

Design and Performance Analysis of Solar Powered Absorption Cooling System for Computer Laboratory

Khagendra Kumar Upman^a, B.L.Gupta^{b*}, Dhananjay Kumar^c, Prashant Kumar Baheti^d

^{a,c}Apex Institute of Engineering and Technology Jaipur 302017 India.

^bDepartment of Mechanical Engineering, Govt. Engineering College Bharatpur 321001 India.

^dDepartment of Computer Science and Engineering, Govt. Engineering College Bharatpur 321001 India.

Abstract: This study covers the performance analysis of solar thermal cooling system for a computer lab situated in Government Engineering College Bharatpur using Flat Plate Collector, Evacuated Tube Collector and Compound Parabolic Collector. The computer lab has the floor and roof area 198.55 m². The peak cooling load is calculated and it is 34.940 kW, accordingly 10TR vapor absorption cooling system was adopted. The 10 TR vapour absorption system was operated by a field of collector area varying from 80-120 m². The other parameters like hot storage tank, cold storage tank, pump, cooling tower etc are used. The simulation was carried out on TRANSOL Program for Bharatpur city situated in east of Rajasthan (INDIA). Parametric study and performance analysis of solar thermal cooling system has been carried out, considering the annual solar fraction, primary energy savings and electrical (grid) COP. It can be conclude that solar thermal cooling system is technically feasible because it offers good solar fraction in the range of 0.52-0.75 in the considered city and collector areas. The primary energy savings reaches up to 52%. In the solar thermal cooling system as the collector area increases the solar fraction also gets increased but after an optimum collector area it starts decreasing because at elevated temperature heat losses are also higher. If we use a high collector area then we have to increase either the capacity of storage tank or the cooling demand of the building otherwise there will be no effect of collector area after an optimum value. The highest solar fraction has been observed as 0.63, 0.72, and 0.75 for FPC/ETC/CPC for the collector area range in 80-120 m².

Keywords: Vapor Absorption system, Solar Thermal Collector, Solar Fraction, Primary Energy

1. Introduction

To improve the thermal comfort conditions, particularly in the summer season, there is growing demand of

conventional vapour compression air conditioners. This growing demand not only increases electricity consumption but also global warming. Building architectural characteristics and trends like increasing ratio of transparent to opaque surfaces in the building envelope to even popular glass buildings has also significantly increased the thermal load on the air conditioners [Henning 2007]. The conventional vapour compression refrigeration cycle driven air conditioner using grid electricity, increases the consumption of electricity and fossil energy. Energy sources based on fossil fuels such as coal, oil, gas, nuclear, etc., are cause serious environmental hazards and are scarce in nature, location and volume. To reduce environmental pollution and global warming in Balghouthi et al. [2005] suggested the solar power air conditioning in place of conventional vapour compression air conditioning systems. Assilzadeh et al. (2005) carried out the modeling and simulation of absorption solar cooling system with TRNSYS program. In this paper a 3.5 kW (one ton refrigeration) system was simulated by using a typical metrological year file containing the weather parameters for Malaysia. The optimized system consists of 35 m² evacuated tubes solar collector at 20°. They suggested that in order to achieve the continuous operation of the generator and increase in the reliability of the system, a hot water storage tank is essential for high quality performance. Pongtornkulpanich et al. (2008) share the experience with fully operational solar driven 10 ton LiBr/H₂O single effect absorption cooling system in Thailand. They analyzed the data collected during 2006 and show that 72 m² evacuated tube solar collector delivered a yearly average solar fraction of 81%, while LPG -fired backup unit supplied the 19% thermal energy. They show that the initial cost of installation is higher than that of the conventional vapour compression system due to higher cost of solar collector array and chiller. Technology advancement, large production, and increase in price of electricity in future can make it more cost competitive with the conventional

system. Mateus et al. (2009) performed the energy and economic analysis of an integrated solar absorption cooling and heating system in three different location and climates. An office building, a hotel and a single family house were used for analysis and it was found that with the present energy cost, the solar integrated system is not justifiable in any location, using economical consideration only. Annual solar fraction is achieved 20-60% and compare to the flat plate collectors, vacuum tube collectors allow a reduction in collector area between 15 and 50 %. Eicker et al. (2009) develops a full simulation model for absorption cooling systems, combined with a stratified storage tank, dynamic collector model and hourly building loads. They found that depending on control strategy, location and cooling load time series, between 1.7 and 3.6 m² vacuum tube collector per kW cooling load are required to cover 80% of the cooling load. Tsoutsos et al. (2010) take for granted that the air conditioning is responsible for a large percentage of the greenhouse and ozone depletion effects. They suggest the solar cooling system for zero emission technologies and to reduce energy consumption and CO₂ emission. In this paper a study is carried out to simulate the solar absorption cooling system for a Greek hospital that required 123911 kWh annual cooling energy. The peak power of cooling was 121 kW and to meet this 70 kW absorption and 50 kW compression chillers were used. They find out that 200 m² solar thermal collector area is not suitable for this application and solar fraction of 74.23% is achieved with the 500m² collector area. Y Hang et al. (2011) carried out economical and environmental assessment of an optimized solar cooling system for a medium sized benchmark office building in Los Angeles (California) having the floor area 4983 m². In this building 150 kW capacity absorption chiller was used with varying collector area of 80-490 m². The Payback is calculated as 13.8 years when the 40% subsidy is provided on capital investment.

Renato M. Lazzarin (2013) analyzed the solar thermal cooling system with the flat plate, evacuated tube collector and parabolic trough collectors with tracking system. The system are evaluated during sunny days and compared with the PV driven system and found that the PV driven system is now quite comparable. Eicker et al. (2014) performed the primary energy analysis and economic evaluation of solar thermal cooling and solar photovoltaic cooling system, the comparison is made for three different climates corresponding to the Palermo, Madrid and Stuttgart. The same building area and geometry was used

with a different user profiles and construction properties, consequently different cooling loads, in total 12 cases are taken into consideration. The primary energy savings reaches 50% with photovoltaic cooling systems while in the case of solar thermal system relative primary energy savings reaches 37% in Palermo, 36% in Madrid and 29% in the Stuttgart. Various literature conclude that the primary energy saving and, economic analysis are different for different climates, countries and electric prices. In the present work parametric study and performance analysis of solar thermal cooling systems has been performed considering the annual solar fraction and relative primary energy savings. In the solar thermal cooling system, three types of collectors (FPC, ETC and CPC) with wide variance of area ranging from 80 m²-120 m² have been considered.

2 Specification of Building Coupled with Solar Air Conditioning.

The building being used in this research work is a computer lab situated in Government engineering college, Bharatpur rectangular shape building with envelope of 15.69 m length and 12.65 m width. The height of the building is 3.64 m and total floor area is 198.55 m². The entire building is used for laboratory purpose in day time only and whole area is conditioned. The detail dimension of building is given as follows:

1. Length of building = 15.690 m
2. Width of building = 12.655 m
3. Height of building = 3.64 m
4. Dimensions of 5 south wall glass windows = 1.65 × 1.5 m
5. Dimensions of 5 west wall glass windows = 1.65 × 1.5 m
6. Dimension of north wall door = 2.55 × 1.5 m
7. Dimension of north wall door = 2.52 × 0.92 m

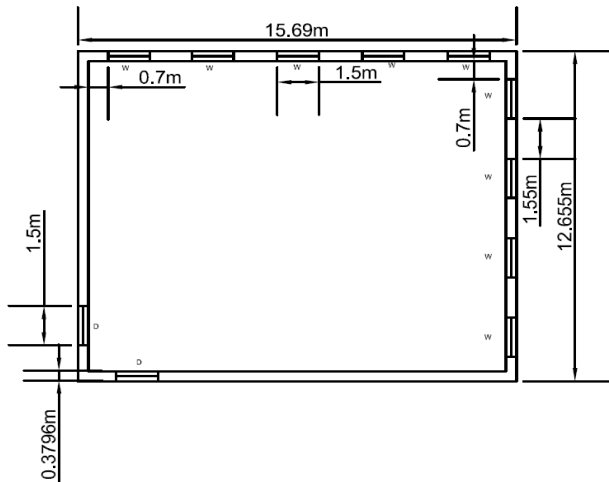


Fig.1 Computer lab of Govt. Engg. College Bharatpur (Top view)

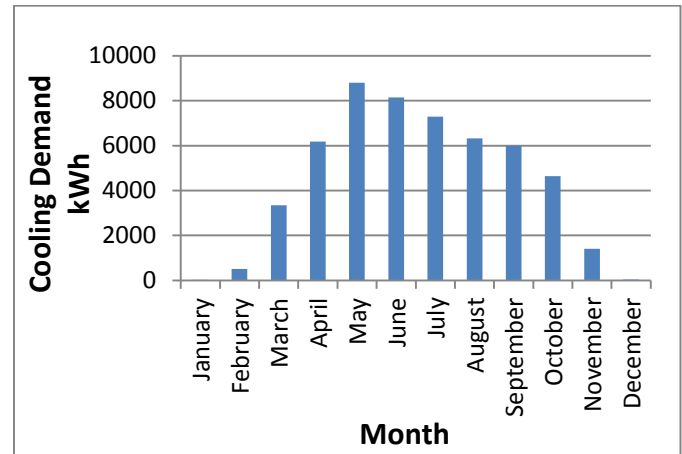


Fig. 2 Annual Cooling Demand

Table 1 Climatic condition of Bharatur City

S.No.	City Parameters	Bharatpur
1	Climate Zone	Hot and Dry
2	Latitude °N	27.2170
3	Longitude °E	77.4895
4	Elevation (m)	183
5	Maximum Temp.(C)	41.6
6	Average RH (%)	55

3. Building Cooling Demand Analysis

After the maximum cooling load of the building was calculated the model of solar thermal cooling system was made in the TRANSOL software and selecting the appropriate input data and parameters. Fig.2 shows the annual cooling demand of simulated case and it has been observed that the annual cooling demand is high for Bharatpur city because of the high ambient temperature. The cooling demand is high in the months of May, June and July because the temperature is increased in the month of May, June and July.

4 Solar Thermal Cooling Systems

This system is simulated using a configuration SCH 601 from the program as shown in the fig 3. This configuration shows the complete heating, cooling and domestic hot water application. In this study only cooling is considered for analysis purpose. The solar thermal cooling system is composed of a solar collector field, solar storage tank, heat exchanger, cold storage tank and vapour absorption chiller. The solar collector field captures energy from the sun and exchanges it with the solar storage tank through an external heat exchanger. Two pumps are used in the solar collector loop, one is from solar collector to heat exchanger and another is from heat exchanger to solar storage tank. These pumps are known as primary and secondary pump respectively and operated by solar loop control depending on solar radiation intensity. The pump flow rate is constant. The system stops the pumps if the temperature in the solar storage tank exceeds the maximum security value. A vapour absorption machine (VAM) is directly connected to the solar storage tank, this machine is turned on when cooling is required and the temperature of the solar tank is over a set point temperature [Bongs, 2009]. The heat coming from the absorber and condenser is released by cooling tower controlled by a variable frequency drive that increases

energy efficiency and reduces electrical energy consumption. The cold water coming out from the evaporator of vapour absorption machine is stored in the

cold storage tank. An electrically operated compression cooling machine is used as a backup in order to cover complete cooling demand of the building. This compression cooling machine is operated when there is need for cooling and the temperature of the cold storage tank is below than the specified set point temperature.

Table 2: Parameters considered for simulation of solar thermal cooling system

Component	Parameter	Value	Source
Solar Collector	Surface Area m ²	80-120 m ²	Henning 2007
Solar Heat Exchanger	Thermal transfer coefficient	11 kW/K	Eicker et al. 2014
Solar Storage	Type	Vertical	
	Volume	5000 ltr	
Thermal Chiller	Type	Absorption	Mateous et.al 2009
	Nominal Cooling power	35 kW	
	Nominal COP	0.7	
	Pump power	210 W	
Cold Storage Tank	Type	Vertical	Eicker et al. 2014
	Volume	1000 ltr	
Compression Chiller	Nominal cooling power	10.5 kW (Back up)	
	Nominal COP	3.5	
Cooling Tower	Nominal Power	75 kW	Advances Cooling Tower Pvt Ltd. Mumbai.

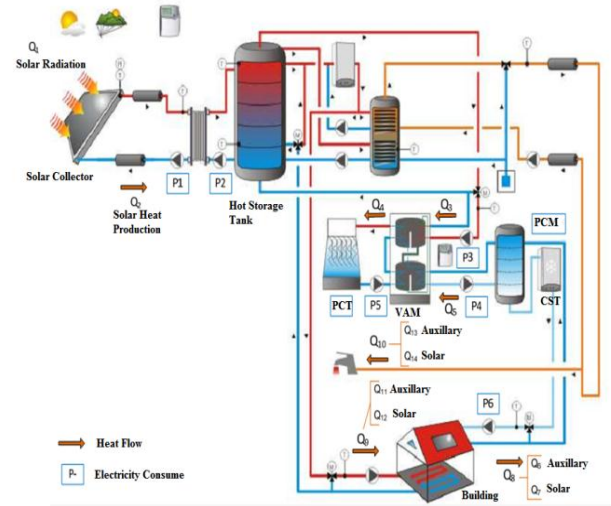


Fig.3: Schematic of solar thermal cooling system [TRANSOL]

5 Solar Fraction

It is the ratio of the annual cooling effect produced by the solar to the total annual cooling demand of the building.

$$\text{Solar Fraction} = \frac{\text{Annual cooling effect produced by solar absorption chiller}(kWh_{th})}{\text{Annual coling demand of building}(kWh_{th})}$$

Fig 4 shows the variation of solar fraction for various collector area of FPC, ETC and CPC. It is clear from the fig 4 that in FPC, as the collector area increases the solar fraction also increases because more heat is collected by the collector and supplied to the solar thermal cooling system that produce the more amount of solar cooling. At small collector area of 80 m² the annual heat production is low for Bharatpur city and solar thermal cooling system produce the low amount of cooling If the collector area is increased from 80 m² to 120 m² the solar fraction increases from 52 % to 63 %..In the solar thermal cooling system when ETC type collector is used than as the area of collector is increased then the solar fraction is also increase but after an optimum collector area it starts constant because the elevated temperature heat losses are also higher. If we utilize a high collector area then we have to increase either the capacity of storage tank or the cooling demand of the building otherwise there will be no effect of collector area after an optimum value. The solar fraction has been observed as 0.71, 0.71, 0.72, 0.72, and

0.72 for the area of 80m², 90 m², 100 m², 110 m² and 120m² for the Bharatpur city. The solar fraction has been observed for CPC as 0.74, 0.75, 0.75, 0.75, and 0.75 for the area of 80m², 90 m², 100 m², 110 m² and 120m² for the Bharatpur city.

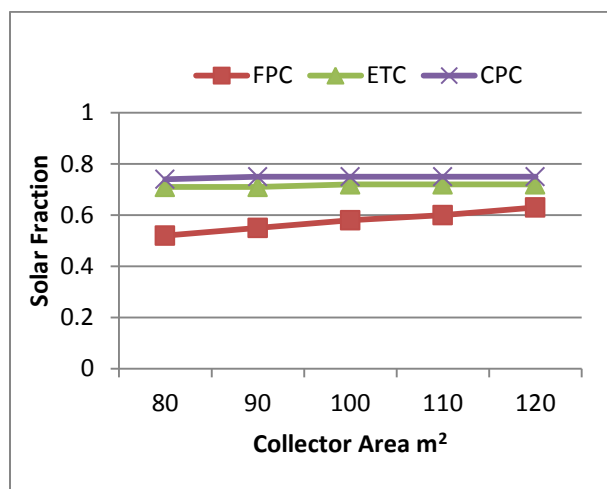


Fig 4 Solar fraction for different areas

6. Primary Energy Savings

Primary energy consumption is calculated from energy consumption of the cooling systems by dividing it to the conversion factor 0.36 [Eicker et al.]. In the solar thermal cooling system the electrical energy is consumed by pumps, controls and electrical chiller used as a backup. In the solar photovoltaic cooling system the electrical consumption is done by the compressor, condenser fan and blower. The primary energy savings is the difference between the primary energy consumption by the solar thermal cooling system and the primary energy consumption by the compression based cooling system operated by grid power.

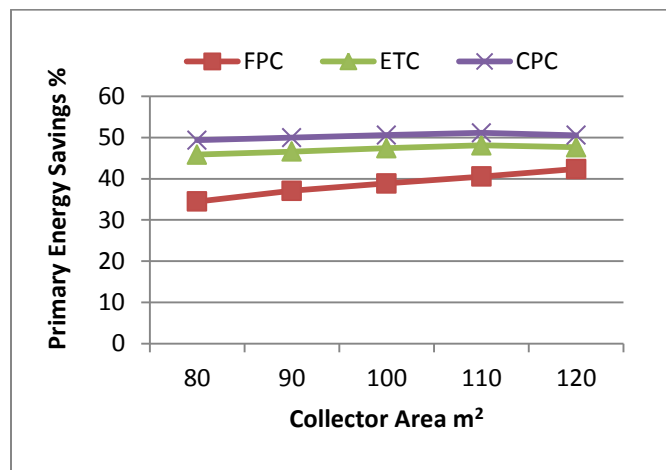


Fig. 5 Relative primary energy savings for different areas

Fig.5 shows the relative primary energy savings for the different areas. It has been observed that increased the collector area, relative primary energy savings is increased. In this study we found that for flat plate collector growth in primary energy savings due to increased area of collector. The relative primary energy savings reaches up to 42% for the collector area ranging 80- 120 m². It has been observed that increased the collector area, relative primary energy savings is increased. But an optimum collector area the relative primary energy saving is decrease. At high collector area the collected heat is increased in all the type of collector but in the case of ETC and CPC the heat losses also increase, so with the increase in the collector area the increment in the primary energy savings are higher for the FPC and lower for the ETC and CPC. In the ETC and CPC after an optimum collector area the primary energy savings gets decreased. For the same cooling machine type, capacity and building cooling load increase in collector area does not produce much effect in case of primary energy savings. The highest primary energy savings is 51.13% for CPC, 48.1% for ETC, 42.34% for FPC.

7. Conclusions

Technical feasibility of solar thermal cooling system is evaluated based on the basis of solar fraction and primary energy savings.

7.1 Solar Fraction

- The solar fraction is highest for the CPC type collector and lowest for the FPC.
- It has been observed that for flat plate collectors the highest solar fraction occurs at 120 m² collector area, in the case of ETC highest solar fraction is at collector area of 100 m², In the case of CPC highest solar fraction occurs at 100m².
- In the solar thermal cooling system as the collector area increases the solar fraction also gets increased but after an optimum collector area it starts decreasing because at elevated temperature heat losses are also higher. If we use a high collector area then we have to increase either the capacity of storage tank or the cooling demand of the building otherwise there will be no effect of collector area after an optimum value. The highest solar fraction has been observed as 0.63, 0.72, 0.73 for FPC/ETC/CPC for the collector area range in 80-120 m².

7.2 Primary Energy Savings

- In the solar thermal cooling system the highest primary energy saving is highest for CPC 49-52 % and lowest for the FPC 34-42%. It is between 45-48 % for ETC. The primary energy savings are highest for CPC and the primary energy savings are lowest for the FPC
- Among the three types of collectors CPC has the higher primary energy savings.
- At high collector area the collected heat is increased in all the type of collector but in the case of ETC and CPC the heat losses also increase, so with the increase in the collector area the increment in the primary energy savings are higher for the FPC and lower for the ETC and CPC. In the ETC and CPC after an optimum collector area the primary energy savings gets decreased. For the same cooling machine type, capacity and building cooling load increase in collector area does not produce much effect in case of

primary energy savings. The highest primary energy savings is 51.13% for CPC, 48.1% for ETC, 42.34% for FPC.

8. References

1. Advances Cooling Tower Pvt Ltd. Mumbai 2014 "Quotation for supplying the cooling tower" at Government Engineering College Bharatpur (Raj.) India.
2. Assilzadeh F., Kalogirou S. A., Alia Y., Sopiana K., 2005 "Simulation and optimization of a LiBr solar absorption cooling system with evacuated tube collectors" Renewable Energy Vol.30., pp. 1143-1159.
3. Balghouthi M., Chahbani M. H., Guizani A., 2005 "Solar powered air conditioning as a solution to reduce environmental pollution in Tunisia" Desalination Vol. 185, pp.105-110.
4. Bongs C. 2009 "Benchmarks for comparison of system simulation tools - Absorption chiller simulation comparison" A technical report of subtask C, Task 38 Solar Air-Conditioning and Refrigeration.
5. Eicker U., Colmenar-Santos A., Teran L., Cotrado M. 2014 "Economic evaluation of solar thermal and photovoltaic cooling systems through simulation in different climatic conditions: An analysis in three different cities in Europe" Energy and Buildings, Vol. 70, pp. 207-223.
6. Eicker U., Pietruschka D. 2009 "Design and performance of solar powered absorption cooling systems in office buildings" Energy and Building, Vol. 41, pp. 81-91.
7. Energy Conservation Building Code (ECBC) User Guide, Bureau of Energy Efficiency (2007).
8. Enibe S.O. 1997 "Solar refrigeration for rural applications" J Renew Energy, Vol. 12, pp. 157-67.
9. Fan Y., Luo L., Souyri B. 2007 "Review of solar sorption refrigeration technologies: Development and applications" Renewable &

- Sustainable Energy Reviews, Vol. 11, issue 8, pp. 1758-1775.
10. Hammad M.A., Audi M.S. 1992 "Performance of a Solar LiBr-Water absorption refrigeration system" Renewable Energy, Vol. 2, No. 3, pp. 275 -282.
 11. Hang Y., Qu M., Zhao Fu. 2011 "Economical and environmental assessment of an optimized solar cooling system for a medium-sized benchmark office building in Los Angeles, California" Renewable Energy, Vol. 36, pp. 648-658.
 12. Hartmann N., Glueck C. Schmidt F.P 2011 "Solar cooling for small office buildings: Comparison of solar thermal and photovoltaic option for two different European Climates." Renewable Energy, Vol. 36, pp. 1329-1338.
 13. Henning H.M. 2007 "Solar assisted air conditioning of buildings – an overview" Applied Thermal Engineering, vol. 27 pp. 1734–1749.
 14. Kim D.S., Infante Ferreira C.A. 2008 "Solar refrigeration options – a state-of-the-art review" Int. Journal of Refrigeration, Vol. 31, pp. 3–15.
 15. Lazzarin R.M. 2014 "Solar cooling: PV or thermal? A thermodynamic and economical analysis" Int.Journal of Refrigeration, Vol.39, pp. 38-47.
 16. Mateus T., Oliveira A.C. 2009 "Energy and economic analysis of an integrated solar absorption cooling and heating system in different building types and climates" Applied energy, Vol. 86, pp. 949-957.
 17. Mazloumi M., Naghashzadegan M., Javaherdeh K. 2008 "Simulation of solar lithium bromide –water absorption cooling system with parabolic trough collector" Energy Conversion and Management, Vol. 49, pp. 2820-2832.
 18. Pongtornkulpanich A., Thepa S., Amornkitbamrung M., Butcher C., 2008 "Experience with fully operational solar driven 10-ton LiBr/H₂O single effect absorption cooling system in Thailand" Renewable energy Vol. 33, pp. 943-949.
 19. TRANSOL, <http://aiguasol.coop/en/transol-solar-thermal-energy-software/> (accessed June 2017).
 20. Tsoutsos T., Aloumpi E., Gkouskos Z., Karagiorgas M. 2010 "Design of a solar absorption cooling system in a Greek hospital" Energy and Building, Vol. 42, pp. 265-272.