Design, Simulation, Construction of Swimming Pools: A Comprehensive Review

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Abstract.

In the colder months, to maintain both indoor and outdoor swimming pools comfortable, a significant amount of heat is required. This drives the development of various heating systems with the goal of lowering energy consumption, as well as operating and capital expenses. Despite the fact that they were created in the 1960s,, There hasn't been a thorough examination of these technologies. As a result, this study provides a crucial complete overview of the evolution of swimming pool heating systems that are being used in our daily life and the world orientation of people who use swimming pools in all its types and for different applications. The first section of this study examines the various heat exchange methods that is used to quantify or forecast heat dissipation and gains in swimming pools. Following that, a summary of several passive and active technologies is provided. Solar collectors, geothermal energy,heat pumps, loss heat recovery, and aggregation techniques are some of the active heating methods utilized in indoor swimming pools. The technologies of solar collectors, geothermal energy, PCM storage, heat pumps, waste heat recovery and biomass heaters, are some of the active heating systems utilized for outdoor swimming pools.

Keywords: Pool Solar Collector, heating swimming pool, indoor swimming pools system .

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1. INTRODUCTION

Outdoor pools that are exposed to the elements dominate the global swimming pool scene. The average temperature for comfortable swimming, according to ASHRAE, is 27°C, however it can vary by up to 5°C. However, due to seasonal and diurnal variations, a comfortable use of a pool cannot be at all times unless it is heated. In several nations, solar energy is used to heat swimming pools. The Copper Development Association published a handbook on solar pool heating in the early 1970s, which was used to build many solar pool heaters, and the prototype, built in Pasadena, California, was still running successfully after twenty years. By 1993, solar heaters had been installed in over 200 public pools in Germany. Solar pool heating capacity in the United States reached 762 megawatts in 2007. China was the world leader in solar water heating technology as of 2010, accounting for 70.5 percent of the 149 GWh of energy consumed, followed by the EU and Turkey. It is against the law in Spain to heat outdoor swimming pools with anything other than renewable or residual energy. In many ways, the potential of solar pool heating is justified. The availability of a pool would be increased if it was heated [1].

In indoor/outdoor swimming pools (ISWPs/OSWPs) (Fig. 1,2), swimming can be done at any time of year, and it is unaffected by the weather outside. Not only is heat required to keep the water at a pleasant temperature, however, it is also to keep the inside at a comfortable temperature. Indoor humidity will rise as a result of water evaporation, necessitating more ventilation.

As a result, heat must be delivered in order to warm the inducing external air[2].

FIGURE 1. Indoor swimming pool (ISWP)

FIGURE 2. Outdoor swimming pool (OSWP)

2. MODELS OF HEAT TRANSFER IN SWIMMING POOLS

A swimming pool heat transfer model is the most basic requirement for studying the performance of swimming pool heating systems. The term "pool total heat flow" has been proposed to describe pool water oscillation, which includes heat obtained from the sun and heat lost by radiation, convection, evaporation, conduction, and water regeneration. This model's mathematical formula was reported in publications of [3,4], and it is as follows

$$\rho_{\mathrm{w}} \cdot c_{\mathrm{w}} \cdot V_{\mathrm{p}} \cdot \frac{\mathrm{d}T_{\mathrm{p}}}{\mathrm{d}t} = \sigma_{\mathrm{io}} \cdot Q_{\mathrm{s}} - Q_{\mathrm{e}} - Q_{\mathrm{cv}} - Q_{\mathrm{cn}} - Q_{\mathrm{r}} - Q_{\mathrm{rf}} \qquad (1)$$

where, ρ_w ,c_w, Vp and Tp are density of the water, the specific heat ,the temperature of the pool and its volume, respectively. and σ_{io} is a constant used to distinguish between an outdoor and an indoor swimming pool. The σ_{io} of ISWPs is 0, while the σ_{io} of outdoor pools is 1. Heat losses from evaporation, convection, conduction, radiation, and replenishing water are Q_e, Q_{cv}, Q_{cn}, Q_r, and Q_{rp}, respectively; and time is t. Each of the above-mentioned heat acquisition and loss components is discussed in greater details further down

2.1 Evaporative heat loss

The conversion of the pool's liquid water to gaseous water causes evaporative heat loss (Q_e). The Q_e computations for ISWPs and OSWPs are different, thus they are explained individually[2].

a. Evaporative heat loss in ISWPs

Q_e is determined for ISWPs using the water evaporation rate (E_e), which is expressed as follows:

$$Q_{\mathrm{e}} = H_{\mathrm{e}} \cdot A_{\mathrm{p}} \cdot E_{\mathrm{e}} \qquad (2)$$

WhereA_p denotes the pool's surface area and H_e denotes the latent heat generated by evaporation of water. E_e is an occupied pool and equal 1 for an empty pool, distinct empirical correlations for occupied and unoccupied pools are employed to determine E_e, as shown in Table 1., with the coefficient (w_e) given by the equation below [5].

$$w_{\mathrm{e}} = \left[w_{\mathrm{a}}^2 + \left(0.12 \cdot \left(4 \cdot (1 - R_{\mathrm{a}}) - (T_{\mathrm{a}} - T_{\mathrm{w}})\right)^{0.5}\right)^2\right]^{0.5} \qquad (3)$$

where w_a denotes wind speed parallel to the water's surface, R_a denotes relative humidity, T_a denotes ambient air temperature, and T_w denotes water surface temperature.

Table 1A summary of the Ec's empirical equations

References	Equations (un-inhabited pool)	Equations (inhabited pool)

[5] $E_{\mathrm{e}} = 3 \times 10^{-5} \cdot w_{\mathrm{e}}^{1/3} \cdot (\mathrm{e}^{0.06T_{\mathrm{w}}} - R_{\mathrm{a}} \cdot \mathrm{e}^{0.06T_{\mathrm{a}}})$——

[67] (general forms) $E_{\mathrm{c}} = \gamma_e \cdot (\Delta p)^n$——

[8] $E_e = K_e \cdot \rho_{\mathrm{sw}} \cdot (\rho_{\mathrm{r}} - \rho_{\mathrm{sw}})^{\frac{1}{3}} \cdot (S_{\mathrm{w}} - S_{\mathrm{r}}) \; ((\rho_{\mathrm{r}} - \rho_{\mathrm{sw}}) > 0)$ $E_{\mathrm{e}} = 0.113 - \frac{7.9\times10^{-5}}{F_a} + 5.9 \times 10^{-5} \cdot \Delta p$

[9] $E_e = 0.00005 \cdot \Delta p((\rho_{\mathrm{r}} - \rho_{\mathrm{sw}}) \leq 0)$——

As seen from Table 1, the variance between both the saturated vapor pressure and The partial vapor pressure of water at the surface of the room air is represented by Δp, while F_{a} denotes the pool's factor of utilization, which is computed using the following equation [6] .

$$F_{\mathrm{a}} = N_{\mathrm{e}} \cdot A_{\mathrm{m}} / A_{\mathrm{p}} \tag{4}$$

Where A_m denotes each swimmer's pool area at maximum number of swimmers, and N_e denotes the overall counts of the swimmers. K_e is a constant which is found from the difference between the air density at room temperature (ρ_r) and the density at surface of water is ρ_{sw}; when " ($\rho_r - \rho_{sw}$) > 0.02 " the " K_e" is 35 and "40" when "($\rho_r - \rho_{sw}$)= 0.02"[68]; S_w and S_r represent the the saturated air specific humidity at room air temperature and water surface, respectively; n and γ_e are factors that vary between studies[67]. Different researches have been undertaken to explore the evaporation phenomenon in ISWPs in addition to the Table 1's empirical correlations.

a. *Evaporation loss in OSWPs*

The heat loss of evaporation (Q_e) for OSWPs is computed using an empirical correlation which combines the vapor pressure differential and the heat transfer coefficient of evaporation, as indicated below

$$Q_{\mathrm{e}} = h_{\mathrm{e}} \cdot A_{\mathrm{p}} \cdot (p_{\mathrm{s}} - p_{\mathrm{a}}) \tag{5}$$

Here, the saturated vapor pressure is ρ_s at the surface of water;" pa" is the partial vapor pressure of room air; and" h_{e}" is the heat transfer coefficient of evaporation, which is a function of the speed of wind and is represented as follows:

$$h_{\mathrm{e}} = c + d \cdot w_{\mathrm{a}}^{z} \tag{6}$$

Where (c, d, and z) are some constants estimated by several researchers, as seen in Table 2 [310].

Table 2 Various parameters affecting the q [3,9]

Authors	c(W/m^2. Pa)	d(W.s/(m3.Pa))	z(—)
[11]	0.0850	0.0508	1
[12]	0.0360	0.0250	1
[13]	0.0423	0.0565	0.5
[14]	0.0638	0.0669	1
[15]	0.0506	0.0669	1
[16]	0.0890	0.0782	1

2.2 Convective heat loss

Convective heat loss is caused by the heat transfer induced by the movement of the pool water and surrounding air (Qcv). It is calculated using the temperature difference between the water surface and the ambient air, as shown in the equation below

:

$$Q_{\mathrm{cv}} = h_{\mathrm{cv}} \cdot A_{\mathrm{p}} \cdot \left(T_{\mathrm{p}} - T_{\mathrm{a}}\right) \tag{7}$$

The convective heat transfer coefficient is h_{cv}, it is determined in the ISWPs model using Newton's law of cooling, which is represented as the following equation [17]:-

$$h_{\mathrm{cv}} = \frac{k \cdot Nu}{L_{\mathrm{c}}} \tag{8}$$

where k is the thermal conductivity, L_c is the pool's characteristic length, and Nu is the Nusselt number, which can be represented as follows [18]:-

$$Nu = 0.14 \cdot Ra^{\frac{1}{3}} \tag{9}$$

Ra denotes Rayleigh's number. h_{cv} is calculated from empirical equations in the OSWPs model:

$h_{cv} = 2.8+3.0\cdot wa$[19] (10)
$h_{cv} = 3.1+4.1\cdot wa$ [3] (11)

[4] also created a novel approach for calculating convective loss based on the Bowen formulation [20] as:

$$Q_{\mathrm{cv}} = R_{\mathrm{B}} \cdot Q_{\mathrm{e}} \tag{12}$$

The Bowen ratio R_B can be estimated by taking into account the effect of ambient pressure on evaporative and convective heat transmission [20].

2.3 Conductive heat loss

Convective heat loss is caused by the temperature difference between pond water and soil.(Q_{cn}). According to several studies, Q_{cn} contributes so little to the overall loss in heat of the pool which then can be overlooked. However, according to [21], Q_{cn} should be considered in specific situations, such as when moist soil exists or subsurface water flow, which could result in a considerable increase in conduction heat loss. Also conductive loss is calculated based on soil temperature profile :

$$\rho_{\mathrm{s}} \cdot c_{\mathrm{s}} \cdot \frac{\partial T_{\mathrm{s}}}{\partial t} = k_{\mathrm{s}} \cdot \frac{\partial^2 T_{\mathrm{s}}}{\partial x^2} \tag{13}$$

where T_s, k_s, c_s, and ρ_s are the soil's temperature, thermal conductivity, specific heat, and density, respectively; and x is the depth beneath the earth. Q_{cn} can also be calculated using the assumption that T_s is uniform and unaltered [10]:-

$$Q_{\mathrm{cn}} = \frac{1}{2L_{\mathrm{s}}} \cdot Q_{\mathrm{s}} \cdot k_{\mathrm{s}} \cdot A_{\mathrm{s}} \cdot \left(T_{\mathrm{p}} - T_{\mathrm{s}}\right) \tag{14}$$

where L_s is the pool's characteristic length; Q_s represents the non-dimensional conductive heat rate which may be computed using shape variables [18]; and A_s is the conduction to ground surface area.

2.4 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_r):

$$Q_{\mathrm{r}} = A_{\mathrm{p}} \cdot \varepsilon_{\mathrm{w}} \cdot \sigma_{\mathrm{s}} \cdot \left(\left(T_{\mathrm{p}} + 273\right)^4 - \left(T_{\mathrm{sur}} + 273\right)^4\right) \tag{15}$$

where ε_w is the water's emissivity; σ_s is the Stefan-Boltzmann constant, which is 5.67×10^{-11} kW/(m2.K4); and T_{sur} is the ambient environment's upper surface temperature. T_{sur} is the indoor surrounding surface temperature in the ISWPs model. T_{sur} is the sky temperature (T_{sky}) in the OSWPs model, which may be computed using the Table 3 correlations. The dew point temperature is T_{dew}, the sky's emissivity is ε_s, and the cloudiness factor is c_c.

2.5 Water heat loss due to refilling

Difference temperature between pool water and the replenishing of fresh water makes the recover any lost water (Qrf). Because the pool water is lost due to evaporation and drainage, new water is required to replenish the pool[10]expresses the Q_{rf} as follows:

$$Q_{\mathrm{rf}} = c_{\mathrm{w}} \cdot m_{\mathrm{rf}} \cdot \left(T_{\mathrm{p}} - T_{\mathrm{rf}}\right) \tag{16}$$

where T_{rf} is the temperature of the new water being refilled, and m_{rf} is the mass flowrate of the fresh water being refilled. T_{rf} was constant at 15 °C in the [10] investigation. The values of m_{rf} are discussed using several examples. Ontario's laws indicated that fresh water of about 20L should be daily refilled back into the pool for each swimmer, with maximum amount of water refilling volume being 15% of the pool's volume, according to a Operator's Manual for Swimming Pools[22] . The volume of water that is daily refilled of a pool was 5% of the pool capacity, according to the Italian standard UNI 10637. [10].

Table 3 Various correlations for T_{sky}

References	Correlations
[23]	$T_{\text{sky}} = (T_{\text{a}} + 273) \cdot (0.8 + T_{\text{dew}}/250)^{0.25} - 273$
[3,10]	$T_{\text{sky}} = (T_{\text{a}} + 273) \cdot (\varepsilon_{\text{s}} + 0.8 \cdot (1 - \varepsilon_{\text{s}}) \cdot c_{\text{c}})^{0.25} - 273$
[4]	$T_{\text{sky}} = (T_{\text{a}} + 273) \cdot \varepsilon_{\text{s}}^{0.25} - 273$

2.6 Solar heat gain

The sun's energy is absorbed by buildings in ISWPs, which affects the temperature of the air inside the room. Heat that transferred from the pool water to the indoor air will be hampered. However, because the pool's water cannot be heated directly by the sun, the heat received from the sun (Q_s) is not taken into account in the ISWPs' heat transfer model. The solar thermal energy can be easily absorbed by the swimming pool in an OSWP. The following equation[19]expresses the Q_s:

$$Q_{\text{s}} = \alpha_{\text{s}} \cdot G_{\text{s}} \cdot A_{\text{p}} \tag{17}$$

In the researches [319], On the other hand, the sun's absorbance is 0.85, and it utilizes an average annual absorption coefficient calculated using the method stated above [424].

3. SWIMMING POOL HEATING APPLICATIONS

For swimming pool applications, two main categories are used which are passive and active techniques. This rating is recommended,This according to Varming Consulting Engineers Ltd. provides information on their website. [25].In passive design applications, natural forces (such as wind, sunshine, and gravity) are employed instead of fuel or grid energy to meet cooling, ventilation, and heating purposes. ponds ‘roofs can be used as a passive heating system type [26]. To achieve the aims of heating, cooling, and ventilation, active applications use fuel and power, such as wind turbines and the solar collectors.

3.1 Evaluating the efficiency and performance of swimming pool

Solar energy is frequently utilized to heat swimming pools in order to achieve comfortable temperatures. For this, **Al-Aboushi** Conducted a research study in 2015 on heating swimming pools, obtaining comfort conditions and extending the season of using the swimming pool for an indoor swimming pool in West Amman with an area of 30 square meters and a volume of 50 cubic meters as shown in the Fig. 3 below, 150 evacuated tubes with a diameter of 47 mm and a length of 1500 mm were used at the same time. The outcomes showed that the evacuated solar tube composites were successful in providing thermal comfort over a nine-month period.During the winter season (December to February), the solar energy system with the electric heater can be used to obtain the suitable temperature for swimming pool use.

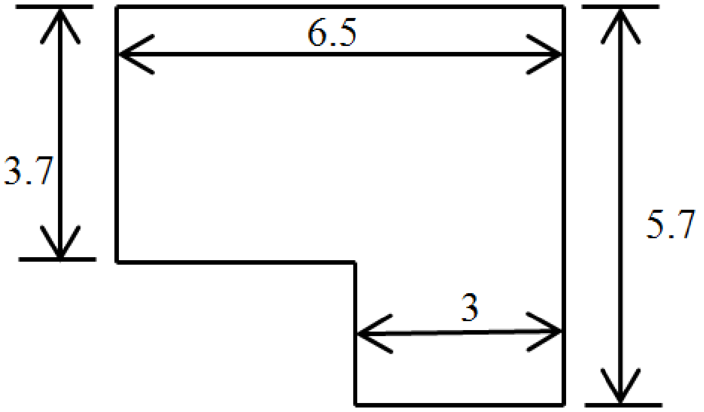

FIGURE 3: Schematic diagram of the swimming pool [27]

In the year of 2021 and regarding utilizing various types of flat plate solar collectors, **Laith et al.**Conducting a theoretical research on the thermal performance of Baghdad's indoor swimming pool ((Olympic swimming pool closed people)). The external dimensions of the closed hall are length (95 m), width (51 m) and height (16.5 m) as displayed in Fig. 4, it included two swimming pools. Heat losses were calculated for a period of 4 months (November, December, January and February) Solving the equations of the mathematical model using the program (MATLAB).and,according to findings black single cover solar collector and glass cover solar collector with selective absorber plate composing the system, black double glass solar collector, double glass collector with selective absorber, black rubber tube collector without glass cover, the solar refractive index is maximum when using two glass solar collectors and a selective absorption panel, and less when using a solar collector with black rubber tubes without glass cover.

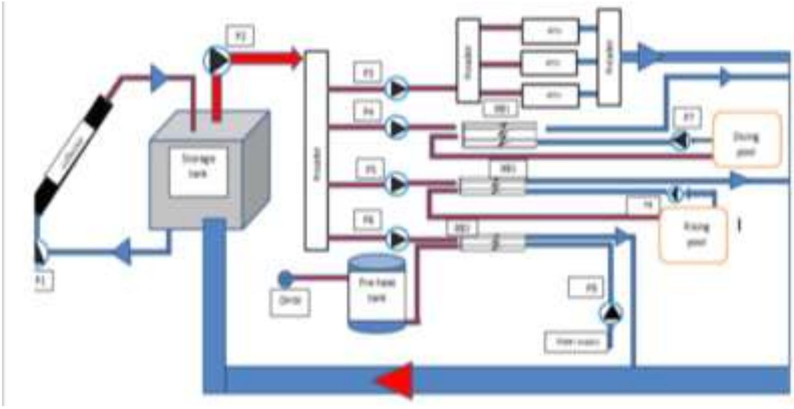

FIGURE 4. Schematic diagram for proposed solar heating system [28]

In 2019 a research into the solar heating of a swimming pool was performed by **R. S. Goncalves et al.**Solar pool heating systems' long-term energy efficiency in four Brazilian cities(Brasilia, Fortaleza, Porto Alegre, and Saddler) was investigated, with the pool area fixed and all types of glazed and unglazed solar and thermal energy taken into account. Complexes at various places with a total size of 150 square meters and a pool temperature of 30 degrees Celsius. For each city, meteorological data such as temperatures, horizontal surface radiation, and clarity index were used in the analysis .Additionally to data statistical analysis employing (ANOVA),the results were calculated utilizing the feature of developing the arithmetic code (the turkey). Unglazed sun collectors outperform glazed solar collectors, providing a 37 % fraction of solar energy in Braslia,(69%) in Fortaleza, (21%) in Porto Alegre, and(59%) in Saddleux, according to the findings. which is explained In Figure 5, However, as the temperature rises to 26°C, the area of the unglazed collector increases to 200m2 every year. Brasilia's solar fraction is increased 79 %, while Porto Alegre's is up 44 %. For city pairs such as Porto Alegre and Saddle Luis, as well as Brasilia and Saddle Luis, significant variances were found.

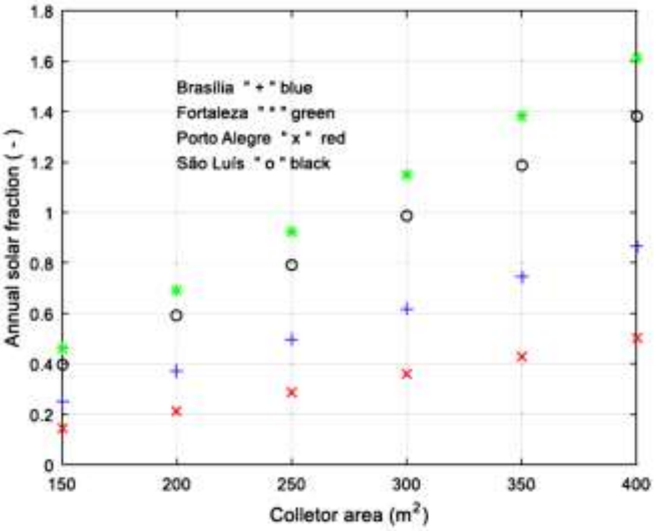

FIGURE 5. Depending on the surface area of the collector, the annual solar fraction changes. (unglazed collectors).)[29].

Matteo Dongellini et al. Three versions of flat solar collectors (unglazed and glazed collectors) were chosen for a dynamic solar heating simulation of the outdoor swimming pool at latitudes (44.47)N and (11.43)E. (vacant) Three restrooms, a communal paddling pool, and a swimming pool for sports activities are all available. The numerical model was created in the MATLAB/Simulink environment, as shown in Figure 6, and provides for hourly predictions of solar panel heat energy, liquid temperature, inlet/outlet collector work, and heat gains and losses in the pool. They also concluded that the value of the pool water temperature substantially impacts the scaling of solar collectors only in the event of very large swimming pools in order to limit the absorption area of solar panels. According to numerical data, unglazed and vacuum collectors are the most optimal modes for heating outdoor swimming pools because of their high efficiency at low climatic coordinate values.

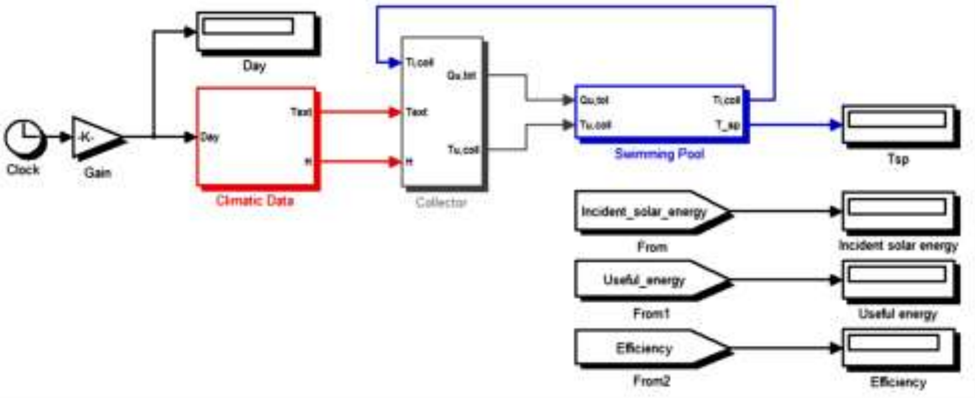

FIGURE 6. Model layout created in MATLAB and Simulink [30]

3.2 Financial feasibility of a solar powered swimming pool

There are many swimming pools in Kathmandu, most of them are outdoor. It is usually known that the season of swimming is limited to couple of months from May to September due to the decrease in ambient temperatures to 10 °C during the winter season. **Atmesh and Rabindra** performed research aimed to design, analyze performance and evaluate the financial feasibility of a solar powered swimming pool in Kathmandu. Solar energy was used to design an unglazed heating system of water for a pool. It is consisted of a solar collector with an area of 60% of the basin's surface to heat the water of the pool to a pleasant temperature of 23 °C. The study found that by utilizing the solar collector area, the pool may be used for an additional four months (March to November) throughout the extended season.season and that is displayed in Fig. 7. On the other hand, using a swimming pool cover reduces loss of evaporation by around 95To demonstrate how elements such as pool size and climate zone effect pool temperature and energy, as the tools given in this research contribute in predicting the size of the pool required. It is feasible for the swimming pool to minimize the consumption of power cooling by (25 % -30%) and peak demand by (25 % -30 %) depending on the size of the cooling system (30 %-35 %). Heating saves money by 30 percent to 45 percent in addition to saving money on cooling. and loss of radiation by 53%. Without placing a cover, the temperature of swimming pool will drop by another 0.9°C and thus shorten the season period by 16 days as shown in Fig. 8 below.

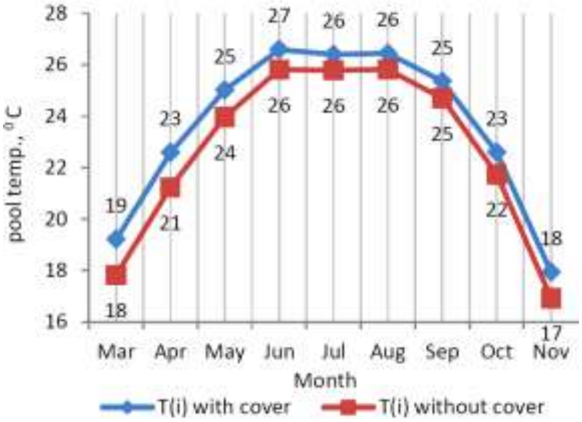

Figure 7. The influence of the cover on the pool's temperature [1]

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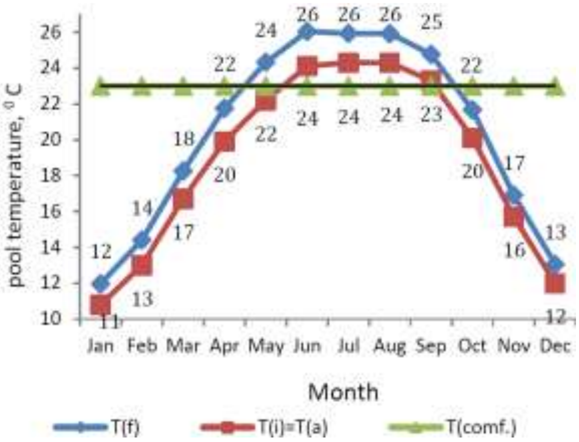

Figure 8. Effect of cover on pool temperature [1]

Buonomano et al. Submit a research paper to evaluate the efficiency and economics the construction of a solar hybrid system to power a creative renewable energy facility that serves a swimming pool area that is both indoors and outside, and to determine the indoor/outdoor pool heating requirement to maintain swimmer comfort. The system's performance was assessed using the TRANSYS dynamic simulation program, as illustrated in Figure , As a created simulation tool that allows for the calculation of both heat losses in indoor and outdoor swimming pools, as well as economic energy for the overall system performance, While the renewable energy plant generates both electricity and thermal energy, The analysis showed that the system's energy performance is outstanding due to full utilization of the energy produced and the necessity to increase the proposed system's economic profitability during internal operating mode.The thermal energy from the PV/T collector is mostly used to warm the water in the swimming pool, with a minor amount of solar heat used to make hot water, During outdoor operation, however, the opposite happens. Regarding the expense in money, it was found that the system's investment cost will be returned within two years, as investment in this sector results in financial profits and economic recovery.

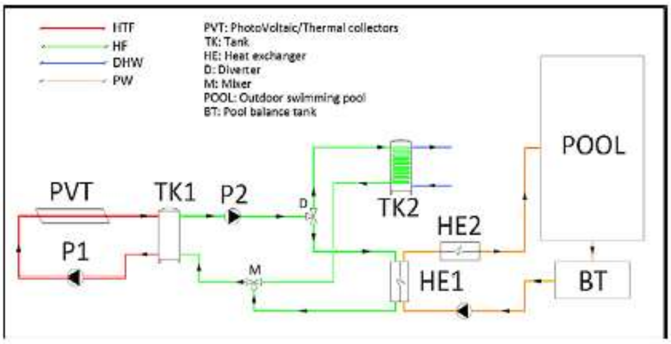

Figure 9. Heating system layout[10]

Natali et al. In order to increase their efficiency, a study was conducted to make energysavings more efficent in indoor swimming pools.The study was relied upon to conduct the current study on a public indoor pool and provided a dynamic simulation using the TRANSYS program in which the layout is displayed in Fig. 10, and conducted an experimental measurement campaign to ensure that the system ran with standards Numerical model using real data. A hypothetical model of the swimming pool was taken and energy efficiency measures were analyzed on it, as the first procedure focuses on reducing the rate of evaporation loss from the surface of the pool, The second step entails increasing the amount of warmth supplied by renewable sources. Both ideas reduce the overall amount of heat needed, and when the heat pump is used with the new exchanges, the heat content of the water that is ejected is recovered, lowering the amount of heat that must come from non-renewable sources, as well as a modeling approach that allows for repeated analyses by adapting the system. The factory was investigated with various general swimming systems and their efficiency was verified in order to save energy.

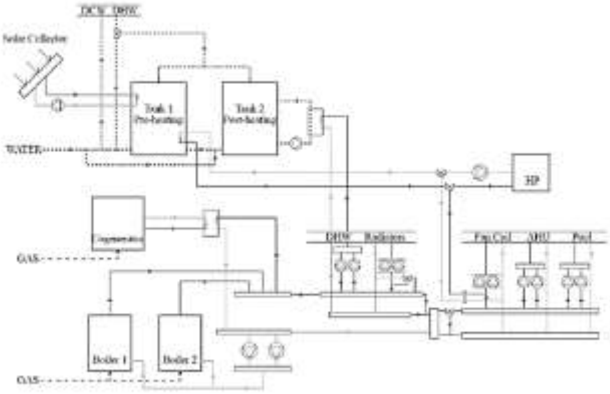

Figure 10. TRANSYS system layout of the Pool [31]

Curtis and Mark As indicated in Figure 11, Mark Ali conducted research on the use of swimming pools as heating components for air conditioning units. Previous investigations of the PACMET mathematical model, which was used in this project, had temperatures determined using a building energy model. To demonstrate how elements such as pool size and climate zone effect pool temperature and energy, as the tools given in this research contribute in predicting the size of the pool required. It is feasible for the swimming pool to minimize the consumption of power cooling by (25 %-30 %) and peak demand by (25 % -30 %) depending on the size of the cooling system (30 % - 35 %). Heating saves money by 30% to 45%in addition to saving money on cooling.

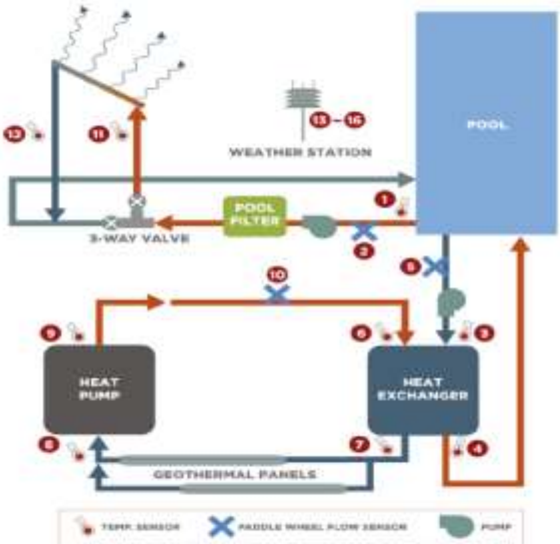

Figure 11. Schematic of the experimental system and instrumentation locations [32]

3.3 Effect of flow rates on the performance and effectiveness of solar collectors

L.N.Cunio and AB Sproul He conducted an experimental study and a theoretical analysis to determine how low flow rates affected the effectiveness and performance of non-corrugated, unglazed, and uninsulated solar collectors for an outdoor swimming pool. The study revealed that the increase in electrical energy is by 80%, and it can be provided to solar collectors that operate on the flow, which reduced the rates by 75%, and at the same time the efficiency of the collector decreased by about (10%-15%) only. The thermal energy to electrical energy ratio of the proposed complex has also been improved by 400%.Fluid flow rate and input and outlet temperatures were tested to see how lowerflow rate affected the proposed collectors. As described in Fig 12, the low flow rate of the swimming pool can save a significant amount of energy while having no detrimental impact on filter performance or water quality, When deciding the size of the pool, using a low-power pump with a low flow rate only diminishes the pool's effectiveness by roughly 10% -15%. The pickup, installation and operating times, and an effective improvement in the performance of the operating coefficient (COP), which means lower operating costs.

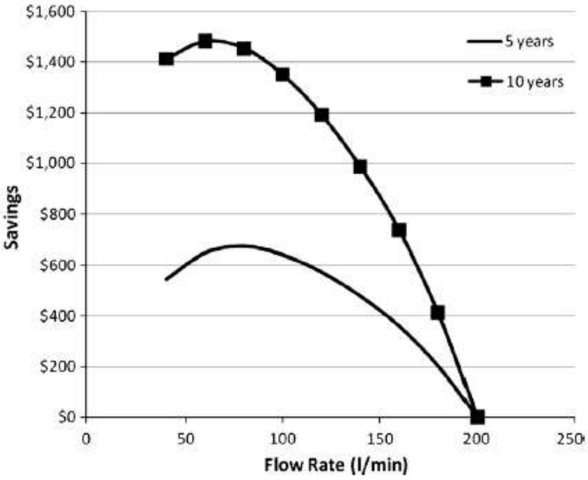

FIGURE 12. Illustrative savings from reduced flow[33]

Zhao et al. made a study of high-efficiency solar swimming pool heating systems under an ideal and low-flow level which is depicted in the Fig. 13 below. The typical operating pump was utilized with a flow rate of (0.07) kg/m2 and a low flow of (0.016) kg/m2 with a longer runtime with the necessity for a bigger combined area (+17%) in order to reach the BAU equivalent heat. The results showed that under low flow, 7.5% of the energy was achieved with a fourfold increase in the system performance factor (COP) with a value of (64) and that the system The high-efficiency solar pool heating examined in this study provided significant energy savings and greenhouse gas reductions in countries with high pool density such as Australia and the United States of America.

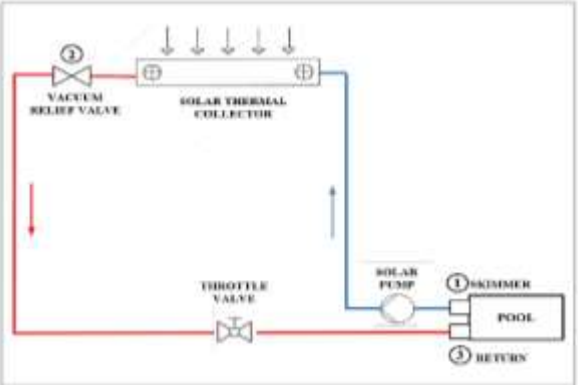

FIGURE 13. Schematic layout of the residential solar pool heating system [34]

Ciuman and Lipska In an indoor swimming pool, conducted an experiment to validate numerical modeling of air, temperature, and humidity. Where this study is concerned with the empirical identification of physical events that occur in actual indoor swimming pools and determining whether the facility's numerical model has been constructed using Ansys cfx 14.5 as shown in Figure 14. Indoor swimming measures as a parametric condition for numerical CFD computations and results validation. The empirical measurements of the (VDI) equation were obtained from among (6) formulas (Carber, Smith et al., VDI, Ashrae, Biassin and Krum Shah), where the discrepancies ranged between 32-48% and this indicates that this formula is applied in other calculations.

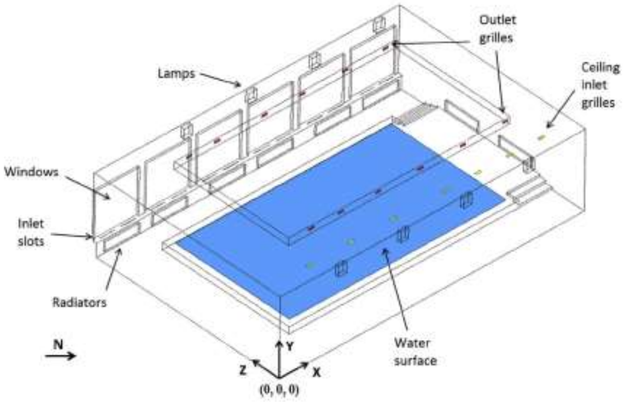

FIGURE 14. The numerical model of the indoor swimming pool [35]

3.4 Thermal losses for solar heated swimming pools

Bernhard et al. Evaluate the outdoor pool's sensitivity under dynamic situations.As demonstrated in Figure 15, a model that may reflect the behavior ,of a swimming pool (water temperature and energy consumption) has been shown, regardless of the climatic conditions.Thanks to the model provider and the observations, the heat loss in this study was determined (ambient air, temperature, relative humidity, wind speed trend and global solar radiation)The experiment was carried out at a public outdoor swimming pool in La Reunion, Mauritius, where the results were compared to a dynamic simulation of the pool. The emissivity, etc.) is constant. Solve a global model on the RK4 method. Measure the temperature of the bath every (3) minutes and calculate the percentage of heat loss, the most important of which is evaporation, which accounts for between (55%-70%), and a test was carried out for four cases (1) and (2) with similar data and conditions, as well as the fourth case with similar ambient conditions (in terms of wind speed and humidity), While the third instance is unique, particularly in terms of the line's slope, which is more significant and corresponds to increased thermal losses as wind speed increases, contributing to convection, evaporation, and a lower ambient temperature. They concluded that moisture leads to high evaporation losses, and the intensity of thermal radiation remains the same regardless of the situation as displayed in the Fig. 16 below.

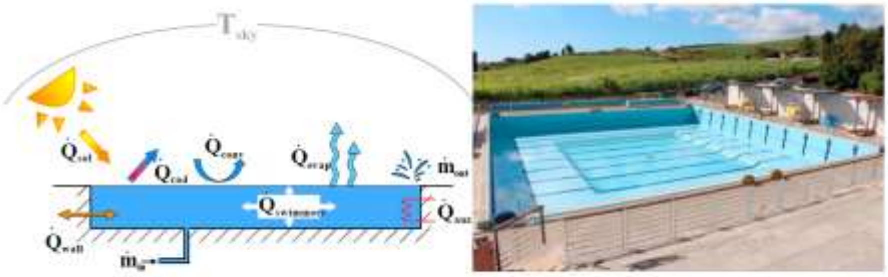

FIGURE 15. of a swimming pool and the major phenomenon that affects the energy and mass balance of the pool under test. [36]

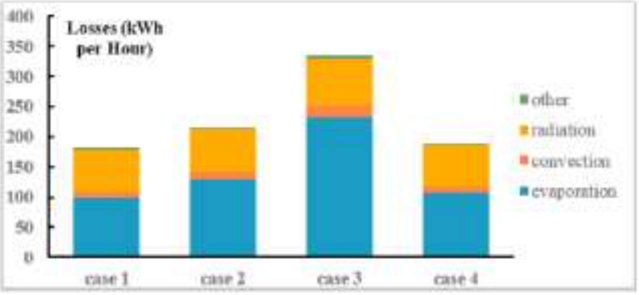

FIGURE 16. Analysis of the origin of energy losses for each investigated case[36]

Marko et al. Studied Mathematical Modeling and Thermal Simulation of Solar Heated Indoor Swimming Pool Performance. The demand for indoor pool hall energy and pool losses was calculated using a mathematical model of the swimming pool that was described in a publication along with the multi-zone construction model of the swimming pool using the TRNSYS program. This demand is shown in Fig. 17 below. Because the hall is the primary source of loss, heating and ventilation in the swimming pool hall are necessary to raise air humidity due to evaporation and thus reduce energy consumption. They concluded through simulation that the heating of the pool water represents about 22%, while the ventilation and heating in the swimming pool hall is about 60% and therefore the evaporation losses were the highest value is in a range of (46%-54%) of overall losses of the swimming pool, and the study found that, up to 87% of the water heating requirements can be met by the solar thermal system, and the maximum area for collecting solar energy was obtained, equivalent to 26.4%, while avoiding stagnation.

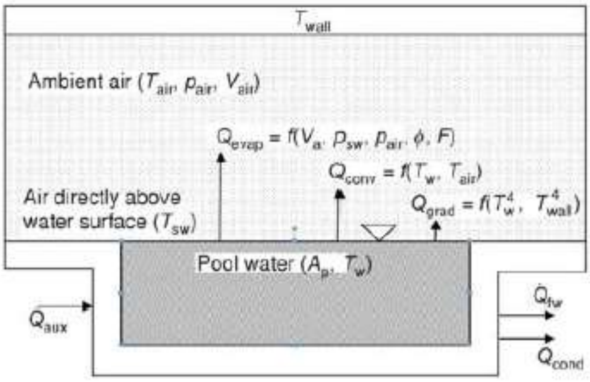

FIGURE 17. Swimming pool energy balance model scheme [37]

Ali .H Tarradstudied a detailed guide numerical modeling of thermal modeling for the optimal design of outdoor swimming pools with respect to heat loss and temperature change of the pool with climatic conditionsas shown in the Fig. 18 below. A hypothetical pool size (100 m^3) for recreational purposes, the design temperature range (24-29) degrees Celsius, the ambient air temperature from (10-20) degrees Celsius, and the relative humidity of 50% with the wind speed range (1.8-18) km/h were studied. The study showed that the great losses are from evaporation, which occupied the highest percentage among the pool components (54%-79%) and heat loss outside the pool (49%-40%) depending on the wind speed which is depicted in Fig. 19. The current technology also showed the possibility of maintaining comfort for swimmers who have (15%. -17.5%) has less demand for convection compared to the previously published design model. To compensate for the evaporation rate from the pool of accounts solely, fresh water was introduced as make-up water (1 % -1.5 %).

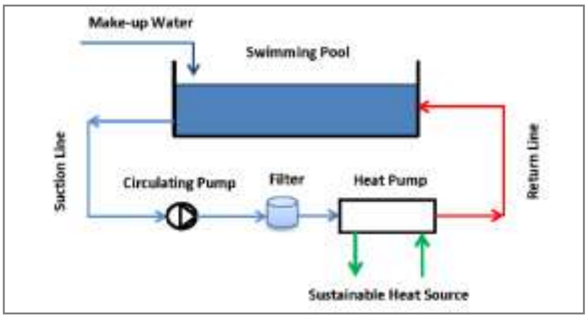

FIGURE18. A schematic diagram of swimming pool integration with sustainable heat source [38]

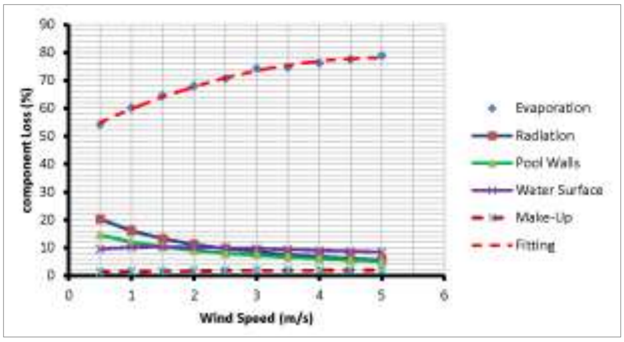

FIGURE 19. Design heating load required for the investigated swimming pool [38]

3.5 solar-powered heat pumps

chow et al. A solar-powered pump system analyzes the water in an indoor pool and the heating of the environment. Figure 20 shows the first system built by the researchers for an indoor swimming pool using a novel solar heat pump (SAHP) casing. The energy performance is then assessed using the winter operation plan and the TRANSYS simulation program. The simulation results showed that the total system's COP can reach 4.5 and that, compared to a conventional power system, a factor fractional energy saving of 79 % can be achieved. The designed system can also meet energy requirements, reheat pool water to 32 degrees Celsius, while keeping the air temperature in the pool area at 29 degrees Celsius throughout the operating period. This study looked into the use of solar supplemental energy for water heating and space heating in an indoor pool area heat pump system and water heating in Hong Kong's subtropical climate.

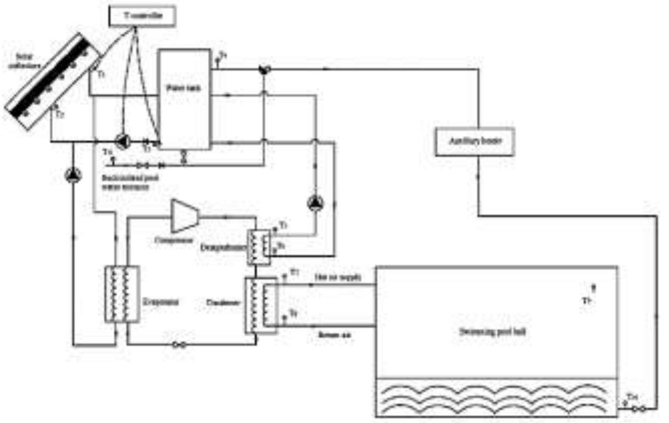

FIGURE 20. A diagram of the indirect solar supported heat pump system is shown below[39]

Peng sun et al. He researched the dehumidification pump to reduce the energy consumption of the indoor swimming pool when the heat content of the outside air was higher than 18.6 kJ/kg. This device not only recovers latent heat from moist interior air, but also gathers heat from outside air to heat both indoor and outdoor air as well as pool water. This is done by evaluating the indoor environment in terms of comfort for people (including space data and pool temperature). On a typical spring or summer day, they discover that the indoor space temperature should be set to (28.2, 29.8, and 27.8) degrees Celsius, respectively. The latent heat from the evaporator can entirely satisfy the demand to heat the pool water on a typical summer day, but on an autumn day, the majority of it is required. Dehumidifiers can save energy and money when compared to typical heat pump dehumidifiers. The mechanism is depicted in Figure 21.

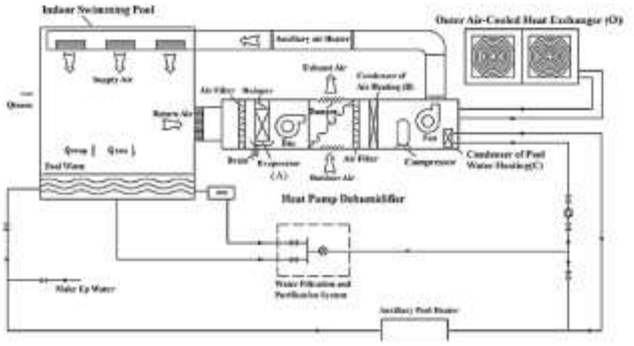

FIGURE 21. Diagram of the indoor swimming pool's energy supply system [40]

Yumrutas and ilgaz conducted a study in Gaziantep city, Turkey, on the performance of integrated solar swimming pool heating, auxiliary heat pump and underground thermal energy as shown below in Fig. 22. The source employed in the suggested model included a heat pump, an underground energy storage tank, and solar collectors. For tolerable water and solar collector temperature, appropriate tank capacity, and duration to meet cyclic conditions, MATLAB software was used to integrate the configurations, and meteorological data was inserted in COMMIER software. The findings indicated that when repeating a 50 m2 underground area, the thermal energy storage tank's volume would be 300 m3, the pool's size would be 100 m2, and the periodic operation would be 6 years. According to the study, the swimming pool heating system satisfied all of its initial solar energy requirements (using a heat pump(13.82%), it did so to an extent of 86.18%).

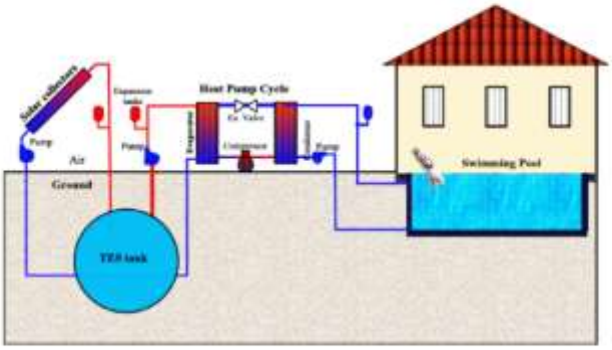

FIGURE 22. Schematic representation of the swimming pool heating system [41]

R. Starke et al. Four distinct heating system designs were simulated using the TRANSYS software to study the thermal analysis of solar heat pumps for swimming pools (see Figure 23).An air-to-water heat pump that is conventional and uses ambient air as a heat source is used in southern Brazil to heat outdoor swimming pools (ASHP) An air-to-water heat pump (SA- ASHP), an AW water-to-water heat pump (SA- WSHP), several parallel solar collector designs, and two systems (SA - DSHP).According to the present study of economic analysis, solar heat pump systems beat conventional heat pump systems by 48%, with a seasonal performance factor (6.7 to 8.2), (SA) - ASHP and (SA - DSHP) configurations. Benefits are only noticeable when the solar field is around 99 square meters..

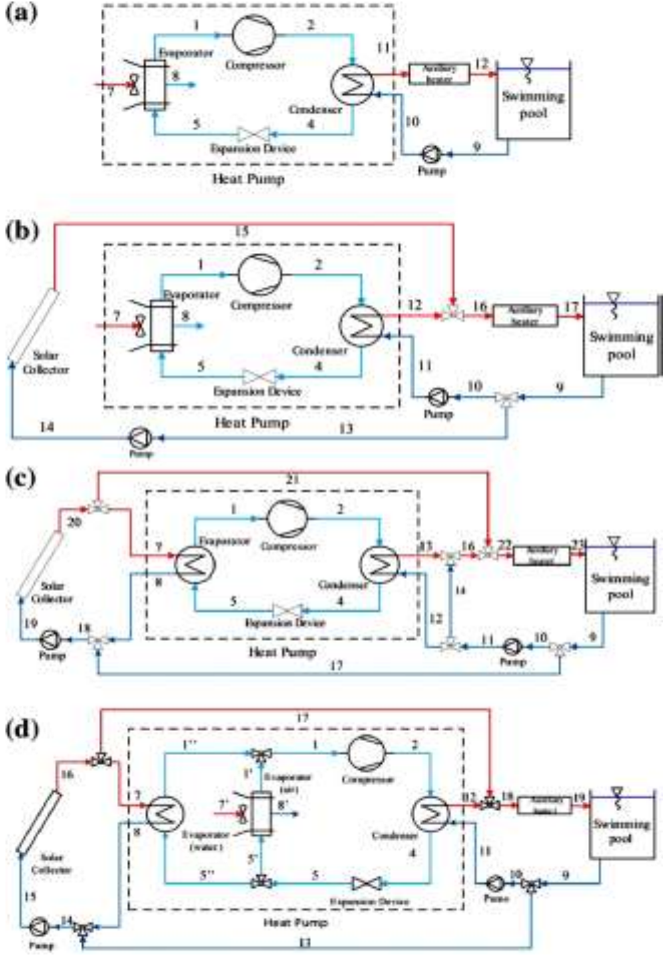

FIGURE 23. Diagram of the a-ASHP, b-SA-ASHP, c-SA-WSHP and d-SA-DSHP system [42]

Ali. H. Tarrad He investigated the heating mechanism and energy analyses for the purification of above-ground outdoor swimming pools, Where the pond volume (100 m3) and a temperature of (28) ° C were used to determine the dependence on transient temperature and heating load requirements. It took a long time for the heat pump to raise the pool water from a temperature of (12) degrees Celsius before using it, and the wind speed was between (8-18) km/h, and the air temperature was (15. -20)°C with humidity (50 %), and it was concluded that heat loss due to evaporation was in the range (54 % -69 %) depending on wind speed, and surface convective loss (15% -21%) at (1.8)-18) km/h.To maintain the swimming pool's thermal aspects, the heating load is derived from either land or sea water. This heat source was taken with the swimming pool to control the water temperature, taking into account the purpose of calculating the operation of the complex to assess the load.

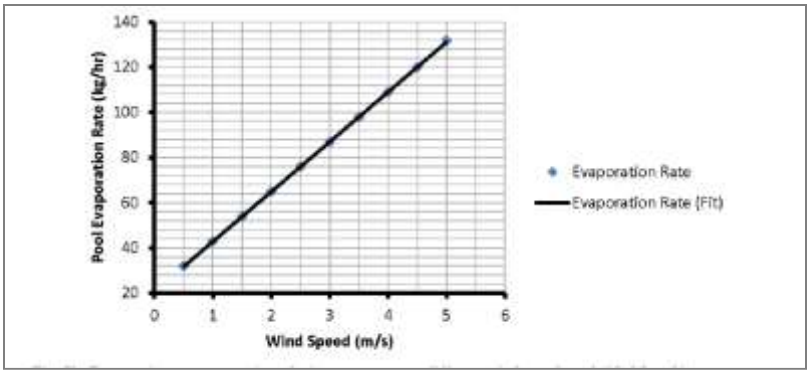

FIGURE 24. Comparison of evaporation rates during occupancy at various wind speeds and at ambient temperature of (15)°C [43]

3.6 Estimating the demand for thermal energy for swimming pools

Pablo and Ramon He investigated a dynamic simulation model (Figure 25), as well as experimental verification of the estimation of thermal energy demand in indoor swimming pools by observing the pool under real-world conditions and calculating evaporation and loss, as well as clarifying the utility of modeling tools and solving complex thermal cases with acceptable accuracy, yielding an average error of 1.77 %.It was carried out in two stages, firstly, a complete monitoring system was positioned in a general populace indoor pool in Archean municipality and compared with the results of the model, secondly, data was taken from four other swimming pools to reaffirm good conduct of the model. They come to the conclusion that facility managers can better control decision-making and identify and model suitable energy efficiency measures to reduce the facility's overall energy waste thanks to the developed model's ability to forecast real-time heating demand as well as demand for indoor air temperature and humidity.

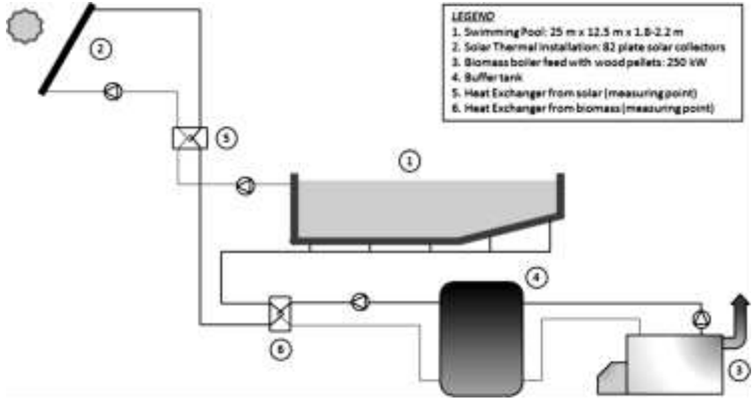

FIGURE 25. Archina Pool's simplified setup diagram [44]

Dimirtis ALkatsaprakakis He conducted research on the development of a combined solar energy system for the manufacture of hot water and thermal pools in Pankritan (Crete), as depicted in Figure 26. In order to meet the stadium's thermal energy requirements for hot water and swimming pool heating, a study of solar collectors was conducted. The performance of the proposed system was also simulated using an annual time series of average hourly values, And he described the method for calculating the dimensions, which includes calculating the thermal energy production in one solar collector, the total thermal energy from a series of solar collectors, and then the total thermal energy production from all the series for each group of solar collectors. He also discussed calculating the outlet temperature of the solar energy pools, which is followed by factoring in the hot water demand and calculating the new water temperature in thermal storage. It has been shown that using biomass and solar energy together may completely meet a huge amount of thermal demand.

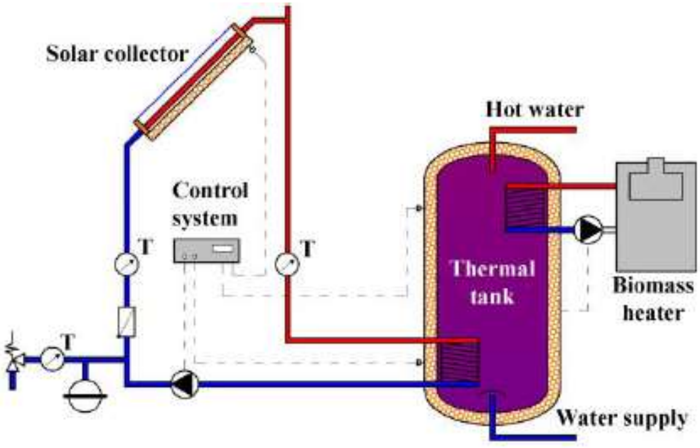

FIGURE 26. The proposed solar-combi system's general layout [45]

Marin et al. Looked at the application of predictive control to improve the indoor energy effectiveness of solar-powered swimming pools.According to the findings, after the new control algorithm is defined, TRANSYS software can be used to execute a dynamic pool simulation over a public indoor pool in Spain. Figure 27 shows how ESO predictive control can reduce a swimming pool's energy usage by 18.76% while using 42.64%j,/less fuel than a traditional PID controller. This makes solar thermal energy more efficient, reduces boiler use, and reduces fuel consumption, in addition to obtaining greater economic benefit, which leads to reduced operational costs in order to estimate the savings in boiler energy at the end of the year.

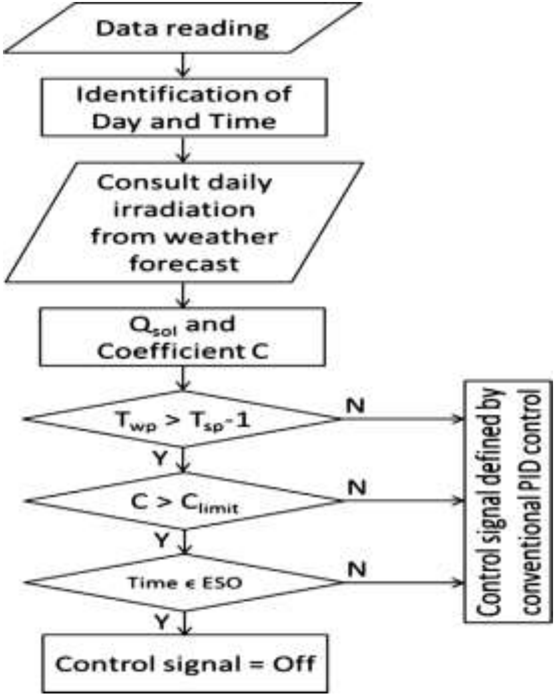

FIGURE 27. The proposed predictive control's primary algorithm ESO [46]

Khaled M.Bataineh studied in Indoor swimming: a transient analytical model heating powered by solar energy shown in Fig. 28 below. The study was conducted for an Olympic swimming pool inside the aquatic center on the campus of the Jordan University of Science and Technology, where the surface area of the pool was (25 * 15) m and the depth varied from (1-2.5) m and a capacity of (675 m3) of water. Solar heating was achieved through the use of hot water generated by heat exchange in collectors with evacuated tubes. The effectiveness of the proposed systems was evaluated in relation to the heat loss coefficient of the collector, the effect of covering the pool to prevent heat loss, and the usage of hot water produced by heat exchange in evacuated tube collectors, The outcomes demonstrated that utilizing a collector that covers 53% of the pool's surface results in 100% primary energy savings for pool heating, while using a collector that covers 40% of the pool surface saves 40% of the primary energy for heating the pool. The pool deck saves 87 % of energy, with a complex area of 26.6%of the pool deck saving 59 %. The results showed that a complex area of 200 square meters was the best choice, with a unit energy cost per kWh of $0.011.

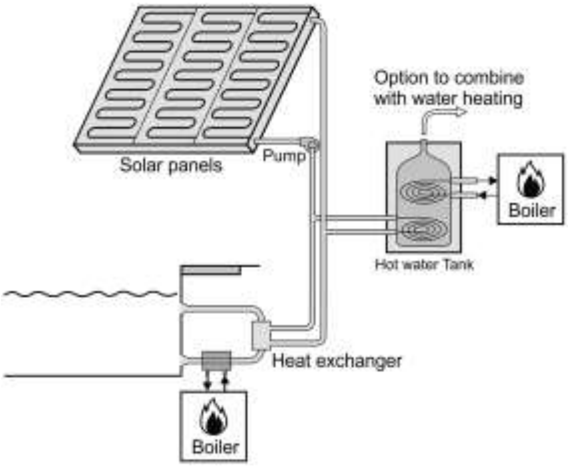

FIGURE 28. Schematic for solar thermal system with auxiliary heater for swimming[47]

3.7 Swimming pool heating systems

Ruiz and Martinez A solar heating design analysis for an outdoor swimming pool based on the TRANSYS model was investigated and experimentally confirmed in the form of private outdoor pools with an area of more than 100 square meters, where supplementary heating systems are typically installed. Also, by recording the temperature variations in the water and weather forecast data acquired at the pool site, the validity of the TRANSYS model for the private outdoor pool with an area of around 50 m2 was ensured. To learn more about the rise in temperature of the swimming pool in the pool areas during the swimming season as well as the associated costs, the swimming pool model was contrasted with the experimentally recorded model. This study uses a thorough system simulation with TRANSYS to ascertain the effect of the solar system's absorption field's magnitude on the swimming pool's thermal behavior. The goal of this study is to determine the impact of the size of the solar system's absorption field on the swimming pool's thermal behavior utilizing a comprehensive system simulation using TRANSYS.

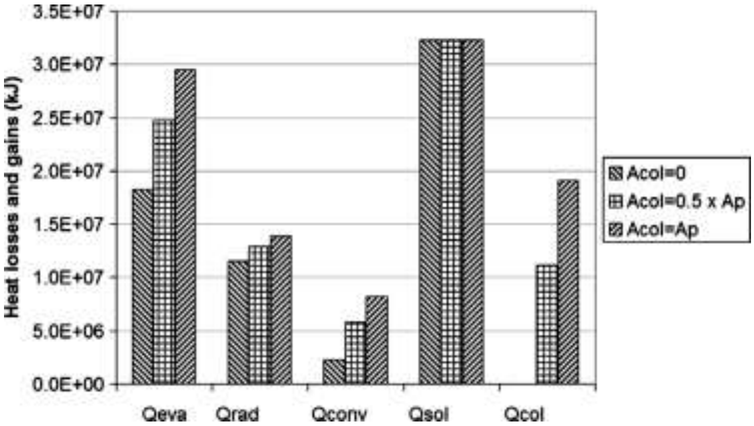

FIGURE 29. Thermal gains and losses for various collector regions in a pool in June [3]

Woolley et al performed a study of the design of models and testing verification of the thermal behaviour of the pool using swimming pools for air conditioners as heat sinks and verifying weather data to predict the pool hourly temperature in Limits of (1.1) °C, where a pool was monitored in Davis as is seen below in Fig. 30 to confirm the simulation result and that swimming pools can save about 40% of peak cooling compared to residential air conditioning and heating and cooling may occur at the same time and then the best heat is obtained from cooling equipment and replaces energy Heating the pool directly. The results showed that the mathematical model's predictions match well with the results of measuring the temperature of the swimming pool (see Fig. 31), indicating that the swimming pool can be used as a heat sink for a heat pump during the cooling season or as a heat source for a heat pump during the heating season. And the experimental period is closely related to an R squared of 0.967.

FIGURE 30. Photo of pool in Davis California used for experimental validation [4]

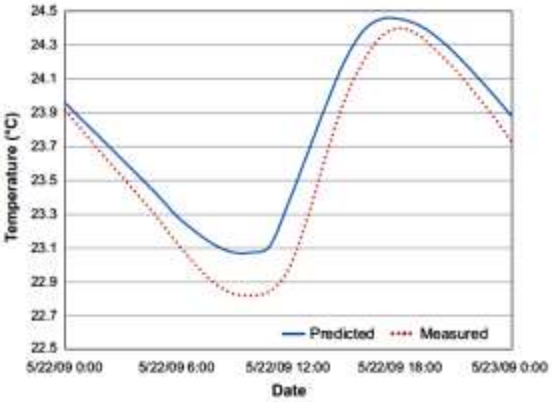

FIGURE 31.measured temperaturesand Predicted for a case of very good accuracy [4].

santos et al. He did research on measuring and tracking the thermal performance of solar energy for heated swimming pools with various coverings, as seen in Figure 32, to enable year-round pool use in southern European climates, where the world's radiation is within (1800) kWh/m2 and the air temperature ranges from (0-40) degrees Celsius throughout the year, and three swimming pools were used to study their thermal performance. The study found that the majority of the solar energy that reaches the pool is lost due to optical reflection, and that the remaining water and walls absorb the residue, and that losses due to evaporation are only significant in an outdoor pool, and that solar energy gain is higher for an open pool 86 % NC outdoor pool, compared to CCF pool with floating cover (34%), and (30%) for 2C pool (2 covered pools)

FIGURE 32. Views of the NC and 2C swimming pools are shown from left to right [48].

Zsembinszki et al. In this work, phase change materials (PCM) were utilized and presented in two parts technique in outdoor swimming pools, where outdoor swimming pools were heated in Mediterranean climatic zones by direct solar radiation and without extra heating systems. The first is to use PCM to coat the pool's side walls and bottom, and the second is to employ PCM in the exterior heat exchanger (see Figure 33).The behavior of the outdoor pool is analyzed by simulation using weather data at three different temperatures in different places and compared with experimental measurements where the water is maintained at a suitably high temperature and used when needed. , The research found that the use of phase change materials (PCM) improves water conditions, particularly when employed in heat exchangers, because it allows the heat content to be delivered at any moment.

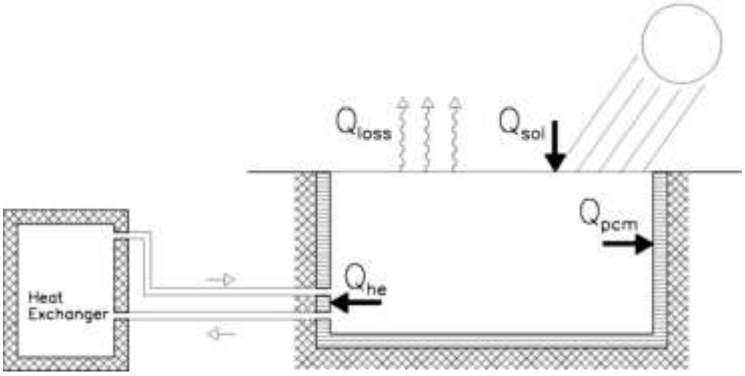

FIGURE 33. Heat flow rates in an outdoor pool with PCM encapsulated in the walls and bottom and connected to a heat exchanger[49].

3.8 Rate of evaporation losses for swimming pools

Jimenez et al. The objective of doing a study on the examination of models used in swimming pool heating systems was to enhance the scope of the research by pointing to less established regions, as the results showed that there is a wide disagreement about calculating the evaporation rate and a deficiency in the standard method for calculating the internal and external occupied swimming pool losses. Few or many waves produced by swimmers in different climatic conditions. The study found that using a heat pump to create additional heat from air to water due to lower outside air temperatures is an efficient and cost-effective choice, and that using a night cover, as recommended, saves large amounts of energy. When the pool is not in use, heat loss is decreased, which does not just apply at night.

F. Asdrubali Researchers created a micro-model to assess water evaporation in indoor swimming pools in practice, where it leads to excessive energy consumption in the pool station.Figure 34 was built as an experimental device to evaluate the rate of evaporation of water from the pool, and the model was placed in a climatic chamber to adjust the ambient parameters of water temperature and pool humidity. The computation of the factor (K) in the usual indoor regions of swimming pools, as well as a proposal for a novel model for predicting and evaluating evaporation flow rate in swimming pools. An excellent agreement was obtained between the internal model and comparison with the most well-known models, particularly models [5] and [15] derived from measurements in real complexes.

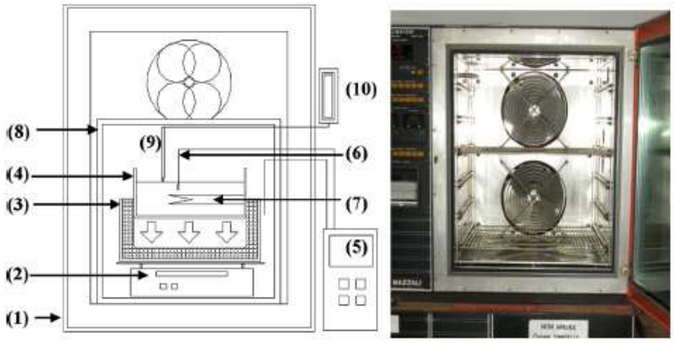

FIGURE 34. Experimental apparatus for water evaporation measurements [50]

S. Lugoa et al. Analyzed the influence of shadowing on the performance of an outdoor pool. Experimental and numerical calculations were used in the research. Figure 35 shows a test loop. To confirm the validity of that data for each component of the model as well as for the whole model, taking into account the shading factor and working on constructing and validating the shading equation in the model to know the differences in pool temperature to estimate losses. Because the pool was in a hotel, it was surrounded by trees and plants, which provided shade on the pool deck throughout the day, reducing direct sunlight.At assembly temperature RMSE = 0.148 °C, MBE = -0.058 °C, and coefficient of determination R2 = 0.9723, the model margin error was determined to be 0.41 percent. The findings indicate that this model can be used to develop and optimize solar thermal systems for outdoor swimming pool heating applications. The thermal collector has been shown to be economically and technically viable for swimming pool heating applications in Mexico, with temperatures adequate for pool use and returns on investment of less than one year.

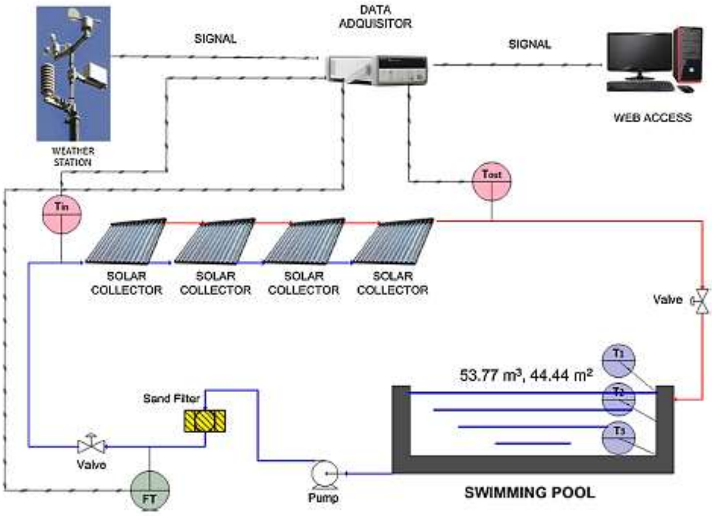

FIGURE 35. Solar system and monitoring schematic [51]

M. Mohammed shah [6]He conducted research on predicting evaporation from occupied indoor swimming pools in order to quantify energy consumption and determine the volume of air conditioning equipment. Two new correlations, one studying physical phenomena and the other simply experimental, were demonstrated. Data was obtained from indoor swimming pools ranging in size from 64 to 1209 m2, with occupancy ranging from 64 to 3 square meters per inhabitant, and temperatures of (25-30) °C and (26-32) °C, After comparing the new correlations to the present one, it was determined that the new experimental correlation performed better with an average of 16.2%, and the new correlation came in second. Hypothetical relationship with a 26.2% mean deviation, in which novel correlations provide reliable methods for estimating evapotranspiration in inhabited basins.

Ilona Rzezuik calculated the rate of the evaporation from the water for indoor swimming pools see Fig. 36. The results experimentally validate the published evaporation rate models in the swimming pool, where a test was conducted using a model of an indoor swimming pool measuring 99 cm / 68 cm /22 cm. In order to imitate pool conditions, a six-nozzle water sprinkler was set up, and measurements of the sports pool (water temperature: 24°C) and leisure pool (water temperature: 34°C) were taken.The findings indicated that the Shah, Chrome, and Biasin models and the air temperature were around two degrees Celsius higher than the water temperature, while the humidity ranged between 40 %t and 55%. were considered the best suitable for the results of measurements in laboratory conditions, whether in occupied or unqualified swimming pools.The lowest estimate is 12% for Shah and 18% for the Bayesin and Crum equations, therefore it is recommended that the equations for Shah (9) and the Bayesin and Crum equations be published (19-21).

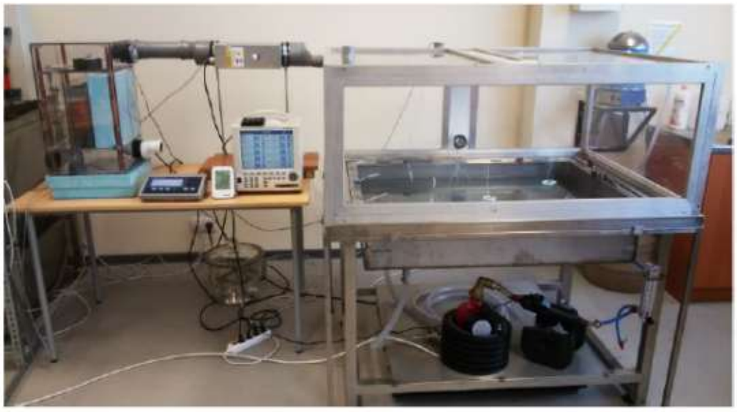

FIGURE 36. Experimental stand [52]

M. Mohammed Shah[8]Numerous applications call for the precise ratio of the rate of evaporation from undisturbed water surfaces to air, particularly in unlicensed indoor swimming pools and swimming pools holding spent nuclear fuel.so a study was conducted to evaluate the available correlations of the rate of undisturbed evaporation from the surface of water pools to cool the air.Many correlations were shown for such calculations, containing data from sources ranging from (0.07-425) m^2swimming pools Water temperatures range from (7-94) to (6-35) degrees Celsius, and air temperatures range from (6-35) to (7-94) degrees Celsius , as well as humidity (28 % -95 %) and comparing the available electronic correlations with the data, Shah's relationship (1992) provided the best agreement with an average of 18.2 %, while Boelter et al. (1946) provided the second best correlation with 26.2%, while all other correlations provided unacceptable high deviations , where he recommends a relationship Shah in all design accounts.

4. Conclusion from previous literature

Through our study of the previous research, we found how the solar heater system is an important part in using solar energy to heat water and be utilized in the swimming pools. So, here we list some of the important conclusions:

1. 1. The majority of energy is lost through evaporation. As a result, it is advisable to cover the pool at night to prevent energy loss due to evaporation, which can be accomplished with a thin film cover.
2. Only the uncovered SC swimming pool suffers from large evaporative losses.
3. Increases in solar collecting area result in an increase in the solar system's solar fraction factor.
4. When compared to similar earlier study, mathematical models and MATLAB software can be utilized to compute the sun fraction factor of the solar heating system and solve the equations while producing satisfactory findings.
5. Solar collectors with no glazing performed better than glass collectors.
6. The lowest allowable pool water temperature has a significant impact on solar collector sizing.
7. Due to their great efficiency, evacuated tube collectors are the most ideal typologies for heating outdoor swimming pools, according to numerical results.
8. Swimming pool heating with solar thermal collectors is a viable solution.
9. The efficacy of a standard solar thermal collector can be reduced by 10-15% by using a low-power pump to regulate the flow rate through the collector.
10. 10. The low flow rate scenario is a viable and alluring alternative due to the energy savings and efficient COP optimization.
11. While the COP climbed roughly four times from 15 to 64, the low flow scenario achieved considerable pump energy savings of 75%, and around 300 GWh of electricity may be saved each year.
12. Predictive controls in swimming pools may enable more efficient use of solar thermal energy and reduce boiler use, resulting in lower fuel consumption and better economic benefits.

13. Lowering the setpoint temperature from 28 to 27 degrees Celsius reduced the energy demand of an indoor pool by 7.4%.
14. The majority of the solar energy that enters the pool is lost due to optical reflection. The remainder is absorbed by the pond's water, walls, and other components.
15. Convective losses and long-wave radiative exchange are the two main ways that the bulk of solar energy that is captured is lost.

5. REFERENCES

1. Poudyal, A. & Bhattarai, R. N. Design and Analysis of a Solar Swimming Pool Heating System Statement of Problem Design Formulation. 131–139 (2014).
2. Li, Y., Nord, N., Huang, G. & Li, X. Swimming pool heating technology: A state-of-the-art review. *Build. Simul.***14**, 421–440 (2021).
3. Ruiz, E. & Martínez, P. J. Analysis of an open-air swimming pool solar heating system by using an experimentally validated TRNSYS model. *Sol. Energy***84**, 116–123 (2010).
4. Woolley, J., Harrington, C. & Modera, M. Swimming pools as heat sinks for air conditioners: Model design and experimental validation for natural thermal behavior of the pool. *Build. Environ.***46**, 187–195 (2011).
5. Mathisen, H. M. & Mathisen, H. M. Evaporation from svimming pools. (1990).
6. Shah, M. M. Prediction of evaporation from occupied indoor swimming pools. *Energy Build.***35**, 707–713 (2003).
7. Shah, M. M. Methods for Calculation of Evaporation from Swimming Pools and OtherWater Surfaces. *Energy Build.***49**, 306–309 (2014).
8. Shah, M. M. Evaluation of available correlations for rate of evaporation from undisturbed water pools to quiet air. *HVAC R Res.***8**, 125–131 (2002).
9. Rajagopalan, P. & Jamei, E. Thermal comfort of multiple user groups in indoor aquatic centres. *Energy Build.***105**, 129–138 (2015).
10. Buonomano, A., De Luca, G., Figaj, R. D. & Vanoli, L. Dynamic simulation and thermo-economic analysis of a PhotoVoltaic/Thermal collector heating system for an indoor-outdoor swimming pool. *Energy Convers. Manag.***99**, 176–192 (2015).
11. Shah, M. M. Improved method for calculating evaporation from indoor water pools. *Energy Build.***49**, 306–309 (2012).
12. Rohwer, C., Turner, K. M., Ingerson, I. M. & Shannon, J. W. Discussion of "Evaporation from Free Water Surfaces at High Altitudes". *J. Irrig. Drain. Div.***83**, 1215–1257 (1957).
13. Livingstone, D. M. & Imboden, D. M. Annual heat balance and equilibrium temperature of Lake Aegeri, Switzerland. *Aquat. Sci.***51**, 351–369 (1989).
14. Richter, D., Neubert, W. & Klämt, A. *Temperatur und Wärmehaushalt des thermisch belasteten Stechlin-und Nehmitzsees*. (Akad.-Verlag, 1979).
15. Smith, C. C., L~f, G. & Jones, R. MEASUREMENT AND ANALYSIS OF EVAPORATION FROM AN INACTIVE OUTDOOR SWIMMING POOL CHARLES. *Sol. Energy***53**, 3–7 (1994).
16. Chandrasekare, M. E., Kramer, M. D. K., Hunen, M. K. S. & Bazzucchi, M. V. ISO/TC 180 Solar energy.
17. Winterton, R. H. S. Newton's law of cooling. *Contemp. Phys.***40**, 205–212 (1999).
18. BERGMAN, T. L., LAVINE, A. S., INCROPERA, F. P. & DEWITT, D. P. Fundamentals of Heat and Mass Transfer, 7th edn. (2011).
19. Lam, J. C. & Chan, W. W. Life cycle energy cost analysis of heat pump application for hotel swimming pools. *Energy Convers. Manag.***42**, 1299–1306 (2001).
20. Bowen, I. S. The ratio of heat losses by conduction and by evaporation from any water surface. *Phys. Rev.***27**, 779–787 (1926).
21. Govaer, D. & Zarmi, Y. Analytical evaluation of direct solar heating of swimming pools. *Sol. Energy***27**, 529–533 (1981).
22. McKeown, D. Swimming Pool Operator's Manual. *Toronto Public Heal.* (2009).
23. Handbook, A. A. & Atlanta, G. A. UAS: American Society of Heating. *Refrig. Air Cond. Eng.* (2003).
24. Wu, H., Tang, R., Li, Z. & Zhong, H. A mathematical procedure to estimate solar absorptance of shallow water ponds. *Energy Convers. Manag.***50**, 1828–1833 (2009).
25. *Difference between passive and active applications. Available*. (2020).
26. Sharifi, A. & Yamagata, Y. Roof ponds as passive heating and cooling systems: A systematic review. *Appl. Energy***160**, 336–357 (2015).

27. Othman, F., Sadeghian, M. S., Ebrahimi, F. & Heydari, M. A Study on Sedimentation in Sefidroud Dam by Using Depth Evaluation and Comparing the Results with USBR and FAO Methods. *Int. Proc. Chem. Biol. Environ. Eng.* **51**, 6 (2013).
28. Haddy, L. M. & Hassen, A.-S. D. M. Thermal Performance Prediction of Indoor Swimming Pool Solar Heating System Using Different Types of Flat-Plate Solar Collectors. *Assoc. Arab Univ. J. Eng. Sci.* **28**, 08–18 (2021).
29. Gonçalves, R. S., Palmero-Marrero, A. I. & Oliveira, A. C. Analysis of swimming pool solar heating using the utilizability method. *Energy Reports* **6**, 717–724 (2020).
30. Dongellini, M., Falcioni, S., Martelli, A. & Morini, G. L. Dynamic simulation of outdoor swimming pool solar heating. *Energy Procedia* **81**, 1–10 (2015).
31. Natali, A., Bottarelli, M. & Fausti, P. A Methodology of Energy Optimization in Indoor Swimming Pool. *Tec. Ital. J. Eng. Sci.* **64**, 135–142 (2020).
32. Harrington, C. & Modera, M. Swimming pools as heat sinks for air conditioners: California feasibility analysis. (2013) doi:10.1016/j.enbuild.2012.12.038.
33. Cunio, L. N. & Sproul, A. B. Performance characterisation and energy savings of uncovered swimming pool solar collectors under reduced flow rate conditions. *Sol. Energy* **86**, 1511–1517 (2012).
34. Zhao, J., Bilbao, J. I. & Sproul, A. B. High-efficiency residential solar pool heating systems. *Proc. ISES Sol. World Congr. 2019 IEA SHC Int. Conf. Sol. Heat. Cool. Build. Ind. 2019* 417–425 (2020) doi:10.18086/swc.2019.09.02.
35. Ciuman, P. & Lipska, B. Experimental validation of the numerical model of air, heat and moisture flow in an indoor swimming pool. (2018).
36. Bernhard, M., Marc, O., Quilichini, E. & Castainglasvignottes, J. Sensitivity analysis of an outdoor swimming pool under dynamic conditions. *Procedia Manuf.* **35**, 124–129 (2019).
37. Mancˇic´, M. V., Zˇivkovic´, D. S., Milosavljevic´, P. M. & Todorovic´, M. N. Mathematical modelling and simulation of the thermal performance of a solar heated indoor swimming pool. *Therm. Sci.* **18**, 999–1010 (2014).
38. Tarrad, A. H. Heating Mechanism and Energy Analyses for Over-Ground Outdoor Swimming Pool Technology. *Asian J. Appl. Sci. Technol.* **1**, 8–22 (2017).
39. Chow, T. T., Bai, Y., Fong, K. F. & Lin, Z. Analysis of a solar assisted heat pump system for indoor swimming pool water and space heating. *Appl. Energy* **100**, 309–317 (2012).
40. Sun, P., Wu, J. Y., Wang, R. Z. & Xu, Y. X. Analysis of indoor environmental conditions and heat pump energy supply systems in indoor swimming pools. *Energy Build.* **43**, 1071–1080 (2011).
41. Ilgaz, R. & Yumrutaş, R. Heating performance of swimming pool incorporated solar assisted heat pump and underground thermal energy storage tank: A case study. *Int. J. Energy Res.* **46**, 1008–1031 (2021).
42. Starke, A. R., Cardemil, J. M., Escobar, R. & Colle, S. Thermal analysis of solar-assisted heat pumps for swimming pool heating. *J. Brazilian Soc. Mech. Sci. Eng.* **39**, 2289–2306 (2017).
43. Tarrad, A. H. A PERSPECTIVE NUMERICAL STEP BY STEP THERMAL MODELING FOR OVER- IJESMR I nternational J ournal OF E ngineering S ciences & M anagement R esearch. (2017).
44. Marín, J. P. D. & Garcia-Cascales, J. R. Dynamic simulation model and empirical validation for estimating thermal energy demand in indoor swimming pools. (2020) doi:10.1007/s12053-020-09863-7.
45. Katsaprakakis, D. Introducing a solar-combi system for hot water production and swimming pools heating in the Pancretan Stadium, Crete, Greece. *Energy Procedia* **159**, 174–179 (2019).
46. Delgado Marín, J. P., Vera García, F. & García Cascales, J. R. Use of a predictive control to improve the energy efficiency in indoor swimming pools using solar thermal energy. *Sol. Energy* **179**, 380–390 (2019).
47. Bataineh, K. M. Transient Analytical Model of a Solar-Assisted Indoor Swimming Pool Heating System. *J. Energy Eng.* **141**, 04014048 (2015).
48. Anuciada Santos, A., Gomes Sousa, C., Lillo B., I. & Ruiz H., V. MONITORING AND

MEASUREMENT OF THERMAL PERFORMANCE OF SOLAR HEATED OUTDOOR SWIMMING POOLS WITH DIFFERENT COVERS Anuciada. 1–11 (2006) doi:10.1115/isec2006-99031.

49. Zsembinszki, G., Farid, M. M. & Cabeza, L. F. Analysis of implementing phase change materials in open-air swimming pools. *Sol. Energy***86**, 567–577 (2012).

50. Asdrubali, F. A scale model to evaluate water evaporation from indoor swimming pools. *Energy Build.***41**, 311–319 (2009).

51. Lugo, S., Morales, L. I., Best, R., Gómez, V. H. & García-Valladares, O. Numerical simulation and experimental validation of an outdoor-swimming-pool solar heating system in warm climates. *Sol. Energy***189**, 45–56 (2019).

52. Rzeźnik, I. Study on water evaporation rate from indoor swimming pools. in (2017). doi:10.1051/e3sconf/20172200150.