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The solar contribution to air conditioning systems for residential buildings

Marderos Ara Sayegh
Faculty of Mechanical Engineering, University of Aleppo, Syria
email: arasateg@scs-net.org

Abstract

The synchronizing of cooling loads with solar radiation intensity is an important advantage when we utilize solar energy in cooling or air conditioning in residential buildings. Practical experience confirms that appropriate design of these systems can achieve good results to use solar energy in air conditioning projects if they compared with conventional systems. This paper aims to investigate the theoretical behavior of thermal parameters and their interaction in absorption cooling systems powered with solar energy, which use thermal storage tank and auxiliary heater, with flat plate solar collectors. To achieve this goal, a computational program is prepared to estimate the behavior of different thermal characteristics and coefficients of an absorption cycle, like coefficient of the performance (COP) and solar useful heat gain, in range of generator temperature varies between 80 and 100°C, and an evaporator temperature varies between 5 and 15°C, for a climatic conditions of Aleppo, where the cooling loads data, solar radiation intensity or other information were introduced. We found that there is a good agreement between our computational results with comparison to practical results, or the measurements of installed projects. The results assure too, that it is suitable to install solar assisted absorption cycle of air conditioning system in climatic conditions such as that of Aleppo.

Keywords: Solar cooling; Solar buildings; Air conditioning

1. Introduction

Insuring the appropriate comfort conditions for cooling and air conditioning purposes in summer season is one of the main futural applications of solar energy especially in regions, which enjoy with reasonable higher rates of solar intensity on a long period of the year.

Many solar assisted AC and cooling systems have been installed in different countries for residential buildings, and the researches are going on to reach economical and efficient thermal systems if they compared with conventional systems [1,2].

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The advantage of solar assisted cooling is the synchronization of cooling loads with solar radiation intensity [3,4].

2. The main parts of solar AC system

Most cooling systems assisted by solar energy, are composed of four main parts, they interact together as integrated unit, these parts are shown in Fig. 1 [5,6].

A solar AC system may operate under any of the following situations:

- When the solar energy is available, and the cooling is needed, the heat is supplied to the cooling cycle from solar collectors directly.
- When the solar intensity is available and there is no need for cooling, so the gained heat from the solar collectors is added to the storage.
- When the solar intensity is available and there is no need for cooling, while the storage has been fully, in this circumstance the solar energy will be discarded.
- When the solar energy is not available and the storage tank has already stored, so the storage tank may be used to supply the heat to the cooling cycle.
- When neither of the solar energy is available nor the storage tank hasn't stored energy, the auxiliary source of energy must be used.

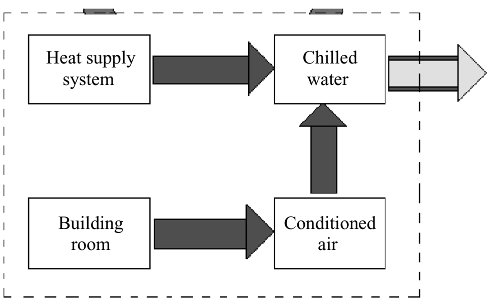

Fig. 1. The main parts of a solar assisted air conditioning system.

3. Computational program for system calculations

3.1. Solar collector calculations

A suitable PC program has developed to determine the cooling loads, which must be extracted from the building every month in cooling season, we assume that the flat plate solar collectors which are located on the roof of the building has an area 80 m^2, and the absorptivity of the collectors is ($\alpha = 0.9$) and the ($Fr = 0.75$), the overall heat transfer coefficient of the collector is ($U = 6$ W/m^2 Co), which determined by the manufacturer, we can write the solar collector efficiency [7]:

$$\eta_{\text{coll}} = \text{Fr} \times \left[(\alpha \cdot \tau) - \frac{U_{\text{coll}}(T_{\text{in}} - T_{\text{amb}})}{I_{\text{s}}} \right] = \frac{Q_{\text{ucoll}}}{I_{\text{s}} \cdot A_{\text{coll}}} \quad (1)$$

where T_{in} is the water input temperature to the collector, T_{amb} the ambient temperature, I_s (W/m^2) solar radiation, Q_{ucoll}(W) useful heat from the solar collector, A_{coll} (m^2) the total area of the solar collector.

In other hand the useful heat gain from the solar collector is given as a function of temperature difference by equation:

$$\text{(W)} \quad Q_{\text{ucoll}} = m_{\text{coll}}.Cp_{\text{w}} \left(T_{\text{g}} - T_{\text{in}} \right) \quad (2)$$

This energy is supplied to absorption cycle and T_g is the water outlet temperature from the collector.

The additional needed heat for the generator of the cooling cycle is supplied from the auxiliary heater.

The COP for cooling cycle is determined as a ratio of the heat extracted by the evaporator to the heat added in the generator, COP is given by the equation [1,7]:

$$\text{COP} = \frac{Q_{\text{E}}}{Q_{\text{g}}} \quad (3)$$

The thermal efficiency of the solar cooling system determined by parameter called solar thermal ratio (STR), and this parameter is calculated from the equation:

$$\mathrm{STR} = \mathrm{COP} \cdot \eta_{\mathrm{coll}} \tag{4}$$

while solar contribution (f) is given in equation: We can predict the auxiliary heater contribution (H_{aux}) in the relation:

$$H_{\mathrm{aux}} = 1 - f$$

$$f = \frac{Q_{\mathrm{ucoll}}}{Q_{\mathrm{g}}} \tag{5}$$

$$f = \frac{Q_{\mathrm{ucoll}}}{Q_{\mathrm{E}}} \mathrm{COP}$$

3.2. Absorption cycle calculation

The PC program can calculate the parameters of (H_2O–LiBr) cooling cycle, by using an experimental equations, and the following assumptions are to be considered:

(1) The state of the refrigerant, that is leaving the condenser, is saturated liquid.
(2) The state of the refrigerant, that is leaving the evaporator, is saturated vapor.
(3) The outlet temperature of the in condenser is equal to the absorber temperature outlet.

After calculating the parameters of the cycle, we can calculate the heat exchanged with ambient through four heat exchangers (generator, absorber, condenser, evaporator) which is illustrated in Fig. 2.

The heat exchanged to or from cycle components are given by equations:

$$(\mathrm{kW}) \quad Q_{\mathrm{g}} = (M - m)h_4 + mh_7 - M \cdot h_3 \tag{6}$$

$$(\mathrm{kW}) \quad Q_{\mathrm{A}} = (M - m)h_6 + mh_{10} - M \cdot h_1 \tag{7}$$

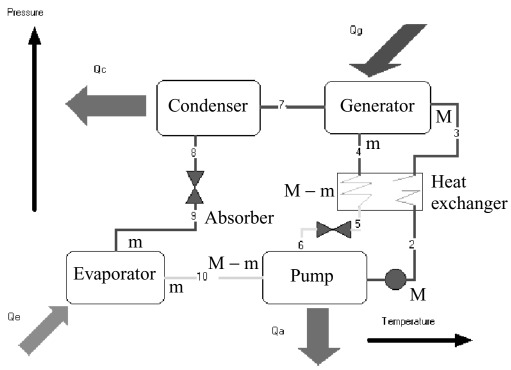

Fig. 2. The main parts of (H_2O–LiBr) absorption cycle.

$$(\mathrm{kW}) \quad Q_{\mathrm{c}} = m(h_7 - h_8) \tag{8}$$

$$(\mathrm{kW}) \quad Q_{\mathrm{E}} = m(h_{10} - h_9) \tag{9}$$

where M (kg/s) is the flow rate of the binary solution of the (H_2O–LiBr), while m (kg/s) is the refrigerant flow rate.

By neglecting the pumping power as compared to the heat added to the generator, the heat balance equation can be given [6,7]:

$$Q_{\mathrm{g}} + Q_{\mathrm{E}} = Q_{\mathrm{c}} + Q_{\mathrm{A}} \tag{10}$$

4. Results and discussion

After including the mathematical equations of the design parameters of the cooling cycle in the program, we achieved the results as a function of the solar radiation intensity through 5 months (from 1 May to 30 September), where AC is needed in this period in Aleppo for the residential buildings.

The results were tabulated in tables for Aleppo city, considering the above mentioned collector thermal specifications.

Table 1
Results concerning the solar collectors and auxiliary system

Month	May	June	July	August	September
η_{coll}	0.243	0.272	0.285	0.292	0.264
I_s (W/m^2)	598	597	592	590	625
Q_{ucoll} (kW)	11.625	12.991	13.498	13.782	13.2
Q_{aux} (kW)	–2.144	5.854	8.463	11.299	–0.631
f	1.226	0.689	0.615	0.549	1.05
H_{aux}	–0.226	0.311	0.385	0.451	–0.05
STR	0.187	0.186	0.203	0.199	0.183

Table 2
Climatic and thermal data for Aleppo city

Month	May	June	July	August	September
T_{amb} (°C)	31	35	37	38	32
T_d (°C)	27	27	27	27	27
T_{in} (°C)	75	75	75	75	75
T_g (°C)	90.4	92.2	92.9	93.2	92.4
$Q_{cooling}$ (kW)	7.31	12.89	15.68	17.08	8.71
COP	0.771	0.684	0.714	0.681	0.693
Q_g (kW)	9.481	18.845	21.961	25.081	12.57
m_a (m^3/s)	0.987	1.741	2.117	2.306	1.18

Where $Q_{cooling}$ (kW) is the needed cooling load, Q_A (kW) the heat extracted in the absorber, Q_c (kW) the heat extracted from the condenser, R the circulation factor of the cycle.

From Tables 1–3 we obtain Fig. 3.

Table 1 shows the collectors efficiencies values (η_{coll}), the maximum value is in June, July and August, because the value of solar radiation intensity is maximum, also the useful energy comes from the collector (Q_{ucoll}, W) has a maximum value in these months.

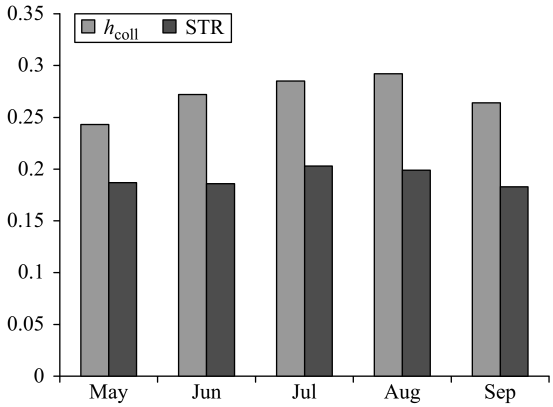

Fig. 3. Relation of STR with η_{coll}.

But the solar contribution reaches maximum value in May, so there is more over energy, which must be stored.

After that the solar contribution is decreases to the minimum value in August, where maximum cooling load is needed. The value STR is nearly constant.

Table 2 shows the value of cooling load ($Q_{cooling}$, kW) and generator heat (Q_g) in addition to COP.

It is obvious that minimum COP occurs during the period of minimum cooling load, this leads to decrease the heat from the auxiliary heater. Fig. 3 shows the relation between STR and η_{coll} during those 3 months.

Fig. 4 shows the solar contribution (f) and the auxiliary heater relation, where the maximum values of them are in May and June, while Fig. 5 shows the relation between the cooling

Table 3
Main values of heat exchanges in the absorption cycle

R	m (kg/s)	M (kg/s)	Q_E (kW)	Q_g (kW)	Q_A (kW)	Q_c (kW)	COP
11.16	0.007	0.078	15.68	21.95	20.886	16.6	0.74

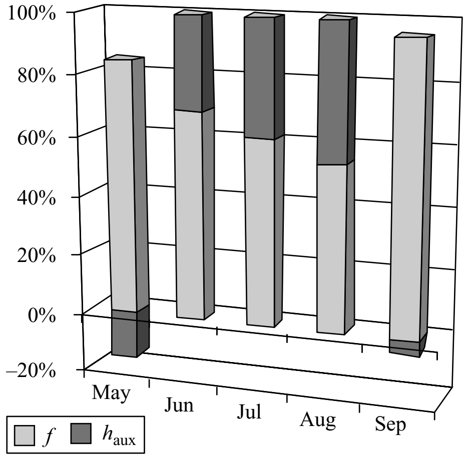

Fig. 4. Solar contribution (f) with auxiliary heat needed.

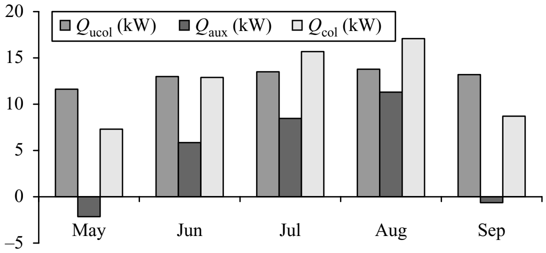

Fig. 5. Cooling load–auxiliary heater–solar intensity.

load and the auxiliary heater, and the solar intensity according to the months.

Fig. 6 shows the changes of COP through the 5 months, and the Fig. 7 shows cooling load ($Q_{cooling}$, kW) and the heat added in generator (Q_g) through the same period of AC.

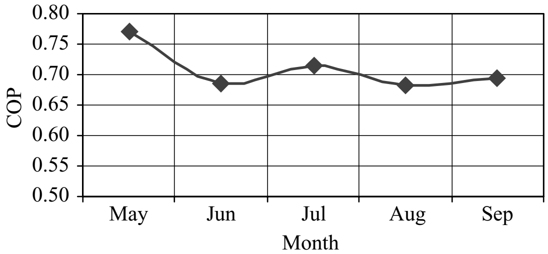

Fig. 6. COP changes in the cooling period.

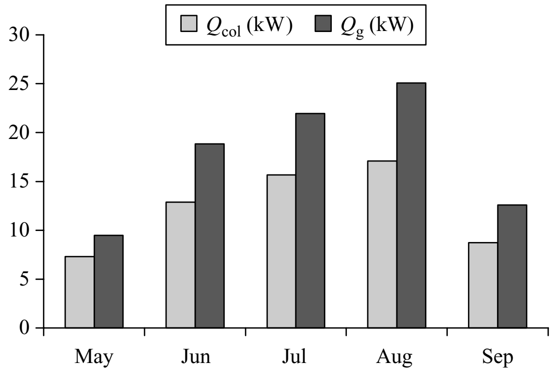

Fig. 7. Cooling load with Q_g.

The COP is calculated as a function of generator temperature (T_g), for the three values of evaporator temperature (T_e) as shown in Fig. 8.

– T_e is constant, COP increases by increasing T_g.
– T_g is constant, COP increases by increasing T_e, so we can conclude that to achieve higher values of COP, we must increase T_g if we want to decrease the T_e.

Fig. 9 shows the relation between STR and T_g for three values of solar intensity: $I_s = 1000$ W/m^2, $I_s = 700$ W/m^2, $I_s = 400$ W/m^2.

To evaluate the results, we compared the results of the program with experimental results of solar cooling projects that were installed in some countries. The results obtained from this program can ensure the solar contribution of

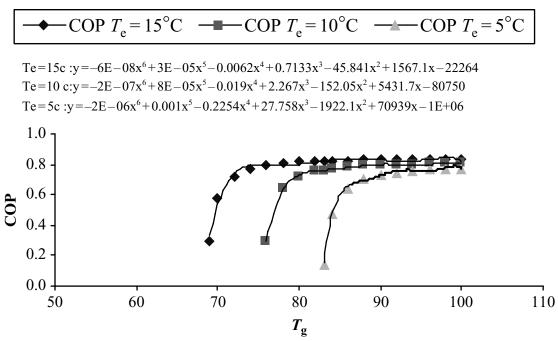

Fig. 8. COP as function of generator temperature.

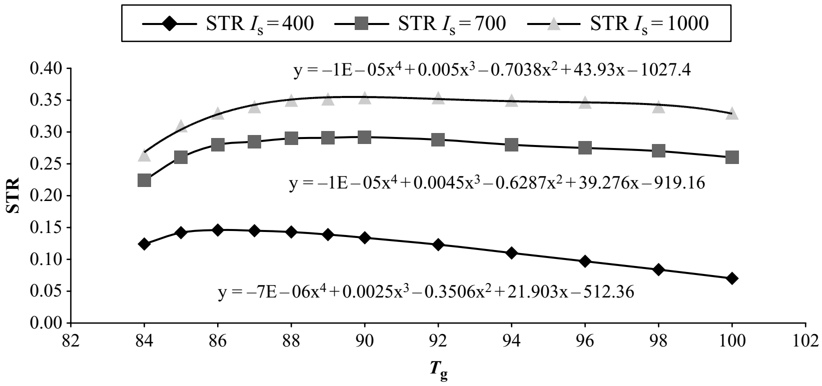

Fig. 9. STR function of generator temperature for different intensities.

up to 80%, where the average value of STR is about 24%. In this condition the system can produce cooling load of about 12.3 kW which is equal to the experimental values.

5. Summary

– We can apply this program to determine the thermal parameters of the absorption cooling cycle, which use LiBr as an absorber and water as a refrigerant when it is assisted by solar energy.
– Results show that the solar radiation intensity of Aleppo especially in summer period is suitable to achieve the needed cooling loads in summer.
– The installation of seasonal heat storage tank enables us to decrease the AC load differences, which must be supplied by an auxiliary system.

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