Building-to-vehicle and vehicle-to-building concepts toward net zero energy building: A small solar house case study in China

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Abstract. In the future, the number of electric vehicles will increase significantly, promoting the integration of renewable energy into buildings and electric vehicles, which helps to achieve energy greening in transportation and architectural fields. The system includes renewable energy, buildings, electric vehicles, and energy storage systems. In this paper, the mathematical model of each system is established, and the electricity consumption of the building and the power generation of PV panels are predicted by the Energyplus software, and the economic evaluation index is proposed. In addition, the research analyses the effect of electric vehicles as electrical vectors in integrated PV panels and storage. The small solar residential data shows that through building-to-vehicle and vehicle-to-building solutions, on-site renewable energy utilization can be achieved, which is also conducive to building a zero-energy-consumption home.

1 Introduction

The economic development and population growth have exacerbated energy consumption, which in turn leads to emissions of carbon dioxide, causing global temperature rise. Industry, architecture and transportation areas are the world's three major carbon emissions. Since most of the carbon dioxide emissions come from the combustion of fossil fuels, energy greening in building and transportation is very important for achieving carbon peaks and carbon.

In recent years, electric vehicles have shown great advantages in response to energy and environmental problems, and with the breakthrough of battery technology, electric vehicles have been favored by countries with electricity oils[1]. In 2020, the global car sales fell by 14% year-on-year, but the pure electric vehicle rose by 41%, and the sales volume reached 31.25 million. In order to promote electric vehicles, China has introduced a series of policies and norms[2]. Electric vehicles need to be need to be charged nearby, so that in the future, the relationship between buildings and transportation will be closer.

Building-to-vehicle(B2V) and vehicle-to-building(V2B) facilitate collaborative planning of building energy systems and electric vehicles to build zero energy consumption. B2V technology can charge an excess capacity of photovoltaic production installed on the building roof to the electric vehicle. V2H function describes a scene, i.e., an plug electric vehicle (PEV) not only supplies charge from the grid, but also provides a spare power supply (such as a home) to the island load (such as a home) during the peak of the power grid[3,4]. The charge and discharge electric vehicle is also an effective means of electricity storage[5,6,7]. V2H systems with roof PVand electric vehicles have been explored to improve PV utilization[8]. An electric vehicle integrated operation decision model is proposed[9]. The study is simplified based on a short time electrical energy and thermal energy demand data associated with electric vehicle charging stations and electric vehicle charging stations. The simulation of a certain day in summer is designed to minimize the operating cost of the construction and charging station (about 23% of the economy).

Economic issues of electric vehicles are also considered. It is found that the initial cost of electric vehicles is higher than traditional diesel or gasoline cars, but in the long run, the power cost of electric vehicles is expected to be much cheap[10]. Moreover, considering the vehicle to the grid (V2G) cycle cost related to the battery degradation, the study found that the aging of the battery will reduce the system income[11,12]. Through experiment, the experience formula between the battery discharge depth and the number of cycles was derived[13]. A method based on semi-empirical lithium-ion battery capacity attenuation model is used to quantify the electric vehicle (EV) battery from only the degradation of several vehicle grid services. Detailed electric vehicle battery pack thermal model and electric vehicle power system model for capturing battery temperature and operating parameters that change the electric vehicle while driving and providing various grid services, including current, internal resistance, and State of Charge(SOC) [14].

Although electric vehicles with bidirectional charging and discharging have been developed, most of them are concentrated in office buildings, and the scene is relatively simple. This paper focuses on two-story single-family buildings in the Hailar pastoral area of Inner Mongolia to explore the role of electric vehicles in moving towards zero-energy buildings and achieving low-carbon goals in the transportation sector.System description.

1.1 Building

1.1.1 Location

The building in this study is located in the pastoral area of Hailar District, Hulunbuir City, Inner Mongolia Autonomous Region, China, in the northeast of Inner Mongolia (longitude: 119.75°E; latitude: 49.6°N) 。The geographical location is shown in Figure 1. Hailar is the border city, the wood imports are convenient, and the residents are based on grazing.

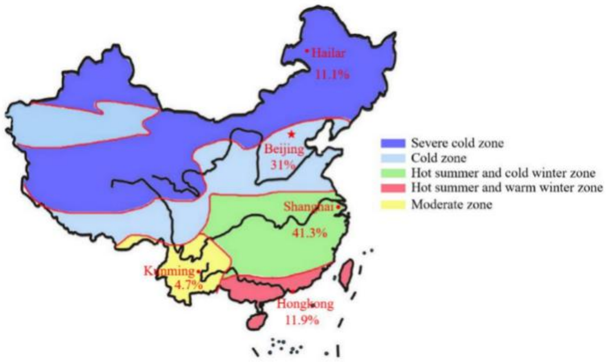

Fig. 1. Geographical location.

1.1.2 Structure

The building in this study is a double wooden structure building. The appearance is shown in Figure 2, with an area of 56m^2 per layer, a building area of 112m^2, and a planar partition is shown in Figure 3. This article only considers the electric load of the building.

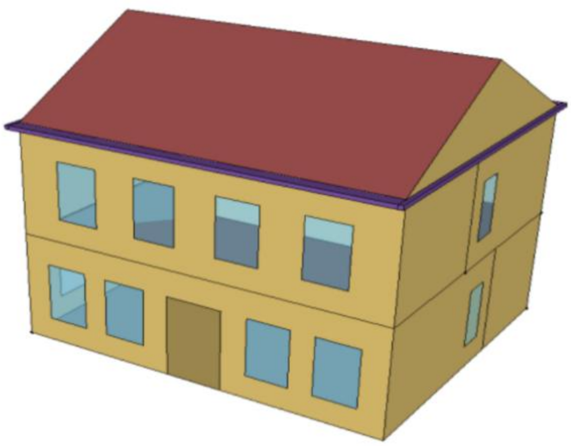

Fig. 2. Building appearance.

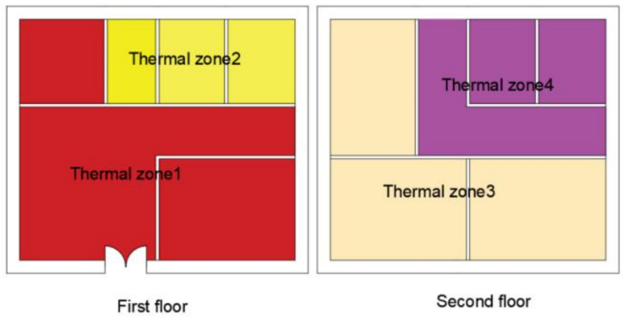

Fig. 3. Building layout.

1.2 System

The system consists of building, solar photovoltaic, household batteries, electric vehicles and grids. The energy flow of electricity is shown in Figure 4. When the demand side (building electricity and electric vehicle) is greater than the supply side (the power generation of the PV panels), the battery is added to the supply test. If the demand side is still greater than the supply measurement, the electric vehicle can charge the building from the grid. When the demand side (building electricity and electric vehicle) is less than the supply side (the amount of power generation of the solar PV panels), the excess amount can be stored in a household battery. The flow chart of the control strategy is shown in Figure 5.

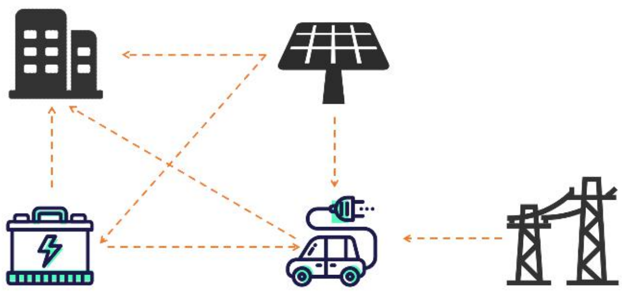

Fig. 4. Electric energy flow.

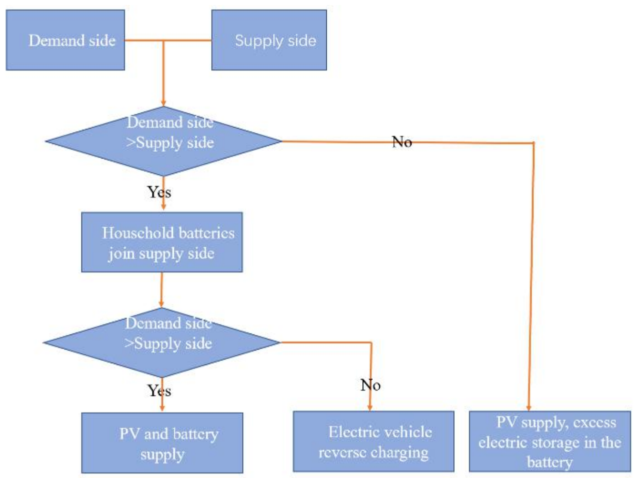

Fig. 5. Control Strategy.

2 Mathematical models

2.1 Electric vehicle model

The Tesla model 3 was selected for this study, with a battery capacity of 75KWh and a battery life of 605Km. The core component of the electric vehicle is a battery, and the model of electric vehicles adopts a vehicle model with charge and discharge function[15].

$$\frac{d}{dt}E_{bat} = \eta_{bat}P_{cha} - \frac{P_{dis}}{\eta_{bat}} \tag{1}$$

Where E_{bat} is the energy stored in the battery. P_{cha} are the Charge and discharge power,respectively. Assuming that the efficiency of the charging is equal,it could be represented by η_{bat}.

2.2 Household battery model

The household battery is a lithium-ion battery, and the implementation characteristics of the battery charging power are shown in Figure 6[16].

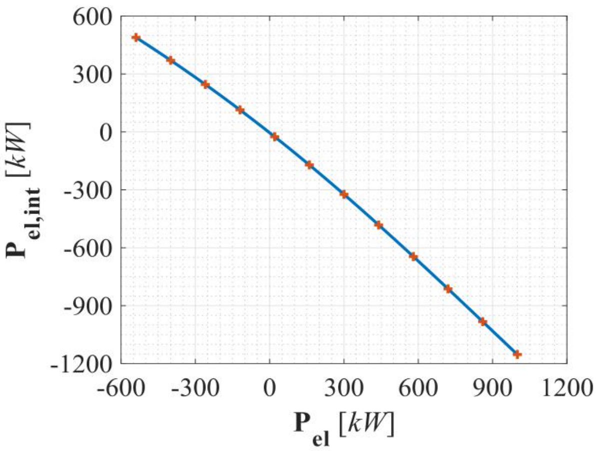

Fig. 6. Battery charging characteristics.

2.3 PV model

The PV model uses the equivalent diode model in EnergyPlus software.

$$I = I_L - I_0\left[\exp\left(\frac{q}{\gamma k T_c}(V + IR_S)\right) - 1\right] \tag{2}$$

$$I_L = I_{L,ref}\frac{G_T}{G_{T,ref}} \tag{3}$$

$$\frac{I_0}{I_{0,ref}} = \left(\frac{T_c}{T_{c,ref}}\right)^3 \tag{4}$$

Where I_L is the photocurrent, $G_{T,\ \mathrm{ref}}$ is the reference condition of solar radiation,1000 W/m^2, $T_{c,ref}$ is the temperature of reference,25 ℃, T_{c} is the PV module operating temperature, ℃。

2.4 Evaluation index

$$E_{\mathrm{eco}} = \frac{(\mathrm{cost}_{pv} + \cos t_{battery} - \cos t_{grid})}{\mathrm{cost}_{\mathrm{Grid}}} \tag{5}$$

Where E_{eco} is the Economic index, cost_{pv} is the power generation cost of the pv system, $\mathrm{cost}_{battery}$ is the cost of battery, cost_{grid} is the electricity savings from PV power generation minus the cost of charging electric vehicles from the grid, and the cost_{Grid} is the electricity cost of the system without PV.

4 Result

The PV power generation is shown in Figure 7. It can be seen from the figure that the pv power generation is larger in summer and smaller in winter. The power generation starts to decline rapidly from August. From March to August, PV power generation exceeded 250KWh/m. In November and December, pv power generation was the lowest of the year, less than 175KWh/ m.

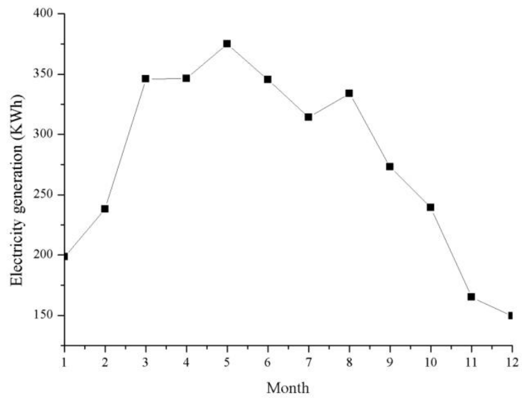

Fig. 7. The electricity generation of solar PV.

The building electricity consumption is shown in Figure 8. The building's electricity consumption includes lighting and HVAC equipment. It can be seen from the figure that the building electricity consumption is larger in winter and smaller in summer. Electricity consumption in October, November, December, January, February and March exceeded 300kwh per month. The maximum power consumption in January is 459.64kwh. Monthly electricity consumption in May, June, July and August is around 250kwh.

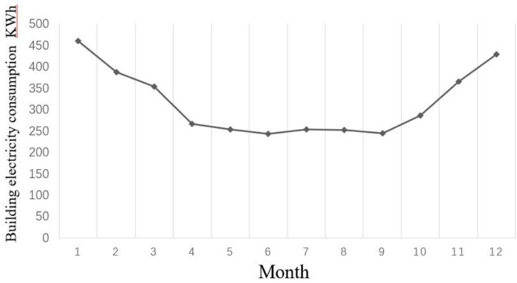

Fig. 8. Building electricity consumption.

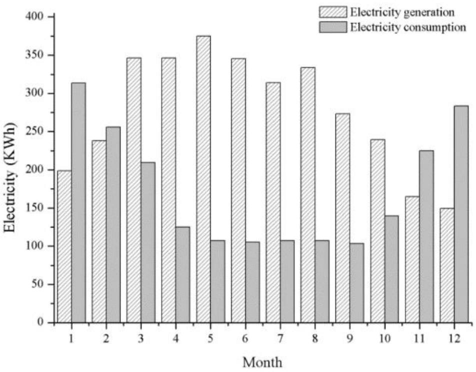

Fig. 9. The comparison of building electricity consumption and PV generation.

According to the simulation results, the annual PV power generation is 4992.10kwh, and the building electricity consumption(lighting, and HVAC equipment) is 3791.78kwh, which exceeds 20% of the actual building electricity consumption and generates 1200.32kwh of electricity. On the whole, this small building can achieve zero energy consumption, but on a month-to-month basis, there is a serious mismatch. The comparison between building energy consumption and photovoltaic energy generation is shown in Figure 8. Electricity consumption is high in winter and low in summer. From March to October, photovoltaic energy generation is larger than building electricity consumption, while in November, December, January and February, photovoltaic energy generation is smaller than building electricity consumption.
According to the Tesla model 3 electric vehicle used in this article, the battery life is 605Km and the battery capacity is 75KWh. The abundant power can charge the electric vehicle about 16 times, and the annual mileage can be 9680 kilometers. In winter, assuming that the electric vehicle has 30% of the electricity to charge the building in reverse every week, it can provide about 80KWh of electricity per month, which can reduce the requirement on the capacity of the household battery.

5 Conclusion

In this paper, a small wooden structure building in Hailar, Inner Mongolia, China is taken as an example. By using Energyplus to simulate the photovoltaic power generation and building electricity consumption, the mathematical model of electric vehicles, household batteries and photovoltaic panels is established, the control strategy of the system is defined, and the economic evaluation index is constructed. It is preliminarily found that the power generation of solar PV panels integrated in buildings can meet the charging demand of household electric vehicles, which is conducive to realizing the carbon reduction goal in the transportation field. Meanwhile, in winter when supply and demand do not match, the reverse charging of electric vehicles for buildings can reduce the capacity of household batteries.

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