Using the Heat of Sun to Cool: A Case Study of 100 TR (350kWth) Solar Air-Conditioning System

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Abstract

This case study presents the solar assisted cooling technology of 100 TR developed by using double effect Li-Br absorption chiller and running since last 10 years at Kailash Cancer Hospital and Research Center (KCHRC) run by an NGO Muni Seva Ashram near Vadodara, Gujarat, India. The cooling load of the cancer hospital is 600 TR and provided by the biomass-fired boiler. The key object of opting for solar air conditioning was to reduce the biomass consumption. After the implementation of the system, out of 600 TR, 100TR is generated with the solar thermal cooling system. This technology designed and established with double effect evaporator runs with steam which is generated by Scheffler dishes (solar concentrator). Solar generated steam is sent to double effect vapor absorption Li-Br chiller which chills the water to 6°C. This water is piped to the cancer hospital (cooling area) and is sent to Air Handling Units (AHU) which chills the air and ducts to the central air-conditioning system in the cancer hospital. Being sustainable, the institution was looking for replacing and saving wood and thus use of solar concentrator was a perfect and economical solution for cooling. The success of this system, along with the economic benefits, will lead to many new solar thermal cooling systems in developing countries and hopefully, will spread to other countries all over the globe.

Keywords: Solar cooling, Scheffler dish, vapor absorption Li-Br, Air-Handling Unit

1. Introduction

The requirement of space cooling is rising over the globe due to the adverse effect of the global warming. Basically, air conditioning is defined as the simultaneous operation of temperature, humidity, purification and distribution of airflow to space (Daut et al. 2013). It is important to provide safe and clean cooled air in the hospital as well. Conventionally, the air conditioning is driven by electricity. It leads to an increase in peak electricity demand in developing countries. In addition to that, the growing cooling demand in summertime lead to the overload of the national electric grid and it will turn to blackout or the fluctuations in electric supply (Kalkan 2012). Higher usage of vapor compression cooling machines also leads to increased GHG (Greenhouse gases) emission by leakage of refrigerant as well as the usage of fossil fuel to generate the electricity. Total CO_2 emissions from the cooling sectors amount to approximately 4 GT of CO_2 emissions in 2018 (equivalent to 11.8% of the world's direct CO_2 emissions) (Birmingham Energy Institute 2018).

The Kailash Cancer Hospital and Research Center (KCHRC) is situated in a small village called Goraj which is 30 km away from the city Vadodara. The hospital is operated by Non-Governmental Organization named "Muni Seva Ashram". The Kailash cancer hospital serves the people with all modern and hi-tech equipment and amenities which require an air-conditioned environment. Electricity for grid was not able to provide continuous and constant cooling due to fluctuations in voltage. So, the authorities decided to shift from the electric air conditioning to the sustainable cooling. Previously the air conditioning was done by steam generated with a wood fired boiler. The total cooling load is 600 TR of the hospital.

2. Solar cooling technologies

Transformation in global temperature and climate will increase external and interior heat loads and might be injurious to health and harm work productivity of millions of people (Schulte and Chun 2009; Ford and Ford 2011). Cooling is having a major contribution to the climate change (Aprea et al. 2012). In such a scenario, solar cooling can be considered viable as well as a sustainable alternative. Moreover, in most cases, the availability of solar radiation and demand for the cooling match. In this section, available technologies for solar cooling are explained. Solar assisted

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cooling structures are either solar electricity driven or solar thermally driven. Figure 1 illustrates the various cooling technologies.

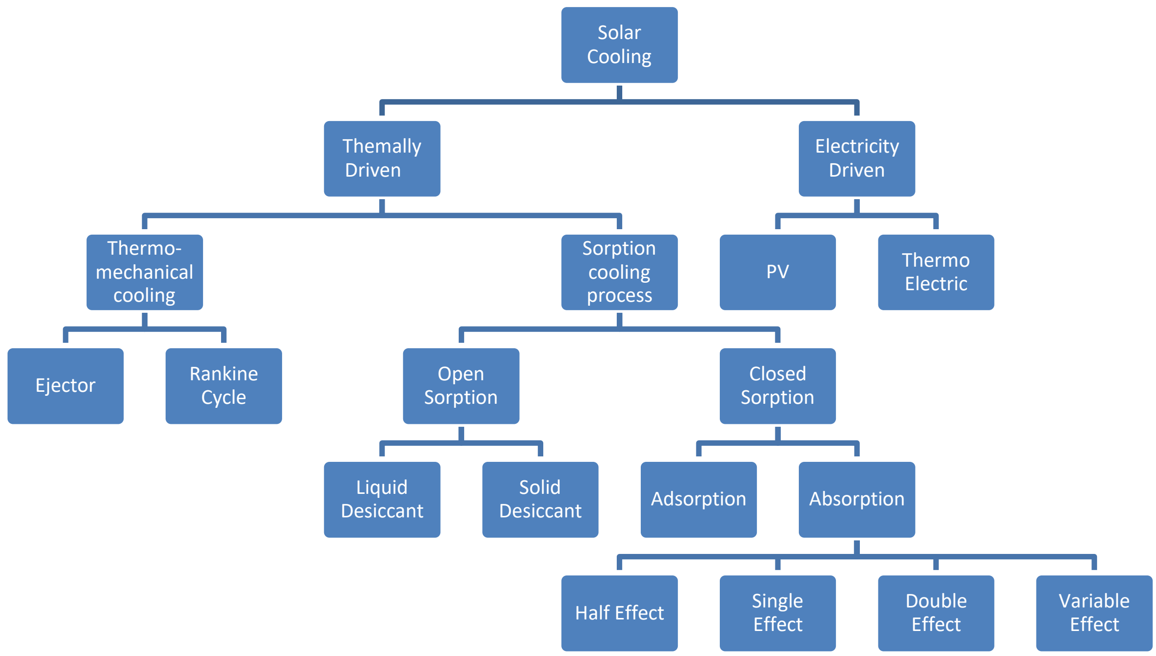

Figure 1 Classification of solar cooling technologies

Solar PV cooling is a simple technology with the low maintenance cost. However, the storage system (batteries) is very expensive. It is the viable option to use solar PV cooling method during sunshine hours to meet the electricity demand. In the solar thermal cooling system, the heat from solar can be used to run the prime movers to compress the refrigerant. The basic principle of thermal driven cooling and electricity driven cooling is represented in Figure 2.

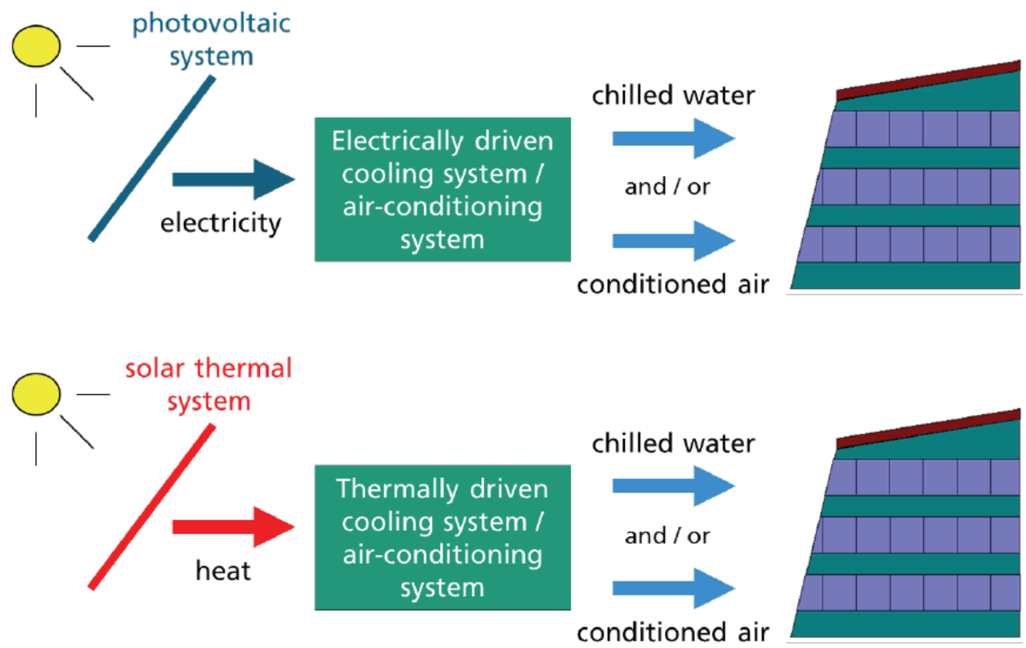

Figure 2 Principles for solar driven cooling systems (Mugnier 2015)

The comparison of COP with respect to hot water inlet is shown in Figure 3. It can be pointed out from the figure that the double effect absorption system is having a higher COP. Hence, the presented technology discussed in this paper is designed on double-effect absorption.

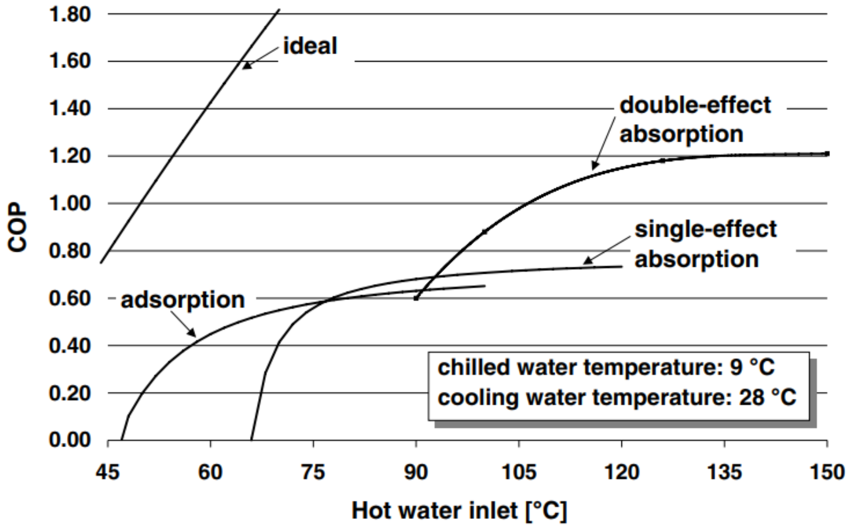

Figure 3 COP comparison of various cooling technologies (Henning 2007)

2.1 Absorption cooling

Among the described technologies, the absorption cooling in the most commonly used method under solar cooling. The system has a vapor compression machine that provides cooling by expansion of refrigerant. Figure 4 describes the absorption cooling cycle. The double effect absorption system utilizes two generators. The superheated refrigerant from the first generator is input for the second generator. The second generator will produce the additional refrigerant effect. And this is the reason why the COP is higher for the double effect absorption system.

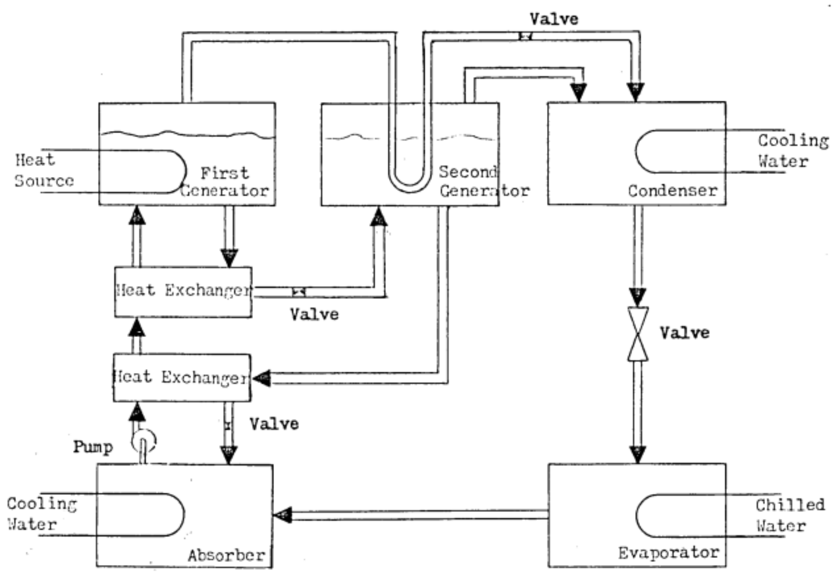

Figure 4 Double-effect absorption system (Vliet et al. 1980)

As compared to the single effect system, the water cooling load is lower per ton of cooling. On the other hand, this system requires the higher temperature, two generator (primary and secondary) and two exchangers, making the system more complex and expensive. However, the higher COP of the system makes the double-effect system relatively viable.

For the absorption cooling system, a combination of two refrigerants is used i.e. Lithium bromide with water, and ammonia with water. Three refrigerant pairs are used for VARS are commercially available in the market: Lithium-Bromide (LiBr)-Water solution, Water-Ammonia and Lithium Chloride (LiCl)-Water system. Currently, absorption chillers using LiBr-Water as the working pair are the most commercially developed (Baniyounes et al. 2013; Henning 2007). While naming these, first of the pair is the sorption agent and the second the refrigerant.

3. System description

In 2008, after a pre-feasibility study, it was found that a site had rich solar radiation of 5.29 kWh/m^2/day (RETScreen 2018). The system was installed in 2008 and is running in good condition. This portion provides the information about solar supported cooling system. As it mentioned before, the solar cooling system is installed at the hospital for space cooling in the hospital. The total cooling load of the hospital is 600 TR out of that 100 TR cooling is done with solar thermal assisted cooling. The hospital has installed the Scheffler dishes as a solar concentrator. It generates steam to drive the components of absorption cooling cycle. Figure 5 represents the aerial view of the site with the installed system.

Figure 5 Aerial view of the cancer hospital with solar assisted cooling system

The system has 100 concentrators with 12.5 m^2 capacity each. The solar concentrator system consists of 3 rows with 15 pairs each and fourth row with 5 pairs of Scheffler dishes (it can be observed from the Figure 5). The total collector area being 1,250 m^2. To completely utilize the solar energy, the system has an automatic East-West tracking. North-South tracking is done manually by every two days. The system arrangement is done in such a way that, the Scheffler dishes placed in a pair with the help of standing dish reflecting the sun rays on the one side of the receiver placed in its focus and the sleeping dish deflecting the sun rays on to the other side of the receiver. Figure 6 illustrates the arrangement of Scheffler dishes and the receiver.

Figure 6 System arrangement

Steam header pipes are positioned overhead the receiver and the header pipe is filled till half. The water flows into the receiver due to gravity. Due to the high concentration of sunlight on the receiver, water passing through from it receives excessive heat which is returned to the header pipe via thermo siphon effect. This circulation continues until the water reaches to its boiling point. Water with an initial temperature of around 55°C, gets and converted into a steam of pressure 7.5 bar and the temperature of the steam is 167°C. From the header, the steam is drawn and supplied to Vapor Absorption Chiller (VAC). Figure 7 represents the block diagram of the system.

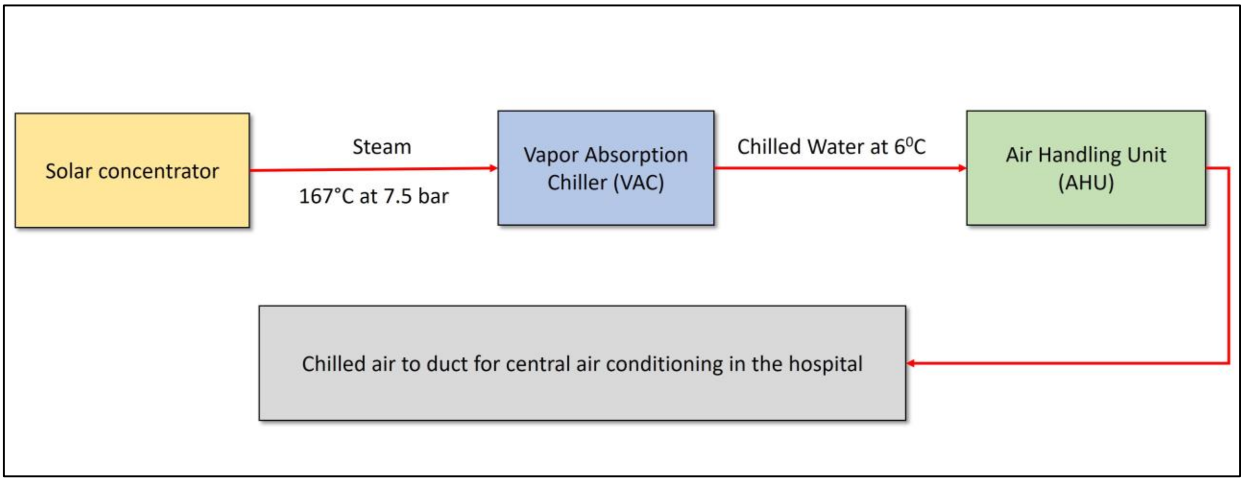

Figure 7 Block diagram of the system

To ensure that the steam maintains the required temperature and pressure, the steam is first sent through back-up biomass boiler, which supplies additional heat if needed, ensuring that Vapor Absorption Chiller (VAC) always gets the steam at desired temperature and pressure. If desirable, the boiler can also run the air-conditioning system at night times and also during bad weather days (during monsoon and cloudy days). Figure 8 presents the picture of a Vapor Absorption Chiller machine. The COP of the double effect evaporator based VAC is 1.12–1.14.

Figure 8 Vapor Absorption Cooling (VAC) machine

4. Solar – Biomass Hybrid cooling system

This system is directly driven by solar energy. There is no such provision for storage. So as the cooling system is operated by solar energy, there is a fluctuation in the steam production due to weather effects. Hence, it is required to provide backup/support system. To provide a constant supply of steam, a biomass-fired boiler is installed that work as a support system. It is capable of fulfilling the shortage of steam due to weather effects. The boiler is equipped with an automatic controller which can detect the variation in the steam parameters like temperature and pressure, and accordingly feeds the boiler to produce more steam acceptable for the VAC. Figure 9 represents the biomass-fired boiler from the site.

Figure 9 Biomass fired boiler from the site

The steam is condensed while heating a Li-Br solution of the VAC system and is pumped back to the solar concentrator to be heated and produce steam again. The return temperature of the hot water is 161°C from the VAC to the solar concentrators. In this way, the steam carries heat from solar collectors to the VAC system in a closed loop. Figure 10 represents the block diagram of the solar –biomass hybrid cooling system.

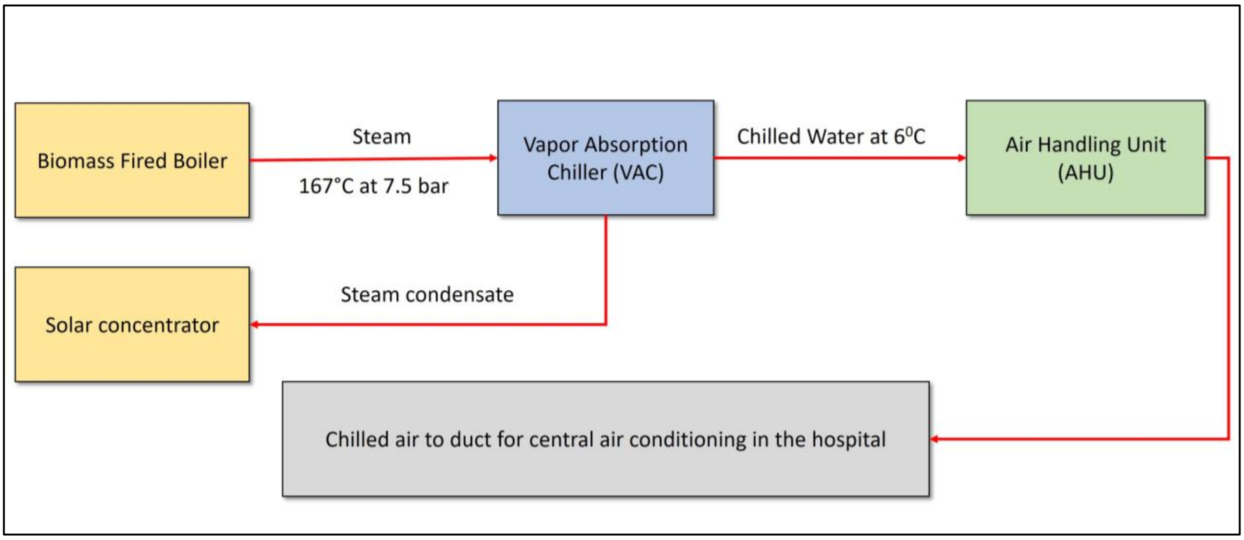

Figure 10 Block diagram of solar-biomass hybrid cooling system

As it is already mentioned that chilled water from the VAC at 6°C is fed into Air Handling Unit (AHU). Here, the fin coil exchanger in AHU chills the air which is pumped in the cancer hospital for space cooling. The chilled water becomes heated to 12°C from 6°C due to it giving away its chillness to air and is again pumped to VAC for re-chilling and thus building additional closed loop. Figure 11 shows the design schematics of a complete solar cooling system.

The cooling load supplied by the system is 100 TR (equivalent to 350kW thermal power). The system works from 10:30 AM to 4:30 PM. Steam at 167°C at 7.5 bar pressure is generated by harnessing solar thermal energy. The system runs approximately 300 days in a year.

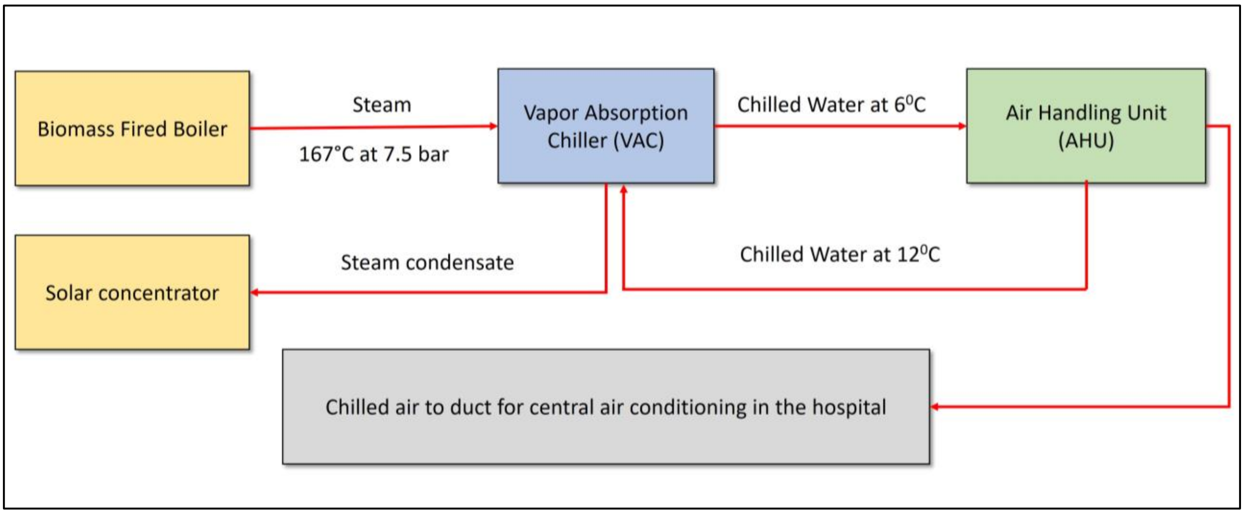

Figure 11 Design schematics of solar cooling system

5. Operation and Maintenance

The total cost of 100 TR solar assisted solar cooling was ₹ 12.5 million INR* (Indian Rupees). This is India's first largest cooling system. At the time of the installation, MNRE supported this iconic project by providing the subsidy of ₹ 5 million INR**.** MNRE is abbreviated as Ministry of New and Renewable Energy, which is the nodal ministry for the renewable energy. The Ministry is mainly responsible for research and development, intellectual property protection, and international cooperation, promotion, and coordination in renewable energy sources such as wind power, small hydro, biogas, and solar power. Other than the subsidiary price, the remaining amount was borne by the Ashram. This is the only cost for the solar assisted cooling system, it does not include the cost of the backup boiler and VAC system. The Ashram installed this 100 TR Vapor Absorption Chiller, made by Thermax, a Pune (India) based company. By considering the subsidy IRR and payback of the system are 26.63% and 3.5 years respectively. While without the subsidy, the IRR and payback of the solar thermal cooling system are 12.92% and 6.4 years respectively.

By installing the 100 TR solar cooling system, around 1000 kg /day of wood biomass is saved. Earlier the air conditioning was done by steam generated with boiler fed from biomass. At that time, the cost of wood was ₹ 2 / kg but due to the shortage of wood, the price hiked and currently costs ₹ 6 /kg. The system requires 3 people for the operation. Every day, the workers fill the steam header with make-up-water which evaporates and thus needs be continually supplied with fresh water. Also, they are responsible for the manual tracking of a solar concentrating system. After 5 years of successful operation of the system, in the year 2013, the mirrors were changed under the UNDP–MNRE repair and renovation project. To reduce the reliance on imported mirrors, the organization has worked with local glass experts of Messer's ARS Gastec. They have developed specific side coatings for solar grade mirrors and also developed methods of sealing edges which gives them a longer life.

6. Conclusion

The growing earth temperature leads towards to the growing cooling demand over the globe. Conventional cooling methods are highly responsible for the emission of greenhouse gases, which is asking for sustainable cooling technologies. Solar assisted cooling could be the perfect solution. The presented validated case study introduces 100 TR solar thermal assisted cooling system, which is responsible for the space cooling of the cancer hospital in a rural area of Vadodara, India. This case study includes the design criteria, manufacturing practices, installation, operational & maintenance experience of these India's first largest solar supported cooling system. The system installed in 2008 and running in good condition. This case study is a significant example of a sustainable renewable cooling application. Because previously the space cooling of the hospital was done by a biomass-fired boiler. By implementing this system, approximately 1000 kg of wood mass is saved daily. The success of this system, clean environment approach, as well as the economic benefits, will lead to new similar systems for empowerment in developing countries.

* 1 USD = 71.68 INR [on 07/09/2018]

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