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A Proposition for Solar Collector Incorporation in an Office Size Vapor Absorption Air Conditioning System with Low Electricity Consumption

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Abstract: A water vapor absorption air-conditioning system is proposed for installation at residential buildings and offices within the extreme weather of Iraq. The hot water required for evaporating water content of LiBr solution is supplied by a series of flat plate and concentrated solar collectors with a basic design that is expected to raise the temperature of water to the required value. Space saving and cost reduction are considered; therefore, the system can be easily manufactured and installed. Theoretical calculations and recommended data for design are given, and compared with a similar existing system. The proposed system is expected to run and deliver the required cooling capacity at relatively low electricity consumption, less than 1,500 W. The cost of manufacturing is also low since simple and cheap components are involved, for instance, a conventional air cooler is proposed as a substitution for a cooling tower. Although the expected coefficient of performance for the system is low compared to the available vapor compression system (about 0.3), the free of charge solar heat source turns it in more cost-effective unit regarding the increasing electricity consumption of conventional air conditioners and shortage in electricity supply hours, especially in Iraq.

Keywords: air conditioning system, lithium bromide, solar collector, coefficient of performance, electricity consumption.

在办公室规模的低耗电吸汽式空调系统中安装太阳能集热器的提议

摘要：建议在伊拉克极端天气条件下，在住宅楼和办公室安装吸水汽空调系统。蒸发溴化锂溶液中的水分所需的热水由一系列平板和聚光太阳能集热器提供，其基本设计有望将水温升高到所需值。考虑节省空间和降低成本；因此，该系统可以很容易地制造和安装。给出了设计的理论计算和推荐数据，并与类似的现有系统进行了比较。预计所提议的系统将以相对较低的电力消耗（低于1,500宽）运行并提供所需的冷却能力。由于涉及简单且廉价的组件，因此制造成本也很低，例如，建议使用传统的空气冷却器作为代替冷却塔。尽管与可用的蒸汽压缩系统相比，该系统的预期性能系数较低（约0.3），但免费的太阳能热源使其成为更具成本效益的单元，因为传统空调的电力消耗不断增加，而且空气不足。供电时间，尤其是在伊拉克。

关键词：空调系统、溴化锂、太阳能集热器、性能系数、耗电量.

1. Introduction

The extreme weather of Iraq is becoming more and more uncomfortable, especially during summer when the temperature reaches unexpected numerical values [1]. According to the data of the past three years, temperatures at midday during the summer season recorded such a high range that special considerations should be taken in order to find solutions to face this serious challenge [2]. A considerably huge amount of energy is thus required to maintain the indoor temperature within the comfort level, and accordingly,

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heavier and heavier electrical loads are expected year by year. Meanwhile, the government of Iraq and especially the Ministry of Electricity are striving to cover the residential demand, which is increasing randomly with a big factor every year. However, if the situation remains without a true pace in the yard of new energy sources, the existing electricity production is unable to supply the residential sector with electricity even for half of the day hours.

For this reason, renewable energy, namely solar energy, should be incorporated into the current production of electricity in order to sustain the national electricity network with clean energy [3]. On the other hand, conventional air conditioning devices are still high in electricity consumption appliances. These appliances consume approximately 50% of the total electricity consumption compared with lighting and other household appliances. This leads to the necessity of finding new designs where air conditioning systems can have a lower impact on electricity. These can be achieved either by designing air conditioners that are run with solar energy (Photo Voltaic) or alternatively incorporating solar energy in the air conditioning system as a heat source.

Small air conditioning systems which are powered by photovoltaic panels can be found in local markets. However, these air conditioners are still small in their output cooling tones because they maintain low power consumption, which sounds unfeasible for modern buildings and residential areas after a rough comparison with their prices. Many researchers have attempted to convert these devices into high-performance ones at low electricity consumption [4]-[6].

The other technology for incorporating solar energy in a system of air conditioning is still in its infant stage because the amount of heat required for running the system and keeping the comfortable indoor temperature during the long span of summer day hours requires special and sophisticated technologies. On the other, this technology is promising in terms of high cooling capacity, low energy consumption, and small space requirements [7]-[9].

In this research, a design is proposed for an integrated solar air conditioning system that can be used in residential buildings and offices since the peak cooling loads occur at midday when the ambient temperature reaches its highest level. The solar radiation beam is in its highest intensity. The proposed system uses an absorption chiller that can deliver chilled water at a relatively low temperature using a solution of LiBr and H_2O. In contrast to a conventional absorption system, the heat source required for generating the concentrated solution is solar energy instead of a conventional boiler or an electrical heating element. The solar energy is absorbed by a series of flat and concentrated solar collectors, and the cooling tower, which supplies cold water required for condensation of water vapor, is replaced by a commercial air cooler that utilizes the evaporation of water to cool stream of air that reduces the temperature of cooling water.

Thus, this research is unique in reducing the cost and the overall size of the air conditioning system; i.e., reducing the cost is achieved by using solar energy and low-cost components for installation. However, size reduction is achieved by reducing the size of components to be suitable for residential installation. It should be noticed that the vapor absorption air-conditioning systems available in markets can deliver 50 kW and higher. In comparison, the proposed system is designed to deliver about 15 kW, which is comparable to the conventional vapor compression system used in residential buildings and offices.

2. Description of the Main Components of the System

To have solar energy incorporated in an air conditioning system, the solar-heated medium (distilled water) is circulated in a heat exchanger where the coolant solution losses some of its water content through the boiling process inside a vacuum space. The higher the temperature of the solar-heated medium, the faster the evaporation of water within LiBr solution and, subsequently, the higher the system efficiency absorbing heat from the indoor environment.

As a comparison, if the process of evaporation is achieved by an electrical heating element, then the overall electricity consumption for the system jumps to a high level because of this resistive load. On the other hand, the solar-heated medium can be brought to a temperature that is close to the boiling temperature of distilled water. Moreover, the solar radiation beam during the summer season in Iraq is rarely interrupted except during those few dusty days, see Fig. (1), which shows the solar radiation beam within Amarah City, Maysan Province, Iraq (31.8379ºN, 47.1421ºE) during August 2016 [10].

The extreme hygroscopic salt of Lithium Bromide (LiBr) is utilized as a desiccant medium in the solar integrated air conditioning system. The 50% LiBr solution can reduce the pressure of mixing water to 80% [11]. This ability offers two advantages; first, it creates a vacuum pressure required for rapid evaporation. Second, it absorbs heat required for evaporation from the coolant medium (chilled water). The only disadvantage of LiBr is its high corrosive character which can be overcome by utilizing non-corrosive chambers.

In order to be fully understood, the mechanism of the system by which it approaches a low-temperature coolant and the main components of the proposed system are described below:

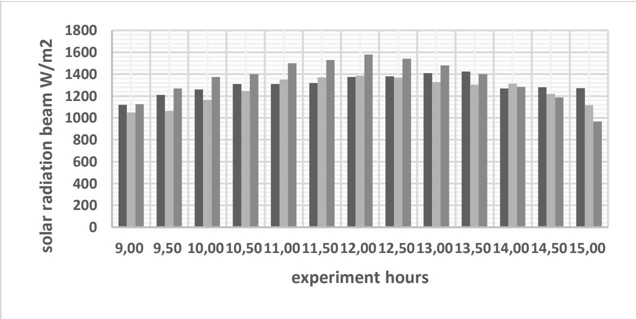

Fig. 1 Average solar radiation beam within Amarah City, Iraq (August 2016)

2.1. The Solar Collectors

There are two flat collectors connected in series via a water pump, and their output is connected to a concentrated collector, see the schematic diagram of Figure 2.

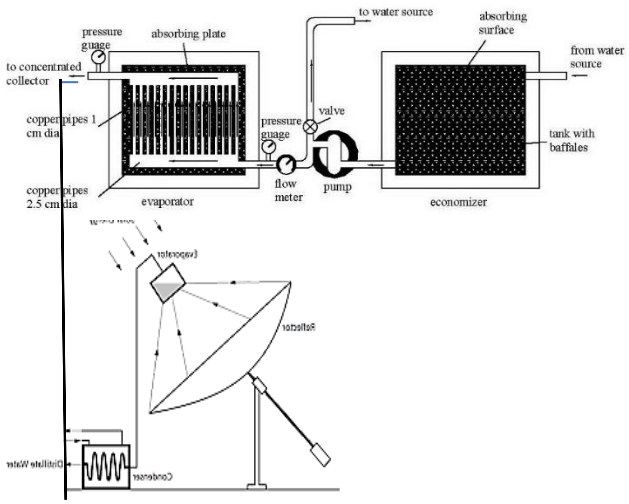

Fig. 2 A schematic drawing of the series of solar heaters

According to the data taken during August 2018, an ambient temperature range of 35˚C- 55˚C was recorded during the day hours from 9:00 AM to 3:00 PM. This temperature range ensures an output water temperature of almost 72˚C, which is after passing the concentrated collector, a temperature above boiling level is reached that is sufficient for evaporating the water content of LiBr solution in the generator since the generator is maintained under vacuum pressure.

2.2. Generator and Condenser Chamber

The suggestion is to have both processes of vapor generation and water condensation in the same vacuum chamber. This ensures rapid evaporation and condensation and subsequently rapid generation of concentrated LiBr solution, which is necessary for better efficiency of the chiller representing the heart of the air conditioning system.

2.3. Absorber and Evaporator Chamber

The water evaporated from the solution of LiBr at the generator is condensed in the condenser and runs in drops of water around the unmixed chilled water pipes inside the evaporator. The concentrated solution of LiBr, which enters the absorber in the shower after exchanging heat with the upgoing dilute LiBr solution, is so reactive to the water drops in the evaporator so that heat is extracted from the network of chilled water in order to convert the water drops into vapor before reacting with the shower of concentrated LiBr solution in the absorber. Hence, chilled water with a relatively low temperature is expected to enter the fan coil and extract heat from the indoor space.

2.4. Fan Coil in a Floor Standing Arrangement

The suggestion for all components except solar heater and air cooler should be incorporated in a floor-standing compartment. There is more than one reason beyond this suggestion, among others; space-saving, less heat loss, and simple portable design. The supply of chilled water to the fan coil is passed through a storage tank which is well insulated with a capacity of 100 kg. A tilt angle of inclination is set to the coil for the drain of condensate drops around the chilled water coil. In addition, the stream of the air cooler, which acts as a cooling tower, can be mixed with the returned indoor stream to reduce its temperature. However, this suggestion represents an option that can be ignored if the output of the air cooler is humid and may negatively affect the unit efficiency. The schematic drawing in Figure 3 also shows the position of the fan coil, which is installed in the same compartment where the vapor generator and evaporator are located. As it is clearly seen, the size of the compartment is comparable to the convention floor standing air conditioners.

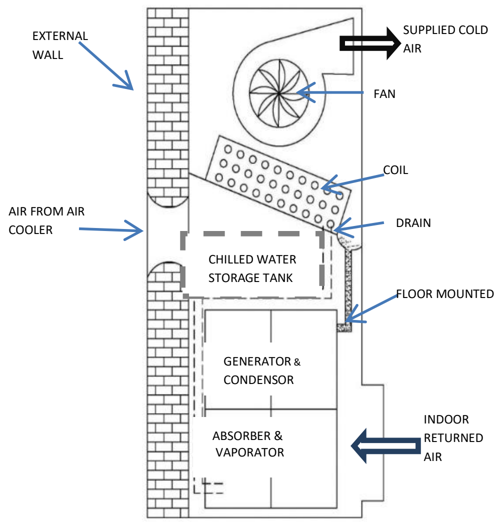

Fig. 3 A schematic drawing of the fan coil inside the floor-mounted compartment

2.5. Air Cooler as A Cooling Tower

During the summer season in Iraq, the weather is so dusty and dry that using a cooling tower does not seem practical since a huge amount of water is required to substitute the rapidly evaporated water beside the clay sediment caused by the dust [12]. As an alternate, the water pool of a conventional air cooler can be used as a cooling tower because the dust is trapped by the damp media of the surrounding windows. In addition, the evaporation of water is less because there is no direct exposure to the open sun. This is expected to result in better water-saving; besides (as mentioned above), the relatively cold air stream of the air cooler can be mixed with the returned indoor air stream that passes through the fan coil; hence an improvement in the efficiency is achieved. Moreover, an extra water pump is required to supply the water from the water pool of the air cooler to the condenser.

2.6. Hot and Chilled Water Storage Tanks

In a solar air conditioning system, it is essential to have hot and chilled water storage tanks to overcome the mismatch between solar gain and cooling loads [13], [14]. In order to reduce the heat loss from the hot water tank, the storage tank was incorporated in the solar heater, where a large part of its surface is exposed to direct solar radiation. The same was suggested for the chilled water storage tank, which is incorporated in the indoor unit and positioned in the neighboring space of the fan coil. This is also necessary for improving the efficiency of the whole system. As suggested in [15], an optimum storage volume of a hot water storage tank rages for 50 kg/m^2 of solar collector area and 2 – 4 times volume for a chilled storage tank. Although this recommended volume is promising for better efficiency, the suggested system has smaller volumes since the extreme weather of Iraq can be more space and cost-effective in reducing the size of both storage tanks.

3. General Layout of the Components

Figure 4 below shows a schematic diagram for the general layout of the above-mentioned components. This layout should be made more compact upon manufacturing for the reason of space saving. As it is shown, there is a heat exchanger midway between the generator and absorber. This heat exchanger assists the evaporation of water for the dilute solution of LiBr and H_2O.

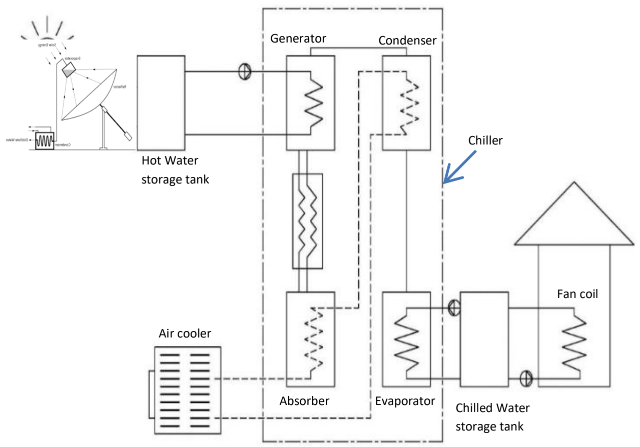

Fig. 4 A schematic diagram of the general layout of the system

Since the temperature of the absorber has a stronger influence on the overall efficiency of the system, the water that comes from the air cooler is first passed in the absorber before it enters the condenser [16]. During the summer months in Iraq, the ambient temperature is 45˚C – 55˚C between 10:00 AM and 6:00 PM, which neglects the usage of auxiliary heating devices in the hot storage tank. Nevertheless, strict control of pressure and temperature is required to avoid the crystallization line of LiBr solution as this may negatively affect the flow of solution through the generator and absorber.

As seen, five pumps are required to keep the system running, which represent the only electricity-driven components. The total electricity consumption does not exceed 1 kW. This makes the system more economical in electricity consumption than conventional air conditioners, which normally consume more than 3 kW of electrical power.

4. Thermal Process Involved in the System

Figure 5 shows the P – T diagram of the thermal cycle of the processes that occurred inside the system.

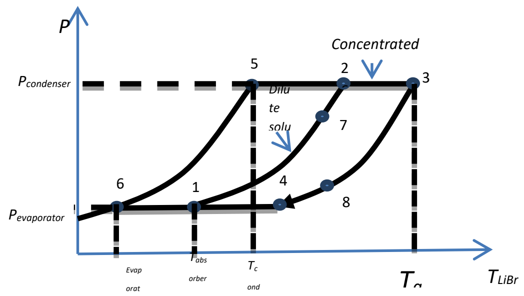

Fig. 5 A schematic diagram of the thermal cycle of the system on *the P-T* diagram

There are seven thermal processes involved in the suggested system; these are:

➢ In the thermal process within the heat exchanger (lines 1-7), the dilute solution enters the heat exchanger at point 1 and leaves at point 7. Both its temperature and pressure are rise. The concentration of LiBr during this process is held constant.

➢ The thermal process in the generator causes the water in the dilute solution to boil at a constant condenser pressure. This process is indicated by lines 2-3, where the dilute solution enters the generator at point 2 and leaves with different higher concentrations at point 3. The concentration, however, does not reach the crystallization line because the temperature of water supplied by the solar heater did not exceed 90˚C [17].

➢ The thermal process inside the heat exchanger with the high concentration solution preheats the diluted solution before entering the generator. This is indicated by lines 3-8. The concentration of LiBr does not change during this process.

➢ The thermal process occurs in the absorber where heat is extracted from the chilled water after the reaction of high concentration solution with the water vapor inside the evaporator. This process occurs in the absorber and is indicated by the lines 8-4-1. The overall efficiency of the system is decided in this process which occurs at the relatively low pressure of the evaporator.

- The thermal condensation process inside the condenser occurs at a constant condenser pressure using the cold water received from the air cooler. This process is indicated by lines 2-5.
- The thermal process during the flow of water from the condenser. Because the water flow passes through an orifice, heat is lost, which causes a drop in temperature and pressure. This process is indicated by lines 5-6.
- The thermal process occurs in the evaporator at low pressure, resulting in evaporating the water coming from the condenser and immediately being absorbed by the high concentration solution. The evaporation of water inside the evaporator needs heat extracted from the chilled water flowing in the absorber hence reducing its temperature further. This process is indicated by lines 6-1.

The high-concentrated solution is converted to a low concentrated one after reacting with the water vapor and should be pumped back to the generator, thereby completing the cycle.

5. Theoretical Calculations

Fan coil and air cooler have basic calculations found in the textbooks of air conditioning, among which [11] is recommended. For a solar collector, however, the following equations are applied:

Under steady-state conditions, the actual heat delivered by a solar collector can be found from the mass flow rate and constant specific heat ($\dot{m}C_p$) of water flowing through the collector and the difference between the inlet and outlet temperatures of water, i.e.

$$Q_s = \dot{m}C_p(T_o - T_i) \tag{1}$$

where T_i is the inlet water temperature, and T_o is the outlet water temperature. The collector efficiency can be obtained from the formula suggested by [18];

$$\eta_s = F_R\left[\tau\alpha - \frac{h_L(T_i - T_\infty)}{G_l}\right] \tag{2}$$

where G_l is the solar incident per square area and F_R is a correction factor which can be obtained from the equation:

$$F_R = \frac{\dot{m}C_p}{A_c h_L}\left[1 - exp\left\{\frac{h_L \grave{F} A_c}{\dot{m}C_p}\right\}\right] \tag{3}$$

where A_c is the collector area and $\acute{F}$ is the collector efficiency factor which is the ratio between the losses heat transfer coefficient from the solar collector h_L to the heat transfer coefficient from the fluid to the ambient air h_o, i.e.

$$\grave{F} = h_L/h_o \tag{4}$$

It is beyond the scope of this research to provide data on the specific consumption of heat by the LiBr absorption refrigeration unit as a function of the evaporation and condensation temperatures. Nevertheless, the heat energy and coolant requirements of our simple LiBr absorption unit can be estimated. The thermodynamic properties of LiBr solution are given by the American Society of Heating, Refrigeration, and Air conditioning Engineering (ASHRAE) [19].

Assume a cooling load of 5 ton (which is equivalent to 60,000 Btuh) is required to maintain an indoor temperature T_{air} at 25˚C, and the following calculations are required:

- Heat extraction by the cooling water
- The evaporation rate of cooling water
- The mass flow rate of LiBr solution (dilute & concentrated)
- Amount of heat the heat exchanger
- Heat transfer between the hot water coil and the dilute solution in the Generator.

The following calculation procedure is based on energy balance around the main components (refer to Figure (5) to follow up with nomenclature and equations);

- Mass flow rate of the chilled water (m_c) = heat transfer at evaporator / enthalpy difference of water vapor and liquid which is expressed as follows:

$$\dot{m}_c = \dot{Q}_e/(h_v - h_l) \tag{5}$$

- Mass balance at the absorber yields: mass flow rate of chilled water at the evaporator + mass flow rate of LiBr solution at the generator = mass flow rate of LiBr solution at the absorber; i.e.

$$\dot{m}_c + \dot{m}_g = \dot{m}_a \tag{6}$$

- However, the mass flow rate of LiBr solution in the generator X solution concentration ratio at the generator = mass flow rate of solution at the absorber X solution concentration at the absorber. In the symbolic form:

$$\dot{m}_g . x_g = \dot{m}_a . x_a \tag{7}$$

Substituting in equation (2) yields:

$$\dot{m}_g = \dot{m}_c . x_a/(x_g - x_a) \tag{8}$$

Moreover, the mass flow rate of LiBr at the absorber can also be estimated from equation (6).

- The heat transfer at the heat exchanger can be calculated using either the mass flow rate of solution at the generator or the mass flow rate of solution at absorber, which has already been found. Thus:

$$\dot{Q}_{HE} = \dot{m}_a(h_{gi} - h_a) = \dot{m}_g(h_g - h_{HEo}) \tag{9}$$

where:

h_{gi} - enthalpy of solution at the inlet of generator;

h_{HEo} - enthalpy of solution at the outlet of heat exchanger.

- The heat exchanged in the generator between the hot water and LiBr dilute solution can be expressed as follows; the heat input at the generator = the mass flow rate of chilled water X enthalpy of vapor at the generator + mass flow rate of LiBr solution at the generator X enthalpy of solution at the generator – mass flow rate of LiBr solution at the absorber X enthalpy of solution at the entrance of generator. In the symbolic form:

$$\dot{Q}_g = \dot{m}_c . h_{vg} + \dot{m}_g . h_g - \dot{m}_a . h_{gi} \quad (10)$$

➢ The heat rejected by chilled water = the heat transfer inside the condenser + the intercooler between condenser and absorber; i.e.,

$$\dot{Q}_r = \dot{Q}_c + \dot{Q}_{ac} \quad (11)$$

On the other hand, the heat transfer at the condenser ($\dot{Q}_c$) is found as follows:

$$\dot{Q}_c = \dot{m}_c h_{vg} + \dot{m}_g h_g - \dot{m}_a h_{gi} \quad (12)$$

And the intercooler between condenser and absorber ($\dot{Q}_{ac}$) is found as follows:

$$\dot{Q}_{ac} = \dot{m}_c h_{vc} + \dot{m}_g h_{gi} - \dot{m}_{HEi} h_{HEi} \quad (13)$$

Substituting equations (12) and (13) in equation (11), the heat rejected by the chilled water is obtained.

➢ The coefficient of performance of the chiller can be found from the ratio of heat rejected by the chilled water at the absorber to the heat supplied to the generator; i.e.,

$$COP = \dot{Q}_r / \dot{Q}_g \quad (14)$$

➢ The COP of the system is the ratio of output cooling load (60,000 Btuh) and the total heat supplied by the solar heater. i.e.,

$$COP = \dot{Q}_o / \dot{Q}_s \quad (15)$$

6. Recommended Data for Design

The proposed system should fulfill practical data recommended by the manufacturers of a conventional absorption chiller to achieve the expected performance. Nevertheless, in the proposed system, a boiler or an auxiliary heater is not involved in supplying heat to the water flowing in the generator. As described above, the only heat source is solar energy received by the flat and concentrated collectors. However, this high-temperature level will violate the standard manufacturing data of LiBr absorption chillers since the required inlet temperature should be above boiling temperature.

To overcome this deficiency, a lower generator pressure than the one recommended should be achieved to ensure a lower boiling temperature of the water content within the solution of LiBr. We refer to Figure 6 for the relationship between the pressure and temperature of pure water.

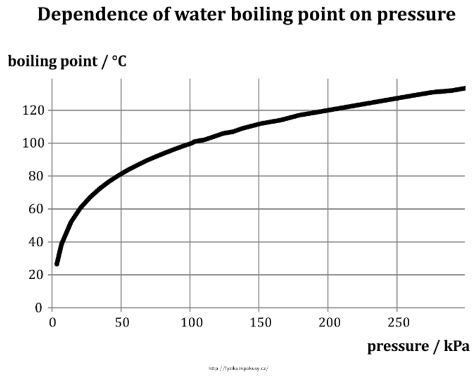

Fig. 6 Dependence of water boiling temperature on pressure

Thus, the data tabulated in Table 1) is applicable for the system proposed, which ensures an acceptable coefficient of performance compared to the conventional absorption systems of air conditioning.

Table 1 Design pressure and numerical temperature values for chiller components

Chiller Components	Temperature (˚C)	Pressure (kPa)
Generator	90	5
Absorber	40	< 1
Condenser	45	5
Evaporator	6	< 1

The mass concentration ratio of dilute LiBr solution entering the heat exchanger should be above 50%, and for the concentrated solution leaving the heat exchanger should be above 60%. As a matter of fact, a concentration above this ratio could push the solution to the crystallization line, which represents a serious problem that may result in choking the flow of the solution [20].

According to [21], the coefficient of performance for solar-assisted air conditioning systems does not exceed 0.7. It is not an encouraging value compared with the comparable vapor compressed air conditioning systems, which reach as high COP as 3.

However, solar-assisted air conditioning systems generate nearly as twice as much waste heat as compressive refrigeration machines. This affects overall energy consumption and cooling tower sizing; for each refrigeration unit, an absorption chiller must reject around 2.5 units of heat versus approximately 1.3 units for a vapor compression machine [22].

The temperature for chilled water was maintained at 9˚C, and the water temperature supplied by the cooling tower is 28˚C. These data can be achieved by our system since the outdoor temperature is much higher in Iraq than the one in Malaysia; hence the outlet temperature of the solar heater is higher than the one recorded. Therefore, according to the curve above, the COP of our system is expected to approach a value of 1. In addition, the air cooler suggested as a replacement for cooling water can be dual function component; i.e., besides supplying cold water to the condenser and absorber, it can also play a role in reducing the total cooling load by mixing the air coming from the air cooler with the returned indoor air. However, this should still be an option.

7. Conclusion

Although the summer season is flooding with solar energy in Iraq, the incorporation of solar energy (as a form of green energy) in electricity generation as well as in air conditioning systems is still in the infant stage that a real and brave attempt is required to fund researches, investments, and designers in order to make use of such huge, free of charge energy. The investments and installation shall not be easy and cheap at the first stages. However, the uncountable advantages of solar-assisted air conditioning systems that consume lower electricity definitely have fruitful results. No matter how low the coefficient of performance for our suggested system, it still represents a seed in the fertile soil of renewable energy field.

As mentioned in the beginning, the weather in Iraq is becoming more and more unbearable after the uncontrolled consumption of fossil fuel by main power plants and private diesel power generators. In addition, the thousands of air conditioners that blow heat everywhere convert life in Iraq, especially in the summer season, into such hell-like. For this reason, the above-mentioned ideas should be adopted by the Ministry of Industry and put in a site where remarkable data is required to improve the design suggested and meet the desired requirements.

As a matter of fact, up to this time, the air conditioning systems with absorption chillers are still manufactured on a large scale, making them economically unfeasible for installation at small offices and houses. Thus, the described design is made to substitute the conventional air conditioners used in residential building since it is compact, easy to install, and of the most importance, consume lower electrical power.

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