

Construction Technology and Strategy of Natural Light Environment in Urban Underground Space

Jinyao Wang¹ Xinming Jia²

1. The Experimental Division of Information and Technology, Yunnan University, Yunnan, 650091, China

2. School of Architecture and Urban Planning, Chongqing University, Chongqing, 400044, China

Abstract: In underground space, daylighting plays an important role in increasing the spacious sense, improving the ventilation effect, and more importantly, reducing the negative visual and psychological effects brought by the underground space, such as enclosed monotony, unknown direction and isolation. In this paper, the technical means of utilizing natural light in underground space were elaborated from the two aspects of passive daylighting method and active daylighting method, aiming to bring natural light into the underground as much as possible so as to fully satisfy people's longing for nature for those who work and live in the underground space.

Keywords: Urban underground space; Natural light; Passive daylighting; Active daylighting

Corresponding Author: Jinyao Wang, Yunnan University, Jinshi Community, Jinchun Street, Panlong District, Kunming, Yunnan, China, 152615911@qq.com

1. Introduction

In underground space, daylighting is not only to meet the requirements for illumination and energy saving, but more importantly, to meet people's psychological requirements for perceiving such natural information as natural sunlight, sense of direction, day and night shift, weather change, season and climate. At the same time, daylighting in underground space can improve the spacious sense of space and improve the ventilation effect to greatly reduce the visual and psychological negative effects brought by the underground space, such as enclosed monotony, unknown direction and isolation. Therefore, it can be said that the design of daylighting has a multi-faceted role in improving the underground environment, including but not limited to meeting the physiological needs of human beings. There are two kinds of methods of utilizing natural light in underground space.^[1]

2. Passive Daylighting Method

Passive daylighting is used in buildings that lie directly below the surface. The skylight and atrium cannot be placed on those near-surface structures whose ground is used as road or for other functions.

2.1 Skylight Daylighting

Skylight lighting, also known as the top lighting, is a lighting method which introduces the natural light into the room via the window in the top of the room or hall. For daylighting method in underground space, there are five major skylight forms according to different building functions, which are rectangular skylight, zigzag skylight, flat

skylight, horizontal skylight, sunken (or pit) skylight.

Due to the diversity of skylight layouts and shapes, underground space with skylight lighting also varies. Some of the skylights are narrow as the gap, such as Thermal Baths Vals designed by Peter Zumthor, creating a dark and quiet atmosphere for the underground space. Some of the skylights correspond to small squares, courtyards, gardens and other outdoor open spaces, which not only provide sufficient light for underground space while keeping the ground space open but also introduce the above-ground landscape into the underground space. A good example is Glass Pyramid, the extended project of the Louver, which enhances the openness of underground spaces and the communication of aboveground and underground spaces and thus creates an open dynamic space.

2.2 Side Window Daylighting

It is feasible to open a clerestory window on the outer wall of the semi-basement above the ground level (about 1/3 of the height of the semi-basement)^[2] for daylighting or a light well interlinking with the ground along the outer wall of the basement and open a window toward the light well to collect natural light. Such daylighting forms in underground buildings are suitable for underground warehouses, garages or some business offices which are usually attached to the main body of the above-ground buildings and require little illumination and visual environment art for daylighting.

The advantage of using side window daylighting in underground structures is that in the side-lit room, the user is able to feel as if they were in the above-ground building. For example, in an underground hotel on St. Michael's

Peak, the main entrance, the lobby, and the rooms are all adopting side window daylighting which allows the main function room to have plenty of natural light.

2.3 Patio Daylighting

The combination of underground buildings and sunken courtyards is one of the direct ways to acquire natural light. The underground buildings can be connected with the natural environment through sunken courtyard or patio, and the visual circulation can be formed by opening large lighting glass doors and windows in the indoor open space, thus forming an interaction. It is more suitable for spatial organization change in small and medium-sized cultural and entertainment venues.

The advantage of patio daylighting is that it is not constrained by the terrain. Natural lighting and outward viewing can be achieved either on slope or flat ground.

2.4 Sunken Plaza

The sunken plaza is commonly used for open space in large areas of the city (such as downtown plaza, traffic plaza in front of station, plaza and greening plaza in front of large building). A part of the ground is built to "sink" to the natural ground standard and below. Generally, the height is about 4 m. The sunken plaza makes the plaza space present the changes of space forms, such as positive or negative, light or dark, noisy or quiet and closed or spacious. Large lighting glass doors and windows or a transparent colonnade can be established towards the sunken plaza on the underground buildings surrounding the sunken plaza, so as to let the surrounding underground space integrate with the open space in the plaza. Natural light of the underground space can be acquired through the sunken plaza. At the same time, because the people enter the underground space across the sunken plaza, the difference between the above-ground and the underground space is reduced to a great extent. For example, in the Rockefeller Center, if the people enter the underground plaza from the Fifth Avenue, they do not feel that they are in the underground. While in the Wave Culture Town, by use of a large number of plazas and ramps to strengthen the connection between the above-ground and the underground, the people unwittingly shuttle between the above-ground and the underground, thus the concept of ground layer is obscured. The underground buildings with sunken plaza mostly refer to multi-functional public activity types, such as shopping, entertainment, leisure, walking traffic etc.

Because of the similar daylighting methods, the underground buildings relying on the sunken plaza daylighting have similar shortcomings with those relying on side window daylighting, that is, requirement for the site. The establishment of the sunken plaza needs a large open urban space.

2.5 Underground Atrium Sharing Space Daylighting

The sharing space of underground atrium is a straight atrium space directly formed through the vertical superimposition of all layers and relatively independent functional spaces of a large underground multi-storey building complex. The large daylighting dome over the top is composed of space grids and lighting glass surfaces. Therefore, the effects of bad weather may be avoided like wind, rain, scorching sun and severe cold etc. And the underground space surrounding the atrium will absorb the natural light to a certain extent.

The advantage of the sharing space in the underground atrium is that it has a significant effect on natural lighting in the underground buildings with no connection to the above-ground. But its disadvantage is that it depends on the progress of science and technology to a great extent. For example, the loss of light inevitably exists in the system and it is not realistic for the outdoor scene obtained from the periscope. Therefore, the development of science and technology, especially in optics, is a key factor in improvement of the lighting vertical shaft system.

2.6 Combining with the Entrance

In areas short of urban land, natural lighting is usually combined with the entrance and exit of underground space. The aim is to maximize the introduction of natural light and improve the environmental quality of underground space on the smallest ground. The usual practice is to do a transparency disposal in the entrance. This approach is commonly used as an underground space for transportation hubs. For example, the famous DABASHI subway station in Japan are combined with ventilation tower and rain cover on its entrances and exits, with a transparent and conspicuous "wind wing", which marks the subway entrances and exits and also becomes a landmark of the city.

3. Active Natural Daylighting Method

The underground space is completely isolated. Therefore, the natural light can not be acquired by use of side window and skylight. Active sunlight system is hereby required to transfer the natural light to the isolated underground space through channel, pipe and optical fiber. The basic principle of active sunlight system is to calculate the change of the sun's position (Solar altitude angle, azimuth)^[3] according to the season and time, take the heliostat tracking system as sunlight collector and adopt efficient light-guiding system to send the natural light to deep underground space which needs light.

3.1 Mirror Reflection

The mirror reflection daylighting is to use the reflector of the plane or curved mirror to send sunlight to the part of

the room that needs to be illuminated through one or more reflections. This kind of daylighting method usually has two ways: one is to combine the plane or curved reflector with the sun shading facility of the lighting window, which is both reflection and sun shading; the other is to install the plane or curved reflector on the device to track the sun, as the heliostat, after its once or twice reflection, the sunlight is sent to the room for lighting. Heliostat is a device for positioning reflection of sunlight. It can accurately reflect the sunlight to a fixed position by tracking the sun. Comparing with the direct introduction of sunlight by ordinary skylight glass, it not only improves the illumination, but also prolongs the time of lighting with natural light within the room. In addition, the light is scattered to avoid the glare and uniformity of the illumination is improved to acquire more comfortable lighting effect.

3.2 Light Guiding by Using Light Pipe

The daylighting method with light pipe varies with different system equipment forms and operation places. The light pipe is a kind of natural lighting product of health, energy saving and environmental protection. Its working principle is to use the physical properties of natural light to collect natural light and transmit it to the use space through the material of high reflectivity.

The whole system consists of seven parts. In fact, it can be summed up in three parts: sunlight collection, sunlight transmission and sunlight irradiation. The sunlight collector is mainly composed of such three parts as heliostat, concentrator and reflector. There are many ways to transmit sunlight, including air transmission, mirror transmission, transmission of light pipe, optical fiber transmission and so on. The materials used in sunlight consist of diffusing panel, light transmittance prism or special materials for lighting, which make the light from the light pipe have a different distribution. The corresponding light distribution materials should be selected as required by the lighting place in the design.

In terms of type, the light pipe can be divided into active and passive type. The passive guide pipe mainly uses the shape of light cover and material treatment to collect the sunlight. The cover is mainly made from organic glass. Internally, the array of triangular reflector is used to gather the light. This method is greatly affected by direction of sunlight. The whole structure of the light pipe consists of light cover, rain proof plate, adjustable light pipe, extended light pipe, sealing ring and astigmatic plate. The active light pipe is a condenser installed in the lighting part that can be adjusted along with the direction of sunlight. The rest is basically the same as the passive light pipe. The device can obviously improve the efficiency of sunlight collection. But the disadvantages exist in the high cost and low popularity of the equipment.

3.3 Optical Fiber Light-Guiding Daylighting

Optical fiber light-guiding daylighting is a method by using optical fiber to transmit the sunlight to the position where the light is needed within the room. The idea of optical fiber light-guiding daylighting has been proposed for a long time, but it's been only over ten years for wide applications in engineering. The core of optical fiber light-guiding daylighting is the optical fiber (for short optical fiber), which is also known as optical waveguide in optical technology. It is a kind of conductive material. This material is an optical fiber drawn from the principle of full reflection of light. It has a serial of advantages including fine wire diameter (usually only tens of microns, and one micron is a millionth of a meter, thinner than a human hair), light weight, long service life, good softness, anti-electromagnetic interference, water resistance, chemical corrosion resistance, rich raw materials of optical fiber and low energy consumption of optical fiber production. Particularly, the light derived from the optical fiber has no ultraviolet line and infrared radiant line. So it has been widely used in many fields, such as building lighting and daylighting, industrial lighting, aircraft and automobile lighting, and landscape lighting and so on. The effect is remarkable. In terms of technology, this method needs corresponding equipment to cooperate in realization of the lighting function. Similar to the light pipe, the solar optical fiber optic conduction system is composed of three parts including light condensation, light guiding and astigmatism.

In the natural daylighting mode, due to the excellent optical conductivity of the optical fiber, the attenuation of natural light is very small in the conduction process. As the sunlight is collected only from the sun, daylighting efficiency in the system is greatly affected by the weather. In a cloudy day, because the energy density of natural light is too low, daylighting effect will be reduced greatly. In physical properties, optical fiber has a poor resistance to ultraviolet and high temperature, which is easy to aging and poor in durability. Additionally, the cost is high for the optical fiber system, and the structure is relatively complex for the lighting device^[4].

3.4 Daylighting Method by Light Transmission of Prism

The main principle of daylighting by light transmission of prism is to rotate two prisms to generate refraction of four times of light. The light-receiving surface always controls the direct light on the vertical direction. This technology was developed in 1981, and was mainly used to transmit and allocate light at that time. This principle for controlling mechanism is to make the prism rotate on the horizontal plane when the azimuthal angle and altitude angle of the sun change. When the sun is lowest, two prisms are used on the same direction, which enlarges the refraction

angle, so the light injection increases. In addition, when the altitude angle of the sun enlarges, it is necessary to reduce the refraction angle. Under this condition, appropriately adjust the direction of each prism, that is to say, set up proper rotating angle, so that the refraction light of each prism will be offset to some extent. When the sun is highest, control the two prisms on mutually opposite directions.

For large-scale daylighting in underground space, light transmission system of prism is generally formed by multiple light treatment interfaces, which give it certain morphological characteristics and construction shape.^[5] The improvement project of main workshop of power plant in south city at Shanghai World Expo Park is a typical case adopting this kind of daylighting mode.

Light guiding system of reflector group is mostly used in the design of daylighting of the interface of the top of the space, and it is a daylighting method integrating function and landscape as a whole. In the meantime, due to its complicated structure, this system causes certain limitations. From the aspect of technology, this complicated structure has high technological requirements, which increases construction difficulties in the aspect of light treatment. The components can realize the treatment of natural light via mutual coordination. Therefore, each element involved in natural light transmission should undergo detailed analysis of space.^[6]

3.5 Photovoltaic Effect Indirect Daylighting Illumination

Photovoltaic effect indirect daylighting illumination (established photovoltaic daylighting illumination)^[7] is to convert the light into electricity and then convert the electricity into light for illumination by using the optical-electrical characteristic of solar energy battery, but not directly use the illumination method of daylighting.

The advantages are as follows: (1) energy conservation and environmental protection; (2) power supply method is simple and the scale will not affect the power generation efficiency; (3) long service life, simple maintenance and management, unmanned operation is possible; (4) relatively low comprehensive cost, the investment is economical; (5) the installation is not restrained by regions, the scale can be determined as required, solar energy power supply is considerably appropriate for solving the power problems in mountainous areas, deserts, offshore and high space without electricity, with wide application fields.^[8]

4. Conclusion

One of the main reasons for psychological disorders of

people who enter underground buildings or move around in it is the closure nature of underground environment. Therefore, the design of underground space should take more consideration of introduction of natural light. If condition permits, passive daylighting should be applied to fully make use of natural light ray. If the condition is worse, active daylighting should be applied by using available technological means, to transmit natural light into the secluded underground space via holes, pipelines, optical fibers, etc. To make urban underground space to be the organic continuation and expansion of aboveground space by all sorts of means, eliminate the seclusion and closure state of its basic shape, and link the underground space with the aboveground space and form an entity in space shape is the major way to solve the psychological and physiological problems of people who are in underground buildings.

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