

Simulation based design methods and economical analysis for solar driven absorption cooling systems

Dirk Pietruschka^{1*}, Ursula Eicker¹, Jürgen Schumacher¹, Victor Hanby²

zafh.net - Centre of Applied Research Sustainable Energy Technologies

¹University of Applied Sciences Stuttgart, Schellingstr.24, 70174 Stuttgart,

²Institute of Energy and Sustainable Development, De Montfort University,

The Gateway, Leicester LE1 9BH UK

*dirk.pietruschka@hft-stuttgart.de, Tel +49 711 8926 2674, Fax +49 711 8926 2698

Abstract

In the paper a systematic investigation is carried out to correlate the collector areas with the required cooling power and energy demand of one office building with different cooling load characteristics. A full simulation model was developed for LiBr absorption systems, combined with a stratified storage tank, a steady state collector model and dynamic building load files. As the absorption chillers allow reduced generator temperatures under partial load conditions, the control strategy has a strong influence on the system design and performance. It could be shown that a building with the same maximum cooling power, but very different load time series, requires collector areas varying by a factor 4 to achieve the same solar fraction. A better correlation was obtained between the building cooling energy demand and the collector surface area necessary to cover 80% of the total energy demand: for the location Madrid, about 2.5 - 5 m² of collector area is needed per MWh of cold, i.e. there is only a factor 2.5 between different cooling load characteristics. The cost analysis shows the dominance of the chiller and the solar thermal system to the total system costs. In the best operation case, the solar thermal system has about 40% net efficiency, which demonstrates the need to use the produced thermal energy not just for cooling, but also for warm water or heating production and thus lower the total cost.

Keywords: Absorption cooling, simulation, cooling costs

1. Introduction

Irrespective of the local climate conditions, the design of solar driven cooling systems and the reached solar fraction strongly depends on the cooling load characteristic of the building, the control strategy of the absorption chillers and the installed cooling distribution system [1,2]. However, cooling systems are commonly 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. The cooling energy requirement is then estimated very roughly from the number of full load hours of that building. If a solar thermal system is used to cover the heating energy demand of a thermal cooling plant, collector area and storage tank volumes are then simply related to the maximum cooling power of the machine. 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 simultaneous simulation of the cooling energy demand of the building and the solar air conditioning system offers more reliable results for dimensioning of the solar cooling system. A simple design approach has been described by Henning [3] and others [4 - 6] where hourly dynamic building loads were combined with the collector equation, an energy balance model for additional storage and a constant COP of the cooling system. 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 of 1-2 kWh storage energy gave solar fractions above 70%. Although different building cooling load files were generated the influence of the specific time series of the building cooling load was not analysed. Furthermore, with this method it is not

possible to consider the influence of different control strategies of the ACM and different cooling distribution systems of the buildings.

However, results from our recent work [1,2] have shown that the building load time series of three different building types, the control strategy of the ACM and the cooling distribution system has a decisive influence on the solar fraction, which was calculated by a complete dynamic system model using the simulation environment language INSEL [7]. The main aim of our current work is to demonstrate that different cooling load time series calculated for one single building can significantly influence the reachable solar fraction and the resulting costs of solar cooling systems. Four different cooling load files of one office building located in Madrid (Spain) with the same maximum cooling power but varied window orientation, with and without sun protection on the windows and internal loads of different height are analysed.

2. Building cooling load characteristics

To evaluate the energetic performance of solar cooling systems under varying conditions, different building cooling load files for one office building 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 placed in Madrid was 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:

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

Additionally, the orientation of the main window area of the office building was moved to the East (Case 1a) and to the West (Case 1b). All other parameters are the same as described for Case 1.

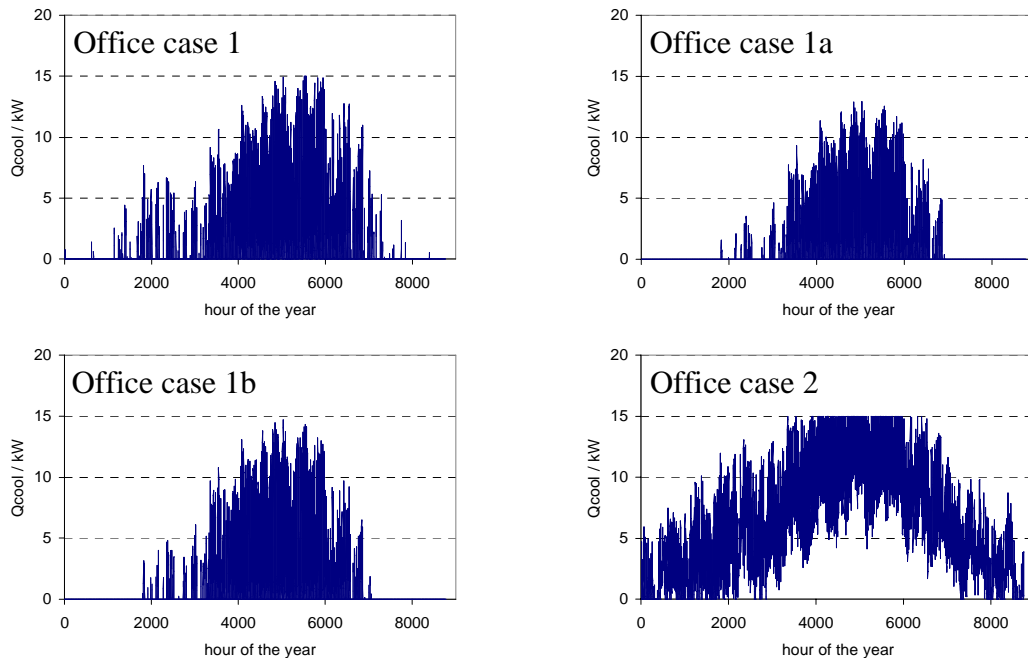


Fig. 1: Cooling load files of the analysed office building located in Madrid

Fig. 2: Annual cooling energy demand of the analysed office buildings located in Madrid

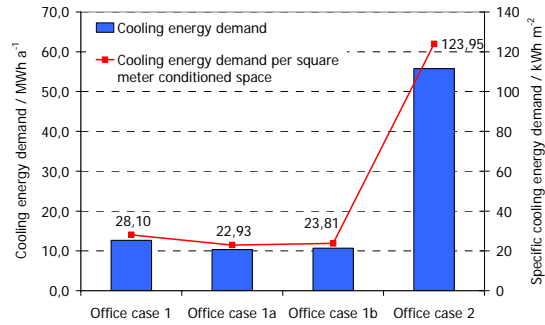


Table 1: Parameters of the investigated buildings

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 1a	450	1350	39	11	39	11	0	0	0	0	0.3	4
Office case 1b	450	1350	39	11	11	39	0	0	0	0	0.3	4
Office case 2	450	1350	39	39	11	11	90	90	90	90	0.3	28

The parameters of the simulation are summarised in Table 1 for all analysed cases. The resulting cooling load files and the annual cooling energy demands are shown in Fig. 1 and Fig. 2. The fixed air exchange rates of 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.

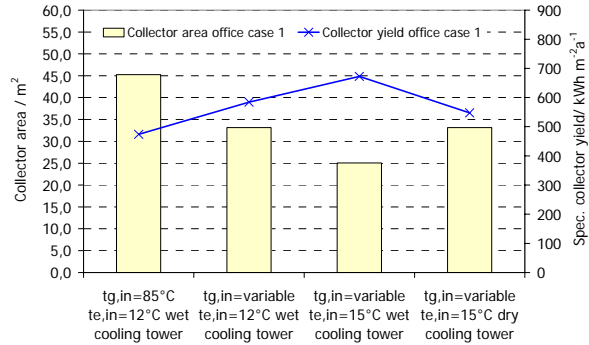
3. System simulation results

3.1 General influence of thermal system components

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 12 643 kWh and an average COP of 0.6 the system requires 21 143 kWh of heating energy. To achieve a solar fraction of 80% for the given cooling load profile, a collector surface area of 45 m² and a storage tank volume of 6 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 33 m², i.e. 2.2 m² kW⁻¹ (Fig. 3).

The cold water temperatures were set to 12°C / 6°C and a fixed cooling tower temperature of 27°C delivered by a wet cooling tower 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 and a wet cooling tower (also used for free cooling) the required collector surface area is only 25 m², i.e. only 1.7 m² kW⁻¹. At cold water temperatures of 21°C / 15°C also a dry cooling tower can be used for the recooling. However, this system reaches only recooling temperature levels above the ambient temperature. Especially on hot summer days the higher absorber and condenser temperature levels require much higher generator temperatures and consequently larger collector areas to achieve a solar fraction of 80%. During 26 h of the year the recooling temperature is too high for the ACM to reach the required cooling power.

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 474 kWh m⁻² a⁻¹ for an annual irradiance of 1746 kWh m⁻² a⁻¹, i.e. the solar thermal system efficiency is 27%. For the improved control strategy, the collector yield increases up to 550 - 670 kWh m⁻² a⁻¹ depending on the cold water temperature levels.

3.2 Influences 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 25 and 36 m² and a storage volume of 1 m³ are required for case 1 (low internal and high external loads). This design covers 80% of the total heat demand of 23 MWh. The same building now dominated by internal loads (case 2) has a cooling energy demand, which is 4.4 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 67 and 103 m², depending on control strategy, are now required with a storage tank volume of 6 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 3 to 4 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 2.5 for completely different load files and are about 1.2 - 3.2 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.

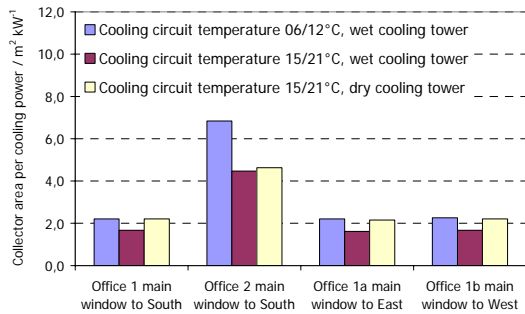


Fig. 4: Collector area per max. cooling power

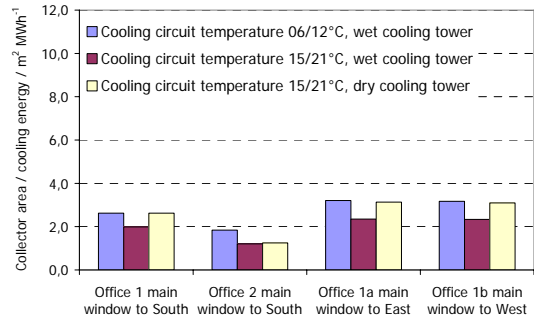


Fig. 5: Collector area per annual cooling energy

The simulation results for all analysed cases are summarised in table 1.

Table 1: Simulation results for different generator inlet temperatures $t_{g,in}$ and wet or dry cooling towers (WCT, DCT)

Cooling load file	Cooling distribution temperature [°C]	Cooling energy ACM kWh	Collector area m ²	Heat storage tank volume m ³	solar fraction (-)	Specific collector yield kWh/m ² a	COP thermal (-)
Office case 1, $t_{g,in}=85^{\circ}\text{C}$, WCT	06 / 12	12643	45	6,00	0,80	474	0,60
Office case 1, $t_{g,in}$ =variable, WCT	06 / 12	12643	33	1,00	0,80	585	0,55
Office case 1, $t_{g,in}$ =variable, WCT	15 / 21	12613	25	1,00	0,80	673	0,64
Office case 1, $t_{g,in}$ =variable, DCT	15 / 21	12643	33	1,00	0,80	548	0,60
Office case 2, $t_{g,in}$ =variable, WCT	06 / 12	55689	103	6,00	0,80	770	0,59
Office case 2, $t_{g,in}$ =variable, WCT	15 / 21	44454	67	6,00	0,80	796	0,72
Office case 2, $t_{g,in}$ =variable, DCT	15 / 21	49748	69	6,00	0,80	870	0,70
Office case 1a, $t_{g,in}$ =variable, WCT	06 / 12	10320	33	1,00	0,80	505	0,53
Officecase 1a, $t_{g,in}$ =variable, WCT	15 / 21	10320	24	1,00	0,80	599	0,61
Officecase 1a, $t_{g,in}$ =variable, DCT	15 / 21	10320	32	1,00	0,80	485	0,57
Officecase 1b, $t_{g,in}$ =variable, WCT	06 / 12	10713	34	1,00	0,80	496	0,55
Office case 1b, $t_{g,in}$ =variable, WCT	15 / 21	10713	25	1,00	0,80	589	0,62
Officecase 1b, $t_{g,in}$ =variable, DCT	15 / 21	10713	33	1,00	0,80	479	0,58

3.3 Influence on the costs of the solar cooling systems

To plan and project energy systems such as solar cooling systems, economic considerations form the basis for decision making. The costs in energy economics can be divided in three categories: capital costs, which contain the initial investment including installation, operating costs for maintenance and system operation and the costs for energy and other material inputs into the system. The analysis presented here is based on the annuity method, where all cash flows connected with the solar cooling installation are converted into a series of annual payments of equal amounts. The calculated costs and cost distribution for office case 1 and 2 are shown in figure 6.

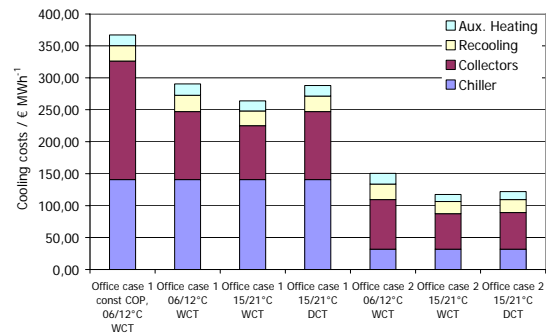


Fig. 6: Influence of different cooling load files and control strategies on the costs of solar cooling systems

The total costs for the produced cold were between 0.12 and 0.37 €/per kWh cold with the lower costs always obtained for longer annual operation hours of the solar cooling system (office case 2 with high internal loads). The chiller investment is between 21 and 53% of the total cooling costs.

References

- [1]Eicker, U., Pietruschka, D., Schumacher, J. "Energetic and economical performance of solar powered absorption cooling systems", Solar air conditioning, international conference, Kloster Banz, Bad Staffelstein, Germany, 2005
- [2]Eicker,U., Jakob,U., Pietruschka, D., Schumacher, J. "Energieeffizienz und Wirtschaftlichkeit solarer Absorptionskälte" 15. Symposium Thermische Solarenergie Staffelstein" Kloster Banz, Bad Staffelstein, Germany, 2005
- [3]Henning, H.-M. "Solar-assisted air-conditioning in buildings – a handbook for planners", Springer-Verlag 2004, ISBN 3-211-00647-8
- [4]Kim, D.S., Machielsen, C.H.M. "Evaluation of air-cooled solar absorption cooling systems" Proceedings of the International Sorption Heat Pump Conference, Shanghai, China, 2002
- [5]Mendes, L.F, Collares-Pereira, M., Ziegler, F. "Supply of cooling and heating with solar assisted heat pumps: an energetic approach", Int. J. Refrig. Vol 21, No.2, pp 116-125, 1998
- [6]Sumath, K. "Study on a solar absorption air-conditioning system", International Congress of Refrigeration, Washington, D.C., USA, 2003
- [7]Schumacher, J. "Digitale Simulation regenerativer elektrischer Energieversorgungssysteme", Dissertation Universität Oldenburg, 1991 www.inselDi.com