JAES | JOURNAL OF APPLIED ENGINEERING SCIENCE | www.engineeringscience.rs
ISTRAŽIVANJA I PROJEKTOVANJA ZA PRIVREDU

Indexed by

ECONOMIC FEASIBILITY OF HEATING SOURCE CONVERSION OF THE SWIMMING POOLS

Ala'a M. Al-Falahat
Department of Mechanical Engineering, Faculty of Engineering, Mutah University, P.O Box 7, Al-Karak 61710 Jorda

Jenan Abu Qadourah
Department of Architecture Engineering, Faculty of Engineering, Mutah University, P.O Box 7, Al-Karak 61710 Jordan

Saad S. Alrwashdeh
Department of Mechanical Engineering, Faculty of Engineering, Mutah University, P.O Box 7, Al-Karak 61710 Jorda

Key words: *conventional heating source, economic feasibility, swimming pool, photovoltaic/heat pump*

doi:10.5937/jaes0-34474

Cite article:

M. Al-Falahat A., Abu Qadourah J., S. Alrwashdeh S. (2022) ECONOMIC FEASIBILITY OF HEATING SOURCE CONVERSION OF THE SWIMMING POOLS, *Journal of Applied Engineering Science*, 20(1), 276 - 284, DOI:10.5937/ jaes0-34474

Online aceess *of full paper is available at: www.engineeringscience.rs/browse-issues* doi:10.5937/jaes0-34474

Paper number: 20(2022)1, 924, 230-238

ECONOMIC FEASIBILITY OF HEATING SOURCE CONVERSION OF THE SWIMMING POOLS

Ala'a M. Al-Falahat[1], Jenan Abu Qadourah[2] and Saad S. Alrwashdeh[1]*

[1]Department of Mechanical Engineering, Faculty of Engineering, Mutah University, P.O Box 7, Al-Karak 61710 Jordan
[2]Department of Architecture Engineering, Faculty of Engineering, Mutah University, P.O Box 7, Al-Karak 61710 Jordan

Conversion from conventional heating systems is developed to address the emission of CO_2 in the environment, global warming, rising costs, potential shortages of fossil fuels, for all energy source alternatives available. This study reviewed the economic feasibility associated with converting the current heat source to a renewable energy source of heating swimming pools located in Jordan. Many modern heating systems techniques are proposed in this study such as solar heat collectors, heat pump and photovoltaic assisted heat pump. Solar heat collectors are a device that collects and/or concentrate solar radiation from the sun and allow for heating the water. In addition, a growing interest in photovoltaic/heat pump systems is considered, which combines photovoltaic cells and heat pump systems. Hence converting solar energy into electricity and then heat through the heat pump. The Initial and operation cost for all proposed techniques is evaluated. As a result, it is found that the best economical alternative option that can be installed on the available area of the building is photovoltaic with a heat pump system during the heating season. The operation cost of the current source (diesel boiler) is about 179,974 US$ and the total cost of heat solar thermal collector is about 936,540 US$ but the total cost of the proposed photovoltaic/heat pump system is nearly 251,060 US$, which save about 45,134 US$ yearly of the total commercial building electricity bill that is selected with a payback period of fewer than two years. In addition, available space on the rooftop of the selected building is well fitted with photovoltaic panels which are around 2000 m2. This result suggests that utilizing a PV/HP system for hotel pools is advantageous both financially and environmentally.

Key words: conventional heating source, economic feasibility, swimming pool, photovoltaic/heat pump

INTRODUCTION

Nowadays, environmental, global warming, rising costs, potential shortages of fossil fuels, and the need for more efficient biofuel conversion drive the development of equipment for more efficient energy consumption [1, 2]. Traditional heating options, such that diesel/gas boilers or electric heaters are commonly used to increase and maintain the temperature used for applications such as swimming pool heating which relatively has high initial and operating costs. As a result, it is important to create a renewable heating system with low operation costs for swimming pools. Therefore, due to rising fuel prices, environmental concerns, and potential fuel shortages in the future, alternative methods for heating swimming pools have been developed [3-5]. Many modern heating systems, such as heat pump, solar heat collectors, geothermal energy, biomass heaters, and waste heat recovery, have been developed to supply heat for many applications such that swimming pools. Solar energy is one of the most attractive energy sources for heating considering its abundance and widespread availability [6, 7]. Over the past decades, a major choice is connected to the usage of heat pump, which enables the use of renewable energy from the environment [8-10]. Therefore, a growing interest in photovoltaic/heat pump (PV/HP) systems are considered, which combines PV cells and heat pump systems as shown in figure 1. Hence converting solar energy into electricity and then heat through a heat pump [11-13]. With a combined solar PV system, the operation bills could be zero and can save money on pool heating.

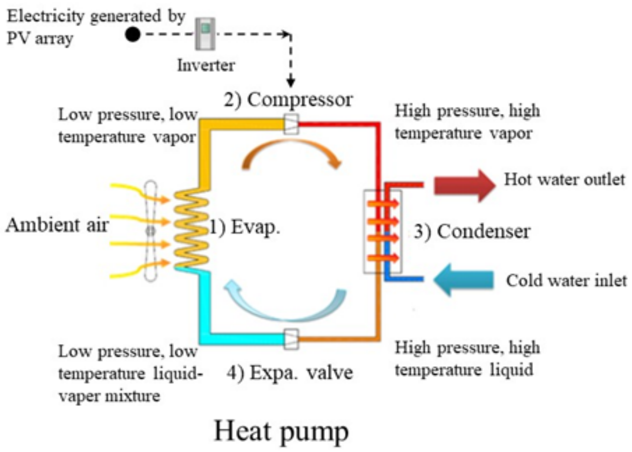

Figure 1: The diagram of the PV-HP system applied in the swimming pool

Another technology, which focuses on harnessing solar energy is the solar heat collector. Solar collector systems are a long-standing technology that is receiving increase attention in term of research and development which is a device that collects and/or concentrates solar radiation from the sun and allow for heating the water as displayed in figure 2.

alaa.falahat@mutah.edu.jo

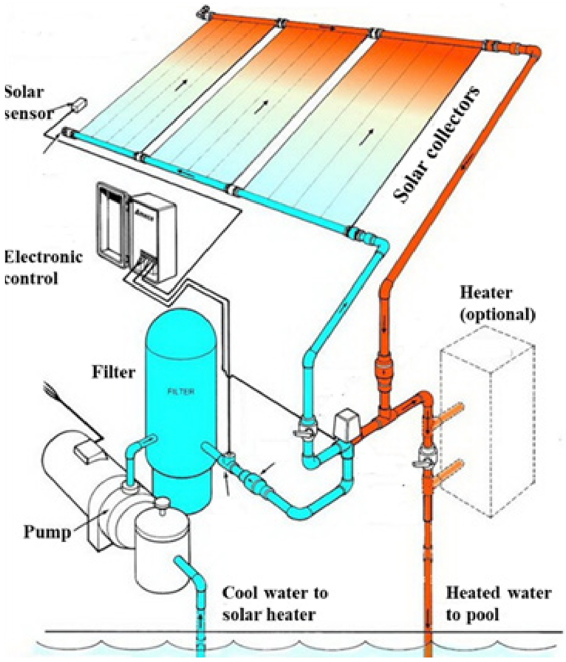

Figure 2: solar pool heater system diagram

This paper aims to study the economic feasibility of using PV-HP system and solar water collector as a heating source of the swimming pools and comparing with the existing traditional heating source taking into consideration the operation cost and initial cost. The proposed system's performance is evaluated using the developed simulation platform (PVsyst), which would be a promising approach in this direction [14, 15].

SYSTEM DESIGN METHODOLOGY

Commercial building

The selected commercial building is an Ayla hotel building located in Aqaba-Jordan and covers huge areas, including 430 hectares of land which has three swimming pools. The building has about 2000 m^2 of available rooftop area. According to historical statistics, Aqaba has the greatest radiation on the horizontal plane of any Jordan governor [16], As shown in table 1. The highest irradiation on the horizontal plane at Aqaba comes during August throughout the whole year with average irradiation of 7420 Wh/m^2/day approximately. While the lowest irradiation comes during December with average irradiation of 5330 Wh/m^2/day approximately. The characteristics of the swimming pools facilities examined in this study as shown in table 2, namely the volume of each pool, the surface area, and the current heating source of each pool. Despite some similar features, there are clear differences in dimensions between the pools, the total volume about 465 m3 to 767 m3 and 570 m3 of the family pool, main pool, SPA pool respectively this difference is related to the difference in the surface area. Also, the water temperature is about 28 ˚C and 48 hours heating up time.

Table 1: radiation distribution in Aqaba

Month	Solar radiation in Wh/m^2/day
January	5430
February	6230
March	7530
April	7190
May	7270
June	7400
July	7350
August	7420
September	7270
October	7020
November	6050
December	5330

Table 2: Description of the three pools and the current source of its heating

Pool name	Volume (m^3)	Surface area (m^2)	Heating source
Family pool	465	310	Diesel boiler
Main pool	767	515	Diesel boiler
SPA pool	570	380	Steam (electrical heat)

While the Diesel boiler is used as a heat source for the family pool, the SPA pool is used as a steam heat exchanger (heat pump). The analysis is performed in two stages. Firstly, the data was collected from the past three years recorded bills of energy consumption as a monthly data record of consumption levels. secondly, with the data collection, the three pools are characterized, and the operation and initial cost for the water heating system are calculated and analyzed. Finally, the heating load for the three swimming pools are evaluated and taking into consideration all heat gains in and out for the swimming pool according to live data from the previous three years and calculating the real heating loads and energy consumption is determined, therefore, the total heat transfer (Vaporization, Convection, Radiation) of the operation months at three pools (Family and main and SPA pools) is computed as shown in appendix A1, A2 and A3. Additionally, several saving measures are pointed out and examined. It should be noted that the calculation was done by using the PVsyst software based on the equations presented in detail elsewhere such as reference [5].

Heating loss calculation

The precise amount of heating energy and heat source consumption is computed to design the proposed heating source and estimate the initial cost of alternative options as well as compare the operating costs. During the winter months, a significant amount of heat is required to keep both indoor and outdoor swimming pools warm. A swimming pool heat transfer model is the most basic prerequisite for studying the performance of swimming pool heating systems. As a result, the next sections discuss each of the heat gain and loss component calculations.

Evaporation heat loss

The calculation of the evaporative heat loss Q_e of the ISPs or OSP are different as follow the first one is calculated according to the water evaporation rate.

$$Q_e = H_e A_p E_e \tag{1}$$

where A_p describes the surface pool area, H_e describes water evaporation latent heat and E_e is a water evaporation ratio which is calculated elsewhere such as [17]. On the other hand, the heat loss from the OSP is calculated depending on the vapour pressure difference and evaporative heat transfer coefficient as elsewhere such as [18].

Convection heat loss

It is determined using the temperature difference between the water surface (T_p) and the surrounding air (T_a), which is stated as the following equation

$$Q_{cv} = h_{cv} A_p (T_p - T_a) \tag{2}$$

where h_{cv} is the coefficient of the convection heat transfer and A_p is the water surface area.

Conduction heat loss

it is computed by the result of the temperature difference between the pool water and pool walls which can be neglected because it is so small compared to other losses, However, the evaluations of conduction heat loss can be done by using the governing equation as follow

$$\rho_s c_s \frac{\partial T_s}{\partial t} = k_s \frac{\partial^2 T}{\partial x^2} \tag{3}$$

where ρ_s,c_s,k_s and T_s indicate the density, specific heat, thermal conductivity, and the temperature of the walls, respectively.

Radiative heat loss

it is calculated by deference between the pool water temperature and the temperature of the surrounded air as follow

$$Q_s = A_p \varepsilon_w \sigma_s (T^4{}_p - T^4{}_{sur}) \tag{4}$$

where ε_w represents the emissivity of the water and σ_s is a Stefan-Boltzmann constant which is (5.67×10^{-11} kW/(m^2.K^4)).

Refilling water heat loss

The temperature differences between the pool water (T_p) and the refilling freshwater (T_{rf}) causes the refilling water heat loss (Q_{rf}). Because pool water evaporates and drains, new water is necessary to refill the pool. The refilling water heat loss expressed as [19],

$$Q_{rf} = c_w m_{rf} (T_{p-} T_{rf}) \tag{5}$$

where m_{rf} is the mass flow rate of the refilling fresh water and c_w is the specific heat capacity of water (4.18 kJ/kgK).

Heat obtain from the sun

The solar heat gain of pool water is computed using the equation prescribed by Lam and Chan [20], as follow.

$$Q_s = \alpha_s G_s A_p \tag{6}$$

where α_s is the absorption coefficient (0.85 is used) and G_s global solar irradiation. Now, the summation of heat transfer (Vaporization, Convection, Radiation) of the operation months at three pools (Family and main and SPA pools) are computed as shown in the Appendix section.

Heating load calculation results

Figure 3 shows the monthly average of the heating load of the three pools during operation months, the swimming pool's operating months usually in winter are from October to March, and it takes a lot of heat to keep the water temperature at a comfortable level of 28 °C. The monthly average values of the radiation, vaporization and convection heat transfer by the pools are calculated as shown in the Appendix (Table A1, A2 and A3) and noted that the main pool is the highest heating load through the operation period from October to March about 221,166, 132, 155, 185 and 206 kW, respectively. Based on these results, we may conclude that higher consumption is related to larger facility sizes of about 767 m^3, superior water utilization, and a greater number of visitors. The average energy loss by the 570 m^3 SPA pool size is displayed as shown in figure 2, the higher and the lower consumption months are in October and December about 163 kW and 97 kW respectively. The required heating load for the family pool are calculated as presented in Figure 3, it can be observed the lowest heating load required for this pool, this is because the pool size is smallest about 465 m^3 compared to other pools and a little number of visitors.

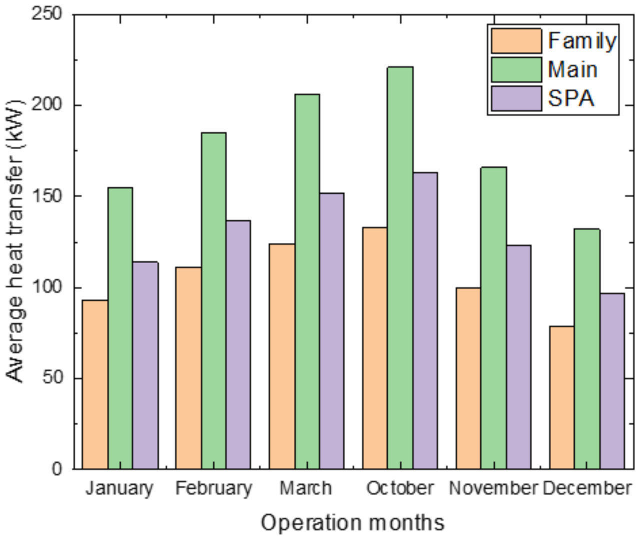

Figure 3: the average heat load of the hotel's pools at operation months

Traditional heating source

The current diesel boilers are the only equipment responsible for producing the thermal energy of three available pools. The boiler produces the hot-water supplying the energy to the swimming pool heat exchangers, the amount of the diesel oil consumption through the operation period is shown in tables 3,4 and 5 for the family pool, main pool, and SPA pool respectively. In this study, about 255,202 litres of diesel oil are required annually for the heating of the pools, particularly, 65,655 litres, 109,068 litres and 80,479 litres for the family pool, main pool, and SPA pool respectively. The total costs can be estimated as follows; heating of the family pool 46,301 US$/ year, main pool 76,917 US$/year and SPA pool 56,755 US$/year, for a total operation cost of 179,974 US$/year. It should be noted that the initial cost of a diesel boiler is neglected. As noted in tables 4,5 and 6, the higher energy utilization is in October about 13,946 litres of diesel oil for the family pool and 23,767 litters for the main pool, also, 17,095 litters for the SPA pool which might be due to the daily operating hours of 24 h/day at the pools in the same month.

RESULTS AND DISCUSSIONS

A proposed heating technique including solar heat collectors, heat pump and photovoltaic-heat pump system is selected. A view of all the run times for our full range and the different heating source options, also, the approximate amount of operation cost on the operation time at the available three pools to make a concise and easy decision. Solar collectors have been widely used in swimming pools heating systems, due to their considerable energy-saving potential, different investigations of the use of solar collector technology are presented as [21-23]. The author found that the heating system with solar collectors was economically competitive when compared with a conventional heating system. The calculation of the collectors is performed from the beginning of October to the end of March as shown in tables 3,4 and 5. Based on the collected data the average number of collectors needed for a family pool is about 291 solar collectors to meet the monthly heating requirement of the pool which are needed 500 m2 as a space on the rooftop of the hotel buildings. 484 solar collectors are required for the main pool to offer a monthly heating consumption by installing them on the 1,300 m2 roof space. For the third pool, 950 m2 is wanted from the rooftop space to instal 375 solar collectors as shown in table 5. The second alternative for the heating source is a heat pump which can always be chosen as an upgrade to have faster heat-up times or to match with solar generation. In some cases where power may be a problem where the heat pump will go and most often the pump controller is recommended for all-year-round swimming. In addition, an inverter heat pump has an extremely high-efficiency output with an average coefficient of performance of 10 [24]. The heat pump is known for its long lifetime, and this is shown by our extensive 25-year warranty on the heat exchanger, and extended warranty on all parts. Also, a heat pump requires very little maintenance throughout its lifetime. Once the unit is set up correctly, all that is required is ensuring the area around the unit is cleared from debris regularly with good airflow maintained. Tables 3,4 and 5 show the calculated monthly energy loss and the initial cost for the proposed heat pump. The pools are considered to operate in the interval from October-March and the cumulated values for the whole operation period of the pools are also displayed. It can be noted that the initial cost of 8,466 US$, 14065 US$ and 10378 US$ for each pool family, main and SPA pools respectively. Table 3: Operation cost of diesel option as a heat source and initial cost of alternatives of the family pool through the operation period Finally, it can be added third alternative heating source to enhance the energy-saving potential of heat pump, photovoltaic system assisted heat pump (PV/HP) have been proposed. It can create electricity and then heat the water by using heat pump technology [25]. This technology can provide us hot water with the temperature that can reach up to 80˚C, this degree of heating can cover more than 90% of the heat process in the targeted facilities (swimming pools heating 40˚C-45˚C, domestic hot water 50˚C-65˚C and space heating 50˚C-60˚C). One of the most important factors a the heat pump is the COP (coefficient of performance) while the swimming pools have a high flow and low-temperature difference between the inlet and outlet it has the highest COP can reach up to 10 in some cases which are used in this study [24]. The simulation is performed in (PVsyst) to assess the overall system performance of different PV/HP system configurations. The PV/HP systems are designed based on the available area on the rooftop space at the hotel building. Thus, the PV installation area required to meet the 37 kWp output power capacity of the photovoltaic is about 230 m2 for the family with a total

Table 3: Operation cost of diesel option as a heat source and initial cost of alternatives of the family pool through the operation period

Available options / Month	Diesel		Solar water heater (SWH)		Heat pump		
	Litter	US$	Req. area (SWH) m^2	Number of collectors	kWh	heat pump cost (US$)	Daily operation hours
January	9,772	6,891	590	295	9,927	1,259	17
February	10,536	7,430	614	307	10,704	1,358	20
March	12,954	9,135	564	282	13,160	1,669	22
October	13,946	9,835	651	326	14,167	1,798	24
November	10,139	7,149	567	284	10,300	1,307	18
December	8,307	5,859	511	255	8,439	1,071	14
I	65,655	46301	Avg. collectors	291	Total	8,466	

Table 4: Operation cost of diesel option as a heat source and initial cost of alternatives of the family pool through the operation period

Available options / Month	Diesel		Solar water heater (SWH)		Heat pump		
	Litter	US$	Req. area (SWH) m^2	Number of collectors	kWh	heat pump cost (US$)	Daily operation hours
January	16,233	11,448	980	490	16,491	2,093	17
February	17,504	12,344	1,019	510	17,781	2,256	20
March	21,521	15,176	937	468	21,562	2,775	22
October	23,167	16338	1,081	541	23,535	2,987	24
November	16,843	11877	943	471	17,110	2,172	18
December	13,800	13540	848	424	14,019	1,778	14
I	109,068	76917	Avg collectors	484	Total	14,065	

Table 5: Operation cost of diesel option as a heat source and initial cost of alternatives of the family pool through the operation period

Available options / Month	Diesel		Solar water heater (SWH)		Heat pump		
	Litter	US$	Req. area (SWH) m^2	Number of collectors	kWh	heat pump cost (US$)	Daily operation hours
January	11,978	8,447	723	361	12,168	1,544	17
February	12,916	9,108	752	376	13,121	1,665	20
March	15,879	11,199	691	346	16,132	2,047	22
October	17,095	12,055	798	399	17,366	2,204	24
November	12,428	8,764	696	348	12,625	1,602	18
December	10,183	7,180	626	313	10,345	1,313	14
I	80,479	56,755	Avg collectors	357	Total	10,378	

installed cost of the PV and HP system is approximately 59,239 US$ as displaced in table 6. Moreover, the PV installation area needed on the rooftop for the main pool and SPA pool is 400 m^2 and 260 m^2 respectively, with a total cost of 104,373 US$ and 87448 US$ for the main pool and SPA pool. It should be noted the operation cost of the PV/HP system is neglected.

System cost and economics

The heating cost of the current boiler system can be comparable to the proposed heating source cost alternative systems namely, soler heating collector, heat pump and photovoltaic connected with heat pump. As shown in table 7 the yearly operation cost of the current pool heating system is displaced along the operation period, in addition, only the initial cost of the alternative system is also displaced. It should be noted the operation cost of the proposed heating source is negligible. A diesel boiler will heat the pools much quicker than other alternative options but normally costs more to do so, which is about 179,974 US$ yearly operation cost. It should be noted the installation cost of the boiler is ignored in the calculation. Normally, the heat pump is the least expensive option to heat the pools from an operational cost standpoint of 32,910 US$ in addition, about 125,530 US$ as fully installed cost, that means, the total cost will be 158,440 US$ as clearly seen in table 7. A heat pump also requires very little maintenance throughout its lifetime. Once the unit is set up correctly, all that is required is ensuring the area around the unit is cleared from debris regularly with good airflow maintained. The heat pump is known for its long lifetime, and this is shown by our extensive 25-year warranty on the heat exchanger, and extended warranty on all parts. Next, the availability of solar energy makes solar heating systems a good option for outdoor swimming pools which an economic analysis showed that solar pool heating systems are highly cost compared to conventional systems using conventional fuel, which is around 846,273 US$. However, according to an analysis of solar and conventional heated pools, this option is exempted due to the large rooftop area of 3,050 m2 required. Even though the PV/HP systems have longer payback periods than available options [26]. It is worth pointing out the PV/HP systems take up significantly less roof space about 880 m2 to maintain the

Table 6: Sizing results for three pools cases

Family pool				
Item	Capacity	Unit	Price US$	Total area required
Solar water heater collectors (2m^2)	-	291 collectors	225,672	800 m^2
Heat Pump (HP)	150 kW	-	26,798	-
P.V system	37 kWp	-	32,440	230
Main Pool				
Solar water heater collectors (2m^2)	-	484 collectors	409,031	1,300 m^2
Heat Pump (HP)	2*115 kW	-	49,365	-
P.V system	65 kWp		55,007	400
SPA Pool				
Solar water heater collectors (2m^2)	-	357 collectors	30,1837	950 m^2
Heat Pump (HP)	2*115 kW	-	49,365	-
P.V system	45 kWp		38,082	260

Table 7: yearly heating cost for the current system and the initial cost of the alternative system

	Diesel		Heat pump		Solar water heater		Heat pump with PV	
	Initial cost	Operation cost (US$)	Initial cost (US$)	Operation cost (US$)	Initial cost (US$)	Area (m^2)	Initial cost (US$)	Area
(m^2)								
Family pool	0	46,301	27,798	8,467	225,670	800	59,240	230
Main pool	0	76,917	49,365	14,065	409,030	1,300	104,370	400
SPA pool	0	56,755	49,365	10,378	301,840	950	87,450	250
Total	0	179,974	125,530	32,910	936,540	3,050	251,060	880

thermal source of the same pool as displayed in figure 2 presents the roof area occupied by the three pool heating systems. The total cost of this option is cost around 239,777 US$ when the operation costs could be zero. This option for heat pump with PV offers extra 1000 m2 to be used for PV system with 186 kWp that can save about 45,134 US$ yearly. The big advantage of this system is the available roof space that would have had the photovoltaic system on it can now be generating electricity which can be used when the heat pump is not being used. Utilizing the space for the aesthetics of the site is needed, which is it possible to exploit areas within the site to install the largest possible number of photovoltaic panels. Therefore, the total area available is found to install the PV system about 2000 m2 rooftops. Based on the shape and design of the building, this design was proposed for the installation of panels to exploit all the space and the direction of the panels is suitable for the angle of the sunlight to be efficient and the results are as high as possible. Overall, despite the higher upfront costs of PV/HP pool heating systems in comparison to the other available systems, PV/HP system presents a better cost alternative, particularly for the facilities with limited roof space or with inevitable shadings on the roof. Further, such systems can achieve good economic values with reasonable payback periods.

CONCLUSION

This work studies an alternative heating source option of the hotel pools. Through this work, we first studied data obtained from the real heating source system of a hotel's pool. We trying to investigate the application of alternative options of the heating source systems which are solar collector pool heating system, heat pump and PV/HP system. The experiment is conducted in Jordan/Aqaba which has the greatest radiation on the horizontal plane of any Jordan governor. From the analysis, an initial design procedure was presented, and the energy source conversion was evaluated through the use of the PVsyst simulation tool. The results showed that the proposed systems can well satisfy the pools heating demands and it is found that the initial cost by applying a PV/HP is the cheapest and meet the available rooftop area of the hotel. The total cost of this system is 251,060 US$ and the payback period is less than two years when compared with diesel boiler system during the heating season, the result indicates that using PV/HP system for hotel's pools are beneficial both financially and environmentally. The focus of future studies on this area should be on improving system exergy efficiency through system configuration optimization and parametric analyses. A life cycle study of the system should also be in place to analyze the consequences on the environment.

REFERENCES

1. Zhao, J., Patwary, A.K., Qayyum, A., Alharthi, M., Bashir, F., Mohsin, M., Hanif, I., and Abbas, Q. (2022). The determinants of renewable energy sources for the fueling of green and sustainable economy. Energy 238, 122029.
2. Baz, K., Cheng, J., Xu, D., Abbas, K., Ali, I., Ali, H., and Fang, C. (2021). Asymmetric impact of fossil fuel and renewable energy consumption on economic growth: A nonlinear technique. Energy 226, 120357.
3. Silvio Alejandro Jiménez, V.C.M.A.A.B. (2015). Swimming pool heating systems: a review of applied models. Tecciencia 10, 17-26.
4. Yantong Li, N.N.G.H.X.L. Swimming pool heating technology: A state-of-the-art review. Building Simulation.
5. Li, Y., Nord, N., Huang, G., and Li, X. (2021). Swimming pool heating technology: A state-of-the-art review. Building Simulation 14, 421-440.
6. Katsaprakakis, D.A. (2015). Comparison of swimming pools alternative passive and active heating systems based on renewable energy sources in Southern Europe. Energy Energy 81, 738-753.
7. Ringstad, A. (2018). The science of solar energy.
8. Sandia National Laboratories, U.S.N.N.S.A.U.S.D.o.E.O.o.S., and Technical, I. (2010). Renewable Energy Overview.
9. Alrwashdeh, S.S., Alsaraireh, F.M., Saraireh, M.A., Markötter, H., Kardjilov, N., Klages, M., Scholta, J., and Manke, I. (2018). In-situ investigation of water distribution in polymer electrolyte membrane fuel cells using high-resolution neutron tomography with 6.5 µm pixel size. AIMS Energy 6, 607-614.
10. Göbel, M., Kirsch, S., Schwarze, L., Schmidt, L., Scholz, H., Haußmann, J., Klages, M., Scholta, J., Markötter, H., Alrwashdeh, S., et al. (2018). Transient limiting current measurements for characterization of gas diffusion layers. Journal of Power Sources 402, 237-245.
11. Alessandro, M., Aste, N., Claudio, D.P., and Fabrizio, L. (2021). Photovoltaic-thermal solar-assisted heat pump systems for building applications: Integration and design methods. Energy and Built Environment.
12. Simko, T., Luther, M.B., Li, H.X., and Horan, P. (2021). Applying Solar PV to Heat Pump and Storage Technologies in Australian Houses. 14, 5480.
13. Alrwashdeh, S.S. (2018). Investigation of the energy output from PV racks based on using different tracking systems in Amman-Jordan. International Journal of Mechanical Engineering and Technology 9, 687-694.

14. Al-Falahat, A.M. (2021). Examination of the Dynamic Behaviour of the Composite Hollow Shafts Subject to Unbalance. IJMERR International Journal of Mechanical Engineering and Robotics Research, 572-576.
15. Alrwashdeh, S.S. (2018). Modelling of operating conditions of conduction heat transfer mode using energy 2D simulation. Int. J. Online Eng. International Journal of Online Engineering 14, 200-207.
16. S. Alrwashdeh, S.M.A.F.A.S.M. (2018). Solar radiation map of Jordan governorates. IJET International Journal of Engineering & Technology 7, 1664.
17. Shah, M.M. (2012). Improved method for calculating evaporation from indoor water pools. ENB Energy & Buildings 49, 306-309.
18. Ruiz, E.M.n.P.J. (2010). Analysis of an open-air swimming pool solar heating system by using an experimentally validated TRNSYS model. SE Solar Energy 84, 116-123.
19. Buonomano A, D.L.G.F.R.D.V.L. (2015). Dynamic simulation and thermo-economic analysis of a PhotoVoltaic/Thermal collector heating system for an indoor-outdoor swimming pool. Energy Convers. Manage. Energy Conversion and Management 99, 176-192.
20. Lam, J.C.C.W.W. (2001). Life cycle energy cost analysis of heat pump application for hotel swimming pools. Energy conversion and management. 42, 1299-1306.
21. Singh, A.K.T.G.N.S.R.G.S.R.K. (2020). Active Heating of Outdoor Swimming Pool Water Using Different Solar Collector Systems. Journal of Solar Energy Engineering 142.
22. Chow, T.T.B.Y.F.K.F.L.Z. (2012). Analysis of a solar assisted heat pump system for indoor swimming pool water and space heating. Applied energy. 100, 309-317.
23. Dehghan, M.P.C.F.R.E.B.-J.R. (2021). A Review on Techno-Economic Assessment of Solar Water Heating Systems in the Middle East. Energies Energies 14, 4944.
24. company, M. (2021). heat pump of the highest quality and sophisticated inverter electronics. Volume 2021.
25. Ji, J., Pei, G., Chow, T.-t., Liu, K., He, H., Lu, J., and Han, C.J.S.e. (2008). Experimental study of photovoltaic solar assisted heat pump system. 82, 43-52.
26. Herrando, M.a.M.C.N. (2016). Hybrid PV and solar-thermal systems for domestic heat and power provision in the UK: Techno-economic considerations. Applied energy. 161, 512-532.

APPENDIX

Table 1A: The monthly heating consumption of the family pool

Month	Vaporization		Convection	Rad	Feedwater	Solar	Total (GJ)	Operation hours	Average KW
	Kg/h	GJ	GJ	GJ	GJ	GJ			
January	110	199	20	39	5	-12.45	250	514	93
February	155	254	9	17	7	-17.81	270	554	111
March	194	351	3	5	9	-36.33	332	681	124
October	223	404	-5	-10	10	-42.35	357	733	133
November	140	245	9	19	6	-19.92	260	533	100
December	92	167	18	39	4	-15.01	213	437	79

Table 2A: The monthly heating consumption of the main pool

Month	Vaporization		Convection	Rad	Feedwater	Solar	Total (GJ)	Operation hours	Average KW
	Kg/h	GJ	GJ	GJ	GJ	GJ			
January	183	331	33	64	9	-20.69	416	516	155
February	258	422	15	29	11	-29.59	448	556	185
March	233	584	4	8	15	-60.35	551	684	206
October	370	671	-8	-16	17	-70.35	593	736	221
November	232	407	16	31	11	-33.09	431	535	166
December	153	277	30	64	7	-24.94	535	438	132

Table 3A: The monthly heating consumption of the SPA pool

Month	Vaporization		Convection	Rad	Feedwater	Solar	Total (GJ)	Operation hours	Average KW
	Kg/h	GJ	GJ	GJ	GJ	GJ			
January	135	244	24	47	6	-15.24	307	514	114
February	191	312	11	21	8	-21.83	331	554	137
March	238	431	3	6	11	-44.53	407	681	152
October	273	495	-6	-12	13	-51.91	438	733	163
November	171	300	11	23	8	-24.42	318	533	123
December	113	204	22	47	5	-18.41	261	437	97

Table 4A: Energy unit prices of the present heating sources

Energy source	Unit Price US$	Unit
diesel	0.78	Litter
LPG	942	Ton
Electricity	0.310	kWh

Paper submitted: 16.10.2021.
Paper accepted: 07.12.2021.