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Virtual case study on small solar cooling systems within the SolarCombi+ project

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Introduction

The project SolarCombi+, supported by the Intelligent Energy Europe program, aims at achieving a better market potential for small scale solar cooling systems in combination with traditional solar thermal systems for domestic hot water preparation and space heating. The reduction of the design effort for such systems offers an important potential for cost reduction. Therefore an extensive simulation **case study** was carried out in order to determine standard system configurations. This paper concludes the applied methodology and shows selected results. The best results are available online also and were used to develop package solutions, which work best under different circumstances, for each thermally driven chiller of the five participating industry partners (ClimateWell, Rotartica, Solution, Sonnenklima, Sortech).

Methodology of virtual case study

Initially two common hydraulic system configurations for solar heating and cooling systems have been identified by means of a market analysis and the expertise of institutional and industry partners. The difference of the two systems is the integration of the hot water storage. System C (Figure 1) allows for the following operation modes:

- direct solar operation bypassing the hot storage
- operation with heat from solar system and storage
- operation with all heat extracted from storage
- fossil operation with all heat provided from boiler and bypassed storage

The water for DHW preparation is preheated in the solar storage and – if necessary – heated to 60°C in the boiler.

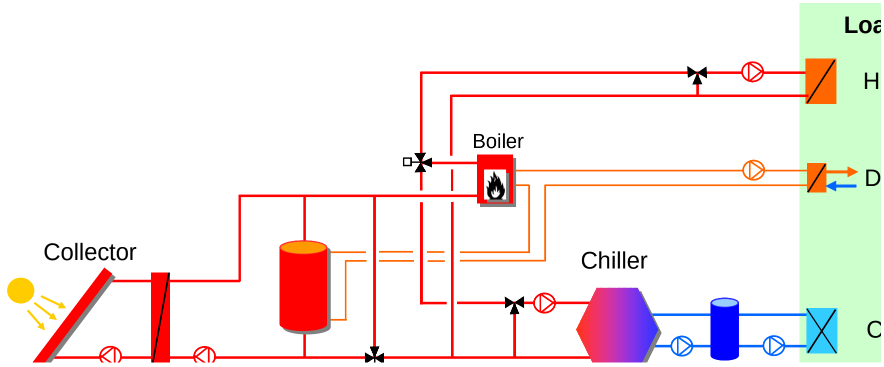

Figure 1: System scheme C, simulated for chillers ClimateWell 10, Sonnenklima suninverse and Rotartica 4.5

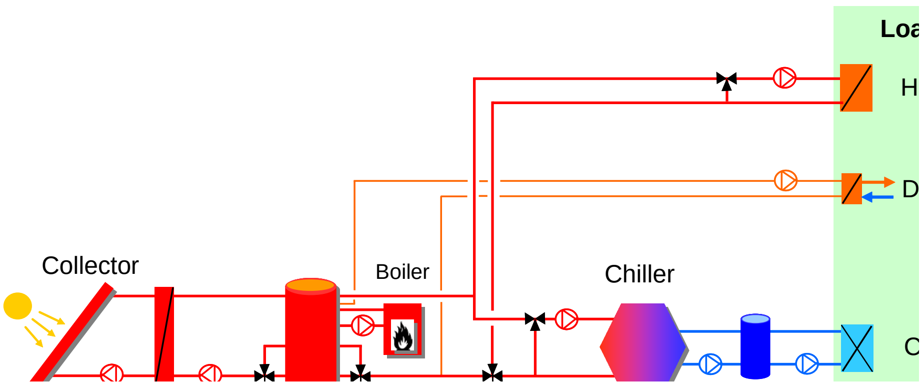

Figure 2: System scheme E, simulated with Sortech ACS08 and EAW Wegracal 15 (Solution) chillers.

In the second configuration (scheme E, figure 2) the hot water storage comprises the core of the system. All heat sources charge it and all consumers obtain their energy

from it. Specific characteristics are:

- In order to quickly reach the minimum driving temperature for the chiller with the solar system, an additional outlet is located in the middle of the storage.
- The top 200l are always maintained at 60°C for the DHW preparation.
- The return flow on the load side is fed into the storage in a stratified way.

Each of the five industry partners opted for their chiller to be analyzed in one of the identified configurations. A multitude of parameters were varied in course of the study:

- 3 locations (Strasbourg, Toulouse, Naples)
- 5 applications (Office with fan coil, 2 residential building standards each with fan coil and with chilled ceiling)
- 2 collector types (flat plate and vacuum tube)
- 2 heat rejection technologies (adiabatic dry cooler and open wet cooling tower)
- 5 collector sizes: 2…5 m²/kW reference power (see below)
- 3 hot water storage volumes: 25-50-75 l/m²

In order to reduce the simulation effort and improve the numerical stability no coupled simulation of building and system was carried out in this study. Instead load files of the respective locations and buildings were created in separate simulations. This made it necessary to account for two things. Firstly the load had to be covered at all times as the building response to other conditions could not be determined. Secondly, since the included chillers have a wide range of chilling capacities (4.5kW…15kW nominal capacity), it was necessary to adapt the load file to the chilling capacity. For this reason the following scaling factor was introduced for each chiller, location and application:

$$f_{scale} = \frac{P_{ref}}{P_{coolingload,\max}} \tag{1}$$

$P_{coolingload,max}$: maximum cooling load of the respective load file

P_{ref} = $f(t_{hot}, t_{cool}, t_{chilled})$: reference chilling capacity of the specific chiller under the operation conditions determined by the temperatures t_{hot}, t_{cool}, $t_{chilled}$

t_{hot} = 95°C

t_{cool} = 27°C for wet cooling tower and 32°C for adiabatic dry tower

$t_{chilled}$ =18°C for chilled ceiling and 12°C for fan coil

Starting from a unified control strategy for all chillers, the following details were adapted individually:

- Allowed operating temperature for chillers, especially minimum hot water temp.
- speed control of the cooling tower fan
- speed control of the solar pumps

The overall electric performance of the solar cooling system is highly dependent on the electricity consumption. Therefore a standardized approach to determine the electric power consumption of the pumps in the three chiller circuits based on the required hydraulic power was used.

$$P_{el,circuit} = \frac{\Delta p_{circuit} \cdot \dot{V}_{circuit}}{\varepsilon_{Pump,circuit}} \qquad [W] \qquad (2)$$

ε_{Pump} : Efficiency of pump [-]
$\Delta p_{circuit}$: Total pressure drop of the respective hydraulic circuit [Pa]
$V_{circuit}$: Volume flow rate in hydraulic circuit [m³/h]
Manufacturer's data was used for pressure drops and volume flows of the chillers. The remaining values (pressure drops of other components and efficiency of pumps) were derived from experience with existing installations. For the electricity consumption of the other components values were defined as in IEA SHC Task 32 [2].
The reference system consists of a boiler and a compression chiller with a COP dependent on the temperature difference between ambient air and provided cold water.

$$COP = 3.62 - 0.06 \cdot (t_{amb} - t_{CW}) \qquad (3)$$

In total 660 simulations were carried out per chiller if all variations were included (some industry partners excluded certain configurations for their chiller). [2] [3]

Results

The evaluation of the system is done with help of energetic performance figures for subsystems as well as for the overall system on the one hand. On the other hand, economical and environmental parameters are considered. The objective of the simulation study is to provide information on reasonable system dimensioning and not

to compare different chillers. Therefore the results are presented as averages over all chillers and relative to the result of the medium sized system (3.5m²/kW reference power and 50l/m² aperture area). Absolute values of best configurations will be available from the online data base on the project homepage.

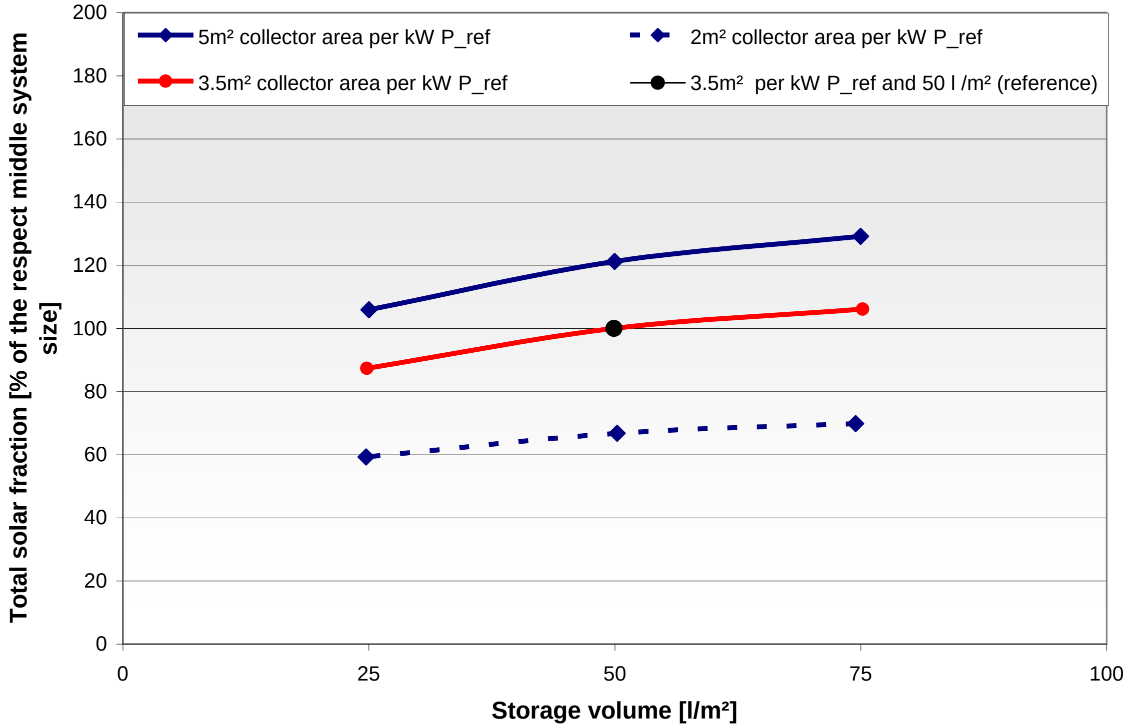

Figure 3: Deviation (average over chillers) of specific gross solar yield with respect to the respective medium sized system (black dot=100%) for the system configuration Naples, chilled ceiling, flat plate collector, wet cooling tower, residential building.

Figure 3 shows the total solar fraction relative to the result of the medium sized system. It clearly increases with growing aperture areas and growing storage sizes but at a slowing pace. Optimal solar fraction requires very large storages (>75l/m²) in order to bridge days with low irradiation.

For good dimensioning of the system it is essential to find a compromise between energetic performance and costs. The specific costs of primary energy savings (c_PE) have been found adequate for this objective. This evaluation number is defined as the cost of the primary energy saved by the solarcombiplus system in comparison to a conventional system with gas boiler and compression chiller. Figure 4 illustrates, that the costs of systems with large collector areas are close to the medium sized system. Contrarily the costs increase a lot from a medium system size to a smaller system size (up to 450%). Therefore a reasonable system size will

have 3.5 to 5 m² of collector aperture area per kW of reference chilling capacity and a specific storage volume of around 50l/m.

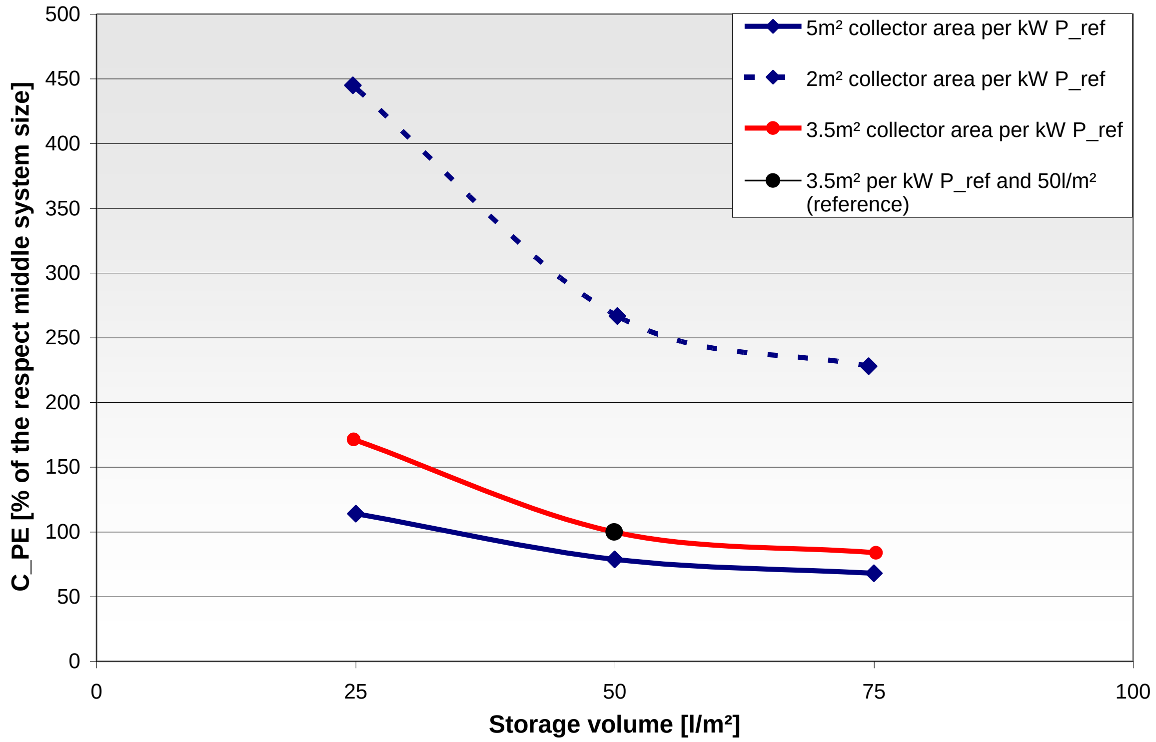

Figure 4: Deviation (average over chillers) for cost of saved primary energy with respect to the medium sized system as in figure 3.

Conclusion

Within the project SolarCombi+ a comprehensive methodology for an extensive simulation study has been developed. A large number of simulations have been carried out providing valuable information on system behavior and performance. These results were used to define pre-dimensioned package solutions for the chillers of the participating industry partners. The best configurations are also available from an online data base at the project homepage (www.solarcombiplus.eu).

Acknowledgement/Disclaimer

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