Energy and economic performance of solar cooling systems in office buildings worldwide

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Abstract

Solar thermal cooling systems have been installed as pilot projects in most regions of the world, but due to the low number of total installations there is not yet much experience available about system sizing and design. Furthermore the cooling load of building projects varies widely, mainly as a function of internal loads, but also building insulation standard, window type and shading system and obviously climate.

To counter the lack of experience and to evaluate the potential of energy efficient solar cooling systems, a systematic system design study has been carried out covering most climatic regions worldwide. For each technology investigated, an energy optimized control strategy was developed which maximizes the primary energy efficiency. This control strategy was implemented in the simulation environment INSEL and system models were developed for a range of thermal cooling technologies and validated with operating experiences from different plants monitored by the authors.

To cover a very broad range of applications, cooling loads were dynamically simulated for office buildings with different isolation standards, sun protection systems and internal loads in moderate heating dominated climatic conditions in Germany (Stuttgart and Cologne), for dry and warm climates (Madrid), hot and dry climates (Riyadh) and hot and humid climatic conditions such as Jakarta in Indonesia. Different sorption technologies were then compared ranging from single to triple effect absorption cooling systems as well as adiabatic and open desiccant cooling systems. Solar cooling fractions of the total heating and cooling demand were determined as a function of collector surface and chiller nominal power. Then the energy demand and consumption was used to calculate the economics as well as the primary electricity consumptions and the CO_2 emissions.

It could be shown that a reduction of nominal chiller power by 30% to 40% or more hardly effects the solar cooling fraction for most climates, but significantly increases the machine operating hours and thus improves the economics. The lower the nominal power of the chiller,

the higher the recommended ratio of collector surface area per kW. For a given machine nominal power, solar cooling fractions increase with collector surface area until saturation is reached. Collector surface areas can be as high as 5 m² to 10 m^2 per kW with still increasing solar cooling fractions, but acceptable specific collector yield reduction. The economic optimum is reached for less solar cooling fraction and thus lower primary energy savings.

Single effect absorption cooling systems easily reach 80% solar cooling fraction for all but very humid climates. Primary energy ratios can be over 3.0, depending on system design and cooling load data. Double or triple effect chillers have slightly lower solar fractions, but require much less collector surface area. Adiabatic and desiccant cooling systems as air based open systems have significantly lower thermal energy need, but require more energy for cold distribution, so that primary energy ratios are comparable to the best closed systems.

The economic view on single effect absorption machines shows that a sensible planning of the system components is necessary for a successful realization of solar thermal cooling. This study shows that solar thermal cooling is more comparable in hot climates than in moderate European climates. Annual and investment costs strongly depend on the locations. The annual costs vary between 43,598 €/a and 147,118 €/a. Investment costs vary between 393,956 € and 769,263 €. Nearly 50% of the total investment cost consists of the costs for the solar thermal collectors. The specific costs per kWcool in German locations vary between 0.25 and 1.01 €/kWcool, in Spanish locations between 0.13 and 0.30 €/kWcool. In hot climates like Jakarta and Riyadh the specific costs are as low as 0.09 to 0.15 €/kWcool. The specific costs vary strongly between different absorption cooling machine powers. An economic view on the payback times is not comparative since the payback times vary between 17.1 years and 1455.3 years. Therefore two outlook calculations were carried out to get a payback time of 10 years: For a payback time of 10 years electricity prices have to vary from 0.18 €/kWh (Riyadh) to 5.56 €/kWh (Cologne). Otherwise investment costs have to be reduced by a factor of 2-3 at least to achieve a payback time of 10 years. But although there is no way for solar cooling systems to be represented economically they have a high ecological value. CO_2 and primary energy savings of 30 – 79% are achievable and mainly have to be taken into account.