Research on Facade Components Design of Primary School Buildings in the humid tropics Based on Noise Insulation Performance and Natural Ventilation——Take Shenzhen Xinzhou Primary School as an example

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Abstract: As the noise and energy consumption problems in high-density urban development zones become increasingly serious, a structural design based on noise insulation and natural ventilation was proposed by taking the façade design of Shenzhen Xinzhou Primary School as an example. The design and structure of the façade were studied and analyzed, and its actual noise insulation performance and ventilation capacity were evaluated through field measurement. The experimental results testified that the façade could reduce noise by up to 10 dB and the ventilation amount could meet the ventilation requirements of primary school classrooms, which provides guidance and reference for the subsequent design of façades with natural ventilation and noise insulation.

1. Introduction

With the rapid development of high-density cities and the rapid increase in urban road traffic, the noise problems incurred by them are becoming more and more intense. Studies show that high-intensity environmental noise is hazardous to people's health, and affects their sleep quality, distracts their concentration, reduces memory, and even damages their hearing [1]. In the field of architectural acoustics, one of the important means of noise insulation to cope with outdoor noise inside a building is to reduce the noise of the building façade. However, the noise reduction performance of the building facade is often enhanced by means of improving the airtightness of the facade windows at the expense of decreasing natural ventilation. Although mechanical ventilation can be used to assist ventilation, it can also cause an increase in the energy consumption of the building. Compared with mechanical ventilation, natural ventilation, as a simpler, more effective, and inexpensive technology, is widely accepted as the major ventilation method. For classroom, office, and other places where people gather and stay for a long time, the ventilation capacity of the building is particularly important.

Therefore, the study of façade structure with noise insulation and ventilation performance combined has gradually attracted the attention of many researchers. Given the current research on the design of the composite-function façade with natural ventilation and noise insulation in China and abroad, Tang
(2020) classified and simulated the typology of the structure designs with ventilation and noise insulation in China and foreign countries by means of the case study and computer simulation [2]. In the end, the models of façades with noise insulation and natural ventilation could be categorized into three types, namely vertical baffle, horizontal baffle, and composite baffle. Then through computer simulation experiments, it was finally concluded that the noise insulation performance of the vertical baffle and the composite baffle with a complete vertical baffle was better, which could provide certain guidance for this study. For the study of horizontal baffle type, Sakamoto et al. studied the noise insulation effect of the horizontal sunshade louver façade on windows using modeling and field measurement [3]. For the study of vertical baffle type abroad, Bajraktar et al. studied the noise reduction of staggered-structure double façades through experimental simulation [4]. Also, Liu et al. proposed an acoustical model for the staggered-structure window of natural ventilation and sound insulation [5]. Ho proposed an acoustic balcony by acoustically designing the shape of the pick-out balcony [6]. Besides, in noise insulation through greening, Chen proved that the density and tree species of green wall plants had some influence on the sound insulation performance through field measurement and simulation studies [7].

Although the research on façade structure with natural ventilation and noise reduction has progressed at home and abroad, there are few cases about engineering practice. To some degree, it indicates that architects’ thoughts on the noise reduction and sound insulation capabilities of façades are still very inadequate. The performance requirements of noise insulation and ventilation shall be considered comprehensively at the scheme design stage of the building. It can not only control the building modeling effect but also reduce the energy consumption in the subsequent use of the building. Therefore, it is of certain practical significance to study the design of such composite façade. In this paper, we analyzed the design strategy of the composite façade with noise reduction and natural ventilation of Xinzhou Primary School and conducted a study on its structure based on field measurement to summarize its characteristics and performance, which provides references for the subsequent design.

2. Research Method
The research method used in this paper is mainly design analysis and field research. The existing design of composite façades with noise reduction and natural ventilation was summarized according to the previous literature research. Taking Shenzhen Xinzhou Primary School as an example, we studied the design of a composite façade with noise reduction and natural ventilation and further evaluated the noise insulation performance and ventilation effect through the field measurement to test the feasibility of the design. In the end, we discussed the composite façade with noise reduction and natural ventilation and summarized the advantages and shortcomings of this study.

In the field research, an AWA6291 sound level meter and a small loudspeaker playing white noise were used. The A-weighted sound pressure level (hereafter referred to as SPL) was used for the measured data. The field measurement method was the loudspeaker facade noise measurement method based on the acoustical standard, which is the preferred method for determining the apparent sound reduction index of facade components [8].

3. Structural Design Analysis

3.1. Climate Analysis
The case project of Xinzhou Primary School is located in Shenzhen, Guangdong. Shenzhen has a subtropical monsoon climate. Its prevailing wind direction is southeast and northeast, and the average wind speed is between 2.0 m/s - 3.0 m/s. Therefore, it has good natural ventilation conditions. But the transition season is relatively longer in hot and humid areas. In this case, indoor comfort can be adjusted through natural ventilation so as to reduce the energy consumption of air conditioners for cooling.

Meanwhile, classrooms should have qualified ventilation capacity to maintain good indoor air quality. According to the design specifications of primary and middle schools, the minimum number of air changes in primary school classrooms is 2.5 times per hour [9].
3.2. Environmental Noise Analysis

Specifically, the project is located in Xinzhou, Futian, Shenzhen (Figure 1), and the north and west are residential areas, which are residential buildings and kindergartens, respectively. The Xinzhou 9 Street in the south belongs to the urban arterial road, and the noise is higher. The Xinzhou South Road to the east also belongs to the urban arterial road, but the noise is lower because of the dense trees on both sides of the road. Therefore, considering the above site conditions, the main sources of noise in the buildings are the south and the east.

According to the 2019 Shenzhen Environmental Status Bulletin, the average equivalent sound level of regional environmental noise in the city is 57.2 dB, which is at an average level \(^{[10]}\). The weighted average equivalent sound level of arterial road traffic noise is 69.7 dB, which is 0.7 dB higher than that of the previous year. With the gradual increase of road noise in the city, there is a growing demand for sound insulation and noise reduction of roadside buildings. In the requirements of the relevant scale in China, the main functional space for school research and education is a class 1 sound environment functional area. In such areas, quietness shall be ensured and the daytime noise limit shall be below 55 dB (A-weighted sound level) \(^{[11]}\).

In response to the site noise, reducing the noise of the main road at the southeast was considered in the design. According to the field measurement, the noise level outside the windows on the southeast side of the site was 60 dB (A), which was in line with the noise situation of the Environmental Status Bulletin. Therefore, the building façade should achieve a noise reduction capacity of not less than 5 dB.

Based on the noise conditions on-site, the design team chose a composite façade mainly consisting of vertical baffle components as a priority to address the weak sound insulation problem at the window frontage. The vertical baffle could block the noise mainly transmitted along straight lines through blocking the ventilation openings of the windows on the façade. Ventilation was generally achieved in two ways, which were partial opening ventilation at the front of the baffle and opening ventilation at the flanks of the baffle. When only vertical baffles were used for sound insulation (Figure 2-a), road noise tended to be transmitted into the room through the lower side of the baffle, so the airtightness of vertical baffles was improved by combining with horizontal baffles (Figure 2-b).

In the further refinement of the design, the horizontal baffle shape introduced the design concept of vertical greening and integrated the function of flower pond (Figure 2-c), and the final form is a whole piece of horizontal concrete baffle picked out with a flower pond in the middle. In order to improve the noise reduction performance of the horizontal baffle, the cross-section of the horizontal baffle is designed with the bottom slant cut, so as to block and reflect the noise direct sound (Figure 3 left).

The vertical baffle components are the key technical points in the project to achieve ventilation and noise reduction. The design team designed an L-shaped vertical baffle component based on acoustical principles, which was assembled outside the opening fan window for ventilation. The L-shaped vertical baffle component has a structure of double-layer aluminum plate with a cavity in the middle, with the front plate blocking the front air vent and the side plate perpendicular to the façade (Figure 3, right). The L-shaped aluminum plate has a perforated plate on one side and a solid plate on the other side, and the solid plate has a good sound reflection effect. When the noise comes in from the perforated side, it can be reflected and absorbed by the double-layer aluminum plate to reduce its noise energy. Besides,
the horizontal baffle plate can improve the airtightness of the vertical baffle component so that a better noise reduction and ventilation effect can be achieved.

Figure 3 Noise reduction of elevation horizontal baffle & Component ventilation diagram

3.3. Summary of Design Study
The façade design of Xinzhou Primary School follows the design concept of a green campus. The façade design conditions are determined from environmental research and analysis. Based on acoustic principles, the façade form is selected, and the detailed structure of the façade is designed, and the façade greening, ventilation requirements, noise insulation requirements, and other elements are integrated. Finally, the resulting façade is evaluated and optimized to obtain the final design result. The façade design integrates various elements such as form, acoustics, greening, and ventilation, to meet the needs of existing buildings for the diversity and complexity of composite façades.

4. Structure Field Measurement Study

4.1. Noise Field Measurement Study

4.1.1. Noise Experimental Design
In order to verify the performance and practical effect of the façade with noise reduction and natural ventilation, a second-floor south-facing classroom façade was selected as the object of the field measurement, and objective environmental acoustic data were measured on-site for analysis. The A-weighted SPL data were used as the field measurement results for quantitative comparison. Because the A-weighted SPL reflected the subjective perception of the human ear on the objective intensity of noise, the sound perceived by the human ear became louder as the SPL increased. Due to construction errors on-site, the gaps between the façade components and the window surfaces were filled with acoustic insulation cotton in field measurement to achieve the ideal sound insulation state.

This experiment only tests the sound insulation capacity of the components, without considering the noise insulation of the horizontal baffle on the ground floor. Therefore, the loudspeaker was placed at a horizontal distance of 5m from the second-floor façade window, and the incidence angle of acoustic waves on the loudspeaker was 45°. The acoustic source of the loudspeaker was white noise with the decibel value remain constant, so as to ensure the accuracy of the experiment.

In this field measurement, two experiments were mainly designed, and each experiment consisted of four groups (as shown in Table 1).

(1) Experiment 1 is the field measurement for the noise reduction capacity of the façade. The measuring point is located behind the façade, 1 m right from the façade components, 1.2 m from the ground (Figure 4). By testing the data of window opening and closing, the sound reduction capacity of the façade can be assessed visually by comparison.

(2) Experiment 2 is to test the impact of the façade on the sound environment of the classroom. The main measuring points are uniformly distributed in the 3*4 lattice with a distance of 2 m (Figure 5).
Field measurement steps:
(1) First, put the loudspeaker in the experimental position, and the angle between the loudspeaker and the field measurement components was 45 degrees. Then detect the noise environment around the experimental environment and measure its SPL decibel value. Turn on the loudspeaker to play white noise and set the volume to the maximum. Use the sound level meter to measure its SPL value to ensure that the decibel value was 20 dB higher than the environmental noise. Then the experiment officially started.

(2) The windows were open or closed according to the experimental group requirements. Each time the sound level meter was used for measurement in the corresponding field measuring point. The loudspeaker kept playing white noise throughout the whole process, and the time integration measurement method was used to record. The measurement time for each measuring point was 30 seconds to ensure the accuracy of the measurement.

Table 1. Experimental design table

| Experiment 1 | A Control group - Open an ordinary window | B Open the window corresponding to the component | C Control group - Close all windows |
|--------------|-----------------------------------------|-----------------------------------------------|----------------------------------|
|              | ![Image](image1.png)                     | ![Image](image2.png)                          | ![Image](image3.png)             |
| Experiment 2 | A Control group - Open all windows (With components) | B Open an ordinary window (With components) | C Open the window corresponding to the component |
|              | ![Image](image4.png)                     | ![Image](image5.png)                          | ![Image](image6.png)             |

4.1.2. Data Comparison
The weather condition on the day of the field measurement at Xinzhou Primary school was sunny with a temperature of 28 degrees Celsius. There was no interference from people inside or outside the class for field measurement. The measurement lasted for 1 hour and 30 minutes. When the white noise was not turned on, the noise level outside the window on the southeast side of the field measurement site was 60 dB(A). Sixteen sets of data were obtained through field measurement. The sound level meter recorded the SPL values in various frequency bands and under different weighting methods. In order to evaluate the noise reduction performance, the A-weighted SPL was used as the comparison value. For
the lattice data processing, the measured data were converted into isograms and the isograms were used to compare the indoor noise conditions under different conditions in a visualized manner.

(1) The data in Table 1 were obtained from the field measurement experiment for noise reduction capacity of the façade. Comparing the AB group of experiments, it could be seen that the façade inhibited about 10 dB of sound reduction. Comparing the BC group, it could be known that the component with noise reduction and ventilation only had 5 dB of sound reduction less than the window. The CD group proved that the noise reduction component with the window closed could increase the sound reduction by about 4 dB.

Table 2. Sound pressure levels of each group in experiment 1

| Experiment 1 | group A | group B | group C | group D |
|--------------|---------|---------|---------|---------|
| SPL(dB)      | 82.1    | 69.3    | 64.2    | 59.6    |

(2) In the field measurement for classroom noise environment, a 3*4 lattice with a distance of 2 m and uniformly distributed measuring points with a height of 1.6 m was adopted. Forty-eight sets of data were obtained, and the measuring point data (Table 3) were converted into isograms (Figure 6) for visual comparison.

Table 3. Sound pressure level of each measuring point in experiment 2

| Experiment 2 | a  | b  | c  | d  | e  | f  | g  | h  | i  | j  | k  | l  |
|--------------|----|----|----|----|----|----|----|----|----|----|----|----|
| group A (dB) | 59.7 | 62.5 | 63.6 | 58.1 | 59.3 | 58.5 | 57.8 | 57.8 | 58.7 | 58.5 | 58.1 | 57.7 |
| group B (dB) | 60.1 | 65.5 | 62.8 | 60.1 | 61.7 | 60.9 | 59.8 | 60.9 | 60.2 | 59.6 | 60.1 | 59.9 |
| group C (dB) | 68.9 | 78.4 | 73.1 | 69.8 | 72.0 | 71.4 | 69.9 | 72.2 | 72.4 | 69.9 | 71.2 | 71.8 |
| group D (dB) | 68.4 | 77.4 | 70.4 | 68.4 | 70.6 | 70.3 | 68.6 | 70.6 | 72.6 | 68.5 | 69.9 | 70.8 |

Figure 6 Isogram of sound pressure level of each experimental group in experiment 2

The distribution of the SPL was consistent with the acoustic principles, which showed that the noise level decreased from the side near the window to the interior. The data of the measuring points in the middle row of the noise source were higher than that of the measuring points on both sides, which was consistent with the sound propagation characteristics. Some of the data near the interior walls showed a rebound, which was due to the reflection and diffraction of sound. The average values of the four groups A, B, C, and D were 59.2 dB, 61 dB, 71.8 dB, and 70.5 dB respectively. The difference between groups C and D in terms of the average noise SPL was less than 2 dB, which proved that even if most of the windows were closed, the noise could still affect the indoor sound environment from the windows without sound insulation. Compared with groups A and C, the overall noise environment of the classroom in group B decreased by 15% compared with group C in terms of SPL, and the component showed 10.8 dB of noise reduction. Also, group B was only 1.8 dB higher than group A in terms of sound reduction, where the latter with all windows closed showed the best sound insulation capacity. In the case of opening only the component windows, the classroom gained about 10 dB improvement in sound insulation, which was also only 1.9 dB higher than the extreme case with all windows closed and showed a better effect.
4.1.3. Summary of Noise Field Measurement
The comparative analysis of the data obtained from the field measurement verified that the façade with ventilation and noise reduction of Xinzhou Primary School could achieve sound insulation of about 10 dB. When the noise level outside the window was 60 dB in the field experiment, the classroom could have an acoustic environment of less than 55 dB. It was in line with the noise reduction design requirements for the façade in the beginning.

4.2. Ventilation Effect Field Measurement
To test the ventilation capability of the façade, wind speed measurements were conducted at several measuring points on the site on September 29, 2020. During the field measurement, only the indoor component window at one side of the road and the windows and doors at the corridor side were opened. Outdoor control points were set up.

The area of the air vent (i.e. the component window) of the façade with natural ventilation and noise reduction was 0.77 m². The classroom was 8m long, 7.9 m wide, and 3.6m high, and the minimum ventilation volume was calculated to be 570 m³/h. When the wind speed outside the window was measured to be 1.4 ~ 2.6 m/s, the average wind speed of the vent was measured to be 0.18 m/s, and the actual ventilation volume was 499 m³/h. According to the Climate Bulletin of Shenzhen in 2019, the annual average wind speed in Shenzhen is 1.9 m/s, and the average perennial climate wind speed is 2.6 m/s [12]. When the wind speed in Shenzhen is at the average value, the ventilation volume of the façade with natural ventilation and noise reduction is expected to be 1.3 to 1.8 times the measured value. Therefore, the ventilation capacity of the component with natural ventilation and noise reduction can be greater than 570 m³/h in terms of ventilation volume, which can meet the demand for ventilation and air exchange in primary school classrooms.

5. Conclusion
This paper introduced a design of the façade with natural ventilation and noise reduction combined for Xinzhou Primary School in Shenzhen through research, and the field measurement results show that it can achieve 10 dB of sound insulation and good ventilation capacity. The façade has the advantages of standardized structure, integration of greening elements, and friendliness to the urban interface, which has certain applicability. The disadvantages lie in that the components with noise reduction and natural ventilation may have different sound insulation amounts for sound sources from different directions, but the field measurement in this paper did not consider the situation of multi-angle sound sources. Meanwhile, the ventilation capacity measurement did not take into account the opening of windows during and after the class, so there are certain limitations, which can be explored in depth in the future.

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Figures 1 and 3 are provided by Atelier Y. Other charts are drawn by the author.

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