Solar Absorption Air-Conditioning Systems

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ABSTRACT

In hot climates, one energy source abundantly available is solar energy, which could be used to power solar cooling system based on absorption cycle.

Solar cooling systems are used to provide comfort cooling and to provide refrigeration for food and medicine. This system is particularly applicable to large applications (e.g. commercial buildings) that have high cooling loads for large periods of the year. Peak cooling demand of the building and the availability of solar radiations are in phase and matches perfectly. This makes solar cooling of the buildings a potential renewable energy source and green solution. Lithium bromide (LiBr)-water absorption units are more suitable for solar application since their operating (generator) temperature is lower and thus more readily obtainable with low-cost solar collectors.

Conventional vapor-compression cooling systems are powered by electricity, which is expensive and its production is mainly dependent on fossil fuel. Reducing the use of vapor-compression air conditioning systems will also reduce their effect on Global Warming and Ozone layer depletion.

Today absorption chillers deliver 50% of the commercial space cooling load worldwide. This innovative green solution of solar powered absorption air conditioning system coupled with thermal storage system application will reduce total electricity consumption and increase total cooling capability of the system for given cooling demand load.

1.0 SOLAR ENERGY AND ABSORPTION AIR-CONDITIONING SYSTEMS

1.1 Solar Energy

Sun is a continuous fusion reactor in which hydrogen is turned into helium. Total energy output from the sun is 3.8×10^{20} MW, which is equal to 63 MW/m^2 of sun surface. Earth receives only a tiny fraction of this emitted energy, equal to 1.74×10^{11} MW (or 341 W/ m^2 average). However, even with this small fraction, it is estimated that 84 minutes of solar radiations falling on earth can satisfy world energy demand for one year (about 900 E Joules).

The amount of solar energy available at any specified place depends upon three factors:

1. Location (latitude and longitude)
2. Date
3. Time of the day

1.2 Solar Energy Collection

Solar energy can be converted to chemical, electrical, and thermal processes. Solar energy is converted to electricity through photovoltaic conversion (sun to electricity). Solar thermal conversion in the form of hot water, steam or other heat

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transfer fluids can be used for space heating and cooling, domestic water heating, power generation, distillation and processes heating.

The major component of a solar thermal air conditioning system is solar collector. These are heat exchangers that absorb solar radiation energy, convert it into heat and transfer this heat to heat transfer fluid (air, water or oil).This collected thermal energy either can be used directly for air-conditioning or can be stored in thermal energy storage tanks for later use at night times when sun is not available. There are two types of solar collectors: stationary (non-concentrating) and concentrating.

1. Non-concentrating collector has same intercepting and absorbing area.
2. Concentrating collector are mostly sun-trackers uses concave reflecting surfaces to concentrate solar beams to a small receiving area and increase the radiations flux to many times. This also produces high temperatures of heat transfer fluids.

Table 1. Solar Collectors and their Important Properties

Motion	Collector Type	Absorber Type	Concentration Ratio	Indicative Temperature Range (° C)
Stationary	Flat-plate collector (FPC)	Flat	1	30-80
	Evacuated tube collector (ETC)	Flat	1	50-200
	Compound parabolic collector (CPC)	Tubular	1-5	60-240
Single-axis tracking			5-15	60-300
	Linear Fresnel reflector (LFR)	Tubular	10-40	60-250
	Cylindrical trough collector (CTC)	Tubular	15-50	60-300
	Parabolic trough collector (PTC)	Tubular	10-85	60-400
Two-axis tracking	Parabolic dish reflector (PDR)	Point	600-2000	100-1500
	Heliostat field collector (HFC)	Point	300-1500	150-2000

Source: Solar Energy Engineering :Processes and Systems / Soteris Kalogirou.—1st ed .2009, Elsevier Inc.

1.3 Solar Absorption Air-Conditioning: System Description

The difference between solar absorption air- conditioning and traditional fossil fuel fired unit is that energy supplied to the generator is from solar collector units. The heat from the sun can be used directly to the absorption machine or can be first stored in a thermal storage tank and then used in absorption machine. Due to intermittent nature of solar energy, it is a better option to use a thermal storage tank to store this heat first. This serves two purposes: first the intermittent nature of solar energy can be overcome; second the stored heat can be utilized in night time when sun is not available. In case hot water storage tank is not available, a buffer tank of suitable capacity is recommended. The second option is to use a chilled water thermal energy storage tank. In this case absorption chiller that matches with the peak solar energy available is used and chilled water is produced for off-peak loads.

Table 2. Absorption Chillers Heat Source Requirement

Type	COP	Heat Source Temp (°C)	Type of solar collectors matched
Single Effect	0.75	98 °C hot water	Evacuated tube collectors
Double Effect	1.4	180 °C hot water	Compound parabolic collectors/Parabolic trough collectors/Linear fresnel reflector
Triple Effect	1.8	250 °C steam at 40 bars	Parabolic trough collectors/Linear fresnel reflector

Solar absorption air-conditioning systems can be configured in many different ways. It is recommended to use stand-by chiller with solar air-conditioning system. This relives when cooling is not available from solar system in bad weather conditions. For this multiple heat source streams can be used in conjunction with solar heat. The alternatives must be evaluated very carefully to satisfy particular needs and requirements. Broadly, we can categorize solar absorption air conditioning systems into following options:

1. Option 1: Utilizing solar energy as prime heat source and auxiliary heater as secondary heat source (hot water / steam operated chillers).
2. Option 2: Utilizing solar energy as prime heat source and fossil fuel and/or waste heat as secondary heat source (multi-energy units).
3. Option 3: Utilizing two different absorption machines; one working with solar hot water and other is direct fossil fired.
4. Option 4: Onsite power with cogeneration.

2.0 CASE STUDY

2.1 Introduction

The assumption is made of an office building in Riyadh, Saudi Arabia having air-conditioning load of 240 TR. We shall analyze the suitability of LiBr absorption chiller that shall be operating with hot water from solar collectors. Heat pipe type evacuated tube solar collectors (ETC) are used to generate hot water and to use it as prime heat source (100% heat from hot water) for single effect absorption chillers (COP 0.8).

Area available on roof for the installation of ETC is approximately 4000 m^2. ETC specified can produce temperature between 75 °C and 120 °C.

2.2 Basic Parameters

2.2.1 Environmental Conditions

A. **Outdoor Air (ASHRAE 1%)**

Design DB Temperature: 43.8°C (111°F) DB
Design WB Temperature: 22.22°C (72°F); for cooling towers selection

B. **Solar Radiation Data**

Table 3. Monthly Averaged Direct Normal Radiation (kWh/m^2/day)

Jan	Feb	March	April	May	June	July	Aug	Sep	Oct	Nov	Dec	Annual Average
5.04	5.68	5.75	6.2	7.49	8.8	8.33	7.92	7.32	7.12	5.83	4.89	6.7

Table 4. Monthly Averaged Daylight Hours (hours)

Jan	Feb	March	April	May	June	July	Aug	Sep	Oct	Nov	Dec	Annual Average
10.7	11.3	12.0	12.7	13.3	13.6	13.5	12.9	12.3	11.6	10.9	10.6	12.12

2.2.2 Heat Source Water System

Table 5. Hot Water Supply and Return Temperatures for Absorption Chiller

Location	HW supply (°C)	HW return (°C)	Delta T (°C)
Solar collectors on roof	98	88	10

2.2.3 Chilled Water System

Table 6. Chilled Water Supply and Return Temperatures from Absorption Chiller

Location	CHW supply (°C)	CHW return (°C)	Delta T (°C)
At the plant exit	7.0	12.0	5.0

2.2.4 Condenser Water System

Table 7. Condenser Water Supply and Return Temperatures for Absorption Chiller

Location	CW supply (°C)	CW return (°C)	Delta T (°C)
At the plant exit	32.0	37.5	5.5

2.3 System Description

2.3.1 Evacuated Tube Collectors

Area available on roof for solar evacuated tube collectors is 4000 m^2. Hot water temperature required by absorption chiller is 98 °C. Hot water and heat available from this system can be calculated as following.

Consider 30 numbers of tubes in 1 system; we require 3 systems connected in series to produce required temperature.

Flow Rate Calculation:

Area required for one system = 6 m^2

Area required for three systems (one section) = 18 m^2

With 4000 m^2 available roof area = 4000 / 18 = 222 Number of sections can be installed

Flow rate per section = 1.8 m^3 / hr

Flow rate per 222 sections = 1.8 x 222 = 399.6 m^3 / hr

Heat Calculation:

Annual average direct normal radiations = 6.7 kWh/m^2/day.

Contour aperture area for one system = 3.979 m^2

System efficiency = 85%

Average total heat available = 6.7 x 3.979 x 3 x 222 x 0.85 = 15,092 kWh/day

Table 8. Estimated Hourly Solar Radiations

Hr	Solar Radiations (kW)	Hr	Solar Radiations (kW)
1	0	13	2325
2	0	14	1940
3	0	15	1292
4	0	16	440
5	0	17	260
6	0	18	0
7	260	19	0
8	440	20	0
9	1292	21	0
10	1940	22	0
11	2325	23	0
12	2585	24	0

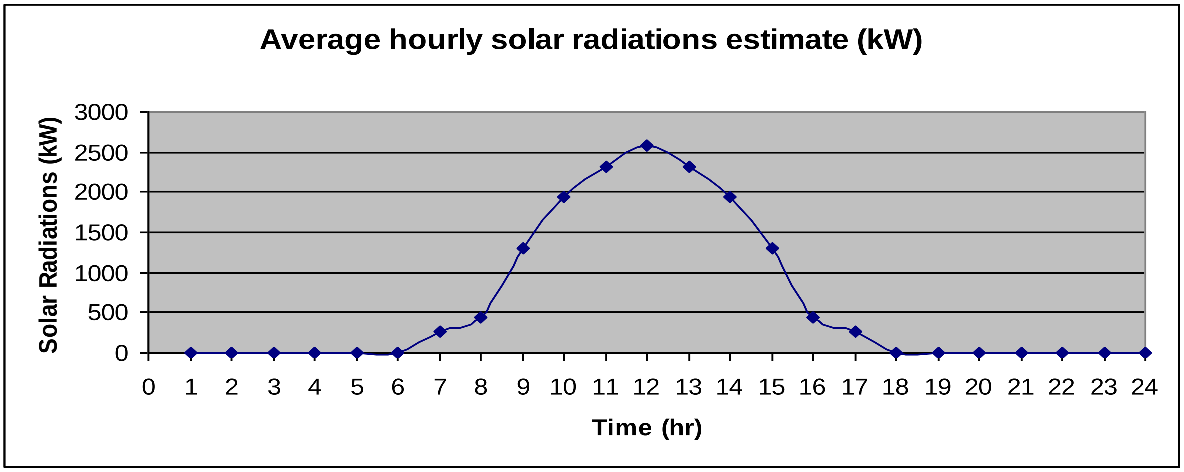

Figure 1 *An estimation of hourly solar radiations availability for 4000 m^2 roof area and with above ETC collector specifications.*

2.3.2 Chillers

Solar radiations available at peak can produce hot water sufficient for 537 TR of air conditioning. We can install a chiller of 550 TR capacity to run on this hot water.

Table 9. Nominal Design Conditions

Nominal Capacity (TR)	Chilled Water			Condenser Water			Hot Water		
	Flow (l/s)	LWT (°C)	EWT (°C)	Flow (l/s)	LWT (°C)	EWT (°C)	Flow (l/s)	LWT (°C)	EWT (°C)
550	95	7	12	198	37.5	32	65	88	98

Our selected chiller requires 230 m^3 / hr and 2635 kW at 100% capacity operation. This means that available flow of 399 m^3 / hr and 15092 kWh/day from solar collectors is sufficient for chiller operation and system can be run for approximately 6 hrs on solar hot water at 100% capacity.

2.4 System Integration

If system air-conditioning load and solar radiations are analyzed together, it is seen that peak of solar radiations availability and office building air-conditioning load do not coincide. Solar radiations are available from 0600 hrs till 1800 hrs, with different varying direct normal radiations. The peak exists somewhere around 1200 hrs.

Table 10. Estimated Hourly Air-Conditioning

HR	AC Load (TR)	AC by Solar (TR)	AC by TES (TR)	HR	AC Load (TR)	AC by Solar (TR)	AC by TES (TR)
1	60	0	60	13	204	483	-279
2	60	0	60	14	216	403	-187
3	60	0	60	15	228	269	-41
4	72	0	72	16	240	91	149
5	96	0	96	17	180	54	126
6	120	0	120	18	132	0	132
7	144	54	90	19	60	0	60
8	180	91	89	20	60	0	60
9	216	269	-53	21	60	0	60
10	192	403	-211	22	60	0	60
11	204	483	-279	23	60	0	60
12	192	537	-345	24	60	0	60

(-) negative sign of TES capacity shows charging mode of excess solar cooling available and positive sign shown discharging of stored cooling.

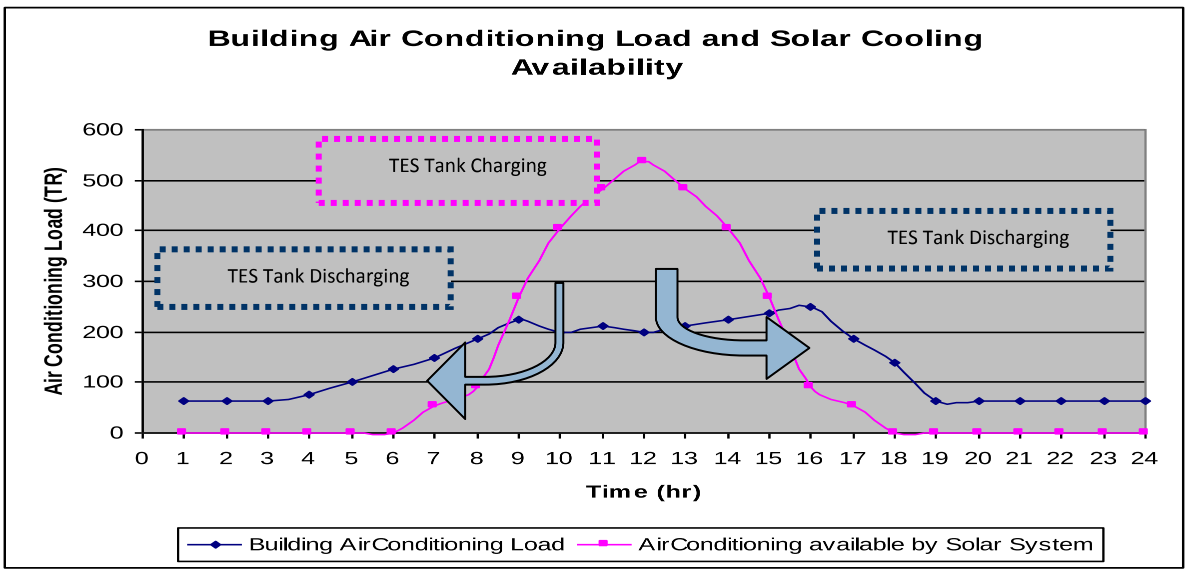

Figure 1 *A comparison of building air-conditioning load and solar cooling availability.*

The available solar radiations can produce 537 TR of air-conditioning at peak solar radiations. The air-conditioning load of the office building is estimated to be 192 TR at this time. The surplus cooling available can be stored in thermal energy storage tanks for use in sun depleting hours.

2.5 Global Warming Impact Estimation-TEWI Calculations

Total equivalent warming impact (TEWI) is a method for estimating direct and indirect global warming potential of equipment. The direct component relates to release of refrigerants (like HFCs) to the atmosphere whereas indirect effect is the production of carbon dioxide in powering this equipment.

The concept of GWP has been developed to compare the ability of a greenhouse gas to trap heat in the atmosphere relative to the effect of carbon dioxide (CO_2) and varies depending on the time frame considered (usually a 100-year period).

$$\text{TEWI} = \text{Direct global warming potential} + \text{Indirect global warming potential}$$

$$\text{Direct global warming potential} = [GWP \times L \times n] + [GWP \times m \times (1-\alpha)]$$

Where

L = leakage rate per year, kg

n = system operating time, years

m = refrigerant charge in the system, kg

α = recycling factor

$$\text{Indirect global warming potential} = n \times E_{annual} \times \beta$$

Where

n = system operating time, years

E_{annual} = energy consumption per year

β = CO_2 emission per kWh energy production, kg

Below is TEWI calculation for the above case study system compared to a typical HFC 134a system and direct fired double effect absorption system, with following parameters:

Table 11. Total Equivalent Warming Impact Calculation

S. No	Parameter	Solar absorption system (LiBr-Water)	Vapor compression system (R134a)	Direct fired absorption system (LiBr-Water)
1	Capacity	550 TR	550 TR	550 TR
2	Years of operation	25 years	25 years	25 years
3	Operation per year	3600hrs	3600 hrs	3600hrs
4	Power consumption	20 kW	0.65 kW/TR	20 kW
5	Refrigerant charge	5000 kg, water	550 kg	5000 kg, water
6	Leakage rate	N/A	0.5 %	N/A
7	Recycling factor	N/A	0.75	N/A
8	CO_2 emission	0.65 kg/kWh	0.65 kg/kWh	0.62 kg/Tr-hr
9	GWP_{100} for refrigerant	N/A	1430	N/A
10	Direct Effect, kg of CO_2	0	294,940	0
11	Indirect Effect, kg of CO_2	965,250	20,913,750	30,660,495
12	**Net TEWI, kg of CO_2**	**965,250**	**21,208,690**	**30,660,495**

The difference in TEWI for three systems is enormous. The CO_2 emission for solar absorption system is approximately 5% of vapor compression system and 3% of direct fired double effect absorption chiller.

Also it can be seen that the major environmental impact is by indirect effect.

3.0 CHALLENGES

Low fossil fuel prices and intermittency of solar energy are two main challenges. These can be overcome by incentives and energy storage. There is potential primary energy saving for properly designed chilled water systems (40-60%). But higher first cost that is 2 to 2.5 times than conventional electric chillers is another challenge. This can be overcome by:

1. Higher standardization
2. Fewer efforts in planning and design
3. Lower component cost

Small capacity systems are required to penetrate the technology at all levels. Also there is a need for advance operation and control.

The other barriers to growth are:
(Ref: European Solar Thermal Industry Federation)

3.1 Technical barriers – Hardware

1. Lack of units with small capacities (Long term: technical alternative to split units needed)
2. Lack of package-solutions for residential and small commercial applications (domestic hot water, space heating, air-conditioning)
3. Only few available solar collectors for medium temperatures (100-250°C), which could drive double- or even triple-effect chillers
4. Low thermal efficiency (COP)
5. Often: Need for wet cooling tower

3.2 Technical barriers – Software (e.g. planning guidelines, training)

1. Very important: no skills today among professionals (planners, installers)
2. Designs of hydraulic systems not yet standardised, lack of suitable planning guidelines and simple design tools for planners

3.3 Lack of awareness

1. The technology is still emerging, but as solar cooling systems become more standardised, the lack of awareness - by consumers and professionals – will become a key barrier to growth

3.4 Costs

1. Higher initial investment costs compared with conventional cooling systems
2. To date, not cost efficient from a business point of view

3. Often forgotten in today's financial incentive schemes for solar thermal

4.0 CONCLUSION

Solar absorption air-conditioning system can provide 100% of building air-conditioning load. The excess cooling available in the day time can be stored to utilize in the evening, night and early next morning.

The payback of solar air-conditioning system depends mainly on solar radiations available, electricity rates and peak charges. The pay back of these systems shall be significantly shorter in future because of expected high fuel and electricity charges. Also solar cooling shall become a cheaper solution with more research and mass production of solar cooling equipment.

The refrigerant phase out in future shall also make solar absorption air-conditioning system an attractive proposition. By using a thermal energy storage tank with solar cooling, an integrated solution for 24 hrs cooling can be provided.

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INTERNET SOURCES OF DATA

Broad Green Central Air Conditioning Catalog BY 130-06, http://www.broad.com

Solar Resource Data

World radiation data center (WRDC) online archive, Russian Federal Service for Hydrometeorology and Environmental Monitoring; 1964-1993 data http://wrdc-mgo.nrel.gov 1994-present data http://wrdc.mgo.rssi.ru/

Surface meteorology and solar energy, National Aeronautics and Space Administration, USA; http://eosweb.larc.nasa.gov/sse

Solar radiation resource information, National renewable Energy Laboratory, USA; http://rredc.nrel.gov/solar

Climatic Data:

World climatic data, World Weather Information Services; http://www.worldweather.org

U.S. climatic data, National Oceanic and Atmospheric Administration, USA; http://www.noaa.gov/climate.html