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Research on the Performance-Based Parameter of Horizontal Visor of Certain Wall Relative to the Sun Zenith Angle

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Abstract

The horizontal shading is one part of the buildings, outside shading systems. Relative sun elevation angle to the wall ϕ *, and relative sun azimuthal angle to the wall* γ *are introduced. The optimum width for the southern shading of local buildings can be calculated according to the law of solar altitude change over time. In this research, relative sun elevation angle to the wall* ϕ *is key for design parameters determination of horizontal shading component. The present study optimized the design of the horizontal shading on the basis of the traditional design. The new design of the visor could still shade the exceeding sunlight in summer, but at the same time allow enough sunshine in winter. This design is environmental-friendly, energy and material-saving.*

Keywords*: Energy Conservation; Parametric Control; Horizontal visor; Sun Elevation Angle; Optimization of Performance*

1. Introduction

Besides temperature difference between inner and outer, the main reason for the increasing indoor temperature is direct sunshine. The majority of Chinese people live in the northern area of China with latitude higher than the Tropic of Cancer. The southward wall of the departments could obtain abundant sunshine in summer. However, residences have different requirements for sunshine in different seasons. Those who live in the apartments require more sunshine in winter but less in summer, which the traditional visor could not meet. Starting from this problem, the present study is designed to examine and testify the precise parametric of southward horizontal visor, and to design a latest horizontal visor with its component optimized. The design is more economical and environmental-friendly, which overcome the drawback of the traditional horizontal visor, and allows accordant performance both in summer and winter.

2. Method of Research

In this article, formula and geometric approach of relative sun elevation angle to the wall ϕ , and relative sun azimuthally angle to the wall γ are introduced. To block sunshine in summer and to allow it in winter, the width of horizontal visor is calculated and optimized through the formula of solar elevation angle and nature principle, according to the law of solar altitude change over time. Based on this we did optimization on performance of the visor. And used Google SketchUp software to simulate the sun light irradiation, through the shadow area, to determine whether the design is feasible [1].

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3. Formula of Solar Elevation Angle and its Verification

Solar elevation angle and sun azimuthal angle are two of the important parameters showing the position of the sun. Solar elevation angle refers to the angle between incident direction of sunlight and surface [2], with sun azimuthal angle refers to the angle between projection of sunlight and local meridian (Figure 1).

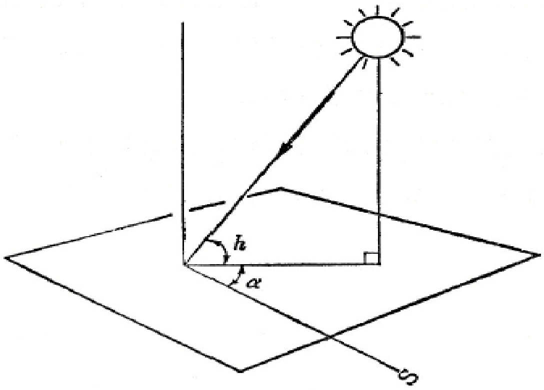

Figure 1. The Angle of the Sun's Height

Therefore, to block unnecessary sunlight in a proper way, we have to follow the law that reveals the relationship between the solar elevation angle change and times in one day. After a long term calculation and verification of mathematicians [3], the calculation formula of the ultimate solar azimuth and h of the solar zenith angle is determined [4]:

$$\cos\alpha = \frac{\sin h \sin\xi - \sin\delta}{\cos h \cos\xi} \tag{1}$$

$$\sin h = \cos\zeta \cos\delta \cos\omega + \sin\zeta \sin\delta \tag{2}$$

Formula ζ：Local geographical latitude

δ：The sun declination Angle $\delta = 23.45° \times \sin[360 \times \frac{(284+n)}{365}]$,

Which n is the date number, such as January 1, n = 1, December 31, n = 365

ω：solar hour angle, ω=（t-12）×15°, AM is positive, PM is negative, t is the time of day

The solar elevation angle at any day during a year can be calculated through formula (1), For example, the solar elevation angel in Guangzhou on June 6th at 14:00 can be calculated in the following way: the longitude of Guangzhou is ζ=23.13 degree, n=157 on June 6th ;the geographic latitude ζ of Guangzhou is 23.13 °, then n = 157 on June 6th , the solar declination angle δ of Guangzhou = $23.45° \times \sin[360 \times \frac{(284+157)}{365}] = 22.75°$, and the solar hour angle ω = (14-12) × 15 ° = -30 °. Bringing all the above figures into formula (1), we can work out the solar elevation angle as 62.87 °, and the calculated values of the solar zenith angle into formula (2-1), could obtain a sun azimuthal angle α as -83.2.

We can calculate any day the sun elevation angle and azimuthal angle, through two equations above. Take Guangzhou city as an example, calculating that two value in 2015, and illustrate them below (Figure 2 and. Figure 3).We found that azimuthal angle grows up to maximum as elevation angle similarly, generally within June and August. That makes sun shading around summer solstice much significant [5].

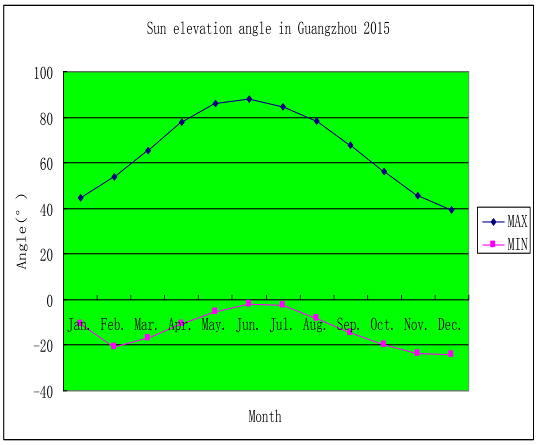

Figure 2. Sun Elevation Angel in Guangzhou 2015

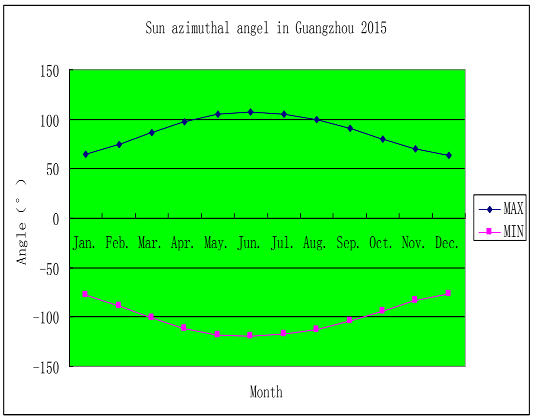

Figure 3. Sun Azimuthal Angel in Guangzhou 2015

4. Performance-Based Designs and Verification of Horizontal Visor

Horizontal visor is one part of the building' outer systems, which can lay an extensive shadow on the southern widows or close-southern windows of the building [6], similarly applying for close-northern windows located in the south of the Tropic of Cancer(Figure 4).

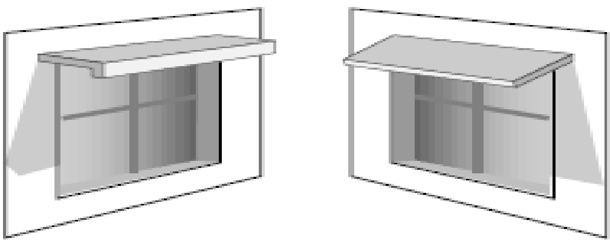

Figure 4. Horizontal Visor

It is also very effective in reducing the temperature of southward wall and blocking direct sunlight. According to the level of sunlight irradiation on the building, the condition of sun irradiation is shown in the figure below (Figure 5).

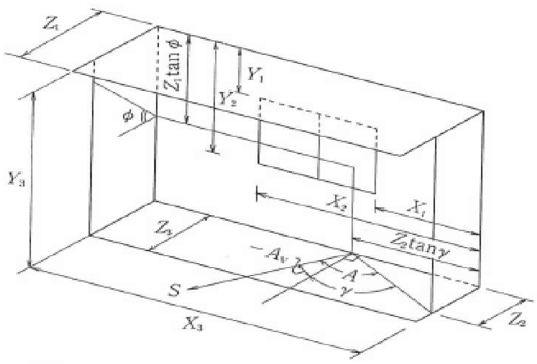

Figure 5. Solar Irradiation

Set h as solar elevation angle, A as sun azimuth angle, Aγ as angle between Normal of wall and south, that is the wall opposed to solar azimuth angle γ＝A-Aγ, Y is vertical length of shadow which is produced by brim shading against the sun(Y1 is in winter, Y2 in summer), Zn as the width of the brim, where Z1 is the width of the horizontal brim, according to the geometric relations we know that[7]:

$$\tanh = \frac{Y}{Z_1 / \cos \gamma}, \quad \text{so} \quad Z_1 = \frac{Y \cos \gamma}{\tanh}$$

To import the wall opposed to solar azimuth angle, according to the geometric relations we can see [8]:

$$\tan \phi = \frac{Y}{Z_1} = \frac{\tanh}{\cos \gamma}$$

So the length of shadow produced by brim shading is $Y = Z_1 \tan \phi$

According to our design principle diagram (Figure 6), we hope that on the summer solstice, the sunlight through the endpoints of the brim, irradiate to the window under-edge, to shade the whole window. On the winter solstice, the sun light through the endpoints of the cornice, irradiate to the window up-edge that we can allow more sunlight shine in room. Brim width which could meet above condition is the most reasonable width [9].

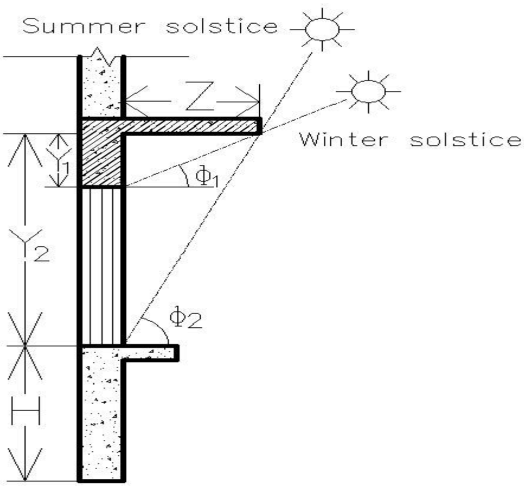

Figure 6. Principle Illustration of Horizontal Visor

According to the design principle, and the wall opposed to solar elevation angle and the wall opposed to solar azimuth angle, and the geometrical relationship, we sum up the following formula [10].

$$Z_1 = \frac{Y_2}{\tan \phi_2} \quad (3)$$

$$Y_1 = Z_1 \tan \phi_1 \quad (4)$$

In this formula:

Z1: The width of the horizontal visor

ϕ 2: The summer solstice wall relative elevation angle of the sun

ϕ 1: Winter solstice day wall relative to the solar altitude angle

Y2: From the summer solstice wall relative solar elevation angle level visor projection to the wall .

Y1: The distance between the horizontal and the wall of the wall at the time of the wall relative to the sun height of the winter solstice day

Figure 6 cornice schematic design of H window along the distance from the ground, for individual preferences, the range of the distances between lower frame of window and ground may take the form of higher window or French window, but its range is stable at 0~0.9m. The winter solstice wall relative elevation angle of the sun visor with ϕ 2 horizontal projections to wall distance Y2, which represents the distance from the lower line of the horizontal visor to the upper frame of the window, is calculated through geometric relation after the reasonable width of horizontal visor was calculated. The range of the distances from the lower frame of window to ground window includes that of French window and that of higher window, determined by individual preferences. Therefore, the reasonable width of horizontal visor, suitable for local users, can be worked out via above two formulas. Based on the width of visor and the distance between the lower line of horizontal visor and the upper frame of the window, the reasonable height of whole window could be inferred [11]

5. Optimized Design of the Horizontal Visor

The method described in the previous section is the traditional way of horizontal visor designing. An optimized design of horizontal visor is described in the following parts, basing on the normal method (Figure7).

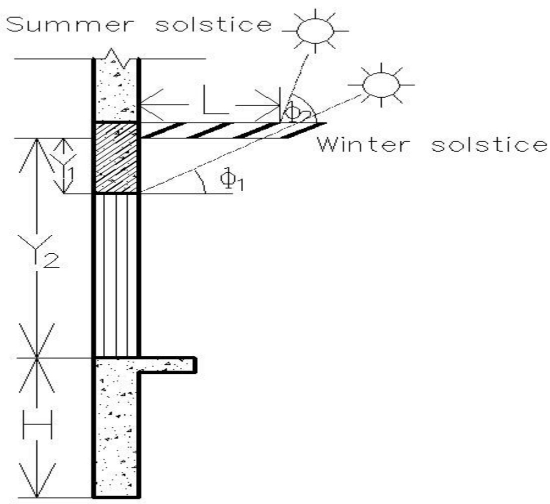

Figure 7.The New Condition of Visor under the Sunlight

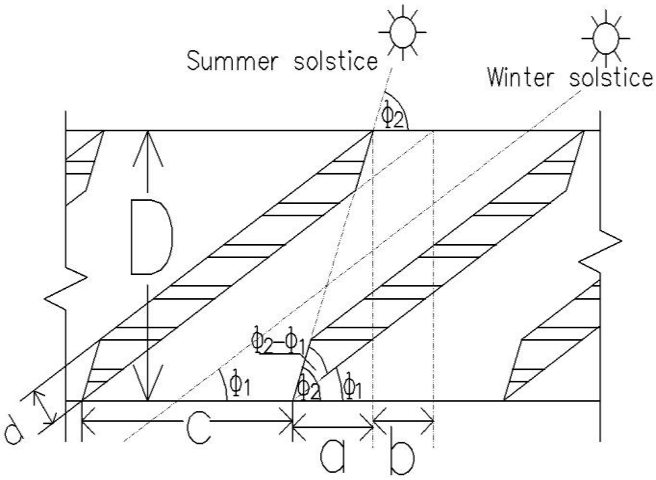

Figure 8. Partial Enlargement of the Condition of Visor under the Sunlight New

The reasonable width of horizontal visor is also calculated through equation (2). In the second step, a new horizontal visor is combined with blade tilts in a staggered way. Each tilt has angle and distance toward others. This design of combination is based on different solar elevation angles. The ideal situation is that when user needs a warm room, the direct sunlight will go through the tilt of the blades above corner. The light could go through the visor onto windows and roof because of the angle and space between tilts. When user needs a cool room, the direct sunlight will fall on the surface of the visor, because the angle of irradiation is higher than tilts' one. Thus, with this design, the horizontal visor can adjust indoor temperature freely by utilizing sunlight, while at the same time with a beautiful outlook and material-saving design.

Next, we will take a closer look at one part of the new horizontal visor (Figure 8), and optimize the design of the leaning tilts. Spacing and tilting blades should make sunlight shine on it directly, thus blocks sunlight with certain degree and cools down rooms. In this manner, the visor could give consideration to both fully utilizing of sunshine and appearance, also cater for concept of material saving or energy conservation [12].

With amplifying part of this new horizontal visor, optimum design for sloping blade can be made:

Figure 8 shows the specific data of solar elevation angles at different time, together with thickness of horizontal visor D and thickness of blades d. As described in the above session, the sunshine in winter is allowed onto the window and roof through the tilts of horizontal visor, so the consistency between the solar elevation angle ϕ 2 and leaning anger of tilt is significant.

As shown in Figure 8, the permanent angle of the tilts in new horizontal visor is (ϕ 2-ϕ 1). As by the geometric relationship shows, $\cot\phi_2 = \frac{a}{D}$, so a= $D\cot\phi_2$; and $\cot\phi_1 = \frac{(c+a+b)}{D} = \frac{(c+a+d/\sin\phi_1)}{D}$, so $(c+a+d/\sin\phi_1) = D\cot\phi_1$, With the a value just calculated, we know $c=D(\cot\phi_1 - \cot\phi_2) - d/\sin\phi_1$.

Therefore, the above calculation shows that, the angle of new visor blade is (ϕ 2-ϕ 1). It is tilted in an angle of ϕ_1, and the distance of each blade is $D(\cot\phi_1 - \cot\phi_2) - d/\sin\phi_1$. Placed in such a way[14], blades are combined into a new level visor, which optimizes the performance and makes a full use of the sunlight to control the room temperature. And, the general sun shade is a material composition, the air flow will have a certain barrier effect, and this grille type of shade, will improve the outer wall with openings. [13]

6. Comparison of the Effect of the Horizontal Sun Shading Board Before and After Optimization

As each object design has an initial achievement, the physical model measurements and software simulation should be using for testing it, generally, the former have better performance on accuracy and immediacy than the later. But for observing more real outcomes directly or modifying them handily on the first step of architectural design, software simulation is the better way, as the author used Google SketchUp to simulate sun shining for judging the project though shaded area[15].

First, we build a model with the visor, besides the visor of the optimized design, the other data of the two models are all same, we put the two models in the comparison, the traditional visor and the optimized as same by overlooking (Figure 9), but through the side view we can clearly see the optimized one with certain gaps (Figure 10).

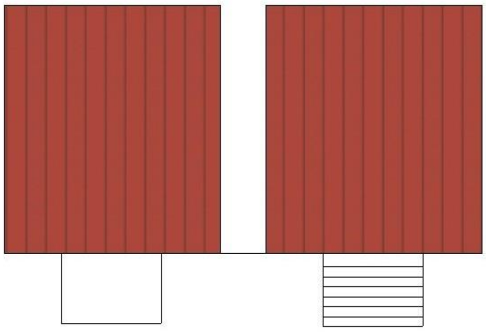

Figure 9. Comparison of the Visors in Overlooking

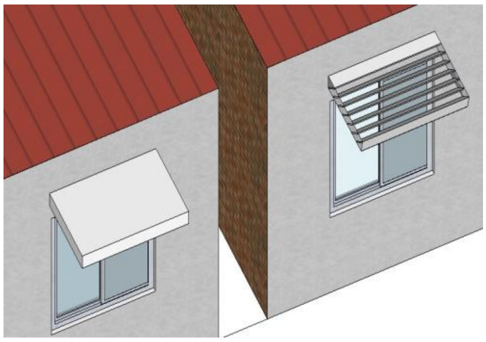

Figure 10. Comparison of Shade in Side View

We take Guangzhou as an example, the day of the summer solstice, we selects the hot July, at half past one in time (Figure 11), contrasting found that after the summer solstice, the traditional visor and optimized visor have same shadow area, same effect of shading (Figure 12).

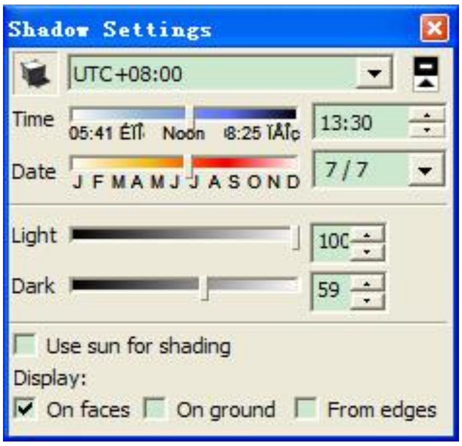

Figure 11. Summer Solstice Sun Solstice Sun Time Point Exposure

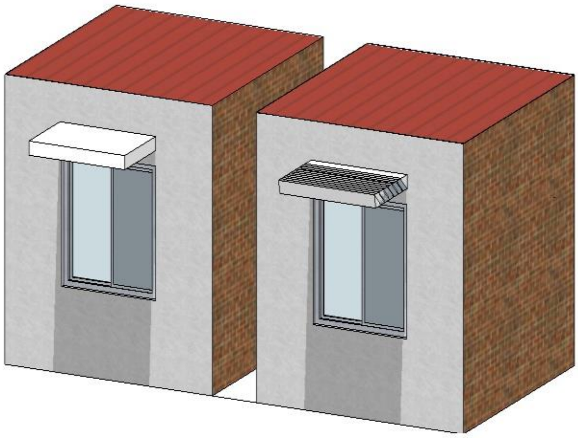

Figure 12. Comparison of the Summer Visor Renderings

On the winter solstice, we choose the most cold November at half past one in time(Figure 13), and then find that the optimized one shading area of the sun is larger than the traditional one(Figure 14).

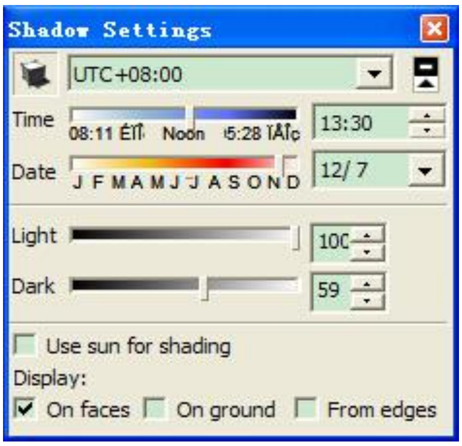

Figure 13. Time Points of the Sun Exposure on the Winter Solstice

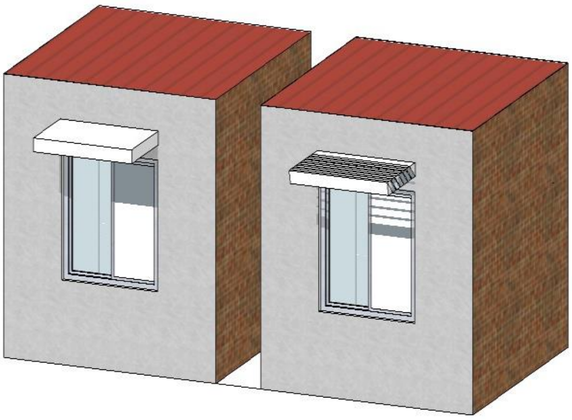

Figure 14. Comparison of the Effect of the Traditional Visor and Optimized Visor Under Sunlight

7. Conclusions

(1) Based on the solar elevation angle of a local area and the south visor width formula $Z_1 = \frac{Y_2}{\tan \phi_2}$, the appropriate width of horizontal visor can be worked out. When the visor width is fixed, the distance from the low edge of the visor to the upper frame of the window can also be calculated according to the formula $Y_1 = Z_1 \tan \phi_1$. Based on the distance between lower edge of the window and the ground, the suitable height of the window can also be calculated. Taking the width of horizontal visor and the height of the window, we can design the shading system suitably for the local area.

(2) The relative solar zenith angle ϕ is the key point to determine a series of design parameters of horizontal shading component. optimization of horizontal visor is possible based on the traditional method. When the width and thickness of horizontal visor is determined, place the blade with the angle (ϕ 2-ϕ 1) at the angle of ϕ_1, with the distance D(cotϕ_1 - cotϕ_2) - d / sin ϕ_1 between each blade were placed. The new level visor placed in such a way can block sunshine in summer and let in adequate sunlight in winter at the same time. And it is advantageous to the outer wall with openings.

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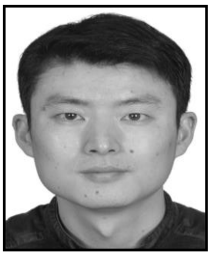

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