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Investigating the performance of air conditioning systems in different climates of the country based on geothermal and solar energy

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Extended Abstract

Introduction

The increasing depletion of fossil fuel resources, together with the environmental pollution associated with their consumption, has intensified the need to develop clean, renewable, and economically viable energy systems. Solar and geothermal energies are among the promising renewable resources that can be integrated into building energy systems to reduce dependence on conventional energy sources and improve environmental sustainability. Iran has considerable potential for solar energy utilization due to its favorable solar radiation conditions, while the relatively stable temperature of the ground provides an attractive opportunity for geothermal heat pump applications. The simultaneous utilization of solar and geothermal energy can therefore provide a suitable solution for heating and cooling buildings under different climatic conditions. Previous studies have investigated hybrid solar–geothermal systems from energy, exergy, economic, and environmental perspectives; however, the influence of different Iranian climates on the seasonal performance, exergy efficiency, exergy destruction, photovoltaic area, and refrigerant flow rate of such systems requires further investigation. Accordingly, the present study evaluates the performance of a hybrid air-conditioning system powered by solar photovoltaic and geothermal energy under different climatic conditions in Iran.

2. Materials and Methods

A hybrid air-conditioning system based on solar photovoltaic (PV) and ground-source heat pump (GSHP) technologies was modeled and analyzed using the Engineering Equation Solver (EES). The proposed system consists of three interconnected thermodynamic cycles. The first cycle is the geothermal loop, in which water circulates through a ground-source heat exchanger (GSHX) to exchange thermal energy with the ground. Depending on the operating mode, heat is either extracted from or rejected into the ground. The second cycle is a vapor-compression refrigeration cycle using R134a as the working fluid. A four-way valve enables the system to switch between heating and cooling modes. In heating mode, the evaporator extracts heat from the geothermal loop and the condenser transfers heat to the building-side loop, whereas in cooling mode the heat-transfer directions are reversed. The third cycle is the building-side heating and cooling loop, in which water circulates through a fan-coil unit to exchange heat with the indoor space. The electrical power required by the compressor, pumps, and fan-coil is supplied by photovoltaic panels, while batteries are employed to store excess electricity generated during periods of high solar availability.

The thermodynamic analysis was based on mass, energy, and exergy balance equations. The analysis considered the exergy supplied to the building, exergy destruction, second-law efficiency, and irreversibility of the main components, including the fan-coil heat exchanger, compressor, evaporator, condenser, expansion valve, GSHX, and PV system. The ground temperature was evaluated as a function of annual mean temperature, temperature-wave amplitude, frequency, time of the warmest day, ground depth, and soil thermal diffusivity. The required length of the GSHX was then determined based on the thermal resistance of the ground, pipe, and circulating water. For the PV subsystem, solar radiation, panel area, electrical output, and exergy input and output were considered. The system was evaluated for six Iranian cities with different climatic conditions: **Isfahan, Yazd, Shahrekord, Tehran, Zahedan, and Tabriz**. A 100 m^2 room with eight double-glazed windows was considered for the final comparative analysis. The heating and cooling loads of the building were calculated using Carrier software, while the governing thermodynamic and exergy equations were simultaneously solved in EES. The model was also validated against previously published results, with differences of up to approximately 15% in some months, mainly attributed to unavailable input data and differences in assumptions between the studies.

3. Results and Discussion

The results demonstrated a strong dependence of the hybrid system performance on seasonal and climatic conditions. The exergy efficiency of the cooling cycle remained relatively constant during the warm seasons and reached a minimum value of approximately **2%**. In contrast, exergy efficiency increased considerably during the cold seasons. This behavior was primarily attributed to the performance of the geothermal heat pump. During the warm seasons, the temperature difference between the ground and ambient environment is relatively small, resulting in lower available geothermal exergy. In the cold seasons, however, the ground temperature remains comparatively stable while the ambient temperature decreases substantially, leading to a larger temperature difference and consequently greater geothermal exergy availability. The highest exergy efficiencies were therefore obtained during the cold months, particularly **January and December**.

The exergy destruction analysis revealed that the **PV subsystem was the dominant source of irreversibility** in the overall system. The photovoltaic cells, AC/DC converter, and battery system were responsible for approximately **82% of the total input exergy destruction**. The second-largest contribution was associated with heat transfer in the evaporator and condenser, which together accounted for approximately **8.955%** of the total input exergy destruction. These results indicate that improving the efficiency of the photovoltaic subsystem and reducing the mismatch between solar energy availability and building demand are key factors for enhancing the overall second-law performance of the system.

The analysis of design constraints indicated that the two major design parameters governing the performance of the proposed system are the **length of the ground-source heat exchanger and the required PV panel area**. Variations in these parameters directly influence the exergy performance of the system. Moreover, climatic conditions significantly affect the optimum design. The study showed that designing the system exclusively for the peak heating or cooling demand can result in considerable exergy destruction during most of the operating year because the PV panel area and GSHX length are then oversized for periods with lower energy demand. The exergy losses resulting from the mismatch between available and required exergy were found to be considerably greater in the PV subsystem than in the geothermal subsystem.

The results further demonstrated that a considerable fraction of the installed PV capacity remains unused during warm seasons. The maximum exergy destruction rate associated with this mismatch occurred in **April**, when the heating and cooling loads were relatively low. According to the analysis, more than **80% of the exergy destruction during this period could potentially be reduced through battery energy storage**. Therefore, rather than sizing the entire system according to the worst-case operating condition, an optimized design based on the average energy demand combined with an appropriate energy-storage system can significantly reduce avoidable exergy destruction.

The refrigerant mass flow rate also exhibited substantial seasonal and climatic variations. For **Isfahan**, the highest refrigerant flow rates occurred during the cold winter months, when both the required PV panel area and GSHX length reached their maximum values. The simultaneous occurrence of high energy demand and relatively low solar radiation during these periods increased the irreversibility of the system, with the additional irreversibility being primarily associated with the heat exchangers of the refrigeration cycle. Similar climatic dependencies were observed among the six investigated cities, demonstrating that a single fixed system configuration may not provide optimum performance across different Iranian climates.

4. Conclusions

A thermodynamic and exergy-based assessment of a hybrid solar–geothermal air-conditioning system was conducted for different climatic conditions in Iran. The results confirmed that integrating photovoltaic energy with geothermal heat pump technology can provide an effective renewable-energy-based solution for building heating and cooling. The system exhibited its highest exergy efficiency during the cold months, particularly January and December, primarily because of the larger temperature difference

between the ground and ambient environment and the consequently improved performance of the geothermal subsystem. In contrast, the exergy efficiency during the warm seasons decreased to approximately **2%**.

The analysis identified the PV subsystem as the principal source of exergy destruction, accounting for approximately **82%** of the total input exergy destruction, while the evaporator and condenser together contributed approximately **8.955%**. The study also demonstrated that the GSHX length and PV panel area are the most important design constraints and that their sizing must be adapted to the climatic conditions and seasonal energy demand of the building. Oversizing these components for peak conditions can lead to substantial avoidable exergy destruction during periods of low demand. In particular, more than **80% of the exergy destruction during April** could potentially be mitigated through appropriate battery storage. Therefore, optimizing the system based on average energy demand and integrating energy storage can improve its overall thermodynamic performance. The findings demonstrate that the climatic characteristics of Iranian cities should be explicitly considered when designing hybrid solar–geothermal air-conditioning systems, and that coordinated sizing of PV panels, GSHX length, refrigeration-cycle parameters, and energy storage is essential for achieving higher efficiency and lower exergy destruction.

Key words: Renewable energy, energy analysis, exergy analysis, air conditioning system

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