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Influencing factor Analysis of collecting capability over a year by the panel typed solar collector for seven representative cities in Yunnan, China

Ming yang[1] Long enshen[1*] Xu kuo[2] Li yanru[1] Zhang yin[1] Jin zhenghao[2]
[1]College of Architecture and environment, Sichuan University, Chengdu, China
[2] Institute for Disaster Management and Reconstruction, Sichuan University, Chengdu, China
E-mail: 502463684@qq.com

Abstract. Solar energy is abundant in Yunnan province, China, and buildings in this area have a surging demand for heat supply over winter season. Targeting on seven representative cities in Yunnan, this paper analyzed the optimum tilt and azimuth angles of the panel typed solar collector within these cities over a year by applying the orthogonal method, and an improved mathematical model in calculating the collected solar radiation was also developed, and the influence of the varying tilt and azimuth angles on the solar heat collection was also analyzed. Results showed that, the collected solar radiation varied in a parabola curve and was slowly decreasing after the azimuth was reaching 0° and the dip angle was approaching the location latitude, when the azimuth angle was varying from -65° to 65° and the dip angle was increasing from 0° to 90°, respectively. And among these cities, the optimum dip angles were ranging from 29° to 33° and the optimum azimuth angles were ranging from -18° to 5°, respectively, which were within the recommended ranges of the local standard. However, the maximum decrease rates of the captured solar radiation can amount to 12.15% and 2.8%, respectively, if choosing the tilt and azimuth angles of the panel typed solar collector randomly.

Keywords: solar energy; dip angle; azimuth angle; orthogonal method

1. Introduction

Most cities in the Yunnan province, China, have a typical plateau climate and are pretty cold in winter, and the heat supply demand is surging with the improving living standard and social development. Whereas most public and residential buildings are not equipped with central heating facilities, since this area is excluded from the regulated concentrated heating area, and the building energy consumption is high and is deteriorating the local environment. In addition, the annual sunlight hours in Yunnan province are about 2200hrs and the solar energy application is of high practical significance, thus it is imperative to utilize abundant solar energy resources locally.

Because the azimuth and elevating angle of sunshine are various in every hour, the solar radiation projected onto the fixed collector varies from time to time. Therefore, it is very important to optimize the dip angle and azimuth angle to ensure the maximum solar capture capability of the collector in the long run state. This is not only related to the initial investment of the system, but also has an important impact on improving the efficiency of solar energy utilization.

At present, many scholars have studied the optimal installation Angle of solar collector. Sachin Muralee Krishna et al. [6] have taken the city of Bangkok as an example to determine the optimum Angle of inclination in order to improve the efficiency of solar energy utilization by establishing mathematical model; Kamal Skeiker et al. [7] have used a mathematical model to calculate the solar radiation from the tilted surface and determined the optimal dip angle and azimuth angle of the solar collector in the main areas of Syria in a certain period of time; Li rongling et al. [8], based on the solar radiation data of Beijing 54511 meteorological observation station and aiming at the maximum cumulative solar radiation

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on inclined plane, have obtained the optimal installation angle of Beijing at different time periods; Zhu dandan et al. [9] based on the analysis of the influence factors of the solar energy capture capability of the collector plate in the whole year, have obtained the optimal dip Angle of some parts of China through the calculation model of the solar radiation of the inclined plane.

On the basis of a large number of research results at home and abroad for reference, our country has enacted a norm[10] in 2009, in which the scope of solar collector's azimuth angle is 0±30° and the range of dip angle is local latitude +20° or -10°. Although the solar energy application engineering has a certain guiding role, solar radiation characteristics are different in different cities, thus their best angles of solar collector are unlike, and the designers will easily get lost when they choose installation angle from a wide range which will cause more investment or less efficiency of the system.

Under the background of the solar energy heating applications in Yunnan province, this paper has analyzed influence rule of the connected heat amount effected by azimuth and dip angle and got the optimization angle of 7 cities. What's more, the author has contrasted the optimized results with the scope in the norm. The outcome can provide references for the design of solar heating engineering in this area.

2. Objects and method of study

2.1 Objects of study

The basic information of 7 representative cities in Yunnan province studied in this paper is given by table 1 in which the meteorological data is from literature [11]. From this table, the range of 7 cities' longitude is from 98° to 103°, and the range of latitude is from 22.7° to 28.5°. Besides, 7 cities' elevation is between 1000 m to 3400 m and their winter temperature is between -5~11℃ which shows that it has cold climate and a rigid demand for heating. The annual total solar radiation energy of cities is 1733.9~ 2112.8 kWh /m^2, with a maximum of 2112.8 kWh /m^2. Thus it can be seen that the solar energy resources in Yunnan have great application potential.

Table 1. The basic information of 7 representative cities in Yunnan province

cities	longitude (°)	latitude (°)	elevation （m）	Winter temperatures （℃）	Annual total direct radiation （kWh/m^2）	Annual total direct radiation （kWh/m^2）
Kunming	102.73	25.04	1930	3.0	1138.2	1951.8
Deqin	98.92	28.48	3350	-5.0	964.5	1733.9
Lijiang	100.25	26.86	2384	3.0	1479.0	2112.8
Lancang	99.90	22.70	1024	11.1	1209.4	2017.9
Chuxiong	101.54	25.01	1777	5.8	1050.8	1826.5
Lincang	100.08	23.88	1493	9.2	1199.8	1973.9
Simao	101.03	23.07	1330	9.0	1045.2	1897.6

2.2 Method

Any installation angle of collector can be expressed by dip angle and azimuth angle. The relationship between the position of the sun and the surface of the earth can be expressed by the height angle and azimuth angle of the sun. On this basis, we can get collected solar radiation at different times by calculating the amount of collected direct radiation, sky scattered radiation and ground reflected radiation.

The following equation can be used to calculate the collected direct solar radiation per unit area H_{bT}:

$$H_{bT} = H_{DN} \cdot (\cos\varepsilon \cdot \sin\beta + \sin\varepsilon \cdot \cos\beta \cdot \cos(A-\alpha)) \quad (1)$$

Where H_{DN} is normal radiation intensity, W/m^2; ε is the dip angle of solar collector, °; A is the azimuth angle of the solar collector, °, in south to 0 °, by east is positive; β is height angle of the sun, °; α is azimuth angle of the sun, °.

To calculate the sky scattered radiation H_{dT}, the following formula can be used:

$$H_{dT} = H_d \cdot (1+\cos\varepsilon)/2 \tag{2}$$

Where H_d is solar scattering radiation, W/m^2. It can be seen that when the plate is horizontal, the amount of sky scattered radiation is the largest.

The amount of ground reflection radiation capture H_{rT} is related to different ground materials, and the formula is given by:

$$H_{rT} = \rho \cdot H \cdot (1-\cos^2\varepsilon)/2 \tag{3}$$

Where ρ is ground reflectance, the ρ of grass is 0.17~0.22, the concrete floor is 0.3~0.37 and the snowfield is 0.7. In this paper, we have set concrete as the ground, and its ρ is 0.3; H is total horizontal radiation intensity, W/m^2.

Finally, we can get the amount of total collected solar radiation per unit area plane at any installation angle H_T:

$$H_T = H_{bT} + H_{dT} + H_{rT} \tag{4}$$

The range of azimuth we chose, apart of 0°, is -65° ~ 65° to 10 ° for interval, a total of 15 bearing point for calculation. And the issue in 0 ~ 90 ° dip angle (from horizontal to vertical), every 10 ° for a total of 10 Angle between points are combined to calculate. At last, the influence rule of solar radiation change under different dip angle and azimuth combinations is obtained by orthogonal method.

3. Results analysis

Taking Lijiang city as an example, this article will first respectively analysis the influence of tilt and azimuth angle of collected solar radiation, and then will find the optimization by the orthogonal method. At last, the results of seven representative cities will be compared with the existing norms.

3.1 Influence of azimuth on collected solar radiation

The effect of different azimuth angles on solar radiation capture under three dip angles is given by Fig 1. It can be seen that when the azimuth was varying from -65° to 65°, the collected solar radiation first increase and then decrease while the dip angle is invariant, and the maximum of the curve is 1750 kWh/m^2 when azimuth is 0°. That is because the sun rises from the east and sets in west and usually has max radiation at noon when the sun is just in south. When the dip angle is different, the influence degree of azimuth change on the collected solar radiation amount is also different. The larger the dip angle is, the steeper the curve is, and the maximum values of the curves are also different.

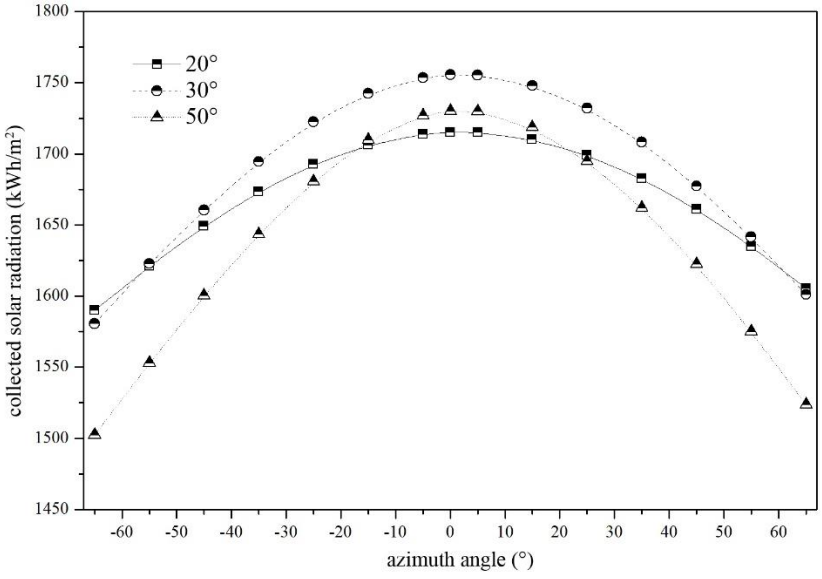


Fig 1. Influence of azimuth angle on collected solar radiation in Lijiang

3.2 Influence of dip angle on collected solar radiation

The effect of different dip angles on collected solar radiation under three azimuths has been showed by fig 2 in which the influence rule of collected solar radiation is lower open parabola with the increasing dip angle from 0° to 90° when the azimuth is fixed. Taking 0° azimuth angle for example, the maximum value of the curve is 1750 kWh/m^2 when the dip angle is 35° and the minimum value is 1150 kWh/m^2 when it is 90°. This is because the collected solar radiation is mainly influenced by the height angle of the sun, so it is usually best when the dip angle close to the city's latitude. What's more, when the azimuth changes, the influence rule of the curves are also different. According to the three curves showed in the picture, they have absolute difference when dip angle closed to Lijiang's latitude, and they are nearly invariant when dip angle is 0° or 90°. That's because the collector is horizontal when dip angle is 0°, there will be no effect if we change the azimuth angle. Then, when dip angle is 90°, the collector will catch lower direct radiation which means the proportion of scattered radiation which is not affected by azimuth will increases.

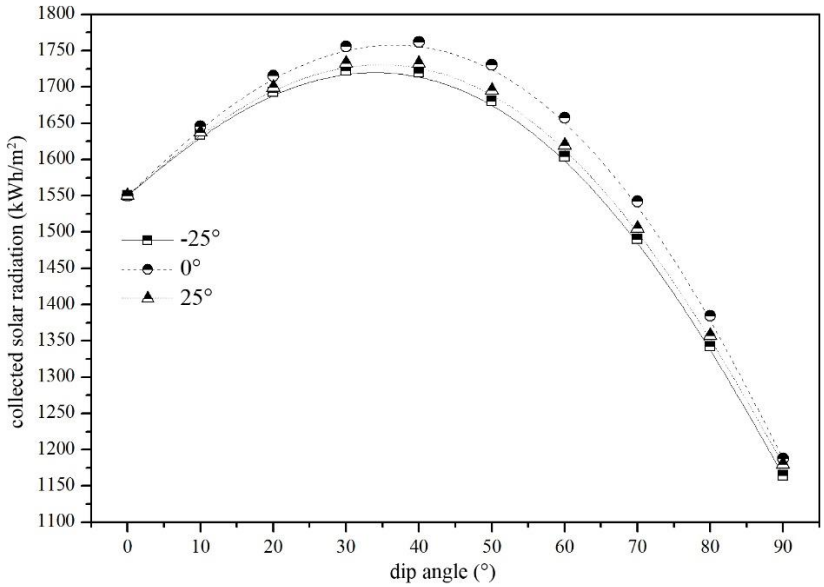


Fig 2. Influence of dip angle on collected solar radiation in Lijiang

3.3 Orthogonal optimization results

Assuming that the installation azimuth of the collector is fixed, and the dip angle of the collector is changed at some interval, the change curve of several heat collection capacity with installation dip angle can be obtained. Similarly, by the same way, several curves of heat collection capacity with the azimuth can be obtained. Finally the optimum dip angle and azimuth angle of the collector will be obtained by coupling optimization.

Taking Lijiang's result for example (Fig 3), we can get the amount of collected solar radiation under different azimuth and dip angles by orthogonal method and the maximum point of the change surface formed by each point. It is showed that the collected solar radiation is max when the dip angle is 35° and the azimuth is 0°.

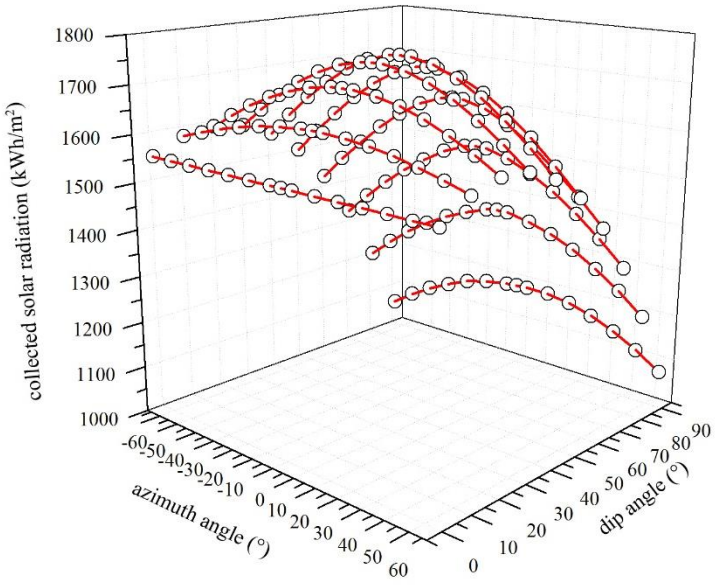


Fig 3. Result from orthogonal method in Lijiang

By using the same method, we can get the optimal angle of solar collector in 7 cities (Fig 4). It is showed that the optimal dip angles of 7 cities are ranging from 29° to 33°, and the azimuth angles are ranging from -18° to 5° with difference among those cities. 7 cities' optimization results are within the recommended range of the local standard, but the maximum attenuation of solar energy capture capability can be 12.15% if the value of dip angle is taken blindly from the specification, and the maximum attenuation of the blind value of azimuth can also amount to 2.8%.

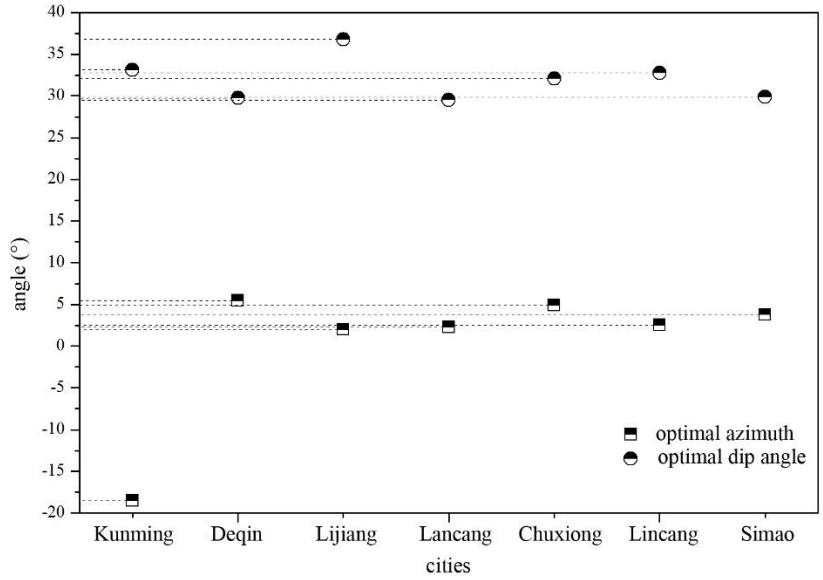


Fig 4. The best installation angle of 7 cities

4. Conclusions

Making solar collectors' optimal installation angle of 7 cities in Yunnan province as a goal, this paper has set up solar radiation collecting math model which was based on hourly meteorological parameters and has analyzed the influence caused by azimuth and dip angle. Finally got the optimization results by orthogonal method. The main results are as follows.

(1) With azimuth angle ranging from -65° to 65°, the collected solar radiation decreased after first increased while the dip angle is invariant, the greater the dip angle, the more drastic the change;

(2) The influence rule of collected solar radiation is lower open parabola with dip angle increasing from 0° to 90° when the azimuth is fixed. When azimuth changes, the curves will have absolute difference when the dip angle closed to Lijiang's latitude, and they are invariant when dip angle is 0° or 90°.
(3) Through orthogonal method, it is showed that the optimal dip angles of 7 cities are between 29° to 33°, and the azimuth angles are between -18° to 5° with difference among those cities. the maximum attenuation of solar energy capture capability can be 12.15% if the value of dip angle is taken blindly from the specification, and the maximum attenuation of the blind value of azimuth can also reach 2.8%. The research has showed the influence rule of azimuth and dip angle on heat collection effect of solar collector and has got the optimal angle of 7 cities in Yunnan province. The results can provide a better reference for the design of solar heating engineering in this area.

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