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DOROTA CHWIEDUK*, ANDRZEJ GRZEBIELEC*, ARTUR RUSOWICZ*

SOLAR COOLING IN BUILDINGS

SŁONECZNE CHŁODZENIE W BUDOWNICTWIE

A b s t r a c t

The paper presents a kind of review of solar cooling technologies applied in construction. There are three cooling technologies: absorption, adsorption and DEC – Desiccant Evaporative Cooling – applied coupled with solar systems. What the stress is placed on are cooling systems of a high installed capacity of several hundred kW. Large scale solar cooling systems are not used in Poland. However, modern public buildings, especially offices with huge glazed facades very often require more energy for cooling than space heating. Solar cooling seems to be prospective technology to reduce energy consumption used by traditional air conditioning units.

Keywords: *solar cooling*, *solar collectors*, *refrigeration systems*

S t r e s z c z e n i e

W artykule przedstawiono przegląd instalacji chłodzenia słonecznego stosowanych w budownictwie. Są stosowane trzy technologie chłodnicze: absorpcyjne, adsorpcyjne oraz oparte na chłodzeniu przez osuszanie i odparowanie, które kojarzy się z instalacjami słonecznymi. Rozważane są systemy dużych mocy rzędu kilkuset kW i więcej. Systemy słonecznego chłodzenia dużej mocy nie są stosowane w Polsce. Jednakże nowoczesne budynki użyteczności, szczególnie biurowce o dużych przeszklonych powierzchniach fasad, wymagają coraz częściej więcej energii do chłodzenia niż do ogrzewania. Technologie słonecznego chłodzenia są perspektywicznym rozwiązaniem na rzecz oszczędności zużycia energii w porównaniu z tradycyjnymi systemami klimatyzacyjnymi.

Słowa kluczowe: *słoneczne instalacje chłodnicze*, *kolektory słoneczne*, *urządzenia chłodnicze*

* Prof. Ph.D. D.Sc. Eng. Dorota Chwieduk, Ph.D. Eng. Andrzej Grzebielec, Ph.D. D.Sc. Eng. Artur Rusowicz, Institute of Heat Engineering, Faculty of Power and Aeronautical Engineering, Warsaw University of Technology.

1. Introduction

Nowadays, solar cooling systems are usually applied in public buildings, offices, hospitals with high cooling demand of several hundred kW. The solar cooling system is generally comprised of three sub-subsystems: the solar energy conversion system, refrigeration system, and the cooling load [10]. The appropriate cooling technology for any applications depends on cooling demand, its distribution in time, temperature levels of the refrigerated object and the heat source. A number of possible “paths” from solar energy to “cooling services” are demonstrated in Fig. 1.

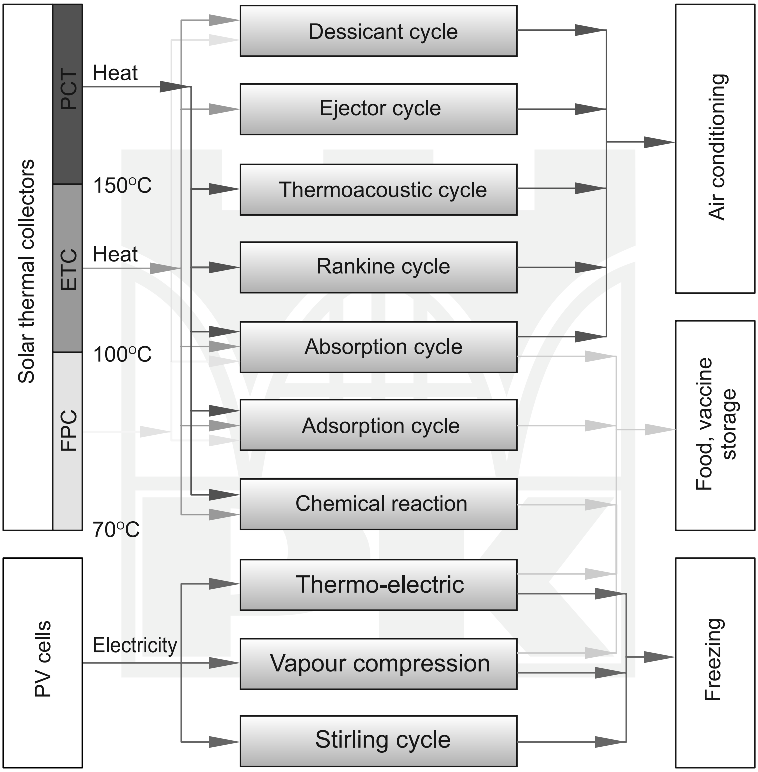

Fig. 1. Solar refrigeration cycles

Starting with the inflow of solar energy there are obviously two significant paths to follow: utilizing solar thermal collectors to convert solar radiation into heat and using PV cells to convert solar radiation directly into electricity [16]. Depending on the type of solar collectors and insolation conditions different temperature levels of solar working fluid can be achieved. This temperature level can be matched to various cycle demands. For example, the Rankine cycle (duplex type) [19] and thermoacoustic cycle [4, 5, 7] require a rather high driving temperature whereas the desiccant cycle functions at lower temperature levels of heat supply [1].

2. Large solar cooling systems

2.1. Absorption systems

Solar absorption refrigeration systems perform a typical absorption refrigeration cycle. Solar radiation is its energy source. Due to the fact that absorption systems require a minimum temperature of 80°C [11, 14, 15] evacuated tube collectors (ETC) are usually used. However, to improve the efficiency of the whole system solar concentrating collectors can be applied.

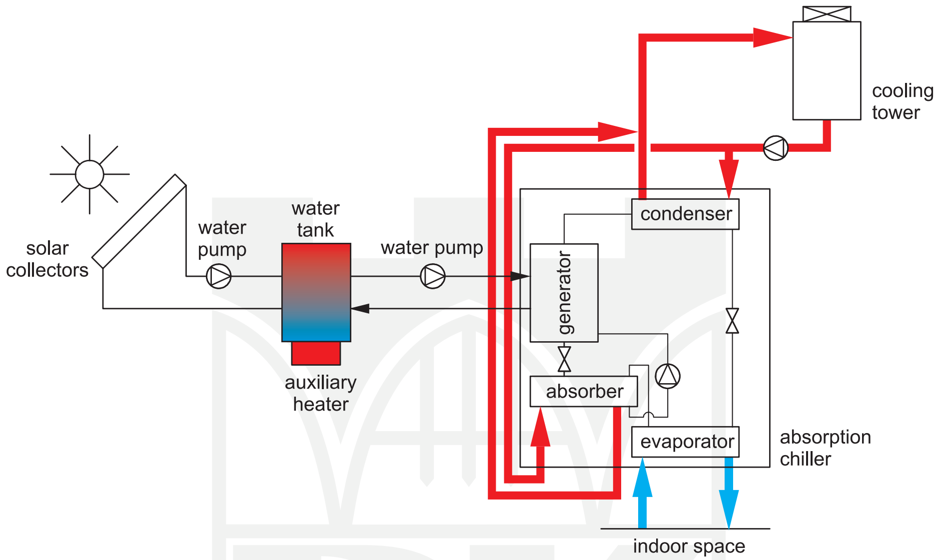

Fig. 2. Solar absorption refrigeration

A relevant application for solar cooling is occurs in buildings which exhibit a high energy demand through air conditioning. Every year the number of buildings that employ such technology increases. Solar cooling systems are mainly used in warm and hot climates. For example, in the year 2006 a solar cooling plant was implemented in the Surgery Hospital for children in Soba, near Khartoum in Sudan. The main aim of the plant was to supply energy for air conditioning throughout the year. Vacuum tube CPC collectors covering an area of 12 000 m² were installed to supply heat to the 50 m³ water store at approximately 100°C. Hot water is used to feed 2 Li-Br absorbers, each of 615 kW. The cooling of the building is accomplished via fan-coil systems. Another example of a great solar absorption cooling technology is the installation at United World College in Singapore with a cooling capacity of 1470 kW and 3900m² of solar collectors [18]. In Europe, the largest absorption solar cooling system is in Rome, Italy (METRO Cash & Carry) with a cooling capacity of 700 kW.

2.2. Adsorption systems

Adsorption refrigeration systems powered by solar energy operate in such a way that the secondary fluid supplies energy alternately to one adsorber, then to another [2, 6, 8] (see Fig. 3). The refrigerant released from the bed during this process flows through a condenser, expansion valve and evaporator generating cooling power. Heat from the condenser is transferred to the cooling tower. Depending on the type of working pairs (solid and fluid) a different temperature of solar working fluid is required to thermally drive the adsorption cycle. If solar irradiation is high, it is possible to use even flat plate solar collectors working at a temperature of 80–90°C.

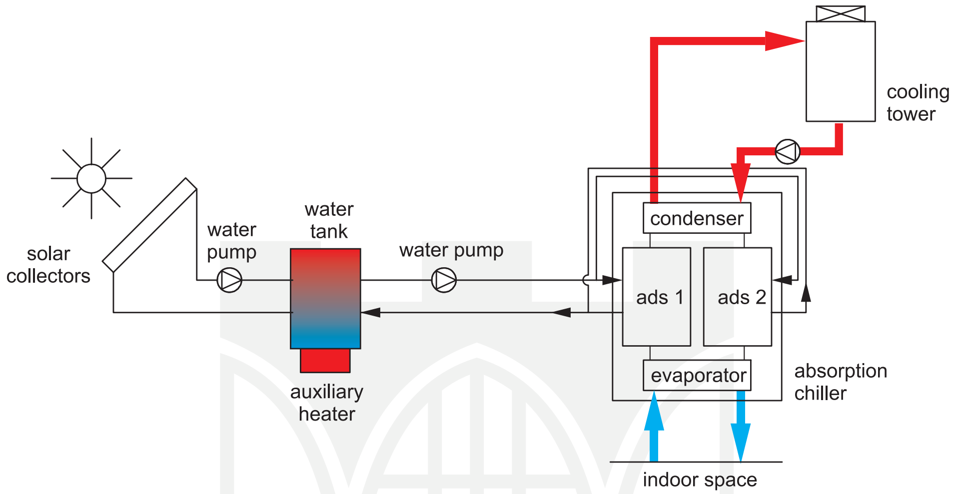

Fig. 3. Solar adsorption refrigeration

Festo in Esslingen-Berkheim (Germany) is currently running the largest adsorption cooling system in the world. Three MYCOM ADR-100 cooling machines produce a nominal output of 353 kW each. The generated cooling energy cools a 26 760 m^2 area of office buildings as well as three atriums with an area of 2790 m^2. The cooling machines were driven by heat from gas boilers and waste heat of compressors. What was introduced as a third source of heat was the solar system with vacuum tube collectors of the absorber surface of 1218 m^2. Thus, gas consumption was significantly decreased. The vacuum tube CPC collectors have been installed on a shed roof of a 30° slope and with an azimuth angle of +17°. The solar collectors covering a surface area of 1330 m^2 consist of 58 collectors of 3.29 m^2 each (CPC30) and 232 collectors of 4.91 m^2 (CPC45). One CPC30 and four CPC45 are respectively connected into series. Water heated in the solar collectors is transported to the two solar buffer storage tanks (of 8500 liters each) [18].

The next large solar cooling plant is located in Viota (Greece). It has been constructed for a cosmetic factory and it is made of 2 adsorption chillers (350 kW each). There are 2700 m^2 of flat plate collectors delivering heat to the adsorption chillers as well as to the factory as process heat. It is evident that the installed capacity of adsorption solar systems is usually significantly lower than that of absorption systems.

2.3. Desiccant Evaporative Cooling (DEC)

An example of solar solid desiccant cooling system shown in Fig. 4 consists of the following elements: two air ducts, two fans, a heat wheel, a desiccant wheel, two evaporative coolers (humidifiers) and a heater. The heater is driven by solar energy. The principle of work lies in the fact that fresh air is dried by removing the heat from this fresh air to heat up the air going out of a building [9]. Subsequently, the fresh air is cooled in the rotary heat exchanger and then cooled by humidification. The drier the inlet air becomes, the more cooled down this air can become during the humidification process.

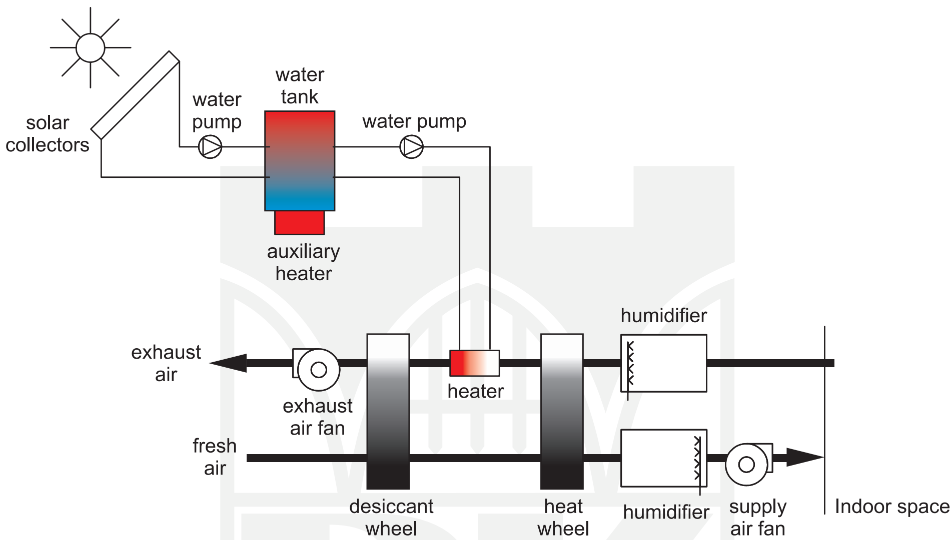

Fig. 4. Solar solid desiccant cooling

The total number of large solar DEC installations in the world is 22 (19 of which are in Europe). Among these DEC installations only 7 systems use a liquid regenerator (DEC liquid) [3, 17, 18]. These DEC systems are predominantly operational in hot humid countries. Their cooling capacity is usually much lower than in the case of adsorption and especially absorption technologies.

3. Present state of solar cooling systems application

In 2011, about 750 solar cooling systems of different capacities were installed worldwide, including small capacity systems (< 20 kW). In 2012, 159 new solar cooling systems were installed around the world [3]. In last six years the number of large solar cooling systems has doubled. At the same time, the total capacity of cooling systems has increased from 9.3 MW to 17.6 MW. case In terms of systems with a cooling capacity above 20 kW there are three dominating technologies: absorption, adsorption and DEC. Table 1 presents the different categories of sorption processes (columns: “Abs”, “Ads”, “DECs” and “DECl” refer to given technologies) with the nominal thermal cooling capacities of the installations in different world regions in 2012. Closed cycles using absorption or adsorption are indicated by "Abs" or "Ads", whereas desiccant evaporative cooling systems with an open cycle are indicated by "DECs" when a solid sorption material, for example, in a sorption rotor is used. When a liquid sorption material is applied the system is referred to as "DECl".

Table 1

Worldwide solar cooling systems in 2012

Continent	Abs [kW]	Ads [kW]	DECs [kW]	DECl [kW]
Australia	300	0	0	0
Asia	976	0	43	350
Europe	10314	2932	703	195
Africa	1265	0	0	0
North America	245	290	0	0
Total:	**13100**	**3222**	**746**	**545**

The list counts 159 installed large-scale solar cooling systems, where 128 installations are located in Europe, 9 in Asia (China, Japan, Singapore, Israel, Armenia), and 10 in America (USA, Mexico), 2 in Africa and 1 Australia. Countries having the largest cooling capacity in solar cooling systems worldwide are presented in Fig. 5.

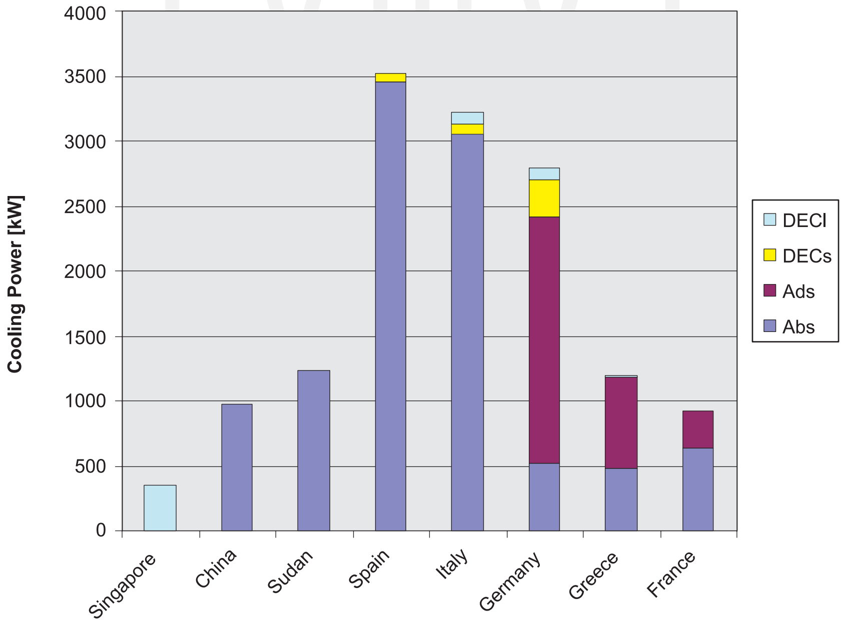

Fig. 5. Worldwide distribution of the cooling power assisted by solar energy. The types of thermally driven chillers applied in the different countries are also listed

In Europe, there are 94 absorption chiller installations, 15 adsorption chillers and 19 DEC (Desiccant Evaporative Cooling) systems. Among the DEC installations, only 5 systems use a liquid regenerator (DEC liquid). The overall cooling capacity of the solar thermally driven chillers amounts to 13.25 MW, with 26% installed in Spain, 23.1% in Italy, 18.2% in Germany and 9% in Greece (Fig. 6).

In Europe, 60% of these installations are dedicated to office buildings, 15% to laboratories and education centers, 7% to factories, 6% to hotels and hospitals and the rest to buildings with different uses (such as, canteens, sport centers, etc).

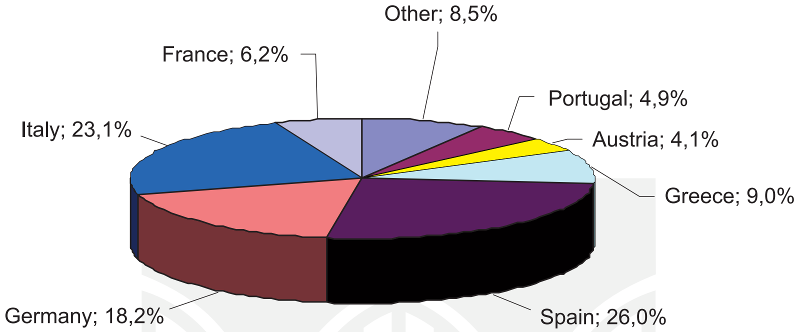

Fig. 6. Percentage of cooling capacity solar cooling systems in European countries

The overall solar cooling capacity is assisted by about 50000 m² of solar thermal collectors [17]. About 50% of the total gross area is made up of FPCs (Flat Plate Collectors), about 40% of VTCs (Vacuum Tube Collectors), about 10% of CPCs (Compound Parabolic Collectors).

In Poland, there is no solar cooling plant with a cooling capacity above 20 kW.

4. Conclusions

According to the National Renewable Energy Laboratory (NREL) (in USA) twenty years ago, most solar cooling systems, of the absorption or desiccant types, were designed to handle 30–60% of all cooling requirements, with the remainder supplied by a backup heat source such as natural gas. Currently, most of the new systems are designed to meet the cooling demand for the entire building, although in many cases backup heat sources do exist [12]. Most applications of this type are located in Europe and the Far East and are mainly used to cool the air in the air-conditioning systems of office buildings.

As mentioned earlier, solar cooling is not being implemented in Poland. However, modern public buildings, especially offices with huge glazed facades frequently require more energy for cooling than for space heating. Solar cooling seems, therefore, to be prospective technology. Its application should reduce the consumption of traditional fossil fuels as traditional air conditioning units largely use electricity produced by coal fired plants.

Furthermore, the solar cooling system does not involve a simple traditional installation located in the HVAC center or boiler room inside a building. The implementation of this technology entails the installation of its component parts, i.e. the solar collectors, to be incorporated into building envelope. It must be emphasized that building-related solar energy issues are not limited to the installation itself, but also to the architectural and civil engineering aspects. Solar collectors can be placed on a special supporting structure on top of a roof, as a stand-alone solar system, or just on the ground. Solar collectors on the roof of a single family house usually look quite good. However, in the case of a big installation, the vast array of solar collectors on a special supporting structure mounted to the flat roof of a building does not look good aesthetically. In addition, such a series of collectors is very much subject to environmental factors, such as low ambient air temperature and wind. As a result, heat losses from solar collectors are great and thus reduce the thermal efficiency of the system. Therefore, it is recommended to incorporate solar collectors into the external walls of a building as their integral element. BIST – Building Integrated Solar Thermal – systems are increasingly popular in different types of modern low-energy buildings, both public and private. All aspects of BIST systems are being considered by the COST Action TU1205 "Building Integration of Solar Thermal Systems (BISTS)".

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