Research and optimization of acoustic environment in ordinary classrooms of middle school

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Abstract. A good classroom acoustic environment will contribute to teachers’ health and students’ learning. Comfortable acoustic environment requires suitable reverberation time, sufficient loudness, uniform sound field distribution, high language clarity, and no acoustic defects such as echo and acoustic focusing. In this study, the optimization strategy of acoustic environment is proposed through the investigation, field testing and numerical simulation analysis of a middle school classroom in Wenzhou under different ventilation conditions. The results show: the key factors affecting the classroom acoustic environment are outdoor activity noise, corridor noise, and classroom teacher-student activity noise. Through optimization, the quality of classroom acoustic environment is improved significantly. Classroom reverberation time (intermediate frequency) decreased from 1.5s to 0.7s; ALC decreased from 9.65% to 4.75%; STI increased from 0.534 to 0.664. The research results provided reference for acoustic design of secondary school classrooms in the future.

Introduction

A comfortable campus environment is conducive to students’ physical and mental health and improve students’ learning efficiency. There are many factors affecting the overall environmental quality of the campus, among which the acoustic environment is an important factor. In recent years, many studies of the campus acoustic environment have been proposed by domestic and foreign scholars, not only investigations and evaluations of outdoor acoustic environment, but also researches of indoor acoustic environment with various function, such as dormitory¹, office², library³, classroom⁴-⁶.

Classroom is the main place for teaching and learning. Classroom acoustic environment is related to the teachers’ teaching quality and students’ learning effect. Therefore, research findings on classroom acoustic environment are emerging. Bridget⁷ summarized the influence of noise on students of different ages. The results show that noise interference has a negative effect on students’ attention, reading and writing, calculation, understanding and memory. Song⁸ investigated the noise status of university classrooms. The results showed that traffic noise and teacher-student activity noise were the main factors affecting teacher-student learning. Hodgson⁹ studied the indoor noise sources, and the results showed that the teacher-student interaction noise was the main indoor noise, followed by the mechanical and electrical equipment noise. At the beginning of the 21st century, foreign scholars have carried out detailed studies on the influence of classroom acoustic environment on different groups, and studies have shown that pupils of different ages have different requirements for signal to noise ratio (SNR).

Under noise interference, low-age students are more difficult to concentrate, so they require higher SNR. However, the domestic research on the acoustic environment requirements of middle school students of different ages is still rare. There is a lack of practical optimization of classroom acoustic environment, and most of them remain in theoretical research such as questionnaire and simulation. In this paper, firstly, the basic data of classroom acoustic environment in a middle school in Wenzhou are investigated, and the demand of middle school students of different ages for acoustic environment is studied. Secondly, the current situation of acoustic environment and the main factors affecting the classroom acoustic environment are analyzed, and thirdly solutions are put forward and transformed. Finally, The post-evaluation of the effect after the optimization is carried out, and a set of applicable technologies are summarized.

1 Research objects and Methodology

1.1 Research objects

The ordinary classroom of Wenzhou No.3 Middle School is taken as the research object. The classroom size is 9.6x7.5x3.75m, with 36 peoples in total. The...
indoor decoration of the classroom is simple. Ceramic tiles are laid on the floor and wall below 1.2m and cement plastering is used on the ceiling and wall over 1.2m. There is basically no acoustic design. The indoor decoration of all ordinary classrooms in this school is basically the same, as shown in Fig.1 for details.

1.2 Methodology

1.2.1 Questionnaire survey

Eight classes of students were selected as the sample, and the anonymous questionnaire was used to investigate the satisfaction of their classroom acoustic environment. Students in different ages evaluated their classroom acoustic environment quality. The content of satisfaction survey includes the respondents’ class and their seat position, main noise influencing factors, language clarity of different disciplines (Chinese, English, Mathematics), and overall satisfaction. The results of servery were used to take descriptive statistics, data analysis and other methods to describe the users’ satisfaction with the classroom acoustic environment, and analyze the main acoustic influence factors and other acoustic characteristics.

1.2.2 On-site test

Six classrooms with poor satisfaction were selected as the measured objects. The measurement method, measuring point arrangement and measuring equipment meet the requirements of GB/T3222.1-2006 Acoustics—Description, measurement and assessment of environmental noise-Part 1:Basic quantities and assessment procedures (ISO 1996-1; 2003, IDT) and GB/T50076-2013 Code for measurement of the reverberation time in rooms, GB/T3222.2-2009 Acoustics—Description, measurement and assessment of environmental noise-Part 2: Determination of environmental noise levels.

Three kinds of open field conditions were measured, which were natural ventilation, no ventilation, natural ventilation with enhanced convection. The measured parameters include environmental background noise, reverberation time and frequency characteristics. Three measuring points are arranged in each classroom with 1.2 m height from the floor. The layout of measuring points in the classroom is shown in Fig.3.

1.2.3 Numerical simulation

The German acoustic simulation software EASE was used to simulate and analyze the situation of the classroom sound field before and after the optimization. The acoustic effects of different schemes were predicted and compared to help reduce the cost of decision-making and optimization.

Based on the drawings and photos, the geometric model in 1:1 ratio was established according to the actual situation, shown as Fig. 4 classroom 3D model diagram.
2 Results and discussion

2.1 Subjective questionnaire

(1) A total of 288 respondents were surveyed. After excluding invalid questionnaires, 243 were recovered, and the recovery rate was 84.37%. Grade distribution as Table 2 shows:

| Grade | Number of Students | Cumulative Percentage |
|-------|-------------------|-----------------------|
| seven | 119               | 48.97%                |
| eight | 64                | 26.34%                |
| ninth | 65                | 26.75%                |
| total | 243               | 100%                  |

(2) As shown in Fig. 5, the questionnaire survey about classroom acoustic environment tells that the overall satisfaction of students is only 55%, and there is a need to improve the classroom acoustic environment.

(3) As shown in Table 3, the main factors affecting the classroom acoustic environment are outdoor activity noise, corridor noise, and teacher-student activity noise in the classroom, among which outdoor activity noise accounts for the largest proportion.

| The most influential noise factor in class | Number of People | Proportion | Accumulate Percent |
|------------------------------------------|------------------|------------|--------------------|
|                                          |                  |            |                    |

(4) As shown in Table 4 and Table 5, there was a big difference in students’ satisfaction with natural sound teaching indifferent disciplines. In this survey, the satisfaction of acoustic environment in language subjects is 55%, and the satisfaction of mathematical acoustic environment is about 70%.

The main reason for the difference of satisfaction might be that the consonants in mathematics teaching are relatively less and the logic is strong so that the unclear part can be obtained from contract relatives. Meanwhile, the English and Chinese teaching contents involve longer sentences, and the consonants are relatively more. Which means if the classroom acoustic environment were poor, difficult to listen and understand, also difficult to reason relatives by logic, it would greatly reduce learning efficiency result in mental stress and fatigue, and lower the satisfaction.

(5) As shown in Fig. 6, under the premise of consistent acoustic cognition, satisfaction decreased

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Table 1. Interior Surface Material of Classroom

| Sound absorption coefficient | Wall surface | Floor | Ceiling | Window |
|-----------------------------|--------------|-------|---------|--------|
| 125Hz                       | 0.10         | 0.01  | 0.10    | 0.35   |
| 250Hz                       | 0.05         | 0.01  | 0.05    | 0.25   |
| 500Hz                       | 0.06         | 0.01  | 0.06    | 0.18   |
| 1000Hz                      | 0.07         | 0.02  | 0.07    | 0.05   |
| 2000Hz                      | 0.09         | 0.02  | 0.09    | 0.07   |
| 4000Hz                      | 0.08         | 0.02  | 0.08    | 0.04   |

Table 2. Proportion of sample grades

| Grade   | Number of Students | Cumulative Percentage |
|---------|--------------------|-----------------------|
| seven   | 119                | 48.97%                |
| eight   | 64                 | 26.34%                |
| ninth   | 65                 | 26.75%                |
| total   | 243                | 100%                  |

Table 3. The proportion of sample grades

| The most influential noise factor in class | Number of People | Proportion | Accumulate Percent |
|------------------------------------------|------------------|------------|--------------------|
|                                          |                  |            |                    |

Table 4. Frequency of loudspeaker apply & hearing clarity in Class 8-1

| Frequency of loudspeaker apply | Chinese | English | Mathematics |
|-------------------------------|---------|---------|-------------|
| Frequently                    | 0.00%   | 0.00%   | 0.00%       |
| Occasionally                  | 3.03%   | 0.00%   | 0.00%       |
| Very few                      | 0.00%   | 6.06%   | 0.00%       |
| Never                         | 96.97%  | 93.94%  | 100%        |

Table 5. Frequency of loudspeaker use & subject hearing clarity in Class 9-1

| Frequency of loudspeaker use | Chinese | English | Mathematics |
|-----------------------------|---------|---------|-------------|
| Frequently                  | 0.00%   | 0.00%   | 0.00%       |
| Occasionally                | 3.13%   | 0.00%   | 0.00%       |
| Very few                    | 0.00%   | 6.25%   | 0.00%       |
| Never                       | 96.88%  | 93.75%  | 100%        |

| Hearings of various disciplines | Chinese | English | Mathematics |
|---------------------------------|---------|---------|-------------|
| unreadable                      | 0.00%   | 0.00%   | 3.13%       |
| Basically clear                 | 15.63%  | 9.38%   | 3.13%       |
| Clearly                         | 28.13%  | 37.50%  | 21.88%      |
| Clearly                         | 56.25%  | 53.13%  | 71.88%      |
with the increase of grade, and the seniors with higher learning pressure were more sensitive to classroom acoustic environment.

2.2 On-site testing

According to Code for sound insulation design of civil buildings ‘GB50118’, indoor allowable noise level ≤ 45dB. The reverberation time limit of 500Hz~1000Hz is: classroom volume ≤ 200m³, reverberation time ≤ 0.8s; classroom volume > 200m³, reverberation time ≤ 1.0s. The reverberation time and indoor environmental noise level are detailed in Table 6.

The results of on-site test were as follows:
(1) When no ventilation, the classroom reverberation time was longer, and the reverberation time was about 1.5s; when natural ventilation, the indoor reverberation time was reduced obviously, which was close to 1.0s.

(2) When no ventilation, the classroom noise exceeded the standard limit, and the sound pressure level was 45~56dB; when natural ventilation, the reverberation time increased by about 10dB. The enhanced convection a certain influence on the background noise after natural ventilation.

Table 6. Reverberation time and indoor environmental noise level

| class | working condition | 500Hz ~ 1000Hz reverberation time | allowed noise A sound level dB |
|-------|-------------------|----------------------------------|-----------------------------|
|       | no ventilation    | 1.4                              | 49.4                        |
| 7-1   | natural ventilation | 1.1                              | 57.9                        |
|       | with enhanced convection | /                              | 58.8                        |
|       | no ventilation    | 1.4                              | 51.1                        |
|       | natural ventilation | 1.0                              | 59.1                        |
|       | with enhanced convection | /                              | 65.3                        |
| 8-1   | no ventilation    | 1.5                              | 46.5                        |
|       | natural ventilation | 1.2                              | 55.6                        |
|       | with enhanced convection | /                              | 57                          |
| 9-1   | no ventilation    | 1.5                              | 52.9                        |
|       | natural ventilation | 1.2                              | 56.3                        |
|       | with enhanced convection | /                              | 56.4                        |
| 7-8   | no ventilation    | 1.3                              | 50.3                        |
| 8-8   | natural ventilation with enhanced convection | /                              | 66.4                        |

2.3 Numerical simulation

The simulation results showed that the reverberation time was about 1.5s at the frequency of 500~1000Hz, and the indoor reverberation time was basically consistent with the measured data, which can further analyze the other indoor acoustic characteristics.

The average sound pressure level in the audience area was 55dB, and the sound pressure level in the first two rows was 60dB. The sound source attenuated obviously with distance, and the sound pressure level in the last two rows was 53dB. When the background noise level exceeded 50dB, it was easy to form sound field interference, resulting in unclear teaching. The average loss percentage of ALC language consonant clarity was 9.65%, and the average STI language transmission index was 0.534. The language intelligibility before the classroom and STI language transmission index were general. The simulation results are shown in Fig. 7.

3 Acoustic environment optimization

3.1 Optimization principles

The school was in the opening period, therefore, renovation time was limited, construction and installation should be convenient and fast; decoration style before and after optimization should be consistent; the indoor sound quality should be ensured to meet the requirements after the optimization.

3.2 Optimization scheme

On the basis of numerical simulation analysis, wide-screen spatial sound absorbs and low-frequency trap sound absorbs were added to the side wall, back wall and ceiling of the classroom, until the indoor
reverberation time was reduced to less than 1.0s. The results were shown in Fig. 9-11.

Considering the length-width ratio of the classroom, the position of sound source and receiver, the sound line analysis diagram was drawn. The decoration of sound absorption materials were demanded to avoid the early reflection position and enhancing the reflected sound, as shown in Fig. 8.

Fig. 8. Sound line analysis diagram of classroom acoustic renovation

Fig. 9. Acoustic renovation plan of ceiling

Fig. 10. Acoustically modified elevation of side wall

Fig. 11. Acoustically modified elevation of back wall

As shown in Table 7, the optimization scheme was checked by numerical simulation, the checking results showed that: (1) the indoor reverberation time is decreased from 1.5s to 0.8s, and the indoor sound absorption met the requirements of the current national standard; (2) 500~1000Hz clarity C50 in the range of 2~9, language clarity after the optimization had significantly improved; (3) ALC was 4.75%, and the language intelligibility is improved to be good; (4) STI was 0.664, which was improved to a good level.

Table 7 Comparison of acoustic parameters before and after optimization

| Parameter          | Before optimization | Optimized  |
|--------------------|---------------------|------------|
| Reverberation time | 1.5s                | 0.8s       |
| ALC                | 9.65%               | 4.75%      |
| STI                | 0.534               | 0.664      |

The original decoration style after renovation was maintained, as shown in Fig. 14 and Fig. 15. After the optimization, the reverberation time (intermediate frequency) of the empty classroom is 0.7s, which is slightly lower than numerical simulation result. The sound absorption effect is better than simulation because the sound absorbed on ceiling was suspended. Before and after the optimization, classroom reverberation time as shown in the Fig. 12 and Fig. 13.

Fig. 12. Reverberation time before optimization

Fig. 13. Optimized reverberation time

Fig. 14. On site photos before and after optimization (side wall)

Fig. 15. On site photos before and after optimization (back wall)

3.2.1 Subjective survey

The Chinese and English recordings were broadcast respectively in the two classrooms before and after the optimization. 27 students from different classes in this school were randomly selected as the survey samples. Three people in a group felt the classroom acoustic environment before and after the optimization. After feeling, the ‘post-optimization satisfaction
questionnaire’ was carried out. Results As shown in Fig. 16: (1) 81% of the respondents thought the optimized effect was significant, and 19% felt the effect was general. (2) 89% of the respondents hope to carry out classroom acoustics optimization, and 11% wanted to maintain the original state.

3.2.2 Summary

The classroom acoustic environment optimization, of which the measured effect and response were good, fully verified the effectiveness of this scheme.

![Fig. 16. Comparison of subjective feelings before and after classroom optimization](image)

4 Conclusions

Acoustics transformation is an important technical means to solve the problem of substandard classroom acoustic environment. Based on engineering practice, this paper draws the following conclusions:

(1) Through this case, it is found that the key factors affecting the classroom acoustic environment are outdoor activity noise, corridor noise, and classroom teacher-student activity noise; Under the premise of consistent acoustic cognition, satisfaction decreases with the grades increasing in middle school, and the seniors with high learning pressure are more sensitive to classroom acoustic environment.

(2) Through optimization, the quality of classroom acoustic environment is improved significantly. Classroom reverberation time (intermediate frequency) decreased from 1.5s to 0.7s; ALC decreased from 9.65% to 4.75%, and the language intelligibility improved from general to good. STI increased from 0.534 to 0.664, the index increased from general to good; 81% of the respondents felt that the effect was remarkable after optimization, and 89% hoped to carry out classroom acoustic transformation.

(3) The technical measures for the acoustic transformation of ordinary classrooms in middle schools are proposed: the distance between the sports field and the teaching building is emphasized. The linear distance between the external window of classroom and the edge of the outdoor sports field is suggested more than 25m. The corridor should adopt sound absorption measures to reduce the impact of noise. Such as speech and footsteps. reverberation time is mainly controlled in the classroom. The sound absorption materials should be considered in combination with the length-width ratio of the classroom and the relative position between the sound source and the receiver, so as to reduce the absorption of the early reflected sound with 30ms.

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Conflicts of Interest

The authors declare no conflict of interest.

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