DESIGN AND PERFORMANCE EVALUATION OF A SOLAR SPACE HEATING SYSTEM USING EVACUATED TUBES SOLAR COLLECTOR IN BAGHDAD, IRAQ CLIMATE

AED IBRAHIM OWAID1, MOHAMMAD TARIQ2, SALAH SUBHE ABD3, RASIASIM ABBAS4

1Solar Researches Centre, Renewable Energies Directorate, Ministry of Science and Technology, Republic of Iraq
2Department of Mechanical Engineering, (Shepherd School of Engineering and Technology, Allahabad, India)
3Solar Researches Centre, Renewable Energies Directorate, Ministry of Science and Technology, Republic of Iraq
4Solar Researches Centre, Renewable Energies Directorate, Ministry of Science and Technology, Republic of Iraq

ABSTRACT

Because of acute shortage of electric power, especially the energy consumed for heating and cooling in the official working hours for government departments and the private sectors grew the idea our design solar space heating system operate on solar power only and for the official working hours because the most of solar energy systems are auxiliary power beside the electric power. In this research, the system is designed for heating of a meetings hall for a period of six hours. The research has been carried out in Iraq under the ministry of science and technology during winter (2011 -2012) for the period from November 2011 to March 2012. The research was started with the design calculations for the required space heating load and this value has been calculated (2092.2W/day). The energy provided by evacuated tubes solar collectors that suit the heating load required and its value (46332kJ/day). The readings have been taken for every ten minutes by using data logger, measuring and recording device and store data of solar radiation rate (solar meter) respectively. The study showed that how the system compensate (9.6 kWh/day) instead of the electric power that consumed for space heating load for hall of area 47.5m2.
Keywords: Evacuated Tube Collector (ETC), Thermal Radiator, Space Heating, Heating Load, Solar Energy, Ambient temperature.

1. INTRODUCTION

Even in today’s world market, with all of the vast technology advancements and improvements, there are still people who live in darkness at night and use candle light or kerosene lamps to study. These people have the knowledge of the existence of electricity. However, the area in which they reside lacks the infrastructure and resources for such an amenity. Also, throughout the world, the demand for useable energy is increasing rapidly, with electricity being the energy of choice. This electricity production, however, does not come free. There is cost associated with the infrastructure for setting up new power production facilities and the rising cost and lack of natural resources such as oil, coal, and natural gas. One solution is to steer away from conventional methods and look for novel, alternative, renewable, energy resources, such as solar energy. The sun is an excellent source of radiant energy. It emits electromagnetic radiation with an average irradiance of 1353 W/m$^2$ on the earth’s surface [1, 2]. The solar radiation incident on the Earth’s surface is comprised of two types of radiation namely; beam and diffuse, ranging in the wavelengths from the ultraviolet to the infrared (300 to 200 nm), which is characterized by an average solar surface temperature of approximately 6000K [3]. The amount of this solar energy that is intercepted is 5000 times greater than the sum of all other inputs terrestrial nuclear, geothermal and gravitational energies, and lunar gravitational energy [1]. To put this into perspective, if the energy produced by, 25 acres of the surface of the sun were harvested there would be enough energy to supply the current energy demand of the world.

When dealing with solar energy, there are two basic choices. The first is photovoltaic, which is direct energy conversion that converts solar radiation to electricity. The second is solar thermal, in which the solar radiation is used to provide heat to a thermodynamic system, thus creating mechanical energy that can be converted to electricity. In commercially available photovoltaic systems, efficiencies are on the order of 10 to 15 percent, whereas in a solar thermal system, efficiencies as high as 30 percent are achievable [4]. To replace fossil fuel, usage with environmental friendly, clean, and renewable energy sources. Among these sources, solar energy comes at the top of the list due to its abundance and more even distribution in nature than other types of renewable energy such as wind, geothermal, hydropower, biomass, wave and tidal energy sources [5]. The sun is a source of nearly all forms of energy on the earth. Our earth receives a continuous stream of energy from the sun. On a clear day, the earth receives 1 kW/m$^2$, when overhead a clear day of solar energy for a few hours per day. Perhaps 4 to 8 kW-h/m$^2$/day can be collected [6]. As solar energy is dispersed form of energy, an effective method of collection is very important. The flat plate collector is the simplest and one of the cheapest means of collecting solar energy for use in system that require thermal energy at low temperatures (<100°C). It is well known that Evacuated Tube Collector (ETC) permit the use of a vacuum of sufficient magnitude about (5×10^{-3} pa) to eliminate convection and conduction heat transfer losses. The vacuum may help to protect a selective surface used on the absorber against performance degradation over the life of the collector. In addition, these collectors generally require a minimum amount of material per square meter of collector and thus provide for the possibility of lower costs.

2 SPACE HEATING LOADS

Estimating loads is based on the principle that the energy loss from a building is proportional to the difference in temperature between indoors and outdoors. The energy from solar heating system is added to a building at rate (q_{radiator}) as given by eqs. 1.
The rate of heating load \( q_{\text{load}} \) in the building due to occupants i.e. (persons, lights, appliances, and incoming solar radiation) which transfer from indoor to outdoor that must be substituted from solar collector to keep comfortable indoor environment in space heated and is given by [7].

\[
q_{\text{load}} = q_{\text{Walls}} + q_{\text{glass}} + q_{\text{Infiltration}} - q_{\text{persons}}
\]

(2)

The heat loss coefficient is given by

\[
U_W = \frac{1}{R_t}
\]

Total thermal resistance of the compound walls is calculated by

\[
R_t = \frac{1}{f_i} + \sum \frac{x_n}{K_a} + \frac{1}{f_o}
\]

(4)

The rate of heat transfer from indoor to outdoor, across glass windows can be calculated by using Eq. (5) [7].

\[
q_{\text{glass}} = U_{\text{glass}} A_{\text{window}} (T_{\text{Room}} - T_{\text{Ambient}})
\]

(5)

\[
q_{\text{Infiltration}} = 1.22 \dot{V} (T_{\text{Room}} - T_{\text{Ambient}})
\]

(6)

The rate of infiltration of the air can be estimated as follows;

\[
\dot{V} = \text{Volume of space} \times n
\]

(7)

### 2.1 The Overall Heat-transfer Coefficient

Consider the plane wall shown in fig 1, exposed to a hot fluid (A) on one side and a cooler fluid (B) on the other side. The heat transfer is expressed by [8].

\[
q = h_1 A (T_1 - T_A) = \left( \frac{K A}{\Delta x} \right) (T_1 - T_2) = h_2 A (T_2 - T_B)
\]

(8)

The heat-transfer process may be represented by the resistance network in fig. 1, and the overall heat transfer is calculated as the ratio of the overall temperature difference to the sum of the thermal resistances [8].

\[
q = \frac{(T_A - T_B)}{\left( \frac{1}{h_1 A} + \frac{\Delta x}{K} + \frac{1}{h_2 A} \right)}
\]

(9)

\[
U = \frac{1}{\left( \frac{1}{h_1 A} + \frac{\Delta x}{K} + \frac{1}{h_2 A} \right)}
\]

(10)

\[
q = U A \Delta T
\]

(11)
3. COMPONENTS OF THE HEATING SYSTEM

After conducting the design calculation, the system components must be cleared as shown in fig. 2. Where the system consist of two solar heaters from the type – Evacuated tube – with (32) tubes and storage capacity of (263) liter for each heater, two solar panels with power (80 watt), solar charger (solar charger rating 12 v d.c /14 amp), battery type (Deep cycle 200 amp. h), electrical reflector, compensation water tank with capacity (1000) liter, conducting water tubes type (1/2" C.P.V.C SCH 80), (Chlorinated Polyvinyl Chloride), circulating pump with (100 watt) power. Two thermal radiators, control unit consists of two parts, the first is fixed within the space which is responsible for measuring and control the space temperature, and the second to be fixed on the solar heater to measure the internal temperature for hot water of the storage tank solar heater.

4 THE OPERATING PROCEDURE OF THE SYSTEM

After installation of the system as shown in fig 2, the system to be left for three days in order to charge the solar heaters storage tank as a primary charging and to charge the battery by the solar charger using the solar panel. then operating the system thereby the control unit which run the circulating pump in case of existence of two conditions, the first is the temperature of the space must be less than (22°C) and the other is the inlet temperature of the hot water in the middle of solar collectors storage tanks must be more than (40°C), where the system working continuous till the space temperature becomes (22°C), it will stop then it will work when the temperature decrease and become less than (22°C) and so on depending on the control unit.
5 DATA ANALYSIS AND EVALUATION OF THE OBTAINED RESULTS

5.1 Test run of the System to the beginning of the Winter Season

From the recorded data and the graphs of the relationship between the exit and inlet temperature of the water from and to the inside space for the month of November, in (21-23-24)/11/2011 days, it is observed that, in the beginning it has been raising the temperature calibration of space in the morning to 24°C to ensure the work of the system. After reaching this temperature, it stopped by the control unit and it has been re-calibrated to temperature 22°C. It has been noted that the continued rise in temperature because of temperature rise of the thermal radiator. After an hour, the temperature gradually decline even up to 22°C until two o'clock in the afternoon and no need to operate the system again so no need for space heating today as shown in fig 6. But in the day 23/11/2011 there was need to operate the system by control unit to the latest half an hour before the two o'clock afternoon because of the decreasing of the space temperature below 22°C as shown in fig 7.
The working of the system until the ninth hour and an half hour in the morning is continued then it stopped by the control unit. When the space temperature reaches 24°C, and then returned to work at 12 o’clock when the temperature decreased and continued to work normal which operation and stop by control unit to the end of office as shown in fig 8. On the day 28/11/2011, there was increasing in hours of working of the system even on decreasing the ambient temperature. It is to be noted that, the system works continuously from 9 o’clock morning to 2 o’clock afternoon. It means the system worked continuously till the required space temperature reached 22°C at twenty past ten o’clock. After that it was stopped by the control unit and then returned to work and continuously till 2 o’clock afternoon as shown in fig 9. By calculating the energy of solar radiation and energy output by evacuated tubes for every ten minutes, it has been observed that the expense of heating load and power consumed for heating every ten minutes results in energy lost or added to the tanks of solar water heaters. Then the relationship has been established between them for the system operation on 30/11/2011. The energy obtain value from the solar energy by the solar heaters for this day was 55328 kJ, and the energy consumed for heating load was 45245 kJ and the energy added to the solar heaters was 10083 kJ, i.e., there energy added in addition to energy consumed in space as shown in fig 10.
Table 1 illustrates the data derived from the operation of the system for a few days in November and December.
Table 1 Data for some days in November and December

<table>
<thead>
<tr>
<th>Day</th>
<th>Date</th>
<th>(ΔT) (°C)</th>
<th>Energy stored in the morning (kJ)</th>
<th>(ΔT) (°C)</th>
<th>Withdrawn or added energy in the evening (kJ)</th>
<th>Energy obtained from solar radiation in solar collector (kJ)</th>
<th>Total energy consumed in the space heating (kJ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wednesday</td>
<td>30/11/2011</td>
<td>26</td>
<td>57439</td>
<td>4.56</td>
<td>10083</td>
<td>5328</td>
<td>45245</td>
</tr>
<tr>
<td>Wednesday</td>
<td>07/12/2011</td>
<td>35.5</td>
<td>87263</td>
<td>1.6</td>
<td>3534</td>
<td>40446</td>
<td>36512</td>
</tr>
<tr>
<td>Thursday</td>
<td>08/12/2011</td>
<td>33.1</td>
<td>73124</td>
<td>2.5</td>
<td>5743</td>
<td>44483</td>
<td>38700</td>
</tr>
<tr>
<td>Sunday</td>
<td>11/12/2011</td>
<td>37.4</td>
<td>82624</td>
<td>-7.5</td>
<td>-16589</td>
<td>43965</td>
<td>61513</td>
</tr>
</tbody>
</table>

5.2 Test run of the System Continuously

The system was operated continuously and the data was registered, as a result the relationship was drawn between the space temperature, hot water temperature, ambient temperature and time. Through the operation of the system continuously depending on the control unit on 13-14/12/2011 with changing the calibration temperature of the hot water for the solar heaters storage from 40ºC to 30ºC in order to ensure the continued operation of the system for longer time. By drawing the relationship between temperatures as shown in fig. 11, it has been observed that the continuous work developed with maintaining the space temperature at 22ºC till the half past seven o’clock evening. When it start to decline with decrease in hot water temperature of the solar heater storage till the temperature decreases to 30ºC at half past 2 o’clock morning and then the system has stopped by control unit. Next day, the control unit operate the system with the water temperature more than 30ºC at 9 o’clock morning due to the rise in solar radiation rate but energy tank temperature limited to 38ºC. Therefore, the energy extracted from that temperature difference is not enough to raise the space temperature to 22ºC as shown in fig 12 and this is due to the lack of primary energy stored from the previous day. Primary energy stored is not enough to raise the space temperature to 22ºC with increasing the solar radiation rate. As the system works continuously by the control unit for the new week and for the day 18/12/2011 and 19/12/2011, it has been observed that, it worked till the half past twelve in the morning on 19/12/2011 with keeping the space temperature 22ºC. After that, the system worked continuously with decreasing in the space temperature up to 18ºC at 7 o’clock then the system stopped by the control unit because the calibrated temperature reaches 30ºC as shown in fig 13.

![Fig 11 Effect of the system working on the solar heater temperatures (13-14) - 12-2011](image-url)
From the corresponding graphs between the energy storage temperature and the space temperature, it has been found that the working of the system will confirm the space temperature at 22°C until the storage tank reaches to 40°C. Then the space temperature starts falling down with continuously with the system working and temperature decreasing of the storage tank. After reaching the previous results, the hot water temperature of the storage tank increased and calibrated to 40°C by the control unit, then the system was operated with the new condition by the control unit on 19/12/2011 and 20/12/2011 at noon it was noted that the system worked continuously till 10 o’clock in the evening with keeping the space temperature at 22°C besides the primary energy storage for the next day as shown in fig 14. On the next day i.e. on 20/12/2011 and 21/12/2011, it has been found that the system started at half past eight with increasing in the solar radiation rate and the hot water temperature for the storage tank exceeded to 40°C, and the it works continuously till the half past eleven at space temperature is 22°C and the hot water temperature of the storage tank 40°C, as shown in fig 15.
The table 2 illustrates the calibrated temperature for the hot water in the storage tank, the difference between the calibrated temperature and the hot water temperature in storage tank in the morning, the energy stored against this difference, temperature difference between the morning time and the evening time at the sunset. In the table 2, it is shown that the added energy to the solar heaters tank for the day (Thursday 8/12/2011), energy added to the end of a week of operation equal to 5743 kJ using natural operation of the system with six hours during the official working time. As for the system to run on Sunday and also for seven hours, there is energy lost in the evening about 16569 kJ. This is due to fact that total charge through the days (Friday and Saturday) is unable raise the energy level of the solar radiation to the same energy of storage tank in the morning. As in the day 12/12/2011 the system was started operation continuously by the control unit. In this day the calibrating temperature of the hot water of the solar heater tanks was 40 ºC and the energy emitted from the thermal radiator was enough to keep the space temperature within 22ºC, as mentioned earlier in table 2. The calibrated temperature was altered to 30ºC for the days: 19/12/2011 to 4/1/2012 in order to test the continuous operation of
the system. It was noted that the resulted energy from the radiator was enough to keep the space
temperature 22°C, as shown by the graphs for these days.

Table 2 The calibration temperature and the stored energy

<table>
<thead>
<tr>
<th>Day</th>
<th>Date</th>
<th>Calibration temperature (T) (°C)</th>
<th>Temperature difference at 9 AM (ΔT) (°C)</th>
<th>Stored energy in the storage tanks (kJ)</th>
<th>Temperature difference at 5 PM (ΔT) (°C)</th>
<th>Energy withdrawn or added in the storage tank (kJ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thursday</td>
<td>09/12/2011</td>
<td>40</td>
<td>35.1</td>
<td>75124</td>
<td>2.6</td>
<td>5740</td>
</tr>
<tr>
<td>Sunday</td>
<td>11/12/2011</td>
<td>40</td>
<td>37.4</td>
<td>82624</td>
<td>-7.5</td>
<td>-16569</td>
</tr>
<tr>
<td>Monday</td>
<td>12/12/2011</td>
<td>40</td>
<td>23.2</td>
<td>51253</td>
<td>2.9</td>
<td>6406</td>
</tr>
<tr>
<td>Tuesday</td>
<td>13/12/2011</td>
<td>30</td>
<td>13.4</td>
<td>29603</td>
<td>5.3</td>
<td>7290</td>
</tr>
<tr>
<td>Wednesday</td>
<td>14/12/2011</td>
<td>30</td>
<td>0</td>
<td>0</td>
<td>-6.8</td>
<td>15022</td>
</tr>
<tr>
<td>Sunday</td>
<td>18/12/2011</td>
<td>30</td>
<td>31.7</td>
<td>70031</td>
<td>-2.2</td>
<td>-4860</td>
</tr>
<tr>
<td>Monday</td>
<td>19/12/2011</td>
<td>30 AM, 4:00 PM</td>
<td>3.3</td>
<td>7290</td>
<td>13.0</td>
<td>32917</td>
</tr>
<tr>
<td>Tuesday</td>
<td>20/11/2011</td>
<td>40</td>
<td>0.7</td>
<td>1546</td>
<td>13.2</td>
<td>79161</td>
</tr>
<tr>
<td>Sunday</td>
<td>25/11/2011</td>
<td>40</td>
<td>12.5</td>
<td>27615</td>
<td>4.0</td>
<td>10825</td>
</tr>
<tr>
<td>Tuesday</td>
<td>27/12/2011</td>
<td>40</td>
<td>6.6</td>
<td>14580</td>
<td>17.1</td>
<td>37777</td>
</tr>
<tr>
<td>Wednesday</td>
<td>28/12/2011</td>
<td>40</td>
<td>2.8</td>
<td>6185</td>
<td>13.0</td>
<td>30045</td>
</tr>
<tr>
<td>Monday</td>
<td>02/1/2012</td>
<td>40</td>
<td>7.7</td>
<td>37559</td>
<td>8.8</td>
<td>-12813</td>
</tr>
<tr>
<td>Tuesday</td>
<td>03/1/2012</td>
<td>40</td>
<td>0</td>
<td>9944</td>
<td>8.5</td>
<td>-16590</td>
</tr>
<tr>
<td>Wednesday</td>
<td>04/1/2012</td>
<td>40</td>
<td>0</td>
<td>0</td>
<td>10.6</td>
<td>23417</td>
</tr>
</tbody>
</table>

Fig 16 Temperatures scheme of the system for a day 20-2-2012

Fig 17 Temperatures scheme of the system for a day 21-2-2012
5.3 Test System operating by one Solar Collector

From the energy system on 20 and 21/2/2012 as shown in figures 20 and 21, the energy lost in the space on the first day were larger than the energy lost on the next day and the obtaining time to the required temperature was less and this is due to increase in the temperature of inlet hot water to the space because of the increasing of the storage tank temperature and the increasing the heat gain, but the energy consumed in the space for the next day against the temperature difference leads to take more time for reaching the required temperature and the system operated with low efficiency.

The system operation is tested by using one solar collector closing the valves which are responsible on the inlet and outlet of water from and to one of the solar collectors. Design of the system is also allow running the system by a single solar collector. After operating the system by one solar collector for the day 20/2/2012, it is found that the space temperature reaches the required temperature of 22°C at 50 past 8 o’clock in the morning when the system operated at 20 past 7 o’clock in the morning as shown in fig. 16. On the next day, the system reach the required temperature at 10 o’clock in the morning as shown in fig 17, or the time required for next day to reach the required temperature was larger in case of operating the system by one solar collector. This was due to the decreasing of hot water temperature in the storage tank in the morning. In figures 18
and 19, the relationships of the temperature into the middle and the bottom of the storage tanks are calculated for space temperature and ambient temperature with time. It is also noted that the temperature of the water to the center of the tank to start the operation of the system for a day on 20/2/2012 as illustrated in fig 18, was 62°C. On the next day for the operation of the system the temperature start operating to 46°C as illustrated in fig 19. From the table 3 it was noted that the energy stored in the morning, the intake and addition of energy from and to the storage tank, the energy gained from the solar radiation, the energy lost due to heating load and the heat loss through the system running by one solar collector.

**Table 3** Data derived from the operation of the system by one solar collector in Feb and March

<table>
<thead>
<tr>
<th>Day</th>
<th>Date</th>
<th>(ΔT) (°C)</th>
<th>Energy stored in the morning (KJ)</th>
<th>(ΔT) (°C)</th>
<th>Withdrawn or added energy in the evening (KJ)</th>
<th>Energy obtained from solar radiation in solar collector (KJ)</th>
<th>Total energy consumed in the space heating (KJ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monday</td>
<td>20/2/2012</td>
<td>-4.2</td>
<td>24743</td>
<td>-4.2</td>
<td>31252</td>
<td>315801</td>
<td>27020</td>
</tr>
<tr>
<td>Tuesday</td>
<td>21/2/2012</td>
<td>-4.3</td>
<td>14350</td>
<td>-4.3</td>
<td>34531</td>
<td>27085</td>
<td>20851</td>
</tr>
<tr>
<td>Wednesday</td>
<td>22/2/2012</td>
<td>-9.6</td>
<td>15685</td>
<td>-9.6</td>
<td>31377</td>
<td>20773</td>
<td>16166</td>
</tr>
<tr>
<td>Monday</td>
<td>27/2/2012</td>
<td>-4.3</td>
<td>15685</td>
<td>-4.3</td>
<td>31377</td>
<td>20773</td>
<td>16166</td>
</tr>
<tr>
<td>Tuesday</td>
<td>28/2/2012</td>
<td>-1.3</td>
<td>21871</td>
<td>-1.3</td>
<td>29984</td>
<td>31419</td>
<td>16742</td>
</tr>
<tr>
<td>Wednesday</td>
<td>29/2/2012</td>
<td>-4.3</td>
<td>15685</td>
<td>-4.3</td>
<td>29984</td>
<td>31419</td>
<td>16742</td>
</tr>
<tr>
<td>Thursday</td>
<td>1/3/2012</td>
<td>14.2</td>
<td>8294</td>
<td>14.2</td>
<td>52427</td>
<td>18488</td>
<td>14121</td>
</tr>
<tr>
<td>Thursday</td>
<td>8/3/2012</td>
<td>9.6</td>
<td>18888</td>
<td>9.6</td>
<td>24725</td>
<td>14121</td>
<td>14121</td>
</tr>
</tbody>
</table>
6 THE TOTAL ENERGY PROVIDED BY THE SYSTEM DURING WINTER SEASON

Initially has been calculated the rate of energy consumed by the hall for heating load run through air conditioners electric that erected originally in the space is then has been calculated rate of energy consumed by the hall for heating by the system powered by solar is then calculated the cost of energy provided by the solar system through an account the cost of energy consumed in running condition electric air conditioners. Through the operation of electric air conditioners installed in the space for a few days has been to get the necessary data listed below to calculate the energy consumed to heating the hall for six hours using electric air conditioners. As well as through the operation of the solar space heating system for the winter season has been know the rate of energy consumed for heating and thermal losses provided by the system each day. The electric energy consumed = 9.6 kWh/ day. The average energy provided by the system for the space heating load and the heat loss = 45585 KJ/day = 12.6 kWh/day. The cost of (kWh) for one of U.S.A. = 0.08 US $ = 100 Iraqi Dinars = 4.4 Indian rupees. Load cost/day = 100 x 9.6 = 960 Iraqi Dinars. Load cost/day = 4.4 x 9.6 = 42.24 Indian rupees. The rate of operating the system/month (In government departments) = 20 days. The rate of operating the system in 2011-2012 = 3.5 month. The rate of operating the system in one season = 20 x 3.5 = 70 days. The energy rate provided by the system during winter season = 70 x 9.6 = 672 kWh The amount provided for the winter season (according to the price in one of U.S.A.) = 960 x 70 = 67200 Iraqi Dinars. = 42.24 x 70 = 2956.8 Indian rupees.

7 CONCLUSIONS

The system worked efficiently for the winter season, six hours a day through two solar collectors. Operate the system through a single solar heater and this makes the system work less efficiently and sunny days, i.e., there is no store enough energy to run the system the next morning. Every square meter of space matched by 1.34 evacuated tube for two solar collectors to get the energy needed to warmed by 22ºC heat for six hours. Every square meter of space matched by 0.67 evacuated tube for one solar collector to get the energy needed to warmed by 22ºC heat for six hours. The system can be run from (12-14 hours). In this situation it requires the use of an additional electric heater for the first hour of work in the next day until the high rate of solar radiation reached to ensure work continuity. The system consumption for six hours per day in the winter season was 45585kJ of the energy gained from the solar radiation or equal to 12.6 kWh per day. The system provide energy rate equal to 9.6 kWh per day or 34560kJ, in case of operating two air-conditioners in the space for six hours till reaches the temperature of 22ºC.

REFERENCES


