Modeling and analyzing solar cooling systems in Polysun

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1. Abstract

A broad study on thermal behavior of solar-assisted single-effect absorption system coupled to the real-time cooling load of different buildings located in several climates was established by using dynamic simulating software "Polysun" [1]. Polysun offers an efficient and state-of-art design of renewable energy systems. As a result of the current project, a steady-state model of the single-effect absorption chiller was developed in the software. The results of a combi-system coupled to a typical low-energy residential building located in Milan, Italy are presented in this paper.

2. Introduction

The need of air conditioning during summer time has been increasing continuously since last decades in both residential and commercial building sectors world-wide. The main reasons for such a trend are improvement in living standard, cooling demand increase mainly due to enhanced insulation against heat losses in the buildings construction, building architectural trends such as increase in the ratio of transparent to opaque surfaces in the building facades as well as increase in average ambient temperature in many regions in the world due to the global warming.

Currently, a few computer programs are available commercially for designing and modulating absorption systems. As examples, TRNSYS [2] and ABSIM [3] are two simulation platforms based on modular concept. However, the complexity of the system implementation and non-user friendliness of the software environment has made them difficult to be used by popular users. Moreover, ABSIM is only able to model and simulate the absorption system itself but not able to forecast the thermal behavior of the whole cooling system i.e. the heat source, heat sink, storage tank, hydraulics, and built environment loads as different components.

Thanks to Polysun, detailed models of solar field, stratified storage tank, hydraulics, and also the building model are available as user friendly components. Besides, a number of different types of controllers with many possible configurations have been developed in Polysun which could influence the efficiency of the chiller as well as solar circuit.

3. Absorption system model implementation in Polysun

Several theoretical or empirical methods have been proposed so far by researchers to model and simulate absorption chiller cycle. An analytic solution of the governing equations of the single-effect closed-cycle absorption chiller at the steady-state condition has been suggested by Kim et al. [4] which is used in the current project. The main advantage of this approach is that it can enable a quick simulation of absorption system with minimal information on working fluids and operation condition. The model is based on the heat exchanger effectiveness definition, Dühring equation and thermodynamic principles of the main constitutive components [4]. The absorption machine model has three pairs of connecting ports enabling heat exchange between heat source, heat sink, and cooling load fluid domains over the component. Energy and mass balance equations of each existing component in the system are solved in a certain manner using so called Explicit Plug-flow Technique.

4. System configuration flexibility in Polysun: Examples

A number of different cooling system configurations are possible to be simulated in Polysun. For example, Figure 1 shows a solar-assisted absorption system integrated to hot and cold water storage tanks as well as wet cooling tower as heat sink. Pool can be also used as heat sink as shown in Figure 2. A combi-system is shown in Figure 3 in which solar thermal collector field as well as the gas boiler as backup are used to provide heating demand during winter and to run the absorption chiller as heat sources during summer to compensate for cooling demand of the building. Domestic hot water demand is also provided through such a system all over the year.

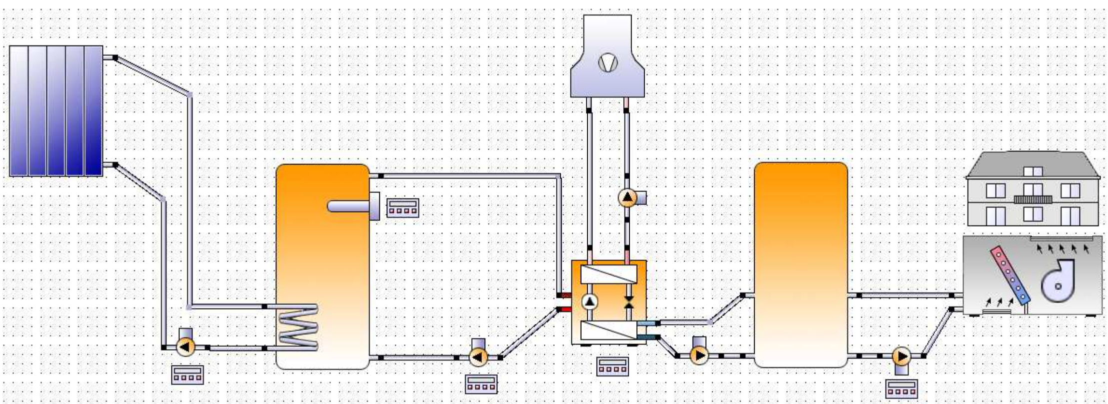

Figure 1. Solar-assisted absorption system integrated to wet cooling tower with hot and cold water storage tanks.

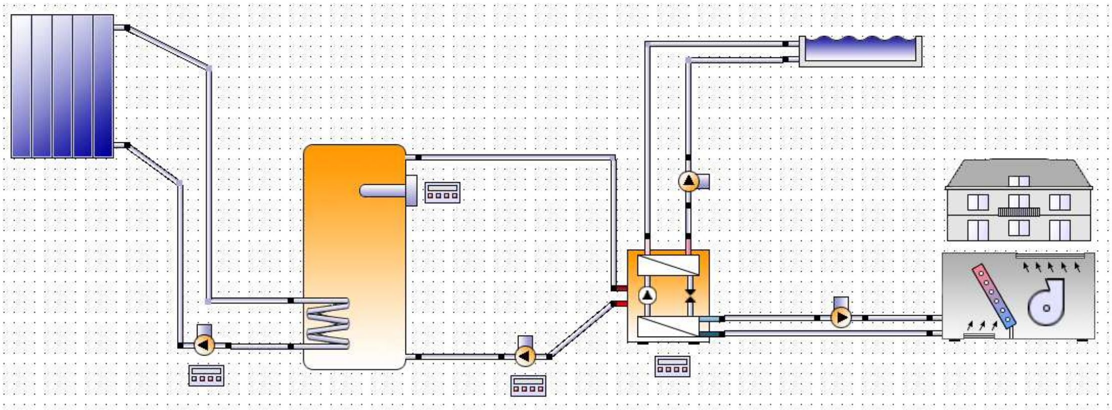

Figure 2. Solar-assisted absorption system integrated to pool as heat sink.

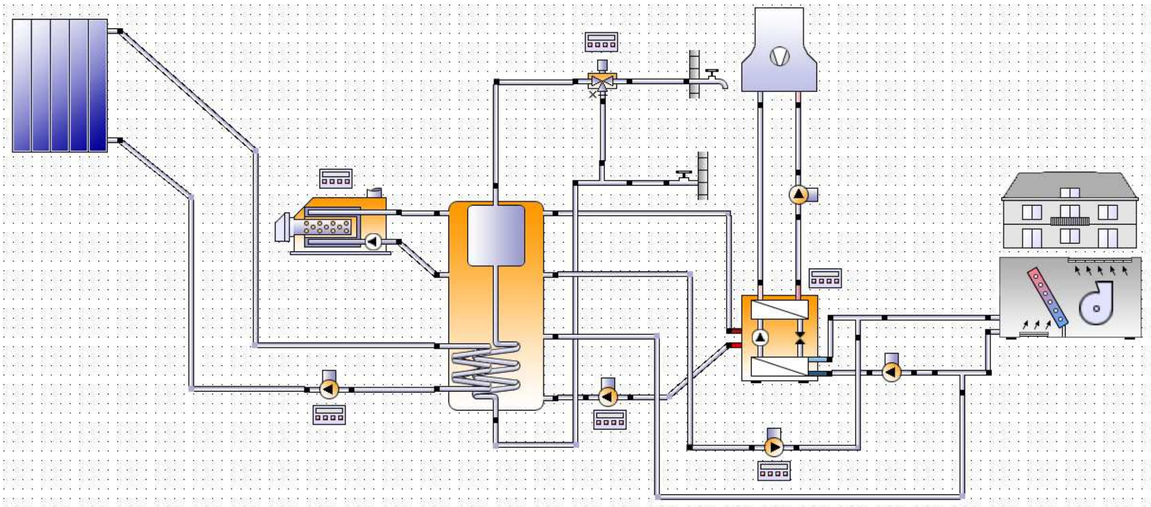

Figure 3. Solar-assisted combi-system for heating, cooling and hot water demand.

5. Results

The combi-system as shown in Figure 3 has been created in Polysun. Several system setups have been tried out as sensitivity approach. It was concluded that the variation of hot water inlet temperature to the generator has a significant impact on the cooling capacity and the performance of the chiller.

A yearly simulation was carried out based on an optimum system specifications tabulated in Table1. The monthly solar fraction as well as monthly cooling energy yield, cooling demand, and energy to the generator are shown in Figure 4-5.

Table 1. Solar-assisted system specifications.

Component	Component specification	Control strategy
Solar thermal collector	Flat plate collector, good quality Total aperture area: 27m^2 Number of collectors: 15 Number of parallel arrays: 1 Tilt angle: 45^o	If collector outflow temp.> tank middle layer temp. +4 then solar loop pump is switched on. If collector outflow temp. < tank middle layer temp. -2 then solar loop pump is switched off.
Auxiliary source	Natural gas boiler with internal pump Capacity: 10 kW	If tank top layer temp.< 80^{o}C then boiler is switched on. If tank top layer temp.>100 ^{o}C then boiler is switched off.
Storage tank	Stainless steel tank Volume: 600 liter Internal tank volume: 41.1 liter Small internal coil heat exchanger	-------
Absorption chiller	Model: Single-effect Solution pair: LiBr/Water Design cooling capacity: 10kW Design cooling COP: 0.8 Design Chilled water inlet/outlet temp.: 12/8 ^{o}C Design chilled water flow rate: 1800l/h Design cooling water inlet/outlet temp.: 25/32 ^{o}C Design cooling water flow rate: 3600 l/h Design hot water inlet/outlet temp.: 100/95 ^{o}C Design hot water flow rate: 3600 l/h Design solution mass flow rate: 0.05 kg/s	If building temp.>cooling set point temp.+1 and chilled water inlet temp. to the chiller>chilled water set point temp.+1 then chiller and chilled, cooling, and hot water loop pumps are switched on. If building temp.<cooling set point temp.-2 and chilled water inlet temp. to the chiller<chilled water set point temp.-2 then chiller and chilled, cooling, and hot water loop pumps are switched off.
Cooling tower	Type: Wet recooler Design cooling capacity: 30kW Design cooling water flow rate: 3600 l/h Design air flow rate: 140 l/s Design inlet/outlet cooling water temp.: 32/25 ^{o}C Approach temperature: 2 ^{o}C	If chiller is switched on then the cooling tower fan is switched on, otherwise it is switched off.
Building	Type: Single family house-Low energy building Specific heating energy demand: 41 kWh/m^2 Annual cooling demand: 27 kWh/m^2 Total floor heated area: 150 m^2 Orientation: East-West Heating set point temperature: 20 ^{o}C Cooling set point temperature: 23 ^{o}C	---------
Heating/Cooling terminal	Type: wall mounted- four pipe fan coil Product name: GEA from Happel Klimatechnik GmbH Nominal heating power: 2.9 kW Nominal cooling power: 1.5 kW Number of modules: 8	If the chilled water loop pump is switched on then the fan is switched on, otherwise it is switched off.
Domestic Hot water	set point temperature: 50^{o}C Daily consumption: 200l/day	----------

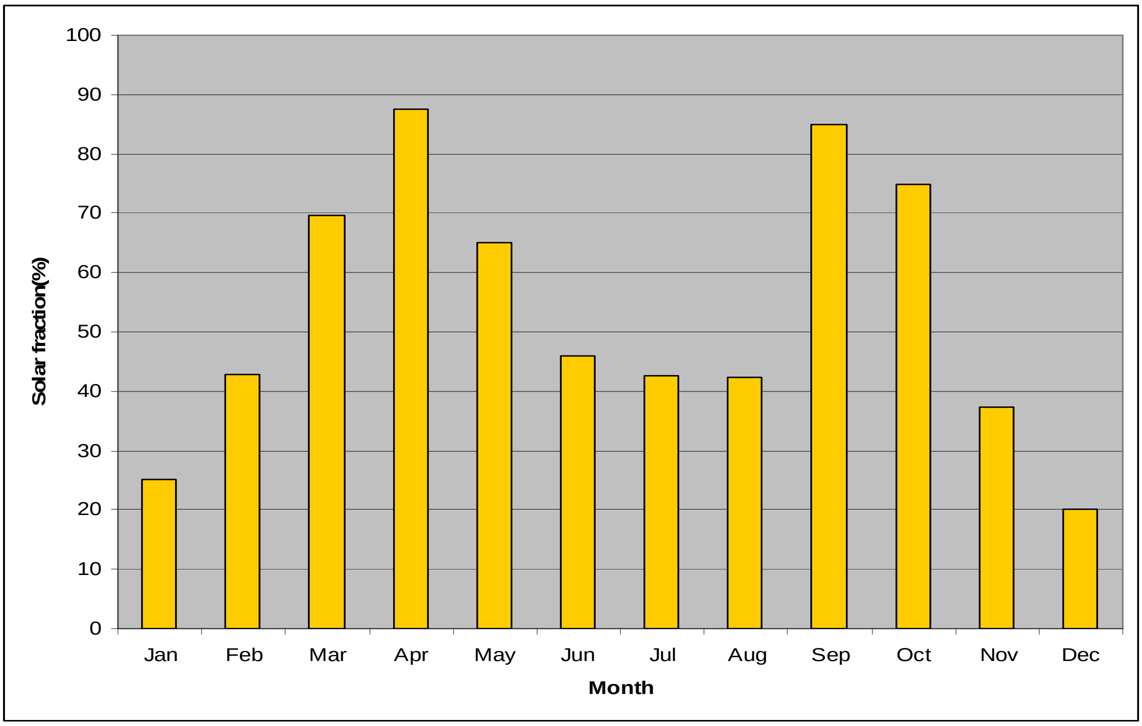

Figure 4. Monthly solar fraction

Solar fraction is defined as the ratio of solar energy yield into the storage tank over the summation of solar energy yield and auxiliary energy into the tank. It is observed that the average monthly value of cooling COP was kept almost constant at 0.82. The cooling water inlet temperature to the absorber or condenser was also a substantial factor since it was realized that the cooling capacity of the chiller decreases linearly by 7% as such a temperature increases by 2oC. Moreover, the control strategies were found to have an important effect on the chiller performance and capacity on one hand and on the other hand on the magnitude of solar fraction. For instance, if the real building temperature is not sensed and compared with the set point temperature and only the chilled water inlet and outlet temperatures are controlled then an overcooling is possible leading to extra cooling yield from the machine that reduces the solar fraction by 45%.

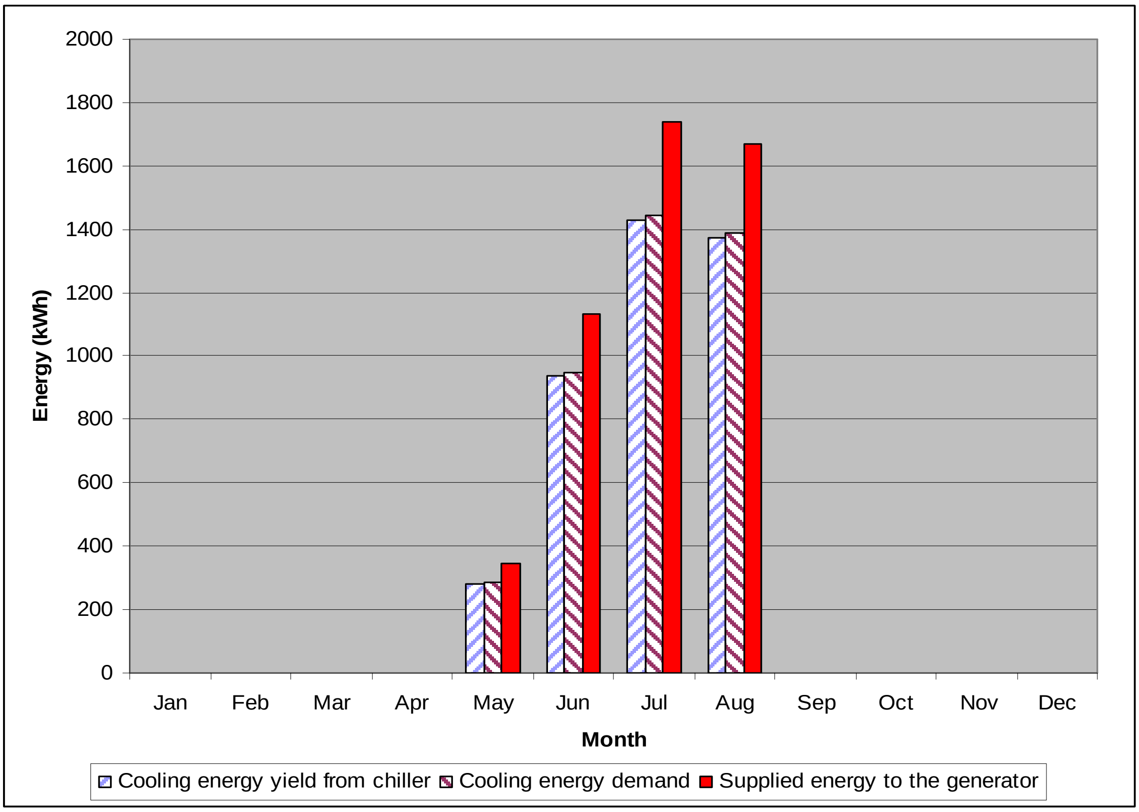

Figure 5. Monthly cooling energy yield, cooling energy demand, and energy into generator.

6. Conclusions

As a conclusion, the new absorption chiller model in Polysun offers an opportunity to many clients to be able to model and simulate a range of different absorption system configurations. Validation reveals that the model has a good compliance with the corresponding measurements.

7. References

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