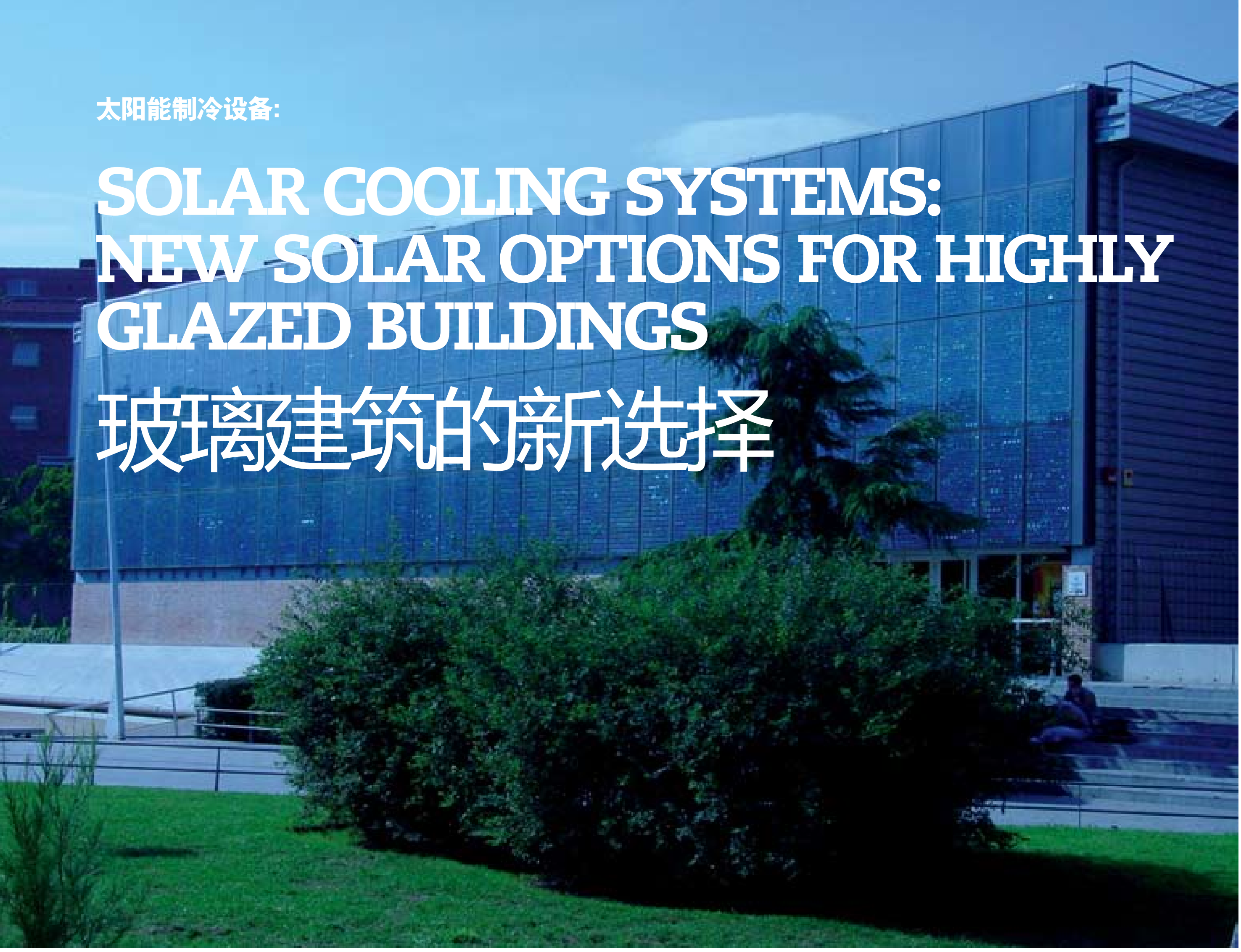
太阳能制冷设备:

SOLAR COOLING SYSTEMS: NEW SOLAR OPTIONS FOR HIGHLY GLAZED BUILDINGS

玻璃建筑的新选择



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在欧洲和全世界，空调和太阳能加热设备的市场年度增长率为百分之几。一方面，这来源于住宅以及办公酒店建筑对空调越来越大的需求。另一方面，也来源于公众环境意识的增加和政策方针的指引。

如果使用消极被动的冷却方式驱散热量，必须使用有效的冷却设备，尤其是外观漂亮的玻璃建筑的冷却。由于采用大量压缩机式冷却机，这些冷却设备的生产和供应价格很低。然而，由于占用大量电能，这些设备对当地环境产生了负面的影响。夏天与国家电网连接的普通压缩机式冷却机的电流需求越来越接近它们的容量极限。同时，在许多南方国家，这些设备在过去几年里一直成为形成国家电网的主要原因。因此，寻找一种由废热或太阳能提供能量的替代型空调设备以及开发一种综合的太阳能加热和冷却设备十分重要。

太阳能冷却市场

用于空气调节的太阳能冷却设备最初出现在20世纪70年代。例如：德国的Dornier-Prinz 太阳能技术股份有限公司（Schubert et al., 1977）或美国的Arkla工业公司（现在为意大利的Robur SpA）（Grossmann, 2002）。由于市场对太阳能冷却设备需求很少，这些太阳能冷却设备的生产终止了。

今天，太阳能冷却设备的市场依然很小。在欧洲，投入使用的冷却功率约为8－9MW。所使用的100—120套太阳能冷却设备使用太阳能热量收集器对建筑物里的空气进行调节。大部分设备在德国和西班牙使用。投入使用的太阳能收集器表面积总量约为20,000m2（见图1）。约60%的闭环系统为吸收式冷却机和约12%的吸附式冷却机。带有吸附轮的DEC系统在开放式吸附空调设备中所占的百分比最高，为25%。液体吸附设备仅占4%。然而，这个潜力很大。在德国，仅消耗在办公建筑的加热和冷却上的电流总量就达到40,000GWh（Nick—Leptin, 2005）。现在，中型和大型的太阳能冷却设

备已得到全面的开发，仅有20kW以下小型设备仍处于研究和开发阶段。

系统技术

太阳能冷却技术已在几年前投入使用。但是，市场上仍无大量整套太阳能冷却设备可以提供。原则上，吸收式冷却机、DEC系统（干燥和蒸发冷却）和临时吸收冷却机已经用于建筑物的空气调节。与之相反，液体吸附冷却机还处在样机制造或现场试验阶段。太阳能冷却设备提供能源的热量技术主要可分为生产冷水的闭式系统和用于空气调节的开式系统。

闭式吸收/吸附冷却机

热闭式吸收（图3）或吸附冷却机（图4）在建筑物内的集成更接近于一般蒸汽压缩冷却机。冷却机提供的冷水温度范围为6° C 20° C。这些设备可用于集中式空调和分布式冷却系统，如风扇盘管和冷却顶板。氨水/水吸收式冷却机可生成温度低至—20° C的蒸汽，这对于制冷过程大有益处。

吸收式冷却机中，制冷剂（水或氨水）由液体吸附剂吸收（溴化锂或水）。在由太阳能直接或间接驱动的高温发电机中，这些制冷剂又从溶液中释放出来。这样便产生了很高的制冷蒸汽压力并足以在冷凝器中将制冷剂压缩。蒸发后，制冷剂蒸汽被吸收在溶液中。而溶液则在吸收器中得到冷却。溶液由溶液泵吸入发电机中并在发电机中再生并回流到吸收器中。解吸附作用的加热温度根据采用技术的不同在75℃ —160℃。在吸附冷却机中，作为制冷剂的水在固体吸附剂上被吸收，类似表面潜伏热处理中的硅胶。随着水分子的增加，潜伏热逐渐消失。这样，需要驱散的只有蒸汽热量。60℃ —70℃的低加热温度可引发储存的水和浓缩压力生成的解吸附作用。

开式吸附辅助空调

开式系统综合了吸附式空气除湿和蒸汽冷却功能，可用在通风系统中调节空气温度。吸附辅助空调采用了有效的工程化技术。DEC系统中（图5），增湿的排气和进气可作为冷却剂使用。进气通过热恢复过程直接进入房间。最低的进气温度约为16℃。硅胶或氯化锂上水的物理吸附可干燥过程中的空气。之后，空气由潮湿蒸汽和通过热交换预先冷却的空气直接冷却。吸附剂的再生需要热量输入，这就是吸附水的解吸附作用。加热温度的最低范围为60℃ —70℃。

参考价值

欧洲所有设备的收集器表面的平均值为2.9 m²/kW。热驱动冷却设备的参考值为3.0 —3.5 m²/kW。对于大多数开式系统，这个参考值与空气量有关。根据1,000 m³/h安装体积流量，这个值可用范围在8 —10 m²（Henning，2005）。这些值仅为粗略参考值。使用闭式吸收式或吸附式冷却机的太阳能冷却系统的总成本范围是5,000 8,000 EUR/kW。有吸附轮的开式系统中，确定的总成本为2,000 —3,500 EUR/kW。

结论

在德国、欧洲和全球，用于制冷和空气调节的能量消耗增加了。在德国，当前能耗的14%用在建筑物制冷（77,000 GWhel），这相当于能量需求的5.8%。利用太阳能冷却、区域加热或生物量调节可大大降低能耗和CO2排放。单效应热冷却机是一个利用太阳能的设备或者是一个完整的太阳能加热系统。如果使用另外的加热系统，低的COP会导致更高的能耗。为达到太阳能冷却系统的经济性，热冷却技术的额外投资成本必须进一步降低，数量多时尤为重要。热量成本很低时，如存在带加热装置的太阳能热量设备，太阳能冷却系统可采用普通的电压缩机式冷却机。在太阳能热量设备逐渐大型化的趋势中，小型热冷却机提供了可有效利用夏天热量的可能。

吸收、吸附和液体吸附技术的许多概念已从样机制造转到现场试验阶段或进入小型生产阶段中。接下来的几年来，小型冷却能力的产品有望得到进一步开发。

SolarNext公司的吸附式冷却剂系统"chillii® STC6"，5.5kW冷却能力，水/硅胶为工质（来源：SorTech）

Adsorption chiller system "chillii® STC6" with 5.5 kW cooling capacity and water/silica gel as working pair from the company SolarNext (source: SorTech)

[illegible]

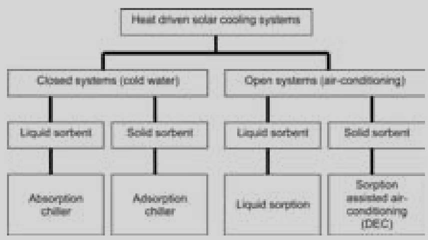
[illegible]	[illegible]			[illegible]	DEC
	[illegible]	[illegible]	[illegible]		
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	6 – 20℃	6 – 20℃	-20 – +20℃	6 – 20℃	15 – 20℃
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Table 1

Solar thermal driven or assisted cooling and air conditioning technologies

technology	absorption			adsorption	DEC
	single-effect	double-effect	single-effect		
refrigerant	water	water	ammonia	water	-
sorbent	lithium bromide	lithium bromide	water	silica gel	silica gel or lithium chloride
cooling medium	water	water	water/glycol	water	air
cooling temperature	6 – 20℃	6 – 20℃	-20 – +20℃	6 – 20℃	15 – 20℃
heating temperature	75 – 100℃	130 – 160℃	80 – 160℃	55 – 100℃	55 – 100℃
cooling water temperature	30 – 50℃	30 – 50℃	20 – 50℃	25 – 35℃	not required
cooling capacity range (per unit)	10 – 20,000 kW	170 – 23,300 kW	5 – 1,000 kW	70 – 500 kW	6 – 300 kW
coefficient of performance (COP)	0.6 – 0.7	1.1 – 1.4	0.3 – 0.6	0.5 – 0.7	0.5 – 1.0

表1太阳能热驱动或热辅助冷却和空气调节技术



太阳能冷却系统的原理分类

Principle classification of solar cooling systems

澳大利亚Gröbming办公建筑使用的SolarNext 公司的新型氨水/水吸收式冷却机系统"chillii® PSC10"，配备10kW冷却能力和湿冷却塔（来源：SolarNext）

Novel ammonia/water absorption chiller system of the company SolarNext, "chillii® PSC10" with 10 kW cooling capacity and wet cooling tower, of an office building in Gröbming, Austria (source: SolarNext)

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Henning H.M., Solare Klimatisierung – Stand der Entwicklung. erneuerbare energien, 2005, No. 2, pp. 7-11

太阳能冷却系统真空管收集器（来源：SolarNext）
Vacuum tube collector for solar cooling systems (source: SolarNext)

The air-conditioning as well as the solar thermal market in Europe and worldwide shows annual growth rates of several percents. In the first case initiated by the growing demand for air-conditioning in residential houses as well as office and hotel buildings and in the second case by increasing environmental awareness or political guidelines.
If the thermal loads can't be dissipated with passive cooling methods, especially in attractive highly glazed buildings, active cooling machines have to be used. Due to the large number of manufactured compressor chillers, these systems are produced and offered at very low prices, however, such systems increase the adverse effects on local environments as a result of using primary energy such as electricity. The high current demand of common compressor chillers abut the national electric networks in summertime more and more on their capacity limits. Simultaneously, in many southern countries, these units have been the main reason for the bottleneck in the electric networks in the last few years. Therefore, it is important to search for alternative air-conditioning units that are driven by either waste heat or solar thermal energy and to develop combined solar cooling and heating systems.

Solar Cooling markets

The first solar cooling systems for air-conditioning were developed in the seventies of the 20th century, e.g. by the company Dornier-Prinz Solartechnik GmbH, Germany (Schubert et al., 1977) or Arkla Industries Inc., USA (today Robur SpA, Italy) (Grossmann, 2002). Due to the lack of demand on the market for solar cooling, the production of these solar cooling systems was stopped.
The market of solar cooling is still small: today in Europe approximately 8 to 9 MW of cooling capacity are installed. These are about 100 up to 120 solar cooling systems, which use solar thermal collectors for the solar air-conditioning of buildings. Most of the systems are realized in Germany and Spain. The altogether installed collector surface is nearly 20,000 m² (Figure 1). Approximately 60% of the closed cycle systems are absorption chillers and around 12% adsorption chillers. The DEC systems with sorption wheels dominate the open sorption air-conditioning systems by 25% and only 4% liquid sorption systems existing. However the potential is very high – in Germany 40,000 GWh of current consumption are accumulated alone for the air conditioning of office buildings (Nick-Leptin, 2005). The technologies for the solar cooling units in the medium and big performance range are fully developed, only the small-scale performance range below 20 kW will be still developed and investigated.

System technologies

The solar cooling technology is used since several years, but there are not a lot of complete solar cooling systems commercially available. In principal absorption chillers and DEC systems (Desiccant and Evaporative Cooling) and occasional adsorption chillers are used for the air-conditioning of buildings. Against it liquid sorption systems are mainly in prototype or field test stage. The technology of heat driven solar cooling systems is mainly divided into closed systems to produce cold water and open systems for air-conditioning (Figure 2).

Closed absorption / adsorption chillers

The heat driven closed absorption (Figure 3) or adsorption chillers (Figure 4) most closely resemble common vapour compression chillers in terms of their integration into buildings. The chillers provide cold water at temperature between 6°C and 20°C. They can also be used for central air conditioners as well as cooling systems with decentralised air treatment, such as fan coils and cooled ceilings. The ammonia/water absorption chillers could generate evaporator temperatures down to -20°C, which are useful for cold processes.

In absorption chillers the refrigerant (water or ammonia) is absorbed by a liquid sorbent (lithium bromide or water). In the directly or indirectly solar powered generator with high heating temperatures, the refrigerant is desorbed from the solution. This generates a high refrigerant vapour pressure, which is sufficient to condense the refrigerant in the condenser. After evaporation, the refrigerant vapour is absorbed in the solution which is cooled in the absorber. The solution is pumped to the generator by a solution pump where it is regenerated and throttled back to the absorber. The heating temperatures for desorption are between 75 and 160°C according to the technology. At adsorption chillers the refrigerant water is adsorbed on a solid sorbent like silica gel among disposal of latent heat on the surface. The latent heat decreases to zero with increasing addition of water molecules, then only evaporation heat has to be dissipated. The desorption of the

西班牙Mataro实验室中太阳能辅助DEC系统的通风PV正面和太阳能空气收集器（来源：zafh.net）

Ventilated PV facade and solar air collectors of a solar assisted DEC system of a library in Mataró, Spain (source: zafh.net)

stored water and the pressure generation for the condensation is already caused by low heating temperatures of 60 to 70°C.

Open sorption assisted air-conditioning

Open systems normally employ a combination of sorptive air dehumidification and evaporative cooling, which is used in ventilation systems for treating air. Sorption assisted air-conditioning is in effect a well-engineered technology. In DEC systems (Figure 5), both the humidified exhaust air and supply air serve as coolants. The supply air is blown directly into the room through heat recovery process. The minimum supply air temperature is about 16°C. The physical adsorption of water on silica gel or lithium chloride serves the air drying in this process. Afterwards the air will be cooled by direct evaporative humidification of the dried and through a heat exchanger precooled air. The thermal heat input is required for the regeneration of the sorbent, this means the desorption of the adsorbed water. The heating temperatures could be chosen very low between 60 and 70°C as well.

Reference values

The average value of the specific collector surface of all systems in Europe is about 2.9 m²/kW. A value of 3.0-3.5 m²/kW could be valid as reference value for thermal driven cooling machines. Usually for open systems the reference value is related to the air quantity, a value between 8 and 10 m² per 1,000 m³/h installed volume flow has been carried out as useful value (Henning, 2005). These values are only rough reference values. The specific total costs of installed solar cooling systems using closed absorption or adsorption chillers are in range between 5,000 and 8,000 EUR/kW. At open systems with sorption wheels specific total costs of 2,000 to 3,500 EUR/kW are determined.

Conclusion

In Germany, Europe and worldwide the energy consumption for cold and air-conditioning increases. In Germany 14% of the total current consumption are used for cooling (77,000 GWhel), which corresponds to 5.8% of the primary energy demand. Thermal cooling by solar or district heating or biomass could be lead to a clear reduction of the energy consumption and the CO2 emissions. An assumption for single-effect thermal chillers is above all a very high solar fraction or betters a complete solar heating system, because low COPs lead rapidly to higher primary energy consumptions, if an additional heating system has to be used. For an economical operation of solar cooling system the additional investment costs for the thermal cooling technology have to be further reduced, which is expected at higher piece numbers. At very low heat prices e.g. with an existing solar thermal plant with heating support, thermal solar cooling systems can be nearly compete today with common electrical compressor chillers. At a general trend to larger solar thermal plants, small-scale thermal chillers offer a good possibility to use efficiently the summery heat.

Many concepts of absorption, adsorption and liquid sorption technology are turned from the prototype into field test stage or into small serial production. In the next few years further projects are expected for the small scale cooling capacity range.

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