Assessment of Standard Small-Scale Solar Cooling Configurations within the SolarCombi+ Project

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Abstract

Small sorption chillers are available on the market for the installation in solar assisted domestic hot water and space heating plants. Their use in office and residential buildings could potentially lead to a significant mitigation of the primary energy consumption and therefore of the CO2 production for air conditioning. However, the economical sustainability of this technology shows significant hurdles due to the costs of the investment and of the plant's design. The latter could be reduced if standard system configurations were considered for installation, as it actually happens in the case of ordinary domestic hot water plants.

Introduction

The air conditioning market both for heating and cooling is expanding rapidly in Europe as a result of increasing comfort expectations; almost 49% of the total energy consumption in Europe is employed for buildings' heating and cooling [1]. About 90TWh of electrical energy are used for summer air conditioning in EU15, the biggest markets being Spain (33TWh), Italy (27TWh) and France (10TWh) [2]. For this reason much effort in the EU energy policy [3] is devoted to the implementation of renewable energies for the management of the buildings' thermal loads [4].

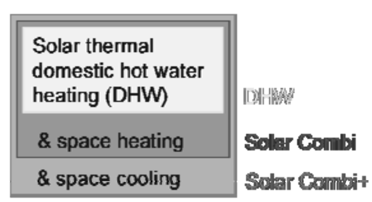

Figure 1 – Solar combi+ system explanatory scheme.

Already today, solar thermal energy for domestic hot water (DHW) preparation and for space heating is a developed technology with a high penetration rate in

some countries, as Germany and Austria. Solar driven sorption chillers were up to now only manufactured in the high power range (>100 kW_{cold}). Today, machines with rated power between 5 and 30 kW_{cold} are available to be included in solar combi+ systems (see Figure 1) for small applications, which make up for the major part of heating and a constantly growing part of cooling demand. Costs of the investment and lack of experience of designers and installers are the most important barriers for a broad diffusion of solar combi+ applications. The assessment of standard system configurations might reduce considerably the design effort for single applications and is the basis for the development of package solutions possibly manufactured at a large scale level.

Methods

The study started from an extensive campaign of numerical simulations carried out in TRNSYS on a basic plant configuration detected through market and technical analysis. Each industrial partner of the consortium opted for one of the two plant layouts represented in Figure 2, which suites best the working features of its chiller.

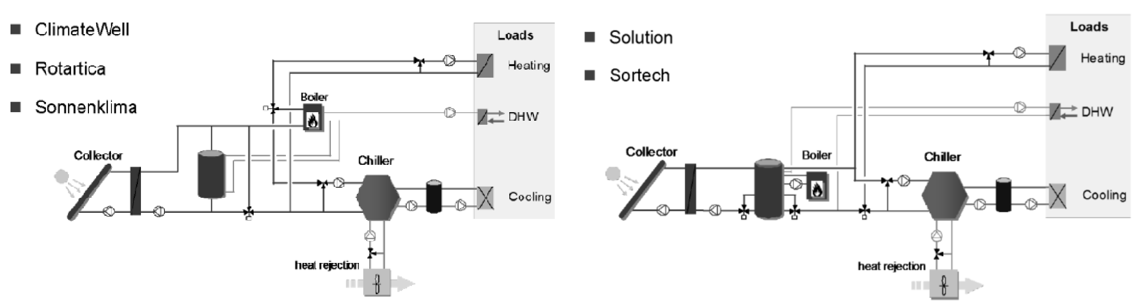

Figure 2 – Solar Combi+ layouts selected by the industrial partners.

Within the basic systems, a number of parameters were varied:

- Geographical location of the solar combi+ plant
- Building in which the solar combi+ plant is installed
- Chiller brand
- Collectors' type (flat plate and evacuated tube collectors)
- Heat rejection system's type (wet cooling tower, dry and hybrid air cooler)

- Chilled/Warm water distribution system (fan coils and chilled ceiling).
- Collectors area
- Hot water storage volume

Three locations were chosen, with fairly different needs in terms of heating and cooling demands [5, 6]; in particular the climatic conditions in Naples (south Italy), Toulouse (south France) and Strasbourg were considered. Three small scale applications were also selected: one office and two residential buildings. The size of the building was adapted to the Reference Power of the specific chiller Power (power delivered at the rated generator temperature and condenser/evaporator temperatures given by the heat rejection/distribution technologies) to allow a fair comparison of the performance of chillers with different sizes. Fan coils were simulated with regard to all the applications, while chilled ceilings were only considered in case of residential buildings. Collectors' area between 2 and 5 $m^2/kW_{Ref.Pow.Cold}$ and warm water storage volume between 25 and 75 l/m^2 of collectors' area were considered.
Among those, four were evaluated as the most interesting for the assessment of the standard system configurations:

- Total solar fraction
- Primary energy saved per year
- Gross Solar Yield

The total solar fraction accounts for the fraction of the total DHW, heating and cooling needs covered through the solar energy utilization. The primary energy saved compares the energy needs of the conventional and the renewable solution. Finally, the gross solar yield accounts for the total yearly energy harvested by the reference area of collectors. Each of the mentioned parameters was used to detect a set of three "standard" system layouts for each set of varying parameters.

Results and Discussion

Table 1 shows results of the simulations run with regard to a residential building placed in Naples and setup with chilled ceilings. The table allows comparing the system performance if semi-fixed parameters are exchanged: flat plate (FP) and evacuated tubes (ET) collectors, wet cooling tower (WCT) and hybrid cooler (HC, dry air cooler + sprinkled water) are taken into consideration. Representative average

values for the chillers investigated are presented. More data than the ones relative to the standard configurations selected (the three performing best) are reported to show the potential improvements achievable through well-designed systems.

Table 1 – Solar Combi+ systems performance related to a residential building placed in Naples. Chilled ceilings used in datasets 1,2 and 3. Fan coils used in dataset 4.

	Coll. type	H.R. type	Coll. area [m2/kW]	Storage Vol. [l/m2]	TOT. Solar Fraction [%]	PE Saved [%]	Gross Solar Yield [(kWh/anno)/m^2]
1	ET	WCT	4.27	50	70	38	555
	ET	WCT	4.27	75	73	45	574
	ET	WCT	5.00	25	67	34	466
	ET	WCT	5.00	50	76	49	515
	ET	WCT	5.00	75	80	56	533
2	FP	WCT	4.27	50	64	29	505
	FP	WCT	4.27	75	68	36	525
	FP	WCT	5.00	25	61	23	418
	FP	WCT	5.00	50	70	39	468
	FP	WCT	5.00	75	75	47	489
3	ET	HC	4.27	50	68	35	547
	ET	HC	4.27	75	71	39	588
	ET	HC	5.00	25	68	35	524
	ET	HC	5.00	50	71	38	534
	ET	HC	5.00	75	77	50	545
4	ET	WCT	4.27	50	63	13	540
	ET	WCT	4.27	75	68	22	580
	ET	WCT	5.00	25	65	18	528
	ET	WCT	5.00	50	69	22	498
	ET	WCT	5.00	75	75	35	534

Once the collectors’ area and the heat rejection system are set, the effect of changing collectors’ type, from ET to FP (dataset 1 and 2), is a slight decrease of the solar energy utilization ability of the system (solar fraction decreases of around 5-10%). A much larger cut is noticed in terms of primary energy saved; reductions between 15 and 30% are obtained, depending on the warm water storage size. This is mostly due to the lower water temperatures that might be reached with the flat plates technology and that affect both summer (chilling) and winter system performance. Moreover, the storage size becomes more and more important as far as the collectors’ return temperature drops.

Comparing the heat rejection systems (datasets 1 and 3), the effect of using a technology that is less effective than the wet cooling tower is a decrease of the performance of the entire plant. The drop of primary energy saved (6-8%) is not so significant as in the case of the solar collectors change; the trend is due on one side to the lower chillers overall performance when coupled with this kind of heat exchanger and on the other side to an higher electrical energy consumption for driving its fans.

Error! Reference source not found. 4 reports the results for the same chillers and application (Naples, residential building); in this case, the building is setup with fan coils as a distribution system for the chilled and heating water. Again a reduction of performance with regard to the first set of data shown in Table 1 is noticed (compare dataset 1 and 4), with a large effect mostly on the primary energy saved: decreases between 40-50% are reported on average. In general chilled ceilings are better suited since higher distribution temperatures (13-18°C) are employed and higher thermal inertia is obtained with respect to fan coil systems. On the other side, in some cases (e.g. refurbished buildings) fan coils are the only useful way for distributing heating and cooling.

Finally, the gross solar yield decreases with larger collectors areas and smaller storage sizes. This reduction is a consequence of lower collector efficiency at higher temperatures and prolonged stagnation periods when the storage is fully “charged”.

The comparison of the four datasets shows that the chilled ceiling, wet cooling tower and evacuated tubes collectors configuration allows the solar combi+ system to perform best from a purely technical and environmental point of view. The simulations for the office application show the same result even when fan coils are considered for the distribution (wet cooling tower and evacuated tubes should be preferred).

Moreover, the best solutions are obtained when the biggest collectors area and storage volume are used. A change of the trend would be obtained for bigger system size (collectors’ area larger than $7m^2$/kW); nevertheless, the highest collectors areas were not investigated since they are not suitable for small applications.

When the solutions close to the best are regarded, the effect of both exchanging technologies and varying components size is not clearly chiller and application

independent. This aspect and cost issues – raw investment costs are considered together with cost of primary energy saved when planning a system - leave a certain freedom to the manufacturers when designing a standard system configuration.

Conclusions

The above discussion shows that standard configurations for solar combi+ systems might be determined, mostly chiller independent, which can be promoted and applied similarly to the standard systems for DHW with reasonably good results in typical utilization cases.

The technologies and sizes of the components to be selected are clearly stated from a environmental-technical point of view. However, considerations about investment and costs per primary energy saved might lead to standard configurations that differ to some extent from the ones showed before.

Acknowledgements

Acknowledgements go to the EACI that funded the Solar Combi+ project under IEE program (contract N°: EIE/07/158/SI2.466793).

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