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An optimization method applied to active solar energy systems for buildings in cold plateau areas – The case of Lhasa ☆

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HIGHLIGHTS

- Develop an optimization model for integrated solar energy systems.
- Apply the model to a typical office building located in Lhasa.
- PV systems are superior to solar thermal systems in cold plateau areas.
- Financial subsidies influence the system more than commercial electricity prices.
- Conduct LCA to compare performances of an optimal system and a conventional one.

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ABSTRACT

Solar energy for building applications may significantly reduce the conventional energy consumption and the related carbon dioxide emissions. The comprehensive utilization of integrated solar thermal and photovoltaic systems is undoubtedly a subject of interest. In the present paper, an optimization model was proposed for integrated solar energy systems, aiming to figure out the optimal utilization and economical efficiency of solar energy resources for buildings in cold plateau areas. A case study in Lhasa city was further carried out in order to evaluate the energy and economic performance of the developed model. The results indicated that solar photovoltaic systems are preferred than solar thermal systems for typical office buildings in cold plateau areas with rich solar energy resources. In addition, a sensitivity analysis was performed to investigate the influences of financial subsidies and commercial electricity prices on the system economical performance. Furthermore, life cycle assessment was conducted to compare and analyze the performances of an optimization system and a conventional system.

1. Introduction

With the remarkable growth of the plateau architectural areas, shortage of traditional building energy supply and fragility of ecological environment are becoming the prominent factors to restrict the development of the plateau areas. As an effective, renewable, safe and eco-friendly energy resource, efficient utilization of solar energy has undoubtedly been regarded as an encouraging solution to global energy shortage, as well as an effective way to achieve sustainable development for human beings. Qinghai-Tibet Plateau, Inner Mongolia Plateau and other plateau areas with abundant solar energy resources show high potentials to develop solar energy systems for buildings on a large scale. In addition, solar thermal and photovoltaic technologies have been widely applied in plateau buildings due to the rapid development of solar energy technologies and the gradual cost reduction of solar energy utilization equipment [1]. Therefore, integrating high-efficient solar energy systems with low energy consumption buildings is of great significance in energy and cost saving for plateau areas, which has drawn more and more attentions in recent years.

Active solar thermal application technologies have recently become a research emphasis in the field of building solar utilization with the rapid development of active solar energy products

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[2–5]. Maurer et al. [6] presented four new and simple models for the building-integrated solar thermal systems, which are more accurate than neglecting the coupling to the buildings and less complicated than detailed physical models. Lamnatou et al. [7] evaluated their patented building-integrated solar thermal collector, and revealed that configuration with collectors in parallel connection may considerably improve the environmental profile of the configuration with collectors in series. Mateus et al. [8] carried out an energy and economic analysis of an integrated solar absorption cooling and heating system for building applications by the TRNSYS software tool, considering different building types (residential, office and hotel) and climates (Berlin, Lisbon and Rome).

On the other hand, photovoltaic (PV) modules which have the peculiar characteristic of being integrated with buildings becomes one of the best options to utilize solar energy by capturing and converting it into electricity directly [9,10]. Hwang et al. [11] analyzed the maximum electric energy production according to the inclination and direction of photovoltaic installations. Vats et al. [12] carried out comparative studies between a building integrated semitransparent photovoltaic thermal system and a building integrated opaque photovoltaic thermal system, which are respectively integrated to the facade and roof of a room with and without air duct for ventilation for the cold climatic conditions of Srinagar, India. Peng et al. [13] systematically discussed issues concerning building-integrated photovoltaic (BIPV) in architectural design in China, and further proposed a novel structural design scheme for BIPV, with the characteristics of easy maintenance and replacement of photovoltaic cell modules, prefabricated in factories and mounted on site. Zomer et al. [14] compared BIPV and building-applied photovoltaics (BAPV) approaches by using typical figures of merit to assess the technology and layout of PV modules to be installed on the building envelope of two Brazilian Airports, and then reached a compromise of pleasant integration and small energy losses. A number of developed life cycle impact assessment (LCIA) methodologies, such as the RECIPE methodology [15], the Eco-Indicator 99 (EI99) methodology [16,17] and the Eco-Scarcity methodology [18], have been applied to conduct life cycle assessment (LCA) of PV systems. In addition, the use of concentration technologies is beneficial on reducing the environmental burdens. Therefore, two widely used methodologies EI99 and EPS 2000 are used to perform the life cycle impact assessment and environmental impact evaluation, respectively, and the results showed that significant benefits are gained using the Building Integration Concentrated Photovoltaics (BICPV) schemes [19].

Several studies have also been devoted to study the combined heating and power system (CHP), which not only produces solar electric energy but also delivers thermal energy as the byproduct [20,21]. Michael et al. [22] combined the electrical and thermal components in a single unit area and proposed a reference guide for flat plate solar photovoltaic-thermal systems, to overcome the disadvantages of the low energy of the solar PV module, the low exergy of the solar flat plate thermal collector and limited usable shadow-free space on building roof-tops. Sanaye et al. [23] presented the energy, exergy and economic optimization of a combined cooling, heating and power (CCHP) solar generation system equipped with conventional photovoltaic, concentrated photovoltaic/thermal (CPVT), and evacuated tube (ET) collectors, to achieve the highest values of relative net annual benefit (RNAB) and exergy efficiency as two objectives.

According to above discussions, a variety of researches have investigated the independent solar thermal technologies, independent photovoltaic technologies and combined photovoltaic thermal systems applied in the buildings. However, few studies focused on the comprehensive photovoltaic thermal utilization systems used in most plateau areas because of the complexity of integrated solar thermoelectricity coupling systems and the shortage of corresponding design methodologies, significantly hindering the promotion of the integrated photovoltaic and thermal systems. Therefore, in this paper, an optimization model coupled with solar thermal and photovoltaic systems is proposed. Based on the developed model, a case study for a typical office building located at Lhasa is illustrated to reasonably configure the solar thermal and photovoltaic systems. This study aims to achieve the optimization utilization and economical efficiency of solar energy resources for buildings in cold plateau areas.

2. Methodology

2.1. Study area

Tibetan plateau is characterized by all year-round sunshine, dry climate and long heating supply period. The solar radiation over the Tibetan plateau is greater than that over other sites in China, which ranks second on earth, following the Sahara Desert [24]. According to the 5-year observation data received by a set of pyranometer instruments set up in Gaize, on the Tibetan Plateau, the average daily radiation was 21 MJ m^{-2} day^{-1} with maximum daily values of 27 MJ m^{-2} day^{-1} occurring in June and minimum values of 14 MJ m^{-2} day^{-1} in December, which is much higher than those measured in other regions at similar latitudes [25].

2.2. Physical model

Based on the climate and energy supply features in plateau cold areas, an active solar energy comprehensive utilization system applicable is proposed. In winter, the system utilizes the solar thermal as the main heating source, while utilizes the power-driven air source heat pumps as an auxiliary thermal source; meanwhile, the system utilizes a photovoltaic power generation system which could deliver the generated power to the grid, relieving the power supply shortage. In summer, ventilation rather than chiller can meet indoor cooling requirements due to relatively low temperature around 16.4 °C in the hottest month of June. The entire system is highly effective and environmentally friendly, and beneficial to protect the fragile ecological environment. The schematic drawing

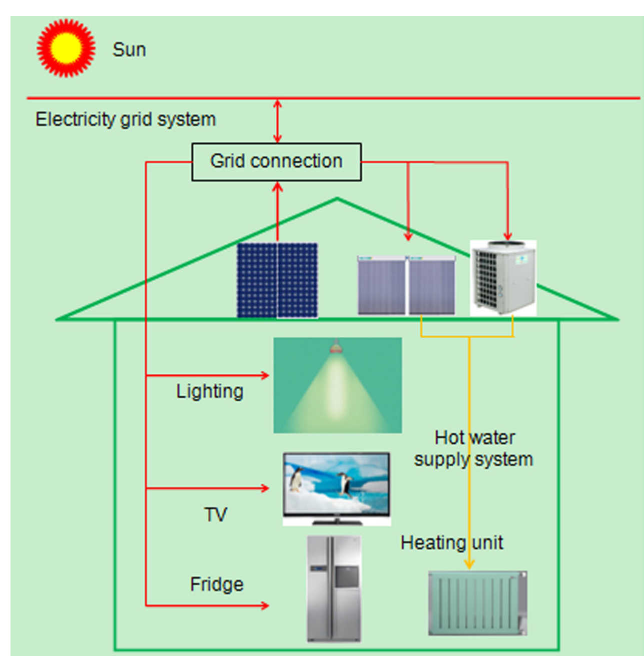

Fig. 1. System physical model.

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