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SPACE COOLING WITH GROUNDWATER PUMPED BY A SOLAR DRIVEN PUMP

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Highlights

- The cooling of a space with a solar PV pumping system integrated well water supplied fan coil was studied.
- CPEP showed that the possibility of a space with well water is possible.
- The cooling performance of solar water pump fan coil couple is dependent on the flow rate of well water.

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ABSTRACT: In this study, it was experimentally investigated that the groundwater of a well is brought to the surface using solar energy, which is one of the renewable energy sources, and the cooling of a place with this water with low energy density. The study evaluated cooling performance on two different days (Exp. 1 and Exp. 2) and at two different cooling water flow rates. The efficiency of the PV system was found to be 8.33±0.44% in Exp. 1 and 8.3±0.44% in Exp. 2. The cooling loads of the cooled buildings differ in Exp. 1 and Exp. 2 due to ambient conditions. The cooling load in Exp. 1 was determined to be 572±22.8 W and in Exp. 2 about 828±33.1 W. The heat loads extracted from the building by the groundwater used as a cooling fluid are 410±16.4 W and 786±31.4 W for Exp. 1 and Exp. 2. The cooling performance evaluation criteria (CPEP) value was found to be 0.72 for Exp. 1 and 0.95 for Exp. 2. Although there was a significant difference between the cooling loads for Exp. 1 and Exp. 2, the cooling load coverage increased with the increase in cooling water flow rate according to the CPEP values. Although in both experiments the cooling load was not fully met and the temperature inside the structure rose slightly during the experiment, it was kept cool.

Keywords: *Solar water pumping, Space cooling, Cooling performance, Efficiency*

1. INTRODUCTION

The rapid depletion of energy resources in the face of increasing consumption, the difficulty of accessing them, and rising costs are drawing attention to renewable energy resources in all aspects of life. 70% of the world's energy is consumed as thermal energy, and in parallel, the cost of energy is continuously increasing [1]. Pumps are widely used to meet water needs for industrial processes, irrigation and drinking water. They are mainly powered by electricity from fossil sources [2]. The idea of integrating PV solar systems with water pumps has been taken up by many researchers worldwide [3]. In India, 0.1 million solar photovoltaic water pumps were in operation for irrigation and drinking water supply between 2014 and 2015, and the government's goal is to reach 1 million by the end of 2021 [4]. Kumar et al. investigated the use of a buck converter in a PV system to pump water. Results proved a suitable combination for solar PV-based water pumping [5]. Speidel attempted to design and build a water pumping system based on solar energy. Solar based pumping system is evaluated as economical and practical feasible [6]. Chinthamalla et al. presented a single-stage solution for a PV-fed three-phase induction motor-driven water pumping system. They concluded that the proposed system provides better performance of the PV source and the induction motor [7]. Bataineh studied the performance of a solar thermal system for driving irrigation pumps. They claim that the optimal efficiency of the pump in May is 14%, in July it is 18%[8]. Foster and Cota discussed that photovoltaic water pumping systems are expected to grow tremendously due to decreasing costs and high reliability and will allow a greater number of farmers and ranchers to take advantage of this low-cost technology [9]. Saini et al. suggested solar energy as the most efficient and economical method for driving a centrifugal pump [10]. Yousuf et al. intend to develop a three-phase induction motor control for a solar-powered water pump. The experimental results met the requirements, as we were able to operate a water pump with a three-phase asynchronous motor with optimal cost efficiency [11]. Renu et al. studied the energy performance of

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solar-powered water pumps. They argued that the AC power pumps have an energy efficiency of more than 28% [12]. Ramazan studied the technical feasibility of a photovoltaic water pumping system. He claims that pumping 50 m^3 of water requires about 5.6 kWp of PV capacity [13]. Hammad studied PV modules with integrated water pumping system equipped with technical capacity. He said that the efficiency of PV systems and pumps on a monthly average is about 4% and 20%, respectively [14]. Daud and Mahmoud studied the energetic performance of a solar-powered water pump operating at a desert well. They concluded that the overall efficiency of the solar water pump is above 3% [15]. Meah et al. discussed the advantages of small-scale remote water pumping: no fuel, low maintenance costs, and a zero-emission process [16]. Meah et al. have investigated the possibilities of solar water pumping systems from a technical and economic point of view. They argued that solar water pumping systems can be economically viable compared to diesel generator water pumps [17]. Chandel et al. have studied the economic and technological benefits of solar water pumping systems. The payback period of the investment in a solar water pump system is estimated at 4-6 years [18]. Hassanien et al. have studied solar energy technologies and their control. They have found that solar energy can be used in an environmentally friendly and cost-effective way to irrigate agricultural fields around the world [19]. Sontake and Kalamkar attempted the review the types of solar water pumping systems and their development period in years. They argued that solar water pumping systems can be a good alternative to meet drinking and irrigation water needs [20]. Arghand et al. experimentally studied direct groundwater cooling of a room with fan coil application. They concluded that the change in groundwater temperature of about 2.2 °C provides more than 3 °C cooling opportunities for space [21]. Zhao et al. proposed to determine the thermal performance of a fan coil unit for cooling an indoor space with cold chilled water. They argued that the heating of the inlet water by 5 °C causes the cooling of the fresh air supply by 4 °C [22]. Solar energy, which is mainly used for heating, is also used for cooling, given the increase in energy costs in recent years [23].

In this study, the cooling of a building by the circulation of groundwater obtained by a pump driven by the electrical energy generated by the PV system through the fan coil was experimentally investigated. Storage of heated water after air conditioning for use and as irrigation water was also evaluated.

Governing equations:

The total efficiency (η_{pv}) of the PV module can be calculated with Eq. (1) [24].

$$\eta_{pv} = \frac{E_p}{G.A_{PV}} = \frac{VI}{GA_{PV}} \tag{1}$$

(A) is the PV area exposed to solar radiation, (V) is the voltage, and (I) is the current output of the PV array. (E_p) is the electrical power output of the PV array. The efficiency of the motor-pump pair of the control unit is denoted as (η_{mp-cu}) and can be determined by Eq. (2).

$$\eta_{mp-cu} = \frac{P_h}{E_p} = \frac{\rho_w x g x \dot{v} x H}{VI} \tag{2}$$

In Eq. (2), (P_h) is the hydraulic power, (ρ_w) is the density of liquid water, (g) is the gravitational acceleration, ($\dot{v}$) is the volumetric flow rate, (H) is the hydraulic head [18], [25]. Pumped groundwater flows through the fan coil unit and is directed into the cooled space. The heat transfer rate between the water and air sides is approximately the same and can be equated as in Eq. (3) [26].

$$\dot{Q}_w \cong \dot{Q}_a \tag{3}$$

In Eq. (4), ($\dot{Q}_w$) and ($\dot{Q}_a$) denote the rate of heat transfer from the air and to the water.

$$\dot{Q}_w = \dot{m}_w c_w (T_{wo} - T_{wi}) \tag{4}$$

($\dot{m}_w$) is the mass flow rate of water, (c_w) is the specific heat of water, (T_{wi}) and (T_{wo}) are the inlet and outlet temperatures of water.

$$\dot{Q}_a = \dot{m}_a c_{pa}(T_{ai} - T_{ao}) \quad (5)$$

($\dot{m}_a$) is the mass flow rate of air, (c_{pa}) is the specific heat of air, (T_{ai}) and (T_{ao}) are the inlet and outlet temperatures of air. The average heat exchange between the water and air can be equated with Eq. (6).

$$\dot{Q}_{avg} = \frac{\dot{Q}_w + \dot{Q}_a}{2} \quad (6)$$

The total heat transfer coefficient (U) of the process can be calculated with Eq.(7) [27].

$$U = \frac{\dot{Q}_{avg}}{A_{fc} F \Delta T_{LMTD}} \quad (7)$$

(A_{fc}) is the heat transfer area, (F) is the temperature correction factor, (ΔT_{LMTD}) is the log mean temperature difference and equated is as in Eq. (8) [28].

Where;

$$\Delta T_{LMTD} = \frac{\Delta T_1 - \Delta T_2}{\ln \frac{\Delta T_1}{\Delta T_2}} \quad (8)$$

Cooling load estimation

When calculating the cooling load of the house ($\dot{Q}_{CL}$), internal ($\dot{Q}_i$) and external ($\dot{Q}_e$) heat loads were determined separately. The internal loads are calculated by considering the lighting ($\dot{Q}_l$) and electrical ($\dot{Q}_a$) appliances. External loads are solar ($\dot{Q}_s$), conduction ($\dot{Q}_c$) heat transfer from walls, doors, glasses, and infiltration from doors and glasses. The cooling load was determined by Eq. (9).

$$\dot{Q}_{CL} = \dot{Q}_i + \dot{Q}_e \quad (9)$$

The heat load caused by lighting can be determined by Eq. (10) [29].

$$\dot{Q}_l = P_l k_u k_s CLF \quad (10)$$

Where P_l is the lightning wattage, k_u and k_s are the usage and ballast factors, CLF is the cooling load factor. The heat load from electrical appliances can be calculated using Eq. (11) [30].

$$\dot{Q}_a = 0.293\, P_a k_a CLF \quad (11)$$

In Eq. (11), P_a and k_a are the manufacturer input rating and the load factor, respectively. 0.293 is the unit conversion factor from Btu/h to W. The solar heat load from glasses can be calculated by Eq. (12) [31].

$$\dot{Q}_s = 0.293\, A\, SC\, SCL \quad (12)$$

Where A is solar imposed glass area, SC is the shading coefficient, SCL is the solar cooling load factor. The conduction heat load on the surfaces of the test structure can be determined using the general relationship in Eq. (13) [32].

$$\dot{Q}_c = 0.293\, U\, A_w\, CLTD \quad (13)$$

In Eq. (13), U is the coefficient of transmission, A_w is the wall cross sectional area, $CLTD$ is the cooling load temperature difference. Infiltration heat load can be defined by Eq. (14) [33]–[35].

$$\dot{Q}_{inf} = ACF \rho_a V c_{pa} \Delta T \quad (14)$$

In Eq. (14), ACF is the air change factor, ρ_a and c_{pa} are leakage air density and specific heat, V is the space volume, ΔT is the inner and outer temperature difference. Cooling performance evaluation criteria ($CPEP$) is defined as in Eq. (15).

$$CPEP = \frac{\dot{Q}_{avg}}{\dot{Q}_{CL}} \quad (15)$$

The error rate of the study can be evaluated with Eq. (16).

$$w_R = \left[\left(\frac{\partial R}{\partial x_1} w_1\right)^2 + \left(\frac{\partial R}{\partial x_2} w_2\right)^2 + \cdots + \left(\frac{\partial R}{\partial x_n} w_n\right)^2\right]^{\frac{1}{2}} \quad (16)$$

In Eq. (16), w_R denotes the uncertainty of the calculated result, and the w_n values are the uncertainty of each measured independent parameter [36].

2. EXPERIMENTATION SETUP DESCRIPTION

The experiments were conducted in a one-story building with two rooms and four windows on the campus of Karabuk University on two different sunny days, July 26, and August 2, 2019. The experiments conducted on these dates are defined as Exp. 1 and Exp. 2, respectively. The solar radiation values and ambient temperature for Exp.1 and Exp.2 are shown in Figure 1.

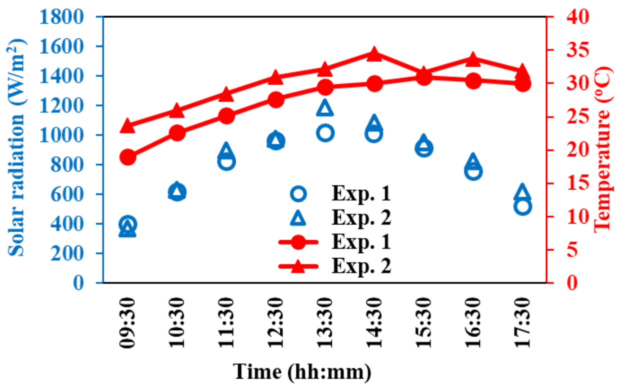
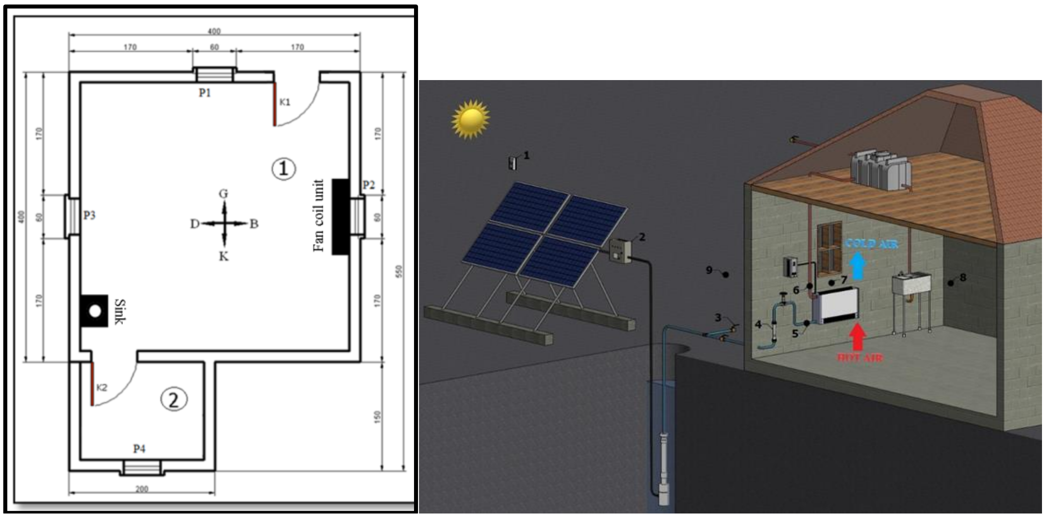


Figure 1. Solar radiation values for two different flow rate experiences

As seen in Figure 1, solar radiation tended to increase until 14:30 and ambient temperature until 13:30 in both experiments. In Exp. 1, the solar radiation and ambient temperature values at 9:30 were 399±20 W/m² and 19±0.08 °C, respectively, and by 13:30 they reached 1018 ±41 W/m² and 29.5±0.12 °C. By 17:30, solar radiation had decreased to 525±26.5 W/m², while ambient temperature increased slightly, reaching up to 30±0.12 °C. In Exp. 2, the solar radiation was 373±18.6 W/m² and the temperature at 09:30 was 23.7±0.1 °C. By 13:30, solar radiation and temperature increased to 1191±56 W/m² and 32.2±0.13 °C. At 17:30, solar radiation and ambient temperature reached 618±31 W/m² and 31.9±0.13 °C, respectively. The average values of solar radiation and ambient temperature were 782±39 W/m² and 27±0.1 °C for Exp.

1 and 839±42 W/m² and 30±0.12 °C for Exp. 2. The daily relative humidity and wind speed values for Exp. 1 and Exp. 2 are 68%, 66%, and 0.08±0.003 m/s and 0.12±0.005 m/s, respectively. The construction plan of the building, the experimental measuring points and the arrangement of the devices are shown in Figure 2 (a, b).



(a) (b)

Figure 2 (a, b). Cooling experiment structure

DC voltage obtained from four PV panels, each with a power of 200 W, integrated into the experimental setup, is fed to the Lorentz brand PS1200 model solar pump control unit. The power of the PV modules arranged in the control unit of the model PS1200 was fed into the submersible pump, and the water extracted from the 10 m deep water well was directed to the existing fan coil unit of the building where the experiments were carried out. In the experiments, it was aimed to cool the building by absorbing the ambient heat into the cool groundwater passing over the fan coil, and both the experimental setup and the flow arrangement were prepared in this way. In Exp. 1 and Exp. 2, water circulation was carried out in the fan coil unit with a flow rate of 0.3±0.008 m³/h and 0.7±0.018 m³/h, respectively. The flow pattern of the experimental setup is shown in Figure 3.

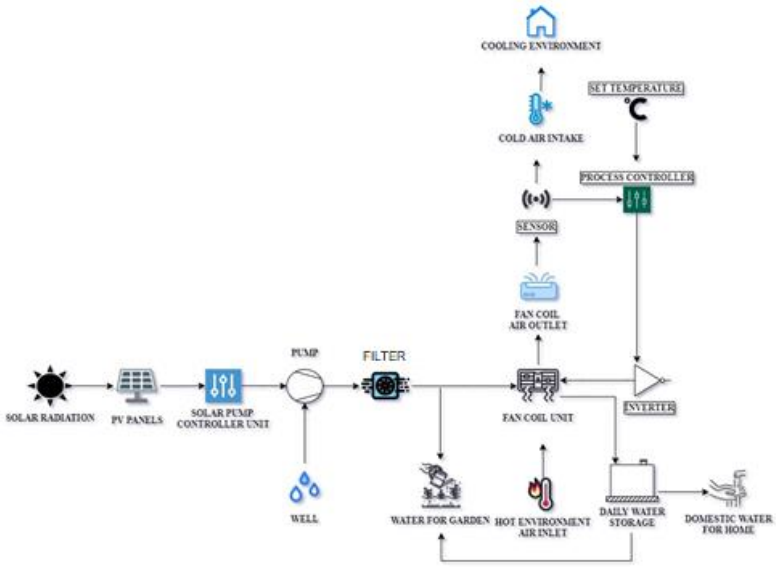


Figure 3. Flow configuration of experimentation setup

The technical data of the PV panels driving the pumps are listed in Table 1.

Table 1. PV panel specifications

Peak Power	200 W
Peak Power Voltage	27,5 V
Peak Power Current	7,28 A
Modul Efficiency	%13,6
PV STC: AM = 1.5, I =1000 W/m^2, T_h = 25 °C	

The measurement equipment for the experimental setup, the specifications and uncertainties, and the descriptions of the measurement points are listed in Table 2.

Table 2. Measurement points and instruments specification

Measurement Point	Measured value	Name of the device	Device properties	Uncertainty
1	Solar radiation	TESS 133 Solar meter	Irradiance range: 0-2000 W/m²,	5%
5,6,7	Temperature	88598 4 channel K thermometer SD card data logger	−200 to 1370 °C, ± (0.3% rdg + 1 °C)	0.42%
9	Temperature	CEM DT-3891G 4 channel data logger	-200ºC to 1372ºC, (0.15% rdg+1ºC)	0.37%
8	Temperature	Process control equipment	Brand: ORDEL Model: PC440; 4 W, 100–240 VAC, auto-tuning, PID control.	0.2%
2	DC Voltage and current	Digital wattmeter	Working voltage: 6.5-100V DC Voltage test range: 6.5-100V DC, Rated power: 20A / 2000W	V~1.06% A~5%
2	AC Current	Clamp meter	Model: Tt-Technic Model: DT-266C 1000A AC 20 - 1000A	3.01%
2	AC Voltage	Multimeter	Brand: UNI-T Model: UT33C; AC Voltage: 200V/500V	4.53%
3, 4	Volumetric flow rate	Flow meter	Model: LZS-15 Type: Long tube Pressure: ≤1Mpa Temperature: 0~60 °C.	4%
7	Air Flow Velocity	Testo 435, anemometer, Vane probe, Ø 16 mm, with telescopic handle max. 720 mm	Measurement range 0.6-40 m/s, operation temperature 0-60 °C	0.5%

In this study, part of the water coming from the pump was directed to the fan coil, while the remaining part was stored for domestic use.

3. RESULTS AND DISCUSSIONS

In this study, the cooling of the space by circulating groundwater brought to the surface by a solar-powered submersible pump fed by PV modules from a fan coil unit positioned in a structure was experimentally examined. The cooling load of the building and the cooling performance of the process were evaluated. The calculated solar energy values based on solar radiation for Exp. 1 and Exp. 2 are shown in Figure 4.

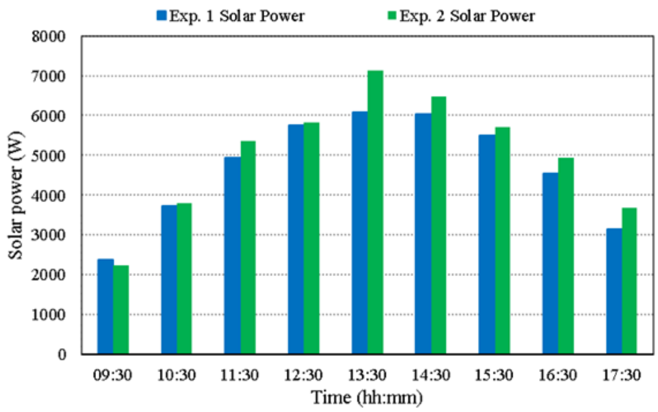


Figure 4. Solar power

The solar energy applied to the PV modules was determined as 2384±178 W and 2229±167 W for Exp. 1 and Exp. 2, respectively, at 9:30, as seen in Figure 4. The maximum solar power values were found to be 6083±456 W for Exp. 1 and 7117±533 W for Exp. 2, respectively. The average solar energy values for Exp. 1 and Exp. 2 are 4675±350 and 5014.33±376 W, respectively. The air flow rate of fan coil unit controlled as a function of indoor temperature are shown in Figure 5.

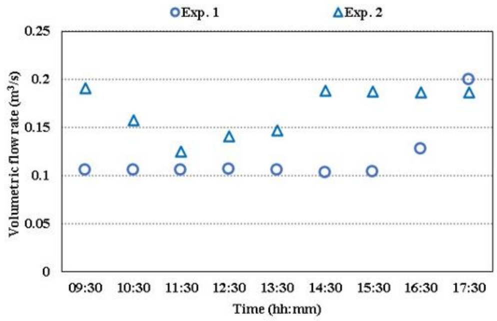


Figure 5. Fan coil fan air flow rate

Figure 5 shows the average values of the time-dependent fan coil air flows for Exp. 1 and Exp. 2 as 0.12±0.003 m^3/s and 0.17±0.004 m^3/s, respectively. The PV panel and pump hydraulic power values are shown in Figure 6 for Exp. 1 and Exp. 2. Also shown are the PV efficiency and the pump control pair efficiency.

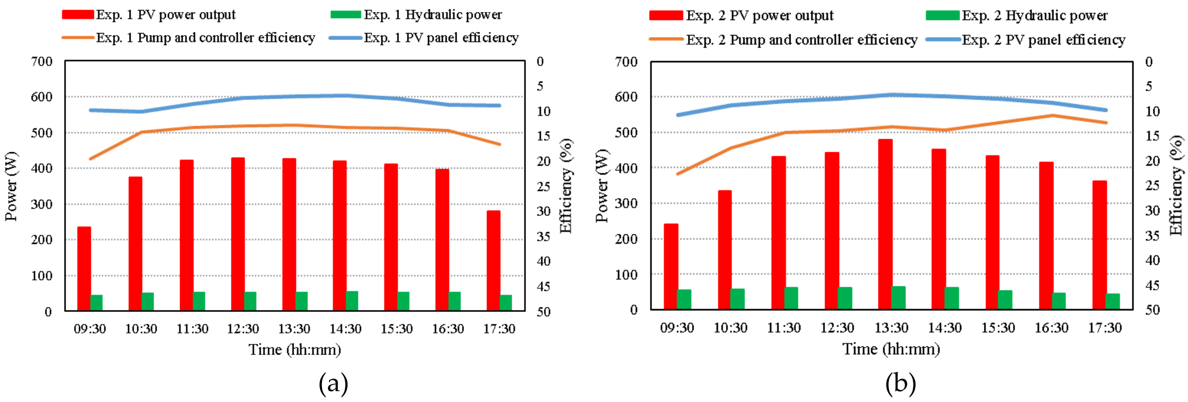
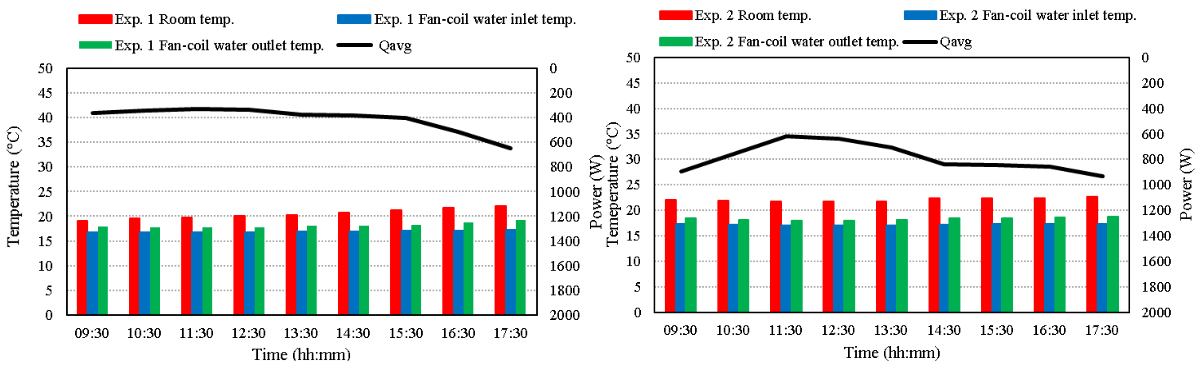


Figure 6. PV electrical power, pump hydraulic power, PV efficiency, and pump controller pair efficiency, (a) for Exp. 1, and (b) for Exp. 2

As can be seen in Figure 6, the average electrical output power of the PV system is 376± 20.3 W, and the hydraulic output power of the pump is 53±2.8 W on average for Exp.1. In Exp. 2, the average PV output power is 398±21.5 W, and the hydraulic power is 56±3 W. The efficiency of the PV system and the pump control pair were determined to be approximately 8.33±0.44% and 14.46±0.78%, respectively, for Exp. 1. For Exp. 2, these values are 8.3±0.44% and 14.55±0.78%, respectively. The decrease in PV efficiency observed in Exp. 2 can be explained by the increasing temperature of the PV cells with increasing irradiance. Khatip reported in his comparative study of solar pump systems that the energy efficiency of a solar submersible pump is in the 10-20% range [37]. The building internal temperature, the fan coil water inlet and outlet temperatures, and the heat load values transferred from the air to the water are shown in Figure 7(a, b).



(a) (b)

Figure 7. Cooling space temperature, fan coil water inlet, outlet temperatures, and heat loaded from space air to water (a) for Exp. 1, (b) for Exp. 2

Looking at the bar graphs in Figure 7, we see that the indoor temperature of the building is about 20±0.08 °C and 22±0.09 °C in Exp. 1 and Exp. 2, respectively. Since the experimental studies were conducted on two different days, the cooling load of the building increased due to the increased radiation and was higher in Exp. 2. This could explain the temperature difference of 2±0.008 °C between the average building interior temperatures in the two experiments. The average water inlet and outlet temperatures of the fan coil unit are 16.9±0.06 °C and 18.2±0.07 °C for Exp.1. For Exp. 2, the water inlet temperature of the fan coil unit was measured as 17.2±0.07 °C and the outlet temperature as 18.3±0.07 °C. It was found that the water passing through the fan coil is cooler than the ambient air passing through the fan coil, so it extracts some heat from the ambient air and cools the ambient air as it leaves the fan coil. In Figure 2, the average temperature change of the water flowing through the fan coil was found to be about 2.3±0.009 °C for Exp. 1 and 1.1±0.004 °C for Exp. 2. Compared to Exp. 1, the decrease in temperature difference in Exp. 2 can be explained by the increase in the amount of fluid passing through the fan coil per unit time. A significant increase in the heat load transferred to the water was observed with the increase in flow rate. The heat load transferred to the water was determined to be 410±16.4 W for Exp. 1 and 786±31.4 W for Exp. 2. The building heat load, the heat load dissipated by water from inside the building, and the CPEP are calculated and shown in Figure 8.

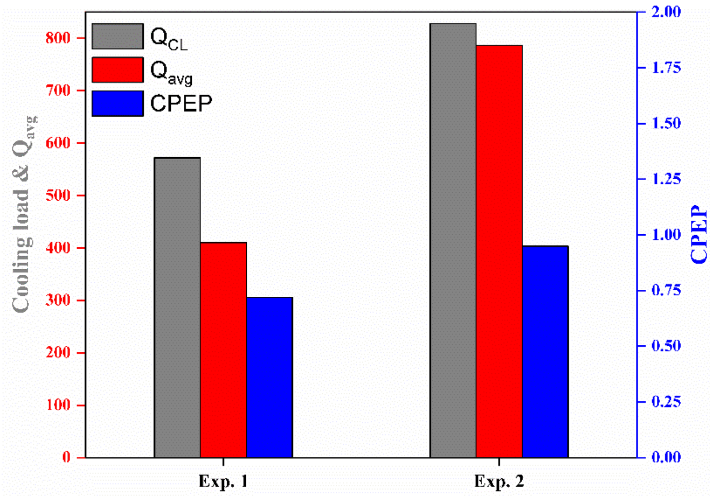


Figure 8. Cooling load, cooling heat rate, and CPEP

According to Figure 8, the heat load values, which are the sum of the internal and external heat loads of the building, were calculated to be 572±22.8 W and 828±33.1 W for Exp. 1 and Exp. 2, respectively. For Exp. 1 and Exp. 2, it was shown that 410±16.4 W and 786±31.4 W of heat can be removed from the building interior by dissipation in the groundwater in the fan coil. CPEP values were determined to be 0.72 for Exp. 1 and 0.95 for Exp. 2. It was found that the cooling capacity obtained in Exp. 2 increased with increasing cooling water flow rate. This study investigated the success of using a solar-powered pump to raise groundwater to the surface and cool a building. Although the cooling load of the building could not be fully absorbed by the groundwater in the fan coil unit and the internal temperature of the building increased slightly during the tests, coolness was achieved inside the building.

4. CONCLUSIONS

The subject of this study is the cooling of an example building with groundwater extracted from the well by a submersible pump powered by a PV module. The work is characterised by its environmentally friendly and energy-saving potential. The study was conducted experimentally with two different groundwater flow rates on two different days. A flow rate of 0.3±0.008 m^3/h was used in Exp. 1 and a flow rate of 0.7±0.018 m^3/h in Exp. 2. PV panel efficiency was determined to be 8.33±0.44% for Exp. 1 and 8.3±0.44% for Exp. 2. In Exp. 1, the building is under the influence of a heat load of 572±22.8 W, while in Exp. 2 this load is 828±33.1 W. A heat load of 410±16.4 W in Exp. 1 and 786±31.4 W in Exp. 2 was transferred from the interior environment of the building to the groundwater circulating in the fan coil in the cooled building. CPEP values were compared to evaluate the relationship between cooling demand and heat load removed from the area by groundwater. While the CPEP value in Exp. 1 was 0.72, a value of 0.95 was determined in Exp. 2. At this point, it was noted that it is possible to cool a room using cool groundwater brought into the ground by a submersible pump powered by solar energy. Furthermore, it was observed in Exp. 2 that despite the increased cooling load, the affordability of the cooling load could be increased by increasing the cooling water flow rate. On both days of the experiment, part of the cooling load of the building was met and it could be kept cool.

Declaration of Ethical Standards

Authors declare to comply with all ethical guidelines, including authorship, citation, data reporting, and original research publication.

Credit Authorship Contribution Statement

Hakan DUMRUL: Conceptualization, Investigation, Methodology, Writing-original draft. **Selcuk SELİMLİ:** Conceptualization, Methodology, Writing – review & editing. **Sezayi YİLMAZ:** Conceptualization, Funding acquisition, Supervision, Writing – review & editing. **Baris KORKMAZ:** Conceptualization, Investigation, Methodology, Writing-original draft.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data Availability

Research data has not been made available in a repository.

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