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# Thermal Performance of Hybrid Solar Swimming Pool and Heating of Building in Kirkuk City-Iraq

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**Keywords:**
Flat solar collectors; Heat transfer; Renewable energy; Indoor space heating; Swimming pool.

**Highlights:**

- A Hybrid Solar System for Swimming Pool Heating and Building Air Conditioning.
- Potential ways to save energy and thermal comfort condition with Hybrid Solar System.
- Spiral-shaped tube solar collectors for heating swimming pools.

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**Abstract**: In the latest development, a solar hybrid system maintains the outdoor pool at a constant 30°C year-round. Solar energy, a crucial renewable energy source, is harnessed through a novel collector design emphasizing the importance of tourism designs and heating concepts with environmental considerations. The technology, widely used in homes, involves measuring unglazed flat solar collectors (3.12 m²) for outdoor dome swimming pools in winter. A 2 m²- collector was integrated into a building and studied for seven daily hours over three months (December, January, and February). The internal heating system relied on a fan for electrical energy, reaching peak efficiency in February. Operating at 700 W/m² radiation intensity and a 0.16 kg/sec flow rate, parameters such as sun intensity, ambient temperature, pond water conditions, solar output, water flow, and humidity were recorded. Thermal losses from the pool were calculated using a flat, oval-shaped tube solar collector, along with the room temperature after the pool had stabilized. The results showed a 0.16 kg/s flow rate optimized collector efficiency, prioritizing these findings for achieving thermal comfort, effective building heating, and preserving indoor pool temperature.

# الأداء الحراري لحمام السباحة وتدفئة المباني بالطاقة الشمسية الهجينة في مدينة كركوك – العراق

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**الخلاصة**

وفي أحدث التطورات، يحافظ النظام الهجين الشمسي الآن على درجة حرارة حمام السباحة الخارجي عند درجة حرارة ثابتة تبلغ ٣٠ درجة مئوية طوال العام. يتم تسخير الطاقة الشمسية، وهي مصدر حاسم للطاقة المتجددة، من خلال تصميم جامع جديد يؤكد على أهمية التصاميم السياحية ومفاهيم التدفئة مع الاعتبارات البيئية. تتضمن هذه التقنية، المستخدمة على نطاق واسع في المنازل، قياس مجمعات الطاقة الشمسية المسطحة غير المزججة (٣,١٢ متر مربع) لحمامات السباحة ذات القبة الخارجية في فصل الشتاء. يغطي المجمع مساحة ٢ متر مربع، وتم دمجه في المبنى ودراسته على مدار ثلاثة أشهر (ديسمبر، يناير، فبراير) لمدة سبع ساعات يوميًا. يعتمد نظام التدفئة الداخلي على مروحة لتوليد الطاقة الكهربائية، ويصل إلى ذروة كفاءته في شهر فبراير. يعمل بكثافة إشعاع تبلغ ٧٠٠ واط/م٢ ومعدل تدفق ٠,١٦ كجم/ثانية، ويتم تسجيل معلمات مثل كثافة الشمس ودرجة الحرارة المحيطة وظروف مياه البركة وإنتاج الطاقة الشمسية وتدفق المياه والرطوبة. باستخدام مجمع شمسي أنبوبي مسطح بيضاوي الشكل، يتم حساب الخسائر الحرارية للمسبح، بالإضافة إلى درجة حرارة الغرفة بعد استقرار المسبح. تظهر النتائج أن معدل التدفق ٠,١٦ كجم/ثانية يعمل على تحسين كفاءة المجمع، مع إعطاء الأولوية لهذه النتائج لتحقيق الراحة الحرارية، والتدفئة الفعالة للمبنى، والحفاظ على درجة حرارة حمام السباحة الخارجي.

**الكلمات الدالة:** الطاقة المتجددة، انتقال الحرارة، المجمعات الشمسية المسطحة، تدفئة الفضاء، حوض السباحة.

## 1.INTRODUCTION

The International Energy Agency (IEA) reported a 2.3% increase in global energy demand in 2019, with fossil fuels accounting for approximately 70% of this demand. An alternative energy project was initiated to address this, leading to a transition towards alternative energy sources. Various technologies, including solar collectors and photovoltaic systems, are employed to harness solar energy. Solar energy finds applications in meeting middle-class needs, such as water and home heating. Particularly, using solar energy to heat public swimming pools is emphasized, considering the two main types: indoor and outdoor [1-4]. Solar collectors, including flat plates, evacuated tubes, and unglazed collectors, offer an efficient means of pool heating [5]. Flat-plate collectors, made of a dark-colored absorber, are the most common and transfer heat to the water. In urban settings, outdoor pools aim for an ideal swimming temperature of 27 °C, although variations are allowed within a 5 °C range [6-10]. Abed et al. [11] simulated a pool in southern Russia, finding that increased absorption areas elevated temperature. Starke et al. [12] explored the thermal behavior of pool water, considering phase change material (PCM) storage systems. Hang et al. [7] evaluated economic and environmental effects, highlighting the efficiency of flat-panel solar collectors with natural gas. Kuyumcu and Yumrutaş [8] analyzed the thermal aspects of Olympic pools in Gaziantep, Turkey, achieving efficiency with waste energy. Marín et al. [9] incorporated predictive control to enhance indoor energy efficiency, reducing energy consumption by 18.76%. Li et al. [10] developed PCM integration for outdoor pools in semi-tropical climates. Abed et al. [11] improved parabolic basin collectors, while Starke et al. [12] studied heat pump performance in southern Brazil. Chow et al. integrated solar collectors and heat pumps for indoor pool space heating. Al-Bayati [13] conducted a theoretical study on solar collector heating for an Olympic pool, revealing the significance of collector design. The overall objective is to assess the thermal performance of a solar collector in heating an outdoor pool in Kirkuk, Iraq, considering the impact of the indoor unit in maintaining the temperature within acceptable limits.

## 2.MATERIALS AND METHOD

### *2.1.System Description of Solar Collector*

A flat, unglazed solar collector was meticulously designed to optimize efficiency. Comprising distinct layers, the solar collector included an absorbing layer crafted from colored aluminum with a selective coating, enhancing absorption. This layer was positioned behind insulation and pipes, featuring oval-shaped tubes (0.5 cm in diameter) to expand the absorption surface. The insulation layer and the cover are constructed from polycarbonate material, ensuring effective insulation. The absorbent plate maintains dimensions of (120–260) cm.

The absorption tube specifications are detailed, with an internal diameter of 0.05 m and an external diameter of 0.052 m. A transparent cover layer, typically made of glass or durable plastic like polycarbonate, has been incorporated. This layer is strategically designed to permit sunlight passage while minimizing heat loss from the collector. The transparent cover plays a pivotal role in trapping incoming solar radiation, fostering a greenhouse effect, and elevating the temperature within the collector. The primary objective of this solar collector design is to facilitate the heating of an outdoor swimming pool during colder months, specifically in

December, January, and February, as illustrated in Fig. 1.

### 2.2.Pool

The pool, measuring 50–100 cm with a depth of 70 cm, features a glass cover positioned on its surface to mitigate losses attributable to evaporation and radiation. Ola has ingeniously devised a method to harness heat directly from horizontal radiation on the pool's surface, involving constructing a glass enclosure within the pool, essentially creating a glass house submerged in the water.

### 2.3.Pump

The pump drew water from the pool and directed it through the solar collector panels. As the water flowed through these panels, effectively collected and exposed to the sun's radiation, heating it. Subsequently, the heated water was circulated back into the pool, providing a resource that can be utilized for various purposes. This process of running the solar collector spanspanned 7 hours each day.

**Table 1** Pump Specifications.

| Type | Power | H.MAX | Q.MAX | P.M | Max liq. Temp. |
|---|---|---|---|---|---|
| QB60 | 0.37 kW | 27 m | 30 L/min | 2850 r/min | <= 45 °C |

### 2.4.Thermocouples Locations

More than five sensors, specifically thermocouples of type K, were strategically positioned at various points, including the entry and exit points, inside the basin, on the collector's surface, and upon entering the home heating unit. This arrangement is depicted in Fig. 1.

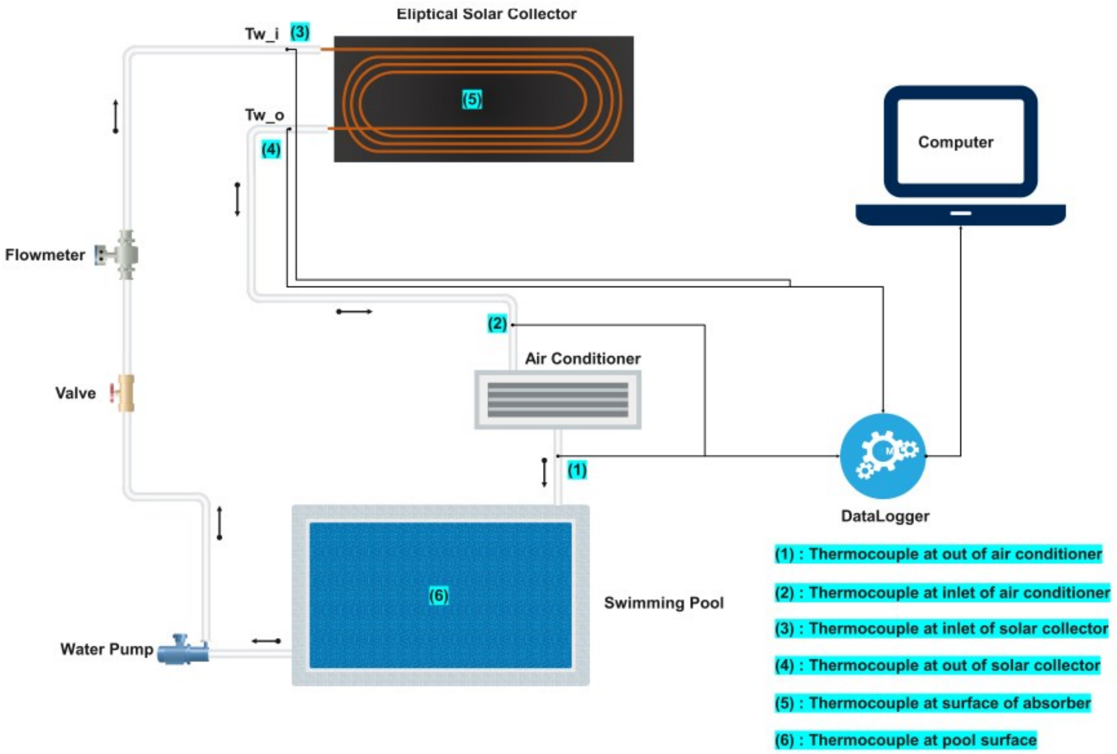


**Fig. 1** The Schematic of a Solar System Employing an FPSC Solar Collector with Pool and Room Conditioning on.


**Fig. 2** A Solarium Complex with a Swimming Pool and its Accessories.

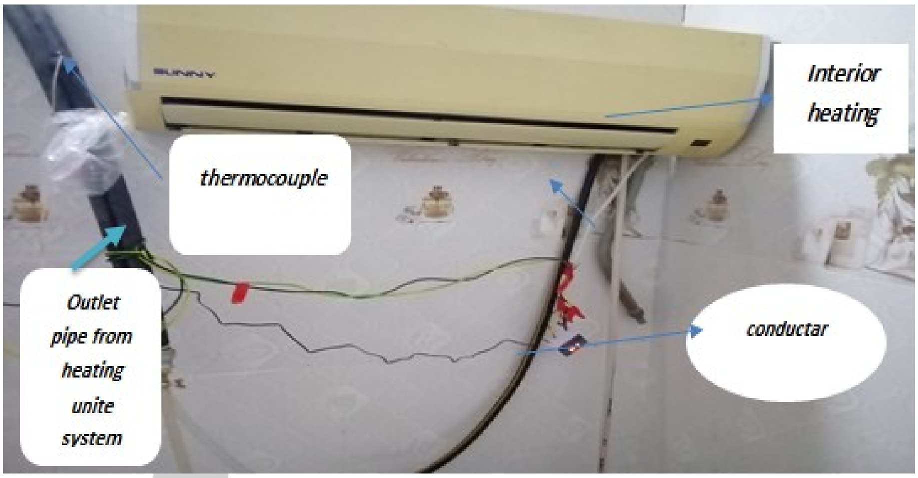


**Fig. 3** A Photograph of an Internal Heating System.

### *2.5.Interior Heating System*

In this scenario, heating the room air provides a dual benefit by warming the pool on the initial day and supplying hot water to the air conditioners' interior. The process involves preheating the room air through an activated sensor when the temperature exceeds 30 °C. Upon activation, the indoor unit run, featuring a coil equipped with a fan designed solely for energy consumption. Additionally, when the indoor unit was engaged, the fan coil within the internal part of the air conditioning system operated exclusively for energy consumption.

## 3.EXPERIMENTAL SETUP

Test information was collected by thermocouples in various locations at the Solar Collector's Intake and Outlet and entrance and exit of the air conditioner, the basin, and the complex's roof, in addition to the average ambient temperature difference. All these values were measured using K-type thermocouples connected to a system of obtaining multiple data loggers for a laptop. The average values at 1-minute intervals using logger software were reported, as described by a mass flow rate through a solar collector. The readings, including relative humidity and flow measurement, were taken every hour between 9:00 and 4:00 pm from December 2022 to February 2023.

**Table 2** Features of measuring devices.

| Parameter | Sensor | Accuracy |
|---|---|---|
| Wind speed | Cup anemometer | ±5% m.s-1 |
| Ambient Relative humidity | Capacitive sensor | . ±0.3% |
| Ambient air temperature | Pt-1000 | ±0.05 |
| Pool temperature | Pt-1000 | ±0.05 |
| Horizontal Solar irradiance | pyranometer | ±0.5% |
| Inlet and outlet collector temperature. | Pt-1000 | ±0.05 |
| Indoor heating units | Pt-1000 | ±0.05 |
| Mass flow rate | Magnetic flowmeter | ±0.5% |

**Table 3** Weather conditions in Kirkuk, February 12, 2023.

| Time (hr) | RH (%) | Wind Speed (m/s) | Title Solar Radiation W/m² | Ta (◦C) | Horizontal Solar Radiation (W/m²) |
|---|---|---|---|---|---|
| 09:00 | 70.6 | 0.1 | 420 | 14 | 22 |
| 10:00 | 63.9 | 0.31 | 460 | 16 | 71 |
| 11:00 | 59.2 | 0.42 | 500 | 17 | 103 |
| 12:00 | 52 | 0.5 | 600 | 20 | 150 |
| 13:00 | 47.3 | 0.12 | 540 | 18 | 131 |
| 14:00 | 42.7 | 0.16 | 511 | 17 | 132 |
| 15:00 | 42.4 | 0.17 | 409 | 16 | 125 |
| 16:00 | 42.7 | 0.11 | 350 | 15 | 108 |

## 4.MODELS OF HEAT TRANSFER IN SWIMMING POOLS

Developing heat transfer in a swimming pool model is essential for investigating the efficacy of heating systems for pools. An evaluation was conducted to assess this model on eight outdoor pools utilizing solar heating based on the energy balance framework presented by [14, 15]:

$$\mathbf{Qreq = Qgain - Q\,loss} \qquad (1)$$

$$\mathbf{Qreq = cp * \rho w * Vp * \Delta Tp} \qquad (2)$$

where $\rho_w$, $c_p$, $V_p$, and $T_p$ are the density of the pool water (kg/m³), the specific heat at a constant pressure of pool water (J/Kg.K), the temperature of the pool (°C), and pool volume (m³), respectively. The heat gains are [1, 2]:

$$\mathbf{Qgain = Qcol + Qp} \qquad (3)$$

$$\mathbf{Qcol = mcol * cp * (Tcol - Tp)} \qquad (4)$$

The efficiency of the flat collector can be found by the following equation [3]:

$$\eta = \frac{\mathbf{m*cp*(T\,out - T\,in)}}{\mathbf{Ic*AC + Qpump}} \qquad (5)$$

where η is the collector efficiency, $I_c$ is solar radiation on a flat plate with a 45°toward the south. (W/m²), AC is the area of the collector (m²) due to direct solar radiation on the pool's surface and is represented by $Q_{pool}$. $Q_{solar}$ is the power transfer to the water for the solar collector array (W), and $Q_{pump}$ is the pump power (W). The heat gains due to direct solar radiation on the pool's surface are represented by $Q_{pool}$ [4, 5]:

$$\mathbf{Qp = \alpha s.IH \cdot Ap\ dt} \qquad (6)$$

As is pool water absorptivity, considered 0.85 [6], I is the horizontal solar radiation W/m², and Ap is the pool surface area (m²). The losses are calculated from [7, 4].

$$Qloss = Q_{eva} + Q_{rad} + Q_{conv} + Q_{mak} + Q_{cond} \quad (7)$$

Q eva, $Q_{conv}$, $Q_{rad}$, $Q_{cond}$, and $Q_{mak}$ are found using the following mathematical expressions.

### 4.1.Evaporative Heat Loss

$$Qeva = Ap.h_{eva}\,(p_w - p_a).m_{occupancy}.t\,eva \quad (8)$$

$$heva = a + b.v \quad (9)$$

where a and b are constants [3]:

a = 0.0506 w / $m^{-2}pa^{-1}$

b = 0.0669 w $sm^{-3}pa^{-1}$

$m_{occupancy}$ is the occupancy factor given by [8]:

$$Occupancy = 4.27 * N / Ap + 1 \quad (10)$$

$P_w$ denotes the saturated water vapor pressure at water temperature, Pa denotes the water vapor partial pressure at air temperature [9, 10], v denotes wind speed (m/s), h eva denotes the evaporative heat transfer coefficient (kJ/kg), and N denotes the number of swimmers.

### 4.2.Heat Loss Due to Radiation

Heat loss by radiation occurs between pool water to the top surface of the ambient atmosphere through long-wave radiation ($Q_{rad}$) [8, 3]:

$$Qrad = \cdot\,\varepsilon_w \cdot \sigma_s \cdot Ap\left((T_p + 273)^4 - (T_s + 273)^4\right).t\,rad \quad (11)$$

where $\varepsilon_w$ is the water's emissivity; $\sigma_s$ is the Stefan-Boltzmann constant, which is $5.67\times10^{-8}$ kW/ ($m^2$.$K^4$) [11]; and Ts is the ambient environment's r surface temperature. $T_{sur}$ is the sky temperature ($T_{sky}$) in the OSWPs [12, 3]:

$$T_{sky} = (T_a + 273) \cdot \varepsilon_s^{0.25} - 273 \quad (12)$$

### 4.3.Convective Heat Loss

The heat transfer generated by the movement of the pool water and ambient air causes convective heat loss ($Q_{conv}$) [13, 14]:

$$Qconv = h_{conv.} * Ap * (T_p - Ta) \quad (13)$$

$$h_{conv} = (3.1+4.1V) \quad (14)$$

where $h_{conv}$ is the convective heat transfer coefficient, and v is the wind speed m/s.

### 4.4.Conductive Heat Loss

The temperature difference between the pond water and the soil caused conductive heat loss ($Q_{cond}$), contributing very little to the total loss of pool heat [15, 5].

$$Q\,cond = 0.05\,(Q\,eva + Qrad + Qconv) \quad (15)$$

### 4.5.Water Heat Loss Due to Refilling

The temperature difference between pool water and freshwater replenishment results in heat water loss ($Q_{mak}$). Since the pool water is lost due to evaporation and drainage, new water is necessary to replenish the pool [7, 16, 17]:-

$$Q_{mak} = mcp \cdot (T_p - T_{mak}) \quad (16)$$

where m is the freshwater flow rate (kg/s), $T_{mak}$ is the temperature of the freshwater being refilled.

### 4.6.Space Heating System Design

The energy consumption $Q_{hp}$ of the heat pump unit is the total energy consumed by the fans and controller during the period.$Q_{hp}$ of the heat pump unit is calculated from [18, 19].

$$Q_{cond} = m\,w \cdot C_{pw} \cdot (T_{in} - T_{out}) \quad (17)$$

where $m_w$ is the mass flow rate of hot water, and $T_{in}$ and $T_{out}$ are the inlet and outlet temperatures to/ from the fan coil unit. Total energy consumed by the fans and controller during the working period.

$$Q_{hp} = \sum(P_{fan} + P_{controller}) \quad (18)$$

where $P_{fan}$ and $P_{controller}$ are the power consumptions of the fan and the controller, respectively. The coefficient of performance of the overall heating system is defined as [5]:

$$COP_{sys} = (Q_{cond})/Q_{hp} \quad (19)$$

## 5.RESULTS AND DISCUSSION

The experiment was conducted in Kirkuk, Iraq (latitude 35.46, longitude 44.39), employing different flow rates of 0.03-0.06 and 0.16 kg/s for seven hours daily, from 9 am to 4 pm. The results were obtained using a flat solar collector with a glass cover for the swimming pool to minimize surface losses from convection, radiation, and evaporation during unoccupied periods. Solar radiation measurements were taken on the fifteenth day of each month from December 2022 to February 2023. The maximum solar radiation occurred at midday in February, reaching 700 W/m². The lowest value was 550 W/m² in January and peaked at 670 W/m² in December around midday. Figure 4 illustrates the relationship between solar radiation and daylight hours, showcasing an increase in solar radiation toward midday and a decrease in the afternoon due to the sun's angle and reduced radiation. Figure 5 demonstrates that acquired energy increased until it peaked in the middle of the day, indicating higher radiation and decreased heat loss. The energy gained increased with high flows, reaching its maximum at 0.16 kg/s, with a value of 900 Watts on February 16, attributing to improved heat transfer with higher flows, as evident in Fig. (6), depicting the temperature difference between entry and exit. Figure 7 reveals the thermal efficiency of the solar collector, peaking in the middle of the day at a flow of 0.16 kg/s, reaching 44% efficiency with a radiation intensity of 570 W/m² at noon. The best efficiency was achieved with the highest temperature increase. Figures 8 and 9 illustrate the stability of the pool temperature with the operation of the internal heating unit and the heat gained by the room with the internal air conditioner. Figure 10 analyzes the total losses of the swimming pool, indicating that evaporation is the largest part, followed by convection and radiation. The losses increased with the temperature difference, reaching their maximum at the end of the day with the highest flow rate. Figure 11 illustrates the relationship between incident radiation and solar radiation intensity on the pool surface, peaking at midday. Figures 12-13 show that theoretical results increased the pool temperature, achieving thermal comfort with the presence of the internal heating unit and indicating the potential for building heating.

**Table 4** Experimental Data of Flow Rate 0.16 kg/sec on December 21, 2022 without Internal Heating.

| Time (hr) | ΔT | Qu(W) | ἠ% | Tp(˚C) |
|---|---|---|---|---|
| 09:00 | 0.6 | 333.564 | 26.73 | 17 |
| 10:00 | 1 | 555.94 | 30.00 | 22 |
| 11:00 | 3 | 667.128 | 41.12 | 25 |
| 12:00 | 4.5 | 833.91 | 45.30 | 27.8 |
| 13:00 | 3.3 | 667.128 | 40.73 | 32 |
| 14:00 | 1 | 555.94 | 38.99 | 33 |
| 15:00 | 0.8 | 444.752 | 29.00 | 34 |
| 16:00 | 0.5 | 200 | 21.37 | 38 |

**Table 5** Experimental Data of Flow Rate 0.16 kg/s on January 21, 2023 without Internal Heating.

| Time (hr) | ΔT | Qu(W) | ἠ% | Tp(˚C) |
|---|---|---|---|---|
| 09:00 | 0.4 | 502.1 | 24 | 17 |
| 10:00 | 1 | 555.94 | 35 | 22 |
| 11:00 | 3 | 667.128 | 40 | 25 |
| 12:00 | 6 | 889.504 | 43 | 27.8 |
| 13:00 | 1.2 | 667.128 | 39 | 32 |
| 14:00 | 1 | 555.94 | 33 | 35 |
| 15:00 | 0.3 | 250 | 25 | 38 |
| 16:00 | 0.2 | 150 | 20 | 43 |

**Table 6** Experimental Data of Flow Rate 0.16 kg/sec on February 21, 2023 without Internal Heating.

| Time (hr) | ΔT | Qu(W) | ἠ% | Tp(˚C) |
|---|---|---|---|---|
| 09:00 | 0.4 | 502.1 | 24 | 17 |
| 10:00 | 1 | 555.94 | 35 | 22 |
| 11:00 | 3 | 667.128 | 40 | 25 |
| 12:00 | 6 | 889.504 | 43 | 27.8 |
| 13:00 | 1.2 | 667.128 | 39 | 32 |
| 14:00 | 1 | 555.94 | 33 | 35 |
| 15:00 | 0.3 | 250 | 25 | 38 |
| 16:00 | 0.2 | 150 | 20 | 43 |

**Table 7** Experimental Test at Flow Rate 0.16 kg/sec on February 21, 2023 with Internal Heating.

| Time (hr) | ΔT (C◦) | $Q_u$ (W) | ἠ% | $T_{room}$ (C◦) | $Q_{room}$ (W) | Tp (˚C) |
|---|---|---|---|---|---|---|
| 09:00 | 0.9 | 112.86 | 8.61 | 19 | 0 | 18 |
| 10:00 | 1.2 | 150.48 | 10.48 | 20 | 0 | 22 |
| 11:00 | 2 | 250.8 | 16.07 | 21 | 125.4 | 28 |
| 12:00 | 4 | 501.6 | 26.79 | 22 | 501.6 | 30 |
| 13:00 | 3 | 376.2 | 16 | 23 | 376.2 | 30 |
| 14:00 | 2 | 250.8 | 15.73 | 23 | 250.8 | 30 |
| 15:00 | 1.5 | 188.1 | 14.74 | 24 | 188.1 | 30 |
| 16:00 | 1 | 125.4 | 11.48 | 24 | 125.4 | 30 |

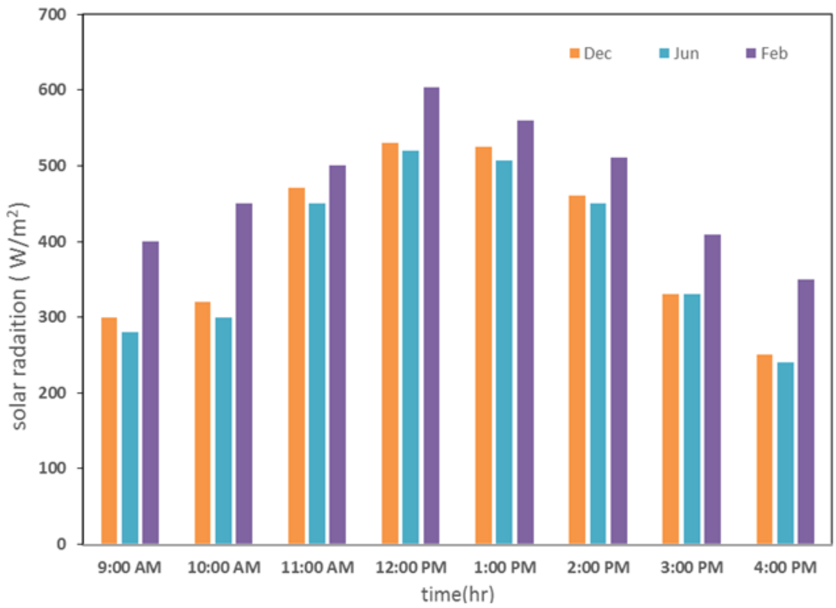


**Fig. 4** Solar Radiation Profile at different Test Times of 17th day from Dec 2022. to Feb 2023, Kirkuk, Iraq.

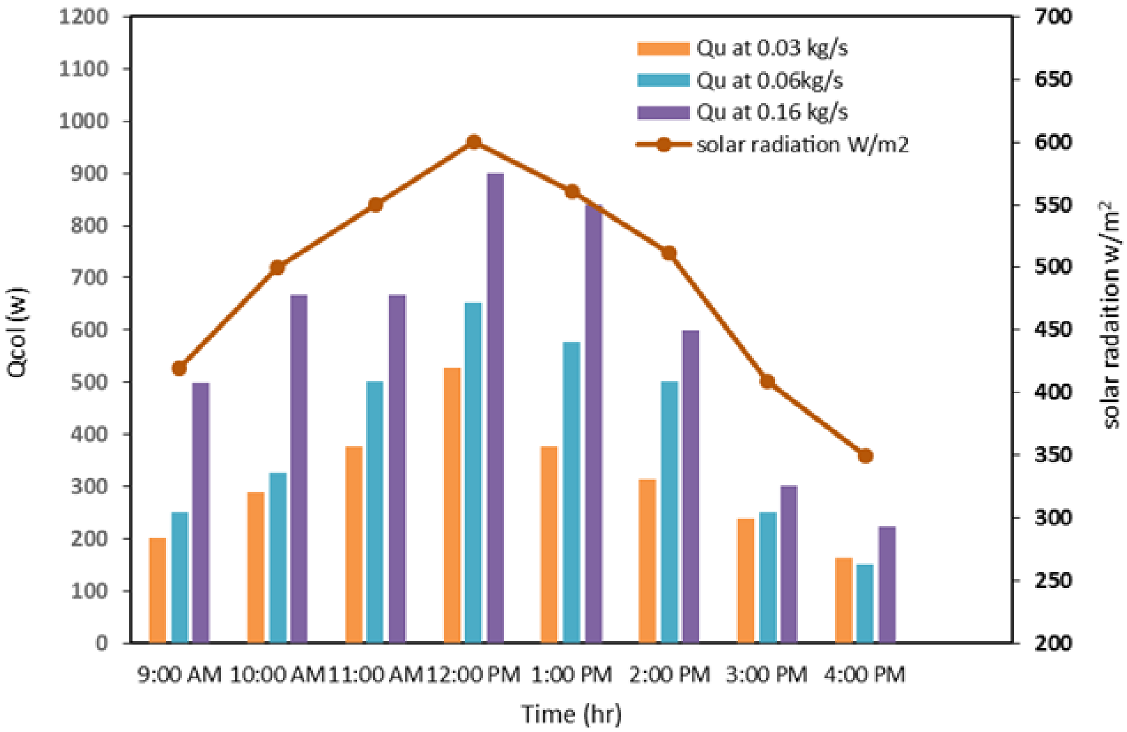


**Fig. 5** Energy Gained with Following Flow Rates (0.03kg/s, 0.06kg/s, and 0.16 Kg/s) 12, 14, and 16th Feb 2023, Kirkuk, Iraq.

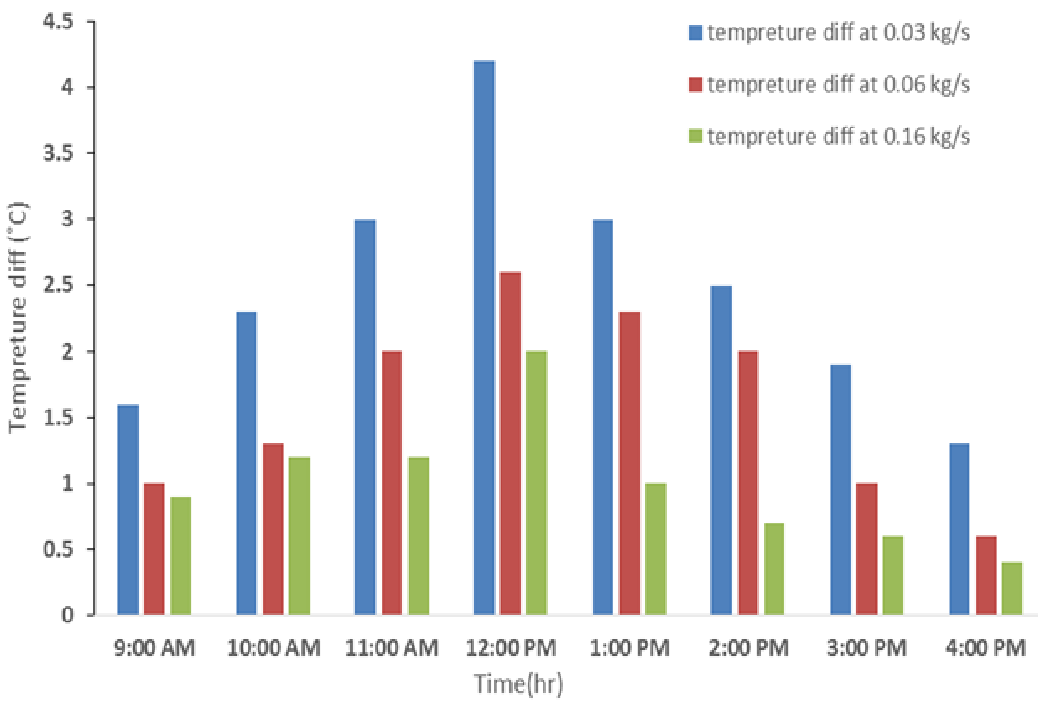


**Fig. 6** Flat Collector Temperature at Different Flow Rates (0.03kg/s, 0.06kg/s, and 0.16 kg/s) on February 12, 14, and 16, 2023. Kirkuk, Iraq.

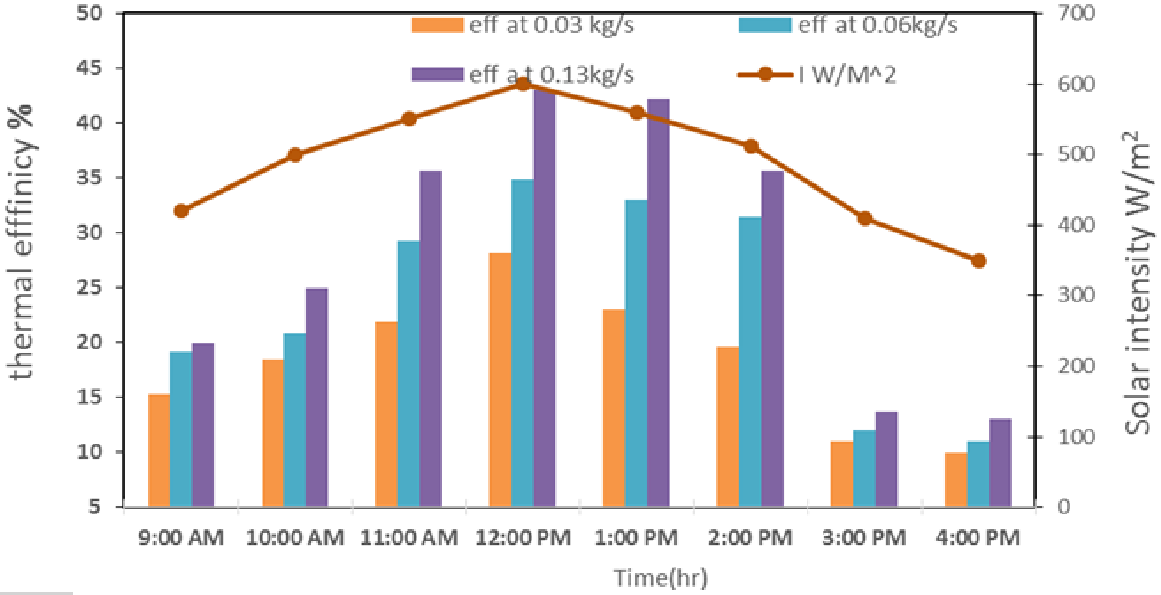


**Fig. 7** Thermal Efficiency with Daylight Hours and Radiation Intensity with Flow Rates (0.03kg/s, 0.06kg/s, and 0.16kg /s) in 12, 14, and 16th Feb 2023, Kirkuk, Iraq.

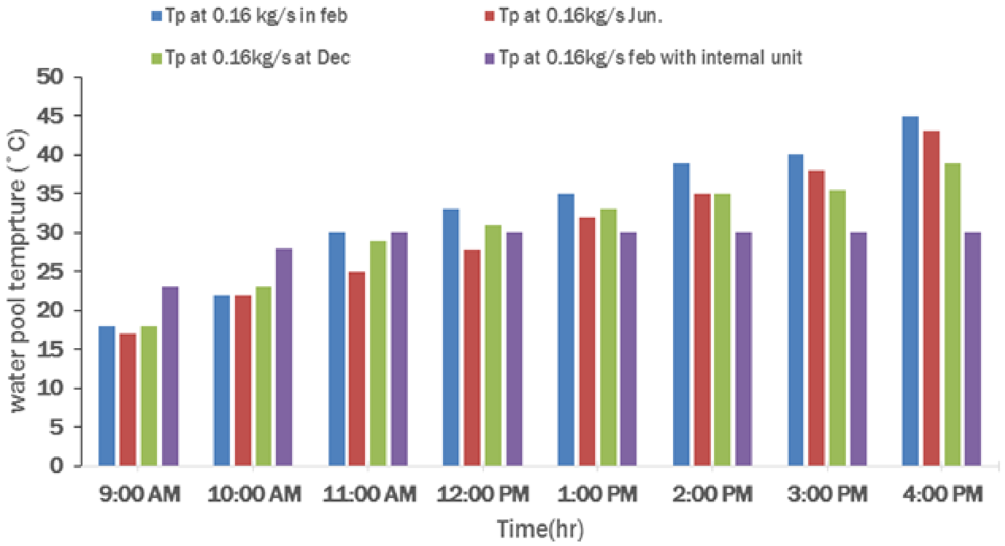


**Fig. 8** The Pool Temperature with the Internal Conditioner 0.16 kg/s on 17th between Dec 2022- Feb 2023 and without the Internal Conditioner, February 18, 2023, Kirkuk, Iraq.

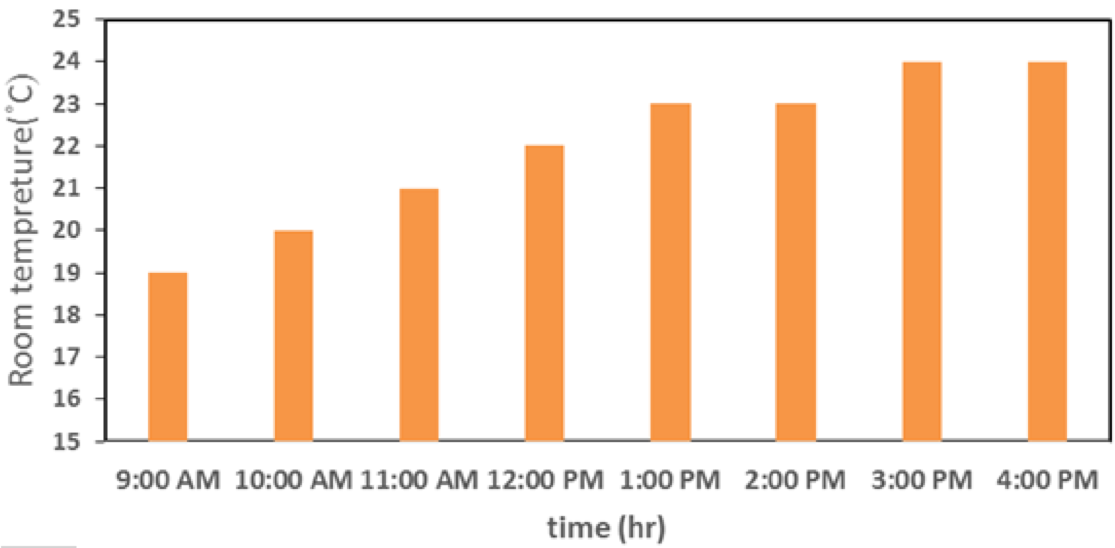


**Fig. 9** Room Temperature Differences Over Time for 25th Feb 2023 for Flow Rates 0.16 kg/s, Kirkuk, Iraq.

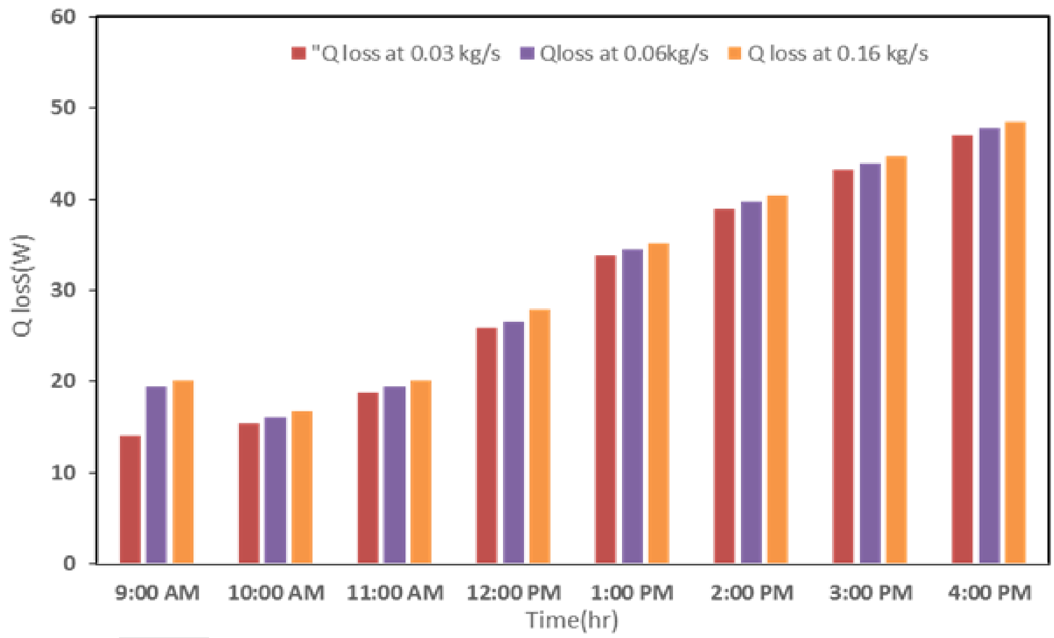


**Fig. 10** The Losses from the Surface of the Pool with Different Flowrates.

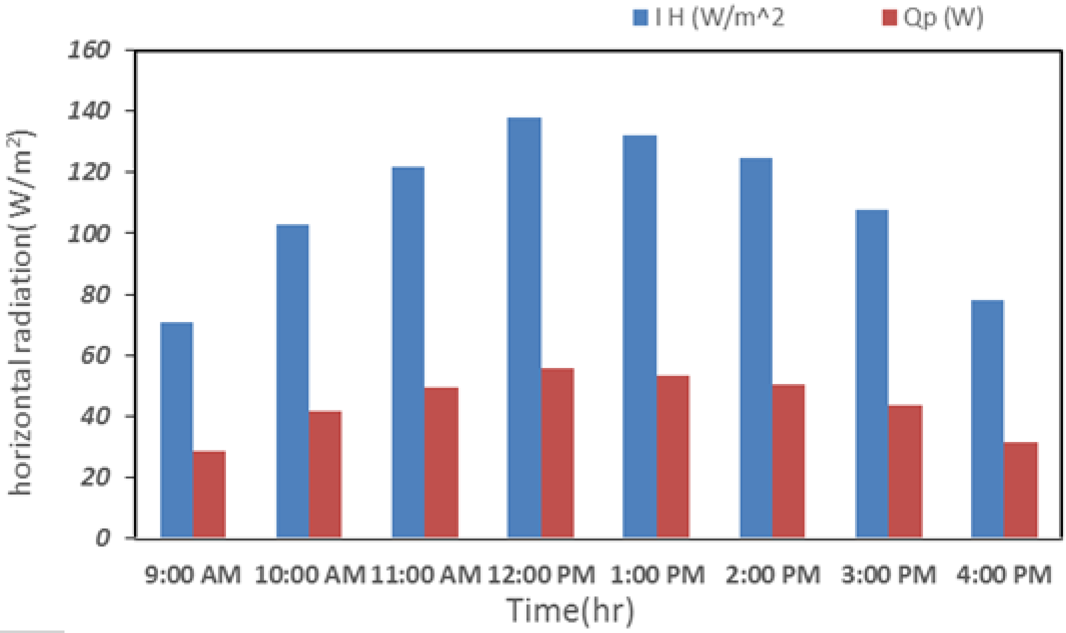


**Fig. 11** Horizontal Radiation, the Energy Gained Directly from the Pool, on February 17, 2023, in Kirkuk, Iraq.

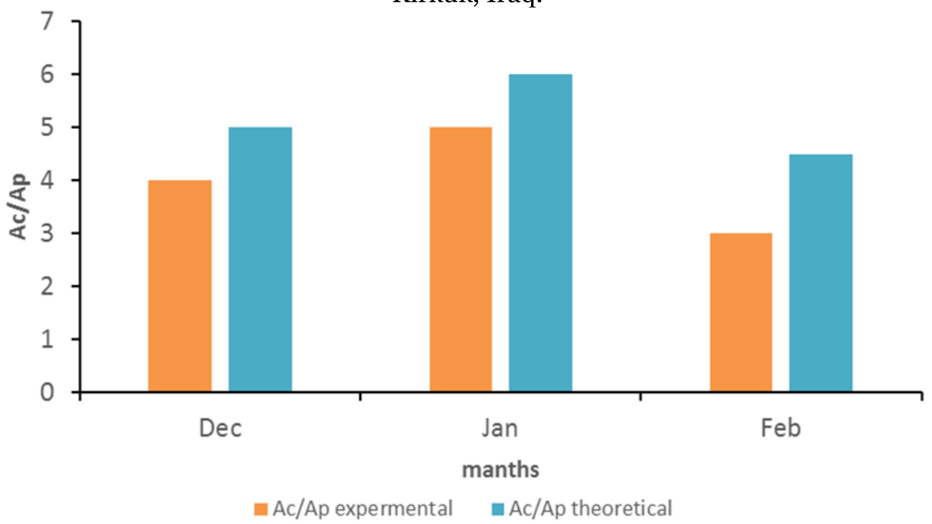


**Fig. 12** The Relationship between the Design Calculations and the Results of the Process.

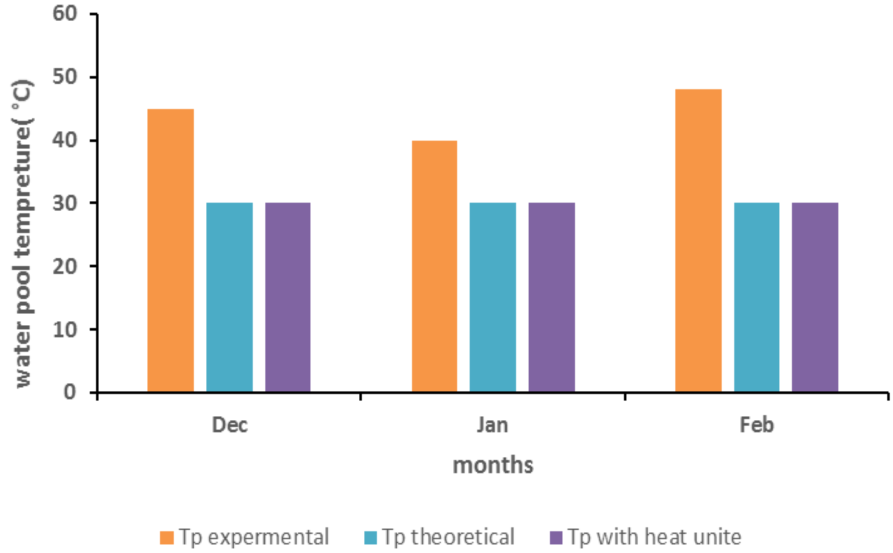


**Fig. 13** End-of-Day Pool Temperature with Solar Heating and Building Heating in Kirkuk, Iraq.

## 6.CONCLUSIONS

This research explores the feasibility of implementing a solar panel system using flat, oval-shaped tube solar collectors to heat outdoor swimming pools. The proposed design has two advantages: heating the pool and conditioning the air in the household. The tests are conducted over three days each month (in December, January, and February) in Kirkuk, Iraq. Analysis of the obtained results revealed enhanced performance for collectors with higher flow rates, contributing to water stability in the basin and maintaining room temperatures at 24 °C. The results of the practical study showed that the design of the solar collector, incorporating spirally shaped tubes with specific lengths, diameters, thermal insulation, and a glass cover, successfully achieved the design parameters within the model for pool size and room air conditioning in the city of Kirkuk.

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## NOMENCLATURE

| | |
|---|---|
| *Ac* | *Area of the solar collector array, m²* |
| *Ap* | *Surface Area of a Pool, m²* |
| *COPr* | *Coefficient of performance ratio* |
| *Cp* | *Specific heat at constant pressure, J/kg K* |
| *a.d* | *Constant evaporation, w / m ⁻² pa ⁻¹* |
| *h eva* | *Average evaporative heat transfer coefficient, W/m² K* |
| *h conv* | *Average convective heat transfer* |
| *Ih* | *Solar radiation, W/m²* |
| *Ic* | *Solar radiation at collector plane, W/m²* |
| *P* | *Pressure, pa* |
| *Q̇* | *Heat flow or power, W* |
| *T* | *Temperature, ˚C* |
| *v* | *Wind speed, m/s* |

| ***Greek symbols*** | |
|---|---|
| *σ* | *Stefan–Boltzmann constant, 5.67 × 10⁻⁸W/m²K⁴* |
| *α* | *Pool water absorbance* |
| *η* | *Thermal efficiency %* |
| *ε* | *Emissivity* |
| *ρ* | *Water density, kg/m3* |
| ***Subscripts*** | |
| *a* | *Ambient* |
| *col* | *Solar collector* |
| *conv* | *Convective* |
| *cond* | *Conduction* |
| *eva* | *Evaporation* |
| *in* | *Inlet* |
| *losses* | *Losses* |
| *mak* | *Makeup water* |
| *p* | *Pool* |
| *rad* | *Radiation* |
| *s* | *Sky* |
| *w* | *Water* |

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