EXPERIMENTAL INVESTIGATION ON SOLAR ABSORPTION COOLING SYSTEM USING THERMAL STORAGE

LA.Chidambaram[a], A.S.Ramana[b], V.Muthu[c], G.Kamaraj[d], R.Velraj[e]**

[a,d]Department of Mechanical Engineering, Annamalai University, Annamalai Nagar, India .

[b,c,**e] Department of Mechanical Engineering, Anna University, Chennai, India .

**Corresponding author Telephone : +91 44 2235 8051 Fax: +91 44 2235 1991

e mail : velrajr@annauniv.edu, velrajr@gmail.com

Conventional cooling technologies that utilize harmful refrigerants consume more energy and cause peak loads leading to negative environmental impacts. As the world grapples with the energy and environmental crisis, there is an urgent need to develop and promote environmentally benign sustainable cooling technologies. Solar cooling is one such promising technology, given the fact that solar energy is the cheapest and widely available renewable energy that matches the cooling load requirements. However thermal storage systems are essential to overcome the disadvantage of the intermittent nature of solar energy and variation in cooling demand. The enhanced utilization of solar energy and other consequences of thermal storage integrated systems have gained the attention of researchers in the recent years. This paper presents an experimental investigation of a 1kW vapour absorption refrigeration system (VARS) that uses R134a-DMAC as the working fluid operated by the heat generated from solar flatplate collector integrated with Phase Change Material(PCM) based thermal storage system. The performance of the solar collector, storage tank and the VARS are obtained from the experimental investigation. The capacity of the storage tank is capable of operating the VARS unit continuously for a period of 8 hours at full load condition. It is observed from the results that the COP increases with increase in generator temperature and decrease in sink temperature. An actual COP of 0.32 to 0.38 is achieved for the designed system under the tested conditions.

Keywords

Solar cooling, Absorption cooling, Solar Collectors, Thermal energy storage, R134a-DMAC , Phase change material, Latent Heat Storage

1. Introduction

The rapid industrialization and human desire to have a high standard of living and comfort has increased the energy demand many folds. The recent energy crisis and the increased awareness for the need of conservation of energy have led a large number of researchers to show interest in energy conservation through energy efficient processes, equipment and devices. Refrigeration and air conditioning consume enormous energy. In recent years, these sectors have witnessed manifold growth, and have become essential not only for human comfort but also for a variety of applications, such as food preservation. Nearly 30% of all fresh produce, in developing countries like India, are lost due to lack of cold storage facilities and unavailability of regular power supply. Conventional cooling technologies are energy intensive and also the emission of gases used in the refrigeration systems affect the environment. Reducing energy consumption and use of sustainable energy technologies are vital to meet the increasing cooling demand in an environmentally friendly manner. Providing thermal cooling would minimize post harvest losses.

Solar cooling serves the cold storage needs in industries as varied as hospitality, pharmaceuticals, chemicals, dairy and food processing, besides serving the residential and office air conditioning needs. Solar cooling depends primarily on solar energy, either by hot water production through solar collectors or electricity production through photovoltaic panels. In comparison with conventional electrically driven compression systems, substantial primary energy savings can be expected from solar cooling, thus aiding in conserving energy and preserving the environment. Another advantage of using solar energy is that the cooling demand is highest when the solar intensity is at its highest, however the problem with solar energy is its intermittent nature. Thermal storage is, therefore, critical.

Kim et al. (2008) have listed a variety of ways to use solar energy for refrigeration. They have ranked absorption and adsorption comparable in terms of their reported performance and ahead of other solar cooling techniques. Chidambaram et al. (2011a) have suggested PCM based thermal storage integration with solar collectors and absorption chillers for performance improvement in solar cooling techniques. Rodrıguez Hidalgo et al. (2008) describe the experimental research on a 50 m^2 flat plate solar collectors driven single-effect commercial $LiBr/H_2O$ absorption machine through a hot-water storage tank that produces 6–10 kW cooling power with a generator driving power input of 10–15 kW, achieving a mean cooling period of 6.5 h of complete solar autonomy. Gonzalez-Gil et al. (2011) have reported a COP of 0.6 with a cooling power between 2kW and 3.8kW for a direct air-cooled lithium bromide water absorption prototype operated by 48 m^2 flat-plate collectors. Praene et al. (2011) have described the design and results of a field test on a 90 m^2 of double-glazed solar flat-plate collectors driven 30 kW $LiBr/H_2O$ single-effect absorption cooling system. Syed et al.(2005) have reported performance of a single-effect ($LiBr/H_2O$) absorption chiller of 35 kW nominal cooling capacity powered by 49.9 m^2 array of flat-plate collectors. Daily average collector efficiency was 0.50 with average COP and solar cooling ratio of 0.42 and 0.11. Umberto Desideri et al. (2009) have analyzed the technical and economic feasibility of replacing/integrating existing compression refrigeration systems with solar absorption cooling systems for meat refrigeration. Chidambaram et al. (2011b) have presented the performance of the solar collector system and the charging characteristics of a PCM based latent heat thermal storage unit, for operation of 1 kW vapor absorption refrigeration unit.

Belen Zalba et al. (2003) have reviewed different PCMs heat transfer and applications. Helm et al. (2009) have described the operation of an absorption cooling system that involves latent heat storage supporting the heat rejection of the absorption chiller in conjunction with a dry cooling system. Soutullo et al. (2011) in their comparison between both absorption chillers with internal and external storage have indicated that in order to reach similar values of storage energy, external storage based system requires more surface. Li and Sumathy (2002) have recommended a partitioned stratified storage tank for solar air-conditioning. The stratified storage tank has an advantage of obtaining higher energy output and providing higher COP when compared to a conventional, fully mixed hot water storage tank. An experimental solar cooling system developed by Agyenim et al.(2010) consisted of a 12 m^2 vacuum tube solar collector, a 4.5 kW $LiBr/H_2O$ absorption chiller, a 6 kW fan coil along with a 1000 litre cold storage tank that functions as a buffer between chiller and cooling demand and. It produced a thermal COP of 0.58.

2. Experimental Set-Up

The schematic diagram of the experimental setup of the solar operated vapour absorption system designed for a capacity of 1 kW integrated with a thermal storage system is shown in Fig 1. Array of flat plate solar collectors, PCM based thermal storage system and Single stage continuous VAR systems are the three major subsystems that constitute solar absorption cooling system. Water is used as heat transfer fluid and the heat energy gained from the collector is stored in the thermal energy storage (TES) tank. A pump with a capacity of 0.25 HP is used for circulating the water from collector to the storage tank. The photographic view of the experimental setup is shown in Figure 2.

The thermal energy storage tank is made of mild steel with a double wall thickness of 5 mm each with an air gap in between the plates and the storage tank is insulated with a glass wool of 100 mm thick. The tank has the dimensions of 1130 mm height and 1169 mm diameter, with a storage capacity of 1250 litres. A total of 800 spherical capsules made of stainless steel is kept inside the thermal energy storage (TES) tank. The spherical capsules are filled with a commercial phase change materials (PCM), HS58, that has a melting temperature of 58-60^{o} C, procured from Pluss polymers Ltd, India. These spherical capsules are surrounded by water that acts as sensible heat storage material and heat transfer fluid. A perforated plate of thickness 8 mm is kept at a height of 370 mm from the bottom of the storage tank. The spherical capsules filled with PCM, are kept above the perforated plate ensuring high thermal mass in the top of the storage tank to promote stratification. In the vapour absorption refrigeration system heat is supplied to the generator from the top of the storage tank.

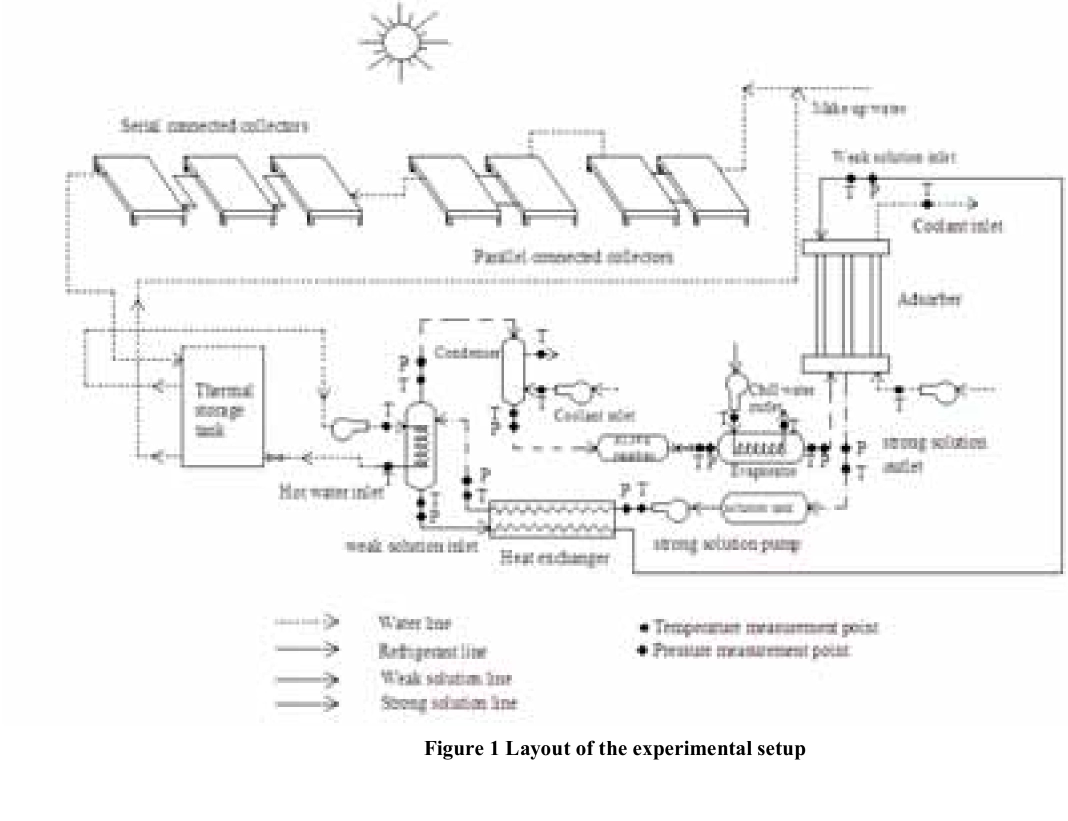

Figure 1 Layout of the experimental setup

Figure 2 Photographic View of the experimental setup

3. Experimental Procedure

The major objective of the present research is to study the charging and discharging characteristics of the storage tank. During the charging process, the storage tank is integrated with an array of solar collectors and during the discharging process the VARS of capacity 1 kW is integrated with the storage tank. Several experiments were carried out at Chennai, India, throughout the year and the results are presented. During the experiment, the intensity of the solar radiation is measured using a pyranometer, with a time interval of 15 minutes. Water at a mass flow rate of 2 kg/min is circulated through the storage tank and the collectors. In the thermal energy storage tank thermocouples are located radially at six locations and axially at five locations to monitor the temperature variation inside the thermal energy storage tank and at the inlet and outlet of the storage tank. The measurements are monitored continuously a data acquisition system.The experiments are continued until the bottom temperature of the storage tank reaches 65°C. Though experiments are carried out for different mass flow rates the results are presented only for the mass flow rate of 2 kg/min. During the discharging process, the hot water stored in the storage tank is allowed to circulate through the generator of the vapour absorption refrigeration system. The temperature of the chilled water to the evaporator is maintained constant by heating the chilled water in a heating thermostatic bath fitted with a 1.5 kW electric heater whose input voltage is controlled by an autotransformer. This heating bath simulates the refrigeration load, which can be estimated by the electrical power input.

4. Results and Discussion

Following sections deal with performance of the various subsystems such as solar collector, storage tank and the absorption refrigeration system during charging and discharging process.

4.1. Charging Process

The temperature of the HTF in the storage tank during the charging process, the instantaneous and cumulative heat stored in the storage tank for the experiment conducted during the month of March are studied in detail and presented. Figure 3 shows the variation of the HTF temperature at various heights in the storage tank during the charging process for a mass flow rate of 2 kg/min. The location of the thermocouple in the storage tank at various heights for the experiment conducted during the month of March with respect to the height of the storage tank is given in the legend. x/L = 0 indicates the bottom of the storage tank. The initial temperature of the water in the storage tank varies from 40 to 43°C, from the bottom to the top of the storage tank, due to the heat stored during the earlier experiments.

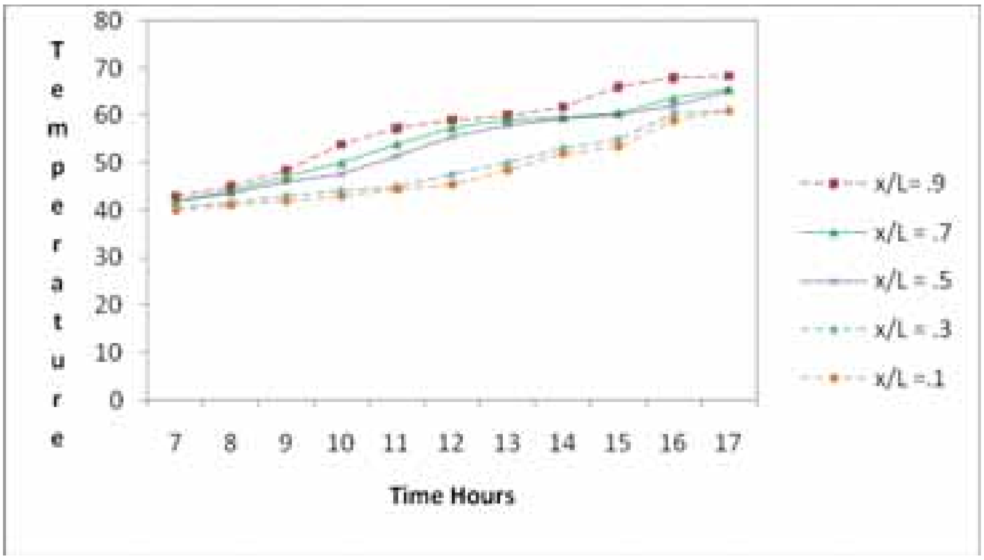

Figure 3 Variation of Heat Transfer fluid temperature at different heights with time in the storage tank

The measurement of the instantaneous heat transfer and the cumulative heat stored in the storage tank for a mass flow rate of 2 kg/min during the charging experiments conducted during the month of March between 7 AM and 5 PM from the solar collector is shown in Figure 4. It is seen from the figure that the instantaneous heat transfer increases until 12 noon and then starts decreasing. The initial increase in the heat transfer is due to the increase in solar insolation. However, after 12 noon the instantaneous heat transfer starts decreasing. The initial increase in heat transfer is due to the increase in solar insolation. However, after 12 noon the instantaneous heat transfer starts decreasing, though solar insolation increases until 1 PM. Around 12 noon, the HTF temperature entering the solar collector increases above 50°C, and hence, the mean temperature of the solar collector also increases, which will reduce the collector efficiency.

Hence, a further increase in instantaneous heat transfer is not observed beyond that time. In the afternoon hours, after 1 PM, since the solar insolation decreases with respect to time, instantaneous heat transfer also decreases.

Figure 4. Variation of Instantaneous and cumulative energy stored with time during the month of March (m = 2 kg/min)

4.2. Discharging Process

The temperature variation of the HTF with respect to time in the storage tank at five different heights during the discharge process are shown in Figure 5.

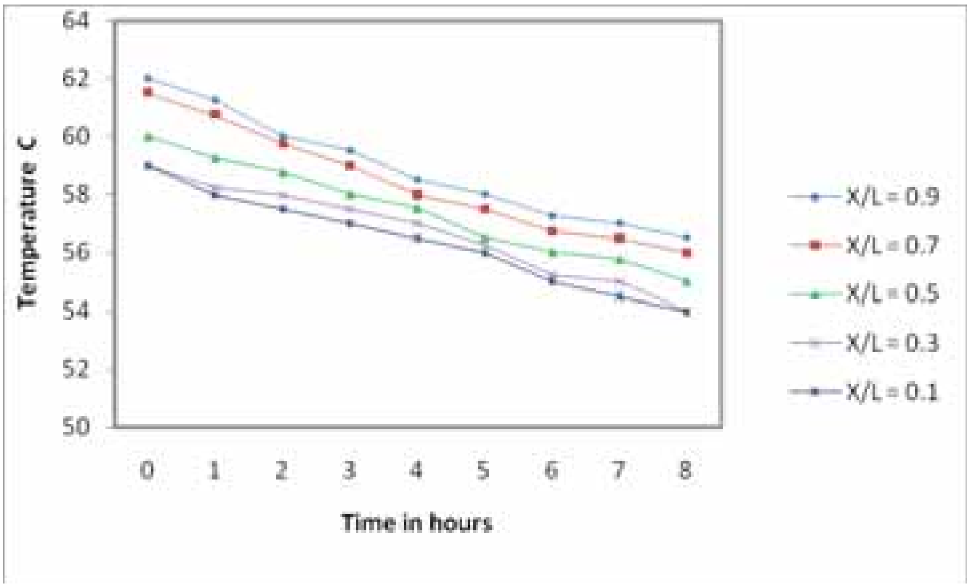

Figure 5 Temperature Variation of HTF in the storage tank during the discharge Process

The results correspond to the evaporator set temperature of 4°C and the sink temperature of 25°C. The higher temperature gradient prevailed along the height of the storage tank during the end of the charging process is disturbed and during the start of discharging process, only a temperature difference of 3°C is present between the top and bottom of the storage tank. Since the heat transfer fluid enters the generator from the top of the storage tank, the HTF is initially at 62°C and as time increases the temperature also decreases. The experiments are continued until top of storage of the storage tank reaches 58°C. It is seen from the Figure 5, initially for a duration of two hours the thermocouple shows a drop of 2°C and another 2°C drop is observed during the remaining 6 hours. This is due to the release of latent heat from the phase change material. The PCM based storage tank is able to deliver a near constant temperature of 60°C for duration of 8 hours. During this period, the bottom of the storage tank attains a temperature of 54°C. The decrease in temperature in bottom of the storage tank is not disturbing the temperature of the heat transfer fluid at the top of the storage tank as stratification is maintained due to low mass flow rate and also due to the presence of PCM capsules at the top of the storage tank.

Experiments are conducted to study the performance of the VARS at various sink temperatures. The sink temperature corresponds to the temperature of water at the ambient conditions. During the experiment, water at the required temperatures of 20°C, 25°C and 30°C are simulated and this water is circulated through the condenser and the evaporator temperature is maintained at 4°C. The cooling capacity is evaluated using the following equation $Q = m_w C_w \Delta T_w$ Where m_w is the mass of the water circulated through the evaporator (0.08 kg/s) ΔT_w is the temperature difference between inlet and outlet of the chilled water passing through the evaporator.

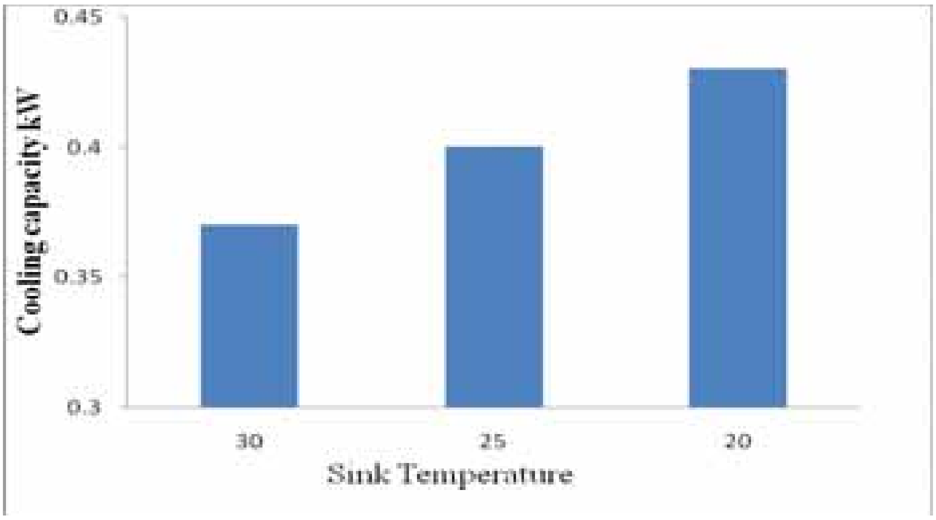

Figure 6 Variation of Cooling Capacity with Sink Temperature (Evaporator Temperature 4°C)

It is seen from the Figure 6 that when the sink temperature is at 20°C the cooling capacity achieved is 0.43 kW and it reduces to 0.4 kW and 0.37 kW respectively when the sink temperature increases to 25°C and 30°C. This reduction in cooling capacity is due to the performance reduction of the VARS as it is operating against higher sink temperature. Hence it is construed that for every 1°C drop in sink temperature, an increase in cooling capacity of 1.4 % is achieved in the VARS.

The COP is evaluated using the following equation

$COP = Q_{evaporator} / Q_{generator}$

where $Q_{evaporator}$ is the cooling capacity of the VARS and $Q_{generator}$ is evaluated using the following equation

$Q_{evaporator} = m_g C_p \Delta T_g$

where m_g is mass flow rate of hot water circulated from the storage tank through the generator (0.33 kg/s). ΔT_g is the temperature difference of the heat transfer fluid between inlet and outlet of the generator.

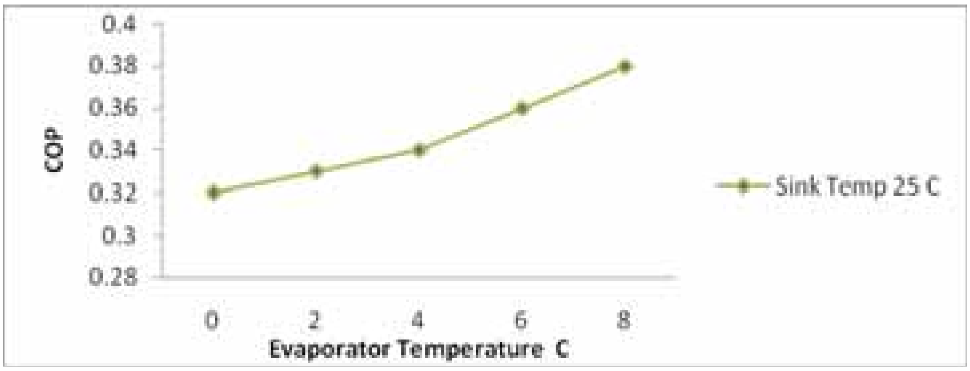

Figure 7 Variation of COP with respect to Evaporator Temperature

Figure 7 shows the variation of COP for various evaporator temperatures varying from 0°C to 8°C by maintaining the sink temperature at 25°C. It is seen from the figure that the COP of the VARS varies from 0.32 to 0.38 as the evaporator temperature varies from 0°C to 8°C. This indicates that when the temperature of the chiller requirement is low the COP of the VARS also decreases. It is observed from the results that an increase of 2.2 % in COP is seen for every 1°C increase in evaporator temperature from 0°C to 8°C.

5. Conclusion

Solar cooling is a promising potential for different applications and offers scope for innovation. Thermal storage system enhances performance efficiencies and contributes to increased environmental benefit. The existence of thermal stratification in the PCM based storage system improves the collector efficiency, and hence, the system efficiency. Lower heat loss due to lesser surface area and higher storage capacity are its additional significant benefits. The PCM based storage system is very useful in providing the required heat at higher uniform temperature for a longer duration due to the large heat capacity associated with the PCM. It is observed that for every 1°C drop in sink temperature an increase in cooling capacity of 1.4% is achieved in the VARS. The coefficient of performance of the vapour absorption refrigeration system increases with increase in evaporator temperature. It is observed from the results that an increase of 2.2% in COP is seen for every 1°C increase in evaporator temperature.

References

Agyenim, F., Ian Knight, Michael Rhodes, 2010. Design and experimental testing of the performance of an outdoor LiBr/H_2O solar thermal absorption cooling system with a cold store. Solar Energy 84, 735–744.

Belen Zalba, Jose Ma Marın , Luisa F. Cabeza, Harald Mehling, 2003. Review on thermal energy storage with phase change: materials, heat transfer analysis and applications. Applied Thermal Engineering 23, 251–283.

Chidambaram, LA., Ramana, A. S., Kamaraj, G., and Velraj, R., 2011a. Review of Solar Cooling Methods and Thermal Storage Options. Renewable & Sustainable Energy Reviews 15(6), 3220-3228.

Chidambaram, LA., Ramana, A. S., Kamaraj, G., and Velraj, R., 2011b. Experimental Investigation on A Latent Heat Thermal Storage Unit for Solar Cooling Application. Green - The International Journal of Sustainable Energy Conversion and Storage 1, 221-228.

González-Gil, A., Izquierdo, M., Marcos, J.D., Palacios, E., 2011. Experimental evaluation of a direct air-cooled lithium bromide water absorption prototype for solar air conditioning. Applied Thermal Engineering, 1-11.

Helm, M., Keil C., Hiebler S., Mehling H., Schweigler C., 2009. Solar heating and cooling system with absorption chiller and low temperature latent heat storage: Energetic performance and operational experience. International Journal of Refrigeration 32, 596 – 606.

Kim DS., Infante Ferreira CA., 2008. Review Solar refrigeration options – a state-of-the-art review. International Journal of Refrigeration 31, 3-15.

Li ZF., Sumathy K., 2002. Performance of partitioned thermally stratified storage tank in a solar powered absorption air conditioning system. Applied Thermal Engineering 22, 1207-1216.

Praene, J.P., Olivier Marc, Franck Lucas, Frédéric Miranville, 2011. Simulation and experimental investigation of solar absorption cooling system in Reunion Island. Applied Energy 88, 831–839.

Rodrıguez Hidalgo MC., Rodrıguez Aumente P., Izquierdo Millan M., Lecuona Neumann A., Salgado Mangual R., 2008. Energy and carbon emission savings in Spanish housing air-conditioning using solar driven absorption system. Applied Thermal Engineering 28, 1734-44.

Soutullo, S., San Juan, C., Heras, M.R., 2011. Comparative study of internal storage and external storage absorption cooling systems. Renewable Energy 36, 1645-1651.

Syed,A., Izquierdo, M., Rodrıgueze, P., Maidment, G., Missenden, J., Lecuonae, A., Tozer, R., 2005. A novel experimental investigation of a solar cooling system in Madrid. International Journal of Refrigeration 28, 859–871

Umberto Desideri, Stefania Proietti, Paolo Sdringola, 2009. Solar-powered cooling systems: technical and economic analysis on industrial refrigeration and air-conditioning applications. Applied Energy 86, 1376-86.