EVALUATION OF STANDARD SOLAR COMBI PLUS SYSTEMS FOR SMALL SCALE APPLICATIONS

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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.

The presented work concerns with the analysis of the methods and the results elaborated within the IEE programme SolarCombi+ project. The aim of this project is to take small scale sorption chillers and identify and promote standardised systems for combined solar water, space heating and cooling production up to cooling loads of 20kW. Accelerating and smoothing the market entry of those systems, the project contributes to achieving energy policy goals of the EU and supports the diffusion of a technology where a group of European enterprises has a favourable starting point for international leadership.

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].

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 kWcold). Today, machines with rated power between 5 and

Figure 1 – Solar combi+ system explanatory scheme.
30kW\textsubscript{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.

The presented paper concerns with the analysis of the methods and the results elaborated, within the IEE programme SolarCombi+ project, in the process of evaluation of standard solar combi+ configurations. Aim of the process is the definition of a reduced number of system configurations, which can be promoted and applied similarly to the standardized systems for domestic hot water production, which work reasonably well in common applications and are independent of the specific products considered.

**METHOD**

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.](image)

Within the basic systems, a number of parameters were varied; so called “fixed”, “semi-fixed” and “free” parameters were identified and a range of values was selected for each one. As fixed parameters of the analysis were taken:

- Geographical location of the solar combi+ plant
- Building in which the solar combi+ plant is installed
- Chiller brand.

Three locations were chosen, representative of different climatic areas between the south and mid Europe, 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 with different specific heating and cooling requirements were also selected: one office and two residential buildings (see Table 1). 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 chillers’ performance.
Simulations were performed for each of the five commercial chillers studied. The three parameters above were named fixed since they cannot be settled by the manufacturer/designer. On the contrary technology related figures might be negotiated to some extent. Within this category were considered:

- Collectors’ type (flat plate and evacuated tube collectors)
- Heat rejection system’s type (wet cooling tower, dry air cooler and hybrid cooler)
- Chilled/Warm water distribution system (fan coils and chilled ceiling).

Fan coils were simulated with regard to all the applications, while chilled ceilings were only considered in case of residential building.

| Collectors’ area between 2 and 5 m²/kW<sub>Ref. Pow. cold</sub> |
| Warm water storage volume between 25 and 75 l/m²collectors’ area |

Table 1 – Thermal loads relative to office application, average and low energy consumption residential buildings. Thermal loads for given application change as a function of the climatic conditions

Finally, collectors’ area and warm water storage volume were considered as free parameters of the analysis. Even in this case however, constraints were decided related to economical and technical performance of the solar combi+ system:

- Collectors’ area between 2 and 5 m²/kW<sub>Ref. Pow. cold</sub>
- Warm water storage volume between 25 and 75 l/m²collectors’ area

The collectors area was scaled with regard to the Reference of the single chiller. A large number of performance, environmental and economical figures were evaluated for about 2500 simulations. Among those, four were evaluated as the most interesting for the assessment of the standard system configurations:

- Total solar fraction
- Total electrical efficiency
- Primary energy saved per year
- Primary energy saved per year and per collectors’ area

The first two are technical parameters. The total solar fraction accounts for the fraction of the total DHW, heating and cooling needs covered through the solar energy utilization. The total electric efficiency is the average ratio of the total thermal loads (for heating, cooling and domestic hot water) and the electrical consumption of the system (comprising chiller and solar circuits pumps, heat rejection system fans, etc). The primary energy saved is an environmental figure comparing energy needs of the conventional and the renewable solution, while the last two join techno-economical aspects to environmental ones. The primary energy saved per collectors’ area accounts for the expense, in terms of system size, of the environmental benefit.

Each of the four parameters mentioned above was used to detect a “best” system layout: for each set of fixed parameters, the system configurations that maximize/minimize the given figure were determined in terms of semi-fixed and free parameters. A set of “good” solutions
that allow for system environmental-technical performance close to the best was also established: the two solutions closest to the best for each set of fixed parameters were taken. This was done since the best environmental-technical solution might not be the most effective from the point of view of marketing-cost aspects.

**RESULTS**

Table 2 shows results of the simulations run with regard to a low energy consumption residential building placed in Naples and setup with chilled ceilings. Naples was selected for the discussion as the most severe environment in terms of cooling needs, due to its high summer temperatures and latent loads induced by the proximity of the sea. 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>
<thead>
<tr>
<th>Coll. type</th>
<th>H.R. type</th>
<th>Coll. area [m²/kW]</th>
<th>Storage Vol. [l/m²]</th>
<th>TOT. Solar Fraction [%]</th>
<th>Electrical Efficiency [-]</th>
<th>Relative PE Saved [%]</th>
<th>Specific PE Saved [(kWh/year)/m²]</th>
<th>Specific CO₂ Saved [(kg/year)/m²]</th>
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Table 2 – Solar combi+ systems performance related to a low energy consumption residential building placed in Naples. Chilled ceilings used.

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.

Table 3 reports the results for the same chiller and application (Naples, low energy consuming 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 2 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.

Table 3 - Solar combi+ systems performance related to a low energy consumption residential building placed in Naples. Fan coils used.

The last column of Table 2 and Table 3 represents the saved CO2 per collectors’ area: CO2 savings between 36 and 72 kg/year/m^2. In absolute terms, the CO2 emissions avoided range between 2 and 4 tons/year in all studied cases. If one bears in mind that the residential building considered could be used by a 4 people family (0.5 to 1 tons CO2 spared each), and that in a typical European city every inhabitant is responsible for around 8 to 10 tons of CO2 emitted per year (transport and economical activities are considered in this figure), it can be noticed that the large scale diffusion of solar combi+ systems would lead to a significant reduction of the CO2 emissions and therefore of the primary energy used. If only heating, cooling and DHW needs are regarded, primary energy savings between about 30 and 60% are reported in case of well-designed solar combi+ systems.

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. This outcome is applicable to all chillers investigated, leading to a “best” standard system configuration, chiller independent. 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 (i.e. the “good” ones), 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. For example, in the case reported, the best technical solution is also the best economical one, if only the cost per saved primary energy is regarded. However, solutions that provide somewhat lower overall effectiveness (e.g. systems setup with a dry cooler or flat plats) might result also in significantly lower system costs.

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/average 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.

Although well designed solar driven solar combi+ systems allow major reductions of primary energy usage and CO2 emissions, their cost is still significantly higher than the one of traditional air conditioning systems. The gap could be easily bridged through national funding schemes for the duration of the market startup phase and consequently to economy of scale.

ACKNOWLEDGEMENTS

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