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# Life cycle assessment optimization of hybrid power gas heat pump integrated with photovoltaic

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**Abstract**

Building energy consumption accounts for a large proportion in the total social energy consumption and solar energy plays an important role in the building renewable energy system. A novel hybrid power gas heat pump system integrated with photovoltaic is put forward in this paper. An optimization design based on life cycle assessment for the solar assisted hybrid power gas heat pump system (SHPGHP) is proposed in consideration of three main environmental impact factors: human health, ecosystem quality and resources. The normalized environmental impact for the system during the whole life cycle is chosen as the objective to minimize the life cycle environmental impact. The influence of main independent decision variables is employed including the photovoltaic ratio, transmission ratio and mixing degree. Results show that the optimal photovoltaic ratio is 0.4. The system's environmental impact potential increases with the increase of transmission ratio and decreases with the increase of mixing degree.


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*Keywords:* hybrid power heat pump; life cycle assessment; optimization; photovoltaic

**Nomenclature**

| | |
|---|---|
| Q | energy consumption |
| P | pollutant emission |
| θ | Photovoltaic ratio |
| η | Transmission ratio |
| χ | Mixing degree |

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## 1. Introduction

With the increasingly significant issues of energy crisis and environmental damage, energy conservation and environmental protection is an important problem the whole society has to face. Building energy consumption accounts for 40% of the total global social energy consumption and energy use in buildings mainly consists of electricity for lighting and equipment, cooling, heating and domestic hot water and other auxiliaries. What's more, HVAC energy consumption accounts for 45% of the total building energy in a typical residential building [1]. As can be concluded building energy consumption plays an important role in social energy consumption and HVAC energy consumption plays an important role in building energy consumption.

A heat pump is a device that transfers low grade heat source into high grade heat source and attracts worldwide attention because of its high efficiency and economic benefits. A gas heat pump, as the name suggests, is a heat pump system that uses a gas engine to drive the compressor to achieve summer cooling and winter warming. The conventional gas heat pump usually runs at partial load, which means with the change of the user needs, the engine operating conditions change frequency and the heat pump system often runs at a relatively low load, even at the idle running state. This leads to a low engine running thermal efficiency and high emissions, thus reducing the operating performance of the whole heat pump system. As the hybrid power gas engine-driven heat pump system has two power sources: the battery and the engine, the engine can run in its economic zone to avoid the defects of conventional gas heat pump systems effectively through the cooperation and coordination of the two sources.

The hybrid power gas heat pump was firstly put forward by the Air Conditioning and Refrigeration Laboratory of Southeast University [2]. The HPGHP system (hybrid power gas heat pump system) combines hybrid-power technologies with gas heat pump technologies, using the gas engine and battery packs as the power sources. The engine can work in the fuel economical zone by optimally matching the two power sources, thus reducing system exhaust emissions and improving system fuel economy. Li[3] found that the HPGHP has a superior thermal efficiency of 37% and 27% respectively for maximum and minimum, while those for the conventional gas heat pump systems are only 33% and 22%. Wang's[4] research showed that HPGHP could achieve a better fuel conversion efficiency than the conventional gas heat pump under different operating conditions and also better environmental benefits on human health and ecosystem quality when running more than 1778 h. Wang[5] designed a steady-state model of the coaxial parallel-type driven system in order to discuss the matching relationships between the compressor dynamic load and driven system and proposed a new way to determine the transmission ratio for optimal matching of the load and source. Based on previous work, Jiang[6] developed the optimal torque curve control strategy for HPGHP to distribute powers between the engine and the battery pack. Simulation results show a good accordance with the demand conditions when evaluating the effectiveness of the model and control strategy. The above literature review shows that the previous work mainly focuses on the matching of engine and battery power to get a better fuel efficiency and the optimization work aims at the fuel combustion and operating efficiency.

Life cycle assessment (LCA) has gained in popularity in the last three decades for the emerging problems of energy and environment. Two main objectives are included in the LCA system: to quantify the environmental impact of a product or a process, or to provide a basement to evaluate the potential environmental improvements for a product or a process. A typical LCA process includes four stages: objective and scope determination, life cycle inventory, impact assessment and assessment interpretation.

The scope of a SHPGHP usually considers the following four phases: raw material gathering, processing & manufacture, operation & maintaining and disposal. All initial inputs of the system are considered in the raw material gathering. Processing and manufacture consider the energy consumption and transportation in construction activities and transportation. Nature gas is the main energy source during operation stage. At the end of the life cycle the system is selectively recycled according to the policy and strategy.

The inventory analysis is a process of objectively quantifying the resources, energy inputs and outputs of a product or process's life cycle, and the list of inputs and outputs of the material flow and energy flow inside and outside the system. Inventory analysis and improvement of the system boundary is a constant adjustment process.

The energy inputs and pollutant emissions during the life cycle can be calculated by equation 1 and 2:

$$Q = Q_1 + Q_2 + Q_3 + Q_4 + Q_T = \sum\left(q_i \times M_i\right) \tag{1}$$

$$P = P_1 + P_2 + P_3 + P_4 + P_T = \sum\left(p_i \times M_i\right) \tag{2}$$