Analysis on the Application of Constant Shadow Space in the Building Veranda during the Peak Period of Students’ Attendance in Hot Summer Areas
--Taking the Southbound Veranda of A University Teaching Building in Guangzhou as an Example

Luo Guohui¹⁺, Liu Yingqi¹, b and Gong Zhaoxian¹, c*

¹College of Architecture and Urban Planning, Guangzhou University, Guangzhou, Guangdong Province, China
*email: krens1@163.com, b email: 184471280@qq.com

Abstract: The shadow space in the outdoor public space is often sought by people when they go out. This paper explains the related concepts of ‘constant shadow’ space in hot summer areas. By taking a university in Guangzhou as an example, the author analyzes the shaping conditions of ‘constant shadow’ space in the southbound veranda during the peak attendance period when it is necessary to seek shading. We simulate and verify the relationship between the sun height angle and the construction of ‘constant shadow’ space through ECOTECT. By doing that, it is expected to provide ideas for the design and optimization of constant shadow space in hot summer areas.

1. A brief introduction to the constant shadow space in hot summer areas
Facing the scorching sun in hot summer areas, the shadow space in the outdoor public space is often sought by people when they go out[1]. As for the sunlight shadow of buildings (structures), researchers related to architectural design have been paying attention to it: For example, Yang Jingwen put forward the concept and theory of bioclimatic architecture, including the exploration of the principle and method of using shadow to reduce the building’s sun exposure; Correa also has a lot of architectural design explorations of shadow utilization. However, most researchers regard shadow as the aesthetic effect of space[2], or treat it as a negative factor[3], and rarely consider its functional application.

The corridor shadow space of teaching buildings in hot summer areas is a common shade place for students during the peak period of their attendance. However, the subsolar point directly influences the shadow space, presenting the dynamic and limited characteristics of different times in the aspects of space-time scale, orientation, shape and length. Based on the travel time rule of users, the planning, design and transformation of corridor buildings (structures) and plants (hereinafter referred to as ‘shadow shaping structure’) can be carried out more actively, fully and effectively on the necessary shading date and in the shading period. Therefore, we can create a continuous constant shadow space (hereinafter referred to as ‘constant shadow’) within a relatively certain range of specific periods (as shown in Figure 1), which can be used to let students seek shading space in the corridor during the peak period of attendance in hot summer areas.
2. Relative definition of the constant shadow space of the veranda of teaching buildings during the students’ attendance

2.1 Judging the calculation times and date of shading during students’ attendance

Taking the daytime commuting time of students in a university in Guangzhou as an example. The class time is from 8:30 to 12:00 in the morning, and from 14:00 to 17:00 in the afternoon. For most of the students’ commuting time, 12 o’clock to 14 o’clock belongs to the noon period, the outdoor light and heat are not very comfortable. And this time period coincides with the peak period of class interval, so the demand for constant shadow space is high (as shown in Table 1).

Table 1. The relationship between students’ travel demand and the environmental comfort in their attendance time in a university in Guangzhou

| Time Interval   | 08:30-12:00 | 12:00-14:00 | 14:00-17:00 |
|-----------------|-------------|-------------|-------------|
| Attendance Reasons | have class in the morning | finish class in the morning | have class in the afternoon |
| Time Period and Environmental Comfort | morning, relatively comfortable | noon and afternoon, relatively uncomfortable | evening, relatively comfortable |

After determining the necessary shading period of constant shadow, it is necessary to determine the local shading date. Zhang Xiangrong and others of Xi’an University of Architecture and Technology have studied the dynamic changes of sun position and temperature in different seasons, and obtained the exact shading date in different places[4]. The shading date in Guangzhou starts on May 24th, and ends on October 4th. Taking the southbound veranda as an example. In order to meet the students’ peak travel demand during the sun shading period, the shape, scale and permeability of the veranda can be designed or modified to ensure the constant shadow space for students to walk during 12 o’clock to 14 o’clock from May 24th to October 4th.

Figure 1. The related concepts of constant shadow in the veranda

2.2 Determine the related concepts of constant shadow in the veranda

In the target constant shadow space, when the vertical height of the main structure [the corridor from a higher floor and the components attached to it (such as beams, HVAC components and other decorative components)] is fixed, the depth of the shadow forming surface changes under different solar altitudes (as shown in Figure 1). As the horizontal depth of the shadow shaping is fixed, the target depth of the shadow forming surface can reach the minimum width of 1200mm (two people can pass it shoulder to shoulder) by reasonably adjusting the vertical height of the components[5].
3. Application and optimization about constant shadow space of the southbound veranda in hot summer areas

Taking the teaching building of a university in Guangzhou as an example, the standard floor slab spacing is 3600 mm, the net width of the corridor is 2400 mm and the thickness of the railings is 150 mm. The vertical components are mainly composed of HVAC equipment and water retaining aluminum plates between beams, and the vertical height reaches 600 mm (as shown in Figure 2).

![Figure 2. Related concept data of southbound veranda of main teaching building in a university in Guangzhou](image)

3.1 Computer simulation of the current situation about the constant shadow space of the southbound veranda

Simulating the shadow shaping structure with vertical height through ECOTECT, the simulation steps are as follows: firstly, model the standard floor (the net width of corridor is 2400 mm, and the height of vertical component is 600 mm); then add 24 grids in the depth direction, so that each grid corresponds to 1/24 of the net width of corridor, which is 100 mm; then input the meteorological data of Guangzhou (CSWD), set the longitude and latitude data of Guangzhou, and determine the shadow period in ECOTECT, with the data displaying is 12:00-14:00; the two main target dates should be set on May 24th and October 4th. Because as the summer vacation lasts from the middle of July to September 1st, so so we can select July 4th and September 4th as the auxiliary dates respectively. The simulation results are shown in Figure 3.

![Figure 3. Changing of the constant shadow space when the vertical height of component is 600mm](image)

From left to right are: the shadow state from 12 o’clock to 14 o’clock on May 24th, July 4th, September 4th and October 4th respectively.

The simulation results demonstrate that when the vertical height of the shadow shaping structure is 600 mm, the depth of the shadow forming surface is 2400 mm on May 24th (which meets the requirement that the depth of the shadow forming surface is greater than or equal to 1200 mm), and the depth of the shadow forming surface is 2400 mm on July 4th (which meets the requirement that the depth of the shadow forming surface is greater than or equal to 1200 mm); on September 4th, the depth of the shadow forming surface is 1700 mm (meeting the requirement), and on October 4th, the depth of the shadow forming surface is 1000 mm (fail to meet the requirement) (as shown in Table 2).
Table 2. Schematic diagram of the relationship between the spatial scale of constant shadow of the southbound veranda and the solar elevation angle from 12:00 to 14:00

| Solar Elevation Angle(°) | May 4th | Summer Solstice | July 4th | September 4th | Autumn Equinox | October 4th |
|--------------------------|---------|-----------------|----------|----------------|---------------|-------------|
|                          | 83      | 90              | 90       | 74             | 67            | 63          |
| Depth of Shadow Plane(mm) | 2400    | 2400            | 2400     | 1700           | 1350          | 1000        |

From May 24th to the summer solstice, the subsolar point moves from the north of the equator to the Tropic of Cancer, during which the solar elevation angle in Guangzhou gradually increases, and the shadow spatial scale also expands; from the summer solstice to July 4th, the subsolar point moves from the Tropic of Cancer to the equator, and the solar elevation angle in Guangzhou gradually increases. During the period from May 24th to July 4th, the solar elevation angle in Guangzhou first increases to the maximum value on the summer solstice and then gradually decreases, and the total shadow spatial scale also increases to the maximum threshold value on the summer solstice and then gradually decreases. During this period, the shadow surface depth and shadow spatial scale of the south facing veranda from 12:00 to 14:00 a day could meet requirements that let two people walk in parallel.

From July 4th to September 4th and to the autumnal equinox, the subsolar point moves from the south side of Tropic of Cancer to the equator, as the solar elevation angle in Guangzhou gradually decreases, and the shadow spatial scale also decreases; from the autumnal equinox to October 4th, the subsolar point moves from the equator to the Tropic of Cancer, the solar elevation angle in Guangzhou gradually decreases, and the shadow forming surface reaches the minimum value of 1000mm compared with that on October 4th, while the constant shadow space has the minimum scale at this time, which does not meet the attendance demand.

To sum up, from May 24th to September 4th, the 600 mm high vertical component of the southbound veranda of the main teaching building in the university can meet the attendance requirement from 12:00 to 14:00; while from September 4th to October 4th, the space scale of the constant shadow gradually decreases, and the shadow forming surface gradually fails to meet the requirements of 1200 mm. In addition, according to the trajectory of the sun and the above simulation results, the shadow space scale of the four time nodes of May 24th, July 4th, September 4th and October 4th, the last one shows the smallest scale. Therefore, it is only necessary to reasonably adjust the vertical height of the shadow shaping structure, and the depth of the shadow forming surface from 12:00 to 14:00 on October 4th should be greater than or equal to 1200mm, which can ensure the two people’s attendance demand in the corresponding period of all days from May 24th to October 4th.

3.2 Computer simulation of constant shadow space optimization of the southbound veranda

Taking ‘50 mm’ as the level difference, the vertical height of the shadow shaping structure starts from 600 mm. Then increase the height with the equal difference, and carry out the simulation until the best constant shadow space scale is obtained. The simulation results are shown in Table 3.
Table 3. The results of constant shadow simulation under the condition that the vertical height of the shadow shaping structure increases by 50 mm (the level difference) when the floorslab spacing is 3600 mm.

| the Vertical Height of the Shadow Shaping Structure (mm) | May 24th | July 4th | September 4th | October 4th |
|--------------------------------------------------------|----------|----------|---------------|--------------|
| 600                                                    | 2400     | 2400     | 1700          | 1000         |
| 650                                                    | 2400     | 2400     | 1720          | 1035         |
| 700                                                    | 2400     | 2400     | 1740          | 1070         |
| 750                                                    | 2400     | 2400     | 1760          | 1095         |
| 800                                                    | 2400     | 2400     | 1780          | 1115         |
| 850                                                    | 2400     | 2400     | 1795          | 1140         |
| 900                                                    | 2400     | 2400     | 1803          | 1170         |
| 950                                                    | 2400     | 2400     | 1810          | 1200         |

According to the above results, it can be seen that as for the southbound veranda of the main teaching building in the university, when the vertical height of the shadow shaping structure is 950 mm, the depth of the shadow forming surface on October 4th represents the most suitable one, and its depth is 1200 mm, which can make the space scale and size of the constant shadow space on the calculation date and during the period from May 24th to October 4th suitable for the needs that two people to walk in parallel in students’ attendance time.

4. Analysis on the design and application of the southbound veranda of the teaching building

4.1 Space simulation of the southbound veranda under different floor heights

When the floorslab spacing reaches 3600 mm, the southbound corridor of the teaching building (net width of its outer corridor is 2400 mm) is composed of beams, heating and ventilation equipment in the beams and other decorative components, and the height of the shadow shaping structure has to be set at 950 mm, which can meet the needs that two people walk in parallel. When the net width is still 2400 mm and the net height of the structure is set at other heights, the vertical height of the structure needs to make some adjustments. By doing that, the spatial scale and size of the constant shadow can be effective and perform temporal and spatial characters. Taking the southbound veranda of a 2400 mm wide teaching building in Guangzhou as an example, the floor heights of 3300 mm, 3900 mm and 4200 mm are adjusted respectively to simulate the constant shadow space. Meanwhile, increasing increase the isochromatic value value of ‘50 mm’ step by step. The simulation results are shown in tables Table 4, 5 and 6.

Table 4. The results of constant shadow simulation under the condition that the vertical height of the shadow shaping structure increases by 50 mm when the floor slab spacing is 3300 mm.

| Floorslab Spacing is 3300 mm (mm) | The Vertical Height of the Shadow Shaping Structure (mm) | May 24th | July 4th | September 4th | October 4th |
|----------------------------------|--------------------------------------------------------|----------|----------|---------------|--------------|
| 450                              | 2400                                                   | 2400     | 1760     | 1100          |
| 500                              | 2400                                                   | 2400     | 1780     | 1115          |
| 550                              | 2400                                                   | 2400     | 1793     | 1140          |
| 600                              | 2400                                                   | 2400     | 1803     | 1170          |
| 650                              | 2400                                                   | 2400     | 1810     | 1200          |
Table 5. The results of constant shadow simulation under the condition that the vertical height of the shadow shaping structure increases by 50 mm when the floor slab spacing is 3900 mm.

| Floorslab Spacing is 3900 (mm) | The Vertical Height of the Shadow Shaping Structure (mm) | May 24th | July 4th | September 4th | October 4th |
|-------------------------------|------------------------------------------------------|---------|---------|--------------|-------------|
| 900                           | 2400                                                 | 2400    | 1710    | 1010         |
| 950                           | 2400                                                 | 2400    | 1720    | 1040         |
| 1000                          | 2400                                                 | 2400    | 1740    | 1070         |
| 1050                          | 2400                                                 | 2400    | 1760    | 1090         |
| 1100                          | 2400                                                 | 2400    | 1780    | 1110         |
| 1150                          | 2400                                                 | 2400    | 1795    | 1140         |
| 1200                          | 2400                                                 | 2400    | 1800    | 1180         |
| 1250                          | 2400                                                 | 2400    | 1810    | 1200         |

Table 6. Simulation results of constant shadow under the condition that the vertical height of the shadow shaping structure increases by 50 mm when the floor slab spacing is 4200 mm.

| Floorslab Spacing is 4200 (mm) | The Vertical Height of the Shadow Shaping Structure (mm) | May 24th | July 4th | September 4th | October 4th |
|-------------------------------|------------------------------------------------------|---------|---------|--------------|-------------|
| 1200                          | 2400                                                 | 2400    | 1710    | 1010         |
| 1250                          | 2400                                                 | 2400    | 1720    | 1035         |
| 1300                          | 2400                                                 | 2400    | 1740    | 1065         |
| 1350                          | 2400                                                 | 2400    | 1760    | 1090         |
| 1400                          | 2400                                                 | 2400    | 1780    | 1110         |
| 1450                          | 2400                                                 | 2400    | 1795    | 1135         |
| 1500                          | 2400                                                 | 2400    | 1800    | 1180         |
| 1550                          | 2400                                                 | 2400    | 1810    | 1200         |

4.2 The relationship between the solar elevation angle and the construction of “constant shadow” space

Through the above simulation results, to meet the students’ attendance needs in the corresponding period, we can conclude these conditions: under the variation of the floor slab spacing of 50 mm, the veranda with 3300 mm floor slab spacing can form the shadow shaping structure, and the vertical height should be 650 mm; the veranda with 3600 mm floor slab spacing, and its vertical height should be set at 950 mm; the veranda with 3900 mm floor slab spacing, and the vertical height should be 1250 mm; the veranda with 4200 mm floor slab spacing, and the vertical height should be 1550 mm. As the solar elevation angle is always kept constant on October 4th, for example, when the southbound veranda with the floor spacing stays at 3300 mm, 3600 mm, 3900 mm and 4200 mm respectively, the difference of 300 mm between the floor slab spacing leads to the equal difference of 300 mm in the vertical height of the shadow shaping structure under the same situation and attendance demand (as shown in Figure 4).

Figure 4. When the solar elevation angle is fixed, the isochromatic change of the floor height of the south veranda is accompanied by the isochromatic change of the vertical height of the shadow shaping structure.
According to the trend of the above results, the more suitable height of the shadow shaping structure can be calculated by combining the solar elevation angle and the shadowing demand at that time. According to the calculation formula of solar elevation angle at noon and the latitude of subsolar point, the declination of the sun (equal to the latitude of the subsolar point) is represented by $\delta$, and the geographical latitude of the observation site is represented by $\phi$. Since October 4th is between the autumnal equinox and the winter solstice, the longitude and latitude of Guangzhou are 113.27° and 23.13° respectively; so the latitude of the subsolar point on October 4th is 63° by combining the formulas (1) and (2).

$$h = 90° - |\phi - \delta| \quad (1)$$

$$\delta = -\arcsin \left( \sin 23°26' \sin \frac{(n-186)\pi}{180} \right), \ n \in [186, 276] \quad (2)$$

For the south veranda with 2400mm net width and 150 mm thick railings of the teaching building at this University, in order to create a constant shadow space with 1200mm width and 1200mm depth and let two students walk in parallel from 12:00 to 14:00 every day from May 24th to October 4th, through the tangent function of the solar elevation angle of Guangzhou on that day, the vertical design height of the shadow shaping structure in the south veranda with known floor spacing can be obtained. Taking $h$ as the sun elevation angle of Guangzhou on that day, $H$ as the floorslab spacing of the south veranda (mm), $H'$ as the vertical design height of the shadow shaping structure (mm), and $L$ as the distance from the external wall to the outer surface of the railing (as shown in Figure 5), the following formula can be obtained:

$$H' = H - \tan h (L - 1200) \quad (3)$$

When $L$ is 2400 + 150 = 2550mm, and the vertical design height $H'$ of the shadow shaping structure is 650mm, 950mm, 1250mm and 1550mm respectively, and the effects are basically consistent with the simulation results.

![Figure 5. Schematic diagram of related concepts in the relationship between solar elevation angle and the shadow shaping structure](image)

5. Conclusion

It can be seen from the above formula that the vertical design height of the shadow shaping structure is positively correlated with the floor slab spacing. Therefore, when the higher the floor slab spacing is, the vertical height of the shadow shaping structure should be avoided to be higher. If not, it will lead to poor lighting in the corridor. The materials of the shadow shaping structure can choose perforated plates with different void densities, folding shutters or vertical greening. In this study, there are still some areas that need to be further improved: the form of veranda only takes the south as an example, and we still need to consider the nature of the construction of the related constant shadow in the veranda in the east, west, north and other directions, which will be further discussed in the follow-up research.

Acknowledgments:

This paper is one of the phased achievements of the general project Research on Formation Mechanism and Design Inspection Method of “Constant Shadow” Outdoor Public Space in Hot Summer Areas.
(51778154) of National Natural Science Foundation of China.

**Bibliography**

[1] Zhao Qingnan, Li Jing. On the design of space environment in architectural shadow areas [C]. Transformation and reconstruction: Proceedings of China urban planning annual meeting in 2011, 2011 (09).

[2] Hourani M M, Hammad R N. Impact of daylight quality on architectural space dynamics: Case study: City Mall – Amman, Jordan [J]. Renewable and Sustainable Energy Reviews, 2012, 16 (6): 3579-3585.

[3] Rockcastle S, Andersen M. Measuring the dynamics of contrast & daylight variability in architecture: A proof-of-concept methodology [J]. Building and Environment, 2014, 81: 320-333.

[4] Zhang Xiangrong. Research on the determination method of outdoor design conditions of sun shading design [D]. Xi’an University of Architecture and Technology, 2020 (06).

[5] Ministry of Housing and Urban-Rural Development of the People’s Republic of China. Residential Design Code [S]. 2011.