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Coupling characteristics of PV generation and energy consumption in PV building: based on operation data of a ZEB in Beijing

Summary

Coupling characteristics of PV generation and energy consumption are important for optimizing PV system design and achieving higher energy-saving and emission reduction goals. Yearly operation data of a Zero Emission Building in Beijing have been analyzed. Electricity and heat consumption, PV power generation with different orientations and types, and also the coupling characteristics of typical office buildings have been investigated. Results show that the annual energy consumption per building area was 64.9 kWh/m^2, and the PV generation was 73.2 kWh/m^2 per building area, achieving net zero emissions in operation stage. Annual self-consumption rate was 30.9%, and the self-sufficiency rate of building electricity consumption was 57.5%. It has also been found the PV generation hours of thin-film modules were 142 hours longer, but their electricity output was 23.1% less than monocrystalline silicon modules with same tilt. The relevant data could provide reference for design and optimization of low carbon of zero emission buildings.

Keywords: PV building, PV generation efficiency, self-consumption rate, self-sufficiency rate

Field of application for the findings: Low carbon or zero carbon buildings

Addressed audience: Researchers in the field of Building PV System

1. Introduction

In China, building operation energy consumption accounts for approximately 22% of total national energy consumption, and carbon emissions also account for around 22% of the total. Promoting applications of renewable energy such as PV system in building sector is a promised way to achieve the national carbon reduction strategy.

PV building is not only applying PV systems on buildings, but also deep integration of electricity consumption and PV output to improve self-consumption rate (SCR), to get better economic performance and realizing building energy conservation and carbon reduction. Generally, both building energy consumption and PV generation are unstable. Therefore, coupling characteristics of PV generation and energy consumption constitute an important foundation for optimizing design of building PV systems.

However, current studies on the coupling characteristics analysis mostly rely on simulated data. Talavera et al. (2019) proposed a method for determining the scale of building PV systems based on the PV SCR and building self-sufficiency rate (SSR), aiming to maximize self-consumption and minimize grid impact. Ma et al. (2022) analyzed the economy and optimized configuration of grid-connected PV-battery systems in residential buildings based on annual hourly simulations. Fresitas et al. (2018) optimized the size of PV system on building facades and roof to improve the SSR through simulation. Zou et al. (2022) established a PV-battery system model to investigate the coupling characteristic in an office building.

Regarding studies based on actual operation data, Fan et al. (2019) established building energy consumption prediction models with monitoring data. Liu et al. (2021) conducted optimization analysis on PV, battery and hydrogen vehicle storage systems based on operation data from a net-zero energy community, but such monitoring data were mainly used for validation.

In summary, most current research on coupling characteristics of PV generation and building energy

consumption is simulation-based, while relatively few studies based on long-term operation data.

This study is based on actual monitoring data of a zero emission office building in Beijing. The annual electricity and heating consumption have been quantitatively analyzed, together with actual electricity generation of PV systems with different orientations and types. The coupling characteristics and comparing results could provide a references for the optimal design of PV and flexible control systems in such low carbon or zero emission projects.

2. Building and PV systems

The building analyzed in this study is located in Chaoyang District, Beijing, China. It is a 2-story office building with a total floor area of 3 025 m², accommodating about 200 office staff. This building has been retrofit to a zero emission building in December 2021. About 236.1 kWp PV panels were installed on the roof and façade (Wuyun et al. 2024).

To conduct research on generation performance comparison of PV systems with different module types, orientations and installation tilts, the building has been specially designed. Monocrystalline silicon, thin film, translucent PV glass, and other types of PV modules were adopted in this building. And all the PV systems were divided into 10 subsystems for metering generation data separately.

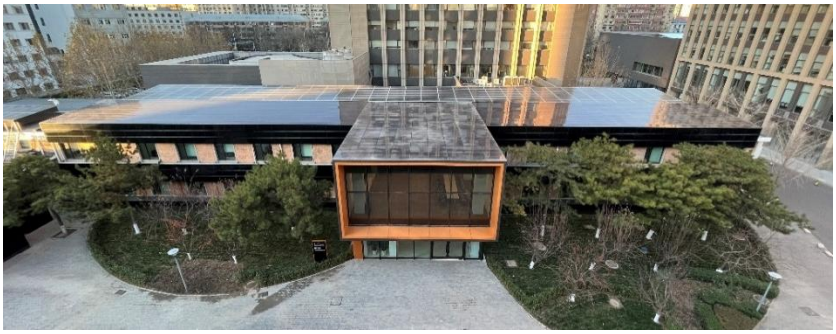
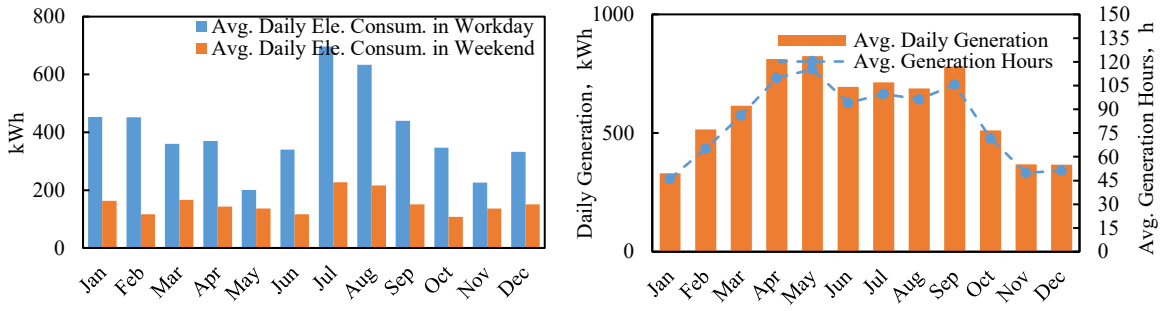


Fig.1: Zero emission building outlook

3. Data analysis

3.1. Building Energy Consumption

According to monitoring data in 2022, the effective period was 314 days (some days monitoring system stops due to covid-19), and total electricity consumption was 102 072 kWh. After converting to 365 days on monthly basis, total electricity consumption was 116 041 kWh, about 38.7 kWh per building area. Because it is an office building, the electricity consumption dropped a lot during weekends, as shown in Fig.2 (a). Besides the electricity consumption, this building had a space heating system using hot water provided by district heating system. The annual heating energy was about 179 576 kWh.



(a) Average daily electric consumption for each month (b) Average daily PV output for each month

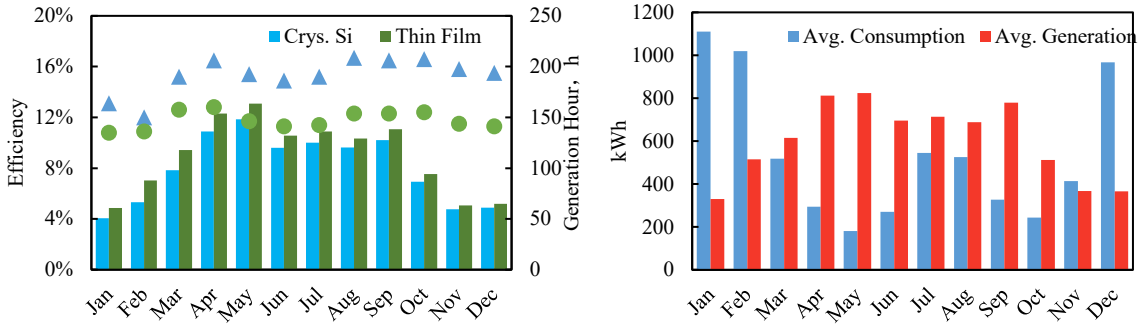
Fig.2: Monthly electric consumption and generation

3.2. PV generation

In 2022, total horizontal solar irradiance during monitoring period was 1250.6 kWh/m², and the total PV

generation was 182 071 kWh. After converting to 365 days on monthly basis, the total PV generation was 219 561 kWh, about 73.2 kWh per building area. And average daily PV generation was 601.5 kWh, annual power generation hours was 990.8 h. The average daily electric power output and power generation hours of PV system for each month are shown in Fig.2(b).

There are 2 PV systems with same area, orientation and tilts on the roof, the difference is that one uses monocrystalline silicon modules (STC efficiency 20%) and the other uses thin-film modules (STC efficiency 15%). Fig.3(a) shows the performance for these 2 systems. It could be found that the PV generation hours of thin-film modules were 142 hours longer. However, thin-film system's electricity output was 23.1% less than monocrystalline silicon system due to the efficiency difference.



(a) Comparison of monocrystalline silicon and thin film modules

(b) Average daily power generation and consumption

Fig.3: Monthly module performance comparison, energy consumption and generation

3.3. Coupling characteristics

Based on the 2022 monitoring data, the total PV generation was 219 561 kWh, and the total energy consumption was 194 523.7 kWh. In general, the annual net energy output was 25 037.3 kWh, about 11.4% of total electricity generation. This building realized zero emission in operation stage.

For the coupling of generation and consumption, annual SCR was 30.9%, and SSR was 57.5%. The SCR was relatively low in transition season, and the SSR was relatively low in winter. The introduction of energy storage and flexible energy consumption technologies could further improve their coupling performance.

These results could provide reference for design and optimization of low carbon of zero emission buildings.

4. References

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