Insulation of piping

Insulation of pipes has been realized according to the German Energy Savings Ordinance (EnEV).

Nominal Diameter	Insulation thickness	Heat transfer coefficient	Resulting loss coefficient
DN20	20 mm	0.035 W/mK	5.03 W/m²K
DN25	30 mm	0.035 W/mK	3.53 W/m²K
DN32	30 mm	0.035 W/mK	3.32 W/m²K
DN40	40 mm	0.035 W/mK	2.52 W/m²K

Table 6: Overview of the used loss coefficient for pipe insulation

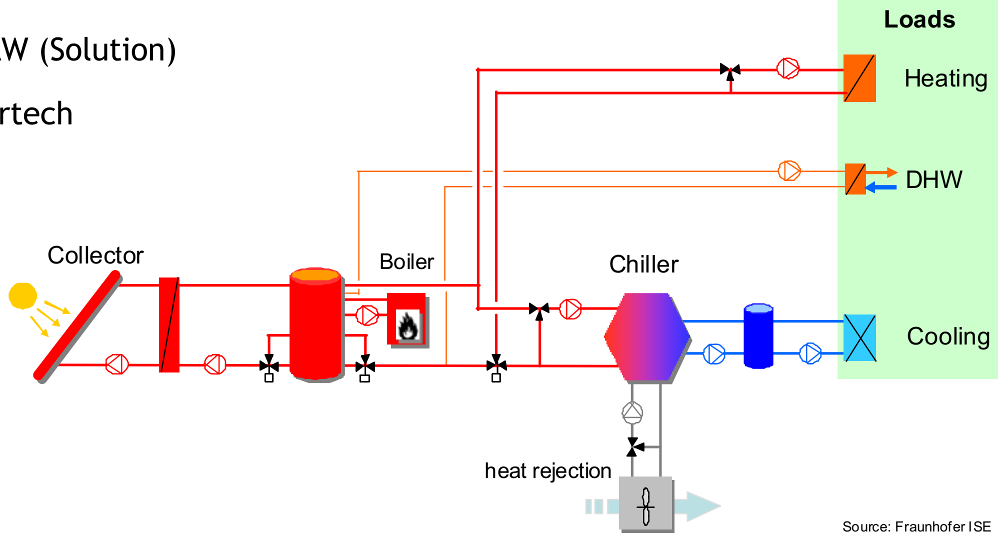
2.8 System E1

System configuration E1

Simulated for:

EAW (Solution)

Sortech



Source: Fraunhofer ISE

Figure 11: System scheme E1

Solar Circuit

The configuration of the solar circuit of this system is similar to the one of system C1. The only difference is that it has a fixed connection to the solar storage. The outlet is located at the bottom of the storage, the inlet is configured for stratified charging. The flow rate of the solar pumps is controlled according to the solar irradiation. If the irradiation is higher than 150 W/m^2 (540kJ/hm^2) the pumps start operating at 20% of their maximum flow rate and reach the maximum flow rate at 800W/m^2. This can be adapted to the manufacturers preferences (e.g. Solution works with fixed flow rates).

In the EAW-system there is no variable speed pump. The specific flowrate per hr and m^2 is 20 l.

Storage

The storage represents the heart of this system. The two heat sources (solar circuit and auxiliary boiler) and loads are connected to it individually. The heights of the connections are adopted from the Task 32 system:

Doubleport description	relative height	Dp Nr.
Inlet of collector loop (stratified)	= 1-1.5/Nmax	1
Outlet of collector loop	= 0.05	1
Inlet of space heating loop	= 0	2
Outlet of space heating loop	= 1-0.5*Vaux/Vstor + 1.5/Nmax	2
Inlet of DHW loop	= 0	3
Outlet of DHW loop	= 1	3
Inlet of cooling loop	= 0	4
Outlet of cooling loop	= 1	4
Inlet of auxiliary heating	= 1-1.5/Nmax	5
Outlet of auxiliary heating	= 1-Vaux/Vstor	5
Inlet of half storage collector loop	= 1-1.5/Nmax	6
Outlet of half storage collector loop	= 0.5 + 0.5/Nmax	6

Boiler Circuit

The auxiliary boiler maintains the upper part of the storage at a certain set temperature if the solar system does not supply sufficient power. For winter operation the set temperature for the storage is 60°C, so DHW preparation is secured at all times. During summer it is increased to 80 °C in case the chiller is operating. The set temperature for the boiler is t_set_storage + 2°C. Thus losses in pipes and by mixing in the storage are compensated.

DHW-Preparation, Heating and Cooling

The hot water circuits for preparation of DHW, heating and cooling are realized identically as in system C1.

Heat rejection circuit

Cooling towers are controlled by a simple on/off strategy.

Chilled water circuit

General

The cooling demand is coupled to the simulation under the assumption that the chilled water always returns from the building with 18°C for activated wall cooling or 12°C for fan coil systems. The water enters the chiller at this temperature and is cooled down to the temperature necessary to meet the cooling load at the nominal mass flow.

Despite the control strategy described above it may occur that the actual cooling rate is higher than the demand. In reality (or in a simulation with a coupled building model) this would lead to a clocking chiller operation with the building acting as short time storage. This behaviour is implemented by an integrator. Excess cooling power is integrated until 1kWh is reached. Then the chiller is turned off and the cooling load is covered from this storage. The integrator works for excess cooling power only. If the cooling load is not met during some time, it is NOT integrated and therefore will not be covered at a later point in time.

EAW chiller (SOLution)

SOLution distributes their solar cooling Kits with cold storage (1m^3 for the EAW Wegracal SE 15). This has been implemented in the Trnsys deck using standard Type 4 as cold storage.

Note: As a conventional system with compression chiller would presumably work without cold storage, the electricity consumption of the pump between chiller and storage must be considered for the system evaluation

3 Energetic and economic performance figures

The outputs of the simulation form a database which contains all the figures required to calculate the defined performance figures.

In the following section 3.2 the calculation of the figures using the simulation output data described shortened in section 1.2 is shown. Section 3.2.1 shows which figures are directly derived from the outputs of the simulations. Section 3.2.2 illustrates how the figures which depend on end-user-defined parameters are determined. Monthly and annual data will be available but the here described performance numbers are annual values.

Input data to be specified by end-user are indicated with { } brackets. A summary of input data to be specified by end-user for post-production of evaluation data is given in section 3.3, section 3.4 gives a proposal for a default solution.

3.1 Definition of performance figures derived from the data base

Gross collector yield q_{coll}

q_{coll} = $Q_{coll} / A_{apertur}$ [kWh / m²]

with Q_{coll} = annual collector energy sum [kWh]

$A_{apertur}$ = aperture area of collector [m²]

Gross collector eficiency $\eta_{collector}$

$\eta_{collector}$ = $Q_{coll} / (Q_{irr}\, A_{apertur}) \cdot 100$ [%]

with Q_{irr} = annual radiation per m² [kWh / m²]

Solar fraction Sf

The single solar fractions for heating, cooling and DHW are calculated as follows in system C1.

$Sf_{cooling}$ = $1\text{-}Q_{aux,cool} / Q_{chiller,tot}$ [%]

$Sf_{heating}$ = $1-Q_{aux,heat} / Q_{heat\ demand}$ [%]

$Sf_{DHW,total}$ = $1-Q_{aux,DHW} / Q_{DHW,demand}$ [%]

Sf_{total} = $Sf_{cooling} + Sf_{heating+} + Sf_{DHW,total}$ [%]

The single solar fractions for heating, cooling and DHW are calculated as follows for system E1.

$Sf_{cooling}$ = $1-(Q_{aux,summer} - Q_{loss,stor} \cdot Q_{aux,summer} / (Q_{aux,summer} + Q_{aux,winter} + Q_{solartosystem}))/ (Q_{chiller,tot} + Q_{DHW,\ summer})$ [%]

$Sf_{DHW,summer}$ = $Sf_{cooling}$(Assumption: $Q_{aux,summer}$ is used for both DHW and cooling in equal parts) [%]

$Sf_{heating}$ = $1-(Q_{aux,winter} - Q_{loss,stor} \cdot Q_{aux,winter} / (Q_{aux,summer} + Q_{aux,winter} + Q_{solartosystem}))/ (Q_{heat\ demand} + (Q_{DHW,demand} - Q_{DHW,\ summer}))$ [%]

$Sf_{DHW,winter}$ = $Sf_{heating}$ (Assumption: $Q_{aux,winter}$ is used for both DHW and heating in equal parts) [%]

$Sf_{DHW,total}$ = $Sf_{DHW,summer} \cdot (Q_{DHW,\ summer} / Q_{DHW,\ demand}) + Sf_{DHW,winter} \cdot ((Q_{DHW,demand} - Q_{DHW,\ summer}) / Q_{DHW,\ demand})$ [%]

With $Q_{solartosystem} = Q_{coll} - Q_{lossHE+SP}$ (Output TRNSYS-deck) [kWh]

$Q_{lossHE+SP}$ = Losses in heat exchanger and solar pipes [kWh]

Total auxiliary heat

For system C1

$\mathbf{Q_{aux,total}}$ = $Q_{aux,cool} + Q_{aux,heat} + Q_{aux,DHW}$ [kWh]

For system E1

$\mathbf{Q_{aux,total}}$ = $Q_{aux,winter} + Q_{aux,summer}$ [kWh]

Coefficient of performance (COP)

Thermal COP of thermal chiller

$\mathbf{COP_{thermal,thermal}}$= $Q_{cold,demand} / Q_{chiller,tot}$ [-]

Electrical COP of thermal and reference system

As the boiler and the collector provide heat for heating, cooling and DHW, the electricity consumption of the boiler and the solar pumps is weighted according to the use of the heat.

Electric efficiency of total system $\eta_{\mathrm{el,\ total}}$

$$\eta_{\mathrm{el,\ total}} = (Q_{\mathrm{cold}} + Q_{\mathrm{heat,demand}} + Q_{\mathrm{DHW,demand}}) / (P_{\mathrm{C}} + P_{\mathrm{HR}} + P_{\mathrm{el,Chiller}} + P_{\mathrm{el,CT}} + P_{\mathrm{el,PS1/2}} + P_{\mathrm{el,Boiler}} + P_{\mathrm{DHW}} + P_{\mathrm{B}}) \quad [-]$$

For system C1

$$\eta_{\mathrm{el,\ cooling}} = Q_{\mathrm{cold}} / (P_{\mathrm{C}} + P_{\mathrm{HR}} + P_{\mathrm{el,Chiller}} + P_{\mathrm{el,CT}} + (Sf_{\mathrm{cooling}} \cdot Q_{\mathrm{chiller,tot}} + Q_{\mathrm{loss,stor}} \cdot Q_{\mathrm{chiller,tot}} / (Q_{\mathrm{chiller,tot}} + Q_{\mathrm{heat,demand}} + Q_{\mathrm{DHW,demand}})) / Q_{\mathrm{solartosystem}} \cdot P_{\mathrm{el,PS1/2}} + P_{\mathrm{el,Boiler}} \cdot Q_{\mathrm{aux,cool}} / Q_{\mathrm{aux,total}}) [-]$$

$$\eta_{\mathrm{el,\ heating}} = Q_{\mathrm{heat,demand}} / ((Sf_{\mathrm{heating}} \cdot Q_{\mathrm{heat,demand}} + Q_{\mathrm{loss,stor}} \cdot Q_{\mathrm{heat,demand}} / (Q_{\mathrm{chiller,tot}} + Q_{\mathrm{heat,demand}} + Q_{\mathrm{DHW,demand}})) / Q_{\mathrm{solartosystem}} \cdot P_{\mathrm{el,PS1/2}} + P_{\mathrm{el,Boiler}} \quad Q_{\mathrm{aux,haet}} / Q_{\mathrm{aux,total}}) \quad [-]$$

For system E1

$$\eta_{\mathrm{el,\ cooling}} = Q_{\mathrm{cold}} / (P_{\mathrm{C}} + P_{\mathrm{HR}} + P_{\mathrm{el,Chiller}} + P_{\mathrm{el,CT}} + (Sf_{\mathrm{cooling}} \cdot Q_{\mathrm{chiller,tot}} + Q_{\mathrm{loss,stor}} \cdot (Q_{\mathrm{chiller,tot}} / (Q_{\mathrm{chiller,tot}} + Q_{\mathrm{heat,demand}} + Q_{\mathrm{DHW,demand}}) \cdot Q_{\mathrm{solartosystem}} / (Q_{\mathrm{aux,summer}} + Q_{\mathrm{aux,winter}} + Q_{\mathrm{solartosystem}})) / Q_{\mathrm{solartosystem}} \cdot P_{\mathrm{el,PS1/2}} + (P_{\mathrm{el,Boiler}} + P_{\mathrm{B}}) \cdot 0.5 \quad Q_{\mathrm{aux,summer}} / Q_{\mathrm{aux,total}}) \quad [-]$$

$$\eta_{\mathrm{el,\ heating}} = Q_{\mathrm{heat,demand}} / ((Sf_{\mathrm{heating}} \cdot Q_{\mathrm{heat,demand}} + Q_{\mathrm{loss,stor}} \cdot (Q_{\mathrm{heat,demand}} / (Q_{\mathrm{chiller,tot}} + Q_{\mathrm{heat,demand}} + Q_{\mathrm{DHW,demand}}) \cdot Q_{\mathrm{solartosystem}} / (Q_{\mathrm{aux,summer}} + Q_{\mathrm{aux,winter}} + Q_{\mathrm{solar2system}}))) / Q_{\mathrm{solartosystem}} \cdot P_{\mathrm{el,PS1/2}} + (P_{\mathrm{el,Boiler}} + P_{\mathrm{B}}) \cdot 0.5 \quad Q_{\mathrm{aux,winter}} / Q_{\mathrm{aux,total}}) \quad [-]$$

For reference system

$$\eta_{\mathrm{el,\ cooling,\ reference}} = Q_{\mathrm{cold}} / P_{\mathrm{el,ref,chiller}} \quad [-]$$

with P_{C} = Hot water to Chiller Pump [kWh]

P_{HR} = Heat rejection pump [kWh]

$P_{el,Chiller}$ = Chiller [kWh]

$P_{el,CT}$ = Cooling tower fan [kWh]

$P_{S1/2}$ = Solar Pumps [kWh]

$P_{el,Boiler}$ = Boiler [kWh]

P_{DHW} = Domestic hot water pump [kWh]

P_B = Boiler pump [kWh]

$P_{el,ref,chiller}$= Electric power consumption of the reference compression chiller [kWh]

Gross storage efficiency $\eta_{storage}$

For system C1

$\eta_{storage}$ = $(Sf_{cooling}\ Q_{chiller,tot} + Sf_{heating}\ Q_{heat,demand} + Sf_{DHW,total}\ Q_{DHW,demand}) \ / \ Q_{solartosystem}$ [-]

For system E1

$\eta_{storage}$ = $(Q_{chiller,tot} + Q_{heat,demand} + Q_{DHW,demand}) \ / \ (Q_{solartosystem} + Q_{aux,total})$ [-]

Storage losses $Q_{loss,stor}$

For system C1

$Q_{loss,stor}$ = $Q_{loss,stor}$ [kWh]

For system E1

$Q_{loss,stor}$ = $Q_{loss,stor}$ [kWh]

Cooling time

Total cooling time = SolarCoolingTime + AuxCoolingTime [h]

Solar cooling time = SolarCoolingTime [h]

Cooling demand time = CoolingDemandTime [h]

Note: Total cooling time may be lower than cooling demand time since there is a small cold storage which covers low demands.

Stagnation time

Stagnation time = StagnationTime [h]

Water consumption M_{water}

M_{water} = V_{water} / 1000 [m³]

Relative boiler consumption

relBoilerConsumption = $P_{el,ref,Boiler}$ / $P_{el,Boiler}$ [%]

3.2 Definition of performance figures calculated with user defined parameters

Input data to be specified by end-user are indicated with { } brackets

Environmental related evaluation numbers

Annual primary energy savings PE_{save}

PE_{save} = $\Delta PE_{fossil} + \Delta PE_{electricity}$ [kWh_{PE}]

with ΔPE_{fossil} = $(Q_{heat, fossil, reference} - Q_{aux,tot})$ / $\{\eta_{boiler}\}\{C_{conversion, fossil}\}$ [kWh_{PE}]

$\Delta PE_{electricity}$ = $(P_{el.ref,tot} - P_{el.SC+,tot})$ / $\{C_{conversion, elec}\}$ [kWh_{PE}]

$\{\eta_{boiler}\}$ = efficiency of boiler [-]

$Q_{heat, fossil, reference}$ = sum of heat demand for heating and DHW in the reference system [kWh]

$Q_{aux,tot}$ = total auxiliary heat for the SC+ system [kWh]

$\{C_{conversion,\ fossil}\}$ = conversion factor fossil heat [$kWh_{heat,\ fossil}$ / kWh_{PE}]

$P_{el.ref,tot}$ = $P_{el,ref,Boiler} + P_{el,ref,chiller}$ [kWh]

$P_{el.SC+,tot}$ = $P_C + P_B + P_{HR} + P_{el,Chiller} + P_{el,CT} + P_{S1/2} + P_{el,Boiler}$ [kWh]

$\{C_{conversion,\ elec}\}$ = conversion factor electricity [$kWh_{elec,\ fossil}$ / kWh_{PE}]

Relative PE_{save}= $PE_{save} / PE_{reference}$ [%]

with $PE_{reference} = Q_{heat,\ fossil,\ reference} / \{\eta_{boiler}\}\{C_{conversion,\ fossil}\} + P_{el.ref,tot} / \{C_{conversion,\ elec}\}$ [kWh_{PE}]

Primary Energy Ratio of a solar combi plus system PER_{SC+} and a reference system PER_{ref}

PER_{SC+} = $(Q_{cold}+Q_{heat,demand} + Q_{DHW,demand}) / (Q_{aux,total} / (\{\eta_{boiler}\}\{C_{conversion,\ fossil}\}) + P_{el.SC+,tot}/\{C_{conversion,\ elec}\})$ [-]

PER_{ref} = $(Q_{cold}+Q_{heat,demand} + Q_{DHW,demand}) / ((Q_{heat,demand} + Q_{DHW,demand}) / (\{\eta_{boiler}\}\{C_{conversion,\ fossil}\}) + (Q_{cold}) /(COP_{el,reference} \{C_{conversion,\ elec}\}))$ [-]

Primary energy coefficient of performance (COP_{PE})

COP_{PE} = $Q_{cold} / (Q_{heat,fossil}\{C_{conversion,\ fossil}\} + P_{el,} \{C_{conversion,\ elec}\})$ [-]

with System C:

$Q_{heat,fossil} = Q_{aux,,cool}$ [kWh]

$P_{el} = P_C + P_{HR} + P_{el,Chiller} + P_{el,CT} + (Sf_{cooling} \cdot Q_{chiller,tot} + Q_{loss,stor} \cdot Q_{chiller,tot} \;/\; (Q_{chiller,tot} + Q_{heat,demand} + Q_{DHW,demand})) \;/\; Q_{solartosystem} \cdot P_{el,PS1/2} + P_{el,Boiler} \cdot Q_{aux,,cool} \;/\; Q_{aux,total}$ [kWh]

System E:

$Q_{heat,fossil} = 0.5\;\; Q_{aux,summer}$ [kWh]

$P_{el} = P_C + P_{HR} + P_{el,Chiller} + P_{el,CT} + (Sf_{cooling} \cdot Q_{chiller,tot} + Q_{loss,stor} \cdot (Q_{chiller,tot} \;/\; (Q_{chiller,tot} + Q_{heat,demand} + Q_{DHW,demand}) \cdot Q_{solartosystem} \;/\; (Q_{aux,summer} + Q_{aux,winter} + Q_{solar2system}\,))\;/\; Q_{solartosystem} \cdot P_{el,PS1/2} + (P_{el,Boiler} + P_B) \cdot 0.5\;\; Q_{aux,summer} \;/\; Q_{aux,total})$ [kWh]

for reference system

$Q_{heat,fossil} = 0$ for the reference system [kWh]

$P_{el} = P_{el,ref,chiller}$ [kWh]

Annual savings in CO2

$CO2_{save}$ = $\Delta PE_{fossil} \;/\; \{CO2_{conversion,\ fossil}\} + \Delta PE_{electricity} \;/\; \{CO2_{conversion,\ elec}\}$ [kg CO2]

with $\{CO2_{conversion,\ heat,fossil}\}$ = conversion factor fossil heat [kg CO2/ kWh_{PE}]

$\{CO2_{conversion,conventional,elec}\}$ = conversion factor conventional electicity [kg CO2/ kWh_{PE}]

Cost related evaluation numbers

Investment costs for Solar system

$I_{solar\ system}$ = {Costs for solar thermal system incl. support, installation [€/m²]} $\cdot A_{aperture}$ + {Costs for storage [€/m³]} $\cdot V_{storage}$ [€]

with $V_{storage}$ = Volume of storage [m³]

Investment costs for thermal chiller

$I_{chiller,\ thermal}$ = {Costs for chiller} + {Costs for heat rejection}

+ {Installation $\text{costs}_{chiller}$} [€]

Investment costs for conventional compression chiller

$I_{chiller,\ compression}$= {Costs for chiller} + {Installation $\text{costs}_{chiller}$} [€]

Operating costs $C_{operating}$

$C_{operating}$ = $\Sigma(Q_{fossil} \cdot \{C_{fuel}\} + Q_{electric} \cdot \{C_{electricity}\} + M_{water} \cdot \{C_{water}\})$ [€/a]

with $\{C_{fuel}\}$ = fuel costs [€/kWh]

$\{C_{electricity}\}$ = electricity costs [€/kWh]

$\{C_{water}\}$ = water costs [€/m³]

Annual costs C_{annual}

Investment costs for the boiler are neglected, as the same boiler is used in both systems.

$C_{annual,reference}$= $a \cdot I_{chiller,compression} + a \cdot \{C_{planning,reference}\} + \{C_{operating,reference}\} + \{C_{maintenance,reference}\}$ [€/a]

$C_{annual,SC+}$ = $a \cdot I_{solar\ system} + a \cdot I_{chiller,thermal} + a \cdot \{C_{planning,\ SC+}\} + \{C_{operating\ ,\ SC+}\} + \{C_{maintenance,SC+}\}$ [€/a]

With factor of annuity a = $\frac{(1+i)^n i}{(1+i)^n - 1}$

{i} = annual interest [%]

{n} = number of years of use [a]

Costs per saved kWh PE

C_{PE} = $(C_{annual,SC+} - C_{annual,reference}) / PE_{saved}$ [€/kWh/a]

If $PE_{save} > 0 \rightarrow C_{PE}$ positive for $C_{annual,SC+} > C_{annual,reference}$

There is no assumption for replacement of system parts and increase of operating costs.

3.3 Summary of input data to be specified by end-user for post-production of evaluation data

$\{\eta_{boiler}\}$ = efficiency of boiler [-]

$\{C_{conversion,\ fossil}\}$ = conversion factor fossil heat – primary energy [$kWh_{heat,\ fossil}$ / kWh_{PE}]

$\{C_{conversion,\ elec}\}$ = conversion factor electricity – primary energy [$kWh_{elec,\ fossil}$ / kWh_{PE}]

$\{CO2_{conversion,\ heat,fossil}\}$ = conversion factor fossil heat [kg CO2/ $kWh_{heat,useful}$]

$\{CO2_{conversion,\ conventional,\ elec}\}$ = conversion factor conventional electicity [kg CO2/ $kWh_{el,useful}$]

{Costs for solar thermal system incl. support, storage} [€/m²]

$\{\text{Installation costs}_{solar\ system}\}$ [€/m²]

{Costs for chiller} [€]

{Costs for heat rejection} [€]

$\{\text{Installation costs}_{chiller}\}$ [€]

$\{C_{fuel}\}$ = fuel costs [€/kWh]

$\{C_{electricity}\}$ = electricity costs [€/kWh]

$\{C_{water}\}$ = water costs [€/m³]

$\{C_{planning,reference}\}$ = costs for palnning, reference [€]

{$C_{operating,reference}$} = operating costs, reference [€]

{$C_{maintenance,reference}$} = maintenance costs, reference [€]

{$C_{planning,\ SC+}$} = planning costs, SC+ [€]

{$C_{operating\ ,\ SC+}$} = operating costs, SC+ [€]

{$C_{maintenance,SC+}$} = maintenance costs, SC+ [€]

{i} = annual interest [%]

{n} = number of years of use [a]

3.4 Proposal of a default solution

Note: We suggest giving default values for each country. The here presented values are to be discussed.

{η_{boiler}} = efficiency of boiler [-]

{$C_{conversion,\ fossil}$} = 0.9 [$kWh_{heat,\ fossil}$ / kWh_{PE}]

{$C_{conversion,\ elec}$ } = 0.6 [$kWh_{elec,\ fossil}$ / kWh_{PE}]

{$CO2_{conversion,\ heat,fossil}$} = 0.25 [kg CO2/ $kWh_{heat,useful}$]

{$CO2_{conversion,\ conventional,\ elec}$} = 0.6 [kg CO2/ $kWh_{el,useful}$]

{Costs for solar thermal system (with vacuum tube collector) incl. support, installation} = 550 [€/m²]

{Costs for solar thermal system (with flat plate collector) incl. support, installation} = 350 [€/m²]

{Storage } = 1000 -200 [€/m³]

{Costs for chiller} = to be discussed… [€]

{Costs for heat rejection} [€]

{Installation $costs_{chiller}$} [€]

{C_{fuel}} = 0.06 Source: www.energieverbraucher.de [€/kWh]

{$C_{electricity}$} = 0.17 Source: Energieagentur NRW 03/2006 [€/kWh]

{C_{water}} = 2 [€/m³]

$\{C_{planning,reference}\}$ = costs for planning, reference [€]
$\{C_{operating,reference}\}$ = operating costs, reference [€]
$\{C_{maintenance,reference}\}$ = maintenance costs, reference [€]
$\{C_{planning,\ SC+}\}$ = planning costs, SC+ [€]
$\{C_{operating\ ,\ SC+}\}$ = operating costs, SC+ [€]
$\{C_{maintenance,SC+}\}$ = maintenance costs, SC+ [€]
$\{i\}$ = 8 [%]
$\{n\}$ = 20 [a]

The Trnsys decks for the virtual case study were created by ISE. The simulation work was divided among project partners as follows:

Chiller	Simulated by	System	Total number of simulations
ClimateWell 10	EURAC	C1	660
Rotartica Solar 7	Uni Bergamo	C1	660
Sonnenklima suninverse	CRES	C1	660
Sortech ACS08	ISE	E1	660
Wegracal SE 15	AEE Intec	E1	165*

*Since Solution markets this chiller only in combination with flat plate collectors and wet cooling towers the other configurations were not simulated for this chiller.

The results of the virtual case study will be available online at: www.solarcombiplus.eu

Annex I: Calculation of electric power consumption of pumps

Efficiency hot water pump	0.2	[-]
Efficiency cooling water pump	0.45	[-]
Efficiency chilled water pump	0.2	[-]
pressure drop in hot water pipes	100	[mbar]
pressure drop in cooling water pipes	300	[mbar]
pressure drop in chilled water pipes	200	[mbar]
pressure drop in wet cooling tower	400	[mbar]
pressure drop in dry cooling tower	150	[mbar]
pressure drop in chilled water distrib. system	300	[mbar]
uncertainty factor	0.15	[-]

$$P_{hydr} = \Delta p_{total} \cdot \dot{V} \qquad [W]$$

$$P_{el} = \frac{P_{hydr}}{\varepsilon_{Pump}} \cdot \left(1 + f_{uncertain}\right) \qquad [W]$$

Chiller	hot water circuit			cooling water circuit		wet	dry	chilled water circuit		
	dp [mbar]	V [m^3/h]	P_el [W]	dp [mbar]	V [m^3/h]	P_el [W]	P_el [W]	dp [mbar]	V [m^3/h]	P_el [W]
Sonnenklima	200	1.2	**60**	320	2.6	**190**	**140**	350	2.9	**135**
Sortech	300	1.6	**100**	610	3.7	**345**	**280**	370	2	**140**
Rotartica	200	0.9	**45**	880	2	**225**	**190**	300	1.5	**130**
EAW	400	2	**160**	900	5	**570**	**480**	400	2	**145**
Climatewell	280	0.9	**55**	280	1.8	**125**	**95**	280	0.9	**125**

Electric Powers are rounded to 5W.