

Enhancement of a linear concentrating photovoltaic system (LCPVS) through preheating water: A simulation study

Manuscript Type

Research Paper

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Article history:

Received : 6 August 2023

Revised: 5 November 2023

Accepted : 9 November 2023

Keywords: Solar Energy, LCPVS, Solar Radiation, Temperature, Thermal Energy, Electrical.

1. Introduction

Nowadays, the question of how to minimize

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ABSTRACT

Growing worldwide energy demands, the drawbacks of fossil fuels, and global climate change have prompted the creation of sustainable, clean power. One of the viable alternatives to the consumption of fossil fuels is the use of solar energy. Solar photovoltaics (PV) and solar thermal are the most widely accessible solar technology. Hybrid solar systems that make use of Concentrated PV Thermal (CPV/T) technology give an alluring option for the generation of both electrical and thermal energy at the same time. CPV reduces the area of PV receivers while capturing the same amount of solar energy through the use of solar radiation that has been concentrated on PV cells. However, a notable concern associated with CPV is the elevated temperature of the PV surface, often necessitating the implementation of cooling measures. This problem can be resolved by the implementation of a CPV/T system. Conditions for modeling a novel CPV/T hybrid system embedded Multi Junction Photovoltaic cells (MJPV) and based on Fresnel Lens (FL) have been presented in this research. The Python programming language was utilized to simulate the functioning of a linear concentrated Photovoltaic System (LCPVS). In addition, the influence of cooling fluid and its impact on the efficiency of MJ cells (MJC) were assessed. The findings indicate that the proposed system's average thermal and electrical energy were 7.259 and 3.737 (kWh) respectively. Moreover, the average efficiency of the new design was 34.713% and the amount of potable and hot water has more optimum outcomes.

traditional energy usage has emerged as a worldwide strategic concern. Growing worldwide energy demands, the downsides of fossil fuels, and global climate change have prompted the creation of sustainable, low-carbon power [1]. Solar energy (SE) is widely recognized as a very promising form of renewable energy (RE) that has the potential to

reduce reliance on fossil fuels and meet energy demands [2,3]. Among the numerous solar energy technologies, photovoltaic (PV) systems offer a promising choice for successfully harnessing SE resources, and they have seen substantial development in recent years [4–7]. Solar cells (SC), Photovoltaic Thermal Systems (PV/TS), Concentrated Photovoltaic/Thermal Systems (CPV/TS), Solar Thermal Collectors (STC), and Concentrated Solar Power (CSP) are the present technologies utilized to transform SE into a useable form of energy [3,8,9]. A solar cell has the capability to convert approximately 15–20% of the incident sun irradiation into electrical energy; the remainder heats the PV, which affects its performance [10,11]. Therefore, numerous studies have been undertaken to mitigate heat in PV systems and to convert SE into both thermal and electrical energy for practical applications.

The discovery of the PV effect can be attributed to Alexandre-Edmond Becquerel in 1839, whereas the construction of the initial PV cell with selenium was accomplished by Charles Fritts after a span of 44 years [12,13]. Researchers have been diligently working to improve the efficiency and decrease the costs of PV cells since their inception. Nearly 170 years ago, they have known the PV effect. Prior to the energy crisis of the 1970s, the utilization of PV technology was not widely adopted. However, following this crisis, PV experienced a significant surge in popularity. In the wake of the energy crisis and continuing into the mid-1990s, the level of interest in PV technology experienced a decline as a result of heightened apprehensions regarding global warming. This significant prevailing concern has also prompted substantial financial investments in the field of alternative energy research. PV systems are widely recognized as a significant application of SE. In addition to their intrinsic advantages, PV systems possess other notable characteristics, including installation flexibility, commercial availability, and a wide range of applications [14]. It is anticipated [15] at by 2050, residential roof installations will account for 14.5% of PV energy output, non-residential roof installations for 11.5%, and (solar) power plants for 21.4%. Furthermore, it is projected that the Levelized Cost of Energy (LCOE) will experience a decrease from 0.085 USD/kWh to

a range of 0.0014 to 0.05 USD/kWh by the year 2050 [16]. However, for linear concentrated photovoltaic/thermal systems (LCPV/TS), increasing performance, regulating costs, and lowering the temperature of PV are significant challenges. The utilization of solar energy concentration is the most effective approach for acquiring a heat source of superior quality. Currently, there is a growing interest in the reduction of heat accumulation's impact on the performance of concentration photovoltaic systems (CPVS). This topic has gained significant attention in academic research [17]. Using solar concentrators with varying geometric concentration ratios (GCR) allows the production of heat at different temperatures. There are two principal types of concentrators based on the form of concentration: reflection and transmission.

The conversion of PV cells to electrical energy is dependent on several factors, including solar irradiation, PV cell temperature, relative humidity, and dust particles deposited on PV panels [18–20]. Nevertheless, the PV cells' temperature has more of an influence on their efficiency. Due to their superior capacity to concentrate SE, Fresnel lenses (FL) have recently garnered significant attention. They are utilized extensively in solar CPVS [21,22], solar soil sterilizing systems [23], solar thermophotovoltaic systems [24,25], and solar water desalination systems [26]. To compete with a conventional PV system, a CPV system must be installed in the right place, and the additional structures must be simple, robust, and inexpensive. PV cells produce from different materials, and one of the efficient PV cells is Multi Junction Photovoltaic (MJPV). Each MJPV layer absorbs sun spectrum energy from its bandgap to the next layer. Due to the fact that each layer has its own narrow absorption spectrum, additional electricity is created. MJPV cells have been specifically designed for implementation in concentrating systems, such as CPV/T hybrid systems, and are capable of operating under different concentration ratios (CR) [27,28]. MJPV also considers third-generation PV cells, which are efficient even at high CR. MJPV has improved dramatically in the previous 30 years. Since 1988, MJPV cell efficiency has improved by 200%. The Fraunhofer Institute for Solar Energy Systems

conducted measurements in 2013 and 2014 to determine the efficiency of an MJPV quadruple-layer cell, resulting in recorded efficiencies of 44.7% and 46% for the respective years [29,30]. Having compared to other PV cells, it has been seen that MJPV cells have achieved significantly higher levels of efficiency. As an illustration, the highest MJPV solar cell efficiencies that have been officially validated exhibited an upward trend, rising from 29.1% in 2018 to 47.1% in 2020 [31].

As aforementioned, the installation of reflectors onto PV modules is a commonly employed and effective technique for enhancing solar irradiation intensity, hence boosting the overall performance of PV systems. The reflectors have been seen to enhance the power output of photovoltaic (PV) systems, reduce the area needed to generate a given amount of power, and expedite the payback period of PV systems. Consequently, much existing research has focused on improving PV panels output in order to create more competitive commercial systems [32–36]. For instance, Boito et al. (2021) investigated the usage of a fixed-receiver Linear Fresnel Reflector (LFR) in CPV. They demonstrated that the utilization of LFR exhibits competitiveness when compared to traditional systems in medium-to-large scale facilities located in appropriate areas. Their simulation results show that a fixed-receiver LFR can improve PV cell output by a factor of about 8.5 [37]. In another study, Meraje et al. (2022) presented a design and experiment of an FL-based CPV/TS integrated with a nanofluid spectral splitter. They determined that the combination of PV reflectors with nanofluid raises the energy-saving efficiency of the experimentally proven ZnO nanofluid spectral splitting CPV/TS from 56.45% to 76.1% [38]. Furthermore, Hmouda et al. (2022) examined the experimental and theoretical modeling of CPV/TS with Ge-Based MJPV. Their experimental results indicated that the overall efficiency of the CPV/TS increased by around 68.7%. In the meantime, the highest recorded thermal efficiency in testing settings was 49.5%, while the maximum electricity efficiency achieved was 36.5% [39]. Moreover, Gupta et al. (2022) propose and experimentally showed the integration of two big FL and six mirrors for efficiently concentrating solar irradiation

throughout the day inside a shared area. In their investigation, the thermal output of their suggested system was compared to that of a single big FL and segmented mirrors. They conducted the instantaneous thermal efficiency of the proposed system exceeds that of a single lens by at least 20% [40].

The world is facing an inevitable energy supply catastrophe. Nevertheless, the ultimate objective is to support and expand energy in a manner that is compatible with the environment; hence, it is essential to investigate RE innovations. The LCPVS is important for two main reasons: first, it generates electricity, and second, the waste heat that it gathers can be recycled and used for heating purposes. As mentioned, various studies have been undertaken to determine the solutions for enhancing the effectiveness and development of an LCPVS; however, as far as the researchers are aware, no study has profited from our suggested new design and method. In the recently evolved system, the well water (WW) underwent preheating within the channel prior to being directed to the tank. Additionally, an investigation was conducted to examine the influence of cooling fluid on the performance of MJPV. Python programming language was utilized in this study to simulate the performance and also a comparison was made between the average efficiency of the proposed system and that of the previous design. The system accommodates a family of six. The experiment employed a configuration consisting of five rows of LCPV modules, each measuring five meters in length (total length of 25 m). This arrangement was used to meet the energy requirements.

2. Proposed system description

The LCPVS consists of the receiver, the FL, the MJPV, the pump, the tracking system, the clean water tank (WT), the glass wall, the hot WT, and the well water tank (WWT). The developed system accommodates a family of six. The simulation utilized 5 rows of 5 m long modules of LCPV modules to supply the needed energy. The height-to-width ratio of a flow channel that was 0.02 m high and had a width of 0.04 m was equal to 1:2. The concentration width of the linear solar concentrator is determined by the

aperture area of EMCORE's Concentrating Triple-Junction (CTJ) solar cells, which measures 0.01 m [41,42]. It is important to acknowledge that there exists a pipe with a diameter of 0.01 m within the channel, which serves to decrease the surface temperature.

Following exposure to sunlight, the activation of pumps I and II were observed. The pump I was responsible for transferring WW to the WW channel, while pump II facilitates the circulation of city water into the LCPVS and hot WT. Pump II facilitates the transfer of water between the municipal water storage tank and the receiver in a bidirectional manner. The water heater warms the water, which is subsequently conveyed via the pipeline to the municipal water reservoir, so elevating the temperature of the reservoir's water. The LCPVS generates two distinct forms of energy, namely electric energy and thermal energy (TE). The MJPV system is capable of converting the solar energy that is harnessed by the lens into both electrical and heat energy. Despite the fact that a portion of the electricity generated is typically used to power the system's pumps and the remainder is used to power household appliances. The larger the quantity of flow rate, the greater the likelihood that pumps will consume more energy, hence decreasing the amount of energy available for other applications.

Through the employment of heat transfer fins positioned at the bottom of the receiver, the TE that is generated is utilized in order to heat the WW that is contained within the tank. The heat causes the WW to undergo evaporation, followed by condensation on the glass wall due to its lower temperature. Subsequently, the purified or distilled water is moved to the clean WT and subsequently employed for home applications. It is required to heat the well water before adding it to the WWT so that the process of evaporation can be sped up. Moreover, it reduces the warmth of the glass wall. Occasionally, following exposure to solar radiation and subsequent circulation of WW within the WW channel, there is an increase in the temperature of the glass wall. Failure to

adequately cool the glass wall results in a prolonged refining process. The achievement of the goal is facilitated by the equivalence between the temperature of the WW flowing through the glass wall and the temperature of the surrounding water. Figure 1 shows the proposed and old desing [43] of the LCPV system.

Maximum solar radiation was received by the PV module, and this radiation enhances the temperature of the MJPV cells. Increasing the MJPV surface temperature reduces the cell's efficiency, which in turn reduces the amount of electricity produced. Therefore, the main aim was to build a balanced and optimally performing system, it is necessary to evaluate and supply a cooling system for the LCPVs to ensure optimal performance. Figure 2 demonstrates that when solar radiation hits the lens, the lens concentrates it on the receiver. The cooling system in the receiver keeps the surface temperature of the MJPV cells from rising, thereby enhancing the average efficiency. The 3D of the proposed LCPVS is shown in Fig. 3 and 4. Moreover, the workflow of the procedures used in this study is illustrated in Fig. 5.

3. Theoretical principle and fundamental mathematics

The following equations were utilized for calculating reasons; this will be described in further depth below. Equation (1) was utilized to compute the heat entering the fluid (q_{total}), which equals the incoming solar heat in the flow channel. To estimate the heat that is being delivered into the fluid, the solar intensity (\dot{q}_{heat}) must be computed utilizing the sun irradiation that was provided as an input (\dot{q}_{rad}) as well as the cell efficiency's dependence on temperature (η_{cell}), where T_{bulk} represents the bulk fluid flow temperature in the channel.

$$q_{total} = \dot{q}_{heat} \cdot (A_{concentrator}) - (R_{channel} \cdot A_{surface} \cdot (T_{bulk} - T_{air})) \quad (1)$$

$$\dot{q}_{heat} = \dot{q}_{rad} \cdot (1 - \eta_{cell}) * 0.85 * 80 \quad (2)$$

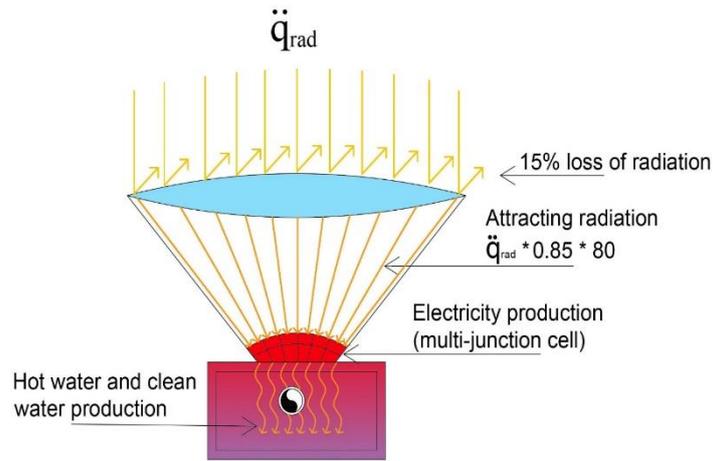


Fig. 2. The LCPVS receiver cross-section

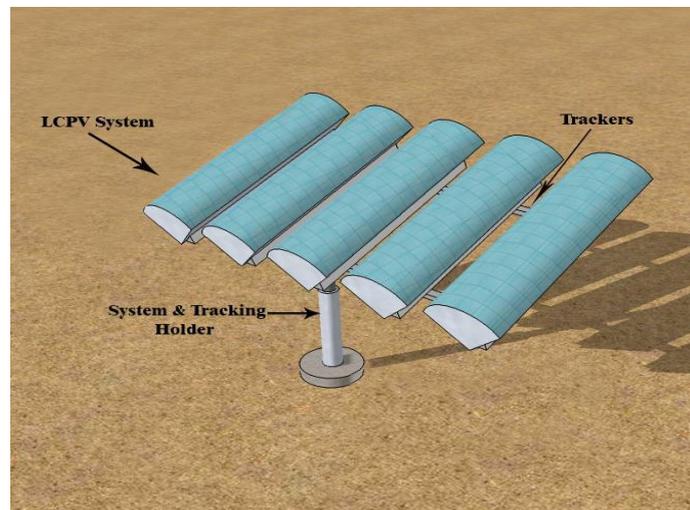


Fig. 3. 3D of the proposed LCPVS

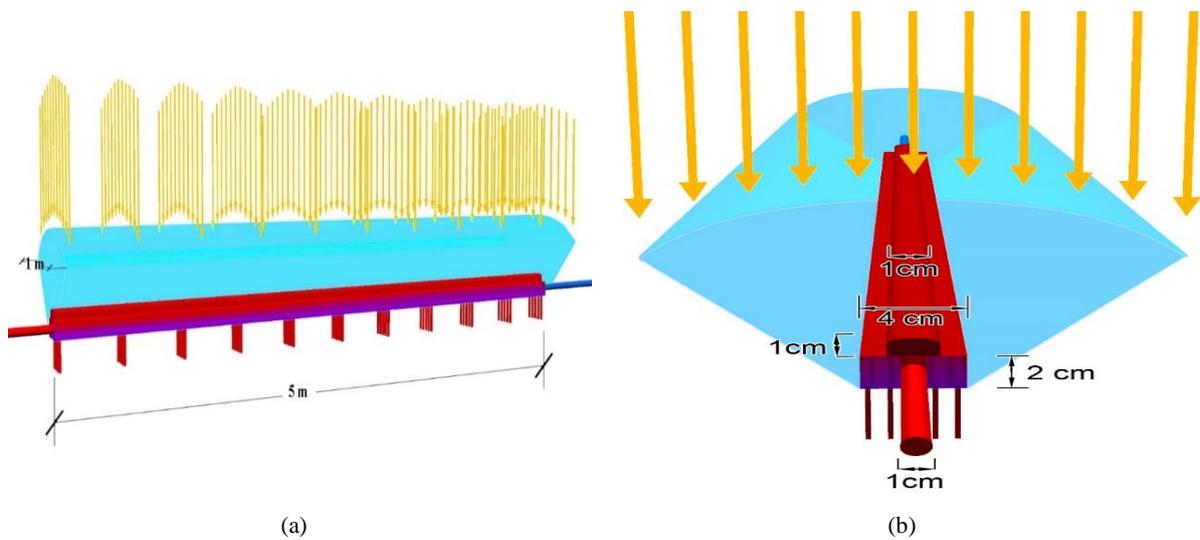


Fig. 4. 3D side view (a) and front view (b) of the proposed LCPVS

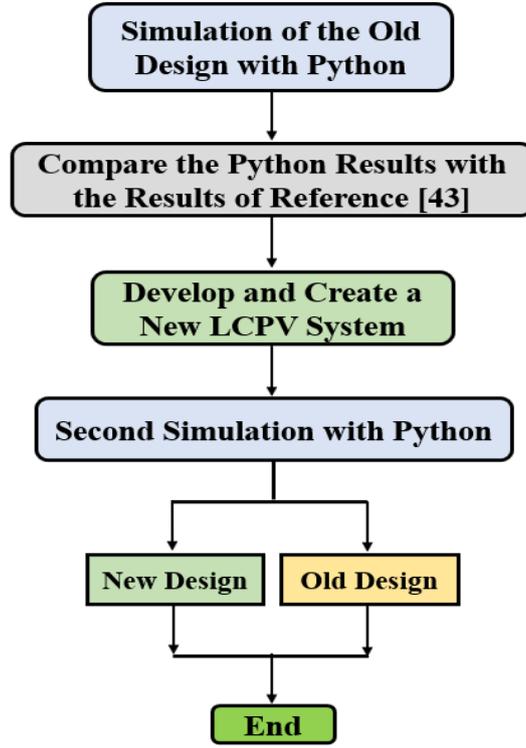


Fig. 5. The workflow of the study

Using Eq. (2) and (3), the heat energy that enters the channel and enthalpy of the fluid are computed. Assuming that heat transmission via the narrow aluminum fins is minimal, \dot{q}_{heat} is the heat of the fluid from solar irradiation. The h_{bulk} was computed utilizing the bulk flow enthalpy ($h_{bulk,i-1}$) plus the enthalpy that is split as a result of the intake of thermal energy h_{heat} :

$$h_{bulk} = h_{bulk,i-1} + h_{heat} \quad (3)$$

$$h_{heat} = \frac{q_{total}}{\dot{m}} \quad (4)$$

Following the calculation of the enthalpy of the bulk fluid for the section, the surface temperature must be determined by calculating the heat transfer coefficient (ht). The Kandlikar correlation (KC) is utilized to evaluate the ht for two-phase and steam flow [44]. Various stages involved in calculating the KC in a vertical tube are illustrated by Eqs. (5) through (15), where Co is the convection number, ht denotes the heat transfer coefficient, x represents the quality, f denotes the friction factor, Fr represents the Froud number, Bo denotes the boiling number, and G is the mass flux [45]. Equations (5) and (6) determine whether the 2

phase flow is nucleate boiling-dominant (NBD) or convective-boiling-dominant (CBD) based on which solution has the greater ht :

$$ht_{NBD} = 0.6683 \cdot (Co^{-0.2}) \cdot (1-x)^{0.8} \cdot fFr_{liquid} \cdot ht_{liquid} + 1058 \cdot (Bo^{0.7}) \cdot (1-x)^{0.8} \cdot ht_{liquid} \quad (5)$$

$$ht_{CBD} = 1.136 \cdot (Co^{-0.9}) \cdot (1-x)^{0.8} \cdot fFr_{liquid} \cdot ht_{liquid} + 667.2 \cdot (Bo^{0.7}) \cdot (1-x)^{0.8} \cdot ht_{liquid} \quad (6)$$

$$Co = \left(\left(\frac{\rho_{gas}}{\rho_{liquid}} \right)^{0.5} \right) \cdot \left(\left(\frac{1-x}{x} \right)^{0.8} \right) \quad (7)$$

$$fFr_{liquid} = 1 \text{ for vertical tubes} \quad (8)$$

The Gnielinski correlation (GC) is used to determine ht_{liquid} in the event that the fluid flows fall within the range $0.5 \leq Pr_{liquid} \leq 2000$ and $2300 \leq Re_{liquid} \leq 10,000$ [46].

$$ht_{liquid} = \frac{(Re_{liquid} - 1000) \cdot Pr_{liquid} \cdot \left(\frac{f}{2} \right) \cdot (K_{liquid} / D_h)}{1 + 12.7 \cdot \left(\left(Pr_{liquid}^{\frac{2}{3}} \right) - 1 \right) \cdot \left(\left(\frac{f}{2} \right)^{0.5} \right)} \quad (9)$$

$$Bo = \frac{q_{total}}{G \cdot h_{fg}} \quad (10)$$

$$G = \rho \cdot U_{liquid} \quad (11)$$

$$h_{fg} = h_{gas} - h_{liquid} \quad (12)$$

$$f = \sqrt{\left((1.58 \cdot \ln(Re_{liquid})) - 3.28 \right)} \quad (13)$$

$$Re_{liquid} = \frac{U_{liquid} \cdot D_h}{\nu} \quad (14)$$

$$D_h = \frac{4 \cdot A_{cross-section}}{p} \quad (15)$$

According to Eq. (16), to determine the ht is to identify whether the flow is turbulent or laminar using the, fluid viscosity, hydraulic diameter, and flow velocity. The Nusselt number (Nu) was determined for laminar flows by employing Eq. (17), which takes into account the ratio of channel width to height being equal to 2 [47]. The Nu for turbulent flows was computed using the Dittus-Boelter correlation, as described by Eq. (18) [48]. Using Eq. 20, it is possible to determine the convective ht following the calculation of Nu . The ht is required to compute the temperature of the surface, which is crucial since it impacts the efficiency of the cell.

$$Re = \frac{U_m \cdot D_h}{\nu} \quad (16)$$

$$Nu = 4.12 \quad (17)$$

$$Nu = 0.023 Re^{0.8} Pr^{0.4} \quad (18)$$

$$Pr = \frac{Cp \cdot \mu}{k} \quad (19)$$

$$ht = \frac{Nu \cdot k}{D_h} \quad (20)$$

In order to get the average efficiency of the cell across the entire length of the LCPVS, it is necessary to calculate the average temperature of the surface. The average temperature of the surface depends on the average temperature of the bulk flow, the average ht , and the thermal energy entering the channel, which was determined by Eq. (21).

$$\bar{T}_{surface} = \bar{T}_{bulk} + \frac{q_{total}}{ht} \quad (21)$$

$$\bar{ht} = \sum_1^i \frac{ht_i}{i} = \frac{ht_1 + ht_2 \dots + ht_{i-1} + ht_i}{i} \quad (22)$$

$$\bar{T}_{bulk} = \sum_1^i \frac{T_{bulk,i}}{i} = \frac{T_{bulk,1} + T_{bulk,2} \dots + T_{bulk,i-1} + T_{bulk,i}}{i} \quad (23)$$

The calculation of the mean cell efficiency ($\bar{\eta}_{cell}$) can be performed using Eq. (24). In this equation, the average efficiency is determined at a room temperature of 36.5% (293.15 °K), and the temperature-dependent drop in efficiency for CTJ solar cells is given as $-0.06\%/^{\circ}K$. The cell properties were determined through experimental cell characterisation and are documented in the CTJ cell specification [49]. Now, the electric power of the system's P_{cell} is computed using Eq. (25), assuming an optical transmittance of 85% and solar concentration of 80.

$$\bar{\eta}_{cell} = 36.5\% - (\bar{T}_{surface} - 293.15k) * 0.06\% \quad (24)$$

$$P_{cell} = \bar{\eta}_{cell} \cdot Rows \cdot Length \cdot Width_{concentration} \cdot q_{rad} * 80 * 85\% \quad (25)$$

The calculation of energy production in kWh involves the multiplication of the power output of the cell in kW by the duration of operation in hours. The simulation was executed on an hourly basis, resulting in the multiplication of the cell's power by one hour to convert it into the appropriate energy unit. After simulating the cell and flow conditions, it is crucial to calculate the variables employed in the LCPV heat storage system. The hot water storage tank was equipped with insulation (R_{tank}). Equation (26) determines the storage tank energy balance, which is responsible for storing heat; E_{tank} is the tank's energy in kJ [50]:

$$E_{tank} = E_{tank,i-1} + E_{in} + E_{citywater} - E_{use} - E_{out} - E_{loss} \quad (26)$$

$$E_{tank,i-1} = \text{tank energy from the previous hour's iteration} \quad (27)$$

$$E_{in} = h_{bulk} \cdot \dot{m} \cdot Time \quad (28)$$

(Note : Time = 1 hour or 3600s)

$$E_{citywater} = V_{use} \cdot \rho_{citywater} \cdot h_{citywater} \quad (29)$$

$$E_{use} = V_{use} \cdot \rho_{tank,i-1} \cdot h_{tank,i-1} \quad (30)$$

$$Re_{liquid} = \frac{U_{liquid} \cdot D_h}{\nu} \quad (31)$$

$$E_{loss} = Surface Area_{tank} \cdot R_{tank} \cdot (T_{tank} - T_{room}) \cdot Time \quad (32)$$

According to the energy of the tank, the enthalpy can be computed by Eq. (33). To compute the fluid temperature of a tank, the tank's heat content is entered into the temperature function. During the hourly iteration, this temperature was used.

$$h_{tank} = \frac{E_{tank}}{Mass_{tank}} \quad (33)$$

4. Evaluation and Comparison of the proposed system results

The solar radiation was determined using an active two-axis tracking device, which accurately follows the sun's trajectory in the sky with a minimal deviation of approximately one degree in both the horizontal and azimuthal locations. Figure 5 depicts the direct solar radiation that makes contact with the surface of the LCPVS at each time, in kW/m², on a typical day (9th and 10th of July) between 6 A.M. and 8 P.M., without concentration.

The solar radiation information utilized in this investigation was obtained from the National Solar Radiation Database (NSRDB) [51]. The next step is to input the flow rate, which is measured in units and volumes of gal/min. The pumps cease operation when the information collected from the sun's radiation parametric table reads 0, indicating the absence of sunlight. The flow rate's volume has an impact on several aspects of the system,

ultimately influencing the quantity of parasitic electricity required throughout the pumping operation. Changes in the *ht* and thermal energy generated, as well as the surface temperature of the channel, may occur as a result of a change in the flow rate. The reason for this phenomenon may be attributed to the utilization of a coupled solar thermal energy system and a PV system by the LCPVS. Additionally, the flow rate has a significant role in determining the condition of the cell and the overall power output of the system.

The Python programming language is comparable to other programming languages. After defining the parameters, the necessary values were substituted. Also included were the formulae for calculating the appropriate parameters. Then, each parameter available in the main equation is recorded. After that, the software was executed and obtained the value of each parameter.

Figure 6 illustrates a decline in sun irradiation throughout the time interval of 1 P.M. to 2 P.M., but the temperature exhibited no significant variation. One possible explanation is to the presence of clouds in the atmosphere during that particular period, resulting in the formation of shadows. However, when considering temperature, this assumption may not hold true, as the current temperature is dependent on the preceding temperature.

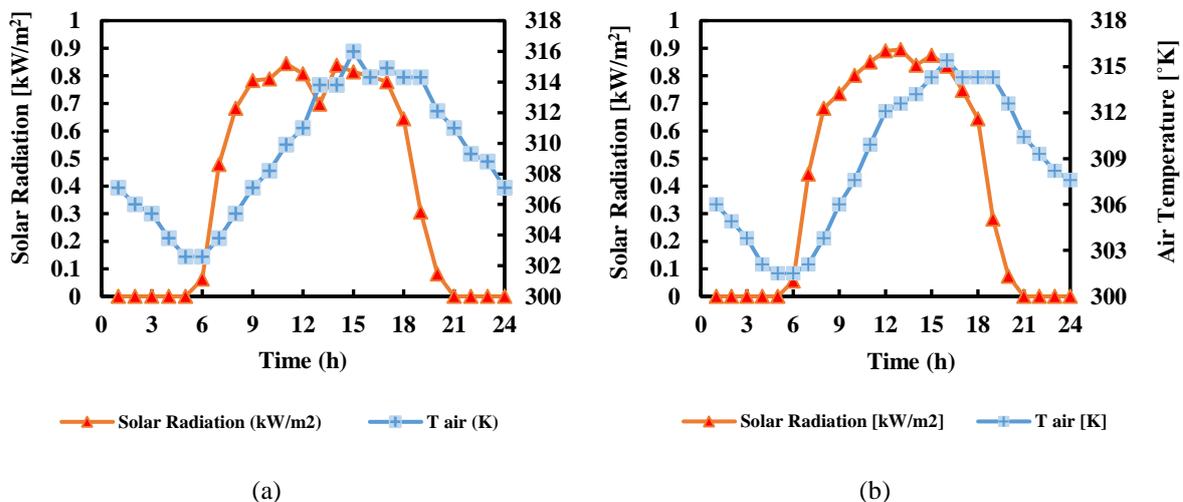


Fig. 6. Solar Radiation and the Temperature variation of 9th of July (a), and 10th of July (b)

To guarantee the correctness of our results utilizing Python programming language, this research's findings were compared to those of a study conducted by Kerzmann et al. [43] using Engineering Equation Solver (EES) (table 1). Both trials found comparable outcomes; however, there was a 0.002 percent margin of error (kWh).

As previously indicated, under the proposed system design, the well water undergoes circulation within the glass wall before entering the main reservoir, resulting in an increase in its temperature. With the proposed system, the well water temperature rises from 293 K to 303 K. This rise in temperature increases the thermal energy's efficiency. Table 2 displays the outcomes of this comparison with a 0.598% increase in system efficiency.

During the 9th and 10th of July, Fig. 7 compares the thermal energy and electric energy consumption of the previous and proposed design. According to the results (Table 2), the electric and thermal energy values are 0.141 and 0.062 (KWh), which are more than those of the previous design. Despite the insignificance of this difference, it should be emphasized that this comparison is just for one day. The new design exhibits a higher magnitude of electric and TE compared to its predecessor due to the utilization of a cycling mechanism that heats the WW by circulating it along the glass wall. Figure 6 depicts the variation in solar irradiation over a specific period of time. This demonstrates the impact of solar irradiation intensity on the increase of electrical and TE.

Figure 8 compares the average efficiency for the previous study and the proposed system. Between 6:00 A.M. and 20:00 P.M., it is evident that the new design (proposed system) average efficiency was greater than that of the previous

study. Moreover, when there is no sunlight, the average efficiency value is equal to zero.

5. Conclusion

A simulation was conducted for the LCPVS, which utilized a crucial fluid cooling channel technology. This simulation really aided in expanding our understanding of the energy and environmental aspects involved. The simulation of the LCPVS exhibited a high degree of adaptability due to the ability to modify certain imputable parameters specific to the system. From such simulations, a number of insightful findings are drawn. Based on prior research, an explicit energy and environmental analysis of the LCPVS has been conducted; this has provided additional information about the LCPVS and has assisted research in the field of CPV. The objective of this study is to determine the most favorable LCPV values that may be obtained by the utilization of simulation flexibility in LCPVs. This was achieved by modifying the simulation parameters and including innovative data inputs. One of the goals of this study was to examine modifications that may be made to LCPVS that will boost the system's overall efficiency. The simulation findings indicate that the proposed system exhibits superior thermal and electrical efficiency when compared to the old design, as a consequence of conducting a comparative analysis between the outputs of both systems. Based on the outcomes, the mean thermal and electrical energy values for the suggested system were determined to be 7.259 and 3.737 kWh, respectively. Furthermore, it is worth noting that the mean efficiency of the new design reached a value of 34.713%.

Table 1. Comparing simulation results for energy

Average efficiency (Python) = 34.113%		
Average efficiency [43] = 34.115%		
	Energy (kWh)	Difference of the outcomes
Average electricity (Python)	3.673 (kWh)	0.002 (kWh)
Average electricity [43]	3.675 (kWh)	
Average thermal energy (Python)	7.116 (kWh)	0.002 (kWh)
Average thermal energy [43]	7.118 (kWh)	

Table 2. The energy comparison of the previous study and the proposed system

Average efficiency (proposed design) = 34.713%		
Average efficiency [43] = 34.115%		
	Energy	Difference of the outcomes
Average electricity (proposed design)	3.737 (kWh)	0.062 (kWh)
Average electricity [43]	3.675 (kWh)	
Average thermal energy (proposed design)	7.259 (kWh)	0.141 (kWh)
Average thermal energy [43]	7.118 (kWh)	

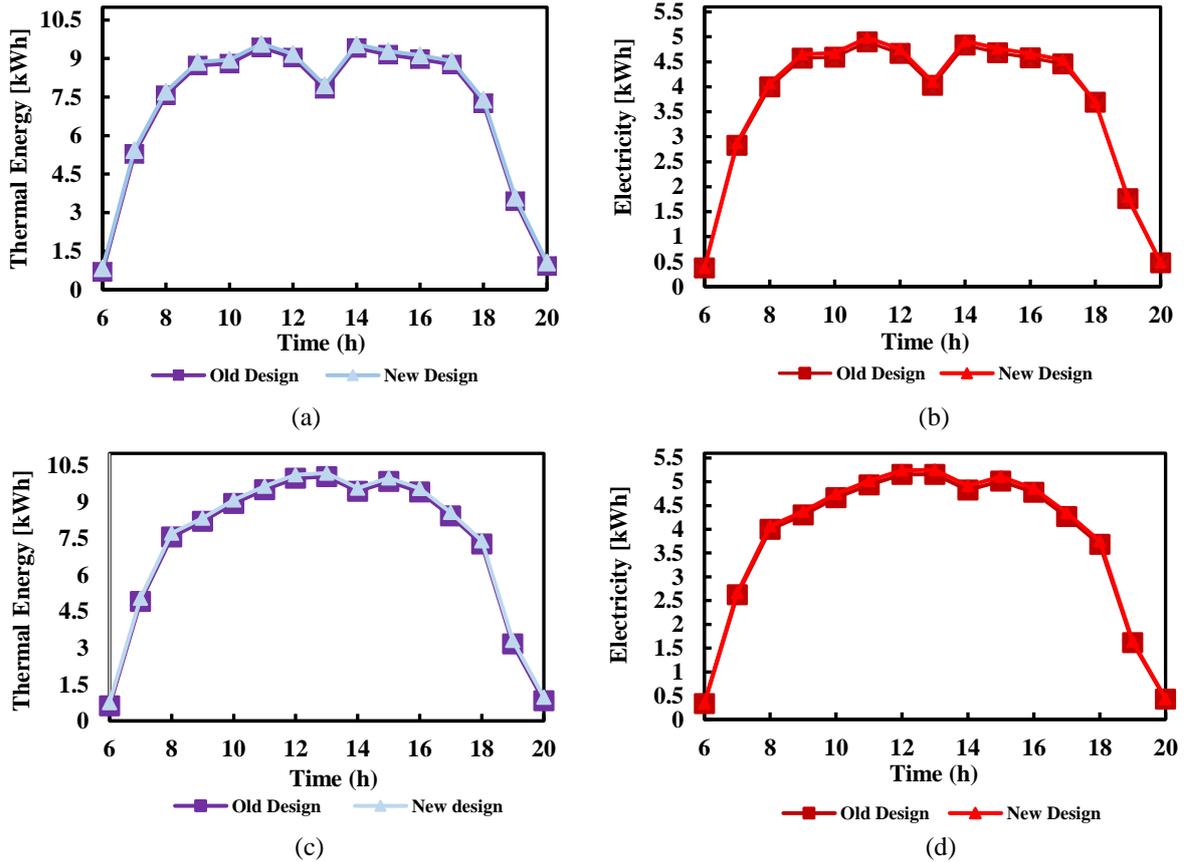


Fig. 7. Thermal energy and electricity in hours on the 9th of July (a) and (b), and 10th of July (c) and (d)

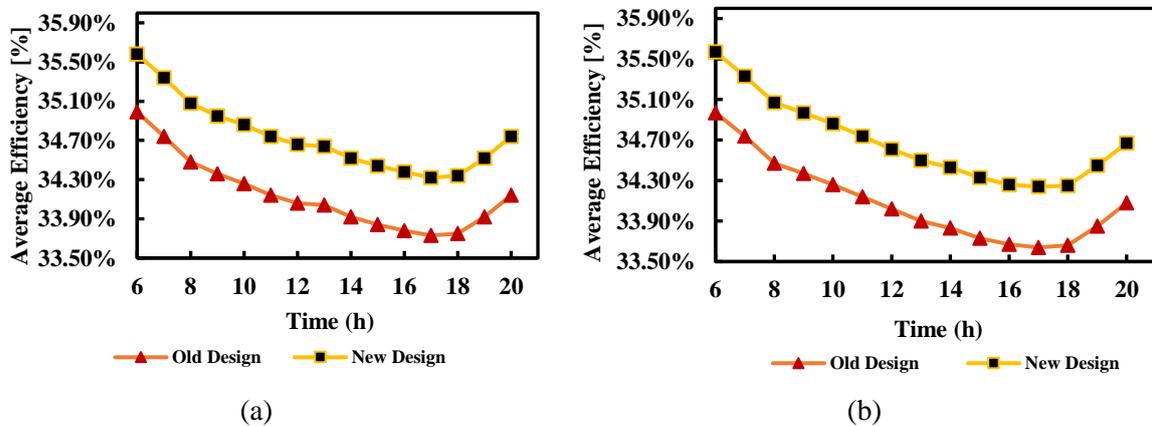


Fig. 8. Average efficiency in hours on the 9th (a), and 10th of July (b)

Aknowlagment:

I have to express my appreciation to Prof. Dr. Ugur Atikol for his supervision of the master's thesis on the topic of the "Design and Optimization of Linear Concentrating Photovoltaic System for Combined Power Heat and Desalination" for sharing his pearls of wisdom with us during the master journey at Eastern Mediterranean University.

Data availability:

Data sharing is not applicable to this article.

Conflict of Interest Statement:

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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