Research on active solar energy comprehensive utilization system for Tibetan rural dwelling

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Abstract. In view of the problem that in rural Tibet the solar radiation is too strong and the deep plan of traditional residential buildings has resulted in poor natural lighting, the author proposed an active natural daylighting system. The system makes full use of the abundant solar energy resources in Tibet without changing the existing structure of the building. It improves the living environment and the indoor comfort by four working modes, including light reflection guidance, thin film amorphous silicon photovoltaic power generation, Synergistic application of lighting and shading and building insulation. The research results show that with this system, the indoor illumination time extends by 3 hours and the average indoor light depth increases by more than 3.5m. Meanwhile, 119.58 degrees' electric power can be provided per year and the building thermal insulation performance can be improved. This system has broad application prospects in rural areas of Tibet and may inspire new ideas for other relevant design.

Keywords. Tibetan Dwelling; Solar Energy Utilization; Photovoltaic Power Generation; Building Lighting and Shading; Building Energy Saving

1. Research Background

The blockhouse, one of the diverse Tibetan traditional dwellings, is the main form of residence for farmers and urban residents[1]. Influenced by the climate features such as strong solar radiation and diurnal temperature difference[2], the blockhouses are mostly facing south and have square plane. In general, the blockhouse has 3 layers; from bottom to top, it is used for captive livestock, human settlements and lofts. The wall is thick and there are only a few small size doors and windows, which are mostly opened on the east and south sides of the second and third floors. The lighting and ventilation of the blockhouse is poor.

The abundant solar energy in Tibet has become the major resources of energy-saving dwellings. The application of solar photovoltaic technology in buildings mainly includes photovoltaic power generation systems[3]-[5], photovoltaic/thermal systems[6][7] and building integrated photovoltaic technologies[8]. Mainly focus on passive solar house, the research on solar energy utilization in Tibetan dwellings is very limited[9]-[13].There are difficulties in using electricity and the farmers and herdsmen’s use of cooking energy in remote areas; the living environment including the effect of lighting and ventilation needs to be improved. So the active solar energy comprehensive utilization system proposed in this paper is suitable for rural residential buildings in Tibet.
2. Active Solar Energy Comprehensive Utilization System Integrating Lighting, Shading, Power Generation and Thermal Insulation

The comprehensive utilization system of solar energy is a multi-functional system which integrates lighting, shading, power generation, heat preservation and insulation. It is mainly composed of the integrated solar energy regulation system and solar lamp. The regulating system is mainly composed of two plates and two rotating shafts. When the solar elevation angle is low and the intensity of sunlight is high, the mode of light reflection guidance can be used to provide more uniform soft light for the interior. When the solar elevation angle is high and the intensity of sunlight is high, the mode of lighting and shading synergistic application can be adopted; hence the upper part of the window is illuminated, and the lower part is shaded to prevent glare. When the solar elevation angle is high and the light cannot enter the room, the mode of thin film amorphous silicon photovoltaic power generation is adopted and the system can provide indoor solar light with electrical energy. When the solar radiation in the afternoon is too strong, or the outdoor temperature is too low at night, the building insulation mode can be used to achieve the effect of heat insulation.

3. Performance Analysis of Solar Energy Comprehensive Utilization System

3.1. Calculation Parameter Assumption

This paper takes Lhasa, one of the most resource-rich regions in solar energy, as the main research area. As the square blockhouse has the largest proportion, it is selected as the main research object. Meanwhile, the solar energy comprehensive utilization system is based on the existing window size, the diameter of the primary shaft is 50mm, while the diameter of the secondary shaft is 25mm. The actual length of the bipolar plate is 925 mm. The area of the photovoltaic panel is 0.402m², and its maximum efficiency is 14.46%[14].

Figure 1. Axonometric Map and Working Mode Diagram of Solar Energy Comprehensive Utilization System
3.2. Computational Mathematical Model and Systematic Evaluation Method

The comprehensive utilization system of solar energy is a composite system composed of reflective panels, photovoltaic power generation panels and thermal insulation panels. Their performance need to be explored through respective calculation methods, models and corresponding systematic evaluation method.

(1) Light Reflection and Indoor Illumination Depth

The main function of the reflector is to increase the depth and brightness of indoor illumination. Fully deploying the system to 90 degrees with the window, we can calculate the solar altitude and azimuth angle of Lhasa during the four days of spring equinox, summer solstice, autumn equinox and winter solstice, through formula (1) (2), and get the result of changes in the indoor illumination depth.

Solar Altitude Angle Calculating Formula:

\[
\sin H_S = \sin \Phi \sin \delta + \cos \Phi \cos \delta \cos t
\]  

(1)

Solar azimuth calculation formula:

\[
\cos A_S = \frac{(\sin H_S \sin \Phi - \sin \delta)}{(\cos H_S \cos \Phi)}
\]  

(2)

In the formula: \(H_S\) is the solar altitude angle, °;
\(A_S\) is Solar azimuth, °;
\(\Phi\) is geographical latitude, °;
\(\delta\) is solar declination, °;
\(t\) is Solar hour angle, °.

This paper focuses on how the reflector panel of this system can influence the indoor illumination depth. Therefore, the vertical distance of the farthest light entering the room is taken as the indoor illumination depth to evaluate the effectiveness of the reflector panel.

(2) Photoelectric Conversion and Effective Photovoltaic Power Generation

Photovoltaic panels are mainly used to convert solar energy into electrical energy. According to the following formula(3), the annual effective power generation can be used as the evaluation basis of photovoltaic panels.

\[
W = QS\eta
\]  

(3)

In the formula: \(W\) is Annual Photovoltaic Power Generation, kwh;
\(Q\) is Annual average total solar radiation, kwh/m²
\(S\) is Effective area of battery, m²;
\(\eta\) is Power generation efficiency.

(3) Insulation and Shading and Amount of Energy Saving
Every mode of the system have certain effect on indoor sunshade. Taking the second floor as the main research object and using the software "Hongye HVAC", the performance can be reflected by the difference of building energy consumption before and after using the system.

3.3. Calculation Results

(1) Indoor Illumination Depth

When the Solar elevation angle is less than 56°06', natural light entering the room is weak. When the angle is higher than 71°06', natural light cannot be reflected by the reflector into the room.

![Figure 2. Variation of Indoor Illumination Depth in Each Direction](image)

Overall, the use of reflectors can increase the average illumination depth by at least 3.5m and the south window increases 6.5m to at least 8m during the winter solstice. The indoor illumination is more stable and its duration of time is extended by an average of 3 hours. (Fig.2)

![Figure 3. Comparison Chart of Load](image)
(2) Effective Photovoltaic Power Generation

The energy consumption of traditional residential buildings that have not been rebuilt in Tibet is generally limited to architectural lighting. The electricity consumption per day is about 0.8 degrees, and the total amount is 288 degrees per year. It is calculated that one photovoltaic panel can generate 119.58 degrees for one year and it can reduce the lighting energy consumption of about 40% of the greenhouse.

(3) Amount of Energy Saving

According to the figure 3, the value of building energy saving is about 8kwh in summer. In winter, the average energy saving amount is 773.01W per hour, and about 18kwh per day.

4. Analysis of The Influence of Key Parameters on System Performance

There are many factors affecting performance of the system, and the window size and the wall thickness are two of the key external factors.

![Figure 4. Comparison Chart of Different Window Size with The System](image)

It is found that the indoor illumination time is prolonged by 1 hour after the window height increases from 1000mm to 1500mm, the depth of illumination increases over 0.4m, and the effective photovoltaic is 47% higher than the former. The heating load in winter increases by 47.38W, while the cooling load in summer has subtle changes. Therefore, within a certain range, as the window get higher and larger, the system can improve the indoor environment more significantly. (Fig.4)

![Figure 5. Comparison Chart of Different Wall Thickness with The System](image)
When the wall thickness decreases from 700mm to 240mm, the indoor illumination time prolongs by 1 hour, and the depth increases by 0.65m on average; the effective photovoltaic power generation capacity is not changed; the heating load increases by 1210W in winter, more than double the former, and the cooling load has subtle change in summer. Above all, the depth of indoor illumination increases with the decrease of wall thickness. However, the heating load increases obviously in winter. (Fig. 5)

5. Conclusion
After formula calculation and software simulation, the solar energy comprehensive utilization system can be used as an innovative design of traditional residential buildings in rural areas of Tibet. Without changing the existing structure of buildings, it can greatly improve the indoor thermal and light environment by increasing the indoor illumination time and depth, providing part of the power for indoor lighting, and reducing building energy consumption. At the same time, it is found that within a certain range, the higher the window, the better the comprehensive performance of the system; the thinner the wall thickness, the less obvious or even worse the performance of the system.

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