Comfort Cooling Application Using Fixed Focus Solar Parabolic Dish Concentrator Integrated with Double Effect Vapor Absorption Machine

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Abstract - *Comfort cooling using solar energy can be done using two types of technologies viz; vapor compression machines (VCM) operating on electricity and vapor absorption machine (VAM) operating on thermal heat. Both technologies are used in industrial process and commercial establishments. In present article, the utilization of solar thermal energy for cooling purpose in commercial and industrial establishments has been discussed. A complete case study based on integration of solar thermal energy system for cooling with the existing system has been studied along with its performance evaluation.* Among the *various available solar thermal technologies, Scheffler dish technology has been used for generation of heat required for operating VAM. The existing electrical VCM system acts as a backup during non-sunny hours. The Scheffler dish technology can generate required heat for double effect lithium-Bromide (Li-Br) vapor absorption machine. The size of solar installation and VAM capacity can be decided depending on the available area and the required cooling load. The annual saving of approximately 1,20,000 units of electricity and reduction of 113 Metric Tons of CO_2 emission was achieved using 320 m^2 of Scheffler dish collector area with a payback period of 6-7 years. The present case study revealed that the solar thermal cooling based vapor absorption machine can be seamlessly integrated with the existing electrical chillers for comfort cooling applications.*

Key Words: **Parabolic dish concentrator, Scheffler dish, Solar cooling technologies, Solar thermal energy, Vapour absorption machine.**

1. INTRODUCTION

Comfort cooling consumes about 30 % of electricity in India which is produced largely from fossil fuels. Solar thermal technology can be used for industrial process heat application as well as it can meet the cooling demands at various sectors. Cooling is used for various applications like space cooling or comfort cooling, industrial process cooling, cold storages, in public health centres for vaccine storage, deep freezing etc. The increased use of refrigeration and air conditioning has created huge demand for electricity and is expected to go up substantially due to global warming and improved lifestyle in India.

Most of the industrial and commercial installations make use of central chillers to meet their cooling demands. These central chillers use either electricity or thermal heat as energy source. The use of solar thermal technology in vapour absorption machines can minimize the use of electricity and reduce excessive use of fossil fuels. India is blessed with abundant solar radiation throughout the year at most of its parts. The requirement of cooling is maximum during the day time when the solar energy is also available at its peak.

A variety of cooling technologies and solar collector technologies have been developed which can be integrated with the existing conventional thermal driven cooling systems. Solar cooling technologies such as vapor compression machines (VCMs), vapor absorption machines (VAMs), vapor jet or ejector cooling system, open cycle desiccant cooling system etc. are commercially available. The electricity driven VCM is widely used. However, in India electricity is either not available all the time or it is very expensive and are forced to use diesel to run DG sets for running the ACs. The VAM can be operated on heat generated by solar thermal technology [1]. The type of solar thermal technology can be chosen depending on the temperature requirement of VAM. The VAM can be single effect, double effect or triple effect. The former require lowest temperature while later is most efficient. Single effect VAM requires a temperature of ~ 80 ^{0}C. For double and triple effect VAM, the temperature requirement is ~ 140 ^{0}C and 180 ^{0}C, respectively. The electricity driven VCM is widely used. However, VAM operating on solar thermal technologies are finding good acceptance in the country [2]. The VCM operating on electricity generated by solar PV technology can be an alternative. However, in India, the solar thermal based cooling systems are most appropriate and a feasible solution for cooling applications.

Solar thermal systems based on concentrating solar technologies (CSTs) are more suitable especially in industrial and commercial installations compared to flat plate collector (FPC) based systems. The CST can provide heat at high temperature to operate VAMs at higher efficiency. With this motivation we have carried out a complete performance and commercial evaluation of CST based cooling system in an industrial establishment in northern India. Herein, Scheffler dish based technology has been used for generation of heat required for operation of double effect Li-Br vapor absorption machine. The observed performance and commercial evaluation analysis revealed that the VAM integrated with Scheffler dish based CST can be a viable solution to obtain industrial solar thermal cooling in India to reduce the use of fossil fuels and to save the electricity.

1.1 Solar Cooling Technologies

Various solar cooling technologies are commercially available which include vapor compression machines

(VCMs), vapor absorption machines (VAMs), vapor jet or ejector cooling system, open cycle desiccant cooling system etc. Commercially available VCMs and VAMs can be operated on solar energy.

1.2 Vapor Absorption Machine (VAM)

The basic principle of working of VAM is based on the absolute pressure that decides the boiling point of water. At 1 bar, water boils at 100 ^{0}C. When the pressure is lowered it boils at a lower temperature. The boiling point of water at 6 mm of Hg is ~ 3.7 ^{0}C. The lithium bromide (LiBr) salt solution is commonly used as an absorbent in LiBr:H_2O cycle of VAMs. The LiBr is hygroscopic in nature and has a strong affinity towards water. This property is directly proportional to solution concentration and inversely proportional to its temperature. Pure water is used as a refrigerant in LiBr VAMs. A general schematic of working of VAM is shown in figure (1) [3]. The four major components of LiBr VAMs are described below.

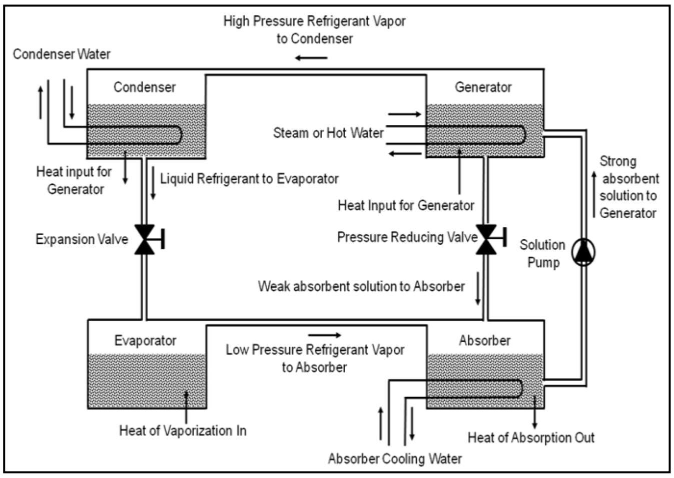

Fig 1- Schematic of working of vapor absorption machine showing four major components.

1.2.1 Evaporator

Water from the condenser comes down into the lower shell, which is at a much lower pressure than the condenser. In fact, the lower shell is at a very high vacuum, the absolute pressure being ~ 6 mm of Hg. When the water from condenser enters the lower shell, a part of it flashes, vaporizes and the balance water gets cooled down to its saturation temperature 3.7 ^{0}C. The water available at 3.7 ^{0}C can be used as the refrigerant. It is sprayed over the tubes containing water to be chilled. The refrigerant water at its saturation temperature picks up its latent heat of vaporization from higher temperature water across the tubes and vaporizes. In the process, water within the tubes gets chilled to the desired temperature and is then available for end use.

1.2.2 Absorber

The absorber is used to maintain the pressure of the evaporator in the vacuum by absorbing the refrigerant vapor evaporated in the evaporator. The refrigerant vapor from the evaporator is drawn into absorber vessel containing the absorbent solution. The vapor gets absorbed into the absorbent, due to its strong affinity for the refrigerant. The cooling water flowing through the cooling coils within the absorber absorbs the heat from the evaporator and some of the residual heat from the concentrated solution. This heat is dissipated through the cooling tower. When the refrigerant vapors are absorbed, a vacuum is created which allows the refrigerant from the condenser to expand into the evaporator causing the refrigerating effect.

1.2.3 Generator

In this heat exchanger, dilute LiBr solution on the shell side is heated up by a heat source for example hot flue gas or steam or Jacket (HT) water within the tubes. In case of availability of solar energy either hot water or steam can be used. Due to heating, water boils out as water vapor and the dilute solution becomes concentrated. Eliminators are provided at the top of the generator to prevent carry-over of LiBr droplets with water vapor. Steam on losing heat to the LiBr solution comes out of the tubes as hot condensate.

1.2.4 Condenser

The water vapor generated in the generator comes to the shell side of the condenser where it condenses over the cooling water tubes. Water thus formed collects in the bottom of the condenser. The dilute solution is separated out into two parts, water and concentrated LiBr solution.

1.3 Concentrating Solar Thermal (CST) Technologies

The concentrating solar thermal (CST) technologies can generate hot water or steam at various temperatures and pressures, depending on the degree of concentration of solar energy. The CST is a device which can concentrate solar radiation using mirrors/lenses, resulting in temperatures in the range of 100 ^{0}C to 450 ^{0}C or even more. These devices need tracking so as to focus sun rays on a receiver all the time. Solar energy is received in direct and diffused form and CST harvests the direct normal radiation. The only exception is non-imaging concentrator, also called as compound parabolic concentrator (CPC) which uses direct and diffuse radiation. The CST systems are used for medium and high temperatures for various applications in industries, commercial establishments and institutions. Various concentrating solar thermal technologies are available and can be deployed depending on temperature range required for the process [1-4, 6], some of them are mentioned in figure 2.

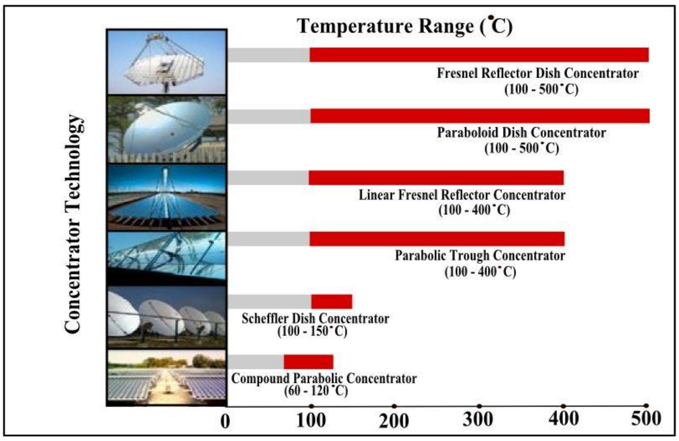

Fig-2: Temperature ranges of different CST technologies.

1.4 Solar Parabolic Dish Concentrator

The solar collectors field consists of solar parabolic concentrators, receivers, automated tracking system, balance of system (BOS) including header pipe, steam drums, control mechanism etc. The heat generated is transferred from the receiver to the water flowing through it. The solar parabolic concentrators are tracked automatically to keep the focus fixed at the point of receiver.

Working Principle of Scheffler Dish:

A schematic of Scheffler dish is shown in fig. 3 [6]. It is a small lateral section of a large paraboloid and has an elliptical shape. The main components of Scheffler dish are reflector support frame, reflectors, receiver and tracking mechanism.

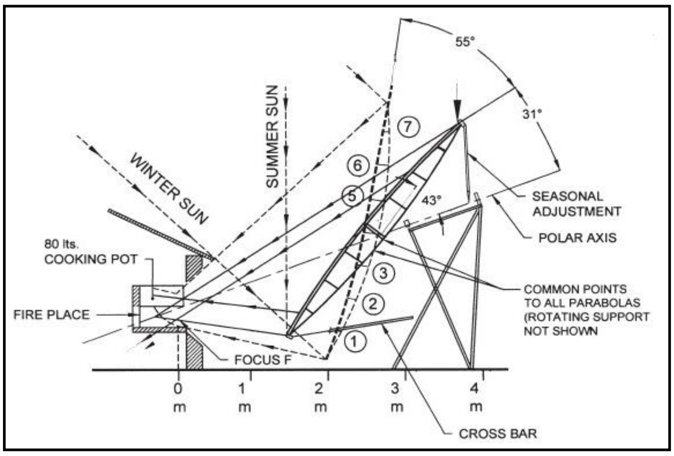

Fig-3: Schematic of Scheffler dish concentrator

The solar radiation incident on the reflector area is concentrated at a fixed focus where receiver is placed. The axis of dish rotation is in the north south direction which is parallel to earth's axis of rotation. As the earth spins around an axis through the north-south pole, the Scheffler reflector spins around an axis parallel to polar axis in the opposite direction [5]. The heat is transferred to the fluid flowing through the receiver which is then used at the application. The peak operating temperature achieved using Scheffler dish is around 150 ^{0}C [4].

2. SOLAR THERMAL COOLING IMPLEMENTATION

Table 1 below gives the overview of the solar installation at an auto ancillary in north India for cooling application.

Table 1: Overview of the solar installation for cooling application

Installation	An Auto Ancillary in North India
Latitude	28.3543° N
Application	Comfort Cooling
Solar Thermal Technology Used	Parabolic solar concentrator (Scheffler) dish
Size and No. of concentrators installed	16 m^2 and 20 Nos.
Solar collector Area of installation	320 m^2
Solar Project Cost	74,00,000/-
Design Cooling Output	30TR (105.9 kW)
Year of commissioning of the system	2010
Earlier arrangement and reason for installation	Electric chillers, Electricity saving
Whether standalone system or integrated	Integrated
Operating temperature of chiller	130 to 150 ^{0}C
Electricity saved in a year	119791 kWh

2.1 Design of Hybrid System

An auto ancillary company in north India decided to utilize solar energy for meeting its heating, ventilation and air conditioning (HVAC) requirement. The total roof top area available for the utilization of solar energy was 700 sq m and it was estimated that ~ 30 TR of solar cooling could be achieved with the available area. It is estimated that the peak HVAC load for the building for HVAC is 110 TR. To meet the HVAC requirement , one 110 TR electrical chiller for the peak demand without any interruptions and solar cooling system with 20 solar concentrators and 30 TR VAM was installed as integrated electric-solar thermal hybrid cooling system.

2.2 Solar Energy for HVAC

Objective of the solar cooling plant was to save electric energy drawn from the state power grid and utilization of solar energy available on the roof top. The purpose of utilization of solar energy is two-fold; first using solar concentrators the heated water can be used by the VAM to produce the required chilled water during summer and second it can be circulated through air handling units (AHU) for providing comfort conditions, during winter period.

Hot water at 140 ^{0}C can be generated using solar thermal system. It consists of solar parabolic concentrators with mirrors as reflector, receiver to receive concentrated solar rays to heat water, water circulation system, and automatic sun tracking system, valves and controls. The parabolic concentrators focus solar radiation on receiver and generate hot water. These concentrators track the Sun's path from morning to evening and the focus is fixed on the receiver. The receivers are connected to the VAM for hot water supply and return back from VAM to solar thermal system.

The hot water circuit is pressurized through N_2 blanketing in the expansion tank. The hot water then pumped to the double-effect VAM. The outlet water from the VAM is returned to the solar concentrators. The VAM generates chilled water of 7 ^{0}C. This chilled water shall be circulated through cooling coils in the AHUs, over which air will flow. In this process, air will be cooled and used for office air-conditioning whereas chilled water temperature increases to 12 ^{0}C at AHU and returned to the VAM. The balance cooling load is met with the electrical chillers. These chillers also cater to the air-conditioning requirement during the initial hours of the day or when enough solar radiation will not be available. Thus, an integrated electrical chiller in parallel with the VAM caters to the air-conditioning load even during cloudy/unfavorable local weather conditions. The control logic will allow the operation of electrical chiller only when there is a shortfall in the solar thermal energy. This integrated system offers the advantage of optimized use of electricity and maximized clean and renewable energy use, while meeting the required cooling load at any time.

Table 2: Technical Parameters of VAM

Description	Units	Value
A) Chilled Water Circuit		
Capacity (± 3%)	TR	30
Chilled water flow	M^3/hr	18.1
Chilled water inlet temperature	^{0}C	12.0
Chilled water outlet temperature	^{0}C	7.0
B) Cooling Tower Water Circuit		
Cooling water flow rate	M^3/hr	56
Cooling water inlet temperature	^{0}C	32.0
Cooling water outlet temperature	^{0}C	35.0
C) VAM Hot Water Circuit		
Hot water consumption	M^3/hr	16.5
Hot water inlet temperature	^{0}C	140
Hot water outlet temperature	^{0}C	135
D) Tube Material of Construction		
Evaporator		Copper(Finned)
Absorber		Cupro Nickel (Mini finned)
Condenser		Cupro Nickel (Plain)
Generator		AISI 430 Ti

2.3 Scheme Implemented

A schematic of the solar installation is shown in figure 4 and figure 5 is actual photograph of solar field.

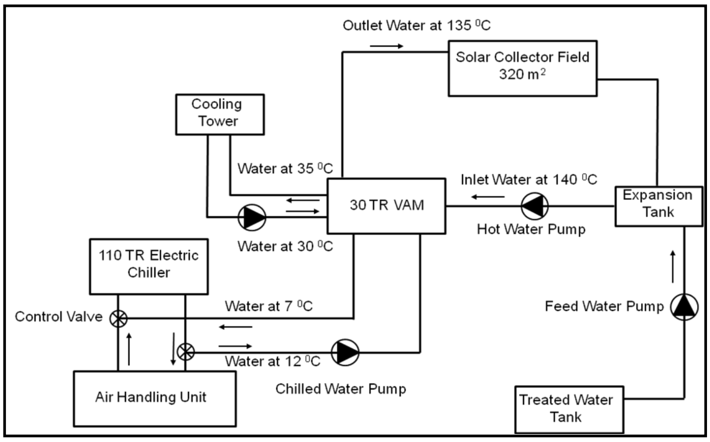

Fig -4: Schematic of the solar installation for an auto ancillary company in north India.

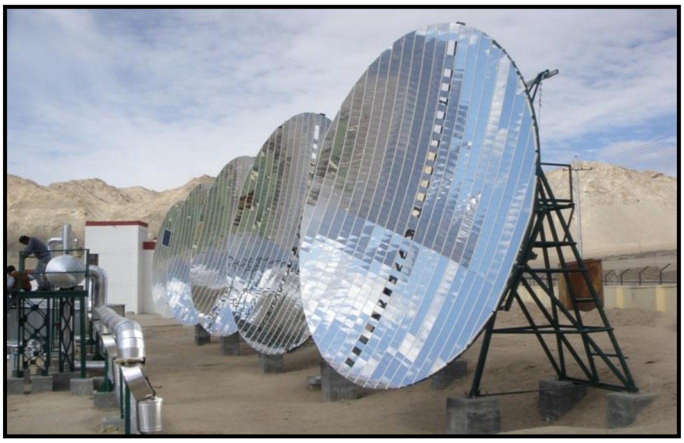

Fig-5: Actual photograph of solar field for an auto ancillary company in north India.

2.4 Advantages of System

The major advantage of the installed solar thermal system integrated VAM for cooling are,

a) Solar reflectors with PLC based tracking system harness solar energy more efficiently compared to non-tracking solar collectors and to produce hot water at 140 ^{0}C

b) The VAM could work more efficiently with high coefficient of performance (COP) of 1.1 compared to COP of 0.60 for low temperature hot water VAM.

c) Saving in cost of solar cooling system and space requirements.

d) Employment of smaller condenser water pumps saves on running cost of pump.

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e) Its a Green Technology and gives operating cost savings too.

3. ANALYSIS OF INTEGRATED SYSTEM

3.1 Performance Analysis

Month wise daily output of the system is shown in figure 6 and annual performance of the solar installation integrated with VAM is listed in Table 3.

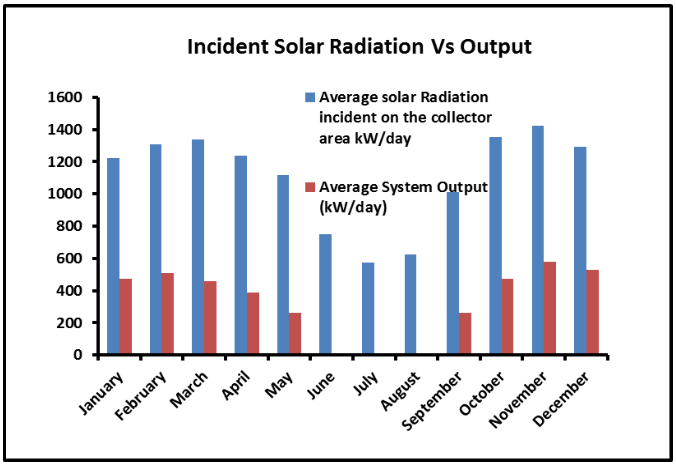

Fig-6: Month wise average daily solar radiation versus system output.

Table-3: Annual Performance of Cooling Installation

Month	Days	TR generation for the period (hours/day)				Energy Saved (kWh) /day	Energy Saved per month (kWh)
		25-30	20-25	15-20	10-15		
January	31	-	6	-	-	477	14773
February	28	2	4	-	-	512	14332
March	31	-	5	1	-	459	14226
April	30	-	1	5	-	388	11649
May	31	-	-	-	6	265	8207
June	30	-	-	-	-	-	-
July	31	-	-	-	-	-	-
August	31	-	-	-	-	-	-
September	30	-	-	-	6	265	7943
October	31	-	6	-	-	477	14773
November	30	6	-	-	-	582	17474
December	31	3	3	-	-	530	16415
Total	**365**	**11**	**25**	**6**	**12**		**119791**

3.2 Capital Expenditure and Economic Analysis

Investment for the solar installation was approximately Rs. 74,00,000.00 which comprised of 20 Scheffler dishes each of area 16 m^2, central tracking system, storage tank and heat exchanger with valves and instrumentation, support structures, hot water pumps and piping, cooling tower, cooling water pumps and piping, solar dish erection and commissioning, commissioning of VAM and integration of solar system with VAM. The economic analysis of the solar system is given in Table4.

Considering the benefits offered by Government of India for renewable energy by way of subsidy and depreciation, the payback is even less than 6 years. Further, carbon credits can improve the payback.

Table-4: Economic Analysis of the solar installation

Parameters	Details
Saving in electricity/year based on performance data	1,19,791 kWh
The cost of electricity at the plant	Rs 9.0/kWh
Savings accrued	Rs 10,78,119 /year
Investment (Excluding cost of VAM)	Rs 74,00,000/-
Simple payback	6.86 Years

4. CONCLUSION

The cooling requirement of a building of an auto ancillary company is partially met by integration of solar parabolic concentrators with existing system. The present case study highlighted that the solar thermal cooling based VAM can be seamlessly integrated with existing electrical chillers for comfort cooling application. Scheffler dish technology can generate required heat for double effect Li-Br VAM. The size of solar installation and VAM capacity can be decided depending on the available area and the required cooling load. Solar based vapor absorption machine for comfort cooling requirements is a suitable substitution of conventional fuel or electricity. An annual saving of approximately 1,20,000 units of electricity and reduction of 113 metric tons of CO_2emission was achieved using 320 m^2 of parabolic dish collector area with a payback period of 6-7 years.

5. ACKNOWLEDGEMENTS

Ministry of New and Renewable Energy (MNRE), Government of India provided a subsidy of Rs. 56,000.00 per dish on investment in solar system. In this project the total subsidy amount was Rs. 11, 20,000.00 for 20 Scheffler dishes.

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