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Energy Conservation Using a Double-effect Absorption Cycle Driven by Solar Energy and Fossil Fuel

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Abstract

Energy conservation is a main theme nowadays in research mainly due to the recent sudden rise and wide fluctuations in energy prices. This uncertainty is viewed as an indication of reaching the depletion point of fossil fuel and consequently, energy conservation has been tackled from all various aspects. Herein, an assessment is made to evaluate the effectiveness of the cooling that result from a double-effect reversed-flow lithium bromide absorption cycle driven by a combination of solar energy and a fuel-fired boiler. The assessment is to show the cycle performance under various proportions of solar contribution to drive the cycle. The analysis was aided with a computer code that was developed specifically to evaluate the instantaneous daily total solar irradiation. The results have indicated impressive effective COP that may be obtained when varying the solar contribution whereby a potential of energy saving at least 45% when only 15% of the roof area is allocated to solar panels. The eventual goals of the study are for potential application in Jordan and in countries with similar environments with the aim to lessen the dependence on fossil fuel.

Keywords: Solar cooling; Energy conservation; Double effect absorption cycle; Use of renewable energy

Abbreviations

C	Sky diffusive factor
COP	Coefficient of Performance
D	Distance from earth to sun
D_o	Mean distance from earth to sun
GJ	Giga Joules
GH	high-temperature generator
GL	Low-temperature generator
H	Hour angle
H-HX	high-temperature heat exchanger
I	Extraterrestrial direct solar beam intensity (W/m^2) at distance D
I_b	Total solar irradiation on a plate tilted at an angle β
I_{bd}	Direct solar beam intensity (W/m^2)
I_o	Extraterrestrial direct solar beam intensity (W/m^2) at mean distance D_o
kW	kilo Watt
l	Latitude angle
L-HX	Low-temperature heat exchanger
SFDeAC	Solar-Fuel driven Double-effect Absorption Cycle

Greek Symbols

α	Altitude angle
β	Tilt angle from horizontal plane of the solar panels
δ	Solar declination angle
ϕ	Azimuth angle
θ	Angle between the direct sun beam and the normal to the panels
θ_z	Zenith angle
ρ	Optical reflectivity of the surrounding
τ	Optical depth attenuation of the solar beam

1. Introduction

Perhaps a reasonable strategy to lessen the degree of dependence on fossil-fuel is not to have a single comprehensive scheme, but rather to consider a multitude of hybrid schemes that seek to optimize the use of energy at the end application. A comprehensive scheme would be as in generating electricity from nuclear power plants since the later is much abundant than fossil fuel in terms of energy content [1].

Furthermore, for Jordan, as the rest of the world, has seen an upward shift in the living standards which lead to an increase demand for energy. In a specific area, a significant increase has been seen in the use of air-conditioning systems that runs on electricity which is normally generated in fossil-fuel power plants. Unfortunately, in addition to being a national burden since for Jordan nearly all natural gas and oil are imported, but it also means that probably more of the fossil fuel will be consumed at faster rates. Therefore, alternative systems that are energy efficient and rely on renewable energies

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may serve to lessen the degree of increase in demand for fossil energy.

Fortunately for Jordan, although it lacks significant resources for natural gas and oil, however, it is one of those countries that have considerable solar irradiation. In a simple calculation, as predicted by the computer code developed herein, the average solar irradiation for Jordan on its 91971 square km is 2.62 x 10^{11} GJ for the months June through September, with the assumption that the entire area treated as a flat plate. This amount of energy is equal to about 1190 times more than the annual need of the country from fossil energy whereby the usage for the year 2007 is about 100,000 oil barrels per day [2] with each barrel contains about 6.1 GJ.

In the current study, energy saving is demonstrated through the utilization of solar energy which is coupled with a fuel-fired boiler to drive an efficient absorption cycle to obtain comfort cooling. Absorption cycles have received considerable attention in an attempt to improve their efficiency [3, 4, 5, and 6]. A successful implementation of solar cooling, however, would consequently imply drastic improvement in performance. The advantages of including the fuel-fired boiler is to make the system more dependable and to extend the operational hours as compared to previous work where the system was considered to be solely driven by solar energy [7]. Specifically, with such a combined system it can be tailored to be driven by a source of free energy at different proportions. Other advantages to the system is that absorption cycles may use water vapor as refrigerant, which is in complete harmony with the environment unlike R12, R22, R134a, etc. Also, it is of less harm to the environment since they lead to an eventual decrease of emission in green gases at power plants. Realistically, however, these systems are relatively large and require substantial initial capital cost, therefore, an initial potential application of these systems would be in large facilities like educational institutions and shopping malls where savings in running cost may offset the initial cost in a reasonable payback period.

The working principle of the basic absorption cycle is that a liquid pump replaces a compressor whereby the power requirement for pumping is far less than in the case of vapor compression. The working fluid in the absorption cycle; i.e., water, once it leaves the evaporator it gets absorbed by a liquid; i.e., lithium bromide solution, whereby the solution is pumped to the pressure of the condenser. In the high-pressure state heat is used to vaporize the refrigerant from the solution with the vapor continuing its typical refrigeration cycle while the high-concentration solution is repeated for absorption at the low evaporator pressure. The compatibility of these systems with solar energy is that the required thermal energy for their operation is required at moderate temperature, which may be provided by solar collectors; i.e., evacuated tubes.The absorption cycles are known for their low coefficient of performance (COP), e.g. about 65%. However, with two generators the cycle may be significantly enhanced, where in this configuration it is referred to as double-effect absorption cycle. There are options on how the generators are connected; namely, 1) in series; where the absorber connects to the high-temperature generator followed by the low-temperature, 2) in parallel; where both generators are connected to the absorber, or 3) reversed flow; where the low-temperature generator is connected to the absorber first followed by the high-temperature generator. The reversed flow arrangement is known to be more efficient yielding a theoretical COP of higher than unity. The overall improved efficiency is consistent with the second law of thermodynamics since the heat is supplied at higher temperature in the case of the double-effect.

The current interest in the absorption cycle driven by renewable energy resources has arisen during the recent intent of establishing a scientific incubator at the Hashemite University with one of the primary projects is in the area of solar cooling for desert climates. The main motive for the high interest in this project was the significant anticipated savings in electrical energy that is used for driving standard air-conditioning units for comfort cooling during operational hours.

Interest in the solar driven absorption cycle is not new. Assilzadeh et al. [8] have investigated the performance of a lithium bromide absorption cycle with application in Malaysia using a basic absorption cycle. Ghaddar et al. [9] have conducted modeling and simulation of a solar absorption system for Beirut. Hammad and Zurigat [10] tested a solar driven cooling system and they reported a COP of 0.55. Qu et al. [11] reported a successful installation at Carnegie Mellon University of a double-effect lithium bromide absorption system driven by natural gas heating source and solar energy collected by an array of parabolic trough solar collectors. They have demonstrated that the solar contribution was 39% during cooling and 20% during heating mode. Duff et al. [12] demonstrated in a building in Sacramento, California the use of the double-effect absorption cycle driven by integrated compound parabolic concentrator evacuated solar collectors, with the original gas-fired generator in the absorption system removed. They have obtained a maximum COP of 1.1.

In this article, the effectiveness of hybrid cooling system; i.e., a double-effect reversed-flow absorption cycle driven by solar energy combined with fossil fuel-fired boiler is assessed in terms of viability for application in Jordan; specifically in Az-zarqa city. The thermal energy required for operating the cycle primarily comes from the solar energy which is collected via evacuated tubes and any insufficiency in thermal energy is augmented by a fuel-fired boiler. A computer code was developed to compute solar irradiation. The system performance is measured using the coefficient of performance (COP) which is specifically defined herein as the net system's cooling divided by the net energy supplied by the boiler. Thus, when the system is solely dependent on solar energy its COP tends to infinity indicating no significant operational costs. The performance and energy savings are cast in terms of the percent of roof areas allocated to solar panels, which permit easiness for preliminary design purposes. The advantage of having the boiler, in addition to extending the time range of operation when solar irradiation drops below the design limit, is to make the overall cycle more reliable in supplying sudden rises in cooling demand as well as when solar irradiation drops due to fluctuation in weather conditions. Additionally, it provides design flexibility of limiting the surface area of the evacuated tubes that to be installed.

2. System Description

The double-effect reversed-flow absorption cycle using lithium-bromide solution is depicted in Figure 1. The shaded items are the components that are necessary for the absorption cycle. Also, shown in the figure the schematic arrangement of the hardware that is required for capturing the solar energy augmented by the fuel-fired boiler. Starting at the condenser the liquid refrigerant; i.e., water, is passed through the expansion valve to lower its pressure to that of the evaporator where absorbed heat completely vaporizes the saturated refrigerant (water). The water vapor is then absorbed by the bromide solution due to the strong affinity between the two, hence diluting the solution concentration. The diluted solution is pumped to a higher pressure corresponding to that of the low-temperature generator (GL), however, passing through a low-temperature heat exchanger (L-HX) whereby gaining heat from the returning high concentration solution coming back from the generators. In the double-effect absorption cycle part of the solution leaving the GL generator is directed to the high-temperature generator (GH), however, passing through a high-temperature heat exchanger (H-HX) whereby it gets heated from the returning high-concentration solution returning from the GH generator.

The required heat for the current system is provided via the solar panels, which consist of evacuated tubes, and augmented by a fuel-fired boiler to meet the demand over specified time range. The evacuated tube solar panels are chosen because they have higher efficiency at a moderately elevated temperature as well as they have moderate cost in comparison with other types of solar collectors. The efficiency of solar panels decreases with the difference between the operational temperature and the ambient. In estimating the solar panels efficiency at the desired temperature, an efficiency of 53% was obtained based on a formula that appears in [8]. However, the value that was used in the analysis is more conservative 39% [13].

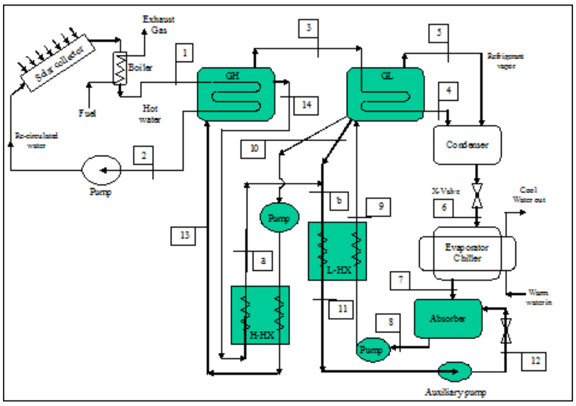

Figure 1: Reversed-flow double-effect lithium-bromide absorption cycle driven by solar energy and fuel-fired boiler.

3. Cycle Performance Assessment

The key parameter in evaluating the overall performance of the cycle is to obtain the Coefficient of Performance (COP), which is a measure of the cooling effects to the amount of the required input power needed to drive the system. The input power is mainly the thermal energy and little of electrical power required to drive the pumps where the later is of insignificant magnitude and hence it was neglected from the analysis.

The state conditions for this cycle are depicted in Table 1, which shows the temperature and the concentration level of the bromide solution along with the water refrigerant conditions at the state points that appear in Figure 1. In arriving at the states shown in the table it was assumed that the L-HX and H-HX have an effectiveness of 75% and 65%, respectively, while the boiler has an efficiency of 85%. Performing standard thermodynamic analysis [14 and 15] with these state conditions leads to 29.2 kW of thermal energy required at the high-generator so that the cycle may deliver 10 tons of cooling. Based on the analysis, the refrigerant (water) released from the GL and GH generators were found to be 0.00573 kg/s and 0.00927 kg/s, respectively, while the corresponding mass flow rates of the solutions leaving the two generators were 0.204 kg/s and 0.0962 kg/s, respectively. Therefore, the resulting COP of the cycle becomes 1.21. In other words, for every 1 kW of cooling the absorption cycle requires 0.83 kW of thermal energy. In the current configuration the solar collectors are intended to supply their maximum collected thermal energy while any deficient thermal energy required for meeting the load demand is offset by the fuel-fired boiler.

Table 1: Thermodynamic state conditions of the lithium-bromide absorption cycle.

State point	Temperature °C	Pressure kPa, absolute	Concentration %	Enthalpy kJ/kg
3	152	52	*Ref. sup vapor	2782.4
4	88	6.682	Ref. sat liquid	368.5
5	82	6.682	Ref. vapor	2653.2
6	38	6.682	Ref. sat liquid	159.2
7	Saturated	0.91	Ref. sat vapor	2511.2
8	40	0.8	58.5	108.2
9	66	6.682	58.5	160.0
10	82	6.682	60.2	200.0
11	49	6.682	63	151.2
12	49	6.682	63	151.2
13	127	52	60.2	285.6
14	152	52	66	348.9

*Note: Ref., sup and sat are abbreviations for refrigerant, superheated and saturated, respectively.

The thermodynamic cycle is depicted in Figure 2 showing the state points for the solution on the equilibrium chart of the aqueous lithium-bromide solution.

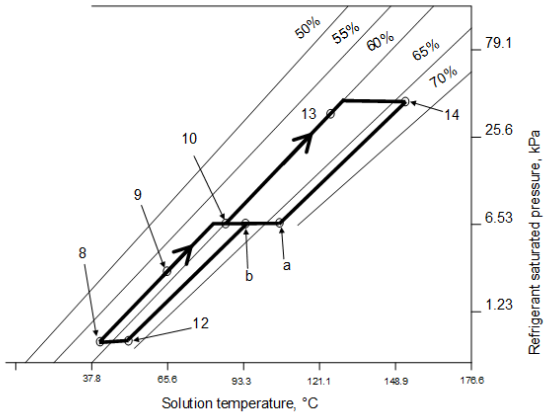

Figure 2: The cycle of the lithium bromide solution shown on the equilibrium chart.

4. Solar Irradiation

The incident solar radiation on a unit area with an arbitrary orientation was determined utilizing a developed computer code using Microsoft Excel-Visual Basic utility. The basic equations [16] that are used in the computer code to calculate the solar intensity begins with the extraterrestrial at the mean earth-sun distance D_o called the solar constant I_o which was established through measurements and found to be 1377 W/m^2. The extraterrestrial solar radiation at the actual distance D from the sun is given as an implied function of time through the following,

$$I = I_o\left(D / D_o\right)^2 \tag{1}$$

Because of the regular motion of the earth around the sun the distance ratio D/D_o can be expressed as a function of the day number N with January 1 is 1. The solar declination angle δ is given as

$$\delta = 23.45^o \sin\left[360\left(284 + N\right)/365\right] \tag{2}$$

The altitude angle α and azimuth angle ϕ can be found from the following equations,

$$\sin(\alpha) = \cos(l)\cos(\delta)\cos(H) + \sin(l)\sin(\delta) \tag{3}$$

and

$$\sin(\phi) = \cos(\delta)\sin(H)/\cos(\alpha) \tag{4}$$

where l is the latitude angle and H is the hour angle which is found by dividing the number of minutes from solar noon by 4.

The direct solar beam I_{bd} that reaches the earth surface is computed as

$$I_{bd} = I\exp\left[(-\tau\sec(\theta_z)\right] \tag{5}$$

where τ is the optical depth attenuation of the solar beam as it passes through the atmosphere and θ_z is the zenith angle; i.e., between the solar beam and the vertical.

Through the declination angle, the local solar time which is correlated with the local standard time along with the altitude and the azimuth angles, the incident angle θ between the sun beam and the normal to the panels is determined through the following equation,

$$\cos(\theta) = \cos(\alpha)\cos(\gamma)\sin(\beta) + \sin(\alpha)\cos(\beta) \tag{6}$$

where β is the tilt angle of the panels and γ is the angle between the projections on a horizontal plane of the sun beam and the normal to the panels.

The total solar radiation I_b incident on a tilted plate at β can now be determined using the following equation,

$$I_b = I_{bd}\cos(\theta) + I_{diffuse} + I_{reflected} \tag{7}$$

where

$$I_{diffuse} = CI_{db}\left(1 + \cos(\beta)\right)/2 \tag{8}$$

and

$$I_{reflected} = \rho I_{db}(C + \sin(\alpha))\left(1 - \cos(\beta)\right)/2 \tag{9}$$

where ρ is the reflectivity of the surrounding and C is a sky diffuse factor.

5. Model Validation

The versatility of the computer code makes it a resourceful tool for predicting solar irradiation on any plate with arbitrary orientation located, not only in Jordan, but in any part of the world at different times throughout the year. However, prior to proceeding with the various design options for supplying the adequate thermal energy to drive the absorption cycle it was prudent to validate the output of the computer code. The output of the code was verified against published data in ASHREA [17] for the extraterrestrial solar radiation intensity throughout the year and against the direct normal at north latitudes 24°, 32°, and 40°. The results of the comparison are depicted in Tables 2 and 3. For the extraterrestrial solar radiation, the code is seen to predict the value with a maximum error of 0.9%. In the case of the direct normal the maximum error was 5.5% occurring at latitude 40° in the early hour of the day. Therefore, the code is considered to yield satisfactory prediction for the solar data.

Table 2: Comparison of extraterrestrial solar intensity from code versus published data

Month	**I_o^1 (W/m^2)**	**I_o^2 (W/m^2)**	**Error Percent**
January	1415.8	1424.3	0.6
February	1401.3	1412.2	0.8
March	1380.8	1392.7	0.9
April	1356.2	1367.7	0.8
May	1336.3	1346.6	0.8
June	1325.6	1333.4	0.6
July	1325.9	1331.7	0.4
August	1337.9	1341.6	0.3
September	1358.7	1361.3	0.4
October	1379.6	1385.2	0.4
November	1404.8	1408.2	0.2
December	1416.8	1422.5	0.4

[1]: Data taken from ASHREA. [2]: predicted values from the computer code

Table 3: Comparison of incident direct beam obtained from code versus published data for the month of July at different latitudes.

Solar time	24°, [1]	24°, [2]	%Error	32°, [1]	32°, [2]	%Error	40°, [1]	40°, [2]	%Error
700	615	647	5.1	640	674	5.2	656	692	5.5
800	754	790	4.7	760	797	4.8	760	798	5
900	823	859	4.3	823	860	4.4	817	856	4.7
1000	858	896	4.4	855	894	4.6	849	888	4.7
1100	877	915	4.3	874	912	4.3	868	905	4.3
1200	883	920	4.2	880	917	4.2	871	910	4.5

[1]: Data taken from ASHREA. [2]: predicted values from the computer code

6. Results

To assess the effectiveness of the Solar-Fuel driven Double effect Absorption Cycle (SFDeAC) in terms of energy conservation, the analysis started by finding the solar panel configuration that yields optimal output. The amount of solar irradiation incident on a plate is dependent on the tilt angle. To determine the optimal tilt angle for Az-Zarqa/Jordan the total solar irradiation on one square meter was computed for various orientations. This was carried out using the computer code for latitude and longitude equal to 32.08° and 36.1°, respectively, which correspond to the location of Az-Zarqa city. The calculations were conducted for the fifteenth day for the months June, July, August and September. The results are presented in Table 4 which shows the total solar irradiation summed up between the hours 8:00 am to 4:00 pm solar time for a plate oriented south and at tilt angles ranging from 40° from the horizontal plane down to 0° degrees decremented by 5 degrees. The results indicate that the maximum solar energy received varies with the tilt angle and at the same time the optimal tilt angle varies with the month whereby it is seen that it ranges from 5° to 30° for the months shown. For the current study the solar collectors tilt angle is set at 20° as an approximate optimal value for the entire hot weather season.

Table 4: Daily total incident solar radiation (kW-hr) on a tilted surface facing south*

Tilt angle deg (β)	June	July	August	September
40	5.91	5.94	6.19	6.47
35	6.21	6.23	6.40	6.56
30	6.47	6.48	6.58	6.60
25	6.69	6.68	6.70	6.60
20	6.86	6.83	6.78	6.55
15	6.98	6.94	6.80	6.45
10	7.05	6.99	6.78	6.30
5	7.07	7.00	6.71	6.11
0	7.04	6.96	6.60	5.87

* The total is for the hours between 8:00 am to 4:00 pm.

For evaluation of any solar cooling systems, the instantaneous solar irradiation for the particular site must be known. In the present work the total solar radiation rate incident on a plate tilted 20° from the horizon was computed utilizing the computer code and the results are depicted in Figure 3. Since solar irradiation varies from day to day the results seen in Figure 3 are for the 15th day which was considered to be typical for the entire indicated months. The figure reveals that the instantaneous total solar irradiation is vividly lower for the month of September than the months June, July and August; a difference of ~100 to ~150 Watts. For this reason the following assessment will exclude the month of September since mainly cooling load drops with lower solar irradiation and normally design parameters are set for maximum conditions. Furthermore, maintaining a 20° tilt angle when excluding September will result in conservative estimates of the solar panels areas, as will be seen later.

The success of solar cooling systems relies on the determination of the minimum surface area of solar panels to meet the cooling demand. However, as mentioned previously rather than depending solely on solar energy the fuel-fired boiler supplies the deficient heat to drive the cycle. The assessment then is to determine the amount of energy contributions from both solar and boiler for different percentages of the roof area that are occupied by solar panels and their effects on the end performance of the system as a whole. Clearly, with higher percent of the roof area given to solar panels will definitely imply less need for the boiler, however, the capital and maintenance costs will rise as well. To carry out the rest of the analysis, the cooling load demand was assumed that it may be approximated as 110 W per each square meter of the roof area; this load is typical for relatively populated buildings.

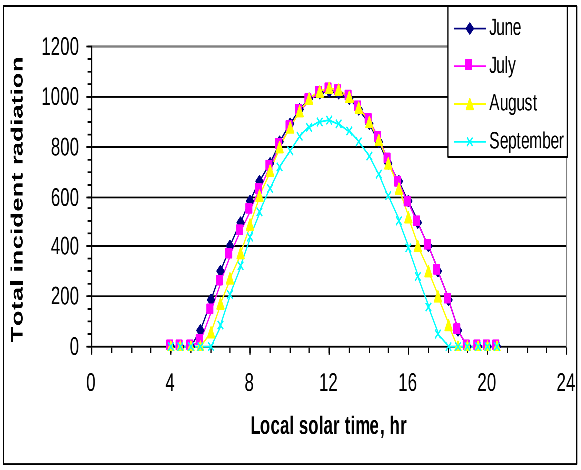

Figure 3: Total solar flux (W) computed on the 15th day for the indicated months.

To evaluate the conserved energy using the SFDeAC system the COP was computed over the entire day for different percent roof areas which to be occupied by solar panels. The COP was defined as the supplied cooling load, which was kept fixed for the entire day and as determined by the roof area size, relative to the net energy inputted by the boiler where the later was assumed to have 85% efficiency. To distinguish this method of computing the COP, it will be referred to herein as the effective COP. Thus, when the system is using all the heat from the solar radiation, the COP will tend to infinity; e.g., with the assumption that power for pumps, electronics, etc is negligible. Figure 4 shows the effective COP over the entire day for different percents of the roof area that are given to solar panels. Clearly it is revealed that for the cases of 15% and 20% the boiler would be turned on for the entire day, however, with the later case the COP is seen to reach up to 9 at solar noon indicating less energy received from the boiler. For larger percentages of the roof area allocated to solar panels; i.e., 25%, 30% and 40%, there are time periods that the thermal energy given to the cycle is entirely supplied by the solar panels thus yielding an infinite effective COP; i.e., the boiler is turned off.

For the purpose of comparison and further analysis the daily COP which was computed as the energy in the form of supplied cooling over a specific time period divided by the amount of energy supplied by the boiler for the same period. The results are given in Table 5 whereby the daily COP is seen to increase either by increasing the solar panel areas (percent of roof area) or by shortening the time period where the later is due to the fact that solar irradiation is higher (Figure 3). Observe that impressive COPs are obtained for percentages of 25% and higher and approaching infinity for 40% during the period 9 am to 3 pm which, for the later case, is an indication that the boiler is remaining basically turned off for the entire period.

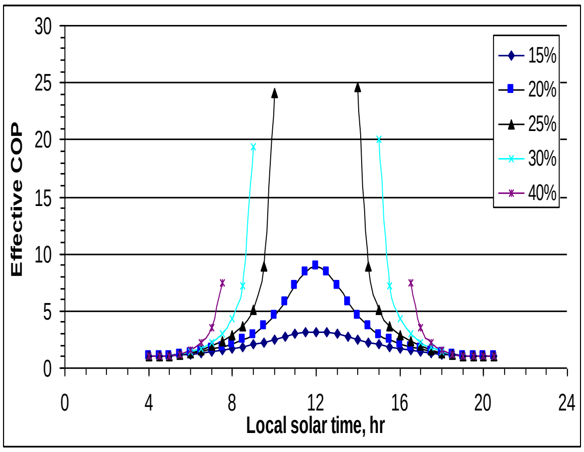

Figure 4: Instantaneous effective COP with varying roofing-area percent allocated to solar panels.

Table 5: System daily COP variation with different daily time periods

Time period	Percent of roofing area used for solar panels				
	15%	20%	25%	30%	40%
7 am to 5 pm	2.16	3.25	5.76	9.41	28.06
8 am to 4 pm	2.39	4.04	9.68	23.36	525.03
9 am to 3 pm	2.66	5.22	23.70	227.51	∞

The results presented in Table 5 was taken further to assess the energy savings when compared with a typical electrical-base air-conditioning unit that runs at a COP of 3.5 with the electrical power received from typical fossil-fuel power plant that has a conversion efficiency of 35% [18]. This means that each one kW of electricity generated 2.86 kW of fossil fuel power is consumed which in turn can be utilized to obtain 3.5 kW of cooling, or equivalently for every 1 kW of cooling 0.82 kW of fossil fuel power is consumed. This information was used as a basis for computing energy saving when using the SFDeAC. Table 6 depicts the percent of energy saving that may result when using the SFDeAC absorption system. The table vividly reveals significant amount of savings on fossil fuel can be obtained even when only 15% of the roof area is allocated to solar panels; assuming that power plants are mainly driven by fossil fuel as the case in Jordan. The apparent savings in energy is that the system's requirement for thermal energy is partially supplied by solar energy, which is a free source of energy.

However, for any scheme that is proposed for energy conservation for it to be adopted it must bring with it financial saving to the end consumer. Considering the current cost of energy in Jordan whereby for electricity it is 0.067 JD per kW-hr; e.g., depending on the usage amount, and for diesel 0.45 JD/L, then for each one kW-hr of cooling the running cost of an electrical-base system that has COP equal to 3.5 is 0.0191 JD while for the SFDeAC with 20% roof area the cost are 0.0127 JD and 0.0103 JD during the daily periods 7 am to 5 pm and 8 am to 4 pm, respectively. Included in these estimates the assumptions that the calorific value and specific gravity for fossil fuel are 46000 kJ/kg and 0.85, respectively. Thus the corresponding percent of savings on running cost is 33.5% and 46.1%, respectively. These impressive savings are a result of using a renewable source of energy; i.e., solar energy. For the 15% roof area during the period 7 am to 5 pm, the running cost is 0.0192 JD which is slightly above than the running cost associated with the electrical-base system. Financial savings on running cost of less than 20% perhaps would not be as attractive simply because of longer payback periods that are associated with relatively high initial capital cost. Nonetheless, given up 20% of the roof area to solar panels may be a plausible solution in many cases; e.g., in public and commercial buildings. Furthermore, the cooling load was based on relatively high cooling demand; however, for smaller buildings and individual homes the cooling load may be less than 80 W/m^2 which means less percent of the roofing area may be allocated to solar panels and still exceed the saving indicated for the case 20% of the roof given up to solar panels.

Table 6: Percent of energy saving using the solar-fossil fuel driven absorption cycle

Time period	Percent of roofing area used for solar panels				
	15%	20%	25%	30%	40%
7 am to 5 pm	45	63	80	87	95
8 am to 4 pm	49	70	88	95	100
9 am to 3 pm	54	77	95	99	100

Potentially therefore these results indicate that this kind of hybrid cooling system driven by solar energy and coupled with fuel-fired boiler for running the absorption system has feasible application in Jordan and in areas that have similar solar irradiation intensity. For example, in the Hashemite University campus, the summer working hours start from 8:00 am to 3:00 pm which coincides with the daily period of higher effective COP. Additionally, most of the buildings have vast roofing areas that can easily afford 25% to solar panels. Similar situations may be found in companies with office buildings that are typically occupied during the day time. Also, the scheme may be implemented to shopping malls during the daylight where appropriate. In multistory buildings, solar panels are now being placed on side walls to offset the limited roof area. Evidently, such a scheme collectively along with other efficient schemes, significant headways may be achieved in energy conservation.

7. Conclusion

A reversed-flow double effect lithium-bromide absorption cycle driven by solar energy and a fuel-fired boiler was considered for the potential of comfort cooling application in local areas with the intent of conserving energy and lowering running cost. A computer code, using Microsoft Visual Basic utility, was developed to compute the solar irradiation in any part of the world and in particular for the Az-Zarqa city/Jordan to aid in evaluating the contribution of the solar energy to the operation of the absorption cycle. The code was verified against published data and found to agree reasonably well yielding an error of ~5% for the incident irradiation as demonstrated. For optimal efficiency the solar panels are positioned such that they are facing south and tilted at an angle of 20 degrees from the horizontal plane. The overall system performance was evaluated based on the effective COP which excludes the contribution of the solar energy. The solar energy contribution was measured in terms of the percent of the roof area that is allocated to solar panels. Results were obtained for various contributions of the solar energy and with the rest of the system's thermal requirement being supplied by the boiler. Energy savings were seen up to 45% on fossil fuel with as low as 15% of the roof area given up to solar panels. However, a 20% of the roof area allocated to solar panels would be necessary for obtaining savings on running cost. The data presented can also be used as guidance for preliminary design for determining the solar contribution based on the percent of the roof area that is to be allocated to solar panels. It was concluded that the SFDeAC is a feasible system for application in Jordan with the intent of saving fossil fuel energy and lowering running cost.

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