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Economic Viability of Solar Absorption Cooling System in Pakistan

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Abstract

In developing countries, electricity demand is ever increasing. The growing trend in the number of skyscraper building structures and increase in the use of electrical equipment installed in industrial as well as commercial buildings.
Shortfall of electricity in Pakistan and a large difference in demand-supply of electricity emphasis on the alternative / cost effective solutions of the electricity and as well as cooling. In this regard, the uses of cooling technologies like Absorption Cooling have been a desired solution due to instantaneous availability of the sun in the region. The ever increasing / expanding infrastructure always required to complete energy demands, along with the necessity of cost reduction and higher reliability requirements, which drives towards the alternative resources to include cost reduction, reliability, available resources and efficiency. This increasing load / demand especially in expansion of projects required increased electricity consumption and resultantly cooling demand. Depending on the region, more than half the energy consumed can be for powering air conditioning and refrigeration equipment. And electrical power costs for cooling are often the largest expenditure for most occupied buildings. Absorption Cooling System (ACS) is an alternative substitute for Conventional Compression Cooling (CCC) when electrical power is unreliable and costly.

Keywords: *Energy Crisis, Air Conditioning, Solar Absorption Cooling System (SACS), Heat Energy, Cost-Benefit Analysis*

Introduction

Pakistan is fronting sewer electricity shortage, since last two decades. Growth rate of energy demand for the country is 8% per year [1]. This condition reflects worst energy crisis in following years. The power industry in Pakistan is generally owned by Wapda (Water and Power Development Authority), which include NTDC (National Transmission and Dispatch Company) and regional power supply companies. The demand would shifts to 54GW till 2020 and 113GW in 2030 [2]. The country had overall shortfall of 5GW between supply and demand in 2015 [3, 4].

In Pakistan, amenities like refrigeration cannot be traditional refrigeration because it requires electricity, which is inconsistent. Among all the consequences of the severe shortfall, a rapid increase in energy consumption for air-conditioning systems [5]. Increasing energy consumption and Peak-loads in summer (originated from air conditioning) makes the situation worst in summer.Depending on the region, more than half the energy consumed can be for powering air conditioning and refrigeration equipment. And electrical power costs are often the largest expenditure for most occupied buildings. Reducing energy use while improving the working environment of a building has always been a common goal [6].

Forgoing in view, the use of renewable energy resources to achieve alternative cooling solutions is a viable solution [2]. In this paper, a solar cooling system based on absorption process is proposed for Pakistan. The selected site has ample solar based energy resources with an average monthly Global Horizontal Irradiation (GHI) of 5.58 kWh/m2/day [3].Primary variable that forces the alternative cooling options is the maximum demand charge. Ideal applications for Absorption Cooling System (ACS) are those where the electric charges are high [7].Absorption cooling cycles are being used for more than 50 years [8]. Water (H_2O) – Ammonia (NH_3) absorption cooling units are found suitable substitute for large industrial applications. The combination of Lithium Bromide (LiBr) as an absorber and Water (H_2O) as an absorbent are common to yield chilled water for cooling purposes [9]. In the late 1950s, the first double-effect LiBr - H_2O absorption chiller was introduced [8, 9]. Now a days, absorption chillers are the dominant alternative for conventional Vapor Compression Cooling Systems (VCCS) when comparing cost, availability, or reliability

[8].The Absorption Cooling System consists of four major parts, i.e., a vapor generator, an absorber, an evaporator and a condenser. Schematic diagrams of the solar-powered cooling system are shown in Fig. 2. The main advantage of the ACS is that no moving part is involved except in solution circulation pump making maintenance much more facile for long term period [10].

Absorption chillers are usually categorized as single, double or triple effect, or they may be categorized as direct, in-direct fired. In direct-fired units, Natural gas, Solar or process heat or some other fuel can be used as heat source in direct fired units. Increasing the number of effects means increasing the Co-efficient of Performance (COP) [7, 8, 11]. The major benefit of using solar based cooling systems is to escape peak electric demand charge and reduction in operating costs. The use of alternative cooling mechanism reduces the incremental cost of electrical energy as well as cooling [7]. In conventional fuel, 65–75% loss occurs in primary energy conversion and electricity generation and distribution [8]. Moreover, electric energy costs (per kW) are 3 to 4 times larger as compared to the gas (per kW). Therefore, the cost per unit of output for absorption system can be lowered by using alternative and cheap fuel source [7]. Analysis related to thermodynamics and economic of ACS are given in Refs. [12, 13]. Renewable resources or residual heat can be used as an alternative source to drive absorption process. A number of economic analysis of using SAACSs for residential cooling as well as industrial cooling are presented by Ref. [8, 14, 15]. Different types of absorption systems are discussed in Ref. [16].

Unfortunately, the COP for ACS is much lower than compression chillers. As COP is not the only criteria to choose between ACS and VCCS. Therefore, Integrated Part Load Value (IPLV) and Applied Part Load Value (APLV) are used to compare both the cooling mechanisms. IPLV is a standard for calculating an annual COP depending upon load profile and the part load characteristics of a chiller. Whereas, same IPLV formula is used or APLV with the exception that condensed and chilled water temperatures and flow rates are considered. The use of close approximations of actual operating conditions gives privilege to APLV over the IPLV [7].Solar Absorption Cooling System (SACS) are used in particular with large industrial or commercial environments with high cooling requirements. Availability of the solar radiations round the year in phase with peak cooling demand make solar cooling systems a promising renewable and green energy alternative for buildings [8].

Pakistan is an industrial as well as agricultural economy. Depending upon requirements, the absorption technology can be used for the cooling purposes. Solar absorption technology can be used with solar, natural gas, utility supply, recovery heat or other fuel source. The efficient usage of the waste heat through heat recovery process to feed the absorption chiller for cooling purpose is much reliable for cost benefit to industries [17, 18, 19].

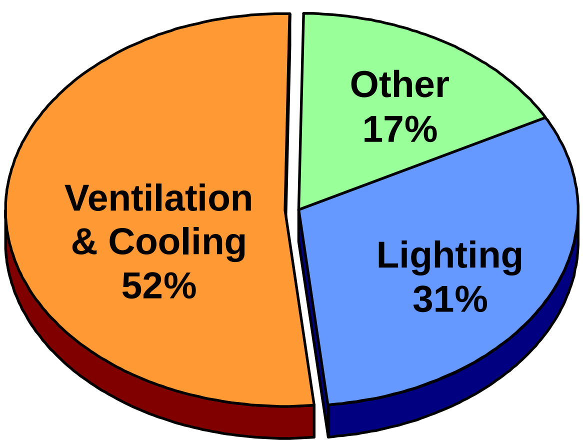

Fig. 1: Comparison of Cooling vs Electricity Consumption [6]

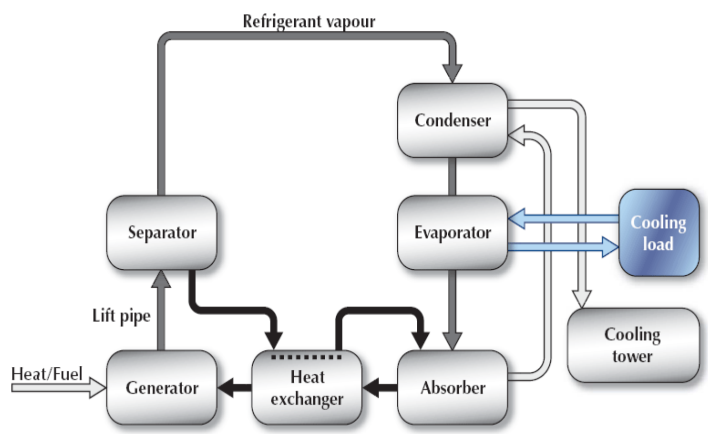

Fig. 2: Schematic Absorption Cooling System [10]

SOLAR RESOURCES OF PAKISTAN

Continuous fusion reaction takes place inside the Sun. Earth receives a small portion of the energy from sun which is equal to 1.74 x 1011 MW. On average, solar radiations of 84 minutes only can fulfill total energy demand on earth for the whole year [20]. Energy can be converted from one form to another i.e. solar energy to thermal, chemical or electrical energy. Heating systems or solar collectors have the large potential to complete world energy demand, provided they are sized correctly [21]. Pakistan is situated in the western part of the Indian subcontinent, in which, sun warms the earth’s surface, the whole year,resultantly increasing the potential for solar energy [10].

Survey Data

According to Pakistan Council of Renewable Energy Technologies (PCRET), Pakistan is in the region of world's peak solar radiations with huge solar potential. Certain regions of Baluchistan and Punjab are in the region with maximum solar radiations. The Annual Direct Normal Irradiance (DNI) vary from 7 to 7.5 KWh/m^2/day in different areas of Baluchistan and vary from 6.5 to 7 KWh/m^2/day in others. It varies from 5 to 5.5 KWh/m^2/day in Northern Sindh and South Punjab and 4.5 to 5 KWh/m^2/day in other parts of Pakistan as shown in Fig. 3 [22].

In winter day length ranges from 8 to 10 hours whereas in summer it ranges from 12 to 14 hours. Annual greater than 200 W/m^2 intensity of solar radiation was observed in many parts of the country. However, the same is not applicable to the coastal and northern regions. Average solar radiations intensity, amount of power generation depending upon the area, capacity of solar panel in different regions of the country is discussed in Ref. [2, 23,24]. Annual DNI above 5 kWh/m^2/day is ideally suitable for solar power in Southern Pakistan [24]. GHI and DNI comparison based on satellite data and ground measurements have been discussed in Ref. [15]. Seasonal solar radiation maps and energy potential of the country are presented in Ref. [24, 25, 26].

Case Study

A site selected in the city of Multan with Latitude 30° 11' 54.1716" N and Longitude 71° 28' 7.3308" E, an agricultural district of southern Punjab, Pakistan, is taken as the experimental case. The city has great potential of solar resources. Monthly average GHI, daily sunlight hour's and clearness index data were seized from NASA, meteorology database [10]. Geological statistical state and climatic and geographical data is shown in Table 1 & 2 respectively. Based on data fetched from RETScreen (NASA), the monthly average daylight hours(h) are shown in Fig. 4. GHI with clearness index for the city of Multan are plotted in Fig. 5. GHI touches highest value 6.36 kWh/m^2/day in June and lowest value of 3.19 kWh/m^2/day in December. Likewise, annual average GHI is 4.92 kWh/m^2/day.

Table 1: Geological Data Generated by RETScreen (NASA)

Parameter	Unit	Values
Longitude	°E	71.469
Latitude	°N	30.198
Frost days at site	day	0
Elevation	m	244
Cooling design temperature	°C	39.61
Earth temperature amplitude	°C	25.5
Heating design temperature	°C	5.3

Table 2: Climatic Data Generated By RETScreen (NASA) – Multan

Month	Air Temperature (°C)	Relative Humidity (%)	Daily Solar Radiation Horizontal (kWh/m^2/d)	Atmospheric Pressure (kPa)	Earth Temperature (°C)	Heating Degree Days (°C-d)	Cooling Degree Days (°C-d)	Clearness Index (0 to 1.0)
January	11.5	44.80	3.44	98.9	12.3	174	77	0.58
February	14.4	38.50	4.22	98.6	15.9	90	141	0.59
March	20.8	30.40	4.99	98.2	23.7	8	340	0.56
April	27	27.20	5.78	97.8	31.5	0	503	0.56
May	31.6	27.10	6.19	97.3	36.4	0	661	0.56
June	34.3	35.40	6.36	96.9	39.2	0	720	0.56
July	32.5	55.60	5.76	96.9	36.9	0	690	0.51
August	30.4	64.20	5.44	97.2	33.7	0	633	0.52
September	29.1	50.90	5.21	97.6	32	0	578	0.56
October	24.7	30.60	4.69	98.2	26.7	0	472	0.61
November	18.9	29.70	3.79	98.7	19.8	9	294	0.61
December	13.6	37.60	3.19	98.9	14.1	106	144	0.59

Annual	24.1	39.30	4.92	97.9	26.9	387	5253	0.57

The assumption made is a University building in Multan, Pakistan having air-conditioning load of 50TR. To make the economic analysis, a comparison between the “LiBr solar absorption chiller” and “Vapor compression chiller” systems, a numerical study have been performed to calculate the consumption of energy for SACS implemented inside the building.

I. Solar Collector

Apricus Evacuated tube solar collectors (ETC) used in Ref [20] are selected as a heat source for single effect absorption chillers to produce hot water with COP of 0.7. For the installation of collectors, available area on the building’s roof is approximately $1000m^2$. ETC can generate hot water between 75°C and 120°C. Temperature of water required by ACS is 98 °C.

3 Systems (with 30 number of tubes for 1 System) in series are required to yield desired temperature. Required flow rate and heat can be calculated as in following sub sections [20].

II. Flow Rate Calculation

Required Area (1 unit) = 6 m^2

Required Area (3 unit/ 1 system) = 18 m^2

For available Area of $1000m^2$

No of $Systems_{Installed}$ = 1000 / 18 = 56

Flow rate (for 1 system) = 1.8 m^3/hr

Flow rate (56 systems) = 1.8 x 56 = 100.8 m^3/hr

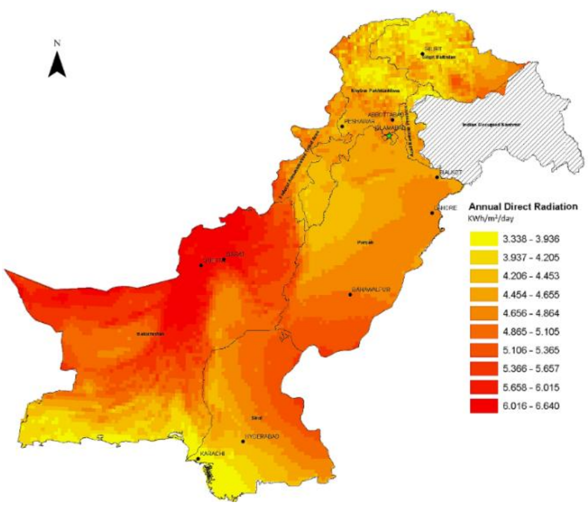

Fig. 3: Solar Irradiance Map of Pakistan [22]

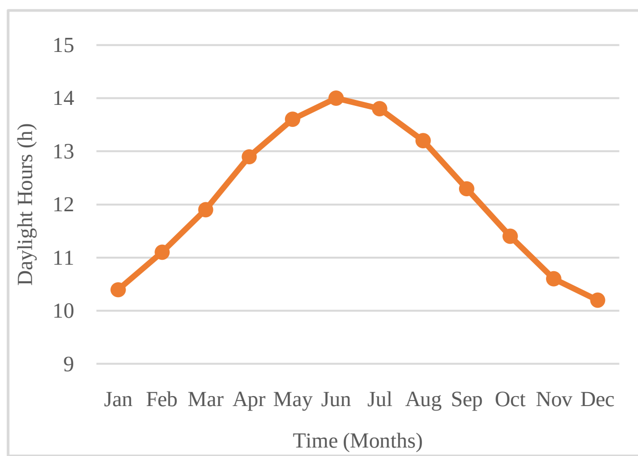

Fig. 4: Monthly averaged daylight hours – Multan

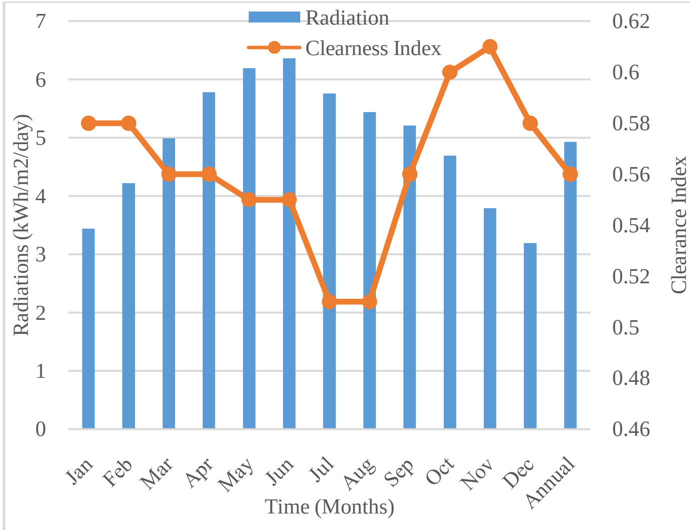

Fig. 5: Monthly averaged GHI and clearness index - Multan

III. Heat Calculation

Average DNI annually = 4.92 kWh/m^2/day.

Contour Aperture area of contour (1 Unit) = 3.979 m^2

η_{System} = 85%

Available Heat$_{Total}$ = 4.92 x 3.979 x 3 x 56 x 0.85 = 2795.55 kWh/day

IV. Chiller Selection

Water fired single effect chiller (Yazaki, WFC-SC50) of capacity of 50TR is used[27]. It can produce chilled water or hot water in comfort cool applications. The absorption cycle is initiated by a heat source (hot water), which ranges from 70^{0}C to 95^{0}C. The heat source is solar collectors and the condenser water is cooled through cooling towers [25]. Selected chiller requires 91.8 m^3/hr and 175kW for 100% operation. The calculated flow of 100.8 m^3/hr and 2795.55 kWh/day from above equations of solar collectors are adequate for operation of the chiller. Requirement of Leaving Water Temperature (LWT) and Entering Water Temperature (EWT) is shown in Table 3.

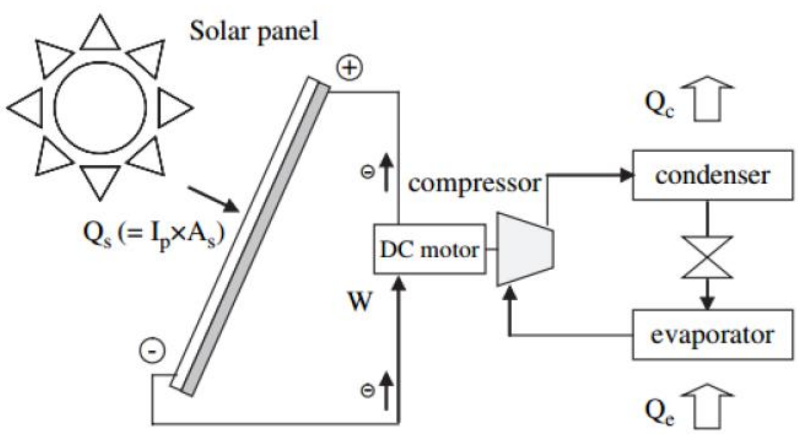

Fig. 6: Schematic Solar Electric Refrigeration System Diagram [28]

Table 3: Nominal Design Conditions for 50TR Chiller [20]

Flow Material	Flow (Litre/s)	LWT (°C)	EWT (°C)
Chilled Water	7.64	7	12.5
Condenser Water	25.5	35	31
Hot Water	12	83	88

Result and Discussion

Results of solar absorption chillers and its effect on the overall scenario of Pakistan are discussed in this section. The main purpose of solar based air-conditioning systems is to replace fossil fuel based systems and to save energy, in the context of economic viability. The renewable resources like solar energy provides an appropriate replacement to reduce energy consumption and GHG emissions. Climates like Pakistan are characterized by large cooling requirements in summer. Therefore, SACS can play a central role in energy savings.Fig. 6 shows working of a solar electric system with a traditional refrigeration cycle, able to run on hot water from solar collector (higher the heat source temperature, a higher efficiency could be achieved).

A price comparison for 25 years life have been carried out between conventional cooling and solar absorption cooling systems by using Wapda Tariff [29].

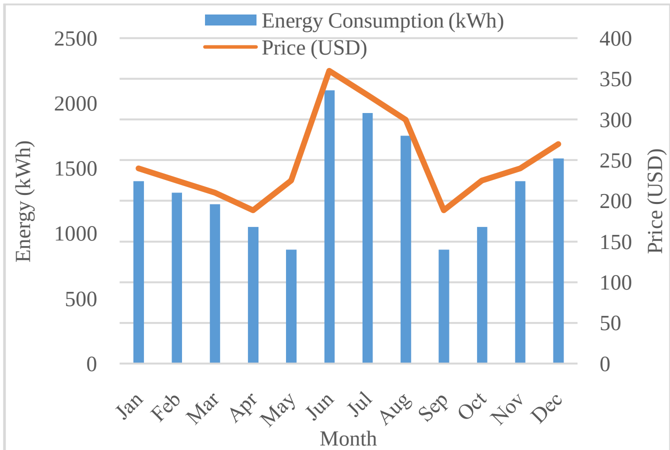

Fig. 7: Monthly Averaged Cooling Load and Energy Price

For the vapor compression based cooling of 50 TR, initial price USD: 23333/50TR and total annual energy price is approximately USD: 2985/Year.

For the solar absorption based cooling (Yazaki WFC-SC50) of 50TR, total price USD: 53467/50TR and total annual energy price is approximately USD: 53/Year.

The initial cost of SACS is 230% more than VCCS. The payback time is approximately 11 years. Average cooling / heating load plotted against price as per WapdaTerrif is shown in Fig. 7.

I. Economic Optimization

Conventional cooling systems have introduced several problems in the power system such as frequent peak demand, increased energy consumption and environmental problems. Most of industries burn hydrocarbons / fossil fuel and use thermal process to produce heat. After completion of the heat cycle, the residual heat is released to the environment as an unused heat. This unused heat can be recovered by using a heat operated system, such as an absorption refrigeration cycle. In this way, the electrical energy procured from the distributor for conventional VCCS can be reduced. A comparison of both the cooling technologies is presented in Table 4.

II. Energy Deficiency

Solar based absorption chillers are not economically viable for developing countries but can also help in reducing worst electricity shortfalls. Using the solar based absorption systems reduce the increase in energy demand of the country. In this way, not only the peak energy demands can be reduced but dependence on the natural fuel resources can also be reduced.

III. GHG Emissions

Heat operated refrigeration systems can be used to reduce GHG effect from CO_2 emission by fossil fuels combustion. To estimate direct (release of refrigerants like HFCs) and indirect (production of carbon dioxide) global warming potential of equipment Total Equivalent Warming Impact (TEWI) method is used [20].

$$TEWI = GWP_{Dir} + \text{Indirect } GWP_{Indir}$$
$$GWP_{Dir} = [GWP \times L \times n] + [GWP \times m \times (1-\alpha)]$$

Where
GWP = Global Warming Potential
L = Leakage rate per year, kg
n = System operating time, years
m = Refrigerant charge in the system, kg
α = Recycling factor

$$GWP_{Indir} = n \times E_{Annual} \times \beta$$

Where

n = System operating time, years

E_{Annual} = Energy consumption per year

β = CO_2 emission per kWh energy production, kg

The CO_2 emission for solar absorption cooling is 717 kg, whereas it is 10749 kg for conventional refrigeration system. The CO_2 emission for SACS is 7% of VCCS.

Table 4: Comparison of VCS and SAC Chillers

Constraint	**Vapour Compression System (R134a)**	**Solar Absorption Cooling (LiBr+ H_2O)**
Capacity (TR)	50	50
Life (Years)	25	25
Power Consumption	0.65 kW/TR	590 W
Initial Cost (USD)	23333	53467
CO_2 Emissions (k0.65/kWh)	10749	717

Conclusion

This proffered paper manifests an insight of the PV potential of Pakistan and an economical appraising of a Solar based Absorption Chillers System for a typical assumed location. The solar air conditioning systems are favorable not only to reduce emission of GHG but also to meet peak electricity demand, in terms of economic viability. Moreover, 100% building air-conditioning can be achieved from solar based absorption cooling systems. The excess solar energy available during the day can be stored by using a thermal energy storage tank to utilize, at night. Hybrid type solar cooling systems can be designed for the future. Recovery or process heat can be used as the heat source in absorption systems for lowering the temperature in industries. Number of effects can be increased to improve overall COP of the ACS.

The payback period of SACS depends upon peak electric demand charges, and available solar radiations. The payback period shall be considerably shorter due to expected rise in fuel and electricity rates in future.

Furthermore, absorption cooling shall become a reliable and low-cost solution with energy efficiency standards applied to industries, further research on the SACS and bulk production of solar cooling equipment.

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