

Energetic and economical performance of solar powered absorption cooling systems

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1- Introduction

Cooling systems are dimensioned to cover the maximum cooling load of a building, which is usually calculated for a given climatic condition, for example one or two summer days. A much better approach is to simulate simultaneously the cooling energy demand of the building and the solar air conditioning system using dynamic simulation tools. A simple design approach combines hourly resolved dynamic building loads with the collector equation, an energy balance model for additional storage and a constant COP of the cooling system (Henning, 2004). Although different building cooling load files were generated, the influence of the specific time series of the building cooling load was not analysed and the solar fractions were related to the ratio of collector surface to building surface area. Collector areas of 0.2 to 0.3 m² per square meter of conditioned space combined with 1-2 kWh of storage energy gave solar fractions above 70%. In the few realised European solar cooling installations, the ratio of collector surface area to cooling power varies strongly and is between 0.5 to 5 m² per kilowatt of cooling power. The results from our work show that the building load time series has a decisive influence on the solar fraction, which was calculated by a complete dynamic system model using the simulation environment language INSEL (Schumacher, 1991).

2 - Building cooling load characteristics

To evaluate the energetic performance of solar cooling systems under varying conditions, different building cooling load files were produced with the simulation tool TRNSYS. The methodology for choosing the building shell parameters is as follows: For

a given chiller power of 15 kW an office building with low thermal mass and for a given chiller power of 100 kW a hotel building with medium thermal mass both south orientated, of rectangular geometry and placed in Madrid were modelled. The dimensions and window openings of the buildings were adjusted, so that the given chiller power could keep the temperature levels below a setpoint of 24°C. To evaluate the influence of the specific time series of the building cooling load, two cases were simulated for both power ranges:

- Case 1: Cooling load dominated by external loads through solar irradiance using high glazing fractions and low internal loads of 2 - 4 W m⁻²
- Case 2: Cooling load dominated by internal loads of 26 - 28 W m⁻² with good sun protection on the windows.

The parameters of the simulation are summarised in Table 1 for all analysed buildings. The resulting cooling load files for the location Madrid are shown in Fig. 1.

Table 1: Parameters of the investigated buildings

Building type	Surface m ²	Volume m ³	Window surface fraction / %				Shading fraction / %				Air exchange h ⁻¹	Internal load W m ⁻²
			North	South	East	West	North	South	East	West		
Office case 1	450	1350	39	39	11	11	0	0	0	0	0.3	4
Office case 2	450	1350	39	39	11	11	90	90	90	90	0.3	28
Hotel case 1	3000	18000	33	33	33	33	0	0	0	0	0.5	2
Hotel case 2	3000	18000	33	33	33	33	90	90	90	90	0.5	25

The fixed air exchange rates of 0.5 h⁻¹ for the hotel and 0.3 h⁻¹ for the office building leads to cooling load files, which in some cases contain cooling power demand during winter and transition periods for southern European locations. For further characterisation of the cooling load files, a Fourier analysis has been carried out for all cooling load files.

The results from the Fourier analysis (Fig. 2) show that the annual mean value, the annual amplitude and the ½ year amplitude of the cooling load are significantly higher for the buildings with high internal and low external loads (case 2). However, compared to case 2 the daily and following amplitudes of the cooling load are higher for case 1, which can be explained as a result of the higher external loads.

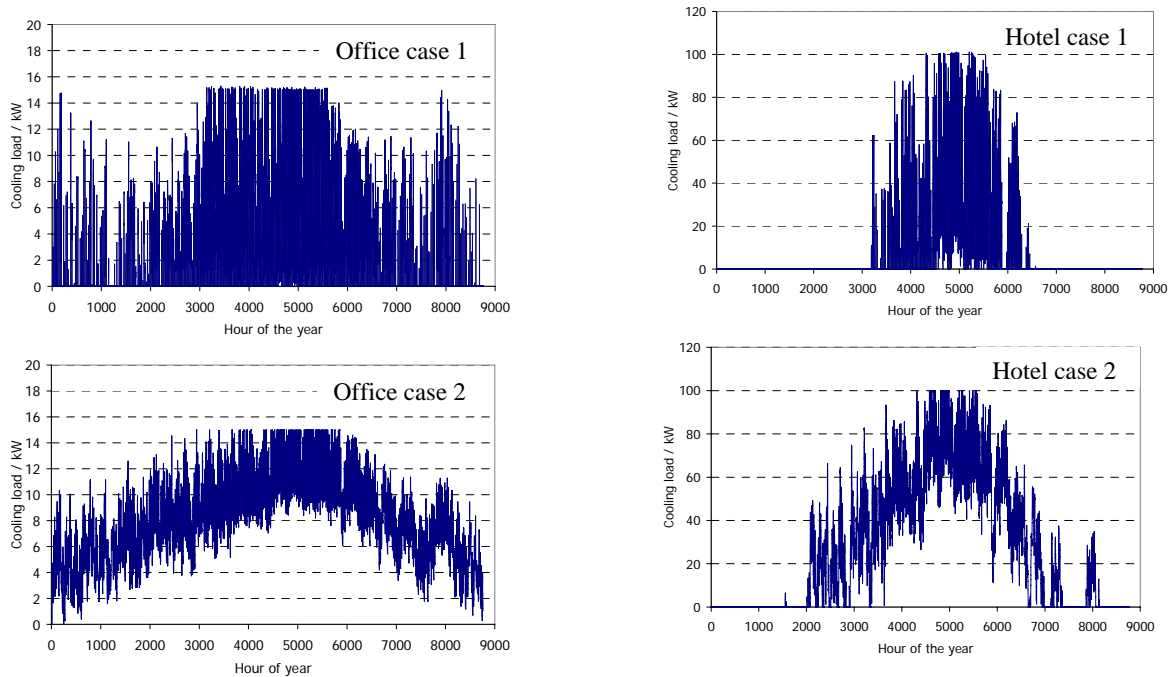


Fig. 1: Cooling load files of the analysed buildings for the location Madrid

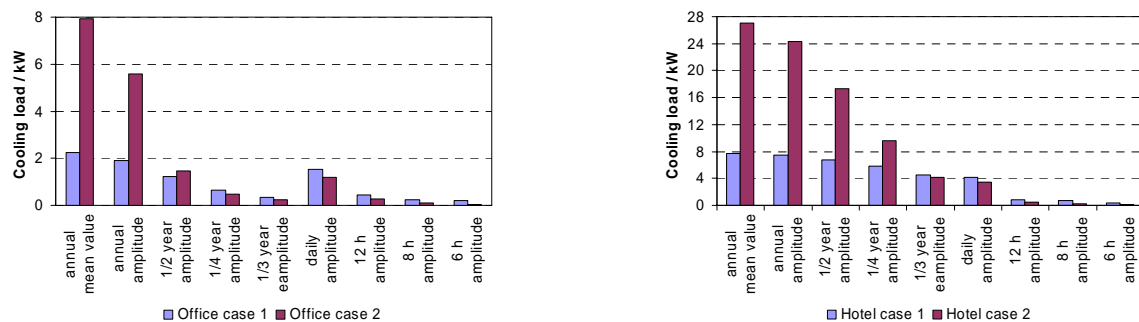


Fig. 2: Fourier analysis of the cooling load files

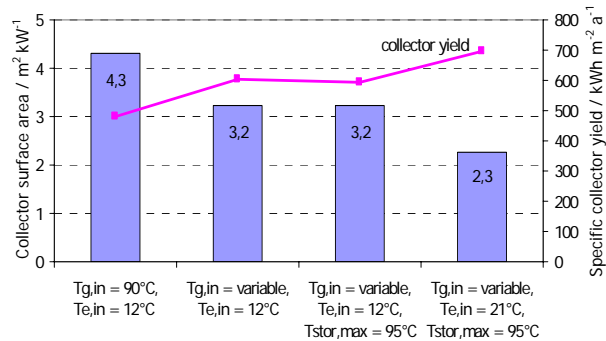
2 – System simulation results

a) General influences of thermal system component design

The influence of various system components such as storage insulation and heat exchanger transfer power was determined for a given cooling load file, in this case the office building dominated by external loads with a 15 kW chiller (office case 1). For an annual cooling energy demand of nearly 20 000 kWh and an average COP of 0.6 the system requires 32 700 kWh of heating energy. To achieve a solar fraction of 80% for the given cooling load profile, a collector surface area of 65 m² and a storage tank

volume of 4 m³ is required, if the generator is always operated at a mean temperature of 85°C. A decisive factor for the system performance is the chosen control strategy: if the controller allows a reduction of generator temperature for partial load conditions, the COP varies for each time step. The collector surface area required to cover 80% of the demand is now reduced to 48 m², i.e. only 3.2 m² kW⁻¹. The cold water temperatures were set to 12°C / 6°C and a fixed cooling tower temperature of 27°C was used. If the cold is distributed using chilled ceilings or thermally activated concrete slabs, the temperature levels can be raised. For cold water temperatures of 21°C / 15°C the required collector surface area is only 34 m², i.e. 2.3 m² kW⁻¹.

Fig. 3: Influence of different control strategies on the necessary collector surface area for 80% solar fraction (Office building case 1)



For the constant generator temperature level of 85°C, the specific collector energy yield is only between 450 and 530 kWh m⁻² a⁻¹ for an annual irradiance of 1746 kWh m⁻² a⁻¹, i.e. the solar thermal system efficiency is between 25 and 30%. For the improved control strategy, the collector yield increases up to 600 - 700 kWh m⁻² a⁻¹ depending on the cold water temperature levels.

b) Influence of dynamic building cooling loads

If a given cooling machine designed to cover the maximum load is used for different cooling load profiles, the influence of the specific load distribution and annual cooling energy demand can be clearly seen. For the office example with 15 kW maximum required cooling power, a collector surface between 48.5 and 60 m² and a storage volume of 4 m³ was required for case 1 (low internal and high external loads). This design covered 80% of the total heat demand of 32700 kWh. The same building now dominated by internal loads (case 2) has a cooling energy demand, which is 3.5 times

higher than in case 1, although the required maximum power is still only 15 kW. To achieve a solar fraction of 80%, collector surface areas between 175 and 300 m², depending on control strategy, are now required with a storage tank volume of 20 m³. This result indicates that the correlation between cooling power and required collector surface area is very weak and thus implicates design errors, if such a simple correlation would be used (Fig. 4). For the same location, the collector surface areas vary by a factor 4 to 5 to achieve the same solar fraction. A much better correlation is found, if the collector surface area is related to the required annual cooling energy demand and not to the maximum power (Fig. 5). The ratios between collector surface and cooling energy demand vary by a factor 2 for completely different load files and are about 2.5 - 6 m² MWh⁻¹ for the location Madrid, depending on solar fraction and control strategy. However, a factor 2 of uncertainty remains in the dimensioning of the collector field for a given building cooling load file.

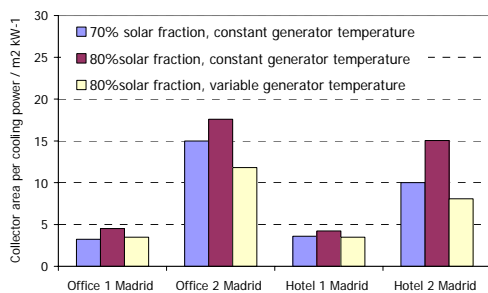


Fig. 4: Collector area per max. cooling power

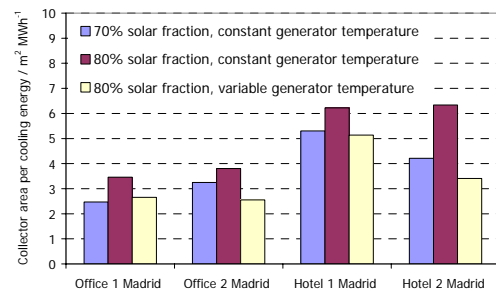


Fig. 5: Collector area per annual cooling energy

The total costs for the produced cold were between 0.2 and 0.35 € per kWh cold with the lower costs always obtained for longer annual operation hours of the solar cooling system. The chiller investment is between 10 and 30% of the total cooling costs.

References

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