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International Journal of Green Energy

ISSN: (Print) (Online) Journal homepage: www.tandfonline.com/journals/ljge20

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To cite this article: Ali Dezhdar, Ehsanolah Assareh, Ali Ershadi & Ahmad Arabkoohsar (17 Sep 2024): Development of a hybrid renewable energy system for residential complexes in solar-rich regions, harnessing the collaborative power of TRNSYS and the response surface methodology, International Journal of Green Energy, DOI: 10.1080/15435075.2024.2399785

To link to this article: https://doi.org/10.1080/15435075.2024.2399785

Published online: 17 Sep 2024.

INTERNATIONAL JOURNAL OF GREEN ENERGY
https://doi.org/10.1080/15435075.2024.2399785

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Development of a hybrid renewable energy system for residential complexes in solar-rich regions, harnessing the collaborative power of TRNSYS and the response surface methodology

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ABSTRACT

This study is focused on creating an optimal solar renewable system using smart methods to improve performance and reduce its life cycle cost. The proposal aims to use a renewable energy system to power an 80-unit residential complex and achieve zero-energy status. The system includes central thermal photovoltaic (PVT) panels, a heat pump, a proton exchange membrane, a Proton exchange membrane electrolyzer, a hot water storage tank, and a fuel cell. This system can provide hot water, cooling, heating, and electricity. The performance of the proposed method was analyzed using weather data from four Iranian cities: Ahvaz, Dezful, Abadan, and Masjid Sulaiman. The four selected cities have a high potential to access solar energy and have many sunny hours daily. This system has been modeled using a new approach in TRNSYS software, optimized to enhance solar energy system performance and reduce life cycle cost (LCC) by Design Expert (DE) software, and utilizing RSM. Abadan is the best area to start the proposed project because it also has high solar potential. The optimized system has capacities of 950 PVT, 77.5 kW for the fuel cell, 20 kW for cooling, 25 kW for heating, and 92.5 kW for electrolysis. The sensitivity analysis showed that the technical and economic performance of the system is mainly influenced by the number of PVTs and the capacity of the fuel cell. The optimized design has the potential to generate 467,414.309 kWh of electricity per year and the LCC is $344,525.169.

ARTICLE HISTORY
Received 23 May 2024
Accepted 27 August 2024

KEYWORDS
Thermal photovoltaic panel; optimization; response surface method; fuel cell; proton exchange membrane electrolyzer; heat pump

1. Introduction

It is necessary to pay attention to renewable systems to promote and develop the application of renewable and clean energy, and energy management for efficient and optimal use. Today, by taking advantage of the studies conducted in the field of renewable systems, we can try to set up clean systems to supply the energy consumption of residential buildings, because the majority of energy consumption in countries is related to residential buildings. Also, environmental pollution is increasing due to the existence of nonrenewable power plants. The best solution to reduce the use of fossil resources and reduce the environmental pollution caused by its production is for every building to use renewable energy sources. The management and provision of energy consumption in buildings with renewable energy, which includes the use of cooling in the summer season heating in the winter season, and the use of electricity for household appliances, can reduce the consumption of fossil resources.

The optimal use of renewable energy sources is essential to reducing CO2 emissions and controlling global warming. Examining the need for energy and matching it with available clean energy sources is the first step to eliminating electricity and energy production systems based on fossil fuels. After determining the need and aptitude of the study area, optimization is a powerful and promising tool for operational problems. The increase in complexity in today's systems, the demand for increased accuracy in design and manufacturing, and the search for optimal methods from the technical and economic point of view create other problems that can only be solved by creating optimization models (Pfeiffer and Mulder 2013). Optimization is a process to maximize or minimize an objective function by having an appropriate range of influencing variables as the governing parameters of the problem. When the energy system is subject to several thermodynamic, economic, and environmental constraints, energy system optimization is widely used to provide insight into different scenarios. Considering more than one output product in several production systems, optimization in these systems is very complex. In recent years, significant contributions have been made in investigating the technical and economic aspects of electric heating and cooling (Broman and Kandpal 2011). These contributions have mainly evolved around thermal performance optimization regarding energy balance, heating and cooling demand availability, pricing and financial incentives, environmental policies, and electricity and heat planning (Salameh et al. 2022). Hybrid solar energy systems come in three types: hybrid power, heating/cooling, and CCHP. They can use solar energy as a power source or an auxiliary power source to power the building (Qu et al. 2022). A hybrid heating system combining solar energy and biogas was implemented. The findings showed that the system's energy efficiency is higher than its exergy efficiency. Specifically, the energy

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efficiency was measured to be 29.7%, while the exergy efficiency was only 4.5% (Chen et al. 2023). Investigating a proposed liquid air energy storage system using solar energy showed that the system can achieve the highest exergy efficiency when the liquefaction pressure is 155 bar, the liquefaction temperature is −183°C, and the discharge pressure is 70 (Zhou et al. 2023). A survey of solar and wind systems in China showed that the system's equalized energy cost can be reduced to $0.1/kWh when 90% of the annual load demand is met (Yang, Yang, and Duan 2022). A study on a proposed solar energy system with a thermal collector showed that the energy efficiency and exergy of the parabolic photovoltaic thermal collector may reach 80.7 and 33.8%, respectively (Zheng et al. 2023). Multiple energy production systems were investigated to supply energy to a public complex. Factors such as weather elements and inaccuracy in predicting energy demand and calculating the output power of facilities lead to an imbalance of energy supply and demand (Wang et al. 2022). An investigation and analysis of a proposed radiant cooling system based on intermittent performance characteristics showed that the cooling design is used without standby for use inside rooms and for long periods (He et al. 2022). The multi-objective performance of the smart building system was studied and optimized to check the energy consumption. The results showed that the optimization-based system can effectively save costs, reduce CO2 emissions, increase the ratio of primary energy consumption, save more costs, and protect the environment (Deng et al. 2021). A solar system in Korea was studied for a residential building, which was analyzed and optimized using a genetic algorithm for economic factors (Sim and Suh 2021). A solar system for residential buildings was simulated and compared the performance of a fan coil and solar dryer cooling systems. The simulation results showed that the solar dryer cooling system has the potential to reduce energy consumption by 17.3% in high-load buildings (Dezfouli, Sopian, and Kadir 2022). A renewable energy production system with natural gas engines, PV panels, fuel cells, and PEM electrolyzers was studied and investigated. In this research, considering the available equipment, thermodynamic, economic, and environmental information about the system is presented to guide accurate decision-making (Mansir et al. 2022). A system based on solar panels and reverse osmosis for generating electricity and fresh water was investigated, and the results showed that PV solar panels have one cubic meter of drinking water per day with a maximum output power of 280 watts and a battery size of 9.22 kWh (Jbari and Abderafi 2020). The issue of energy demand management in the private transportation and construction sectors was investigated in the Roshan network energy zones framework. The results showed that this plan significantly reduces primary energy consumption and carbon dioxide emissions (Calise et al. 2021). A solar energy system for a dairy factory in Mexico was studied in 2022. The findings showed that during the summer, the proposed solar energy system achieved a maximum thermal power of 70.4 kW and a maximum electrical power of 16.2 kW (Acosta-Pazmiño, Rivera-Solorio, and Gijón-Rivera 2022). A solar heating system was optimized using a genetic algorithm. The results showed the potential to reduce carbon emissions is 5480.6 kg equivalent of carbon dioxide per year (He et al. 2022). The combined solar energy system, heat pump, and combustion furnace with hot air drying and vacuum drying technology was studied. Its advantages were saving drying energy and improving product quality. The complementary multi-heat source drying system consists of a solar heat collection system, a heat pump drying system, and a combustion furnace drying system (Yuan et al. 2022). Research has shown that solar panels can produce up to 1,966,084 kilowatt hours, and wind turbines can produce up to 75,900 kWh (Wei et al. 2022). The power system was investigated using a GT (gas turbine) cycle. Sensitivity analysis was performed to evaluate the effect of various parameters on system performance metrics, including total output power, thermal efficiency, exergy efficiency, and pollution emissions. The results showed that with optimization, the exergy efficiency of the system can be increased up to 47.24% (Zhang, Hong, and Jin 2022).

In 2024, İnci investigated the connection of multiple vehicle PEM fuel cells to the power grid as alternative energy sources. In this study, automotive multiplexed PEM fuel cells (PEMFC), which are widely used in FCEVs, support the residential grid by injecting electric power into the connection system. For this, a multi-input dc-dc boost converter interface was designed and used to manage electrical energy from automotive PEMFCs to the power grid instead of a conventional single-input dc-dc boost converter (İnci 2024).

In 2022, İnci et al. investigated sliding mode control for fuel cell-supported battery chargers. In this research, a proton exchange membrane fuel cell with a maximum operating power of 75 kW was used as an energy supplier to feed consumer loads. The system was designed and analyzed for several loading situations from 20% to 100% loading (İnci, Büyük, and Özbek 2022).

In 2023, İnci analyzed the vehicle fuel cell to grid (FCV2G) system with photovoltaic energy support. The designed system is primarily tested to transfer energy from FCV/PV to the grid/houses and the results are verified for dynamic loading situations. It was observed that FCV + PV provide additional electricity to the grid during the peak hours of the day and the energy-consuming houses use the additional energy from the grid during the peak hours (Inci 2023).

In 2024, İnci investigated a single-stage vehicle fuel cell system with harmonic elimination to suppress the effects of electric vehicle parking distortion. The main objective of the study was to propose a dual-purpose control method for fuel cell network integration of FCV-based vehicles to reduce the harmonic pollution emitted to the network by other electric vehicles and connected charging stations. The proposed control method is tested on a single-phase grid connection and, unlike the traditional two-phase structure, is provided directly through the inverter without using an additional converter (İnci 2024).

Considering today's world's need for energy, researchers have put a basic approach toward achieving renewable energies in their agenda or paying attention to the geographical location of countries in the world that have many capacities in the field of producing new and renewable energies Including solar energy has caused the need to develop renewable energies to be taken into consideration. Also, increasing the efficiency and optimization of renewable systems in industries has been recently noticed.

The use of renewable and sustainable energy sources has not only helped to preserve oil and gas reserves, so that instead of being used in the electricity, transportation, household, and commercial-service industries, they are used to produce by-products with the added value of oil and gas in the country, but also reduced environmental pollution. It also helps to reduce the emission of greenhouse gases, which is one of the main causes of climate change in the world today.

Among the main reasons for paying attention to renewable sources, the following can be stated:

(1) All countries in the world have access to renewable resources.
(2) Responding to the growing need for sustainable energy sources in developing countries.
(3) They can be competitive from an economic point of view.
(4) Fossil fuels cause severe environmental pollution.
(5) The global consensus is moving toward controlling global warming and climate change.

Today, it is necessary to pay attention to alternative energies of fossil resources to meet the needs of humans and industry for basic energy, which requires complete studies. Because designing and setting up new systems requires complete and comprehensive information about technical and environmental conditions, equipment type, feasibility, and design. The review of the research background showed that research has been done in the field of using solar energy to produce different energies, but the combination of solar energy and fuel cells needs more studies. A fuel cell is a device that works with hydrogen and oxygen fuel, for this reason, in the present study, a proton exchange membrane electrolyzer was used to produce the hydrogen and oxygen needed by a fuel cell. Proton exchange membrane electrolyzer, which is practical and high-efficiency equipment for separating water molecules from each other and producing hydrogen, has been used. Today, due to the environmental pollution of fossil fuels and the increase in carbon dioxide emissions, it is necessary to pay attention to hydrogen fuel, which is free from environmental pollution. The electricity required for the proton exchange membrane electrolyzer is provided by the solar panel, and on the other hand, the hydrogen burner does not pollute the environment.

In this research, a new method is used to determine the best performance for the simultaneous production of cooling, heat, electricity, and hydrogen-oxygen from an energy and economic point of view. The system's units are the photovoltaic/thermal panels, heat pump, fuel cell system, hot water storage source, and PEM electrolyzer. The fuel cell unit increases the system's performance and uses the generated electrical energy in periods of low or no solar radiation to maintain the suggested solar power system's stability. Using the combination of TRNSYS simulation and the RSM, the parameters affecting the performance of the proposed solar power system, including the number of PVT panels, heat pump capacity, fuel cell capacity, and electrolyzer capacity to reach the optimal solution for the target functions of production power and cycle cost Life is checked. Such a combination has been used for the first time, and according to the analysis, several innovations have been briefly introduced to improve the work, which are as follows in this research:

- Expression of a new clean hybrid system based on different equipment.
- Using TRNSYS software to analyze and model the system.
- Investigating the system's performance regarding climate change in the four cities of Ahvaz, Dezful, Abadan, and Masjid Suleiman.
- Determining the two objective functions of system lifetime cost and electricity generation.
- Use the RSM to perform a multi-objective optimization analysis and find the optimal balance between objective functions and decision variables to achieve the best value.
- Provide an optimal mode analysis to evaluate the impact of design variables on solar system performance.
- Investigating the energy needs of a residential building with 80 residential units and 320 residents.

The main goals of this work are:

- Find the best result.
- Finding the optimal working conditions of the system.
- Meeting the needs of buildings.
- Providing a renewable system with high efficiency.
- Finally, this system's components and units are combined for the first time.

2. System description

Figure 1 shows the schematic of the solar power system based on solar energy with the combination of fuel cells and other equipment, which is a new design of a multiple energy production solar power system to supply the energy needed by buildings. The proposed plan includes PVT panels, a fuel cell unit, a heat pump cooling and heating unit, a hot water storage source, and a PEM electrolyzer. A PVT panel, each of which consists of several solar cells, produces electric power. It is one of the types of solar energy generation systems. In this method, solar cells make direct electricity production from sunlight possible. PVT panels consist of groups of PVT that capture energy from the sun to generate electricity. These PVTs convert sunlight into electricity by creating an electric field between a positive charge on one side and a negative charge on the other.

The water fluid enters the PVT panels and is heated by absorbing the heat of solar energy. By increasing the temperature of the water working fluid, the temperature of the solar panels decreases, and the effectiveness of electricity generation increases. Heated water, which results from the heat exchange of solar panels and the radiation effect, is transferred to the hot water tank. The fuel cell unit uses air oxygen and hydrogen produced by PEM electrolysis as fuel to produce energy. Electrolysis electrolyzes water molecules and produces hydrogen and oxygen by receiving water fluid. The primary source of energy is the PVT panel system. The system powers cooling, heating, and electrolysis for oxygen and hydrogen production.

Electrolysis with proton exchange membrane includes two halves of PEM cell and alkaline electrolysis. In this electrolysis,

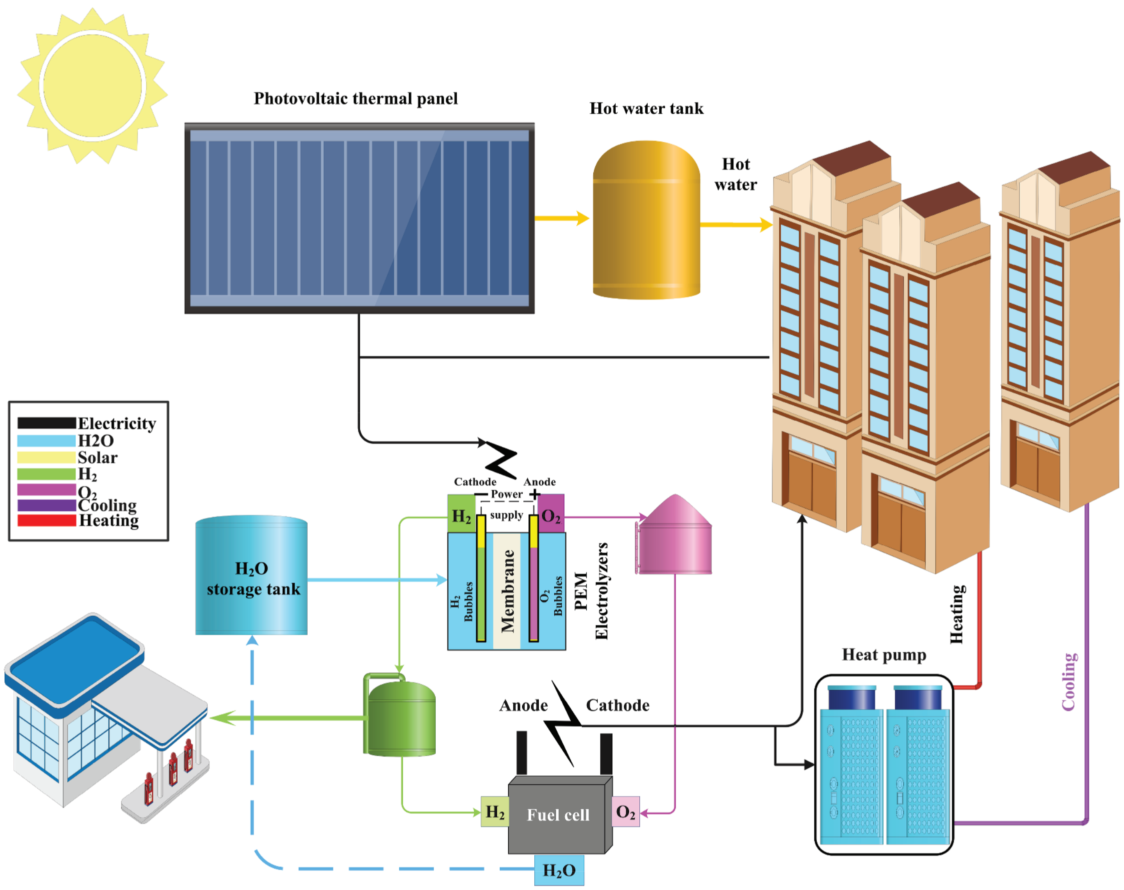

Figure 1. Schematic of the proposed renewable system.

the anion exchange membrane allows -OH ions to leave the electrolyte and remain neutral. As a result, the catalyst will have the highest efficiency.

3. Research methodology

The purpose of this research is to use solar energy to set up a multiple production system (electricity, cooling, and heating) needed by residential buildings with the aim of not releasing environmental pollution. For the stability of the proposed solar system, a fuel cell unit was used, and the required fuel for the fuel cell was provided by the hydrogen and oxygen produced by the system's electrolyzer. Therefore, all production of the proposed system is clean, and the combination of thermal photovoltaic panels (electricity and heat generator) with fuel cells to stabilize the system is a new idea that needs to be studied.

In Figure 2, an illustrated summary of the events and work done, opening the teams' performance in energy production, the introduction of the software used, and the studied cities are discussed.

The method to solve the problem is as follows:

- Modeling by TRNSYS software (TRNSYS software is one of the most well-known simulation tools for energy systems and thermal systems, which is used as one of the most powerful tools for designing and optimizing energy systems. This software consists of a rich library of components, which includes a wide range of systems and technologies, such as types of solar hub panels, electrolyzers, cooling production units, buildings and heating-cooling loads, types of heating systems, etc.).
- A multi-objective optimization was performed with the response surface method to find the best working conditions of the system. (The RSM response surface method is considered one of the methods of experimental modeling and design of experiments. The response surface method is used to identify the governing equation of the phenomenon, which estimates the objective functions (dependent parameters) by the effective parameters (independent parameters).
- Design Expert software is used to optimize the problem. (One of the concepts used in designing experiments is the response level method. This method is useful for analyzing experiments in which many variables affect one or more independent variables, and the goal is to optimize the said response. One of the advantages of using this method and the Design Expert software, in addition to reducing the number of tests, provides the possibility of presenting a mathematical relationship between the independent variable and dependent variables. In addition, in this method, in addition to numerical variables, it is also possible to examine the effect of qualitative variables.)
- Determining two objective functions and five decision variables.

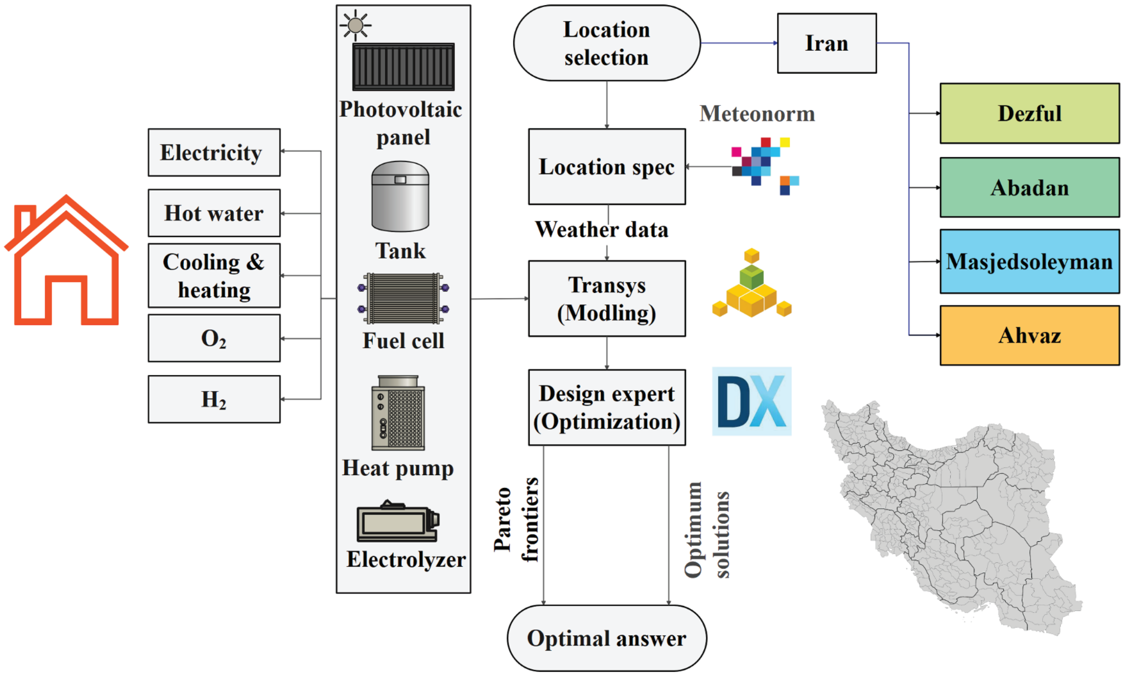

Figure 2. The primary nature of the research.

- Weather information of study cities in Iran is used from Meteonorm software.
- Determining four cities in Iran with high solar potential for the feasibility of setting up a multiple energy production system (Masjid Suleiman, Dezful, and Ahvaz-Abadan).
- Choosing the best city to launch.
- Based on the TRNSYS model and using case study building characteristics and local weather data of the best city in Iran, the electricity demand, cooling, and heating requirements of a residential building were provided.

4. System analysis

Systems based on renewable energy have a different structure compared to fossil energy production technologies (thermal power plants). Because the development process in renewable energy has high initial investment costs and low maintenance costs. In energy production methods from fossil sources, the initial investment costs are relatively low.

The proposed system is modeled using TRNSYS simulation software for transient state energy systems. The relations governing the problem are stated in Table 1 to express it mathematically and check the function of the components used in the following.

A fuel cell is an electrochemical device that converts the chemical energy of a fuel and an oxidant into electric current (DC). The oxidant can be pure oxygen or a gas containing oxygen like air.

The two equations below show the anodic and cathodic reactions that take place in a PEM fuel cell fed with an anode gas containing hydrogen and a cathode gas containing oxygen (Amphlett et al. 1995).

The whole reaction of the fuel cell is:

$$\text{Anode}: H_2(g) \Rightarrow 2H^+(aq) + 2e^- \quad (1)$$

$$\text{Cathode}: 2H^+(aq) + 2e^- + {}^1\!/\!_2 O_2(g) \Rightarrow H_2O(l) \quad (2)$$

The products of the process shown in the superelectricity equation are liquid water and heat.

$$H_2(g) + {}^1\!/\!_2 O_2(g) \Rightarrow H_2O(l) \quad (3)$$

The performance of a fuel cell (output voltage) is defined as a function of thermodynamic potential, activation overvoltage, and ohmic overvoltage, with mass transport losses in each term (Kordesch and Simader 1996).

The main expression for the voltage of a cell is as follows:

$$U_{cell} = E\eta_{act}\eta_{ohmic} \quad (4)$$

Where E is the thermodynamic potential, η_{act} is the anode and cathode activation overvoltage, a measure of the voltage drop associated with the anode and cathode, and “ETA ohmic” is the ohmic overvoltage. Measurement of IR losses associated with solid polymer electrolyte proton conductivity and electronic internal resistances.

The thermodynamic potential is calculated according to the following equation:

$$E = 1.23 - 0.00085(T_{Stack} - 298) + 0.0000431 T_{Stack} \ln(p_{H2} p_{O2}{}^{0.5}) \quad (5)$$

Ohmic overvoltage is calculated according to the following equation:

The Activation Overvoltage is calculated according to the following equation:

$$\eta_{act} = -.0.95 + 0.00234 T_{Stack} + 0.000192 T_{Stack} \ln(A_{PEM}) - 0.0.000192 T_{Stack} \ln(I_{PEM}) + 0.000076 T_{Stack} \ln(C_{O2}) \quad (6)$$

Ohmic overvoltage is calculated according to Equation 18:

Table 1. Relationships governing form.

Equip	Relation	Number
Electricity PVT panel (Dezhdar et al. 2023)	$E_{PV/T} = (\tau\alpha)_n \cdot IAM \cdot G_T \cdot A \cdot \eta_{PV/T}$	(1)
Fluid outlet temperature from the PVT panel (Wei et al. 2022)	$T_{f,out} = \left(T_{f,in} + \frac{\varepsilon_m}{\kappa}\right) \exp\left(\frac{N_{tubes}}{{}_f c_f} \frac{\kappa}{\theta} L\right) - \frac{\varepsilon_m}{\kappa}$	(2)
Fuel cell voltage (Klein et al. 2006)	$U_{cell} = \frac{U_{mod}}{n_{c,ser}}$ $U_{mod} = U_0 - blog(I_{stack}) - R_{ohm} I_{stack}$ $U_{stack} = n_{m,ser} U_{mod}$	(3)
Fuel cell output power (TESS 2004)	$E_{stack} = U_{stack} I_{stack}$	(4)
Calculation of fuel cell energy efficiency is calculated using cell voltage, hydrogen enthalpy in standard conditions, Faraday's constant and the number of electrons. (TESS 2004)	$\eta_E = \frac{U_{Cell} n_e F}{H_2}$	(5)
Total heat produced from the fuel cell (Rashidi and Khorshidi 2018)	$Q_{gen} = E_{stack}\left(\frac{1-\eta_E}{\eta_E}\right)$	(6)
Fuel cell hydrogen consumption (Nemati, Sadeghi, and Yari 2017)	$\dot{V}_{H_2} = \frac{n_{c,ser} n_{m,ser} I_{FC}}{zF\rho_{gas}} S_{H_2} \eta_F$	(7)
Heat pump cooling coefficient (Naseri et al. 2017; Oueslati 2021)	$\begin{cases} f_{totCool} = tc_1 + tc_2 T_{wb,in} + tc_3 T^2{}_{wb,in} + tc_4 T_{db,amb} + \\ tc_5 T^2{}_{db,amb} + tc_6 T_{wb,in} T_{db,amb} f_{sensCool} = sc_1 + sc_2 T_{wb,in} + \\ sc_3 T^2{}_{wb,in} + sc_4 T_{db,amb} + sc_5 T^2{}_{db,amb} + sc_6 T_{wb,in} T_{db,amb} \\ f_{EIR,c} = cp_1 + cp_2 T_{wb,in} + cp_3 T^2{}_{wb,in} + cp_4 T_{db,amb} + \\ cp_5 T^2{}_{db,amb} + cp_6 T_{wb,in} T_{db,amb} \\ f_{Bypass} = bf_1 + bf_2 T_{wb,in} + bf_3 T^2{}_{wb,in} + bf_4 T_{db,amb} + \\ bf_5 T^2{}_{db,amb} + bf_6 T_{wb,in} T_{db,amb} \end{cases}$	(8)
Heat pump heating factor (Asrami et al. 2021; Saedpanah et al. 2020)	$\begin{cases} f_{heat} = th_1 + th_2 T_{wb,in} + th_3 T^2{}_{wb,in} + th_4 T_{db,amb} + \\ th_5 T^2{}_{db,amb} + th_6 T_{wb,in} T_{db,amb} \\ f_{EIR,h} = hp_1 + hp_2 T_{wb,in} + hp_3 T^2{}_{wb,in} + hp_4 T_{db,amb} + \\ hp_5 T^2{}_{db,amb} + hp_6 T_{wb,in} T_{db,amb} \end{cases}$	(9)
Enthalpy and air temperature of the heat pump (TESS 2004) (Kim, Baltazar, et al. 2013)	$\begin{cases} lT_{coilOut} = T_{dbIn} - \frac{\dot{q}_{sens}}{\dot{m}_{air} C_{air}\left(1-f_{bypass}\right)} \\ h_{coilOut} = h_{airIn} - \frac{\dot{q}_{tot}}{\dot{m}_{air}\left(1-f_{bypass}\right)} \end{cases}$	(10)
	$\begin{cases} h_{airOut} = f_{bypass} h_{airIn} + \left(1 - f_{bypass}\right) h_{coilOut} \\ \omega_{airOut} = f_{bypass} \omega_{airIn} + \left(1 - f_{bypass}\right) \omega_{coilOut} \end{cases}$	(11)
Hydrogen production rate of PEM electrolyzer unit (Buonomano et al. 2018)	$\dot{n}_{H_2} = \eta_f N_{cells} \frac{I_{ely}}{nF}$	(12)

$$\eta_{ohmic} = \frac{-\mathrm{I}_{FC} t_{PEM}}{\mathrm{A}_{PEM}} \frac{8}{\exp\left(\frac{T_{Stack}-353}{T_{Stack}}\right)} \left(1 + 1.64 \frac{\mathrm{I}_{FC}}{\mathrm{A}_{PEM}} + \gamma\left(\frac{\mathrm{I}_{FC}}{\mathrm{A}_{PEM}}\right)^3\right. \quad (7)$$

The thermodynamic potential is defined through the Nernst equation. Parametric coefficients in the expression of activation overvoltage η_{act}based on theoretical equations of kinetic, thermodynamic, and Basics of electrochemistry are used. Parametric coefficients in the expression of internal resistance η_{ohmic} are completely empirical and based on temperature and experimental data (Amphlett et al. 1995).

Below is an explanation of the thermodynamics of low-temperature electrochemical reactions used in the fuel cell model.

The following assumptions can be made about the water-splitting reaction:

(a) Hydrogen and air (or oxygen) is ideal gases.
(b) Water is an incompressible fluid.
(c) Gas and liquid phases are separate.

Based on these assumptions, the change in enthalpy ΔH of the water-splitting reaction can be calculated regarding pure hydrogen (H_2), oxygen (O_2), and water (H_2O) at standard temperature and pressure (25°C and 1 atmosphere). The total change in enthalpy for water splitting is the enthalpy difference between the products (H_2 and O_2) and the reactants (H_2O).

The total amount of energy released in the fuel cell reaction is equivalent to the enthalpy changeΔH. The standard enthalpy for water splitting is $\Delta H^0 = 286\ \mathrm{kJ\ mol^{-1}}$.

The total required energy ΔH with the voltage of the neutral heat cell with the expression:

$$U_{tn} = \frac{\Delta H}{n_f} \quad (8)$$

Energy efficiency can be calculated from thermal voltage and cell voltage with the following expression:

$$\eta_E = \frac{U_{cell}}{U_{tn}} \quad (9)$$

The pipes that circulate the fluid behind the photovoltaic panel are used to generate electricity and absorb thermal energy in the photovoltaic panel. Relationships (1) and (2) were used to determine the outlet temperature of the heat transfer fluid and the amount of electricity produced by the photovoltaic panel.

In Equation 1, parameter $\tau\alpha$ is the transmission-absorption of the photovoltaic panel, IAM is the radiation angle modifier, G_T is the total amount of solar radiation of the photovoltaic panel, A is the collector area, and $\eta_{PV/T}$ shows the nominal efficiency of the collector. ε_m Is the emissivity, L represents the length of the collector and the incidence angle.

Type 966 heat pumps is used in the system, which calculates four coefficients for cooling mode and two coefficients for heating mode for bypass deficit, total flow cooling/heating capacity, and sensible cooling/heating capacity.

The enthalpy and temperature of the air coming out of the heat pump are analyzed using Equation 10. When the conditions at the coil air outlet are specified, the coil air is mixed with the bypass air and is calculated from Equation 11.

The life cycle cost parameter was chosen for the economic analysis of the system. LCC is selected as an economic parameter to determine the economic performance of the system and is presented using the Equations 22 and 23 (Buonomano et al. 2018; Saedpanah et al. 2020).

$$LCC = I_C + PWF \times AOC - R_I \quad (10)$$

$$PWF = \begin{cases} \frac{1}{d-i}\left[\left(\frac{i+1}{d+1}\right)^{nL}\right] if\ i^1 d \\ \frac{nL}{i+1}\ if\ i = d \end{cases} \quad (11)$$

It should be noted that in the economic calculations, the life of the system was considered 25 years. I_c is the initial investment cost of the Renewable system of the present work, AOC is the amount is the operating cost of the system during one year, R_I is the resale revenue, 15% of the initial investment cost is estimated for each component. PWF is the present value factor, which is calculated from the inflation rate (i), discount rate (d), and system lifespan (n_L) (Saedpanah and Pasdarshahri 2021).

The life cycle includes the period that begins when the need for an asset is identified and ends when the asset is decommissioned. Life cycle costing is a process for economic analysis and evaluation of the total costs related to purchase, installation, maintenance and repairs, renovation and scrapping, and in general the total cost of ownership of equipment, life cycle management is an approach to making decisions about it. The purchase or acquisition of any new asset is considered and managed by all expenses at different stages. From the application of LCC analysis, we can mention the control and reduction of costs, the selection of the most beneficial purchasing strategy, the economic analysis of the plan, and the economic evaluation of the efficiency of new technology.

The purpose of life cycle cost optimization as a function of the economic goal of this research and also as a measure of system cost is to reduce it.

Table 2 presents the fixed input data for modeling and solving the system.

Table 3 presents the data value of the decision variables to start the modeling process.

Figure 3 displays the flowchart for the problem-solving methodology.

Table 2. Fixed input data.

Item	Parameter	Value
Photovoltaic panel	Dimension	1.658×0.992 m
	Bond thermal conductivity	45 W.m^{-1}.K^{-1}
	Slope	33°
Fuel cell	Electrode area	100 cm^2
	Number of fuel cell modules in series per stack	64 (-)
Hot water tank	Volume	16.5 m^3
Electrolyzer	Electrode area	0.25 m^2
	Number of cells is series	70 (-)
	Number of stacks in parallel	3 (-)
	Thermal resistance	0.0563 K/W
Lifetime	System lifespan	25 years
Heat pump	Bypass fraction	0.1148 (-)
	Cooling energy input ratio	0.256 (-)

Step-by-step problem-solving includes the following:

- Collect the necessary information from authoritative articles.
- Thermodynamic analysis of the problem according to thermodynamic relationships.
- Economic analysis of the problem according to economic relations.
- Analyzing the technical and economic performance of the renewable system.

5. Building

In this research, a building complex has ten buildings with four floors, and each floor has two units. Each unit was considered a typical residential area with an area of 190 square meters, and this building has the structural specifications presented in Table 4 of this information. It should be noted that it was assumed that four people live in each unit, and 320 people live in this building complex. Table 4 shows the characteristics of each team in the selected building complex.

To accurately model and achieve accurate Radiative, Convective, Electric power fraction, and Abs results. The humidity related to the residents inside the building, the level of lighting, and electrical equipment is listed in Table 5.

6. Results

6.1. Validation

Due to being a new system, the photovoltaic thermal panels (PVT) validation was conducted using TRNSYS software by Kanyarusoke et al., as depicted in Figure 4 (Kanyarusoke, Gryzagoridis, and Oliver 2016). The investigation focused on the electricity generation over 20 days, revealing the high accuracy of this transient simulation with a minimal margin of error.

6.2. Case study

The most critical parameter affecting panels' performance in different geographical conditions is the average duration of daily sunlight in the region in hours, which is very high in Iran's central and southern areas. The four selected cities have a high potential for access to solar energy, with high hours of sunshine during the day.

Iran receives solar energy at the highest level in the world as it is located between 25 and 40 degrees north latitude. The amount of solar radiation in Iran is estimated between 1800 and 2200 kWh/m2 per year, which is higher than the world average. More than 280 sunny days per year are recorded in Iran, which is very significant. Currently, there is wide competition in the Middle East in the production of electricity from solar energy.

Table 3. Decision variables data.

Parameter	Value
Fuel cell capacity (kW)	40
The cooling capacity of the heat pump (kW)	20
Heat pump heating capacity (kW)	25
Electrolyzer capacity (kW)	40
Number of PVT panels (-)	450

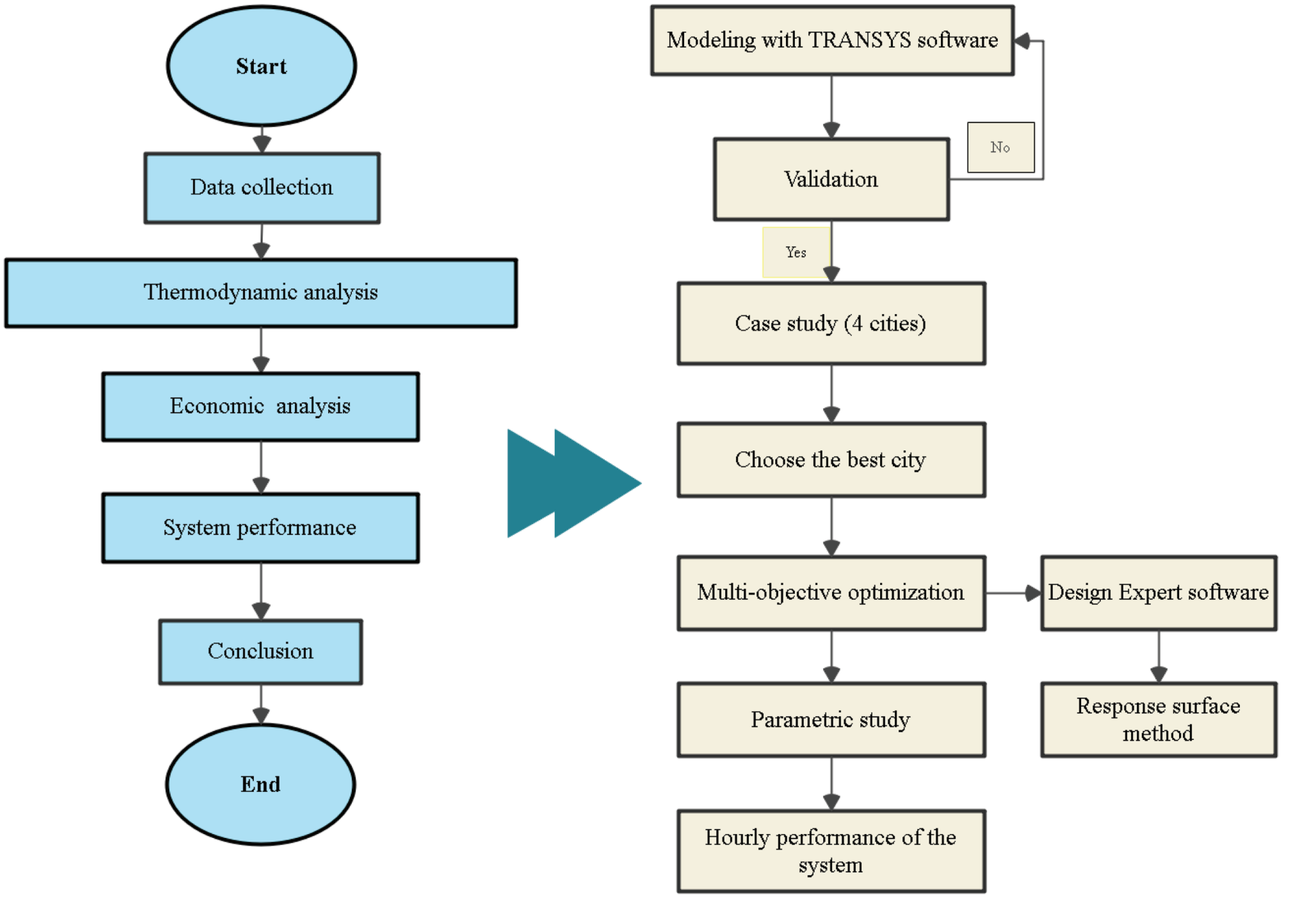

Figure 3. Solution method.

Table 4. Information on all the units within the chosen building complex.

Section	Item	Value	Unit
Building	Area	190	m^2
Window	Number	2	m^2
	Area	3	–
	Overall heat transfer (OHT) coefficient	3	$W.m^{-2}.K^{-1}$
Roof	OHT	0.29	$W.m^{-2}.K^{-1}$
	Solar absorptance	0.5	–
Walls	OHT	0.6	$W.m^{-2}.K^{-1}$
	Solar absorptance	0.5	–
Floor	OHT	0.29	$W.m^{-2}.K^{-1}$
Ceiling	Height	2.9	m

Considering that the amount of electricity produced by solar panels depends on various factors, such as the intensity of sunlight, temperature, and efficiency of solar panels, these factors should be considered for a more detailed examination of the situation.

Due to the system's dependence on renewable solar energy, the selected areas are considered among the most potential solar regions, and these cities have many solar hours. We conducted an hourly analysis to examine how solar radiation intensity and average temperature variations affect the system's efficiency. Throughout the year, Figure 5 shows how the T_0 fluctuates hourly in the cities studied. The studied cities are hot regions with a yearly T0 between 0 and 60 degrees Celsius.

The hourly changes in solar radiation intensity in the studied cities are shown in Figure 6. These results reveal that the power of solar radiation in these cities varies between 0 and 1000 watts per square meter throughout the year. This suggests that the cities studied have a significant potential for solar energy per hour.

6.3. Compare cities

Figure 7 compares the amount of system production power for four studied solar potentials in Iran. This research aims to increase electricity production, reduce pollution emissions, and correctly use renewable energy. For this reason, the results show that the system performs better in Abadan, Ahvaz, and Dezful mosques, respectively.

Table 5. Specifications of loads inside the building.

Gain	Radiative	Convective	Electric power fraction	Abs. humidity
People	72	144	0	0.059
Electrical	14904	4968	1	0
Lights	388	166	1	0

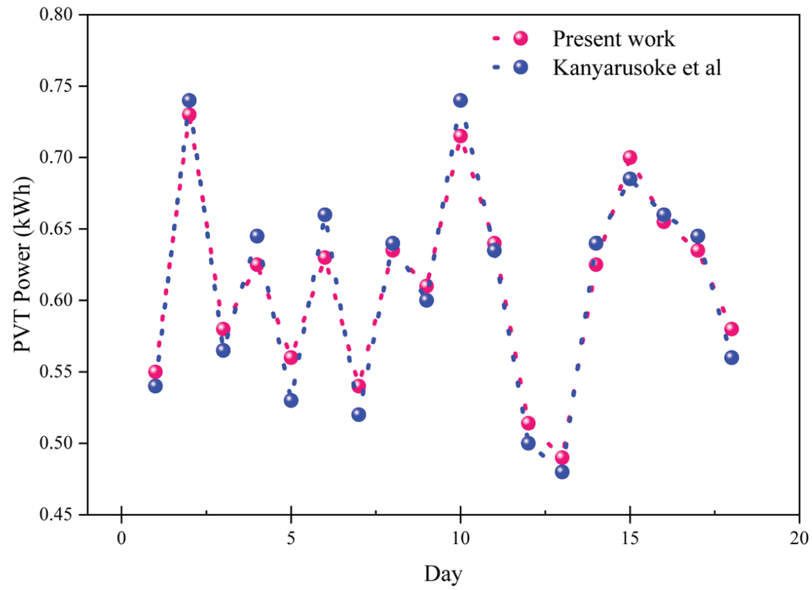

Figure 4. Thermal photovoltaic panel validation.

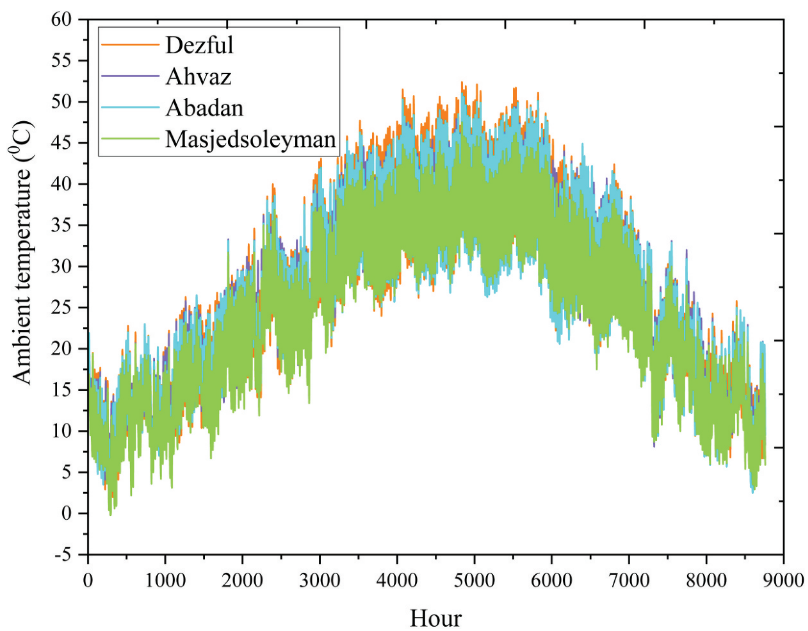

Figure 5. Tracking the fluctuations of temperature on an hourly basis throughout the year.

Figure 8 compares the production power of units, including two solar panel units and a fuel cell, for four study coastal cities in Iran. The results show that the system units in the town of Abadan perform better in electricity production, and the reason is the potential of solar energy in the city of Abadan compared to the other three cities.

Figure 9 compares the system's LCC and thermal comfort coefficient for four study cities in Iran. Abadan City's LCC is lower than the other three study cities. For this reason, the city of Abadan is chosen for this comparison, which is to select the best region in terms of good performance and low cost.

The more positive the value of the thermal comfort coefficient, the more warm the person feels; the more negative the thermal comfort coefficient, the colder the person feels. The ideal value for the thermal comfort coefficient equals 0, and more favorable internal conditions are obtained with matters of the thermal comfort coefficient close to zero. The results show that the thermal comfort coefficient in Abadan city is smaller than in the other three cities, so the need for cooling load in this city is less than in Dezful, which has a higher thermal comfort coefficient.

Figure 10 compares system performance in cooling and heating production in study cities and on an annual basis.

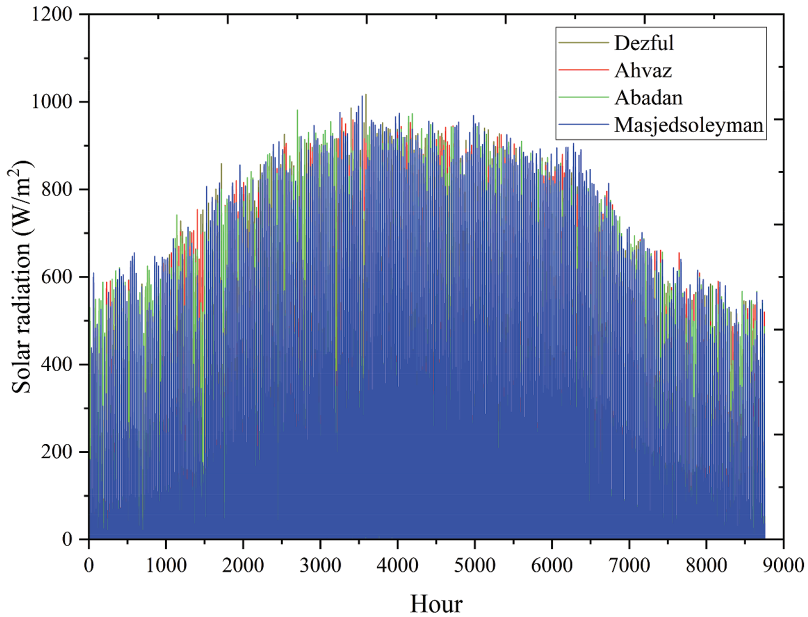

Figure 6. The intensity of solar radiation.

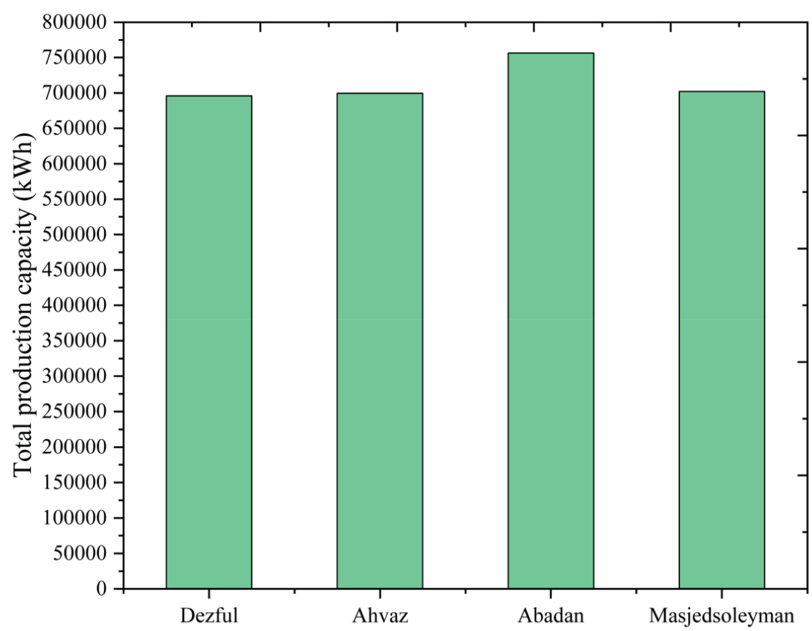

Figure 7. The total production power of flowers during one year.

Study cities are among the hottest regions of Iran, which require more cooling load throughout the year.

The system's cooling and heating production rate is determined according to the city's location and T_0. For this reason, in the cities of Dezful and Ahvaz, which have a higher T_0 throughout the year (according to Figure 5), the cooling production rate is higher, and heating production is lower than in the other three cities. Also, Abadan, which has the lowest T_0 compared to the three study cities, has less cooling production and more heating.

Figure 11 compares the hydrogen and oxygen production performance of the study cities' PEM electrolyzer unit annually. The electrolyzer is powered by the electricity produced by the suggested solar power system. The investigation showed that hydrogen and oxygen production rates in the cities studied are similar. Still, Dezful town had the highest production rates with a slight difference, while Ahvaz had the lowest hydrogen and oxygen production rates.

Finally, after comparing the results of the technical and economic performance of the suggested solar power system in the three study cities of Iran and to increase the power production and the appropriate cost of the system, the city of Abadan, which had a better production capacity and

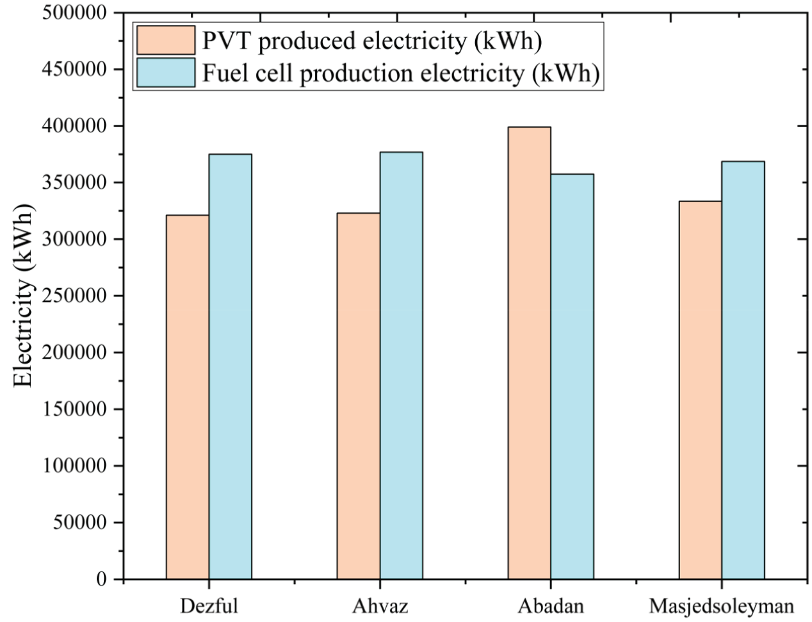

Figure 8. The power production of the entire solar power system.

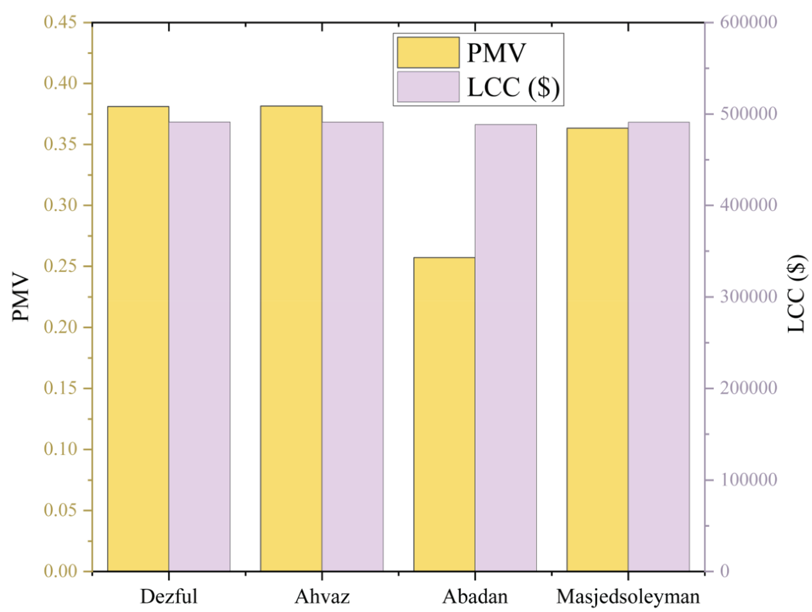

Figure 9. LCC comparison and thermal comfort factor.

a fitter LCC, was selected as the best area for the road. System setup is desired.

6.4. Optimization

This research uses the RSM method for multi-objective optimization, which determines the optimal values for objective functions. RSM is a mathematical tool that establishes the relationship between response variables and independent variables (Allaix and Carbone 2011). The aim is to optimize the output variable influenced by multiple input variables.

The study of optimization in the response surface method can be divided into stages:

- Selection of independent variables from major effects on the system through screening studies and delimitation of the test area.
- Choosing the test plan and conducting tests according to the selected test field.
- Mathematical statistical analysis of experimental data obtained through appropriate polynomial function.
- Assessment of model fit
- Confirming the necessity and possibility of moving to the desired area.
- Obtaining optimal values for each studied variable.

Using CCD, the general second-order model of the response surface method is expressed in Equation 24.

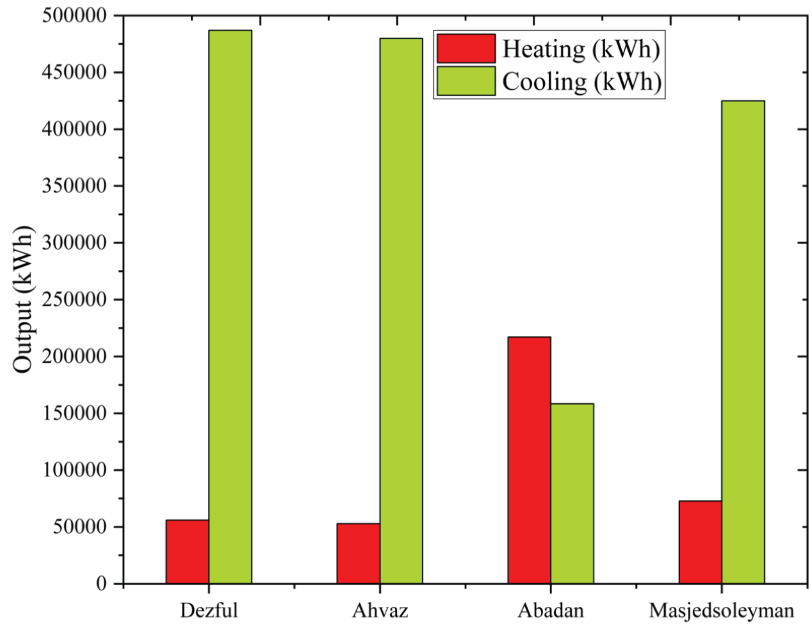

Figure 10. The total annual cooling and heating production in the study cities.

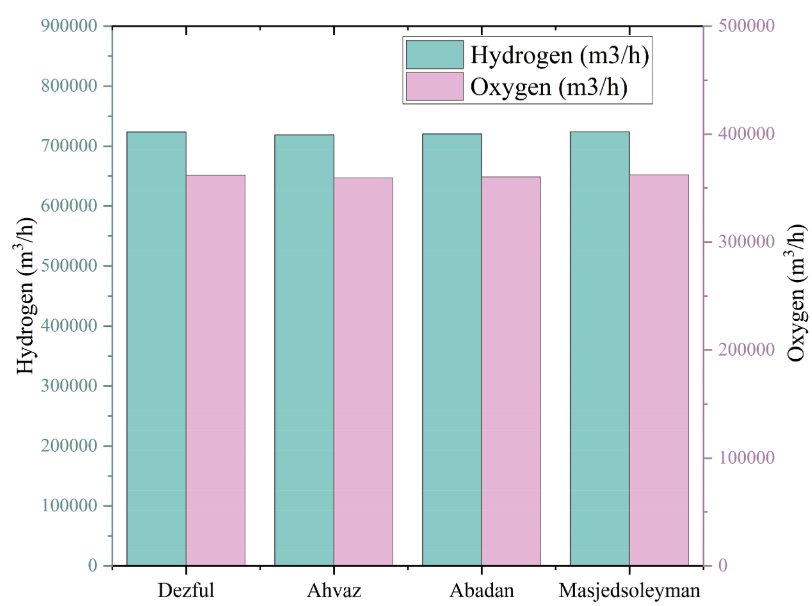

Figure 11. Total annual production of hydrogen and oxygen in study cities.

$$y = r_0 + \sum_{i=1}^{n_f} r_i x_i + \sum_{i=1}^{n_f} r_{ii} {x_i}^2 + \sum_{i<j=2} \sum^{n_f} r_{ij} x_i x_j \quad (12)$$

Where y represents the selected answer, x is the factor, nf is the number of factors and r represents the coefficients of the model obtained from the regression analysis.

The process of using RSM to optimize the problem is illustrated in Figure 12.

Five decision variables were selected as the most influential design parameters on the two objective functions to analyze the suggested solar power system. For optimization, five influential variables introduced in Table 6 were selected to check their impact on solar power system performance and presented as optimization variables.

The assumptions used in the optimization are as follows:

- The target city was Abadan.
- In the economic calculations, the life of the system was considered to be 25 years

Table 7 shows the results of 32 runs from TRNSYS software for optimization analysis. These results include the changes in the objective functions relative to the value of the Optimization variables and the determination of their final value using Design Expert software.

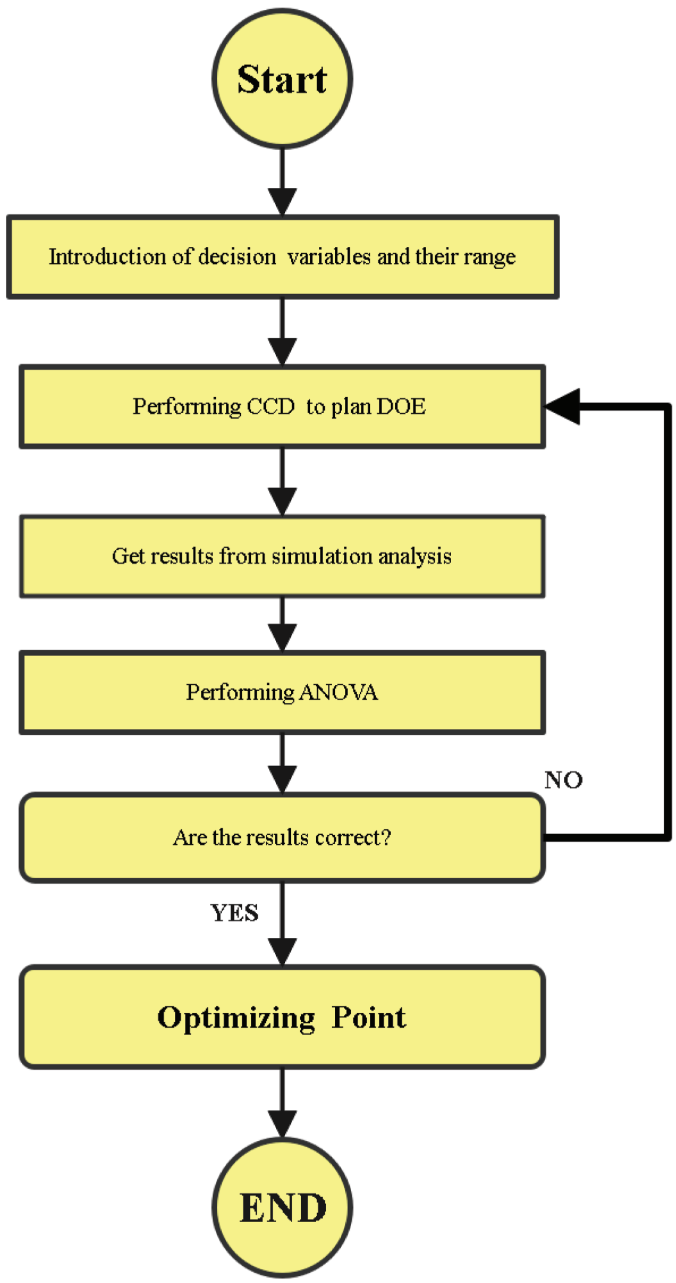

Figure 12. Flowchart of RSM method.

Table 6. Upper and lower limits of decision-making variables.

Name	Goal	Lower	Upper
Number of PVT panels	is in range	450	950
Fuel cell capacity (kW)	is in range	32.5	77.5
Electrolyzer capacity (kW)	is in range	37.5	92.5
The cooling capacity of the heat pump (kW)	is in range	25	55
Heat pump heating capacity (kW)	is in range	20	40

In Figure 13, the process of life cycle cost changes when the production power of the system changes is shown, and these two parameters were determined as two functions to improve the technical and economic performance of the system. It should be noted that the change process of this figure is based on the results obtained in Table 7.

After analyzing multiple objective functions and decision variables, the system has determined that 100 points are optimal for achieving the best solutions. Table 8 displays the results of the RSM method used to determine the optimal values for decision-making variables. This solution was chosen after screening various multi-objective optimization methods.

In this section, we will assess how design variables impact the technical and economic aspects of the system under investigation. We will create 3D surface diagrams by pairing two variables. Each chart will display the impact of alterations. In these two variables on the objective function, provided all other decision variables are maintained at their optimal points. The chart in Figure 14 displays how adjusting two different input parameters can impact the electricity production objective function. The findings indicate that the number of PVTs is one of the most significant variables affecting overall electricity consumption, and the capacity of the fuel cell. All variables work together to achieve an optimal state of electricity production, which is 467,414.309 kWh.

Figure 15 shows the effect of simultaneous changes of two parameters on the LCC objective function. The results show that among the most influential decision variables on the LCC, the capacity of the number of PVT, the capacity of the fuel cell, and the impact of other parameters on the LCC were less. All the variables try to bring the system LCC to an optimal $344,525.169.

6.5. Parametric study

We studied specific design parameters, such as the solar dish area and a heat pump's cooling and heating capacities impacting electricity generation and LCC. The investigation involved increasing specific parameters to observe their effects. Figure 16 investigates the impact of rising heat pump cooling capacity on electricity production and the system's LCC. Based on the results, it's clear that increasing this parameter negatively impacts the objective function of electricity production. However, reducing the electricity produced increases the system's LCC. If we expand the cooling capacity of the heat pump to generate more cooling, it will consume more electricity. It's worth noting that the heat pump relies on the electricity generated by the system. Therefore, if the heat pump uses more power, the power the system supplies to the power grid decreases.

Figure 17 investigates how increasing the electrolyzer unit's capacity affects the solar power system's performance. By increasing the capacity of the electrolyzer, the amount of electricity consumed by this unit to produce hydrogen and oxygen increases, and as a result, the total amount of electricity produced by the suggested solar power system, which is used for residential purposes, decreases. On the other hand, the solar power system's LCC also increases due to reduced electricity produced.

In Figure 18, we will examine how increasing the fuel cell unit's capacity affects the system's overall performance in this analysis. It is important to note that increasing the power of the fuel cell unit increases the amount of electricity generated by the system. Furthermore, the rate of hot water production

Table 7. Extraction results of the designed model for optimization.

Run	PVT panel	F_C	EL	HP-HEAT	HP-COOL	NET	LCC
1	700	55	120	40	30	128957	378006
2	950	32.5	92.5	55	20	169584	471928
3	700	55	65	40	30	232951	328326
4	450	32.5	92.5	55	40	−105506	571432
5	450	32.5	37.5	55	20	74120.2	498724
6	950	77.5	92.5	55	40	323713	428367
7	1200	55	65	40	30	432409	423476
8	450	32.5	37.5	25	40	66557	439939
9	950	32.5	92.5	25	40	162021	455268
10	950	77.5	37.5	25	40	495776	488124
11	200	55	65	40	30	33492.9	506052
12	700	10	65	40	30	3189.96	487791
13	950	77.5	37.5	55	20	503340	420284
14	950	32.5	37.5	55	40	197946	346902
15	700	55	65	40	10	308583	392423
16	450	77.5	92.5	25	40	192324	434280
17	700	55	65	40	50	157319	371230
18	700	55	65	40	30	232951	432451
19	700	55	65	40	30	232951	536576
20	700	55	10	40	30	336946	436147
21	950	77.5	92.5	25	20	467414	354401
22	450	77.5	37.5	25	20	371950	558322
23	450	77.5	92.5	55	20	199887	433939
24	700	55	65	40	30	232951	308701
25	450	32.5	92.5	25	20	38194.9	528341
26	700	55	65	70	30	164882	435515
27	950	32.5	37.5	25	20	341647	382560
28	700	100	65	40	30	462712	450112
29	450	77.5	37.5	55	40	228249	424288
30	700	55	65	40	30	232951	412826
31	700	55	65	40	30	232951	300326
32	700	55	65	10	30	301020	401388

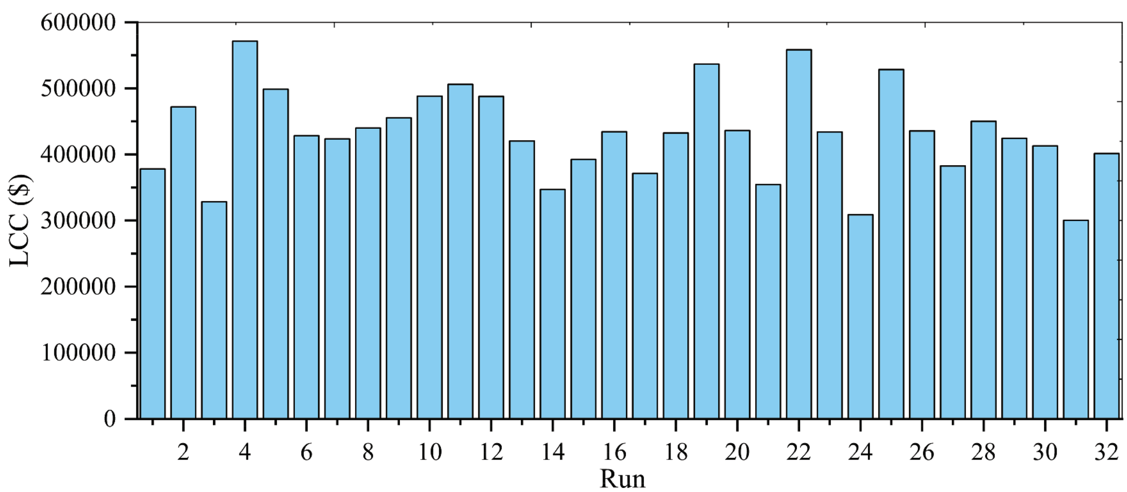

Figure 13. The trend of life cycle cost changes in relation to the simultaneous change of decision variables.

Table 8. Optimal results.

Parameter	Value
Number of PVT panels	950
Fuel cell capacity (kW)	77.5
Electrolyzer capacity (kW)	92.5
The cooling capacity of the heat pump (kW)	25
Heat pump heating capacity (kW)	20
Production capacity (kWh)	467414.309
LCC ($)	344525.169

rises as the fuel cell is responsible for providing both power and heat, with the latter being utilized to heat water. However, it is essential to note that the rise in production capacity also increases costs due to heightened system activity.

Figure 19 shows how the amount of PVT affects electricity production and system LCC. The findings indicate that the more solar panels present, the more significant the electricity produced as the panels absorb more thermal energy. Moreover, as the electricity production increases, the system's LCC decreases.

In Figure 20, we can see how increasing the heat pump's heating capacity affects the electricity produced and the overall cost of the suggested solar power system's LCC. The results show that increasing this parameter hurts both objectives. This is because when the heat pump generates more heat, it consumes more electricity, which is taken from the electricity

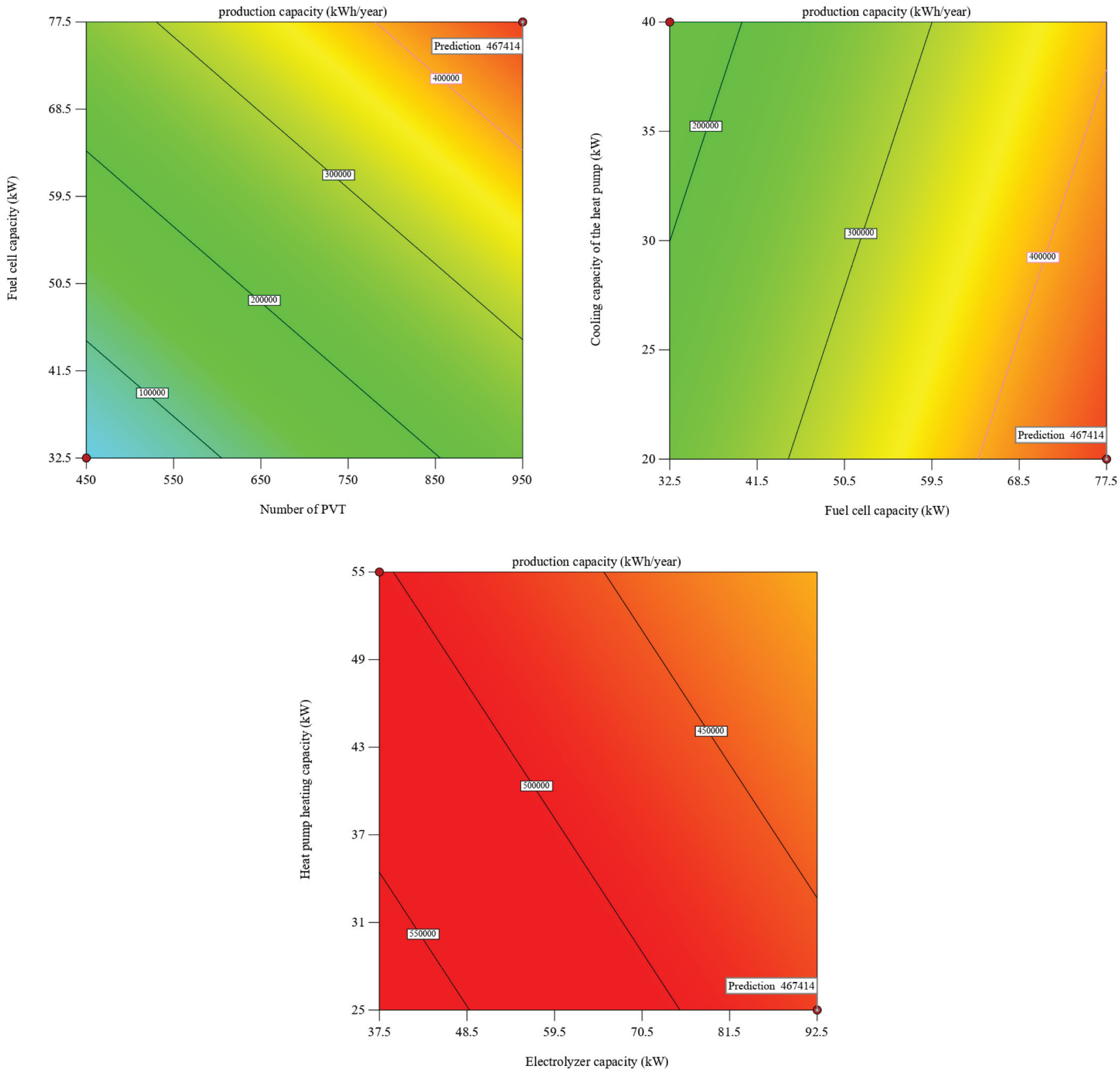

Figure 14. Mutual effects of design variables on electricity production.

generated by the suggested solar power system. Therefore, this increase in power consumption leads to a decrease in the power produced by the proposed solar power system and an increase in the solar power system's LCC. It is important to note that this power reduction generated is supplied to the power grid.

Asset Life Cycle is a period that starts when the need for an asset or equipment is identified and ends with its scrapping after purchase and operation. All costs related to the help in this period are called the LCC of that asset, which is called LCC. Equipment LCC analysis, also called LCC analysis, is a decision-making tool based on engineering economics calculations that can be used to review and analyze an asset's visible and hidden costs during its life cycle. By performing LCC analysis before deciding on the purchase and replacement of equipment, it is possible to examine different scenarios, identify and estimate the hidden costs that the organization will face in the future, and choose the best option among the available methods. Ultimately, I found the right time to change and replace the equipment.

6.6. Hourly performance of the system in Abadan city

In Figure 21, the electricity consumed by the computing building and the amount produced by the entire system in this research and Abadan city are calculated hourly. As the results of the amount of electricity consumed in Abadan city show, the building's electricity load during the year is

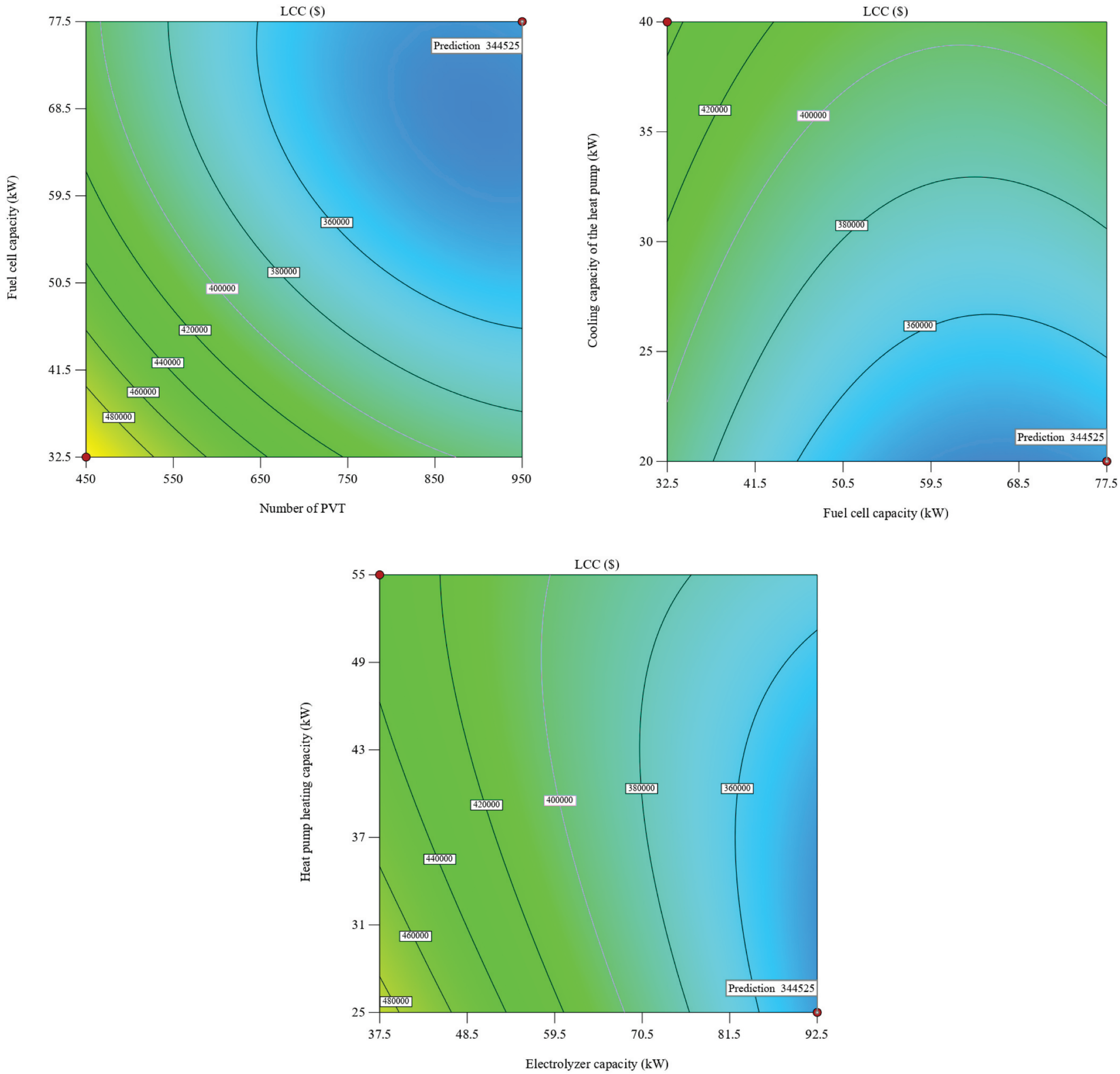

Figure 15. Variable interaction effects on LCC.

approximately between 45 kWh at its lowest value and 200 kWh at its highest value. In all months, the proposed solar power system can supply the electricity demanded by 80 Building units.

Figure 22 displays the hourly electricity production of a PVT in Abadan city for a year. It's important to note that the panels are the primary source of power generation and obtain thermal energy from absorbing solar energy. Consequently, the electricity manufacturing by the proposed solar power system varies with the intensity of solar radiation throughout the year. The findings indicate that the minimum electricity produced by the solar panels ranges between 0-(kWh) and 160 (kWh).

In Figure 23, the fuel cell's yearly and hourly electricity production in Abadan is monitored. The fuel needed by the fuel cell is provided by the hydrogen and oxygen produced by the electrolyzer, and the performance of the fuel cell is affected by the changes and fluctuations in the production of hydrogen and oxygen. The purpose of using a fuel cell is to reduce the fluctuations of electricity production by solar panels due to the instability of solar energy.

Figure 24 shows the cooling and heating produced by solar power for Abadan. As the results show, considering there is a need for heating in the cold season and a need for cooling residential houses in the hot season, the proposed system produces heating during the cold months and in the hot seasons. According to Figure 5, which shows the results of T_0 changes, it can be seen that when the T_0 increases, the solar power system must produce cooling. When the T_0 decreases, the solar power system must generate heat due to the need for heating.

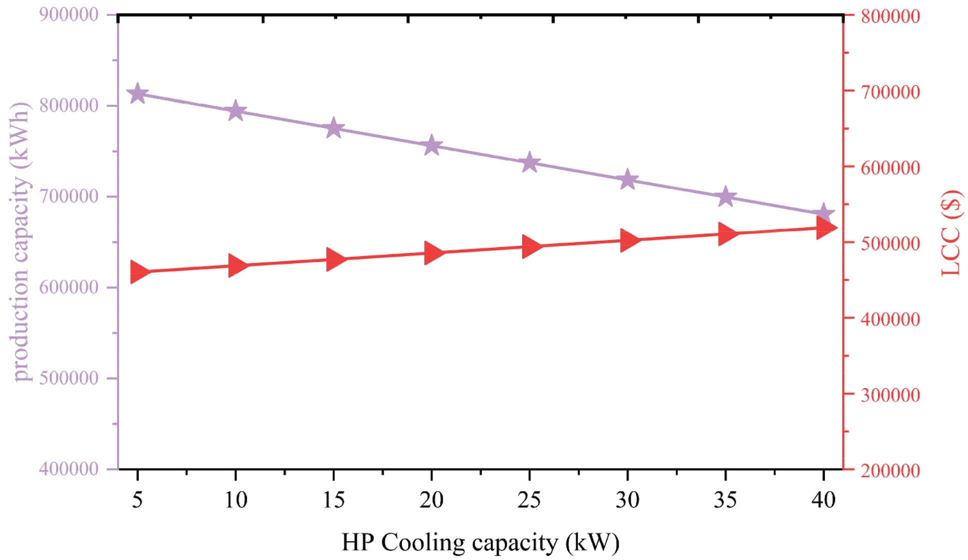

Figure 16. Improving heat pump cooling capacity.

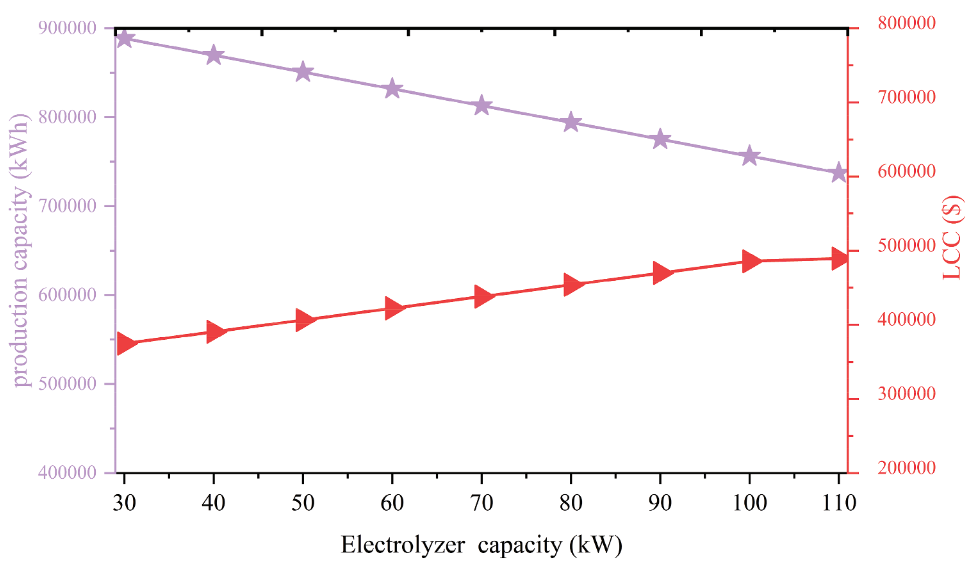

Figure 17. The solar power system's performance with increased electrolyzer capacity.

In Figure 25, the T_0 of Abadan city is calculated hourly, i.e., 8760 hours. The highest temperature is related to the summer, and the lowest temperature range of Abadan city is associated with the winter. Also, the temperature changes of two zones or the selected area in the building have been investigated and calculated hourly, i.e., 8760 hours. As the analysis of the results shows, with the increase or decrease of the T_0, the temperature inside the investigated building also increases and decreases, and the highest temperature is related to June and July. The results show that the temperature inside the building is changing in the range of 21 to 25 degrees Celsius, which is also considered the comfort temperature of this building. So it can be said that the building's comfortable temperature is between 21 and 25 degrees Celsius during the year.

Figure 26 shows the amount of hydrogen and oxygen in the system by the proton exchange membrane electrolyzer unit throughout the year in an hourly manner for the city of Abadan. PVT Panel supply the electricity required by the electrolyzer unit. In other words, it is directly related to solar energy and electricity production by solar panels, which give the electricity needed for the electrolyzer to produce hydrogen. It should be noted that the hydrogen and oxygen produced by the system are used to provide fuel for the fuel cell.

7. Conclusion

One of the current problems in the world is the irreversibility of nonrenewable energies, including gasoline, oil, and gas, which the current industry relies on, and the production of energy needed by residential and industrial buildings, such as electricity, heating, and cooling, using natural resources. Fossils are provided. In addition, due to the decreasing nature of these resources, the increase in pollution caused by burning these resources has caused the spread of environmental pollution, making researcher's think of

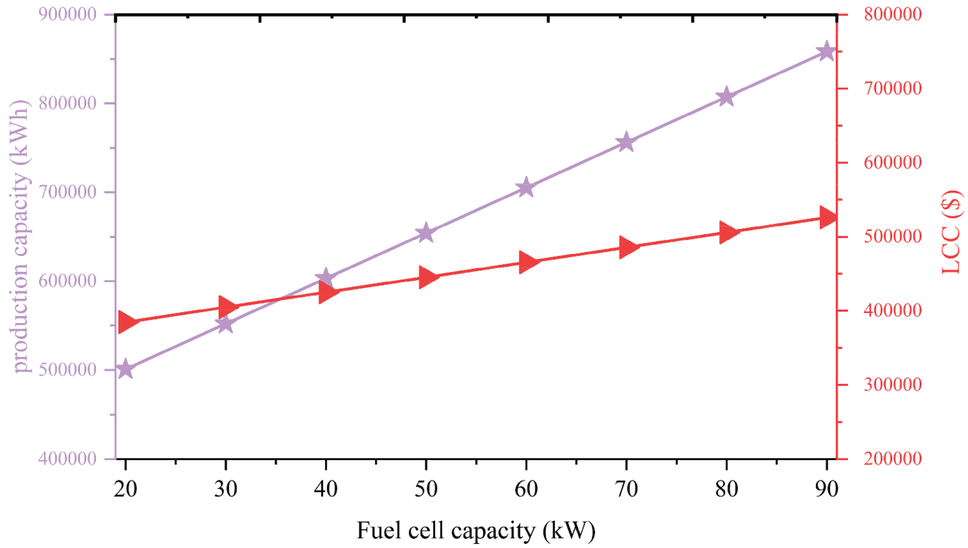

Figure 18. Improving the system's performance by increasing the fuel cell's capacity.

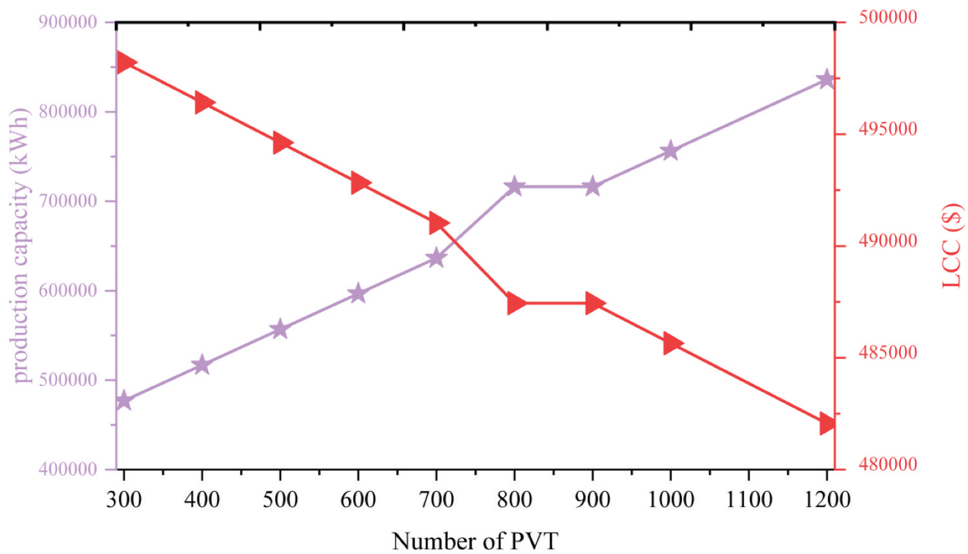

Figure 19. Enhancing system performance by adding more PVT.

alternatives for these resources. One of the alternative sources of fossil resources is renewable energy, which has attracted researchers' attention.

This study involved creating a solar renewable system model and utilizing an intelligent optimization method to increase the system's performance and lower the LCC. The proposed solar power system consisted of five PVT panel units, a heat pump, a proton exchange membrane electrolyzer, a hot water storage source, and fuel cells.

The purpose of designing and optimizing the proposed energy supply system for an 80-unit residential complex in Iran is that this system was proposed for different needs of the building, including hot water, cooling, heating, and electricity. In addition, the use of renewable solar energy helps to reduce the use of fossil resources, and with the reduction of fossil resources, the emission of carbon dioxide caused by the consumption of fossil resources to provide energy for residential buildings is also reduced. To analyze the performance of the proposed system, the weather data of four cities in Iran including Ahvaz, Dezful, Abadan, and Masjid Sulaiman were used. In this research, a new approach with TRNSYS software was used to model the system based on the proposed solar potential energy. To improve the performance of the solar system and lower life cycle costs (LCC) through design with Design Expert software, optimization was done using the response surface method.

The results are summarized as follows:

- A building complex has ten buildings with four floors and each floor has two units. Each unit was considered

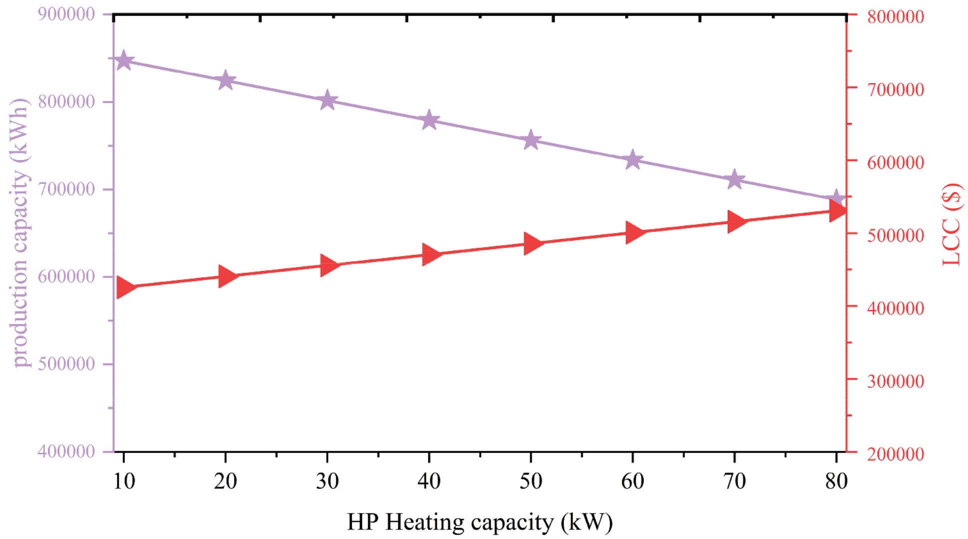

Figure 20. Effect of heat pump capacity on performance and cost.

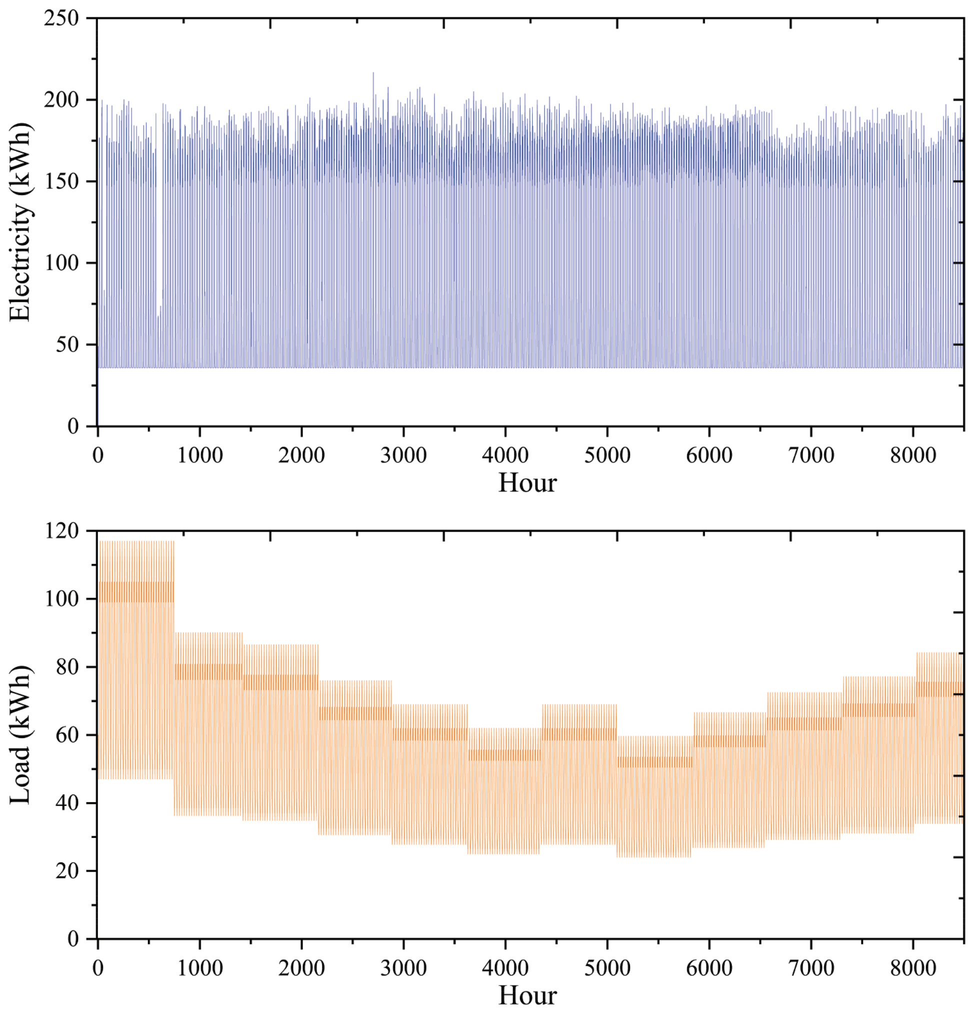

Figure 21. Comparison of produced electricity and electricity required by the building.

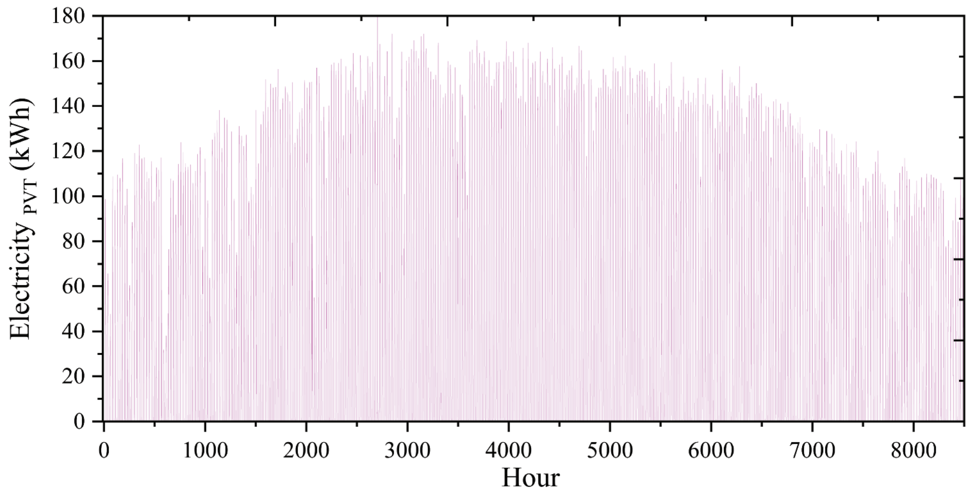

Figure 22. The hourly amount of electricity solar panels produce yearly.

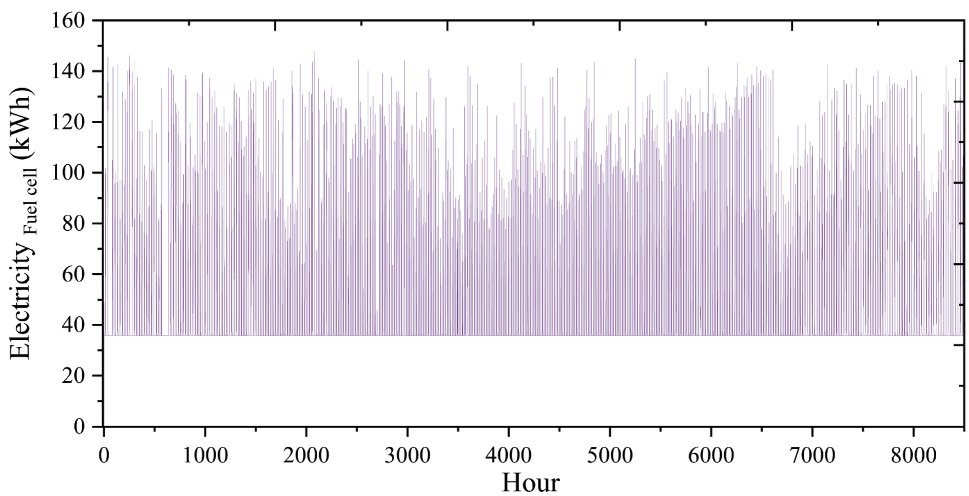

Figure 23. The amount of electricity the fuel cell produces.

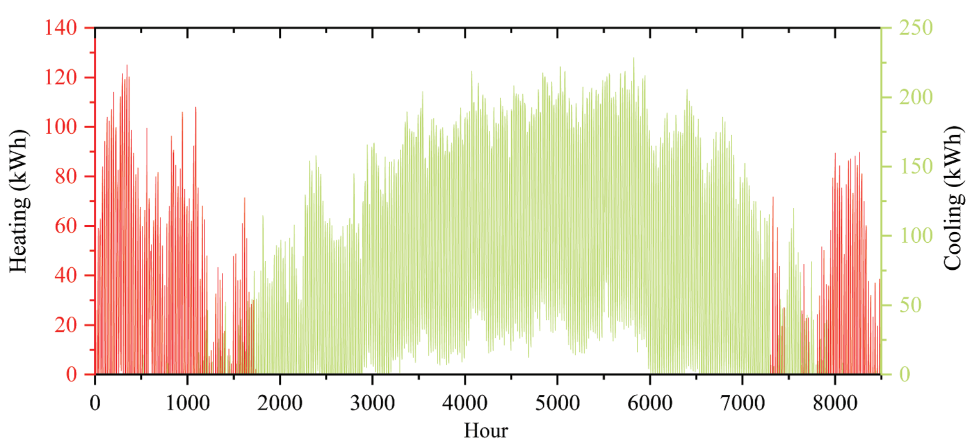

Figure 24. Annual changes in cooling and heating production.

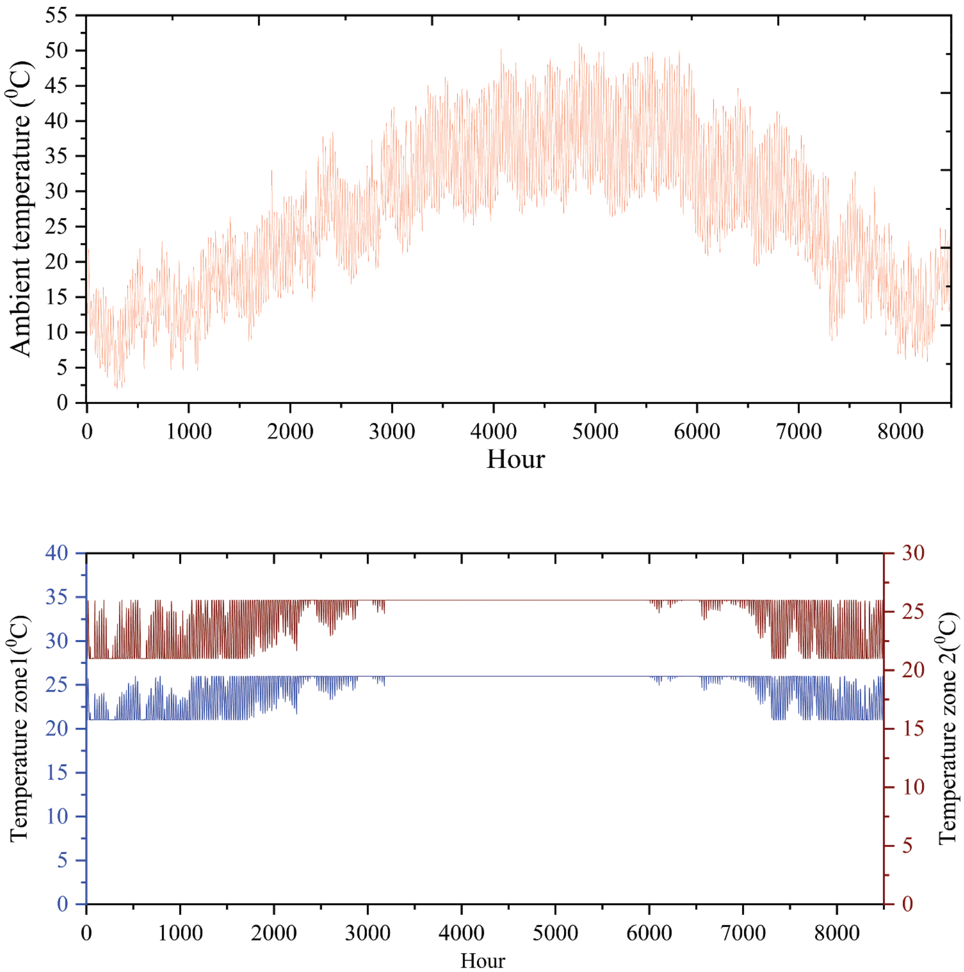

Figure 25. T_0 and temperature of residential complex areas.

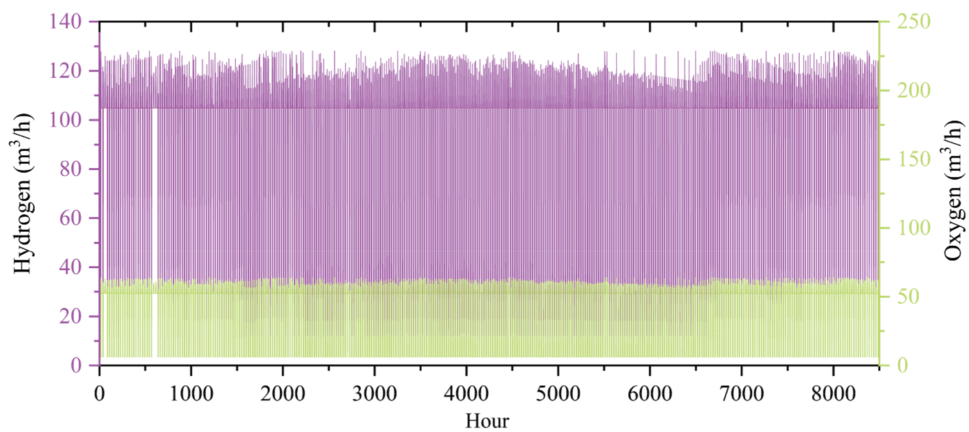

Figure 26. The hourly amount of hydrogen and oxygen the system produces yearly.

a typical residential area with an area of 190 square meters. There are four people in each unit and 320 people live in this building complex.

- The validation of photovoltaic thermal panels (PVT) was done using TRNSYS software with the research of Kanyarusoke et al.
- The most critical parameter affecting the performance of panels in different geographical conditions is the average daily sunlight duration in the region in hours, which is very high in the central and southern regions of Iran.
- Due to the dependence of this system on renewable solar energy, the selected areas are among the most potential solar areas and these cities have many solar hours.
- The studied cities are hot regions with an annual T0 temperature between 0 and 60°C.
- The results show that the power of solar radiation in these cities varies between 0 and 1000 watts per square

meter throughout the year. This shows that the studied cities have a significant potential for hourly solar energy.

- Abadan is the best area for setting up the proposed solar power system, which also has high solar potential.
- A study was conducted to analyze the cost of electricity production and the LCC of the system by examining five decision variables: the number of PVT panels, fuel cell capacity, heat pump cooling/heating capacity, and electrolyzer capacity.
- The LCC of Abadan city is lower than the other three studied cities. For this reason, the city of Abadan has been chosen for this comparison, which is the best region in terms of good performance and low cost.
- The results show that the thermal comfort coefficient in Abadan city is lower than the other three cities, so the cooling load requirement in this city is less than Dezful, which has a higher thermal comfort coefficient.
- In the most optimal mode, using 950 PV_T and a fuel cell with a capacity of 77.5 kW, along with 20 kW cooling capacity, 25 kW heating capacity, and 92.5 kW electrolyzer capacity, it is possible to produce a total of 467,414.309 kWh/year with LCC. An amount of $344,525.169 was received.
  1. The most influential parameters on the solar power system's performance include the number of solar panels and capacity fuel cells.
  2. The solar panel supplies the electricity required by the electrolyzer unit. In other words, it has a direct relationship with solar energy and the production of electricity by solar panels, which gives the electricity needed by the electrolyzer to produce hydrogen.
  3. The hydrogen and oxygen produced by the system are used to fuel the fuel cell.
  4. The results show that the temperature inside the building is changing in the range of 21 to 25 degrees Celsius, which is also considered the comfort temperature of this building.
  5. The minimum electricity produced by solar panels is between 0 (kWh) and 160 (kWh).
  6. By performing LCC analysis before making a decision on purchasing and replacing equipment, it is possible to examine different scenarios, identify and estimate the hidden costs that the organization will face in the future, and choose the best option among the available methods.

7.1. Suggestions

In this section, suggestions are given to the researchers to complete the present work:

- Today, the energy supply of buildings by renewable systems should be the attention of researchers, because fossil energies are running out and they have a lot of environmental pollution. For this reason, studies on the use of different types of renewable energy such as solar, wind, geothermal, etc., should be done by researchers so that the shortcomings of previous studies can be done to an efficient renewable system with high stability and reliability.
- The use of other cooling and heating production units in the current system, such as absorption chillers and water heaters, can lead to a comparison between the costs of the current system and the new system for a better display of costs and the correct use of cooling and heating production units. Because the discussion of cost in the design of renewable systems is considered a basic priority for researchers.
- The use of freshwater production units such as the reverse osmosis system can be suitable for use in areas where there is access to salty sea water and there is little fresh water, and it is important for residential houses to use fresh water.
- Combining the proposed system with wind turbines can help improve system performance and increase system stability.
- Using the neural network optimization method and combining it with the optimization method in the current research can help to improve the accuracy of the system optimization.
- The use of batteries can be used to store more energy and use in critical times and conditions.

Funding

The authors declare that no funds, grants, or other support were received during the preparation of this manuscript.

Nomenclature

A	*area (m^2)*
a	*axial induction factor*
AOC	*system's operating cost during a year ($)*
bf_n	*polynomial coefficients linking the load side Tdb, Twb, and supply side Tdb to the bypass fraction of the heat pump*
c	*specific heat capacity (J/kg.K)*
cp_n	*polynomial coefficients linking the load side Tdb, Twb, and supply side Tdb to the cooling energy input ratio (EIRc) of the heat pump*
G_T	*total solar radiation incident upon the collector surface (kJ/hr.m^2)*
d	*discount rate*
E_{PVT}	*generated electricity by PV/T collectors (kJ/h)*
EIR	*energy efficiency ratio*
$f_{totCool}$	*present fraction of rated overall cooling capacity*
f_{bypass}	*present bypass fraction*
$f_{fBypass}$	*present fraction of rated bypass fraction*
$f_{EER,c}$	*present fraction of rated cooling energy input ratio*
$f_{EER,h}$	*present fraction of rated heating energy input ratio*
f_{heat}	*present fraction of rated heating capacity*
$f_{sensCool}$	*present fraction of rated sensible cooling capacity*
hp_n	*polynomial coefficients linking the load side Tdb, Twb, and supply side Tdb to the heating energy input ratio (EIRh) of the heat pump*
I	*current (A)*
I_C	*initial investment cost ($)*
IAM	*incidence angle modifier*
L	*length (m)*
$F\text{-}C$	*Fuel cell*
LCC	*life cycle cost ($)*

M	*metabolic rate* ($W.m^{-2}$)
$\dot{m}$	*mass flow rate (kg/h)*
$n_{c,ser}$	*number of cells in series*
$n_{m,ser}$	*number of modules in series*
n_f	*number of factors*
n_t	*number of timesteps*
n_L	*lifespan (year)*
N_{tubes}	*number of tubes in the PVT collector*
EL	*Electrolyzer*
HP-HEAT	*Heat pump heating capacity*
HP-COLL	*Cooling capacity of the heat pump*
Q_{gen}	*total heat produced by fuel cell*
R_I	*resale income ($)*
sc_n	*polynomial coefficients linking the load side Tdb, Twb, and supply side Tdb to the sensible cooling capacity of the heat pump*
T	*temperature (℃)*
tc_n	*polynomial coefficients linking the load side Tdb, Twb, and supply side Tdb to the overall cooling capacity of the heat pump*
th_n	*polynomial coefficients linking the load side Tdb, Twb, and supply side Tdb to the heating capacity of the heat pump*
U	*voltage (V)*
x	*factor*
y	*response*
Abbreviations	
DE	*Design Expert*
HP	*heat pump*
PVT	*photovoltaic/thermal*
RSM	*response surface methodology*
NET	*production capacity*
PMV	*predicted mean vote*
a	*air*
f	*heat transfer fluid*
in	*inlet*
out	*outlet*
Greek symbols	
ε_m	*emissivity of the top surface of the collector*
ω	*absolute humidity ratio (kg/kg)*
η	*efficiency*
$\tau\alpha$	*transmittance-absorptance product for PV/T collector*
v	*Wind speed (m/s)*
ρ_a	*Air density* (kg/m^3)
θ	*angle of incidence (°)*

Disclosure statement

No potential conflict of interest was reported by the author(s).

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Author contribution

All authors contributed to the study concept, simulation, design, data collection, and analysis. This performance was supervised by Ali Dezhdar, Ehsanolah Assareh, Ali Ershadi, and Ahmad Arab Kohsar. Ali Dezhdar and all authors wrote the first draft of this version. Ahmed Arab Kohsar reviewed the manuscript, and all authors commented on previous versions of the manuscript. After reviewing all the authors, the final draft was prepared for submission to the journal. All authors read and approved the final manuscript.

Consent to participate

All the authors voluntarily agree to participate in this research study.

Consent for publication

All authors consent to the publication of the manuscript, should the article be accepted by the Editor-in-chief upon completion of the refereeing process.

Data availability statement

The experimental datasets obtained from this research work and then the analyzed results during the current study are available from the corresponding author on reasonable request.

Ethics approval

The authors consciously assure that the manuscript has not been published and is not under consideration for publication elsewhere.

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