International Journal of Engineering, Management, Humanities and Social Sciences Paradigms (IJEMHS)
Volume 30, Issue 02, Quarter 02 (April to June 2018)
An Indexed and Referred Journal with Impact Factor: 2.75
ISSN (online): 2347-601x
www.ijemhs.com

Supermarket Cooling by Solar Power based Vapour Absorption Cooling System

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Publishing Date: June 19, 2018

Abstract

This paper consists of two different research problems. In the first one, the aim is to model and simulate a solar-powered, single-effect, absorption refrigeration system using a flat-plate solar collector and LiBr-H2O mixture as the working fluid. The cooling capacity and the coefficient of performance of the system are analyzed by varying all independent parameters, namely: evaporator pressure, condenser pressure, mass flow rate, LiBr concentration, and inlet generator temperature. The cooling performance of the system is compared with conventional vapor-compression systems for different refrigerants (R-134a, R-32, and R-22). The cooling performance is also assessed for a typical year in Easyday, New Delhi. Higher COP values are obtained for a lower LiBr concentration in the solution. The effects of evaporator and condenser pressures on the cooling capacity and cooling performance are found to be negligible. The LiBr-H_2O solution shows higher cooling performance compared to other mixtures under the same absorption cooling cycle conditions. For typical year in Easyday, New Delhi, the model shows a constant coefficient of performance of 0.94. In the second problem, a numerical model is developed for a typical food retail store refrigeration system to study the effects of indoor space conditions on supermarket energy consumption. Refrigerated display cases are normally rated at a store environment of 24ºC (75ºF) and a relative humidity of 55%.

Keywords: *Absorption, Evaporator, Condenser, Concentration, Refrigerants.*

Introduction to Solar Absorption Cooling System

The energy needed to process and circulate air in buildings and rooms to control humidity, temperature, and cleanliness has increased significantly during the last decade especially in developing countries. This energy demand has been caused by the increment of thermal loads to fulfill occupant comfort demands, climate changes, and architectural trends. The growth of electricity demand has increased especially at peak loads hours due to high use of driven vapor compression refrigeration machines for air conditioning. In addition, the consumption of fossil fuels and the emissions of greenhouse gases associated with electricity generation lead to considerable environmental consequences and monetary costs. Conventional energy resources will not be enough to meet the continuously increasing demand in the future. In this case, an alternative solution for this increasing demand of electrical power is solar radiation, available in most areas and representing an excellent supply of thermal energy from renewable energy resource.

One of the most common solar air conditioning alternatives is a solar powered absorption system. The solar absorption system is similar in certain aspect to the conventional vapor compression air conditioning system in that the electrical compressor; is replaced with a solar-powered generator and absorber. Figure 1.1 shows a commercial flat-plate solar-powered single-effect absorption cooling system. The most standard pairs of chemical fluids used include lithium bromide-water solution (LiBr-H2O), where water vapor is the refrigerant and lithium bromide is the absorbent, and ammonia-water solution (NH3-H2O) with ammonia as the refrigerant and water the absorbent. The implementation of computer modeling of thermal systems offer a series of advantages by eliminating the cost of building prototypes, the optimization of the system components, estimation of thermal energy loads delivered or received from or into the system, and prediction of variations of the system parameters (e.g. temperature, pressure, mass flow rate).

Solar-Powered Single-Effect Absorption Cooling System

System Description

The solar-powered absorption cycle consists of four major parts, i.e., a generator, a condenser, an evaporator and an absorber. These major components are divided into three parts by one heat exchanger, two expansion valves and a pump. Initially, the collector receives energy from sunlight and heat is accumulated in the storage tank. Subsequently, the energy is transferred through the high temperature energy storage tank to the refrigeration system. The solar collector heat is used to separate the water vapor, stream number 2, from the lithium bromide solution, stream number 3, in the generator at high temperature and pressure resulting in higher lithium bromide solution concentration. Then, the water vapor passes to the condenser where heat is removed and the vapor cools down to form a liquid, stream number 4. The liquid water at high pressure, stream number 4, is passed through the expansion valve, stream number 9, to the evaporator, where it gets evaporated at low pressure, thereby providing cooling to the space to be cooled. Subsequently, the water vapor, stream number 5, goes from the evaporator to the absorber. Meanwhile, the strong lithium bromide solution, stream number 3, leaving the generator for the absorber passes through a heat exchanger in order to preheat the weak solution entering the generator, and then expanded to the absorber, stream number 6.

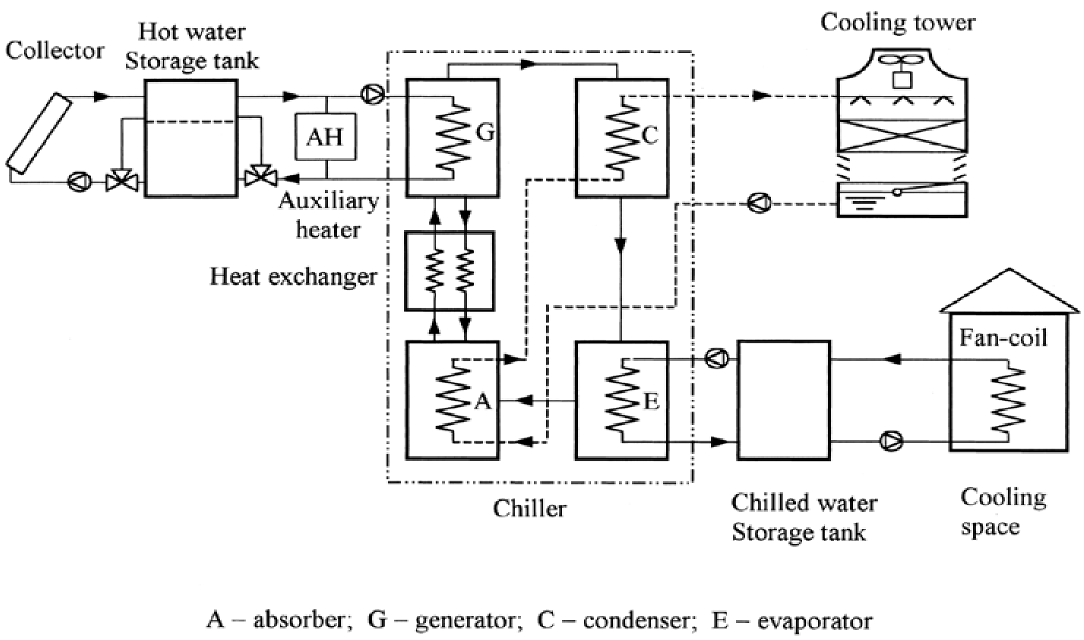

Figure 1: Schematic diagram of the solar-powered air conditioning system

Chemical fluids used include lithium bromide-water solution (LiBr-H2O), where water vapor is the refrigerant and lithium bromide is the absorbent, and ammonia-water solution (NH3-H2O) with ammonia as the refrigerant and water the absorbent. The implementation of computer modeling of thermal systems offer a series of advantages by eliminating the cost of building prototypes, the optimization of the system components, estimation of thermal energy loads delivered or received from or into the system, and prediction of variations of the system parameters (e.g. temperature, pressure, mass flow rate).

Operation Condition

A control volume is taken across each component i.e. the generator, absorber, evaporator, condenser and heat exchanger to analyze the working conditions of all components of the system. The mass and the energy balances are performed and a computer simulation is developed for the cycle analysis. A control volume analysis around each component, which covered the rate of heat addition in the generator, and the energy input of the cycle.

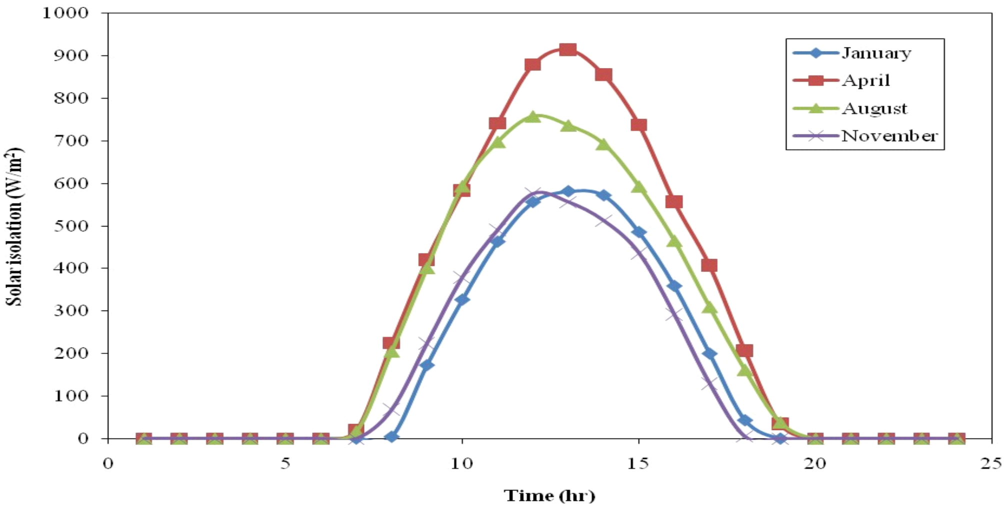

Figure 2: Hourly solar isolation for Easyday, New Delhi

Table 1: Energy flow at various component of the system by CHEMCAD process model

Description	Symbol	Energy (kW)	
		(a)	(b)
Evaporator	Qevap	11.31	11.26
Absorber	Qabs	14.67	14.61
Generator	Qgen	15.26	15.26
Condenser	Qcon	11.89	11.90
Coefficient of performance	COP	0.74	0.74

Table 2: Operation condition CHEMCAD process model

Stream	T (oC)		P (kPa)		x (kg LiBr/kg solution)		m (kg/s)	
	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)
1. Pump outlet	36.2	36.2	6.601	6.601	0.561	0.561	0.056	0.056
2. Condenser inlet	70	71.2	6.601	6.601	0	0	0.0048	0.0048
3. Generator outlet	84.6	71.2	6.601	6.601	0.613	0.614	0.0512	0.0512
4. Condenser outlet to exp. valve	38	37.8	6.601	6.601	0	0	0.0048	0.0048
5. Vapor from evaporator to absorber	4.4	5.4	0.9	0.9	0	0	0.0048	0.0048

6. Solution inlet in absorber	47.1	31.3	0.9	0.9	0.613	0.614	0.0512	0.0512
7. Absorber outlet	36.2	36.2	0.9	0.9	0.561	0.561	0.056	0.056
8. Generator inlet from heat exchanger	62.4	62.4	6.601	6.601	0.556	0.561	0.056	0.056
9. Evaporator inlet from expansion valve	5.5	5.4	0.9	0.9	0	0	0.0048	0.0048
10. Absorber inlet from heat exchanger	53.6	69.3	6.601	6.601	0.613	0.614	0.0512	0.0512
11. Generator inlet from heat exchanger	62.4	62.4	6.601	6.601	0.556	0.561	0.056	0.056

Results and Discussion

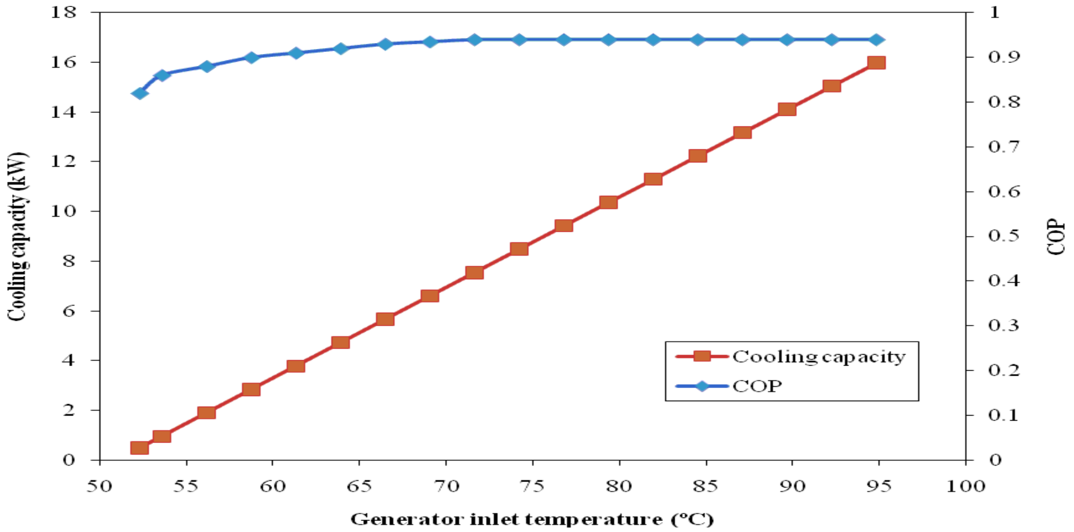

Figure 3: Effect of generator inlet temperature on cooling capacity and COP

Simulation results are presented here for the performance of the solar-powered absorption cooling system. The effect of the variation of the inlet generator heating water temperature is shown in figure 2.5. The cooling capacity varies approximately linearly starting from a low value of 0.47 kW up to 16 kW. The COP rises from a low value of 0.82 to reach a constant value of 0.94. The cooling capacity increases as the inlet generator temperature increases. The COP of the system increases slightly when the heat source temperature increases. The COP would be expected to increase significantly with increasing generator/source temperature, but as the generator/source temperature increases, the heat transfer in all the heat exchangers of the system also increases. The figure shows linear increase in the heat transfer in all of evaporator, condenser and absorber when varying the inlet generator temperature.

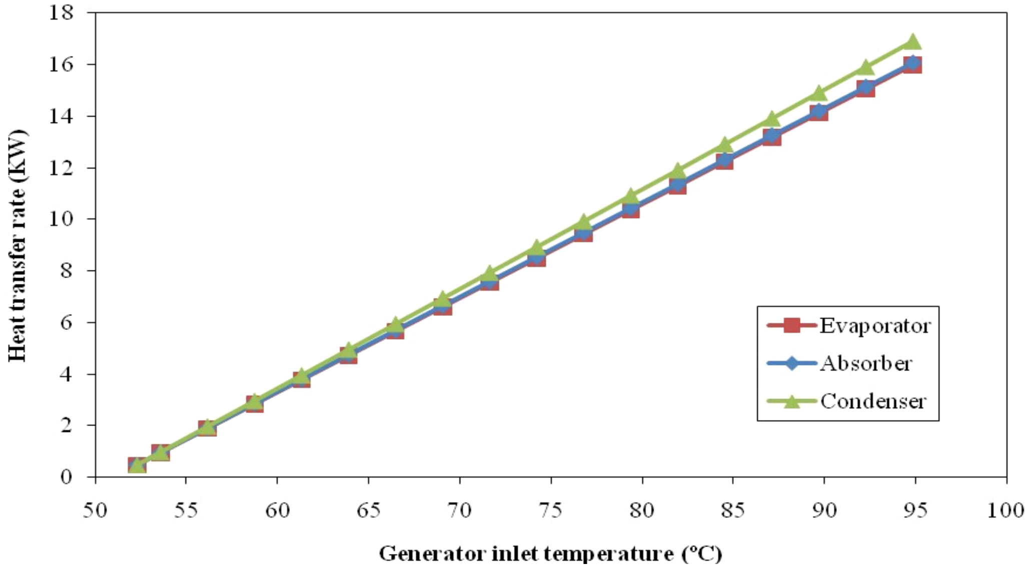

Figure 4: Effect of generator inlet temperature on evaporator, absorber, condenser and generator heat transfer rates

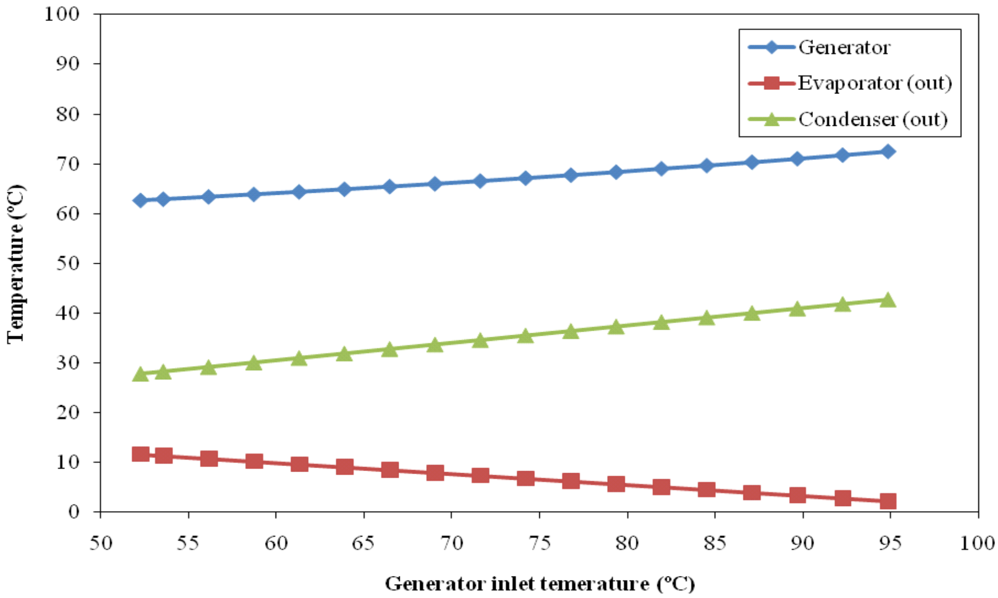

Figure 5: Effect of generator inlet temperature on generator, evaporator and condenser temperatures

Modeling of Supermarket Refrigeration/HVAC System for Simple Energy Prediction

A model was developed for a typical supermarket based on data prepared by the Food Marketing Institute. The store description is as follows:

Store floor area:	3716 m2 (40,000 ft2)
Conditioned space:	2787 m2 (30,000 ft2)

Air supply rate:	14.16 m3/s (30,000 cfm)
Outside ventilation air:	1.84 m3/s (3900 cfm)
Hours of operation:	24 hours/day
People in store:	180 maximum. 92W/person (315 Btuh/person) sensible and 75W/person (255 Btuh/person) latent. People occupancy schedule is shown in Figure 3.2.
Indoor conditions:	24ºC (75ºF), variable relative humidity
Supply air conditions:	13ºC (55ºF), 95% relative humidity

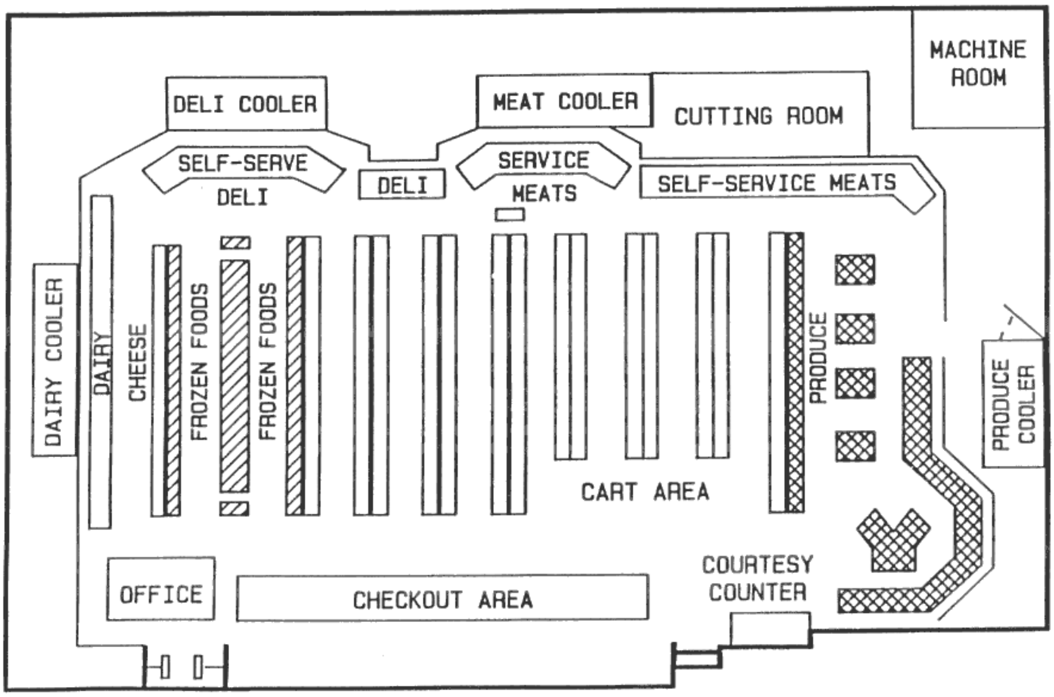

Figure 6: Layout of typical supermarket

Modeling of Supermarket Refrigeration/HVAC System for Simple Energy Prediction

The integration of air curtain with moisture balance for supermarket model is necessary in order to assess the effect of reduced store relative humidity on display case energy requirements. So, thermodynamic analysis was used to simulate supermarket refrigeration/HVAC system using MATLAB software. For the simulated supermarket model described in this work with different types of refrigerated display cases, and located in a hot and humid weather such as Tampa, Florida, the annual average supermarket relative humidity was found to be 51.1%. This simulated store relative humidities were found to be in the range between 40% and 60% during the model year. The results show good agreement with previous model, and the experimental data validates the proposed model. The effect of indoor space conditions on supermarket energy consumption is studied. It is shown that for a 5% reduction in store relative humidity that the display case refrigeration load is reduced by 9.25%, and that results in total store energy load reduction of 4.84%. These results evaluated the integration of air curtain correlation for quick design calculation and for the simulation of different types of display cases within a supermarket model. These results, which are not generally known for typical supermarkets in hot and humid climates, will now allow the designer of the supermarket to simply and quickly determine typical store relative humidity so that savings in display case operation and total store energy load are correctly estimated.

Conclusions

The greatest advantage of solar-powered absorption cooling system when compared to other cooling applications is the greater the sun radiation, the greater cooling performance that can be achieved by the solar refrigeration system. CHEMCAD model shows good trend for cooling capacity and COP when compared with previous models. In order to achieve higher COP, LiBr-H2O mixture is good solution to be used in solar- powered absorption cooling system. According to the results, the cooling performance can be varied with LiBr solution concentration. The results show for higher cooling performance, optimized LiBr solution concentration is suggested. The effects of evaporator and condenser pressures and varying the mass flow rate on the cooling capacity and cooling performance are generally negligible as the results show. The cooling performance is assessed for typical year in Tampa, Florida weather condition and the results show constant coefficient of performance of 0.94. Finally by considering the problem of pollution on the planet due to the burning of fossil fuels the adoption of solar energy to power absorption chillers, even with marginal economic benefits, should not be underestimated.

Scope for Future Work

In the first problem, Lithium bromide-water mixture was used as the working fluid for the solar absorption cooling system. This mixture shows quite good performance for Easyday, New Delhi weather condition. For future work, it is recommended to study the performance for different types of mixtures for optimum cooling performance. It is also recommended that the design specification for each component of the system i.e. generator, evaporator, condenser, and absorber to be taken based on physical data. This will count for the number of tubes of the heat exchanger. The coefficient of performance will be varied with the overall heat transfer coefficient of the heat exchangers.

The effect of store relative humidity was investigated inside a typical supermarket in Easyday, New Delhi. The integration of store relative humidity with the display cases (QLdisplay case) within the moisture balance equation was highly effecting the energy consumption of the retail store. Finding new correlations for the other parameters of the moisture balance equation, i.e., QLproduce, QLmeat, and QLbakery, gives more precise results for the energy consumed inside the retail store with changing the store relative humidity. It is also recommended to modify the model to be working for different weather conditions rather than hot and cold climate as Easyday, New Delhi. In addition, the model can be modified for different supermarket layouts.

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