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FEASIBILITY STUDY OF USING SOLAR THERMAL ENERGY FOR HEATING SWIMMING POOLS IN CENTRAL EUROPEAN CLIMATE (HUNGARY AS A CASE STUDY)

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Abstract: Heating swimming pools using electrical elements is costly and causes environmental impact by producing CO_2 emissions. While renewable energy, such as solar energy, proves a viable alternative source for swimming pool heating. This article aims to simulate various Solar Domestic Hot Water (SDHW) systems in cold climates like Central European countries to define the best system for swimming pool heating. Three different systems were compared: a solar heating system without auxiliary heating or heat exchanger (B6), with a heat exchanger (B6.1) and with a heat exchanger and an auxiliary heating source (B6.2). Also, five crucial variables were chosen, along with the variation of the other parameters using the response surface method (RSM). This system optimisation aims to define an optimal system with less financial expenditure. It was found that the best system is B6, represented by Experiment No 25, which indicates the Collector type: flat plate collector (FPC), pool depth: 1 m, pool temperature: 26 °C, pool covers, and windshield are actively operated. We used the T*SOL Valentine Software-2018 (kWh) to measure the solar contribution for each case. For each vector, our coded values range from [-1, +1]. The formula 2^k (2^5=32 experiments) defines the number of experiments, where k is a vector number. In addition, two more experiments were done to define second-degree non-linear coefficients with a pool depth (B) of 1.5 m and 28 °C pool temperature. These two additional experiments, however, had no impact on our results. Finally, the swimming pool heating systems suitable for this weather were compared. This experiment can help the locals to find the optimal swimming pool heating system for their pools.

Keywords: solar heating; pool heating; auxiliary heating; T*sol; R-script

1. Introduction

In cold climates (such as Budapest), approximately 15% of its consumed energy is for water heating. Moreover, these applications require less than 100 °C, easily achievable by renewable energy, for example, solar domestic water heating (SDWH) technology [1]. Conventional water heating systems using fossil fuels or electric heaters cause a greenhouse effect, high maintenance costs, and are expensive [2]. Hence, the future of solar water heating system technology is promising for its eco-friendly nature and renewable energy usage. Hence, by the end of 2018, Solar water heating collectors' total capacity was 482 GW (where the glazed type was 452 GW, and the rest 30 GW was unglazed type collector) worldwide [3]. Meanwhile, European countries such as Germany, Poland, Spain, Denmark, Italy, Austria, and Switzerland aggregate 27.1 GW [4]. According to the European Solar Thermal Industry Federation (ESTIF), Europe can save up to 5,600 tonnes of crude oil in 2020 by solar thermal energy [5]. By the end of 2050, the European Union will provide a solar thermal capacity of 1200 GW overall. The total solar collector area is 200,000 m^2, whereas there are 19 million m^2 glazed collectors in Europe. A solar collector area of 1000 m^2 can save up to 170 tons of CO_2

emissions, have a natural gas savings of 85000 m3, and have a return on investment (ROI) period of fewer than three years [6].

SDWH can be divided into two parts such as design and operation. The collectors can be designed in many ways. Flat plate collectors (FPC) and Evacuated tube collectors (ETC) are two primary types of solar collectors. The Temperature can reach up to 65 °C, and efficiency can be achieved at 80% in Evacuated tube collectors [7]. However, this varies from meteorological, design, and load profile situations. The temperature variation can freeze water inside the flow channel at night and burst it for its volumetric expansion. So, in this system, 30% Glycol is mixed with water to prevent it from freezing.

It should be noted that evaporation causes the highest energy losses, which can be prevented partially if the cover is adequately used [8]. In this experiment, windshields are also considered to prevent heat loss [9]. In SDWH, energy is converted to thermal energy by solar radiation inside a solar collector. Sometimes, a conventional gas-fired boiler (an electric heater can also be used) is called an auxiliary heater. The auxiliary heater is connected to the heat exchanger, located in the highest part of the storage tank, where solar energy is insufficient [10]. An insulating layer is needed to reduce heat losses in the tank. Solar fraction is the ratio of solar energy sent to the standby tank to the total energy sent to the tank from the solar system and auxiliary heating [11]. Solar or system efficiency is the ratio of energy provided to energy irradiated onto the collector array's active solar surface. The coverage ratio defines how long we get the desired Temperature in a day [12,13].

There was no actual study on using solar thermal energy in central Europe in the literature. Also, the approach using RSM and linear modelling is still missing from the database. The utilisation of solar thermal energy is getting bigger and bigger every day, especially in central Europe in Austria, for example, which is considered the best country to produce solar thermal energy per 1000 capita in 2020 globally. This motivates researchers from other central European countries to investigate the potential of using solar thermal energy for domestic, industrial, and other functions

2. Experimental concepts

The swimming pool in Gödöllő, Hungary, is the actual case swimming pool, and the data are validated through the swimming pool owner. Some fixed parameters have been considered for this experiment, as in Table 1.

Table 1. Main system parameters

Metrological Location	Budapest Ferihegy
Collector area	6 m^2 (1 x 6)
Pool area	33.5 x 11.5 m^2
Solar Collector Inclination	24 °
Pool cover	90%
Cover type	Bubble sheet type
Cover time	7pm - 7am
Working days	15th May - 15th September
Glycol	30%
Daily freshwater requirements	50 l
volume flow rate	40 l/h/m^2 (per collector)
Annual irradiation on each collector	1370.9 kWh/m^2

The B6 system is a swimming pool without auxiliary heating or HX (Heat exchanger). Solar collectors convert direct solar energy to heat energy, mainly heating the domestic water and swimming pool. There are a few types of solar collectors. This article used only Flat plate and Evacuated tube type collectors, as shown in Figure 1. The variables are collector type, pool depth, pool temperature, cover, and windshield. Our desired pool temperature is 26 °C or above, and the pool depth must be 1 m or more as listed in Table 2.

Figure 1. Actual pictures of the studied case

Table 2. Case study variables

Variables		Values	Denoted by
Collector type	Flat Plate Collector (FPC)	Negative	A
	Evacuated Tube Collector (ETC)	Positive	
Pool depth	1 m	Negative	B
	2 m	Positive	
Pool temperature	26 °C	Negative	C
	30 °C	Positive	
Cover	Without Cover	Negative	D
	With Cover	Positive	
Windshield	Without windshield	Negative	E
	With windshield	Positive	

The schematics of the three analysed systems can be seen in Figure 2.

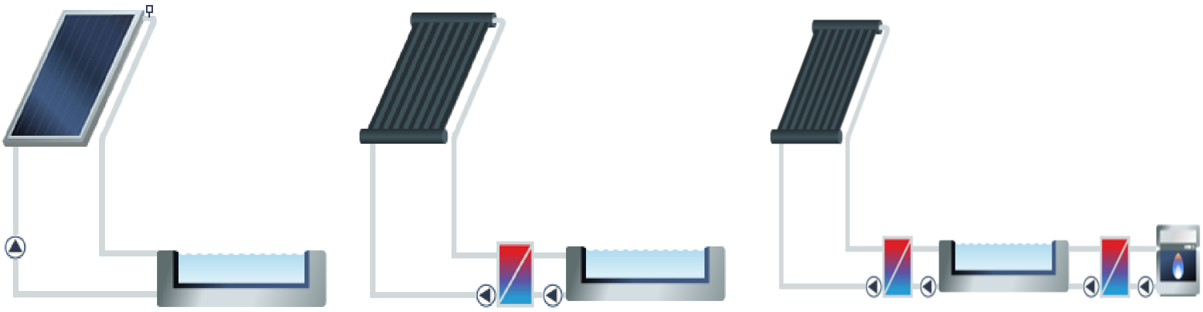

Figure 2. (a) No HX or auxiliary heater, (b) With HX, no auxiliary heater, and (c) With HX and auxiliary heater.

The simulation was conducted using T*SOL software to get the solar contribution ratio which refers to how much solar energy (in kWh) has been contributed to heat our swimming pool. In contrast, linear modelling was conducted using R scripts software using coded values for defining optimal values using the response surface method (RSM). The least-squares approach is used in the programming phase to provide a general rationale for the line's best match position among the data points under consideration.

3. Results and Discussion

Solar contribution refers to how much solar energy (in kWh) has contributed to heating our swimming pool water. From the Figure 3 Pareto plot chart, it is seen that factor A (collector type) has the most significant positive impact, with around 90 kWh annual magnitude. Since A is positive, we get 90 kWh annual magnitude as extra while using ETC. Therefore, we will choose an Evacuated Tube type solar collector instead of a flat plate collector. The following two highest single factors are E and D, having 40 kWh and 30 kWh annual magnitude, respectively. However, these factors are negative; hence choosing the windshield and cover off gives us an additional solar energy contribution of 40 kWh and 30 kWh annually. Apart from single factors, two interacting factors are AE and AD, with a positive magnitude of 10 and 8 kWh annually. The third double factor is DE, with an annual negative magnitude of 5 kWh. From Figure 3 also, it is clearly shown that single Factor C has the highest negative impact of 4.75 (%) magnitude. If we choose 26 °C, we have a higher magnitude. The following two single factors are E and D, with a positive magnitude of 3.9 (%) and 2.8 (%) magnitude. Since they are positive, we will choose the windshield and cover. Besides, the first three highest two interacting factors are CE, CD, and DE, where CE and CD are negatives and DE is positive.

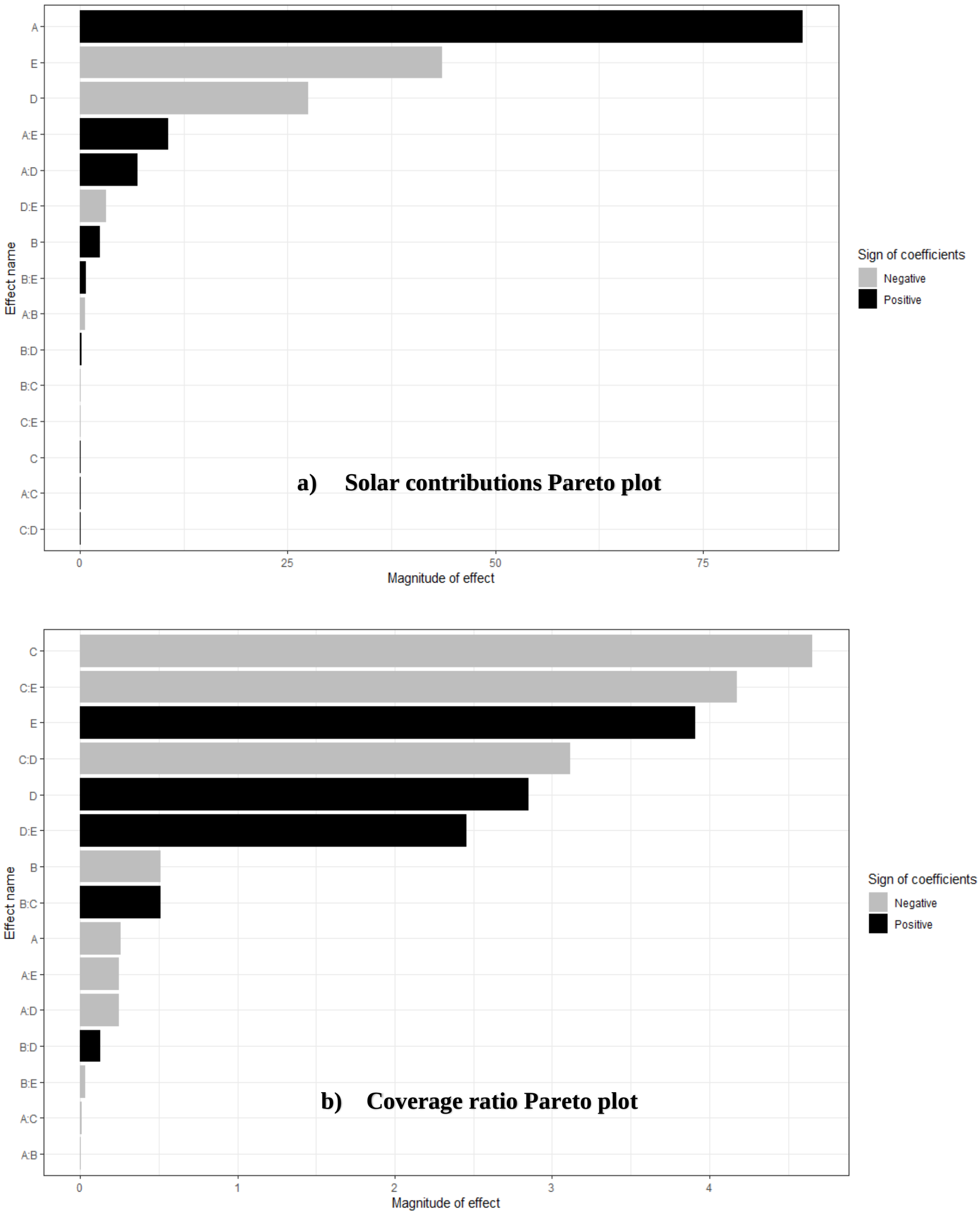

Figure 3. Pareto plot of a) solar contribution and b) coverage ratio

The two factors' interactions are illustrated in Figure 4: AE: we see that for the best efficiency, E is negative, and A is positive. That means the windshield should be off, and an Evacuated Tube collector should be used. AD: if D is negative and A is positive, we get the maximum solar contribution. So, the cover should be off, and we should use an evacuated Tube collector. DE: the system efficiency increases if both factors are negative individually. Both cover and windshield should be off for the highest solar contribution. After considering the solar contribution requirement, coverage ratio and financial perspective, we will choose to experiment no 25 (Collector type: FPC, Pool depth: 1m, Pool temperature: 26 °c, with cover and windshield, are active) for Budapest in the B6 swimming pool heating system as in Table 3.

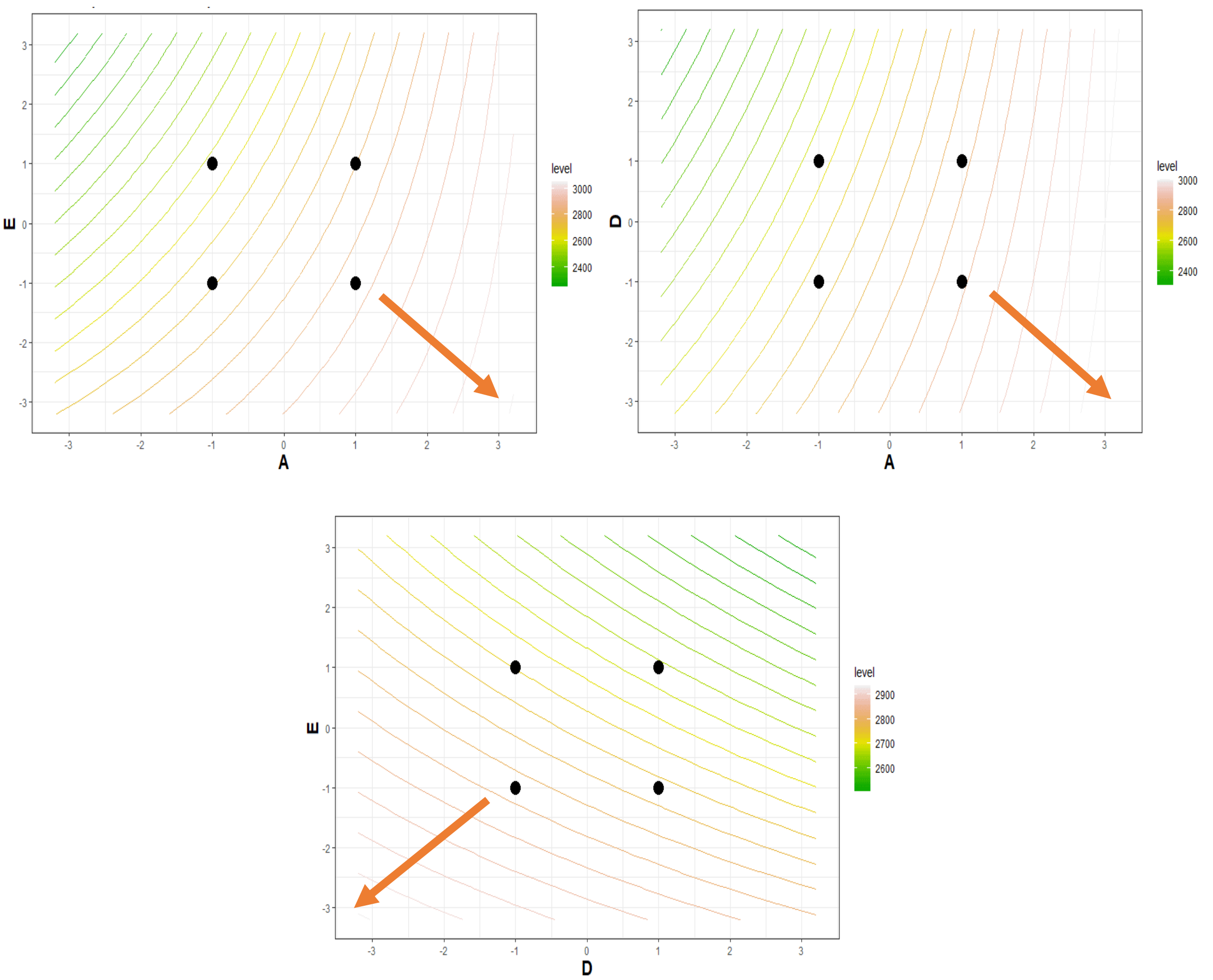

Figure 4. Two factors interaction

4. Conclusions

We used TSOL Valentine Software-2018 and collaborated with MeteoSyn to get the solar contribution (kWh) and coverage ratio (%). For modelling purposes, we used an R-script program where we considered the top five impacting variables: collector type, pool depth, pool temperature, cover, and windshield. Our coded values vary between [-1, +1] for each variable. The number of experiments is determined by the formula 2^k, where k is a variable number. As each variable has two values [-1, +1], the total experiment number was $2^5 = 32$. In addition to these 32 experiments, we conducted two more experiments considering that pool depth (B) is 1.5 m to identify second-degree non-linear coefficients. So, the total number of experiments was 34. However, these two experiments did not affect our measurement as the heating system with auxiliary heating or heat exchanger is costlier, and the solar contribution among them is insignificant. We compare the heating system without a heat exchanger or external heating source (B6). After considering the solar contribution, coverage ratio, pool temperature and financial aspect, we have chosen the best systems in swimming pool heating for Budapest. The best system indicates that the collector type is FPC, pool depth is 1 meter, pool temperature is 26 °C, and has a windshield and cover during closing time. As the government tries to reduce carbon emissions and search for an alternative energy source, this solar heating system can be used widely in central European countries.

Table 3. Optimisation results

	Collector type	SP Dimension	Pool temp	Cover	Windshield	y 1	y 2	y 3
No	[FPC, ETC]	[1,1.5,2]	[26,28,30]	[No, Yes]	[No, Yes]	Solar contribution [kWh]	Coverage ratio%	Ava Pool Temp
1	FPC	1	26	No	No	2740	33.3	20.19
2	ETC	1	26	No	No	2881	35	20.18
3	FPC	2	26	No	No	2744	33.4	20.27
4	ETC	2	26	No	No	**2884**	**35.1**	20.27
5	FPC	1	30	No	No	2740	33.3	20.19
6	ETC	1	30	No	No	2881	35	20.18
7	FPC	2	30	No	No	2744	33.4	20.27
8	ETC	2	30	No	No	**2884**	**35.1**	20.27
9	FPC	1	26	Yes	No	2679	32.6	21.6
10	ETC	1	26	Yes	No	2844	34.6	21.59
11	FPC	2	26	Yes	No	2683	32.6	21.71
12	ETC	2	26	Yes	No	2847	34.6	21.7
13	FPC	1	30	Yes	No	2679	32.6	21.6
14	ETC	1	30	Yes	No	2845	34.6	21.59
15	FPC	2	30	Yes	No	2683	32.6	21.71
16	ETC	2	30	Yes	No	2847	34.6	21.7
17	FPC	1	26	No	Yes	2638	32.1	22.57
18	ETC	1	26	No	Yes	2819	34.3	22.56
19	FPC	2	26	No	Yes	2645	32.2	22.66
20	ETC	2	26	No	Yes	2823	34.3	22.65
21	FPC	1	30	No	Yes	2638	32.1	22.57
22	ETC	1	30	No	Yes	2819	34.3	22.56
23	FPC	2	30	No	Yes	2645	32.2	22.66
24	ETC	2	30	No	Yes	2823	34.3	22.65
25	FPC	1	26	Yes	Yes	2550	31.1	24.42
26	ETC	1	26	Yes	Yes	2773	33.7	24.41
27	FPC	2	26	Yes	Yes	2569	31.2	**24.49**
28	ETC	2	26	Yes	Yes	2778	33.8	**24.49**
29	FPC	1	30	Yes	Yes	2560	31.1	24.42
30	ETC	1	30	Yes	Yes	2773	33.7	24.41
31	FPC	2	30	Yes	Yes	2569	31.2	**24.49**
32	ETC	2	30	Yes	Yes	2778	33.8	**24.49**
33	FPC	1.5	28	No	No	2742	33.3	20.24
34	ETC	1.5	28	Yes	Yes	2775	33.7	**24.49**

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