# Analysis of Solar Powered Air Conditioning Systems for Residential Applications

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## Abstract

In this paper the absorption air conditioning system has been analyzed, and the solar energy has been used as a source for heat required to operating the absorption cycle. The influence of most of the parameters which may affect the performance of absorption air conditioning system has been studied under the climatic conditions of Iraq. The main advantage of solar based air conditioning systems is the synchronization between the cooling demand and the availability of solar energy especially in hot regions like Iraq which contains huge potential of solar energy in summer season. The results obtained indicate the ability of using solar energy to reduce the electricity consumption for air conditioning applications. For a certain space with cooling load 5 Ton (17.5 kW) for climatic conditions (solar radiation intensity 1000 W/m$^2$ and ambient temperature 45 $^o$C) the solar collector with area 40 m$^2$ can provide 75% of required heat to produce this cooling load demand and a collector with area 53 m$^2$ can provide 100 % of required heat to produce this cooling load demand for these climatic conditions.

## تحليل منظومات التكييف التي تعمل بالطاقة الشمسية للتطبيقات المنزلية

### المستخلص

في هذا البحث تم دراسة وتحليل منظومة تكييف الهواء الامتصاصية وتم استخدام الطاقة الشمسية كمصدر للحرارة اللازمة لتشغيل هذه الدورة الامتصاصية. تم دراسة تأثير معظم العوامل التي من الممكن أن توثر على أداء منظومة تكييف الهواء الامتصاصية بالظروف المناخية للعراق.

الميزة الأساسية لمنظومات التكييف التي تعمل بالطاقة الشمسية هي التوافق بين الطلب على التبريد وتوفر الطاقة الشمسية خاصة في المناطق الحارة مثل العراق والتي تحتوي على إمكانيات هائلة للطاقة الشمسية خاصة في فصل الصيف.

النتائج التي تم الحصول عليها تشير إلى إمكانية استخدام الطاقة الشمسية لتقليل الصرف في الطاقة الكهربائية لتطبيقات تكييف الهواء. فالحيز معين يتطلب حمل تبريد مقداره 5 طن (17.5 كيلو واط) وبظروف مناخية ( شدة الإشعاع الشمسي 1000 واط لكل متر مربع ودرجة حرارة الجو 45 درجة سيليزية) فان مجمع شمسي بمساحة 40 متر مربع يستطيع أن يوفر 75 % من الحرارة المطلوبة لإنتاج هذا الحمل ومجمع بمساحة 53 متر مربع يستطيع أن يوفر 100 % من الحرارة المطلوبة لإنتاج حمل التبريد المذكور لهذه الظروف المناخية.

## 1. Introduction

During the last few decades, the consumption of fossil fuel associated with the over loading of the electricity grid for air conditioning purposes, especially at peak demand periods in hot summer increased dramatically in several countries especially in hot climate regions.

Insuring the appropriate comfort conditions for cooling purposes in summer season is one of the main future applications of solar energy especially in regions which enjoy with reasonable higher rates of solar intensity on long period of the year such as in Iraq. During the summer the demand for electricity greatly increases because of the extensive use of air conditioning systems, which increase the peak electric load, causing major problems in the country's electric supply.

The interest in absorption refrigeration systems has increased in recent decades due to the possibility of using weast heat from gas and steam turbines or renewable energies, solar energy in this case, to reduce the consumption of electricity. In addition, they do not contribute to the ozone depletion.

Due to synchronization between the availability of solar energy and need for cooling in hot regions. The use of solar energy to derive absorption cycles for air conditioning of most buildings is an attractive concept.

There are many researchers in literature studied the feasibility of using solar assisted AC systems. Salman Ajib, (2001) [1] analyzed the use of solar thermal energy to operate the absorption refrigeration machine and compare between the absorption and vapor - compression refrigeration machines. He found that, the solar thermal refrigeration systems can be realized and preferred especially in countries with high available resources of sun radiation and a great need for air conditioning. Moncef B. et al, (2005) [2] presented a project aims at assessing the feasibility of solar powered absorption cooling technology under Tunisian conditions. They used (TRNSYS) program to do the simulation. They found that, the absorption solar air conditioning systems are suitable for Tunisian conditions. Marderos A. S. (2007) [3] investigated the theoretical behavior of thermal parameters and their interaction on absorption cooling system for a climatic condition of Aleppo city in Syria. He found that it is suitable to install solar assisted absorption cycle of AC system in climatic conditions such as that of Aleppo city. Z. sayadi et al, (2010) [4] analyzed the feasibility and economic performance of a solar - assisted AC system for a middle house under the climatic conditions of Tunis city. They found that, 30 $m^2$ of evacuated tube collector area with a thermal storage tank of about 1 $m^3$ can cover 87% of the energy needs of a water cooled machine with cooling capacity of 10 kW. Garcia et al, (2011) [5] studied the global modeling of an absorption system working with LiBr - $H_2O$ assisted by solar energy for air conditioning a classroom in Puerto lumbreras, Murcia, Spain. They developed several models for the characterization of the absorption equipment. Their results showed that, the network model predicts with a fair efficiency the value of outlet temperatures and the prediction of COP is not so accurate. AL – Dadah et al, (2011) [6] made experimental work on a solar assisted vapor absorption AC system using propane as a refrigerant and Alkylated benzene (AB300 refrigeration lubrication oil) as absorbent. They found that, the coefficient of performance of the system increases with increasing the generator temperature.

In this paper an investigation has been made to analysis the solar energy powered absorption air conditioning system under the climatic conditions of Iraq. And the effect of most affected parameters has been studied.

## 2. Absorption VS compression refrigeration system

The vapor absorption refrigeration system is one of the oldest methods of producing refrigeration effect. The principle of vapor absorption was first discovered by Michael Faraday in 1824 [7].

The vapor absorption system uses heat energy instead of mechanical energy as in vapor compression systems in order to change the conditions of the refrigerant required for the operation of the refrigeration cycle. In the absorption system, the compressor is replaced by an absorber, a pump, a generator and pressure reducing valve [8].

## 3. Lithium bromide - water absorption system

The working principle of an absorption system is similar to that of a vapor compression machine with respect to the key components (evaporator and condenser). The refrigerant (water) evaporates in the evaporator producing the useful cooling effect ($Q_{ev}$). The water vapor flows to the absorber which can be air or water cooled, in the latter case a cooling tower is necessary to keep the cooling process going. The dilute salt solution exiting the absorber is pumped through the regenerative solution heat exchanger where it is pre- heated in the generator, so that refrigerant vapor is released. The concentrated solution flow back to the absorber. The desorbed refrigerant condenses in the air or water cooled condenser. The condensate is passed thereafter through an expansion valve where its pressure is so reduced as to provoke its partial evaporation causing a substantial decrease of its temperature. The refrigerant flows finally in the evaporator to complete the evaporation.

## 4. Mathematical formulation of solar assisted air conditioning system

In solar energy assisted AC system the required heat for separate the solution in generator is taken from a solar collector as a hot water. Following is the mathematical formulation for complete system (hate plate solar collector and LiBr- water absorption cycle) which is shown in Figure (1) .

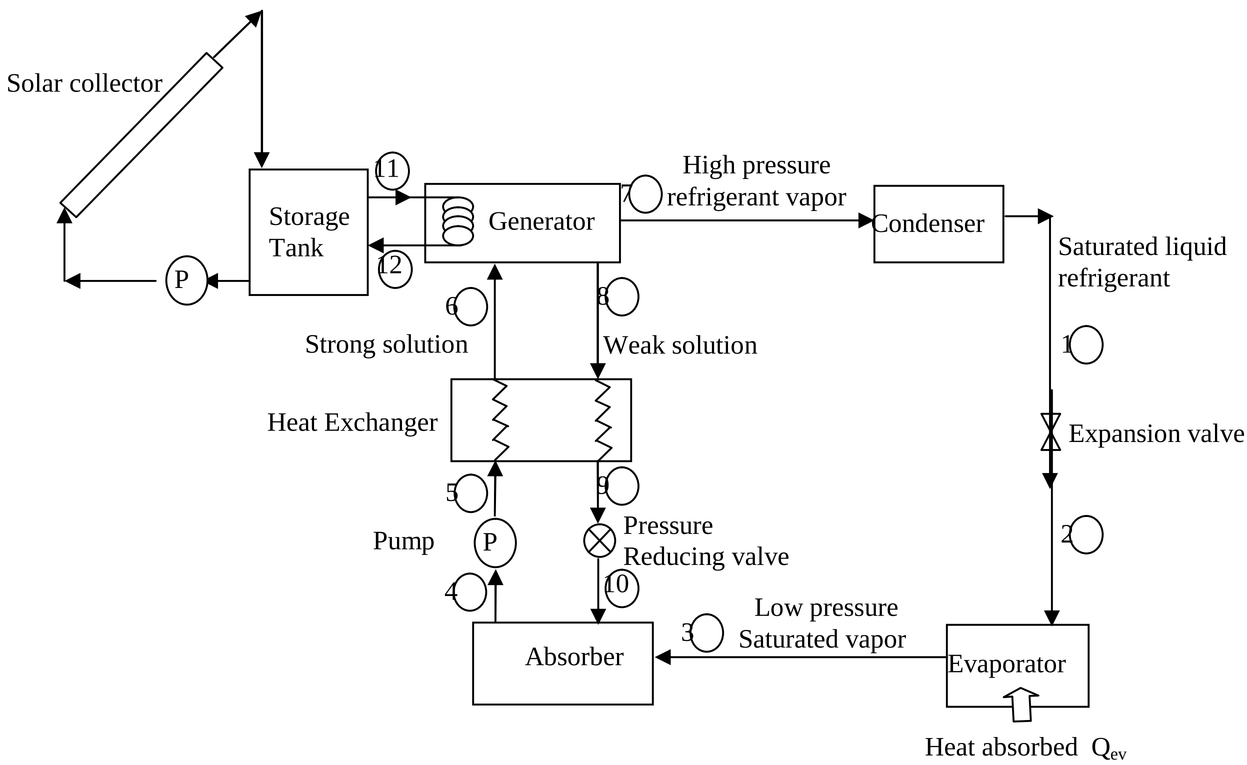



**Figure (1). Solar powered air conditioning system.**

### 4-1. Solar collector

Flat plate collectors are most widely used in this type of applications. For a flat plate solar collector with coefficient of transmittance - absorbency ($\alpha\tau = 0.79$) and ($Fr = 0.75$), the overall heat transfer coefficient of the collector ($U = 6\ W/m^2.C^o$) [2][3].

The solar collector efficiency [3]:

$$\eta_{coll} = Fr \times [(\alpha\ \tau) - \frac{U_{coll}(Tin - Tamb)}{I_s}] = \frac{Q_{ucoll}}{I_s\, A_{coll}} \tag{1}$$

Where:

$T_{in}$ is the temperature of water input to the collector, $T_{amb}$ is the ambient temperature, $I_s$ is the solar radiation intensity, $A_{coll}$ is the total area of the solar collector, $Q_{ucoll}$ is the useful heat from the solar collector.

$$Q_{ucoll} = m_{coll}\, Cp_w\, (T_g - T_{in}) \tag{2}$$

This heat is supplied to the generator and $T_g$ is the temperature of water exit the collector (generator temperature).

### 4-2. Absorption refrigeration cycle

The first step of absorption cycle calculations is to specify and calculate the conditions of all points in the cycle (temperature, pressure, enthalpy, flow rate and concentration of solutions). Then the heat exchanged with ambient through four main components (generator, condenser, evaporator and absorber) can be calculated by the following equations:

Evaporator:

$$Q_{ev} = m_3h_3 - m_2h_2 \tag{3}$$

Where $m_2 = m_3$

Absorber:

$$Q_{ab} = m_3h_3 + m_{10}h_{10} - m_4h_4 \tag{4}$$

$$m_3 + m_{10} = m_4 \tag{5}$$

Condenser:

$$Q_{cond} = m_1h_1 - m_7h_7 \tag{6}$$

Where: $m_1 = m_7$

Generator:

$$Q_g = m_7h_7 + m_8h_8 - m_6h_6 \tag{7}$$

$$Q_g = Q_{ucoll} = m_{coll}\, Cp_w\, (T_g - T_{in}) = m_{coll}\, Cp_w\, (T_{12} - T_{11}) \tag{8}$$

For heat exchanger, the effectiveness can be expressed as follow:

$$\epsilon = \frac{Q_{act}}{Q_{max}} = \frac{Q_{act}}{(mcp)_{min}\,(T_{hi} - T_{ci})} \tag{9}$$

$$Q_{act} = (mCp)_c\,(T_{co} - T_{ci}) = (m\,Cp)_h\,(T_{hi} - T_{ho}) \quad (10)$$

For $(mCp)_{min} = (mCp)_c$

$$\epsilon = \frac{(mCp)_c\,(T_{co} - T_{ci})}{(mCp)_c\,(T_{hi} - T_{ci})} = \frac{(T_{co} - T_{ci})}{(T_{hi} - T_{ci})} \quad (11)$$

Where $T_{co}$ = T6, $T_{ci}$ = T5, $T_{hi}$ = T8, $T_{ho}$ = T9

$$T6 = T5 + \epsilon\,(T8 - T5) \quad (12)$$

The coefficient of performance of the cycle:

$$COP = \frac{Q_{ev}}{Q_g + w_p} \quad (13)$$

Where $w_p$ is the power consumption in small pump used to circulate the solution. By neglecting $w_p$ due to its small value, the coefficient of performance become [3, 4]:

$$COP = \frac{Q_{ev}}{Q_g} \quad (14)$$

**4-3. Solar air conditioning system**

Thermal efficiency of the solar cooling system determined by parameter called solar thermal ratio (STR) which represents the overall efficiency of the system:

$$STR = COP \times \eta_{coll} \quad (15)$$

Solar contribution (f) can be calculated from [3],[9]:

$$f = \frac{Q_{ucoll}}{Q_{ev}}\,COP \quad (16)$$

When the solar energy is insufficient to operate the system, auxiliary heater must be used to provide the required heat. The auxiliary heater contribution ($H_{aux}$) can be calculated from:

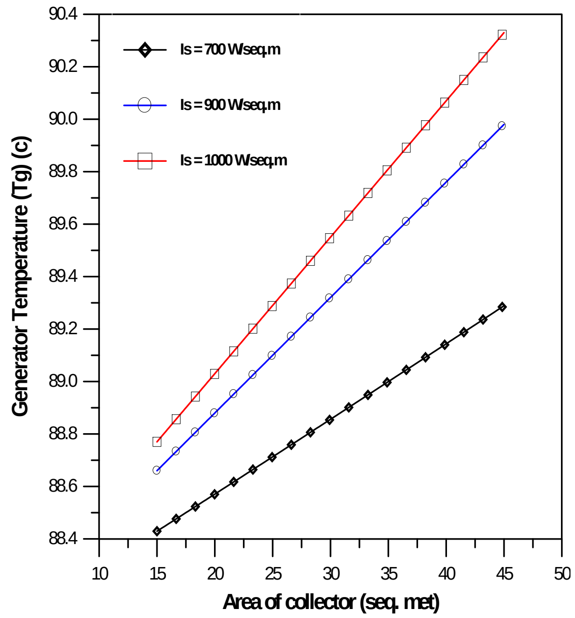
$$H_{aux} = 1 - f \quad (17)$$

## 5. Results and discussion

As mentioned before the absorption cycle needs heat energy to change the condition of refrigerant to produce refrigeration effect. The heat is supplied to the generator to increase its temperature to separate the solution.

Figure(2) shows the variation of generator temperature with collector area for three values of solar radiation intensity (700, 900 and 1000 W/m2) at ambient temperature 45 $^o$ C. From this Figure it can be seen that, the temperature of generator increases with increasing the area of collector for all values of solar radiation due to increase the amount of heat collected with increasing the area of collector which leads to increase the heat transferred to the generator. Also it can be noted from this Figure that, the generator temperature increases with increasing the solar radiation intensity as a result of increasing the amount of heat transfer.

Figure(3) indicates the variation of generator temperature with area of collector for selected values of ambient temperature at solar radiation 1000 W/m$^2$. From this Figure one can observe the increasing of generator temperature with increasing the area of collector for all values of ambient temperature due to increasing the heat transfer as explained in previous Figure. Also the increment in generator temperature for different values of ambient temperature is increased with increasing collector area.




Figure(2). Variation of generator temperature with area of collector for $T_{amb}$ = 45 C$^o$.

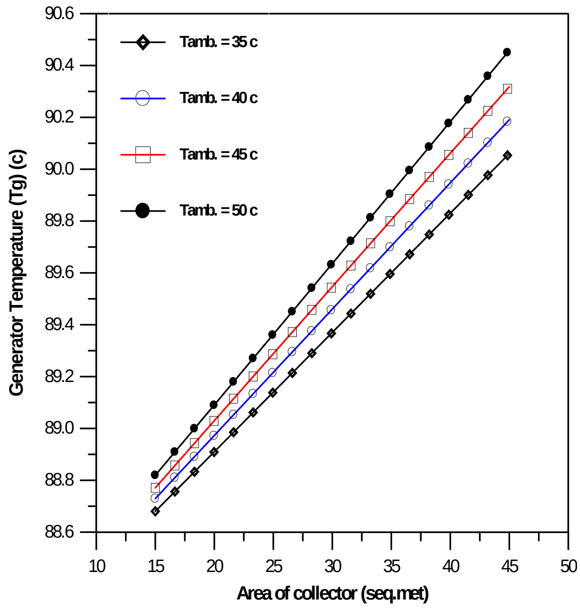



Figure (3). Variation of generator temperature with area of collector for Is =1000 W/m$^2$.

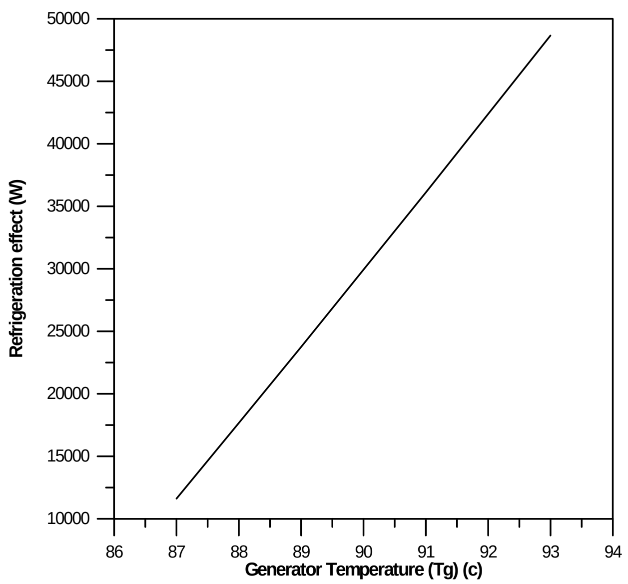



Figure (4). Variation of cooling effect ($Q_{ev}$) with generator temperature .

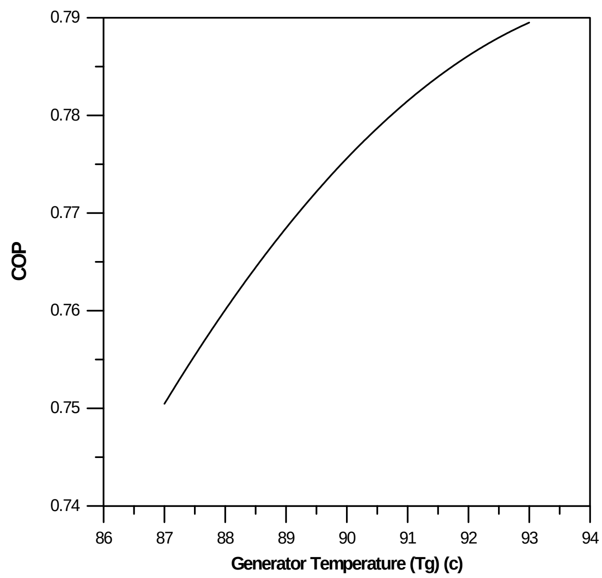



Figure (5). Variation of coefficient of performance with generator temperature .

Variation of cooling effect of the system with generator temperature is presented in Figure (4). From this Figure it can be seen that, the capacity of system is increased with increasing the generator temperature due to increase the efficiency of separation process occurred in generator which lead to maximize the absorption process in the absorber and as a result produce extra circulation for the solution and increasing the flow rate of refrigerant, therefore the heat absorption process in evaporator is increased.

Figure (5) shows the variation of coefficient of performance with generator temperature. From this Figure one can see that, the coefficient of performance is increased with increasing the generator temperature due to increase the heat absorbed in evaporator (cooling effect) as discussed in previous paragraph.

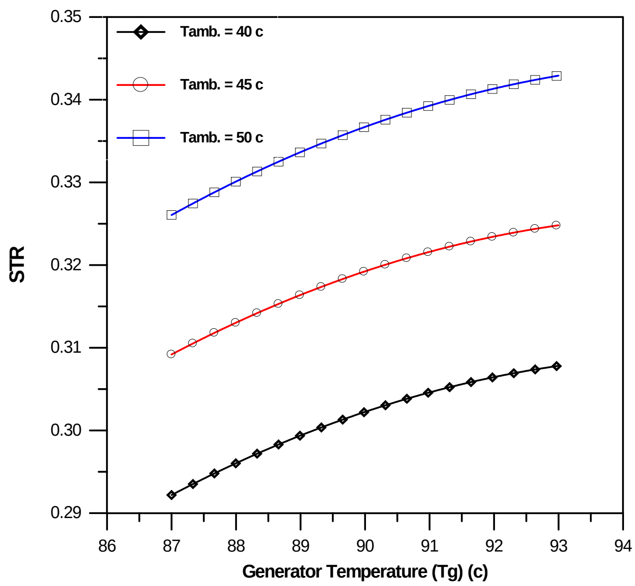



**Figure (6). Variation of solar thermal ratio with generator temperature at Is =1000 W/m$^2$**

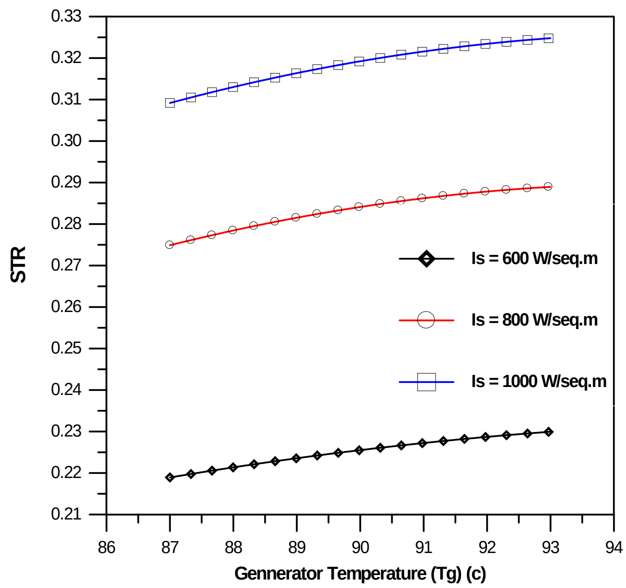



**Figure (7). Variation of solar thermal ratio with generator temperature at $T_{amb}$ =45 $^oC$**

Figure (6) shows the variation of solar thermal ratio (STR) with generator temperature for selected values of ambient temperature at (Is =1000 W/m$^2$). The results presented in this Figure refer to increase of solar thermal ratio which represents the overall efficiency of solar air conditioning system with increasing the generator temperature for all values of ambient temperature due to increase the coefficient of performance of absorption cycle with increasing generator temperature. Also it can be seen that, the STR is increased with increasing the ambient temperature due to increase the efficiency of solar collector and collecting extra amount of heat.

Figure (7) represents the variation of STR with generator temperature for different values of solar radiation intensity at $T_{amb}$ = 45 $^{o}$C. From this Figure one can see that, the STR values is increased with increasing the generator temperature for all selected values of solar radiation due to increase the coefficient of performance. The STR is also increased with increasing the solar radiation due to increase the efficiency of solar collector and the amount of heat transferred.

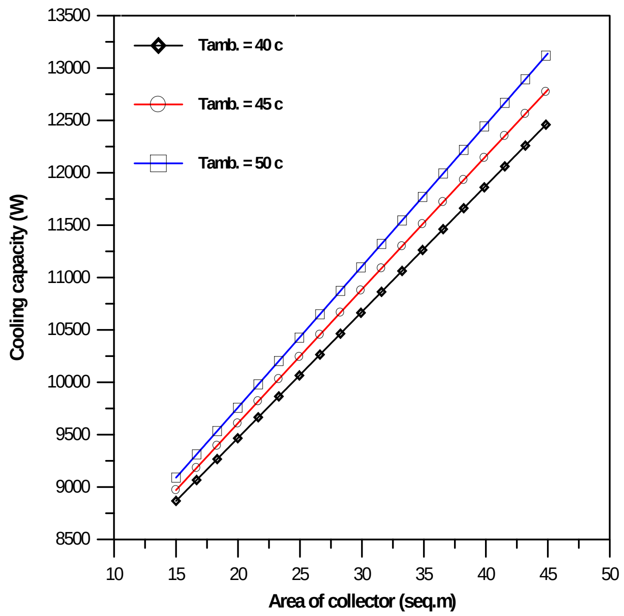



**Figure (8). Variation of cooling effect with collector area at Is =1000 W/m$^2$.**

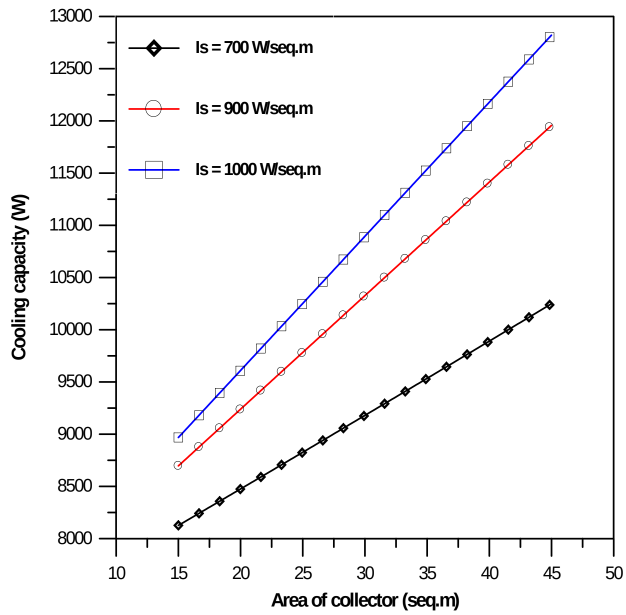



**Figure (9). Variation of cooling effect with collector area at $T_{amb}$ =45 C$^o$.**

Variation of cooling capacity of the system with collector area for different values of ambient temperature at (Is =1000 W/m$^2$) is shown in Figure8. From this Figure it can be seen that the cooling capacity is increased with increasing the area of collector for all values of ambient temperature as a result of increasing the heat absorbed in collector which lead to increase the efficiency of absorption process and enhance the refrigerant flow rate. Also there is increase in cooling effect with increase the ambient temperature for the same collector area due to increase the heat absorbed.

Figure (9) indicates the variation of cooling capacity of the system with collector area for different values of solar radiation at ($T_{amb}$ = 45$^o$ C). From this Figure the cooling capacity increased with increase the collector are for all values of solar radiation due to increase the amount of heat collected in the collector which lead to improve the absorption process and enhance the refrigerant flow rate. The cooling effect is increased also with increase the solar radiation due to increase the heat absorption.

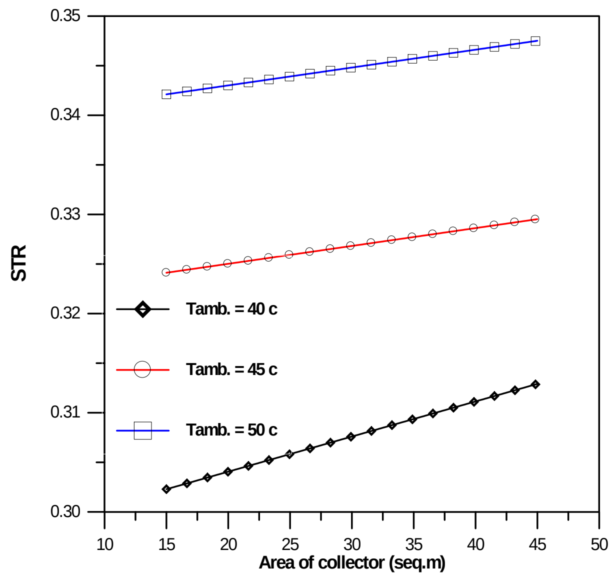



**Figure (10). Variation of solar thermal ratio with collector area at Is =1000 W/m$^2$.**

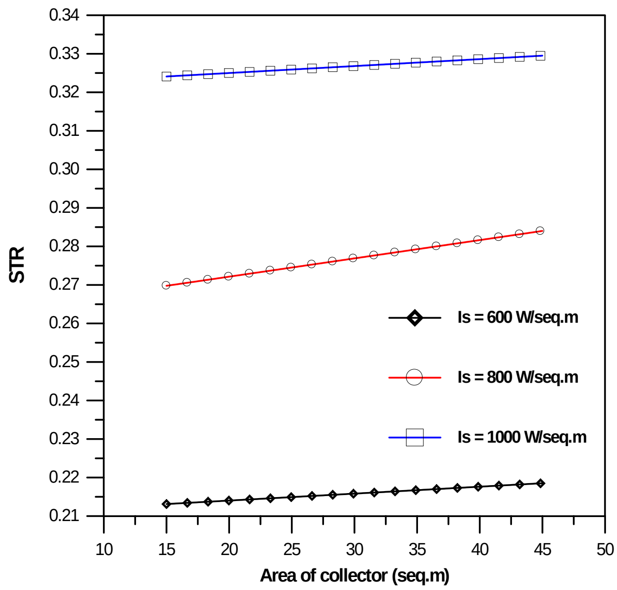



**Figure (11). Variation of solar thermal ratio with collector area at $T_{amb}$ =45$^o$ C.**

Figure (10) represents the variation of STR with collector area for different values of ambient temperature at (Is =1000 W/m$^2$). From this figure it can be seen that, STR is increased with increasing collector area for all values of ambient temperature due to increase the efficiency of the heat collecting and absorption processes. Also STR increased with increasing the value of ambient temperature due to increase the thermal efficiency of solar collector. Variation of STR with collector area for different values of solar radiation at ($T_{amb}$ = 45$^o$ C) is presented in Figure(11). The results presented in this Figure indicate that, STR is increased with increasing the area of collector for all values of solar radiation as discussed in Figure (10). Also STR is increased with increasing the solar radiation due to increase the efficiency of collector and increases the heat collecting.

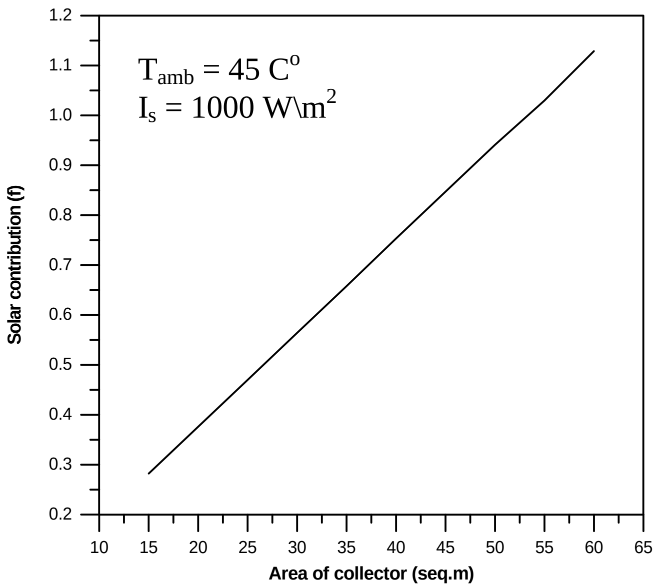



**Figure (12). Variation of solar contribution with Collector area.**

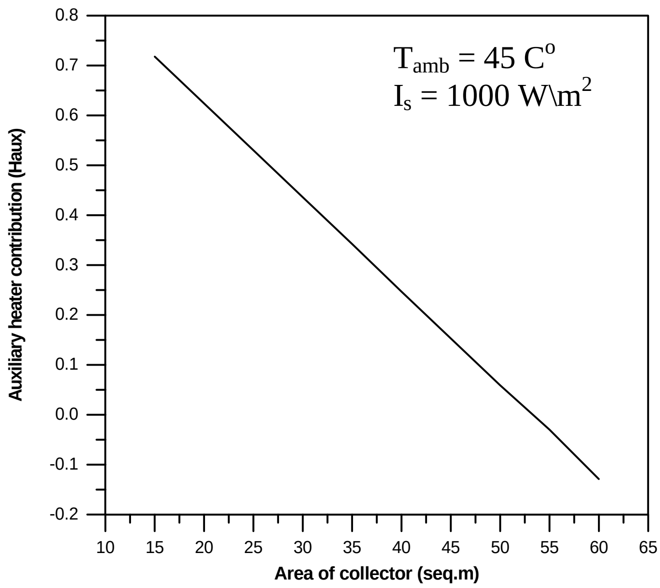



**Figure (13). Variation of auxiliary heater contribution with Collector area .**

Figure (12) shows the variation of solar contribution with area of collector for a certain space with cooling load demand 5 Ton at weather conditions ($T_{amb}$ = 45$^o$ C and Is =1000 W/m$^2$). From this Figure it can be seen that, the solar contribution is increased with increasing the area of collector due to increase the heat collection process and as a result the absorption process is increased. As can be seen from this figure a solar powered air conditioning system with collector area 53 m$^2$ at the mentioned weather conditions can produce the required cooling load and producing extra cooling load require extra area for collector. The results presented in this Figure indicate that, the coupling of absorption refrigeration machines and solar energy can be adequately used to produce the cooling demand for moderate residential applications using solar collectors with reasonable area.

Figure (13) indicates the variation of auxiliary heater contribution with collector area for the same cooling load and climatic conditions mentioned in Figure (12). The auxiliary heater used in this system to store the extra unneeded heat produced by solar collector and give this heat to the air conditioning system in time where the solar energy is insufficient or unavailable. From this Figure one can observe that, the auxiliary heater contribution is decreased with increasing the collector area, since with increasing the collector area the solar contribution is increased and the needing for auxiliary heater is vanished.

## 6. Conclusions

In this paper an investigation was made to study and analyzes the solar assisted absorption air conditioning systems. From the results obtained the following conclusions can be achieved:

1- Solar energy can be used efficiently to provide the heat required to operate the absorption air conditioning systems to produce required cooling for small residential applications.
2- The coupling of solar collectors and absorption refrigeration machines is able to reduce the power consumption for air conditioning applications for hot regions due to the synchronization between cooling demand and availability of solar energy.
3- The area of collector and weather conditions play an important role to increase the cooling capacity of the system.
4- The solar powered AC systems need extra research work to find out the optimum values of affecting parameters and other types of solar collectors must be studied to find out the effect of type of solar collector on the performance of this system.

5- The only disadvantage of this system is its need for large surface area of solar collector.

## 7. References

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## 8. Nomenclature

| symbol | Description | SI unit |
|---|---|---|
| $A_{coll}$ | Total area of collector | $m^2$ |
| COP | Coefficient of performance | - |
| Cp | Specific heat | $J/kg.C^o$ |
| f | Solar contribution | - |
| h | enthalpy | kJ /kg |
| $H_{aux}$ | Auxiliary heater contribution | - |
| $I_s$ | Solar radiation intensity | $W/m^2$ |
| m | Mass flow rate | kg/s |
| $Q_{ucoll}$ | Useful heat from solar collector | w |
| T | Temperature | $C^o$ |

***Greek letters***

| Symbol | Description | SI unit |
|---|---|---|
| $\eta_{coll}$ | Collector efficiency | - |
| $\varepsilon$ | Heat exchanger effectiveness | - |

***Subscripts***

| symbol | Description |
|---|---|
| ab | absorber |
| act | actual |
| amb | ambient |
| c | cold |
| coll | collector |
| cond | condenser |
| ev | evaporator |
| g | generator |
| h | hot |
| in | inlet |
| max | maximum |
| min | minimum |
| o | outlet |