Lighting Design and Statistical Analysis on Sunshine Underground garage

Wanying Qu, Wei Cheng* and Congru Liu
College of Urban Construction, Wuhan University of Science & Technology, Wuhan, China

*Corresponding author email: chengwei@wust.edu.cn

Abstract. In view of the current status of underground garages, the underground sunshine garages are used in the architectural design. After the completion of Tongcheng Yuli community, the questionnaire survey and field measurement were conducted simultaneously. The statistical method was used to analyze the data and the conclusions are as follows: the illumination under skylight is higher. As the distance from the skylight is further away, the speed of illumination decline is first fast and then slow. An exponential distribution occurs. Lane illumination and distance is also exponentially. In the case of unilateral daylighting, the minimum illumination requirement is 30lx, the distance limit is 14.5 meters and there are basically 2 columns. On both sides, the distance of the daylighting port is 30 meters, and there are basically four columns around. The comfortable condition are analyzed in the underground garage. This paper will provide reference for the design in the underground sunlight garage.

1. Introduction
With the rapid development of urbanization, the scarcity of living space is caused by population growth and land expansion. The usage of underground space becomes the inevitable trend of urban development [1]. Underground garage is one of the types. With the improvement of living standards, as of 2019, the number of private car ownership has exceeded 207 million. With more cars and limited resources on the ground, a large number of underground garage constructions have become inevitable. There are some negative psychological reactions in underground garage, such as darkness, damp, depression, uncomfortableness [2]. In order to make better use of underground space and reduce energy consumption, the introduction of daylight can make people eliminate many of the discomfort of the underground space.

At present, there are many researches on natural lighting. Abroad has been more emphasis on the application of natural light. such as, America's Beltran L O [3] studied the performance of sunshine day lighting system in the room with a reflector and a light guide tube; Floyd David B [4] et al. evaluated the performance of the lighting system by real-time monitoring the working face illumination and power consumption of a middle school cafeteria after daylight. As for the exploration and utilization of daylight lighting in underground buildings, many domestic scholars have carried out extensive researches . The influence of partial factor design of natural lighting on energy consumption of underground buildings is studied [1, 5], the form of underground lighting is discussed [2]. More research focuses on the application of new lighting technologies [6-8]. Generally speaking, the research on natural lighting of underground parking with low cost, the joint design of lighting and ventilation, and the related quantitative analysis are still lacking. In view of this, this paper will combine the lighting and ventilation design of the underground garage of Tongcheng Yuli Residential area, analyze
the effect after the implementation of the scheme, and explore the characteristics of energy saving.

2. Project Introduction
Tongcheng Yuli district is located in the east coast of Xiushui River in Xianning City. It was built in 2014. Now there are many residents who live in there. Good environment and user-friendly design are praised by the residents. The comfort of underground garage is higher, in which lighting and ventilation are good throughout the year.

2.1 Parking Design
This project has a good external traffic conditions. It is near the city road in the east of the base. There are two main entrances and exits in the residential area. The main roads in the residential area are ringed internally to form a ring road for motor vehicles, which can save road area and high land utilization rate.

2.2 Underground Garage Design

![Figure 1. Design of underground garage in Tongcheng Yuli district.](image)

There are 125 parking Spaces in the local garage. There are altogether 5 high-rise tower buildings, each of which is T-shaped and has different house type. Shear wall structure is adopted. Except for the central green column grid, the underground space has low parking utilization rate around it.

One-parking- space is designed by 2400*5000 mm in the center column. The column section width is 500mm. According to the principle of increasing column spacing, fewer columns and more parking, three-car-parking per column spacing are arranged. The parking column spacing is calculated by 7800*5000mm.. For structure processing requirements, there is two-car-design with 5400*5000 mm and single- parking- space with 3600*5000 mm. the edge of the basement is in parallel with the superstructure and the underground sunshine garage is simple and square. (Fig.1)

3. Lighting and Vent Design for Underground Garage

3.1 Daylighting Analysis of Underground Garage Skylight
After the completion of the underground garage skylight in this project, it has been well received by the residents. by top lighting design, the above and below ground are connected, which create a changing indoor environment and allow people to feel comfortable and safe in the underground garage. At the same time, the underground garage is designed to create comfortable thermal environment. From July 2016 to July 2018, the outdoor temperature was 28-34°C, while the underground garage was at a constant temperature of 22-26°C.
3.2 Influence Factors of Underground Skylight Lighting

The main factors which affect the lighting of the underground skylight are the shape of the hole, the form of the lighting, window area ratio, the material of the skylight and the layout of the skylight. In Yuli district design, using PC plate window with pyramid square plane, is excellent on lighting effect (Fig.2).

![Figure 2. Dormer design of underground garage.](image)

4. Test Scheme

4.1 The Test Object

The building area of this garage is 3552 m² with a net height of 6 meters. The skylights of four 3 x 3 meters and two 1.5 x 3 meters are installed above the roadway. The distance between the center line of the parking space is 31.2 meters. The distance between the center line and the wall is 19.5 meters. A point is arranged every 4-6 meters on the vehicleway, and a total of 198 measuring points are set up. (Fig.3)

![Figure 3. Lighting point layout of underground garage.](image)

4.2 Test Procedures and Methods

The instruments used in this test are illumination meter, temperature and humidity meter, multi-channel illumination tester and light environment testing system. The measuring points of outdoor environmental parameters are selected in the place without direct solar radiation. Indoor environmental parameters mainly include indoor illumination and glare. The test time was all day on June 10. After analysis, the illuminance at 9 am could reflect the average illuminance value of all day, so the test parameter at 9 am was taken as the calculated value.
5. Daylighting Test Results and Analysis

5.1 Carriageway Analysis

Take the data at 9 o’clock in the morning for analysis. At this time, the outdoor illuminance is 20000lx, and the illuminance of each point around the skylight is basically symmetrical distribution. Therefore, We’ll analyze the illuminance of four points around the parking space near a skylight and the value of the illuminance of the driveway every 4-7 meters. Points with similar readings are marked with the same serial number and the average of them is taken (Table 1).

Table 1. illumination of carriageway.

| Arrangement of points | A   | B   | C   | D   | E   | F   | G   | H   | J   | K   |
|-----------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| illuminancy(lux)       | 1504| 356 | 211 | 146 | 95  | 61  | 43  | 35  | 16  | 4.3 |
| Daylight Factor(%)     | 7.52| 1.78| 1.05| 0.73| 0.48| 0.31| 0.22| 0.18| 0.08| 0.02|

After collating and analyzing the data, the average En is 247.1lx, the minimum E_min is 4.3lx, and the maximum E_max is 1504 lx. The calculated average value of lighting coefficient C_av is 1.24%, the minimum value C_min is 0.02%, the maximum value C_max is 7.51%, and the lighting uniformity is 0.3%. According to the analysis, the average illumination of the driveway (En =247.1lx) Is greater than the minimum standard of 30lx, which meets the requirements of the specification, and the lighting uniformity (0.3%) is low, less than the requirement of 0.5%, but it does not affect the passage of the underground garage.

Statistical regression analysis of traffic lane data shows that the illumination value and daylighting distance are exponentially distributed. With the increase of the distance from the skylight, the illuminance decreases fast first and then slowly(Fig.4). Skylight on both sides, exponential distribution formula is  \( y = 874.76e^{-0.17x} \) (R = 0.8649). When the high standard requirements of 75lx is met, the distance between the maximum two-way daylighting point and the daylighting outlet is 14.5 meters. In unilateral daylighting, the illumination distribution is also exponential,  \( y = 897.25e^{-0.239x} \), \( R^2 = 0.9084 \). When meeting the high illumination standard of the carriageway, the distance between the farthest point and the daylighting outlet is 10.4 meters. According to the minimum lighting standard of 30lx, the distance between the furthest point and the lighting outlet is 14.3 meters. According to the design of three parking Spaces, the basic distance between the two columns can meet the lighting requirements.

5.2 Parking Space Illumination Analysis

The illuminance of a parking space is solved by averaging the four data before and after a column network (Table 2). Parking space illumination En is 80.7lx, the minimum value E_min is 1.2lx, the maximum value E_max is 352lx and lighting uniformity is 1.5%. The illuminance of parking space meets the standard requirements, and the evenness of daylighting also meets the standard requirements.
Table 2. Test values of luminance for parking space. (unit: lux)

| Spot | Lux | Spot | Lux | Spot | Lux | Spot | Lux | Spot | Lux |
|------|-----|------|-----|------|-----|------|-----|------|-----|
| 1    | 321 | 2    | 108 | 3    | 38  | 4    | 47  | 5    | 78  |
| 6    | 105 | 7    | 108 | 8    | 89  | 9    | 127 | 10   | 86  |
| 11   | 91  | 12   | 113 | 13   | 321 | 14/15| 352 | 16/17| 87  |
| 18   | 125 | 19   | 41  | 20   | 43  | 21   | 35  | 22   | 76  |
| 23   | 85  | 24   | 68  | 25   | 23  | 26   | 8.1 | 27   | 8.6 |
| 28   | 25  | 29   | 72  | 30   | 82  | 31   | 37  | 32   | 21  |
| 33   | 18  | 34   | 8.5 | 35   | 4.6 | 36   | 23  | 37   | 52  |
| 38   | 92  | 39   | 31  | 40   | 47  | 41   | 76  | 42   | 54  |

After statistical sorting of the data of the whole underground parking garage and arranging its test illumination values from large to small, the illumination distribution curve of the whole parking garage is shown in FIG. 5, showing an exponential distribution. The exponential distribution formula is $y = 390.8e^{-0.076x}$, and the correlation coefficient $R$ is 0.851. Below the skylight, the illumination is the highest. With the increase of distance, the illumination drops rapidly. When the closer it is to the lighting port, the greater the drop value will be, and the slower the decrease speed will be with the increase of the distance. The average illuminance of the whole parking lot is 113.3Lx, which meets the specification requirements. The skylight area of the whole underground garage is 54m². The two skylights at the entrance extend far to the garage with high illumination, which can be regarded as two skylights. The skylight area is 72 m² in total, the parking area of the underground garage is 3552 m², and the window-floor ratio is 1/50 which is near 1/45 and also meets the parking requirements. When a 3×3 meter skylight is adopted, it is set above the roadway, with a center line interval of 31.2 meters and the lowest illumination of 95Lx. The longest distance from the outer wall is 19.1m, and the lowest illumination is 43Lx, all of which meet lighting requirements in underground garage. The farthest part between two columns is 19.8 meters away from the daylighting hole, the daylighting effect is poor, and the illumination is at least 4.6Lx, which accounts for a relatively small proportion.

Figure 5. Luminance distribution curve of underground garage.

The lighting design of this garage is reasonable, but there are also some problems: the lighting uniformity is poor, the difference between the maximum and minimum illuminance is great, which indicates that the window margin design is too large, and the illumination near the wall edge is low. These problems can be solved by combining with the lighting well.

Subjective evaluation: Through the questionnaire survey of car owners, the car owners generally believe that the underground garage of Tongcheng Yuli Community feels transparent and bright, and the overall light distribution is relatively uniform. The illumination is low only in the corner and the direct contact with the building, but it also meets the basic traffic requirements. The indoor illumination of the garage basically meets the requirements of human vision during the day, and can realize full natural light lighting, reflecting the significance of skylight to the natural lighting of underground buildings.

Passive natural lighting system is adopted in the underground garage of this residential area. Since the lighting load curve of the garage is similar to the sunshine curve, if solar photovoltaic panels are locally equipped, the zero energy consumption goal of the underground garage of the building can be
completely achieved.

6. Conclusions
(1) Window area ratio of 1/50 can meet the lighting requirements. With 3 x 3 meters above the roadway roof and a distance of 30 meters in the center line all meet the lighting requirements of underground garage.
(2) After the skylight is installed in the underground garage, the illumination under the skylight is higher, and as the distance from the skylight is further away, the speed of illumination decline is first fast and then slow, showing an exponential distribution.
(3) The distribution of lane illumination has an exponential relationship with the distance. In the case of unilateral daylighting, the minimum illumination requirement is 30lx, the distance limit is 14.5 meters and there are basically 2 columns. On both sides, the distance of the daylighting port is limited to 30 meters, and there are basically 4 columns around.
(4) After all test values are sorted in order from large to small, their exponential distribution formula is obtained: \( y = 390.8e^{-0.076x} \) (R= 0.851).

References
[1] Wu Wei. Design of natural lighting technology for underground skylight[D], Master Thesis of Southeast University, 2008
[2] Yang Yanmei, Yang Chunyu. Study on natural lighting mode of underground garage[J], Lamps and lighting, 2014, 38(4)
[3] L. O. Beltran, E. S. Lee, S. E. Selkowitz. Advanced Optical Daylighting Systems: Light Shelves and Light Pipes[A]. Annual Conference, Cleveland, OH, 1997.
[4] Bing Xia, Xin Li. "Analysis and comparison on the potential of low-carbon architectural design strategies", Sustainable Computing: Informatics and Systems, 2019
[5] Peng Peng, Zheng Jie. The Influence of Daylighting on building energy consumption[J]. “Acta Energiae Solaris Sinica” 2007, 28(12): 1375-1379
[6] Feng Wei,Li Huimin, Zhao Jingwei. Application of solar Light - guided lighting technology in underground buildings[J]. Research on Architecture science in Sichuan, 2011, 37(2): 250-252.
[7] Qin Yanyao,Dai Huizi, Xu Hang. Study on natural lighting energy saving of light guide tube of green building in Chongqing[J]. chongqing architecture, 2015, 14(11): 5-7
[8] Hu Yujie. Application of solar light guide and daylighting technology in buildings. Architecture and environment 2014(5): 51-54
[9] Wang Chunming, Design of 43kwp roof grid connected photovoltaic power generation system in Tianhe homeland[J]. Building electrical, 2007(2): 13