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EXPERIMENTAL AND THEORETICAL STUDY OF SMART ENERGY MANAGEMENT SOLAR WATER HEATING SYSTEM FOR OUTDOOR SWIMMING POOL APPLICATION IN EGYPT

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ABSTRACT

Conventional sources of energy are rapidly decreasing more and more. Hence, Renewable energy is presently attracting significant**.** Therefore, this paper aims at investigating the techno-economic feasibility of SWHS for swimming pools in tourist hotels and resorts**.** The proposed system presents an active direct system without auxiliary heaters to evaluate the potential for using solar thermal collectors for heating swimming pools of tourist resort; installed in El Gouna city, Egypt, and to size solar collector using TSOL simulation software package to meet the demand of hot water, to analyze the impact of collector design-parameters concerning system cost, system yield and economic values and then carried out experimentally. The simulation results showed that the installed collector power of SWHS is 9,980kW and solar energy contribution to the swimming pool is 25.831MWh. The system efficiency is 75.5% and the annual solar yield obtained is 2153kWh/year. For the economic side, NPV and COE are 5878.37$, 0.0045$/kWh respectively. Plus, the payback period of this proposed system is 18 months. When taking into account the cost of CO_2 emissions, the proposed system avoided 6,720kg annually resulting in saving 6102$. The experimental results illustrated that system sizing is 28 of solar absorber collector and 1hp pool pump. System cost and COE of the system are 8251.37$, 0.0095$/kWh respectively. The cost of one liter of water heated is 0.387$ and the payback period is 14 months. For a multitude of reasons, solar water heating for hotels and resorts is an ideal choice.

Keywords: *Solar Collectors; Swimming Pool; Simulation; Economic Analysis and Experimental Evaluation*

1. INTRODUCTION

World energy consumption is currently at extremely high levels. In this setting, rising global energy consumption and efforts to minimize non-renewable fuel supply become a means of pushing research into alternative technologies for power generation. The global crisis of fossil energy depletion makes solar energy a viable alternative power source (Shah and Solangi 2019). Solar energy, along with wind and wave energy, has become the most important Renewable Energy Source (RES) on the globe in recent decades. Solar energy is now used in a wide range of applications, including domestic hot water (DHW) production, space heating, pool heating, and even cooling using desiccant systems. The evaluation focused on systems that can offer hot water, space heating, and swimming pool heating and are specifically built for single-family homes in southern climes. Southern Europe's climate dictates that room heating is necessary for a shorter amount of time than in other European areas. Solar energy could also be used to generate electricity, as in the case of photovoltaic (PV) panels installed within buildings or for stand-alone uses.

Solar thermal energy for heating water has been chosen (MirunaliniThirugnanasambandam, S.Iniyan 2010) because of its significant social, technological, economic, and environmental benefits, as well as its abundance on the planet's surface. The global solar thermal market, particularly solar heating water, has risen exponentially during the previous two decades. Heating water is a modest but important part of a wide range of production activities in the agricultural, industrial, and service sectors, particularly in places where household hot water is used extensively, such as schools, hospitals, swimming pools, and sports facilities.

According to the REN21 Global Status Report 2019 (Towards, n.d.), the biggest capacity of Solar Water Heating (SWH) was installed in China, Turkey, India, Brazil, and the United States in a variety of sizes, relying on the quantity of hot water needed and the desired temperature (Khalifa 2015). The most typical application of such systems (85 percent) is for domestic hot water (Series and Science 2018). Solar water heating systems can be classified into two categories based on whether or not they require pumps to operate: passive and active, which are further divided into direct and indirect systems (A. Mohammed et al. 2018), (Gawali 2013). Dongellini (Dongellini, Falcioni, and Luca 2015) used a dynamic technique based on a SIMULINK model and the F-chart method to study a system for DHW production based on solar collectors, allowing him to evaluate system performance monthly. A dynamic analysis of a hydraulic solar system for DHW production is provided in the open literature (Tsai 2014) and the findings show that the solar system efficiency is heavily reliant on the DHW profile load. Badescu (Winter 2017) investigated the design of solar thermal collector absorbers to improve the efficiency-to-material-cost ratio. Eismann (Eismann 2017) describes the thermo-hydraulic dimensioning of solar systems with a focus on cost optimization. Duffie and Beckman (Duffie and Beckman 2013) go into great detail about the fundamentals of solar-thermal collectors and system modeling. Research by (Taglia, Scarpa, and Rosa 2014) provides an updated review of flat-plate thermal solar collector models, including a comprehensive classification and discussion of their primary properties and performance. Using TSOL and POLYSUN simulation software tools, an extensive literature review was first conducted to determine the key design difficulties of solar water heating systems in Ireland (Mohan and Reddy 2020).

Using TRANSOL software, Letitia et al., (Letitia, Ştefan, and Damian 2017) investigated a parametric simulation of a solar heating system that consists of vacuum solar panels, and a storage tank in tank to deliver heating and domestic hot water to a normal dwelling. Another study by Mohammed et al., (M. N. Mohammed et al. 2011) uses TRNSYS software to develop

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and verify a direct solar water heating system in Baghdad, Iraq, to meet the demand for hot water for 25 people. A comprehensive simulation environment has been established (Koke, Kuhr, and Clement 2018) that can automatically optimize solar-thermal systems, including collector and system parameters, which are linked to the commercial software POLYSUN package, and optimization problems can be solved using MATLAB. This work (Eduardo et al. 2016) details the creation of software for sizing tiny solar water heating systems using the MATLAB platform, using an approach designed to minimize user participation.

There is also a brief description of the main works involving CFD analysis on thermal solar collectors. Using the OpenFOAM and ANSYS software, several Computational Fluid Dynamics (CFD) simulations of three-dimensional airflow with heat and mass transfer in a complex shape indoor swimming pool were done. Koper et al., (Koper, P. , Lipska, B. , Michnol 2010) used the Ansys-Fluent program and the turbulence model with six Reynolds equations to investigate the circumstances in an indoor swimming pool with numerous basins. This paper (Luis et al. 2017) describes a new method for estimating water evaporation rate in indoor swimming pools using a computational fluid dynamics model and data obtained from three distinct test chambers and an actual swimming pool were used to experimentally validate the model. The goal of the two studies (Luis et al. 2018), (Limane, Fellouah, and Galanis 2018) is to present a laboratory-scale experimental procedure that was developed to validate a new CFD-based methodology for estimating water evaporation rate in indoor swimming pools under a wide range of convective flow conditions with a focus on the most common operating conditions of these facilities. In Portugal, the comparison of simulated and experimental outcomes for solar thermal swimming pool systems has been assessed (Carvalho and Neves, n.d.) using the TSOL simulation software, it was discovered that a proposed modeling strategy is a promising tool, with average relative errors of 9% for typically mixed convection flows in indoor swimming pools, as well as that in southern European climates, a solar combi-system, which will be used not only for space heating but also for swimming pool heating, will provide additional service in comparison to the traditional. Numerical model of a hydraulic solar heating system related to an outdoor swimming pool based on a series of customized blocks constructed using MATLAB/SIMULINK is given by Morini and Piva (Stefano Piva and Gian Luca Morini 2008). This study (Lugo et al. 2019) offers a mathematical model created in TRNSYS to estimate the performance of a solar heating system for an outdoor swimming pool in warm climates, which was validated using experimental data obtained from a 53.8 m^3 outdoor swimming pool in Cuernavaca, Morelos, Mexico. As a result, the model accurately recreated the temperature of the pool under various operating conditions and may be used to generate a technical and economic analysis of solar heating systems in outdoor pools for regions with similar climatic conditions. Falcioni et al (Dongellini et al. 2015) use the MATLAB/SIMULINK environment to create a dynamic model of a "passive" solar heating system for an outdoor swimming pool. The findings show that unglazed collectors are suitable for this application, but evacuated collectors are only beneficial in the event of very large swimming pools to lower the solar panels' absorbing surface. The approach and results of a thermal and hydraulic design for a solar heating field of a semi-Olympic pool at an elementary school are provided (Alanis, Salazar, and Martín-dominguez 2014), the proposed arrangement irrigated 192 solar collectors with the ideal range and just two solar collectors with the lower range at 3 L/min According to the hydraulic design and the application EPANET 2.0.

1.1 Paper objectives and motivation of work

Although various studies have proven that SWHS can deliver dependable and cost-effective systems for a variety of applications (remote/rural locations, residential areas), there have been little researches on hotels and tourism facilities. Despite the previous research, few have studied the equivalent conditions of outdoor swimming pools, which are characterized by high energy consumption for heating and air conditioning as well as demanding comfort criteria. Although that earlier research has been acknowledged, no work in Egypt has studied the impact of climatic conditions on the internal environment of a swimming pool.

Furthermore, few studies have addressed the topic of environmental performance in the tourism business, despite the environmental implications of hotel operations. This research area is a tourist resort's outdoor swimming pool in El-Gouna, Egypt. The goal of this project is to model a solar water heating system, size solar collectors, execute dynamic simulations using the TSOL software package, and validate experimentally to verify the solar water heating system for a swimming pool in a tourism resort in Egypt. The size of a solar water heating system is provided in this paper via mathematical calculations, gathered weather data, and a simulation of the heating system. Therefore, this paper has some specific objectives:

- Estimation of the solar water heater's monthly and annual solar input.
- Differences in temperature between the temperatures in/out of the collector.
- Assisting with the design of solar water heating systems, taking into account the facility's unique hot water usage, the site's climatic features, and collectors' orientation.
- Techno-economic analysis of the proposed solar heating system for the pool of choice.
- Calculation of solar collectors that require a one-meter-cube of water to be covered,
- Determining the cost of energy, cost of water heated and
- Determining proposed system efficiency plus the payback period.

The paper is organized in the sections below. Section 1 provides an overview of solar thermal systems, as well as previous research. Section 2 contains the physical system materials and methods used in this study, including the required mathematical model of a solar heating system for a swimming pool. Section 3 contains the case study including geographic and meteorological information. In section 4, the results of a dynamic simulation using the TSOL software package are presented. Section 5 entails a comprehensive study of all conceivable outcomes, as well as a validation step using experimental commercial data. Section 6 contains the conclusions.

2. MATERIALS AND METHODS

2.1 Mathematical Modeling of Energy Balance System

As people are motivated to raise their levels of physical exercise, commercial swimming pools, particularly aquatic facilities, are becoming more prevalent elements of large towns and cities (Rajagopalan and Fuller 2014). Aquatic facilities consume a lot of energy for water and space heating, with an energy intensity up to seven times that of a commercial office building anywhere in the globe. Because much of the energy is required to heat water to relatively low temperatures, solar energy technologies can provide this demand. A solar thermal system for heating water and swimming pools is widely established in many residential sectors. There are both indoor and outdoor swimming pools available. Summertime is when outdoor pools are most commonly used. Because of the controlled ventilation and humidity, indoor pools can be used all year. When the pool is not in use, it is also advisable to cover it with a pool cover to prevent heat loss. Further research, particularly into the feasibility of merging traditional heat sources with solar collectors utilizing smart control, is needed to boost the uptake of solar heating in commercial pools. As stated in the next section of the case study, an incentive program and education of the new generation of consultants and aquatic centre operators, who are unfamiliar with the potential benefits of solar systems, would also help to enhance their uptake. Equation 1 (Cromer 1994) presents the ratio (R) of square feet of collector area required divided by the pool surface area as follows:

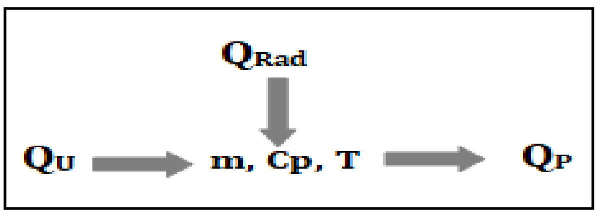
$$R = \frac{\text{Collector Area}}{\text{Pool surface Area}} \tag{1}$$

With an R of 1.0, the collector area is the same as the pool surface area. A collector area half the size of the pool surface area corresponds to a R of 0.5. The majority of a pool's heat loss occurs at the water's surface; the amount of solar heat injected into the pool is determined by the size of the collector utilized. A greater R value indicates that more heat is gained, the water is warmer, and the swimming season is extended. A screened covered pool with a cover has an R value of 0.75 for 180 days winter only (i.e., 6 months) swimming. If the pool dimensions are 50 × 25, or 1250 $m^2$of surface area, the pool needs (0.75 × 1250 = 937.5) about 937 m^2 of solar collectors. Roughly, one collector needs 10 m^2, so this pool needs about 93 collectors. Knowing the collector area, we can calculate its heat energy output as follows (Cromer 1994):

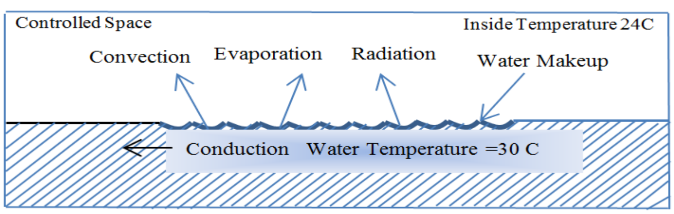
Energy (in BTU*) =
(Collector Rating × Collector Area × No of Days is System Utilized)   (2)

* British thermal unit: The amount of heat necessary to raise one pound of water one degree Fahrenheit is one Btu, which is roughly similar to the amount of heat produced by a standard kitchen match. Energy Produced = (80 Btu/m^2) × 10 m^2× 180 day = 144, 000 Btu/ year.

Figure 1-a (Salgado et al. 2013) depicts the energy balance and control volume used to simulate the swimming pool as thermal storage, whereas figure 1-b (Aboushi and Raed 2016) depicts the heat losses diagram.



a) Energy balance (Salgado et al. 2013)



b) Heat losses (Aboushi and Raed 2016)

Fig. 1 Energy balance & heat losses in the swimming pool

$$\sum Q_U + \sum Q_{Rad} - \sum Q_P = m\ Cp\ dT/dt \qquad (3)$$

The thermal balance is represented by equation 3, in which Q_U represents the contribution of solar collector heating power, Q_P represents heat losses to the environment (W), Q_{Rad} represents heating power gains via direct radiation (W), m represents the swimming pool water mass (m), Cp represents water-specific heat, and T represents the average temperature of the swimming pool at the time. $\sum Q_U$, $\sum Q_{Rad}$, $\sum Q_P$ are defined below as follows (Salgado et al. 2013):

$$\sum Q_U = \eta \times I \times A_c \qquad (4)$$

Where Ac denotes the total solar collector field area (variable), I denote solar irradiation in W/m^2, and η is the solar collector's thermal efficiency as determined by a Certification Laboratory:

$$\eta = 15.856\ [(T - T_0/I) + 0.6571] \qquad (5)$$

Where T is the temperature of the inflow water to the solar collector, which is equivalent to the temperature of a swimming pool, and T_0 is the ambient temperature. Q_{Rad} (W), on the other hand, is defined as (Salgado et al. 2013):

$$\sum Q_{Rad} = \alpha \times I \times A_s \qquad (6)$$

Where A_s is the swimming pool's surface area and α is the water absorptive coefficient.

Evaporation, convection, and radiative losses from the water to the surroundings account for the majority of the heat losses related to the swimming pool water Q_P (W), as illustrated in figure 1-b (Aboushi and Raed 2016), such that:

$$\sum Q_P = Q_{evap} + Q_{conv} + Q_{emi} \qquad (7)$$

According to Ruiz et al., (Series and Science 2018) the most trustable equation for calculating evaporation heat losses Q_{evap} (W) is defined:

$$Q_{evap} = A_s \times h_{evap}\ (P_{v,sat} - P_{v,amb}) \qquad (8)$$

Where Q_{evap} is the evaporation heat flow (W), As is the pool surface area (m^2), h_{evap} is the evaporation coefficient (W/m^2 Pa), $P_{v,sat}$ is the water saturation pressure at the swimming pool temperature (Pa), $P_{v,amb}$ is the partial pressure of water vapor in the air (Pa), and w is the wind speed (m/s). Nonetheless, the installation of a swimming pool cover was thought to limit heat losses, mostly through evaporation and convection, to the point where $Q_{evap} = 0$.

The losses due to convection are defined as (Series and Science 2018):

$$Q_{conv} = A_s \times h_{ca}\ (T - T_0) \qquad (9)$$

Where h_{ca} is the heat transfer coefficient, which is predicted to be roughly 4.4 W/m^2°C for a wind speed of 5 km/hr and h_{ca}=1.39*$V^{0.8}$ for wind speeds higher than that. Finally, T_0 is the ambient temperature (K).

Radiation heat loss (W) is the transfer of heat from the pool to the environment (Aboushi and Raed 2016):

$$Q_{emi} = A_s\ [\varepsilon \times \sigma \times (T^4 - T_0^4)] \qquad (10)$$

Where, ε is the coefficient of water emittance, σ is Stephan-Boltzmann constant (5.6697 x 10^{-8} W/m^2K^4), T is the pool temperature and T_0 is the temperature of the surrounding (K).

2.2 Simulation Using TSOL Package

Simulation may be the greatest option in this type of situation. The SWH systems were analyzed using a variety of simulation techniques. TSOL popularity and applicability in SWH simulation are considerable. TSOL (Berlin-charlottenburg, n.d.) is a commercially available German dynamic simulation program for developing, optimizing, calculating, and simulating solar thermal water heating systems for swimming pools. It does a simulation based on the balance of energy flows and sources, as well as a financial analysis of the system, taking into account energy balancing, pollutant emissions, and expenses, using meteorological data input. The energy provided by the solar system for hot water production and heating, as well as the solar percentages associated with it, are calculated by TSOL. (Liu et al. 2018). The data for the proposed system components are collected, as well as weather resource data, which is merged and simulated using the TSOL software tool. This simulation model was used to find the ideal solar collector area AC by evaluating multiple locations and determining which one had the best thermal behaviour based on the water average temperature, which was mostly during the coldest months (September to March).

To calculate state and temperature changes throughout a simulation period, a thermal energy balance is created. This is the numerical solution of a differential equation in mathematics (Berlin-charlottenburg, n.d.):

$$\text{Temperature differenc} = \frac{\text{The sum of all energy inputs and outputs}}{\text{All heat capacities combined}} \qquad (11)$$

To achieve balancing, the sum of all input energy, output energy, and energy storage via the heat capacity of the system components must equal zero. The following is a definition of system efficiency (Berlin-charlottenburg, n.d.):

$$\text{system efficiency} = \frac{\text{The solar system's generation of energy}}{\text{irradiation of energy into the collection area)}} \qquad (12)$$

The solar system's energy output is the energy transmitted from the solar storage tank to the standby tank (as a result of consumption and, if applicable, a recirculation system regulated in the solar storage tank). Because there is no difference between the solar and standby tanks, the system efficiency of some systems (single storage tank model, e.g. bivalent storage tank or reheated buffer tank) cannot be determined. As a result, storage losses are offset by warming costs. This is how the solar fraction is defined (Berlin-charlottenburg, n.d.):

$$\text{solar fraction} = \frac{\text{The solar system provides electricity to the standby tank.}}{\text{(Solar system + auxiliary heating) energy provided to the standby tank)}} \qquad (13)$$

The following economic efficiency calculation can be presented after a year of simulation: the economic efficiency parameters, such as capital value, annuities, and cost of heating, are estimated while system expenses and subsidies are taken into account. The following formulae are used to calculate economics using the pay-off approach (Liu et al. 2018):

$$\text{investment Costs} = \text{Installation Costs} - \text{Subsidy} \tag{14}$$

$$\text{yearly Operating Costs} = \text{Pump Performance} \times \text{Operating Time} \times \text{Electricity Costs} \tag{15}$$

The cash value of the costs is used to compute the heating price:

$$\text{CV of costs} = \text{Investments} + \text{CV of Operating and Maintenance Costs} \tag{16}$$

The pay-back time is the amount of time the system needs to run for the investment to pay off in cash. A price-dynamic payment sequence's cash value (CV) over T years (lifetime) is as follows (Liu et al. 2018):

$$Cash\ value\ b(T,q,r) = \begin{cases} \dfrac{1-\left(\frac{r}{q}\right)^{T}}{q-r} & for\ r <> q \\ \dfrac{T}{q} & for\ r = q \end{cases} \tag{17}$$

When q is the simple interest factor and r is the price change factor, the price of heating is described as follows (Liu et al. 2018):

$$\text{Heating Price} = \frac{\text{yearly Costs}}{\text{yearly energy yield}} \tag{18}$$

3. SWHS CASE STUDY

The Egyptian swimming pool season runs from September to March, however even during this time, some days are too cold to swim, and the first few hours in the morning are often too cold to plunge. The goal of solar pool heating is to keep the pool water at a comfortable and agreeable temperature throughout warm weather. Solar collectors with open absorber plates are the most efficient and cost-effective in these situations. Solar pool heating systems can offer up to 100% of your pool's heating requirements. The size of the system is determined by the amount of solar insulation available, wind variables, average regional temperatures, and collector orientation and angle. This proposed system is first simulated using the TSOL software tool, and then applied experimentally as follows.

3.1 Site Geography Data

The thermal energy output will be compared to the electric load of the chosen site in the current investigation. The location is a tourist resort's outdoor swimming pool in El-Gouna city, Hurgada, Egypt. El Gouna is an amazing Egyptian touristic resort known for its water sports such as scuba diving, snorkeling, water skiing, windsurfing, and many other exciting activities, and this is since it is rich with several beaches that provide all of the necessary activities for the guests, developed by Orascom Hotels and Development ("ElGouna Information," n.d.), dating from 1989. It's 20 kilometers north of Hurghada and 25 kilometers from Hurghada International Airport, on the Red Sea in Egypt's Red Sea Governorate. El Gouna is a Red Sea Riviera city and the home of the El Gouna Film Festival. El Gouna is located at latitude 27.402484 N and longitude 33.6511438 E, with an elevation of 17.73 meters. Downtown, Tamr Henna Square, and the Abu Tig Marina are the three main locations in El Gouna. Figure 2 shows the location of the study region that was selected (Sakka 2018).

3.2 Site Resources Data

For the heating operating system, meteorological data on solar radiation and temperature is essential. After gaining a thorough understanding of the solar radiation parameters at the desired area, a solar energy utilization project should be developed. Since the angle employed in winter season lighting is about 35° to high protection, the system design estimate is based on solar radiation and temperature data for the selected site. El Gouna's climate is classified as a desert climate. The majority of the year is sunny. Summer in the El Gouna region is always hot and dry, therefore overcast or cloudy days are extremely rare. A typical summer day in May and June will have pleasant bright weather with average temperatures of 29°C with the sun shining for an average of ten hours every day.

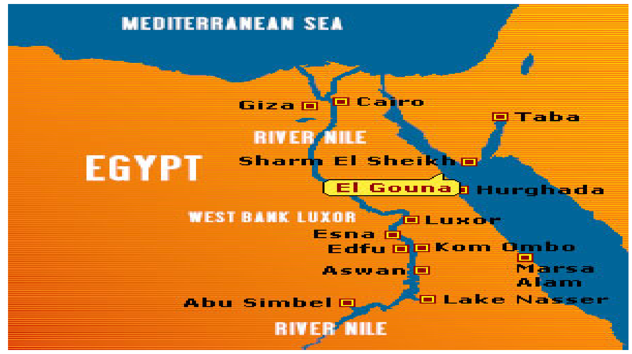
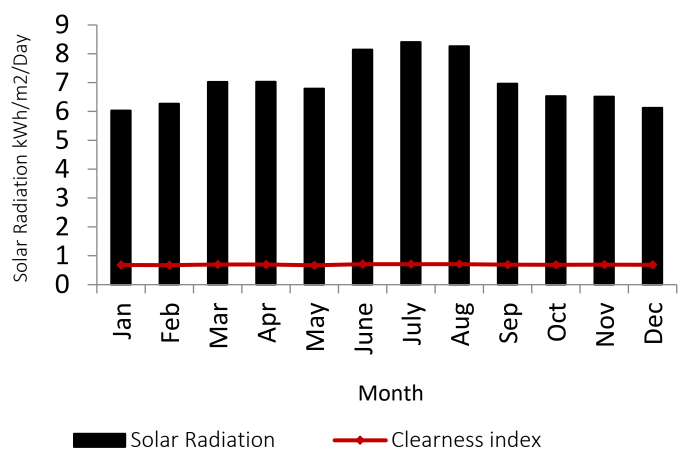
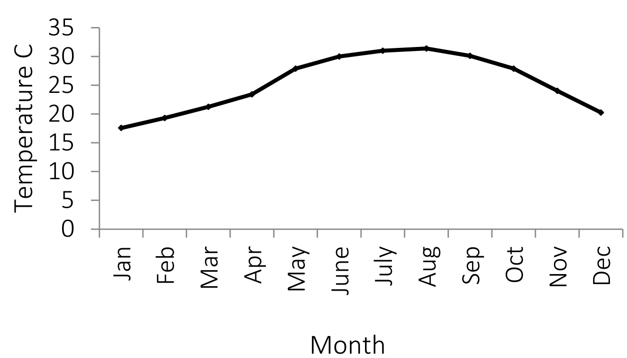


Fig. 2 El-Gouna location map, Hurgada, Egypt (Sakka 2018).

Figure 3-a depicts the monthly average of solar radiation at the site, whereas figure 3-b depicts the monthly average temperatures at the site, both from the National Aeronautics and Space Administration (NASA) ("National Aeronautics and Space Administration, NASA," n.d.). These meteorological data were collected using observations of hourly averages of solar radiation and temperature at the chosen location from 2018 to 2020. The monthly average solar radiation and temperature in this location are 7 kW/m²/day and 25.36° C, respectively. The maximum solar radiation in July of 8.4 kWh/m²/day while the maximum value of temperature in August of 31.3° C.



a) Solar radiation data



b) Temperatures data

Fig. 3 Selected Site resources, 2018: 2020 ("National Aeronautics and Space Administration, NASA," n.d.)

33. Pool Specifications

The pool was assumed to be of sufficient size to meet the needs of a tourist resort for 6 months of the year (September to March) between the hours of 7 am and 6 pm, seven days a week. Figure 4 depicts the perspective of an

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outdoor pool. Pool dimensions used were an area of 52 m^2 (13×4) and an average depth of 1.65. The vertical position with a South-facing orientation was chosen as the optimum for year-round use of our solar collectors and as a suitable option for September and March when we anticipate extending the open pool swimming season. An all-outside-air/recirculation system with additional exhaust fans was used to offer ventilation. The plant was thought to be capable of maintaining a minimum room temperature of 28°C and exhausting air to meet a design relative humidity level within the exhaust fan capacity.

Fig. 4 The view of the interior of the Resort outdoor swimming pool

4. THEORETICAL AND EXPERIMENTAL MEASUREMENTS

4.1 Theoretical Simulation Using TSOL

The proposed system is an active indirect solar water heating swimming pool system without an auxiliary heater, as depicted in Figure 5. Due to their structural simplicity and low cost, unglazed flat-plate collectors are the best ideal for solar water heating systems and have been used worldwide (Struckmann 2008) for the water temperature to rise by a few degrees over ambient air temperature as seen in the selected site temperature. The best collector angle changes depending on latitude; for summer-only, install collectors at latitude minus 10-15° (Khalifa 2015), for winter-only, position collectors at latitude plus 10-15°, and for all-year heating, install collectors at latitude plus 10-15°.

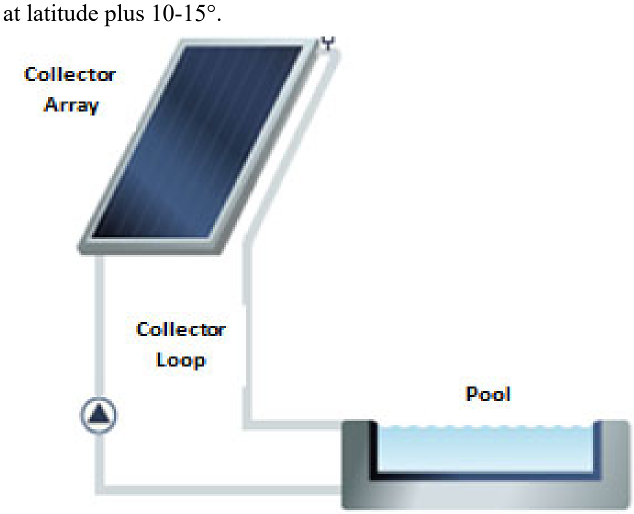


Fig. 5 Proposed SWHS for outdoor Swimming Pool in TSOL® Simulation Tool

Sun collectors absorb solar energy and transfer the heat gain to the pool water immediately. It makes sense to run the pool heating system at a high flow rate while maintaining a low temperature. The maximum efficiency with a solar system will be obtained in this manner. Collectors' absorbers for solar pool heating are completely frost-proof, making them appropriate for use on flat roofs as well. If the solar absorbers are not put higher than six meters above sea level, this proposed system can be used. A three-way ball valve is attached to the filter piping after the sand filter system. A differential temperature controller is used to regulate an automatic three-way ball valve. A water sensor and a solar sensor are included in the solar control. When a temperature differential of 3°C or more is determined through continual measuring; the heating mode is switched on using the three-way ball valve. This guarantees that the solar system is only turned on when there is a source of heat and that your pool water is heated. Table 1 shows all of the inputs and parameters used in this SWHS simulation investigation.

4.2 Experimental Measurements

Any SWHS experimentation activity should be carried out throughout the day and in varied climate conditions to obtain accurate data. Figure 6-a depicts the architecture of SWHS proposed contains a flat plate collector, a storage tank, a pump, a heat exchanger, a filter, a non-return valve to control water flow, sensors, and a single line diagram of SWHS using CAD sketch is exhibited in figure 6-b.

Table 1 Inputs & parameters of SWHS simulation study

Pool Parameters	
Type	Outdoor private pool
Shape	Rectangular
Dimensions	Length: 13.3 m Width: 4 m Depth: 1.65 m
Medium	Water
Thermal Cover	No
Daily fresh water requirement	136 L
Freshwater temperature	Winter: 12 ^{O} C Summer: 28^{O} C
Ground Temperature	From site resource climate data
Desired temperature	34 ^{O} C
Swimming season and usage period	Start: 1 September End: 1 March Usage times: from 7 am to 5 pm every day
Maintenance Schedule Time	From 10:30 am to11:30 pm (according to custome requirement)
Solar Collector Array Parameters	
Type	Flat/unglazed
Dimensions	Gross surface: 1 m^2 Length: 1 m Width: 1 m
Specific Heat Capacity	3000 J/(m^2.k)
Conversion Factor Efficiency	85 %
Heat transfer coefficient	20 W/(m^2.k)
No of collectors	42 (each collector needs 3.5 m^3 wate
Installation	Azimuth angle: 180 ^{o} (facing south) Tilt angle: 0 ^{o}
Shade	N/A
Minimum distance between collect	9 m
Roof layout with photo plan	N/A
Collector Loop Parameters	
Medium	Water Specific heat capacity: 4180 kJ/(kg.k)
Volume flow	250 (L/h)/m^2
Collector Loop Temperature	Collector loop on: 8 ^{o}K (above tank temp) Collector loop off: 3 ^{o}K (above tank temp)

Table 1: Inputs & parameters of SWHS Simulation Study, Cont.

Piping Parameters	
Piping length (one way)	In building: 3 m Outside: 7 m Between collectors: 5 mm/collect
Thermal conductivity of insulation	0.045 W/(m.k)
Nominal diameter	Mains: 20.5 mm Between collectors: 10 mm
Insulation thickness	20 mm
Climate Data Parameters [22]	
Total Annual Global irradiation Monthly Average Solar Radiation Diffuse Radiation Percentage Outside Temperature Monthly Average Wind Speed	2,409.3 kWh/m^2 7 kWh/m^2/day 34.6 % Mean: 25.9 ^{o}C Lowest: 8.9 ^{o}C 4.7 m/s
Emissions Saving parameters	
Reference fuel Fuel calculation Annual efficiency of reference syste	Natural gas HHV: 41112 kJ/m LHV: 37512 kJ/m Based on higher heating value 78 %
Simulation Parameters	
Simulation period	Whole year
Recording interval	One hour
Pre-run period	10 days
Financial Analysis Parameters	
Life span Investment on capital Reinvestment return Energy cost escalation rate Running cost escalation rate Specific electricity cost Specific fuel cost	10 yr 2.5 % 2.5 % 2 % 1 % 0.103 \$/kWh ("Egypt Electricity Prices" 2021) 0.23 \$/m^3 ("Fuel Cost Calculator 2021)

5. RESULTS AND DISSCUSSION

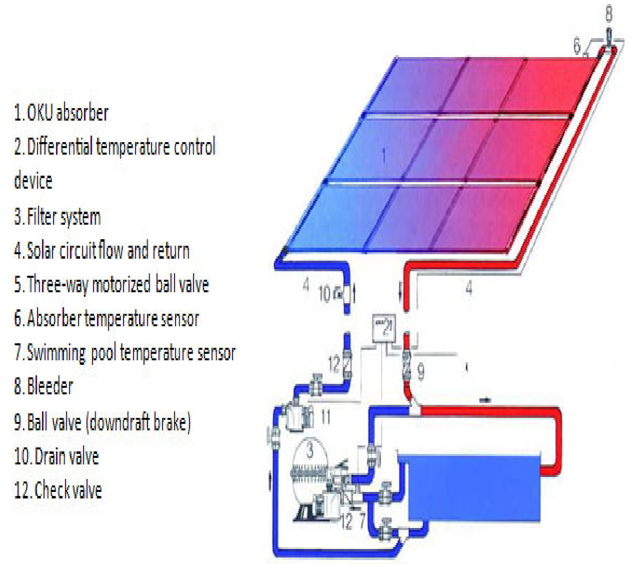
5.1 Theoretical Simulation Results

A mathematical model calculation with variable time increments of up to one hour determines the simulation results of this solar thermal system that is carried out by the TSOL 2021 software package. Supplying the load sustainability is an indication of the system technical performance determined by the percentage of power shortage. Actual yields may differ from these estimates due to climate, usage, and other factors. As follows, the simulation findings are grouped into three categories: technological, financial, and environmental.

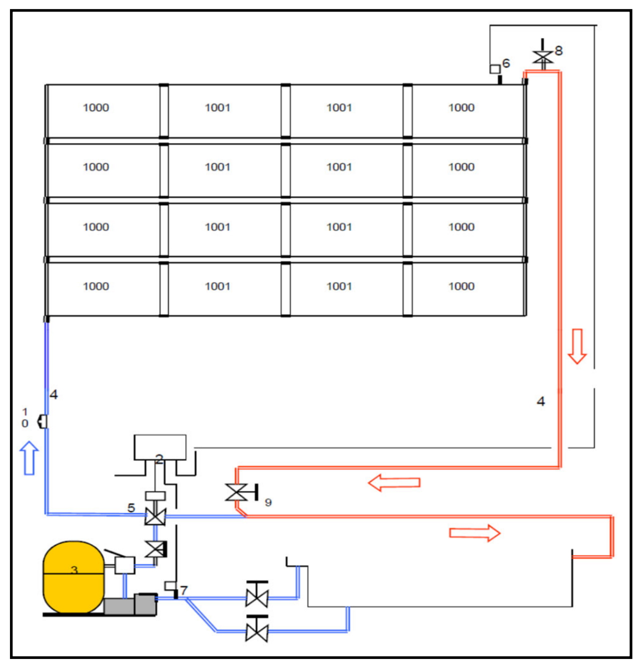
5.1.1 Heat and energy results

Figure 7 depicts the temperature profile variation strategy for the SWHS solar collector. It ranges from 0 to 50 degrees Celsius. Figure 8 depicts the monthly mean and outlet temperatures of the collector, whereas Figure 9 depicts the monthly average temperature of the pool. Table 2 shows the suggested SWHS energy balanced outcomes schematic, while table 3 shows the technical simulation results. Figure 10 depicts the solar energy input to the swimming pool throughout the year against the SWHS suggested efficiency. Figure 11 depicts the monthly heat losses of the pool.

From figures 7, it is found that the highest temperature of solar collectors is in June and July at 40, 45 respectively. Also, monthly average pool temperatures are heated with 5-10 ^{o}C from September to November as seen in figure 9 since the maximum pool heating temperature arrives at 34^{o}C in March and September.



a) SWHS Experimental Layout



b) SWHS CAD Sketch

Operation with filter pump via three-way motor ball valve with difference-temperature regulation

Fig. 6 Architecture of Experimental SWHS Components

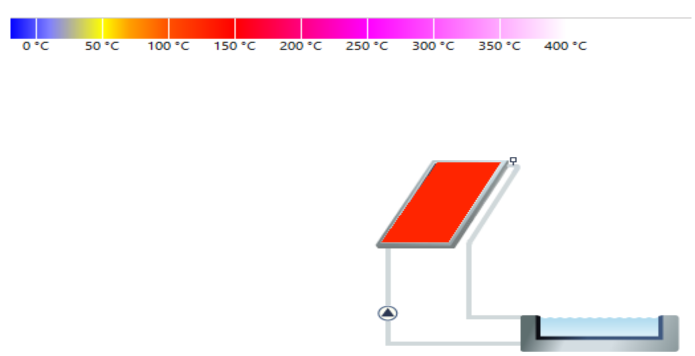


Fig.7 Temperature variation profile scheme of solar collector of SWHS proposed

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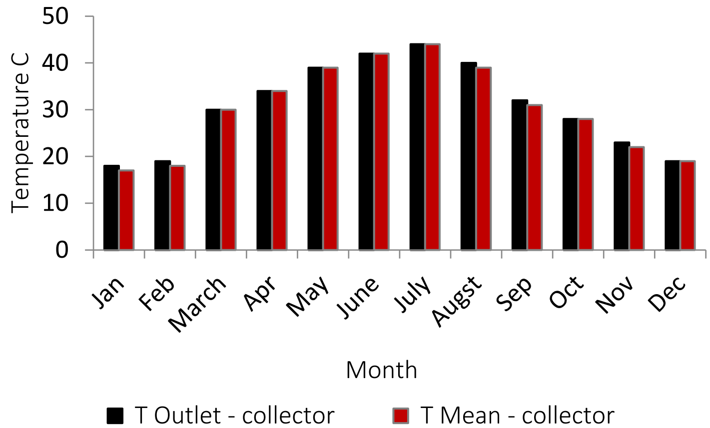

Fig. 8 Mean and outlet monthly temperatures of solar collector of SWHS proposed

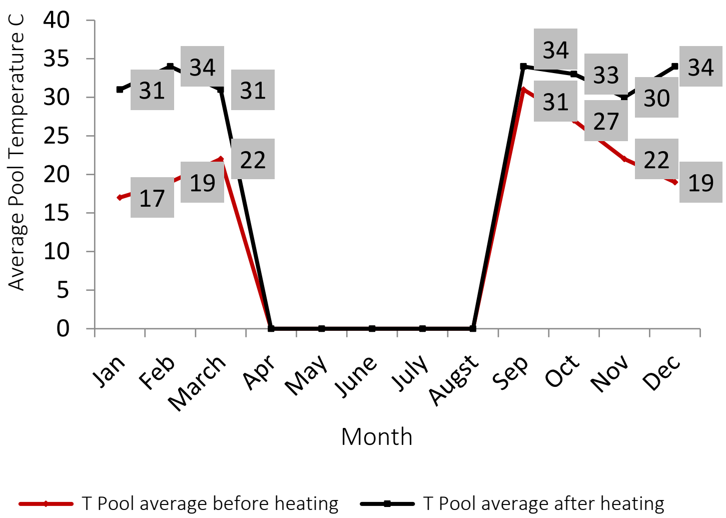

Fig. 9 Monthly average temperatures of the pool of SWHS proposed

Table 2 Energy balanced results schematic of SWHS proposed

1	Irradiation on collector surface (active)	102,192 kWh
1.1	Optical collector losses	18,992 kWh
1.2	Thermal collector losses	55,220 kWh
2	Energy from collector array	26,980 kWh
2.4	Solar energy to swimming pool	25.831 MWh
2.5	Internal piping losses	948 kWh
2.6	External piping losses	200 kWh
11	Swimming pool irradiation	63,620 kWh
11.2	Swimming pool losses	88,083 kWh

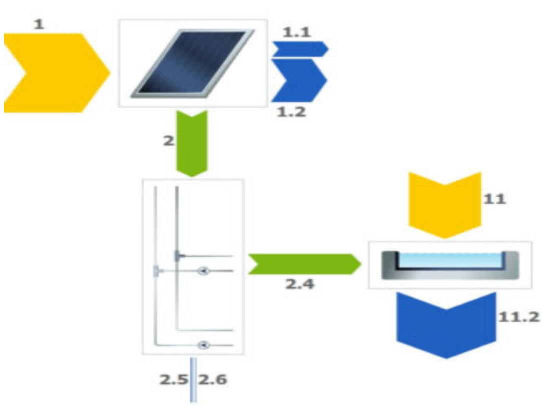

Table 3 Technical Simulation Results of SWHS proposed

Installed collector power	9.980 kW
Installed solar surface area (gross)	42 m^2
Irradiation on collector are – total	101,191.72 kWh
Irradiation on collector are – specific	2,409.33 kWh/m^2
Energy delivered by collectors- total	26,908.07 kWh
Energy delivered by collectors- specific	642.38 kWh/m^2
Energy delivered by collector loop	25,831.70 kWh
Energy delivered by collector loop - spe	615.04 kWh/m^2
Solar energy contribution to swimming	25.831 MWh
Energy from auxiliary heating	0 kWh
Average swimming pool temperature	22.38 ºC
Pool temperature above 34 ºC	1.9 % of operating hours
Annual Solar yield	2153 kWh/year
System efficiency	75.5 %

From tables 2, 3; there are thermal and optical losses causing a shortage in irradiation on collector surface to arrive swimming pool plus losses in pipes. The monthly average swimming pool temperature after heating is 30ºC and above 34ºC at around one hour every day as seen in table 3.

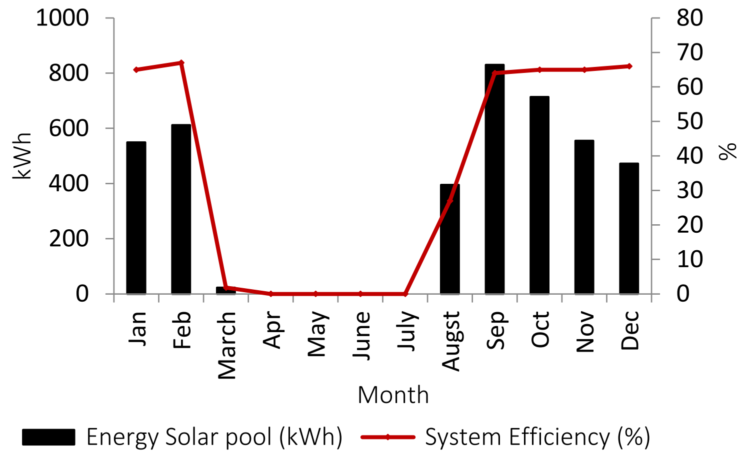

Fig. 10: Solar energy contribution to swimming pool vs. SWHS proposed efficiency

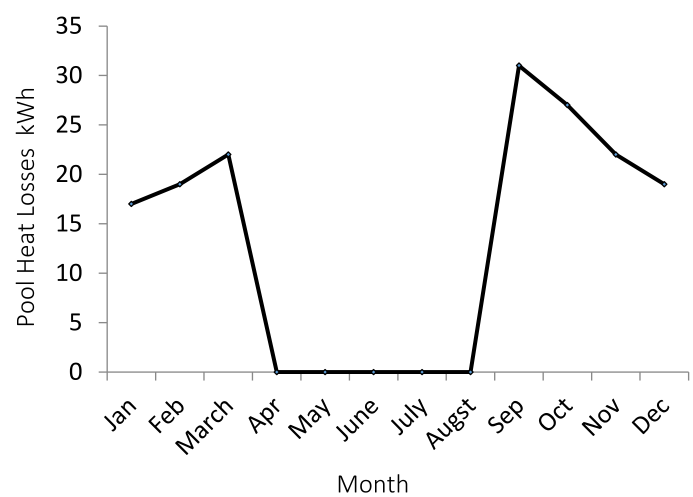

Fig. 11 Monthly heat losses of the pool of SWHS proposed

From figure 10; it is clear that the highest solar energy delivered to the pool is about 800 kWh in September resulting in that system efficiency being 68% while the lowest system efficiency is found in August at 32%. The monthly heat losses of the pool due to internal and external pipe connections rang is from 15 to 30 kWh.

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5.1.2 Financial results

Table 4 summarizes the findings of the proposed SWHS economic simulation. Figure 12 and table 5 show a cash flow chart of financial items presented by SWHS, including profit and remaining investment, during the project's 10-year life cycle.

Table 4 Economic simulation results of SWHS proposed

Net present value	5878.37 $
Remaining investment	1083.8 $
Cost of electric solar energy	0.0045 $/kWh
Cost of 1 liter of water heated	0.403 $
Payback period	1.5 year
Internal rate of return (IRR)	69.6 %
Modified Internal rate of return (MIRR)	23.6 %
Profit (surplus)	7824.173 $

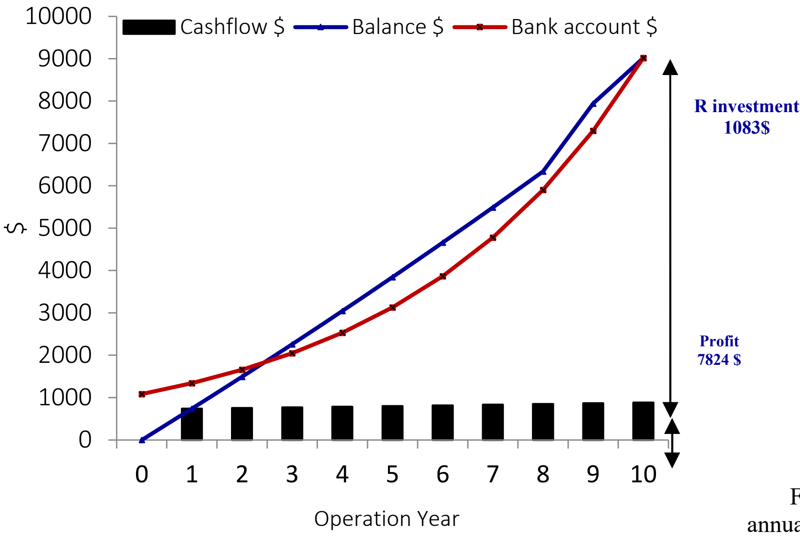

Fig. 12 Cash flow chart including financial items of SWHS proposed along 10 yrs

Table 5 Cash flow financial items of SWHS proposed whole project life span

Year	Savings $	Cash flow $	Balance $	Bank Account $
0	0	0	0	1083.870968
1	738.1935484	738.1935484	738.1935484	1339.677419
2	752.9677419	752.9677419	1491.16129	1655.806452
3	768	768	2259.16129	2046.580645
4	783.3548387	783.3548387	3042.516129	2529.612903
5	799.0322581	799.0322581	3841.548387	3126.580645
6	815.0322581	815.0322581	4656.580645	3864.451613
7	831.2903226	831.2903226	5487.870968	4776.451613
8	847.9354839	847.9354839	6335.806452	5903.741935
9	864.9032258	864.9032258	7938.451613	7296.967742
10	882.1935484	882.1935484	9019.096774	9019.096774
Total		8082.903226		

As seen in table 4; the net present value is 5878.37 $, the cost of eclectic energy due to solar energy system is 0.0045 $/kWh and the payback period is 18 months. From figure 12; the profit at the end of 10 yrs SWHS lifetime is 7824.173 $.

5.1.3 Environmental results of CO_2 saving

In the analysis of the results, the CO_2 emissions saved by the solar system are calculated. It is vital to understand which type of primary energy is saved by the solar system to do so. The CO_2 emissions of a heating system are calculated using emission factors by fuel type. Table 6 shows the results of the proposed SWHS environmental simulation. Figure 13 shows the quantity of CO_2 emissions avoided in kg versus the amount of natural gas saved in m^2 by the proposed SWHS.

Table 6 Emissions Simulation Results of SWHS proposed

CO_2 emissions avoided amount	6,720.90 kg
Fuel saving	3,178.3 m^3 Natural gas (H)
Fuel saving cost in first year	11,442 $

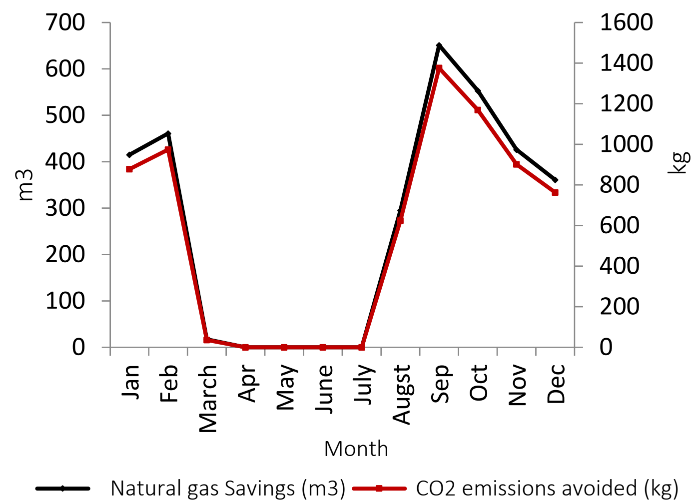

Fig.13 CO_2 emissions amount avoided vs. amount saving of natural gas of SWHS proposed

From table 6; the CO_2 avoided amount due to SWHS is 6,720.90 kg annually that resulting in saving 6102 $ ("CO2 to Dollars Conversion" 2021). Also, the amount of fuel-saving is 3,178.3 m^3 Natural gas that saving in the first year 11,442 $. The biggest amount avoided of CO2 emissions is found in September of 1200 kg as seen in figure 13 because the maximum solar energy delivered to the pool in this month as mentioned before.

5.2 Experimental Validation Results

The proposed SWHS experimental process is applied for the proposed system and carried out, which takes about two days. Figure 14 depicts the proposed SWHS scheme after it has been installed at the chosen location. The system sizing is made up of 28 solar collectors, and the bill of quantity quantities includes specifications shown in table 7. Table 8 describes the major cost indicators of the proposed experimental SWHS.

Fig. 14 SWHS proposed experimental scheme after components installed

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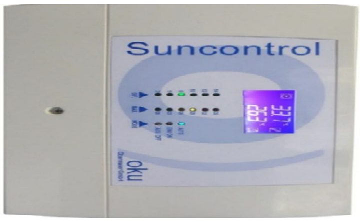
Table 7 Bill of quantity amounts of experimental SWHS proposed

Item	Number
Solar absorber collector OKU, Germany (Solar, n.d.)	28*
Pump, 1 hp	1
Sun control of different temp regulator	1
	
Ball valve	1
House coupling	22 m
Connections	33
Fixation steel rope for falt roof	20 m

* Calculation of pool surface: 13 m length × 4 m width = 52 m^2. For pool without cover; we recommended approx 60% of the pool surface as absorber surface.

Table 8 Important cost items of experimental SWHS proposed

Net present Cost	8251.37 $
VAT Tax	1200 $
Total System Cost	9451 $
Cost of solar energy	0.0095 $/kWh
Cost of 1 liter of water heated	0.387 $
Payback period	1.2 year
Profit	3964.173 $

From table 7; the experimental proposed system size is 28 of solar absorber collector and 1 hp pool pump. The total cost of this system including taxes is 9451 $, the cost of energy is 0.0095 $/kWh and the payback period is 14 months as seen in table 8.

For Environmental concerns; the gas heater consumption for one hour is 12 kW and if it is used for five hours that means resulting 60 kWh. When calculating CO_2 emissions avoided against using gas heater; it is found around 14 TCO_2 avoided since world standard emissions due to electricity generation of 1 kWh equals 0.233 $kgCO_2$ avoided (“Emissions Due to Electricity Generation,” n.d.). The cost saving due to CO2 avoided is 12714$ (“CO2 to Dollars Conversion” 2021).

From the theoretical and experimental evaluation process, it is clear that the proposed system is efficient technically for this application and saves money plus environmentally friendly. Solar energy is an environmentally responsible solution for heating swimming pools since it emits no greenhouse gases or hazardous waste into the atmosphere during operation and avoids the use of fossil fuels, which helps to prevent global warming.

6. CONCLUSIONS

Solar energy's effective use would result in a reduction in fossil energy use in our daily lives, as well as a clean environment for humans. The ideal use of solar collection devices is to heat swimming pools with solar energy. The use of solar pool heaters is becoming increasingly widespread. They're highly efficient, inexpensive to buy, and can generally be used with the sand filtration system's existing pool pump. This means that no additional electricity bills are incurred, and the solar collectors heat your pool in an environmentally beneficial manner. The purpose of this study is to examine the performance of solar energy in outdoor swimming pools in a tourism resort. Both technical and economic factors are considered to determine the best system sizing for supplying the required water heating for a touristic resort pool in El Gouna, Egypt. The renewable energy system, which supplies the estimated demand profile, is simulated using the TSOL software tool, and experimental measurements are then taken. Theoretical simulation of the SWHS system revealed the following:

- The Installed collector power of the proposed system SWHS is 9,980 kW and the solar energy contribution to the swimming pool is 25.831 MWh.
- The system efficiency is 75.5 % and the annual solar yield obtained is 2153 kWh/year.
- For the economic side, NPV and COE are 5878.37 $, 0.0045 $/kWh respectively. Plus, the payback period of this proposed system is 18 months.
- When taking into account the cost of CO_2 emissions, the proposed system avoided 6,720 kg annually that resulting in saving of 6102 $. Also, the amount of fuel-saving of Natural gas in the first year is 3,178 m^3 resulting saving money of 11,442 $.

This theoretical study is applied with an experimental process which results showed that system sizing is 28 of solar absorber collector and 1 hp pool pump. NPC and COE of the system are 8251.37 $, 0.0095 $/kWh respectively. The cost of one liter of water heated is 0.387 $ and the payback period is 14 months. Also, from the environmental side, it is found around 14 TCO_2 avoided using a gas heaters that saving 12714$. Solar energy is an environmentally beneficial option for heating your swimming pool because it does not emit any greenhouse gases or toxic waste into the atmosphere while in use. In the future, we recommend studying solar heating systems for indoor swimming pools and examining the weather effect on the indoor atmosphere of the swimming pool as air velocity, temperature and humidity showed good agreement.

Nomenclature

Abbreviations	
CFD	Computational Fluid Dynamics
COE	Cost of Energy
CV	Cash Value
DHW	Domestic Hot Water
LHV	Low Heating Value
HHV	High Heating Value
NASA	National Aeronautics And Space Administration
NPC	Net Present Cost
PV	Photovoltaic
RES	Renewable Energy Source
SWH	Solar Water Heating
Letters	
A_c	Total solar collector area (m^2)
A_s	swimming pool surface area (m^2)
Btu	British thermal unit
Cp	water specific heat
h_{ca}	heat transfer coefficient (W/m^2°C)
h_{evap}	evaporation rate (W/m^2 Pa)
I	solar irradiation (W/m^2)
m	swimming pools water mass (m)
$P_{v,\,amb}$	water vapor partial pressure in the air (Pa)
$P_{v,\,sat}$	water saturation pressure at pool temperature (Pa)
q	simple interest factor
Q_{conv}	heat movement by convection (W)
Q_{emi}	Radiative heat flux losses (W)
Q_{evap}	Heat flow from evaporation (W)
Q_P	Environment Heat loss
Q_{Rad}	Direct radiation is used to gain heating power.
Q_U	heating power from the solar collectors
R	Ratio
r	price change factor
T	Swimming pool temperature (K)
T_0	Surrounding temperature (K)
Greek symbols	
α	water absorptive coefficient
ε	water emissivity
η	solar collector's thermal efficiency
σ	Constant of Stefan-Boltzmann (5.6697 x 10^{-8} W/m^{2}K^4)

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