Research on Lighting and Energy Consumption in Large Space of Railway Station in Hot-Summer and Cold-Winter Zone in China

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Abstract. Based on surveys and tests of railway stations in hot summer and cold winter zone in China, analyzed the status quo of railway station buildings. A performance analysis model of the Zhengzhou East Railway Station waiting hall was established to analyse the effects of scattered skylights and different aspect ratios on the lighting environment and energy consumption characteristics, provided reference for the design of Railway Stations in hot summer and cold winter zone.

1. Introduction
Railway travel is the main mode of travel for modern Chinese. After decades of development, China's railway network construction has moved toward the "eight vertical and eight horizontal" network. The Railway Station building has been able to meet the needs of social development and people's living, but the problem of inadequate and uneven development has become increasingly prominent. Excessive energy consumption, carbon emissions and air pollution are urgent problems to be solved. Therefore, the focus of the indoor environment of the Railway Station building has been transformed from how to create a more comfortable indoor environment to a new problem of how to improve energy efficiency and reduce pollution while meeting the comfort needs of indoor environments.

Relevant research shows that the average power consumption of Railway Station in China is about 160 kWh/m², which is almost twice the current energy-saving standard for commercial office buildings. In the current energy consumption of Railway Station buildings, the energy consumption of HVAC systems accounts for 30% to 70% of the energy consumption of Railway Station buildings, and the energy consumption of lighting systems accounts for 10% to 30%. Based on the current energy consumption of large-scale Railway Station building in China, it is of great significance to propose corresponding green performance optimization methods under the premise of creating comfortable indoor environmental conditions.

Because the Railway Station has the characteristics of “high spatial structure”, “violent changes in people flow”, “high frequency of use” and “high comfort requirements”, the energy consumption problems of HVAC and artificial lighting are becoming more and more serious. Reasonable use of natural lighting for lighting can avoid the defects of lighting quality and obtain a good environment for use. On the other hand, it also solves the problem of large energy consumption of public buildings. The China Modern Railway Passenger Station has a large volume and a large depth. The waiting hall with high requirements for light intensity is usually located at the center of the passenger station. It is difficult to achieve the lighting requirements of the station waiting room by side lighting alone.
Therefore, a skylight is installed on the roof. On the one hand, it is helpful to solve the problem that light is difficult to introduce, greatly improving the intensity of indoor illumination and reducing the energy consumption in artificial lighting; on the other hand, a large amount of natural light enters the room and affects the indoor thermal environment, increasing energy consumption on HVAC. Therefore, the utilization of natural light has different degrees of influence on the photothermal environment and energy consumption in the building of the Railway Station. It is a multiparameter coupling problem worth studying.

This paper combined the research and analysis and related standards to study the influence of the aspect ratio of the waiting hall building and the change of the skylight window on the indoor light, thermal environment and energy consumption of the station building, and provides the design of the lighting skylight performance for the large high-speed railway station in the hot summer and cold winter zone.

2. Preliminary Research

In order to understand the light and heat environment and energy consumption status of the Railway Station waiting hall, Zhengzhou East Railway Station, Taiyuan South Railway Station, Changsha South Railway Station and Hangzhou East Railway Station were selected for research and testing in China's hot summer and cold winter zone. This article mainly introduces Zhengzhou East Station (ZZES) and Hangzhou East Station (HZES).

2.1. Purpose of testing

Investigate the effects of roof skylights on the light and heat environment and energy consumption of the waiting hall.

2.2. Test time and tools

(1) Test time.

Zhengzhou East Station (ZZES) Test time: 2018.01.12 9 / 00 / 18 / 00

Hangzhou East Station (HZES) Test time: 2018.01.23 9 / 00 / 18 / 00

(2) Test tools: Digital Light meter, WBGT & Heat Index Checker

2.3. Test method

According to the "Method of daylighting measurements" (GB 5699 / 2017), the following test methods are developed:

Illuminance measurement method adopts uniform point distribution method, each point spacing is 30 meters ~ 40 meters, covering the active site area and 3 meters around the site;

The test is carried out while maintaining the normal condition of the lighting port of the site.

2.4. Test results

(1) Lighting test

According to the regulations of "Standard for daylighting design of buildings" GB 50033 / 2013 for traffic building entrance hall and waiting hall: the standard value of lighting coefficient of top skylight is 2.0%, the standard value of indoor natural illuminance of top skylight is 3001x, the lighting coefficient of waiting hall is grade III, and the uniformity of top lighting should not be less than 0.7.

Comprehensive ZZES, HZES lighting test and calculation can get the data as follows. It can be found that the average indoor illuminance and lighting coefficient of ZZES are higher than the standard value, while the indoor average illuminance of HZES is lower than the standard value, which does not meet the standard of roof lighting coefficient. The lighting uniformity of ZZES and HZES meets the requirements of the code, and HZES is superior to ZZES.
In the subject research, ZZES is selected to carry out field investigation, and the energy consumption operation data of the building in 2017 is shown in Figure 2.

From the above figure, it can be seen that the energy consumption of the ZZES is huge, the skylight of the waiting hall is centralized lighting, the area of the centralized lighting skylight is about 12,000 square meters, the indoor photothermal environment and the energy consumption have a great influence, and the actual measured energy consumption reaches 3855 million kilowatts. In summer, a large amount of solar radiation is introduced into the room by the skylight, affecting the indoor thermal environment, and a large amount of air-conditioning energy consumption is generated. Therefore, it is of great significance to study the improvement of the thermal environment and the improvement of energy efficiency in different forms of skylight performance optimization.

3. Parameter Settings

3.1. Height to width ratio (HWR)

In the 19th century, the German architect Mertanz demonstrated that the aspect ratio of public buildings is low and depressed when it is less than 0.2; the public buildings is moderate when the aspect ratio is between 0.2 and 1. Therefore, the study selected typical passenger stations’ sizes which are in hot summer and cold winter zone for comparison, as table 1:
Table 1. HRW of typical Railway Station (RS) which are in hot summer and cold winter zone.

| Name of station       | Height (m) | Width (m) | HWR |
|-----------------------|------------|-----------|-----|
| Hangzhou East RS      | 39.90      | 159.60    | 0.25|
| Zhengzhou East RS     | 39.60      | 165.00    | 0.24|
| Changsha South RS     | 38.20      | 177.00    | 0.21|
| Nanjing South RS      | 37.56      | 156.00    | 0.24|
| Chengdu East RS       | 35.70      | 108.00    | 0.33|

From the above table, it can be proved that the heights of the waiting halls of some large Railway Stations in hot summer and cold winter zone are about 20 ~ 40 m, widths are about 50 ~ 180 m and the HWR are about 0.2 ~ 0.4. From the perspective of architectural comfort, it can be seen that the HWR of the waiting hall of some large Railway Stations in China are suitable.

3.2. Skylight condition
In order to provide passive energy-saving measures to improve the comfort of the waiting hall of ZZES, skylights were installed on the roof of the waiting hall to achieve the effect of natural lighting. At the same time, according to the distribution of roof skylights in the waiting hall, four different lighting conditions are set while each of them has different skylights position as the total area is the same (as shown below). The data of light and heat environment and energy consumption of the waiting hall under various working conditions are compared and analyzed by using Ecotect, and the optimum working conditions can be obtained as the optimum designs of the waiting hall.

![Fig 3. Four kinds of conditions of skylight in waiting hall](image)

condition 1: A single skylight is arranged in the middle of the daylighting atrium.
condition 2: Four skylights are arranged in the middle of the daylighting atrium.
condition 3: Eight skylights are arranged in the middle of the daylighting atrium.
condition 4: Sixteen skylights are arranged symmetrically in the middle of the daylighting atrium.

4. Lighting analysis
In this paper, the aspect ratio and skylight form of buildings with great influence on building lighting performance are studied. The universal model of skylights with three different building HWR and four different conditions is simulated to analyzed indoor light environment changes and energy. Consumption, in order to expand the performance of Railway Station photothermal environment performance. (1, 2, 3, and 4 in the table represent the four different conditions).
Table 2. Comparison of daylighting under different conditions

| HWR   | 1:3  | 1:4  | 1:5  |
|-------|------|------|------|
|       | 1    | 2    | 3    | 4    | 1    | 2    | 3    | 4    | 1    | 2    | 3    | 4    |
| Average daylighting coefficient (%) | 31.8 | 31.7 | 31.7 | 31.1 | 33.5 | 33.4 | 33.3 | 32.9 | 34.4 | 33.3 | 34.4 | 34.0 |
| Average illuminance value(lx)     | 2707 | 2700 | 2701 | 2651 | 2851 | 2838 | 2835 | 2798 | 2930 | 2838 | 2926 | 2896 |

Twelve orthogonal calculations combining three different building HWR and four different operating conditions can be obtained from the above table. It can be found from the table that the average of all 12 simulated average illuminance and daylighting coefficients is higher than the standard value. According to the "Standard for daylighting design of buildings" GB 50033-2013, the comparison of three different aspect ratio lighting simulation results can be concluded: in the large space atrium of large public buildings, the HWR is 1:5 to 1:4 and 1 The average illuminance and the daylighting coefficient of 3 are better, and within the appropriate interval, the smaller the HWR, the better the average illuminance and the average of the daylighting coefficient.

From the comparison of the simulation results of the four kinds of skylights, it can be concluded that in the large space atrium of large public buildings, the conditions and the concentrated daylighting skylights have stronger lighting ability, and the average illuminance and lighting coefficient are higher. Condition 2, condition 3, condition 4, on the basis of meeting the lighting standard, the uniformity of lighting is better. Therefore, it can be concluded that in the case where the skylight area is equal, the concentrated daylighting is more powerful, the distributed lighting uniformity is better, and the more uniform the dispersion is, the better.

5. Energy consumption analysis
According to the above working conditions, we selected and compared the simulation analysis of building energy consumption, as table 3.
Table 3. Energy consumption statistics (10MWh)

|       | 1:3 | 1:4 | 1:5 | 1:3 | 1:4 | 1:5 | 1:3 | 1:4 | 1:5 |
|-------|-----|-----|-----|-----|-----|-----|-----|-----|-----|
|       | cond 1 | cond 2 | cond 3 | cond 4 | cond 1 | cond 2 | cond 3 | cond 4 | cond 1 | cond 2 | cond 3 | cond 4 |
| Jan   | 7578  | 7577  | 7580  | 7579  | 5685  | 5684  | 5687  | 5686  | 4551  | 4550  | 4553  | 4552  |
| Feb   | 6107  | 6106  | 6109  | 6108  | 4573  | 4573  | 4575  | 4574  | 3656  | 3655  | 3658  | 3657  |
| Mar   | 4640  | 4639  | 4642  | 4641  | 3464  | 3463  | 3466  | 3465  | 2760  | 2759  | 2762  | 2761  |
| Apr   | 1553  | 1553  | 1554  | 1554  | 1151  | 1150  | 1151  | 1151  | 910   | 910   | 911   | 911   |
| May   | 392   | 392   | 391   | 392   | 303   | 303   | 303   | 303   | 248   | 248   | 247   | 247   |
| Jun   | 7390  | 7398  | 7372  | 7380  | 5916  | 5925  | 5900  | 5907  | 4988  | 4997  | 4971  | 4979  |
| Jul   | 7390  | 7404  | 7376  | 7385  | 5956  | 5964  | 5940  | 5949  | 5058  | 5067  | 5039  | 5048  |
| Aug   | 3630  | 3646  | 3623  | 3630  | 3041  | 3048  | 3025  | 3032  | 2649  | 2657  | 2634  | 2641  |
| Sep   | 275   | 276   | 275   | 275   | 214   | 214   | 213   | 214   | 176   | 176   | 175   | 176   |
| Oct   | 1538  | 1537  | 1538  | 1538  | 1140  | 1140  | 1140  | 1140  | 902   | 901   | 902   | 902   |
| Nov   | 4614  | 4614  | 4615  | 4615  | 3455  | 3454  | 3456  | 3455  | 2760  | 2760  | 2762  | 2761  |
| Dec   | 6848  | 6847  | 6850  | 6849  | 5136  | 5135  | 5137  | 5136  | 4110  | 4109  | 4112  | 4111  |
| total | 5195  | 5198  | 5192  | 5194  | 4003  | 4005  | 3999  | 4001  | 3276  | 3278  | 3272  | 3274  |

The energy consumption of HVAC and artificial lighting are the main energy consumptions of waiting halls. The HWR and skylight forms of the building affect the energy consumption by influencing the indoor light and heat environment.

With the model width being 180m, we got the HWR of 1:3, 1:4 and 1:5 by changing the overhead space based on the commercial mezzanine. Close to the actual building volume of ZZES, condition one (1:5) consumes 32768 kilowatt hours of energy a year. The data is close to the measured and has certain persuasion.

The comparison of different HWR under the same condition shows that 1:5 has the lowest energy consumption while 1:3 has the highest energy consumption. We concluded that within a suitable HWR range, the smaller HWR is, the lower energy consumption is, and the higher the energy efficiency per unit area is.

From the comparison of the simulations with the same HWR, we found that the energy consumption of centralized mode one is the highest while the decentralized mode four is the lowest. It can be concluded that the decentralized skylight works better on energy-saving than centralized skylight when the total area is the same.

Comprehensive simulation results show that when the HWR is small, it has less energy consumption and higher energy efficiency when the waiting hall is equipped with decentralized roof skylights.
6. Discussion
The waiting hall is the area with the longest passenger stay. It requires a passive energy-saving design with natural lighting to provide passengers with a more comfortable light and heat environment.

In this paper, eco-building software Ecotect is used to simulate the light and heat environment and energy consumption of the waiting hall, and the way of passive energy-saving design for natural daylighting is discussed. Four conclusions are drawn for discussion:

(1) Setting a suitable skylight at the top of the waiting hall can improve the indoor light and heat environment and improve the comfort of the light and heat environment, thereby reducing energy consumption and improving energy efficiency.

(2) In the waiting hall with roof skylights, the smaller the HWR in the appropriate HWR of the building, the better the average illuminance and the average daylighting coefficient of natural lighting, and the better the lighting effect.

(3) Compared with the skylights of the waiting halls with the same area, the centralized lighting skylights have stronger lighting ability, and the distributed lighting skylights have better lighting uniformity.

(4) Based on the influence of light and heat environment and energy consumption in natural daylighting room, the comprehensive simulation results show that the distributed roof sunroof has less energy consumption and higher energy efficiency in the waiting hall with smaller height and width.

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