

Development and Application of Solar Absorption Air-conditioner

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Abstract: Thermal utilization of solar for air-conditioning is a particularly attractive application for solar energy because of the near coincidence of peak cooling loads with the available solar power, and has great meaning to energy saving and environment protecting. Among the various technologies for application, the absorption system appears to be one of the most suitable and promising options for solar cooling, because they are compact, reliable and can be easily integrated into existing systems. This paper introduced the theory, development and character of solar absorption air-conditioning system and its application in the BAPP project of Carnegie Mellon University and Solar Technique application demonstration project of Beijing. Success of these projects approve that solar absorption air-conditioner is feasible technically, and has good economic and environmental benefit. Nevertheless, further improvements should be made to the solar powered air-conditioning systems. Although solar powered air-conditioning systems are readily available in commercial sizes, existing solar cooling systems are not competitive with conventional electricity-driven or gas-fired air-conditioning systems because of their high first cost. Lowering the cost of components and improving their performance could reduce the cost of solar cooling systems. Improvements such as reduced collector area, because of improved system performance, and reduced collector cost will lower the cost of solar components.

Keywords: solar energy; absorption chiller; research; application

1. INTRODUCTION

The sun is a sphere of intensely hot gaseous matter with a diameter of 1.39×10^9 m. The solar energy strikes our planet a mere 8 min and 20 s after leaving the giant furnace, the sun which is 1.5×10^{11} m away. The sun has an effective blackbody temperature of 5762 K. The temperature in the central region is much higher and it is estimated at 8×10^6 to 40×10^6 K. In effect the sun is a continuous fusion reactor in which hydrogen is turned into helium. The sun's total energy output is 3.8×10^{20} mW which is equal to 63 mW/m^2 of the sun's surface. This energy radiates outwards in all directions. Only a tiny fraction, 1.7×10^{-14} kW, of the total radiation emitted is intercepted by the earth. However, even with this small fraction it is estimated that 30 min of solar radiation falling on earth is equal to the world energy demand for one year [1].

As a result of the projected world energy shortage, the use of solar energy for environmental control is receiving much attention in the engineering sciences literature. Solar energy has been used to generate electricity and several studies have investigated the use of power from photovoltaic systems. Unfortunately, photovoltaic technology has low efficiency and high capital cost [2]. Solar cooling is a logical and sustainable technology from the fact that cooling is provided by solar energy, the perpetrator that creates the cooling demand. And thermal

utilization of solar for air-conditioning is a particularly attractive application for solar energy because of the near coincidence of peak cooling loads with the available solar power. Among the various technologies for application, the absorption system appears to be one of the most suitable and promising options for solar cooling, because they are compact, reliable and can be easily integrated into existing systems [3].

Also there are many literatures about solar absorption air conditioning system. Hammad and Audi [4] described the performance of non-storage, continuous, solar operated absorption refrigeration cycle. The maximum ideal COP of the system was determined to be equal to 1.6, while the peak actual COP was determined to be equal to 0.55. Ghaddar et al. [5] presented modelling and simulation of a solar absorption system for Beirut. The results showed that, for each ton of refrigeration, it is required to have a minimum collector area of 23.3 m^2 with an optimum water storage capacity ranging from 1000 to 1500 L, for the system to operate solely on solar energy for about 7 h per day. The monthly solar fraction of total energy use in cooling is determined as a function of solar collector area and storage tank capacity. The economic analysis performed showed that the solar cooling system is marginally competitive only when it is combined with domestic water heating. Zinlan and Ning [6] describe a solar absorption air conditioning system that uses an array of 2160 evacuated tubular collectors of total aperture area of 540 m^2 and a

Lithium Bromide absorption chiller. Thermal efficiencies of the collector array are 40% for space cooling, 35% for space heating and 50% for domestic water heating. It was found that the cooling efficiency of the entire system is around 20%.

2. TECHNOLOGY

A solar absorption air-conditioning system includes solar collector, absorption chiller, heat storage tank, boiler as assistant heat source, fan coil and cooling tower etc. To begin with, the solar energy is gained through the collector and is accumulated in the storage tank. Then, the hot water in the storage tank is supplied to the generator to boil off water vapour from a solution of lithium bromide/water. The water vapour is cooled down in the condenser and then passed to the evaporator where it again is evaporated at low pressure, thereby providing cooling to the required space. Meanwhile, the strong solution leaving the generator to the absorber passes through a heat exchanger in order to preheat the weak solution entering the generator. In the absorber, the strong solution absorbs the water vapour leaving the evaporator. Cooling water from the cooling tower removes the heat by mixing and condensation. Since the temperature of the absorber has a higher influence on the efficiency of the system than the condensing temperature, the heat-rejection (cooling water) fluid, is allowed to flow through the absorber first and then to the condenser^[7]. An auxiliary energy source is provided, so that the hot water is supplied to the generator when solar energy is not sufficient to heat the water to the required temperature level needed by the generator.

The major components of solar cooling systems are absorption chillers and solar collector. Single-effect, double convertible cycle, two-stage, Dual-cycle and other chillers are employed as the cooling devices, while flat-plate collectors, evacuated tube collectors, stationary non-imaging concentrating collectors and dish type concentrating collectors are used as the thermal power in the system.

Earlier researchers often used the intermittent absorption cycle to produce cooling owing to the fact that solar energy is an intermittent heat source. With the development of technologies in continuous absorption cooling systems, especially their higher system performance above intermittent alternatives and their coincidence with the requirement of the air-conditioning (especially for space cooling) demand, continuous solar absorption air-conditioning systems are widely reported and improvements made worldwide.

The performance coefficient of an absorption air-conditioner, defined as the ratio of the heat transfer rate into the evaporator to the heat transfer rate into the generator, can be calculated as a function of the temperatures identified previously. Of the various continuous solar air-conditioning systems, LiBr-H₂O and H₂O-NH₃ are the major working pairs employed in these systems. It is reported that LiBr-H₂O has a higher COP than for the other working fluids. Though it has a limited range of operation, due to the onset of crystallization occurring at the point of the

recuperator discharge into the absorber and stopping solution flows through the device, the low cost and excellent performance of this working fluid combination make it the favourable candidate for use in solar cooling cycles.

Also by comparison^[9], the ammonia-water system has additional disadvantages. The coefficient of performance (COP) for the H₂O-NH₃ system is lower than for the LiBr-H₂O system. Generally, H₂O-NH₃ systems operate at a 10-15% lower solar fraction than LiBr-H₂O systems. It requires a higher generator inlet temperature. Generally, LiBr-H₂O absorption units require generator inlet temperatures of 70-88°C, while H₂O-NH₃ absorption units require temperatures of 90-180°C; which results in the H₂O-NH₃ cooling systems achieving a lower COP when using flat-plate collectors. It requires higher pressures and hence higher pumping power. A more complex system requiring a rectifier to separate ammonia and water vapour at the generator outlet is required. There are restrictions on in-building applications of ammonia-water cooling units because of the hazards associated with the use of ammonia. For these reasons the lithium bromide-water system is considered to be better suited for most solar absorption air-conditioning applications.

The temperature of heat source determines the selection of absorption chillers. If flat-plate or evacuated tube collectors are used, the system can only generate low temperature (lower than 100 °C) hot water, and can drive single-effect absorption chiller only according to the present technology. But if non-imaging concentrating collectors are used, then the system can generate medium temperature hot water or steam (above 150°C) to drive double-effect steam absorption chiller^[8].

Solar energy-driven HVAC systems have operated successfully in the past and some continue to do so today. In the 1980s, Wagner College in New York City installed and operated a hybrid solar/fossil fuel hot water system that powered a single-effect absorption water chiller HVAC and domestic hot water system for two campus buildings of around 6967m² total area. A collector array of 1022 m², aperture array of evacuated tubes with external reflectors provided 104 °C hot water to a 320-ton Carrier absorption chiller, and the system was operated for six years with annual routine maintenance labour averaging 55 man-hours per year. The annual solar energy collection efficiency was around 25% and the COP of the chiller averaged 0.65 because it operated derated most of the time. The system was shut down after the external reflectors on the collectors degraded significantly so as to reduce the attainable operating temperatures. Other solar absorption cooling systems continue to operate elsewhere in the US and overseas, many of which use flat plate collectors and single-effect chillers with operating temperatures up to 104 °C. At these temperatures, the collection efficiencies of the solar arrays are below 20%. The combined energy conversion efficiency, cooling accomplished divided by collectible solar energy, of these solar energy collectors and single-effect chillers is about 15%. So even though solar absorption HVAC systems have

been proven to be technically feasible in the New York City region and in other US and overseas areas, the low energy conversion efficiency and low fuel prices have rendered them uneconomical.

Solar thermal HVAC systems with double-effect absorption water chillers and the new Integrated Compound Parabolic Concentrator (ICPC) evacuated tube collector is now bringing to market. The conversion efficiency for space cooling is almost 60%, four times better than solar thermal systems with single-effect chillers. The new ICPC solar thermal collector efficiency is approximately double the efficiency of other collectors at operating temperatures of 165 °C and the double-effect chiller is almost double the efficiency of single-effect chillers. The preferred heat transfer fluid is water because of its good thermodynamic properties and low cost. However, at these high operating temperatures, the high system pressure mitigates against using the usual thermal storage tanks for solar HVAC systems. At the present cost of fossil fuels, the capital costs for large high-pressure thermal storage, that might provide three hours of solar energy operation at night, can buy over 10 years worth of fuel to operate the systems when solar inventories are low. Therefore, in order to make such systems more cost effective, they are being marketed as hybrid solar/fossil fuel installations with small high-pressure buffer tanks.

Solar lithium bromide/water absorption chillers have better economy compared with electricity-driven chillers^[6]. The COP of these electricity-driven chillers varies from 2.5 to 5.8 and average 2.93 according to statistic data of Department of Engineering (DOE) of American in 2002. Generally thermal of 3 kWh can supply about electricity of 1 kWh to terminal consumer while other parts were lost during the process. Considering the efficiency of grid, the primary energy COP of electricity-driven chillers was between 0.83 and 1.93, and average 0.98. But the primary energy COP of solar/natural gas + absorption chillers was 3.25 considering that solar can supply 60% energy in summer time, natural gas supplied other 40%, and the COP of steam double effect absorption chiller was 1.3. So compared with electricity-driven chiller, solar/natural gas + absorption chiller just consumed about one third primary energy for the same cooling load.

3. APPLICATION

With the development of lithium bromide / water absorption chiller, the technology of solar absorption air-conditioner developed accordingly, and many solar absorption air-conditioning systems of different scale had been setup.

A project named Building as Power (BAPP) ultimately issued in the Intelligent Workplace, a project of the Centre for Building Performance and Diagnostics (CBPD) of Carnegie Mellon University. The Intelligent Workplace is a living laboratory of the advanced building system integration that serves as a test bed for innovations in building facade, interior, HVAC, and currently, for micro-CHP energy supply system, ESS. And advanced protection structure, HVAC system, clean energy and renewable energy (solar energy) are adopted. The building has two control zones, the south zone and the north zone. The south zone includes five short modules in the south end of Intelligent Workplace.

Based on the architectural design of the Intelligent Workplace and its proposed mode of operation both peak loads and load profiles have been simulated making use of the DOE-2.1E. The various loads include:

- Power for lighting, equipment, fans, and pumps
- Cooling for the building and its equipment in summer

- Heating for the building in winter
- Fresh, outside, air supply along with the required
- Dehumidification in summer / humidification in winter

- Cooling/Heating
- Domestic hot water

A typical peak cooling day (July 21st) simulation results are presented below (see table 1). The peak loads are now being used to size the components of the micro-CHP energy supply system. The load profiles will be used subsequently to determine the effectiveness of the system, in particular its annual operating cost over the range of the building operations.

Figure 1 represents the solar air-conditioning system of south zone. HTFS means heat transfer fluid supply, HTFR means heat transfer fluid return, HPS means high-pressure steam, and COND means condensate. And also the test data of one day was demonstrated. The solar collectors have an area of 36.4 m², and efficiency of 0.56 according to calculation.

Table 1: f South zone supply system peak cooling loads in peak cooling day

July21		Sensible load	Latent load	Elec.load	Sub-total
		kW(%)	kW(%)	kW(%)	kW(%)
11: 00am					
Cooling	Space	7.69(33.2%)	3.89(16.8%)		11.58(50%)
Load	Fresh Air	0.56(2.4%)	2.18(9.4%)		2.74(11.8%)
Electricity	HVAC& other			1.79(7.7%)	
Load	Lighting			3.95(17.1%)	
	Office Equip.			2.83(11.4%)	
DHW load					0.46(2%)
Total					23.16(100%)
Global		South Zone			
Wet bulb	Dry bulb	Humidity	Area	Zone	thermostat
temp(°C)	temp(°C)	ratio(%)	temp(m ²)	temp(°C)	set point(°C)
23.9	31.1	16.5	579	23.6	22.2

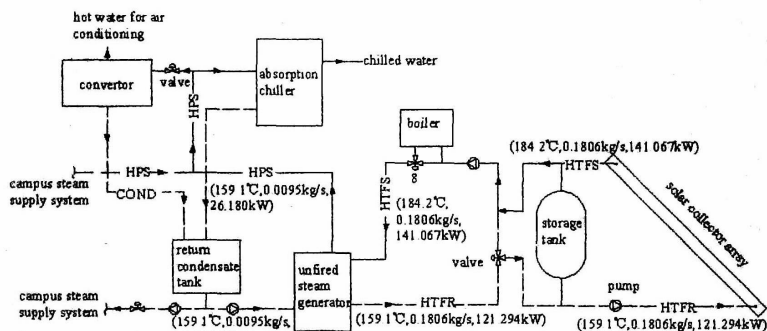


Figure 1: IW south zone solar energy supply system

The solar energy application demonstration project, which was completed by Solar Institute of Beijing, is aimed to set up a good example for 2008 green Olympic in Beijing. The project included a 200 kW solar photovoltaic system and solar air conditioning system, and here mainly introduce the air conditioning system.

The demonstration project had area of 2600 m², and required cooling in summer and heating in winter. The requirements of indoor air temperature were above 16°C in winter and below 26°C respectively. The mission of the project included: (1) Integral optimize the design of the solar air conditioning system to

achieve safety, reliable, energy saving and applicable operation; (2) Investigate the mode of integrate solar energy with building, especially with the roof and wall of building; (3) Investigate the integration of evacuated tube collectors with the system, and especially reasonable match with absorption chiller; (4) Study the optimum distribution of evacuated tube collectors; (5) Study the solar auxiliary system and solar energy storage system; (6) Develop reliable, convenient and intelligentized auto control system; (7) Investigate the operating performance of the solar air conditioning system, and execute economic comparison with conditional air conditioning system.

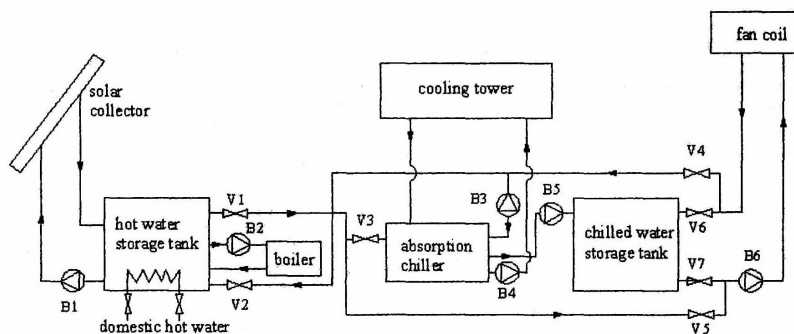


Figure 2: The flow of the solar absorption air conditioning demonstration project

Heat collect and storage system

Solar collector, hot water storage tank, boiler and pump group B1 and B2 comprised the heat collect and storage system.

This project adopted evacuated tube collector, whose operating temperature was 80 ~ 90°C, coat absorptivity was above 0.90, glass tube penetrate ratio was above 0.90, and average efficiency was above 0.4. The solar collector array of 860 m² was comprised of more than 3000 evacuated tubes. These evacuated tubes were installed at the roof parallel in five sub-arrays, and every sub-array

consisted of 5 lines of collectors in parallel connection. Installed in this way can reduce flow resistance of system, and make it convenient to maintain collector. The brackets of collectors were designed and constructed with the roof simultaneously to ensure integration, fastness and waterproof of building.

Large capacity hot water storage tank was adopted to obtain stability of system operating, to reduce the influence of variation of solar radiation. Pump group B1 started when there had solar, and pump the water of storage tank into solar collector to be heated. If B1 stopped, water in the collector will return to hot water storage tank by gravity to avoid

pipeline freezing in winter. If there have inefficient solar radiation or the temperature of water in the storage tank lower than that of setpoint, then the auxiliary boiler and pump group B2 will work to heat the water in storage tank. The hot water stored in the tank can be used to heating or cooling. Also there have water/water heat exchanger to supply domestic hot water when no cooling or heating is needed, and can supply 50 tons hot water every day.

Heating circulation

The heating system consisted of hot water storage tank, pump group B6, fan coil and relevant valves. Open valve V1, V2, V4 and V5, turnoff V3, V6 and V7, and start pump group B6 to pump hot water from storage tank to fan coil to heating.

Cooling and cooling storage system

Cooling and cooling storage system was comprised by hot water storage tank, lithium bromide/water absorption chiller, cooling tower, pump group B3, B4, B5 and B6, cooling storage tank, fan coil and valves.

Open valve V1, V2, V3, V6 and V7, turnoff valve V4 and V5, and start pump group B3 to pump hot water of hot water storage tank into absorption chiller as heat source, and then pump it return back storage tank. Start pump group B4 to pump cooling water from chiller into cooling tower to remove chillers heat. Start pump group B6 to pump chilled water of cooling storage tank to fan coil to cooling.

Absorption chiller requires supply of hot water above 88°C, and can generate chilled water around 8°C. Also large capacity of cooling storage tank was used to ensure stability operation of air conditioning system. Assume that surrounding temperature is 30°C in summer, then temperature difference between chilled water and outdoor air would be 22°C, which was far more small than that between hot water and the surrounding, which is 58°C, so it is necessary to storage chilled water as much as possible to reduce loss.

Control system

Both auto control system and manual control system were used in the system. In general, auto control system was used to collect temperature and flow rate etc of the system to control pump groups and equipments according to control program, and dynamic operating information was shown on the screen. Manual control system was necessary supplement of auto control system to ensure the whole system reliable, safe and controllable.

These projects have demonstrated the technical feasibility of solar HVAC systems. The main advantage of these systems is that they display compression air conditioners, which require approximately 1.5 kW per ton of electric utility provided power, equally important is the fact that the electricity is displaced during the cooling season when electric utilities experience their peak demand for power. Solar HVAC systems provide significant reductions in the charges for both electric and peak demand.

4. CONCLUSION

Solar absorption air-conditioning has the advantage of both the supply of the sunshine and the need for refrigeration reach maximum levels in the same season. Several technical problems associated with the design and development of absorption chillers based on continuous cycles have been successively resolved, and new trends gradually developed towards the redesign of the chiller generator for operation at temperatures lower than 100°C. Nevertheless, further improvements should be made to the solar powered air-conditioning systems. Although solar powered air-conditioning systems are readily available in commercial sizes, existing solar cooling systems are not competitive with conventional electricity-driven or gas-fired air-conditioning systems because of their high first cost. Lowering the cost of components and improving their performance could reduce the cost of solar cooling systems. Improvements such as reduced collector area, because of improved system performance, and reduced collector cost will lower the cost of solar components. A project was concerned in California with improving the performance of solar-fired, double-effect HVAC systems by optimising the design of the high temperature generators in absorption chillers. The results of bench testing of generator tubes and field-testing of a nominal 20-ton absorption chiller demonstrate that the chiller performance can be improved by installing twisted inserts in the generator tubes. Since the driving energy, solar radiation, is highly time-dependent and intermittent, a system, which is designed, ignoring this dynamic nature, is not likely to offer much benefit. And because an absorption chiller consists of many heat and mass exchangers and reservoirs which make the system generally bulky and sluggish. Therefore it is very important to design a system, which is quick and light so that it can take full advantage of the energy coming from the sun. Control strategies are also important in this respect. In the start up period, for example, concentration, volume and flow conditions inside each component are totally different from the design conditions. If the system is not controlled properly in this period, it could waste valuable solar time or, in the worst case, could even be brought into a stagnation position.

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