INTEGRATED SOLAR HEATING SYSTEM FOR THE IN-DOOR SWIMMING POOLS IN WINTER SEASON APPLIED TO SELECTED EGYPTIAN SITES

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ABSTRACT

This work is concerned with solar heating system calculations and thermal analysis of in-door swimming pools in winter season for selected Egyptian sites. The solar heating requirements for constant temperature were investigated. The design and the parametric analysis of the suitable roof-storage tank-integrated liquid solar collector as solar heating system in winter season of the proposed swimming pool which installed in different sites in Egypt are presented. The solar heating load demand is a function of hourly climatic conditions variables such as insolation, ambient temperature, wind speed and relative humidity. The heating solar thermal analysis of this proposed integrated system is divided into five parts; direct solar heat demand for heating pool water, heat loss due to radiation from the water surface, evaporation heat loss, convection heat loss and conductive heat loss to the ground. Furthermore, the winter season energy consumption model and life cycle cost of the solar collector is studied. The results are analyzed based on the proposed integrated solar heating system of in-door swimming pool with case study of 200m^2 surface area and average depth 1.5m in winter season and in the selected sites of Egypt. Winter season is November, December, January and February and the selected sites are Cairo, El-Arich and Mersa- Matruh of Egypt. The results show that the maximum heating load appears in January for Mersa-Matruh and equals 71kW. The values of heat gains by solar collector are found for Cairo, El-Arich and Mersa-Matruh in winter. The system efficiency appears in Cairo, El-Arich and Mersa-Matruh according to its recording climate conditions in winter. The solar radiation has great effect on the solar collector's efficiency.
The solar collector's efficiency is decreased as the wind speed is increased. The evaporated heat losses are great value in Mersa-Matruh according to its recording climate conditions and its location (coastal area). Relative energy save (E_{sr}) values appears as Cairo, El-Arich and Mersa-Matruh according to its recording climate conditions (solar radiation).

KEYWORDS: climatic conditions, Egypt sites, life cycle, solar heating, thermal analysis and swimming pool.

1- INTRODUCTION

The more wide spread use of active solar heating system is closely linked with solar collector in different applications. Many efforts to alleviate global warming of the earth caused by emission of Carbon Dioxide in atmosphere have been undertaken; these emissions are generated by using of fossil fuels. The most important advantages of solar energy compared of traditional fossil fuels used for heating domestic water are clean, cheap and friendly environment. In recent years, solar heating system applied in swimming pools has attracted more and more attention in the world.

A simplified method for calculation heat losses to ground is presented by Medved et al. 2002. The solar collectors with colored absorbers are investigated by Tripanagnostopulos et al. 2000. Simulation of a solar domestic water heating system using a time marching model is presented by Bojic et al. 2002. Feasibility study of solar assisted heating and cooling system for an aquatic center in hot and humid climates is presented by Alkhamisi et al. 1997. Life cycle energy cost analysis of heat pump application for hotel swimming pools that evaporation is a major component of heat loss from the swimming pool, and wind speed has a very closed relationship with the rate of evaporation is investigated by Joseph et al. 2001. Application of heat pump in modern natatorium which calculated the rate of evaporation for the in-door swimming pool is presented by FanQng et al. 2004.

The main aim of this work is using the solar heating system for heating the water of in-door swimming pool as integrated system in winter season and in different sites in Egypt that is based on its climatic conditions.

2- THERMAL ANALYSIS OF THE PROPOSED SYSTEM

2-1 Heating Load Demand for Heating In-Door Swimming Pool

For solar-heating in-door swimming pool, the heat demand is function of hourly climatic variables such as insolation, wind speed, ambient temperature and relative humidity. In-door swimming pool constant temperature in winter season and in the selected sites; Cairo (latitude 30° $05^{'}$ and longitude 31° $17^{'}$), El-Arich (latitude 31^{0} $16^{'}$ and longitude 33° $45^{'}$) and Mersa-Matruh (latitude 31° $20^{'}$ and longitude 27° $13^{'}$) was carried out for this work, Shaltout 1991. The basic design parameters are given as follows:

1- Swimming pool surface area is $200m^2$ and average depth 1.5m.

2- Design average water temperature in winter season for the selected sites in order to obtain the average heating load of the present system is given in Table (1), Shaltuot 1991.

Table (1): Design water temperature in winter season for the selected sites

Winter season / Sites	Nov.		Dec.		Jan.		Feb.	
	T_{max}, ^oC	T_{min}, ^oC	T_{max}, ^oC	T_{min}, ^oC	T_{max}, ^oC	T_{min}, ^oC	T_{max}, ^oC	T_{min}, ^oC
Cairo	25.5	14.0	21.1	10.3	19.7	8.8	21.2	9.8
El-Arich	25.3	14.4	21.4	10.2	19.2	8.5	19.9	9.1
Mersa-Matruh	23.2	13.4	19.5	10.1	18.0	8.4	18.8	8.6

3- The average wind speed at water surface of the present in-door swimming pool in winter for the selected sites is shown in Table (2).

Table (2): Average wind speed in winter season for the selected sites

Winter season / Sites	Nov. W_s, m/s	Dec. W_s, m/s	Jan. W_s, m/s	Feb. W_s, m/s
Cairo	3.6	4.1	3.9	4.5
El-Arich	4.0	4.7	4.8	5.7
Mersa-Matruh	9.3	11.4	11.8	11.8

4- In-door swimming pool temperature keeps constant at 28^oC with average relative humidity in winter season for the selected sites as shown in Table (3).

Table (3): Average relative humidity in winter season for the selected sites

Winter season / Sites	Nov. R.H., %	Dec. R.H., %	Jan. R.H., %	Feb. R.H., %
Cairo	63	60	59	54
El-Arich	71	66	70	69
Mersa-Matruh	68	66	66	65

5- Daily opening time of the proposed swimming pool is 12 hours.

2-2 Governing Equations:

For heating in-door swimming pool system, direct solar energy gains as thermal heat which is demand for heating water of the pool, convection heat losses from the water surface, evaporative heat losses, conductive heat losses to the ground and radiation losses from the water surface were introduced according the following equations:

1- **Direct solar energy gains as heat demand for heating the swimming pool water is given as:**

$$Q_S = \alpha \ I \ A_{SP}, \text{kW} \qquad (1)$$

Where α =0.81 for the present work, (Hahne et al. 1994). Where I, is the rate of solar radiation in winter season for the selected sites and is shown in Table (4).

Table (4): Rate of solar radiation in winter season for the selected sites

Winter season / Sites	Nov. I, kW/m^{2}day	Dec. I, kW/m^{2}day	Jan. I, kW/m^{2}day	Feb. I, kW/m^{2}day
Cairo	4.94	4.56	4.28	5.14
El-Arich	4.65	4.35	3.86	4.37
Mersa-Matruh	4.08	3.62	4.04	4.62

2- **Solar collector heat gains equation is given as follows:**

$$Q_C = \dot{m} \ C_{P_W} \ (T_o - T_{SP}), \text{kW} \qquad (2)$$

Where C_{pw} is specific heat capacity of water and equals 4.814 kJ/kg ^oC T_o is water temperature at liquid flat plate solar collector outlet and T_{SP} is the swimming pool water temperature.

Which the present solar collector characteristics are proposed as the following:

- Fixing of risers on the absorber plate: (embedded)
- Absorber coating: (black mat glass)
- Glazing: (low-iron glass)
- Collector slope angle = Latitude angle of the site + 5 to 10°
- Dimension of the collector 1.6m length and 1.1m width where absorber length 1.5m and 1m absorber width, the spacing between plate and glass cover is 2.5cm, plate thickness is 1.3mm, inner tube diameter 14mm, outer tube diameter is 18mm and tube center-to-center distance is 12cm. Thermal conductivity of plate material is 35W/m^{o}C,

glass cover emissivity/absorptivity ($\alpha\tau$) is 0.88, relative index of glass relative to air is 1.526 and locations of collector is in selected sites Cairo (latitude 30° $05^{'}$ and longitude 31° $17^{'}$), El-Arich (latitude 31^0 $16^{'}$ and longitude 33° $45^{'}$) and Mersa-Matruh (latitude 31° $20^{'}$ and longitude 27° $13^{'}$). Thermal conductivity of the insulation is 0.04W/m^{o}C and insulation thickness is 5cm. Water flow rate per unit area is 0.02kg/m^{2}s. Average inclination angle 52°.

- **Storage Tank Description:**

Dimension of the storage tank is 1.6mx1.1mx$(\frac{1+1.5}{2})$m i.e. storage tank volume =2.2m^3.

- **Instantaneous efficiency of the present solar collector is calculated as:**

$$\eta_i = \frac{Q_C}{A_{SC}\ I_{net}} = \dot{m}\ C_{P_W}\ \frac{(T_o - T_{in})}{A_{SC}\ I_{net}} \quad \% \qquad (3)$$

3- Equation of convective heat losses from water surface is given as:

$$Q_{conv.} = h_C\ (T_{SP} - T_a)\ A_{SP}, \text{kW} \qquad (4)$$

Where h_C is calculated as follows:

$$h_c = 3.1 + 4.1\ W_s, \text{kW/m}^2\text{ K, (Hahne et al. 1994)} \qquad (5)$$

4- Equation of evaporation heat losses is given as:

$$Q_{evap.} = \frac{h_C}{C_{P_{air}}}\ L_W\ (H_S - H_a)\ A_{SP}, \text{kW} \qquad (6)$$

Where L_w is latent heat of evaporation at pool temperature and equals 2.23x10^3 kJ/kg, and H_a & H_s is air humidity at ambient temperature and saturated air humidity, respectively and the evaporation mass flow rate is calculated as:

$$\dot{m}_{evap.} = \frac{h_C}{C_{P_{air}}}\ (H_S - H_a)\ A_{SP}, \text{kg/s} \qquad (7)$$

5- Equation of the conductive heat losses to the ground is given as the following:

$$Q_{cond.} = U_{wall}\ (T_{SP} - T_{ground})\ A_{wall}, \text{kW} \qquad (8)$$

Where U_{wall} is heat loss coefficient of the swimming pool walls

6- Equation of radiation losses from the water surface of the pool is given as:

$$Q_{rad} = \varepsilon_{water}\ \sigma\ (T_{SP}^4 - T_{sky}^4)\ A_{SP}, \text{kW} \qquad (9)$$

Where ε_{water} is emittance of water surface and assumed 0.96. T_{sky} is effective temperature of the sky and usually calculated from the empirical relation, $T_{sky} = T_a - 6$, K.

7- Supplement fresh water heating equation is:

$$Q_{feedwwater} = \dot{m}_{evap.} C_{P_W} (T_{SP} - T_{feed\ water}), \text{ kW} \quad (10)$$

Then the total heating load for heating in-door swimming pool system is summarized as:

$$Q = Q_S + Q_C + Q_{conv.} + Q_{evap.} + Q_{Cond.} + Q_{rad.} + Q_{feed\ water} \quad (11)$$

3- CACULATION OF ENERGY CONSUMPTION AND ECONOMIC EVALUATION

For solar collector heating in-door swimming pool as solar assisted heat system, supplement heat storage tank and hot water boiler is connected in the system to irregularity of solar energy resources.

The hot water boiler must be put into operation when heat produced by solar collector can not satisfy the daily heating requirement of swimming pool. During winter season (November, December, January and February) and for selected sites, Joseph et al. 2001, the energy consumption of hot boiler can be estimated as:

$$Fuel = N_i \times f_i (A_{SC}, \beta)\, l\, \eta_{Boiler} \quad (12)$$

Where

$$f_i (A_{SC}, \beta) = Q_{fi}\, t - I \times A_{SC}\ \eta_{SCi}\ if\ Q_{fi}\ t \geq I_i \times A_{SC}\ \eta_{SCi}$$
$$= 0\ if\ Q_{fi}\ t \leq I_i \times A_{SC}\ \eta_{SCi} \quad \textbf{(13)}$$

Where Q_{fi} is fuel energy consumption of hot water boiler (kWh), N_i is number of day in every month, i is the index of each day in each month, t is opening hour per day of the pool, β in incline angle of south-facing solar collector, η_{Bolier} is efficiency of hot water boiler, f_i (A_{SC}, β) is the monthly average daily heating load supplied by hot water tank (kWh) under area of the solar collector A_{SC} and incline angle β; η_{SC} is monthly average thermal efficiency of the solar collector; I_i is daily solar insolation (kWh/m^2).

In order to maintain the constant temperature of in-door swimming pool, the energy consumption can be calculated by equations (12) and (13).

To investigate the financial aspects of the application solar collector instead of conventional heating system (only fuel), the life-cycle-cost $\dot{C}$ is considered for evaluation in this work. Owing to the hot water boiler (fuel) and hot water by solar collector (only) is always necessary for heating the swimming pool. The primary investment concerned with solar collector is the only consideration.

Monthly cost can be calculated by follow formula:

$$\dot{C} = C_{rf}\ (k,\ n) \times A_{SC}\ C_{SC} + Fuel \times C_{pe} \tag{14}$$

$$C_{rf}\,(k,\ n) = \frac{k\ (1+k)^n}{(1+k)^n - 1} \tag{15}$$

Where C_{rf} is capital recovery factor, k is interest rate, n is life of solar collector, C_{SC} is price of solar collector (Egyptian pound, L.E./m^2), C_{pe} is fuel price of conventional hot water (L.E./kWh). For the economic evaluation, equation (14) can be objective function, and independent variable is incline angle β of south-facing solar collector and area A_{SC} of solar collector.

Energy consumption evaluation and energy efficiency analysis is carried through for this system based on assumptions as follows:

1- A conventional gas boiler is selected as reference scheme and η_{Bolier} =0.88.

2- Winter season (Nov., Dec., Jan., and Feb.) gas consumption is calculated as 19956.7 kWh for reference scheme according to the characteristics of the present system.

3- Thermal efficiency of solar collector η_{SC} is set as constant 0.5.

4- The solar collector price C_{SC} and fuel price C_{pe} is known.

5- Relative energy save ratio E_{sr} is selected as evaluation index which is defined as:

$$E_{sr} = \frac{19956.7 - solar\ energy\ by\ collector}{19956.7} \tag{16}$$

4- RESULTS AND DISCUSSIONS

The solar system for the present in-door swimming pool heating configuration is schematically shown Fig. (1).

According to equations (1-16), the results are drawn. The rate of solar insolation in the winter season for the selected sites is shown in Fig. (2). It is noticed that Cairo site has the highest values of average solar radiation in winter season which is utilized in present application. Direct solar heat gains for heating swimming pool in winter for the selected sites are shown in Fig. (3). It is found that Cairo, El-Arich and Mersa-Matruh in November and December, while in January and February; Cairo, Mersa-Matruh and El-Arich. Solar collector heat gains in winter season for the selected sites are shown in Fig. (4). It is found that the values of heat gains by solar collector as Cairo, El-Arich and Mersa-Matruh in winter season. Furthermore, these amounts of heat gains are sufficient to heating the present pool in the winter season for the selected sites. Average heat load of swimming pool for maintaining constant temperature in winter season for the selected sites is calculated and shown in Fig. (5). It can be seen that the proposed system heat load in Cairo, El-Arich and Mersa-Matruh according to its recording climate conditions in winter season. Owing to balance between the solar energy gains and heating load of the present pool in winter season for the selected sites always be sufficient. The maximum heating load of pool appears in January for Mersa-Matruh and equals 71kW. Figure (6) shows the present system efficiency in winter season for the selected sites. One can conclude that the system efficiency in Cairo, El-Arich and Mersa-Matruh according to its recording climate conditions in winter season. Effect of solar radiation on the solar collector's efficiency is given in Fig. (7). It is cleared from the figure, that the solar radiation has great effect on the solar collector's efficiency. Figure (8) shows the effect of wind speed on the solar collector's efficiency for the selected sites. The solar collector's efficiency is decreased as the wind speed is increased. Evaporated heat losses in winter season for the selected sites are shown in Fig. (9). It is found the evaporated heat losses are great value in Mersa-Matruh according to its recording climate conditions and its location (coastal area). Figure (10) shows relative energy save ratio, E_{sr}, at incline angle 52° in winter season for the selected sites. It is found that E_{sr} values as Cairo, El-Arich and Mersa-Matruh according to its recording climate conditions (solar radiation).

6- CONCLUSIONS

Solar energy utilization has become a key technology in hot water applications in sunny countries. In-door constant temperature swimming pool with $200m^2$ in winter season

and located in the selected sites is presented. Based on the pervious results, some conclusions are drawn as follows:

1- The average heating load of pool is calculated on design parameters and climatic conditions in winter season for the selected sites and the maximum heating load appears in January for Mersa-Matruh and equals 71kW.
2- The values of heat gains by solar collector is found as Cairo, El-Arich and Mersa-Matruh in winter.
3- The system efficiency is effected by climate conditions in winter for Cairo, El-Arich and Mersa-Matruh .
4- The solar radiation has great effect on the solar collector's efficiency.
5- The evaporated heat losses are great value in Mersa-Matruh according to its recording climate conditions and its location (coastal area).
6- E_{sr} values appears as Cairo, El-Arich and Mersa-Matruh according to its recording climate conditions (solar radiation).

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NOMENCLATURES

A_{SC}: solar collector area (m^2)
A_{SP}: swimming pool water surface area (m^2)
A_{wall}: wall of swimming pool water surface area (m^2)
C_{Pw}: specific heat of water (kJ/ kg K)
hc convective heat transfer coefficient (W/m^2 K)
$H_{a:}$ air humidity at ambient temperature
H_S: humidity of saturated air at pool temperature
I_{net}: net solar irradiance on the collector plane (W/m^2)
L_w: latent heat of evaporation at pool temperature (kJ/kg)
$\dot{m}$: mass flow rate of water (kg/s)
$\dot{m}_{evap.}$ mass flow rate of evaporation (kg/s)
Q_{cond}: conductive heat losses to the ground (W)
Q_{conv}: conductive heat losses from the water surface (W)
Q_{evap}: evaporation heat losses (W)
$Q_{feed\ water}$: heat flow rate of fresh water (W)
Q_{rad}: radiation losses from the water surface (W)
Q_{SC}: solar collector heat gains (W)
Qsdirect solar gains (W)
T_a: ambient temperature (^oC)
$T_{feed\ water}$: cold water temperature (^oC)
$T_{ground:}$ ground temperature (^oC)
T_{in}: water temperature at solar collector inlet (^oC)
T_{SP}: swimming pool water temperature (^oC)
T_{sky}: sky temperature (^oC)
T_{wall}: wall temperature (^oC)

U_{wall}: heat loss coefficient of swimming pool walls (W/m^2K)
W_S: wind speed (m/s)

Greek symbols
α: absorptance
β: solar collector tilt angle (^{o})
ε_{water}: water emittance of water surface
$\eta_{boiller}$: boiler efficiency
η_i : instantaneous solar collector efficiency
η_{SCi} : solar collector efficiency
σ : Stefan–Boltzmann constant $5.67 \cdot 10^8$ (W/m^2K)

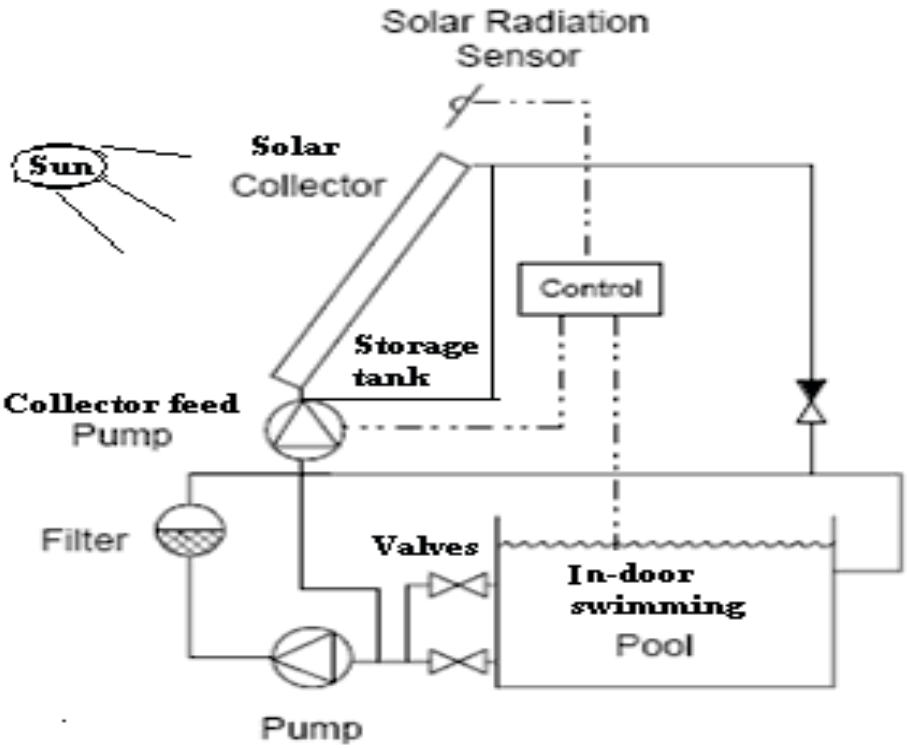

Fig. (1): Schematic diagram of the solar system for heating in-door swimming pool

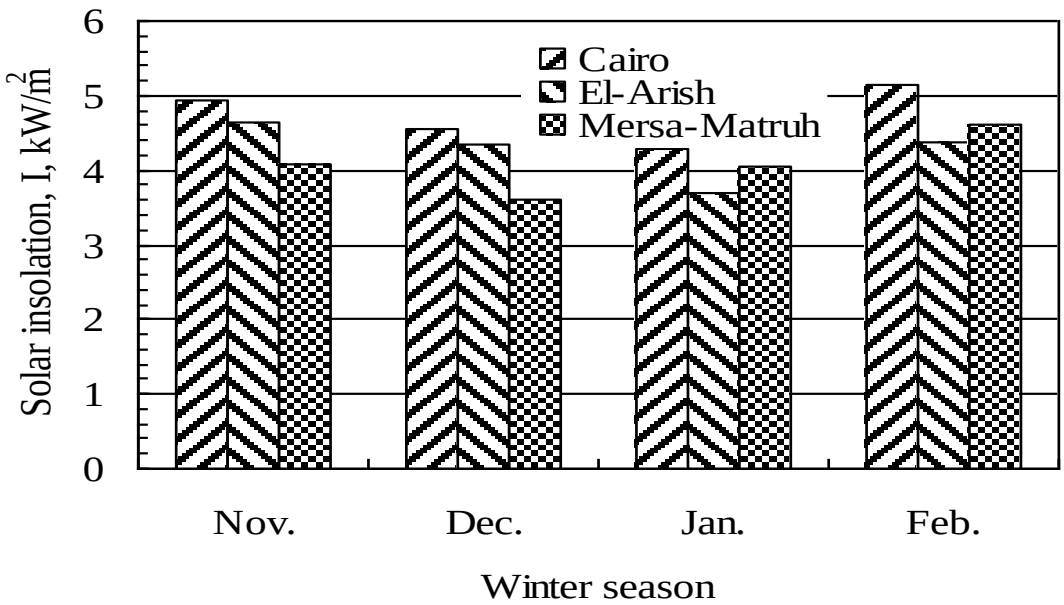

Fig. (2): Rate of solar insolation in winter season for the selected sites

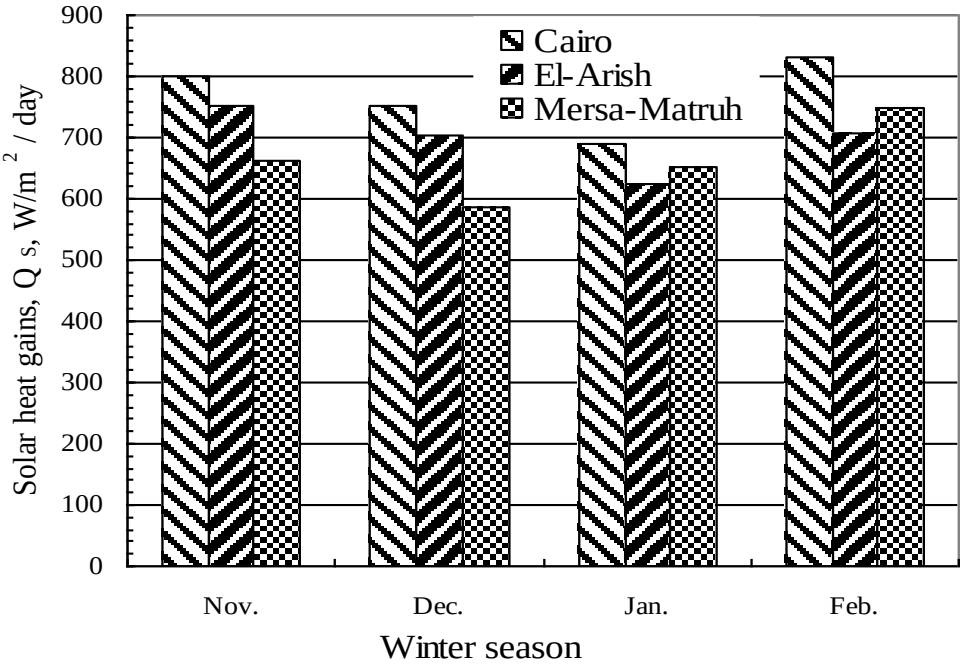

Fig. (3): Direct solar heat gains for heating swimming pool in winter for the selected sites

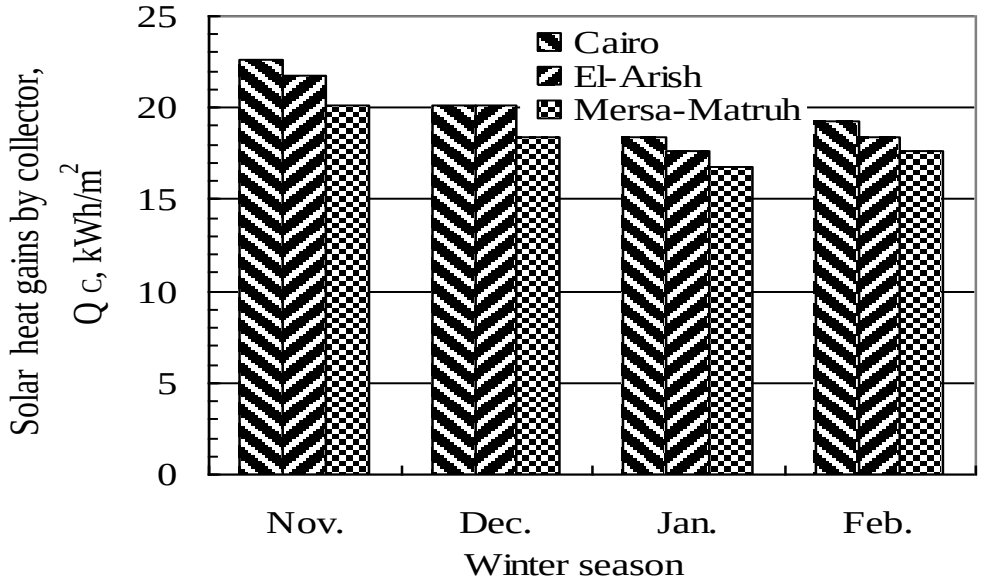

Fig. (4): Solar collector heat gains in winter season for the selected sites

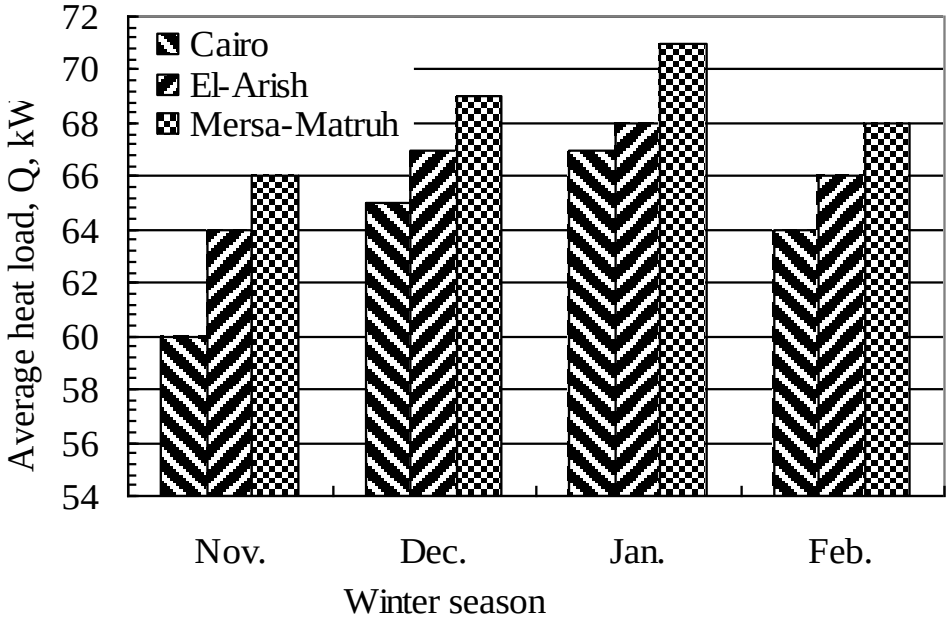

Fig. (5): Average heat load of swimming pool at constant temperature in winter season for the selected sites

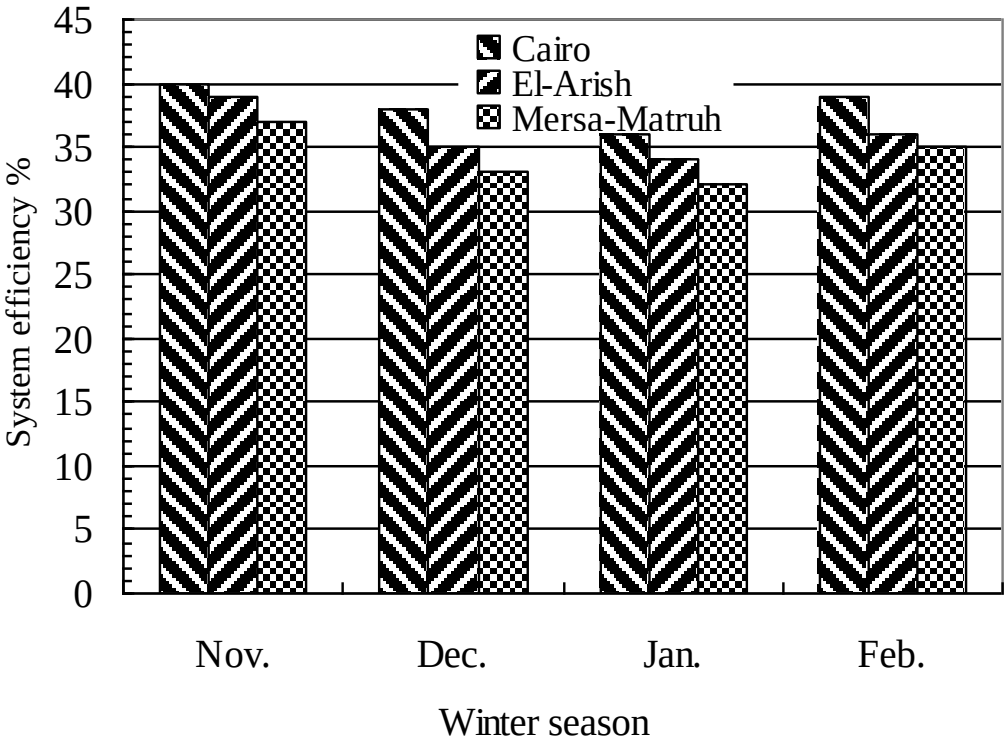

Fig. (6): System efficiency in winter season for the selected sites

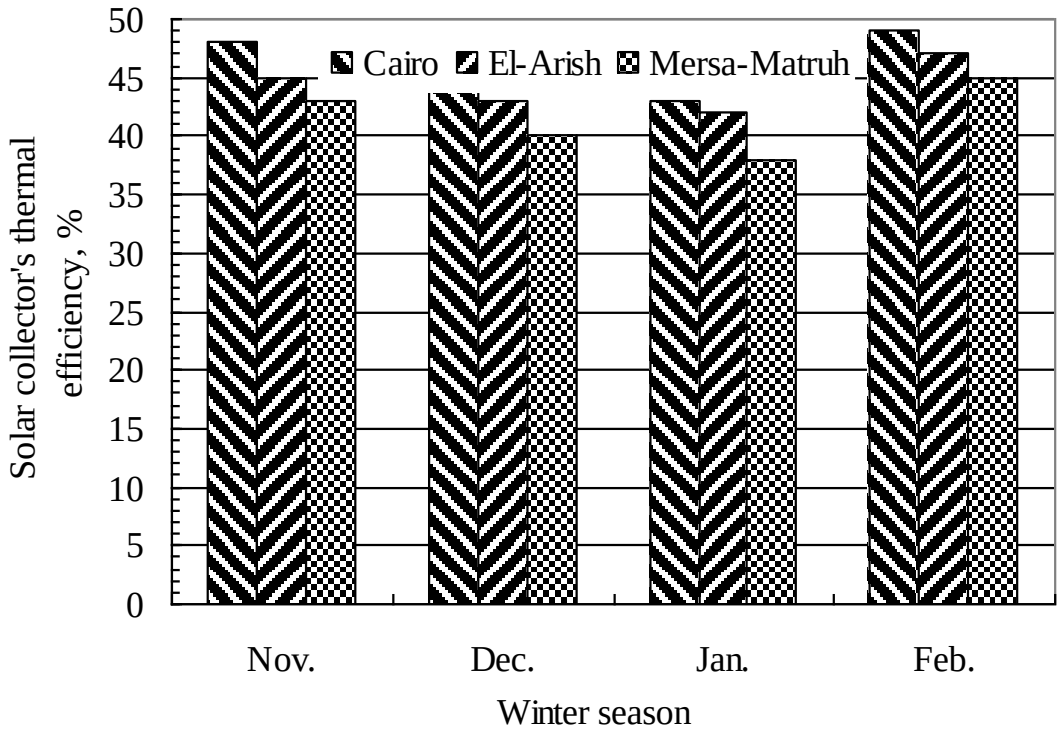

Fig. (7): Effect of solar radiation on the solar collector's efficiecny

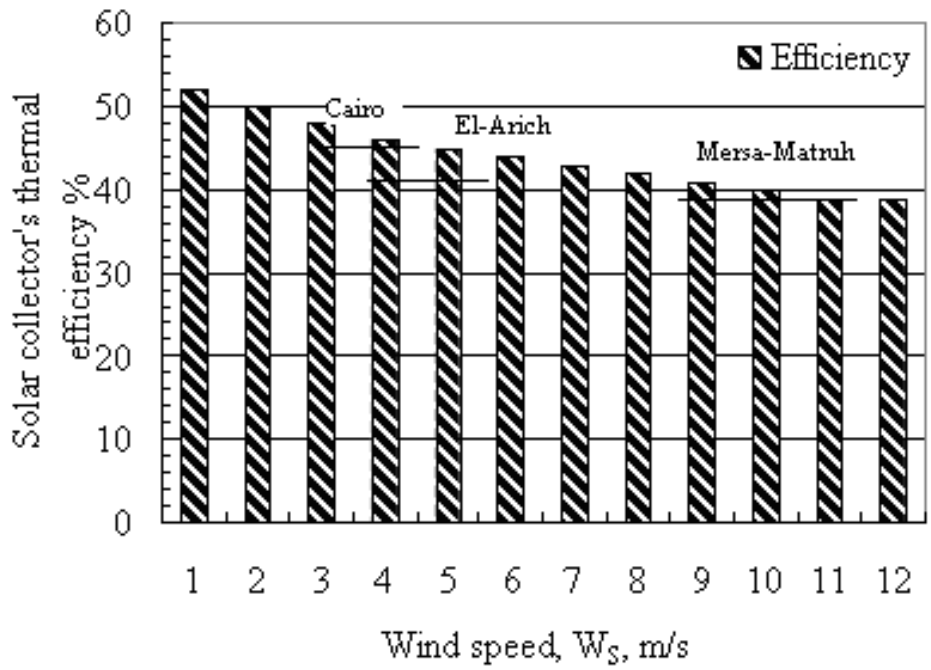

Fig. (8): Effect of wind speed on the solar collector's efficiency for the selected sites

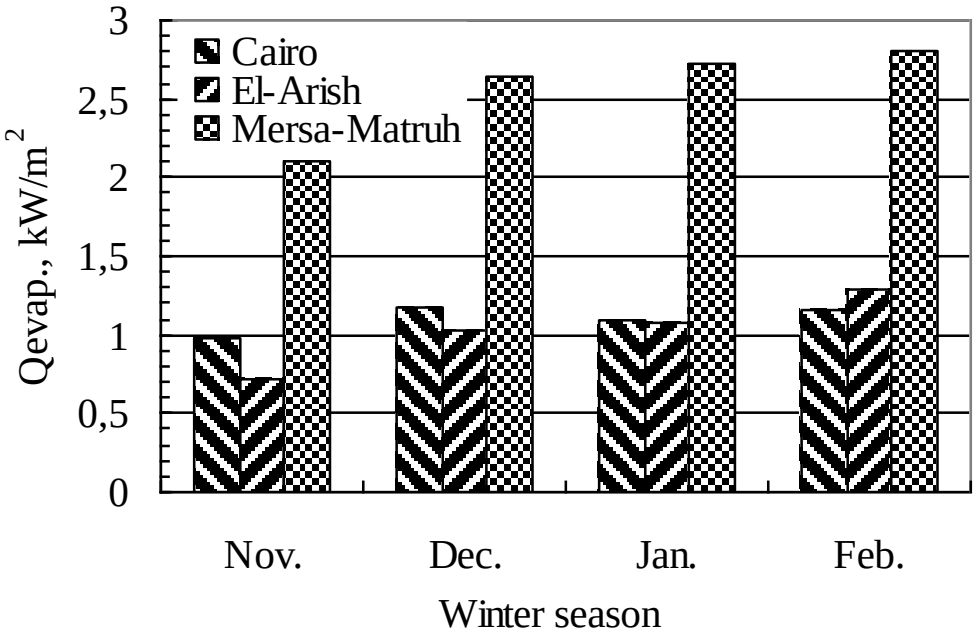

Fig. (9): Evaporated heat losses in winter season for the selected sites

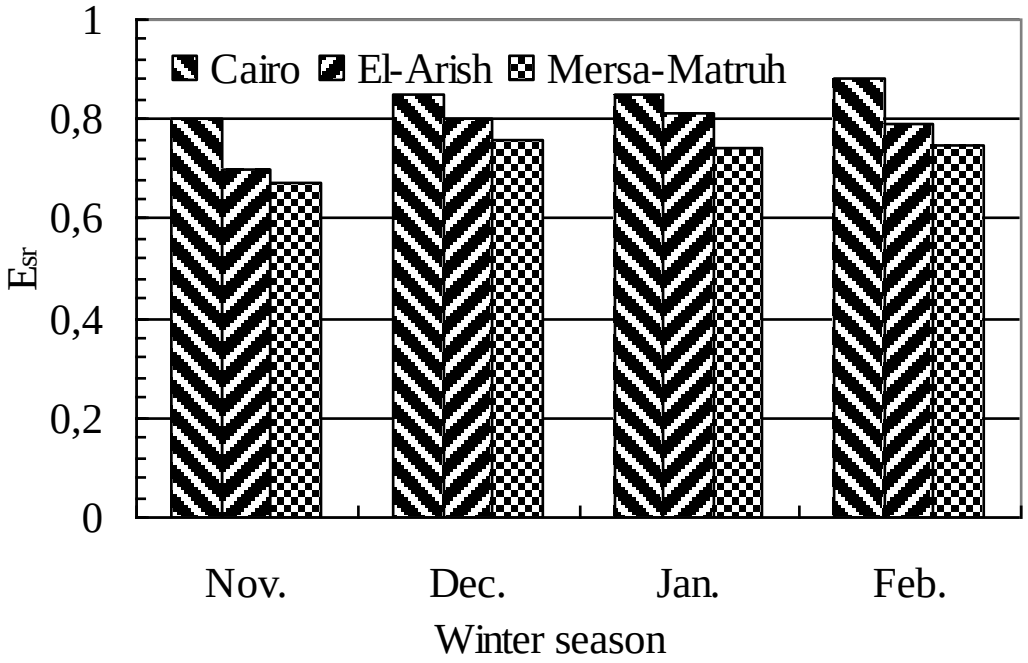

Fig. (10): E_{sr} at incline angle 52° in winter season for the selected sites.