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Acoustic optimization-based design of university teaching spaces to support music performance: a systematic study from building structure to sound transmission

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Abstract The impact of acoustic design of teaching spaces in higher education on music performance has been increasingly emphasized, especially in the field of music education and performance. Traditional acoustic design often neglects the issue of sound source optimization, which affects the quality of performance. This paper discusses the support of college teaching space design on music performance from the perspective of building acoustic optimization. By studying the acoustic environments of different teaching spaces, the influence of noise control, reverberation time, sound field distribution and other factors on the effect of music performance is analyzed. Acoustic evaluation parameters such as early sound support (ST) were used to optimize the acoustic design in combination with the actual case of a multimedia classroom in University H. The acoustic design of the multimedia classroom in University H was optimized. The study shows that the volume of the teaching space is negatively correlated with the early acoustic support, and the optimal support value is between -14.5dB and -12.8dB. Meanwhile, the improved anechoic design of the air-conditioning system effectively reduces the interference of air-conditioning noise on sound quality. The experimental results show that the mean value of the subjective scores of the sound quality of the optimized teaching space exceeds 8 points and reaches the good standard, indicating that the optimized design effectively improves the sound quality of the music performance. This study provides theoretical basis and practical guidance for the acoustic optimization of teaching space in colleges and universities.

Index Terms College teaching space, Acoustic optimization, Music performance, Early acoustic support, Air conditioning anechoic, Sound quality

I. Introduction

With the continuous development of science and technology, the traditional way of education is gradually changing. Music education, as an art education, is also exploring more innovative and effective teaching methods and space design programs. Reasonable teaching space design has become an important part of school construction and education reform, which not only improves the quality of teaching, but also enhances students' learning interest and teachers' teaching efficiency, promotes teacher-student interaction, and improves the overall image of the school [1]-[4]. From the point of view of architectural acoustics principles, the propagation speed, reverberation, and attenuation degree of sound in different materials and spaces all have an impact on the quality and perception of sound [5]-[7]. However, a single reverberation time parameter can not be sound focusing, acoustic shadows, strong acoustic reflections, standing waves, echoes, flutter echoes, acoustic resonance, early acoustic reflections and a variety of sonic auditory sensations and other such factors are considered comprehensively, the ideal teaching space, you need to pay attention to the reverberation time, the reverberation time is well-designed, so that the sound sounds more mellow, fuller sound quality [8]-[11].

Traditional music performance classrooms are usually simply arranged, only some musical instruments and sound equipment, students mostly sit in the center of the classroom, learning and playing, and more than half of the piano room building structure has standing wave phenomenon, the gypsum board used is over-absorbed for music high frequency, and the multi-functional mixing hall design is simple [12]-[14]. However, such traditional teaching spaces cannot meet the diverse needs of students for music learning. Overall, the music performance teaching space needs to be constructed with acoustic function as the main focus, and by focusing on acoustic design, it can ensure good acoustic effect, which can ensure the music transmission and listening effect, and improve students' music appreciation and performance ability [15]-[18].

With the development of higher education, music performance has become an important part of teaching in colleges and universities, especially in teaching spaces such as multimedia classrooms. The acoustic environment of the teaching space directly affects the quality of teaching and the effect of music performance. Traditional teaching space design focuses on functionality and aesthetics, often ignoring the optimization of acoustic effects, resulting in poor sound quality and uneven sound propagation during music performance. In order to improve this situation, the design concept of architectural acoustics has been gradually introduced into the planning of teaching space in colleges and universities, especially in the field of music performance. A good acoustic environment can ensure that performers hear clear acoustic feedback, enhance the coordination and expressiveness of their performance, and at the same time allow the audience to obtain a better sound quality experience. In this study, we will explore the effects of sound source, room morphology, reverberation time, noise control and other factors on the sound quality of teaching spaces. Through a case study of a multimedia classroom at the University of H, this paper will analyze the actual impact of different acoustic parameters on the teaching space and then propose improvement measures. Firstly, existing architectural acoustic theories and design methods will be reviewed and their applications in teaching spaces in universities will be analyzed. Then, the acoustic characteristics of the teaching space will be analyzed through measurements and experiments in combination with actual cases, the problems in the existing design will be evaluated, and finally, the optimization scheme will be proposed and its effect will be verified. This research not only has theoretical value, but also has important guiding significance for the design of actual teaching space.

II. Optimized control of acoustics in the design of teaching spaces in higher education institutions

When acoustic designers carry out acoustic design for college teaching space, most of them only analyze the quality of sound sources on the stage transmitted in the audience hall (sound quality effect), and seldom carry out acoustic research and design from the perspective of the sound sources themselves. When music performance is performed in the teaching space of colleges and universities, the sound sources on the stage mainly include singers and orchestra. If the acoustic conditions around the singers and the orchestra are not conducive to the acoustic balance, mutual hearing, and room acoustic feedback between the singers and the orchestra, then the singers and the orchestra will have difficulty in coordinating to produce a high-quality musical performance. If the sound sources themselves are not of good quality, then the audience will not be able to enjoy a high-level performance even if the sound quality of the teaching space is good.

II. A. Acoustic Architecture of Teaching Spaces in Higher Education Institutions

II. A. 1) Acoustic standards for teaching spaces

Acoustic consultants in the design phase of different functions of college teaching space are acoustic design, given the maximum allowable sound pressure level requirements of college teaching space, mechanical and electrical equipment noise limits and other design information. As this paper mainly focuses on the acoustic design of college teaching space for discussion, so only excerpts from the acoustic design of college teaching space, which is shown in Table 1.

Table 1: Overall noise sound pressure level (dB)

Teaching space	The max allowable overall noise level of noise	The max allowable noise level of HVAC
Opera Hall	≤30	≤20
Rehearsal hall, control room	≤25	≤30
Conductor's lounge, lead actor's lounge	≤40	≤30
Meeting rooms and VIP rooms	≤35	≤30
Offices, administrative rooms and changing rooms	≤40	≤35
The front hall and dining room	≤40	≤35

According to the relevant provisions of the Theater Building Design Code, it is pointed out that when the auditorium and the stage are unoccupied, under the normal operating conditions of ventilation, air conditioning equipment, etc., the limit value of the noise level should be in accordance with the following provisions, i.e., it is preferable for theaters with natural sound performance functions and Class A theaters to be less than the NR30 noise evaluation curve. As can be seen from the data in the table, this paper is carrying out the acoustic design requirements of the teaching space in colleges and universities is higher than the national norms acoustic requirements.

II. A. 2) Basic requirements for building acoustics

When music performance is carried out in college teaching space, its sound propagation involves physiological acoustics, psychoacoustics, musical acoustics, linguistic acoustics, auditory acoustics, noise and other comprehensive factors, and its sound quality is good or bad, which directly affects the transmission of information and the improvement of the quality of music performance. A good indoor sound field in college teaching space should meet the following requirements:

(1) Lower noise. This is one of the main indicators of the acoustics of the teaching space in colleges and universities, noise can reduce the signal-to-noise ratio, mask useful information, destroy the normal distribution of the acoustic field, make the acoustic field staining, resulting in a serious deterioration of the sound quality of the music standard pressure information. The noise source of the teaching space in colleges and universities is mainly the incoming noise from the external environment (outdoor traffic noise, noise in the corridor, etc.) and the noise generated by the indoor equipment, which has a close relationship with the environment around the classroom, the amount of sound insulation of the walls, the amount of sound absorption, and the electrical and mechanical noise of the equipment, which also determines the size of the dynamic range of the information of the music performance that is received by the students.

(2) Appropriate reverberation time. People's subjective evaluation of sound quality includes “clear”, “balanced”, ‘full’, “powerful”, “soft” and other terms, which is closely related to the reverberation time. The length of the reverb time has a great impact on the sound quality, reverb time is long, the sound quality “empty”, ambiguous. Reverberation time is short, the sound quality “dry”, monotonous and boring, only the appropriate reverberation time, the sound quality can be full, strong. Teaching space in colleges and universities to music performance sound-based, reverberation time design should mainly consider the requirements of the music performance sound, so according to the volume of teaching space, choose the appropriate reverberation time, in order to achieve a higher language clarity [19].

(3) Uniform sound field distribution. Ideal college teaching space indoor sound field should be fully diffused, uniform distribution, and there is enough sound pressure level. Sufficient diffusion of indoor sound, can ensure that the students on each seat should be able to hear the loudness of the sound is not too different, but also to ensure that the indoor space at all points of the sound pressure level is equal.

II. B. Optimized design of acoustics for teaching spaces in higher education institutions

II. B. 1) Treatment of the built acoustic environment

The architectural acoustic environment of the teaching space in colleges and universities directly affects the propagation of sound, and a good treatment of the architectural acoustic environment lays a solid foundation for obtaining good sound effects in the future. Each room has its own acoustic characteristics, building materials, space size and shape, interior decoration and placement of facilities are all factors affecting the indoor sound field. If the architectural acoustic environment is not well treated, sound defects such as excessive reverberation, standing waves, echoes, acoustic focusing and resonance will occur [20].

In the early design of college teaching space, it is necessary to pay attention to the impact of the built sound environment on the sound effect. When designing teaching space in colleges and universities, the best room shape is the traditional rectangle, controlling the length, width and height ratio of the room, the ideal ratio is 2.5:2:1.5, avoiding the three-dimensional ratio of indoor space as a positive integer relationship, so as to avoid the generation of standing waves, which affects the clarity of the sound. Choose materials with high sound absorption coefficient and increase the sound absorption area, because smooth walls and floors will produce harmful reflected waves, making the sound ambiguous. Therefore, in the interior decoration can be used in wooden keel ceiling, walls do composite sound-absorbing structure, hanging soft cloth curtains and other methods. Of course, according to the actual situation to control the appropriate proportion of sound absorption and reflection, because the lack of reflective waves will make the sound appear thin, lifeless, as long as the indoor reverberation time is not more than 1.5s, it will not give the electro-acoustic system to bring a significant impact, but also to get a better tone. Avoid the formation of concave or curved surface reflections in the room to prevent sound focusing problems, so that the local sound is too strong and feedback appears whistling phenomenon. Reinforcement of resonance-prone objects to avoid sound resonance.

II. B. 2) Building Acoustic Control Strategies

(1) Control reverberation time. Reverberation time is an important indicator of the overall acoustic performance of the university teaching space building. As high-frequency sound is more easily absorbed by the air in the university teaching space building, coupled with the presence of common high-frequency absorbers (such as tables and chairs) in the building, the shortening of the reverberation time of the high-frequency band is unavoidable, which results in the acoustic effect of the university teaching space building not being able to meet the design requirements.

Therefore, it is necessary to comprehensively consider the volume of indoor objects, materials (including long tables and chairs, high benches or other items that have a greater impact on the acoustic effect) and the amount of acoustic absorption of the setup (acoustic absorption coefficient × area of use), and other factors, as far as possible, to choose acoustic materials that can guarantee the acoustic absorption characteristics (spectral characteristics), in line with the requirements of the acoustic design. And accurately grasp the amount of sound absorption required in the interior space of the building, and try to avoid installing non-essential high-frequency sound-absorbing objects indoors, in order to accurately control the reverberation time of the interior space of the building.

(2) Control sound insulation effect. In the process of construction of building decoration and renovation of teaching space in colleges and universities, the construction unit must adopt effective sound insulation measures according to the characteristics of building materials or structural features in order to improve the sound insulation effect of the building. For homogeneous materials, the construction unit should focus on its quality and surface density. For lightweight composite sound insulation structure, the construction unit should pay attention to the selection of its filler, the design of cavity thickness and the rationality of the connection method. In the construction process, the construction personnel must pay close attention to the negative impact of various influencing factors on the sound insulation effect, to ensure the effective implementation of acoustic design.

II. B. 3) Anechoic design of air-conditioning systems

The air conditioning unit fan in the teaching space of colleges and universities is generally selected according to the design air volume, and the fan noise is higher when running in the highest efficiency zone, while the fan of the variable air volume system air conditioning unit often changes the rotational speed, which requires the fan to run efficiently and stably in the whole working range. If the fan operating point into the unstable zone or low efficiency zone, or even fan rotation frequency close to the building self-oscillation frequency or other equipment rotation frequency and the formation of resonance, will produce a lot of vibration and radiation of low-frequency noise. Therefore, we must do a good job of variable air conditioning system air conditioning unit fan selection, so that the fan in the main operating time at a higher efficiency point, from the root to reduce the source of noise. Determine the fan design air volume and air pressure operating point, there are generally several ways:

(1) the fan design air volume, wind pressure working point selected at the highest efficiency, when the fan air volume is greater than 60% of the design air volume when the efficiency is higher, and when the fan air volume is less than 60% of the working point may enter the unstable zone, resulting in the loss of wind speed, low-frequency noise increases.

(2) 60% of the fan design air volume and air pressure operating point selected at the fan's highest efficiency point, but the fan in the 100% operation of low efficiency, high and low frequency band noise will increase significantly.

(3) The highest efficiency point of the fan is selected at 75%~85% of the design air volume and air pressure working point, because this interval has the longest running time of the fan, and it is a better choice for the variable air volume system.

In this paper, the method (3) is selected for the architectural acoustic optimization of the teaching space in colleges and universities, and the fan selection air volume is set at 85% of the maximum design air volume, and a high-end brand with guaranteed quality is selected.

In the entire college teaching space of the air conditioning system anechoic design, in addition to the air conditioning unit fan selection, spring damping bracket and muffler of the correct choice or not, will also have a certain impact on the system's noise reduction effect. Spring damper selection program in consultation with the relevant units to communicate with the need to consider the vibration isolation efficiency and load-bearing weight of two factors. In the past, the project generally only pay attention to the load bearing and ignore the vibration isolation efficiency, resulting in the wrong selection, affecting the effect. At the same time, the selection should also take into account the load bearing capacity of the spring damper, and the results will be compared with the manufacturer's spring damper parameter table to ensure that the vibration isolation and noise reduction effect, saving construction costs.

In the existing college teaching space acoustic building air-conditioning system selection, ZP120 is the air-conditioning system muffler model of the college teaching space, but comparing the performance parameters and design requirements of the manufacturer's super noise reduction muffler, it was found that the muffler previously provided could not meet the design requirements. After comparing the above problems through multiple communications, we found a muffler that meets the acoustic design requirements of the teaching space of the university, and then proposed to the constructor to change the original muffler into an ultra muffler. Compared with ordinary mufflers, the mufflers in the super muffler are arranged inside the muffler, and the size is bigger, and thermal insulation cotton needs to be set on the outside, which has a more significant effect on the noise reduction of low and high-frequency noise.

III. Calculation methods for acoustic optimization of teaching spaces in higher education institutions

In order to achieve the perfect unity of comfort and acoustic effect, the building of university teaching space usually has extremely high requirements on the distribution of airflow organization and acoustic noise reduction measures in the field. In the process of implementing the high standard requirements, the air-conditioning system, as one of the indispensable systems in the opera house, plays an immeasurable role. For the electromechanical installation process is even more so, because part of the large equipment (such as air-conditioning box in the fan) in operation will produce intense vibration, so a little negligence may cause the system to run too noisy and other issues. The blind implementation of various types of noise reduction measures can easily lead to the system's air volume, cooling, water or power load does not meet the functional requirements of the building, thus seriously affecting people's audio-visual experience.

III. A. Acoustic objective evaluation parameters

III. A. 1) Early Acoustic Support

Stage sound quality research has a relatively short history, but in recent years it has become a hot topic in concert hall acoustics research. There are two main methods of research, one is to investigate the subjective response of musicians playing in real concert halls, and the other is to investigate the subjective response of musicians playing in simulated sound fields (anechoic chambers). In previous studies, some researchers started from the investigation of the subjective response of the orchestra on the stage, delved into the study of the objective physical condition of the stage sound quality, and utilized anechoic chambers and information processing technology to simulate the real reflective sound system and reverberation field, to carry out experimental research on the subjective and objective aspects. The relevant evaluation parameters are as follows:

(1) The parameter of the musician's perception of the sound of his/her own instrument and that of neighboring musicians, i.e., Early Sound Support (ST).

(2) A coefficient indicating the degree to which the musician is “able to play easily and readily” with other instruments in the orchestra, i.e., Early Ensemble Level (EEL).

The expression can be expressed as follows:

$$ST = 10\lg\frac{E_e(20-100MS)}{E_e(DIR)} \tag{1}$$

$$EEL = 10\lg\frac{E_e(0-80MS)}{E_e(DIR)} \tag{2}$$

$$ST2 = 10\lg\frac{\int_{20MS}^{200MS} p^2(t)dt}{\int_{0}^{10MS} p^2(t)dt} \tag{3}$$

On this basis, the international standard optimizes the early support level with the late support level, i.e:

$$ST_{Early} = 10\lg\frac{\int_{20MS}^{100MS} p^2(t)dt}{\int_{0}^{10MS} p^2(t)dt} \tag{4}$$

$$ST_{Late} = 10\lg\frac{\int_{1000MS}^{1000MS} p^2(t)dt}{\int_{0}^{10MS} p^2(t)dt} \tag{5}$$

The exact meaning of this is consistent with the early support level.

The core element of stage sound design is to allow musicians to have good inter-hearing conditions and sufficient room acoustic feedback. Good mutual hearing conditions for the musicians require an abundance of early energy (including direct sound and early reflected sound). The performance of a symphony orchestra on stage is a combination of various sound sources, and the most fundamental and direct way is to optimize the direct sound (direct sound) within the symphony orchestra. The next step is for the musicians to have access to a sufficient amount of early reflected sound, i.e. to have the right amount of early support. For example, in a large fully anechoic room (with almost no reflected sound), if you are not speaking directly to you (no direct sound), you cannot hear the others. Since the sound radiation of the instruments is all directional and there is some possibility of the orchestra blocking each other, it is possible that the players will not hear the direct sound. The lack of reflected sound can make it difficult to hear the rest of the orchestra, making it difficult for the orchestra to synchronize the "ensemble". Finally, musicians want to have adequate room feedback, i.e., a rich reverb sound from the audience (especially the main auditorium), i.e., late support.

III. A. 2) Acoustic sound quality parameters

Indoor sound field simulation can calculate the sound quality parameters of each receiving point in the sound field, including sound field inhomogeneity, reverberation time, lateral reflectivity, early reflected sound, clarity, lucidity, NC/NR curve, reverberation sound energy ratio level, center of gravity time, initial reverberation time, early decay time, binaural center of gravity time, sound field strength, binaural interrelationship number and other sound field evaluation indexes.

(1) Reverberation time. Reverberation time is a physical quantity used to describe the degree of sound decay in the indoor sound field. It refers to the sound source to stop sounding, sound energy attenuation 60dB of the time required. In the project, the reverberation time is mainly calculated using Ilin's formula, and the reverberation time calculation formula is as follows:

$$T_{b0} = 0.161V / -S\ln(1-a) \tag{6}$$

When air absorption is to be considered in the calculation, the formula can be corrected to:

$$T_{60} = 0.161V / -S\ln(1-a) + 4mV \tag{7}$$

(2) Clarity C_{80}. Transparency is used to evaluate the degree of transparency of music, which is defined as the ratio of sound energy received before and after 80ms, corresponding to the formula:

$$C_{80} = 10\lg\frac{\int_0^{80ms} p^2(t)dt}{\int_{80ms}^{\infty} p^2(t)dt} \tag{8}$$

(3) Clarity D. For buildings in general, and for musical performances in particular, the clarity of sound is very critical. Clarity is used for music performance language clarity, which is defined as the ratio of received sound energy and total sound energy within 50ms, corresponding to the formula:

$$D = \frac{\int_0^{50ms} p^2(t)dt}{\int_0^{\infty} p^2(t)dt}(100\%) \tag{9}$$

where $p(t)$ is the energy decay curve.

(4) Center time T_c. The center time is used to evaluate the intelligibility of speech and singing and is determined by the center of gravity of the reflected sound time, corresponding to Eq:

$$T_c = \frac{\int_0^{\infty} t \cdot p^2(t)dt}{\int_0^{\infty} p^2(t)dt}(ms) \tag{10}$$

(5) Lateral Reflection Coefficient (LRC) LF. The LRC is mainly used to evaluate the listener's feeling of being surrounded by the sound field due to the lateral reflection of sound, and is defined as the ratio of the lateral reflected sound energy within 80ms to the total sound energy within 80ms, with the corresponding formula:

$$LF = \frac{\int_{5ms}^{80ms} p_{\infty}^2(t)dt}{\int_{80ms}^{\infty} p^2(t)dt} \tag{11}$$

where $P_{\infty}(t)$ is the sound pressure measured by a figure-of-eight directional microphone, and the integration starts at 5 ms to eliminate the effect of direct sound.

III. B. Calculation of air-conditioning anechoic control

III. B. 1) Calculation of wind turbine sound power level

The preliminary muffler calculation procedure is as follows:

(1) Estimate the sound power level of the fan, viz:

$$L_w = 5 + 10\lg L + 20\lg H \tag{12}$$

where L_w is the total sound power level of the ventilator.

(2) Calculate the sound power level $L_w^{'}$ in each frequency band of the fan, i.e:

$$L_w^{'} = L_w + \Delta b \tag{13}$$

where Δb is the corrected value of sound power level in each frequency band of the ventilator.

Air conditioning and ventilation and other equipment in addition to meet the basic use of the function, in terms of noise control, especially the selection of fans is particularly important, should avoid fans working in the low efficiency zone. When the fan works at low efficiency, the noise generated is much larger than the rated operating conditions, while the need to select the forward blade fan, sound power calculation, the fan must be used to calculate the full pressure rather than the static pressure outside the machine. Because of different manufacturers of air conditioning box internal resistance is not the same, the equipment table parameters are often only static pressure outside the machine, if the air conditioning muffling calculations is the building acoustics professional rather than HVAC professional, may be calculated according to the HVAC professional equipment table parameters outside the machine static pressure, the HVAC professional need to cooperate with the building acoustics professional calculations.

III. B. 2) Natural attenuation of piping systems

The noise of an air-conditioning unit is mainly the noise of the fan inside it. With regard to the determination of fan noise, the relevant design manuals give an estimation method based on parameters such as air volume and wind pressure or power. However, the estimation method is not targeted, and with the improvement of fan technology, many manufacturers have carried out noise reduction treatment of the fan, with the wind volume and wind pressure estimated noise is generally greater than the test data provided by the manufacturer, here this paper suggests that the available empirical formulas for the initial estimation of the manufacturer to provide test data shall prevail in the anechoic design.

The regeneration noise of the straight pipe section, the airflow noise sound power level L_W of the branch pipe is:

$$L_W = L_{WC} + 50\lg v + 10\lg F \tag{14}$$

where L_{WC} is the specific sound power level of the straight pipe, v is the airflow velocity in the straight pipe, and F is the cross-sectional area of the straight pipe.

The regenerative noise of the elbow, the airflow noise sound power level of the elbow L_W is:

$$L_W = L_{WC} + 10\lg f_D + 30\lg d + 50\lg v \tag{15}$$

where L_{WC} is the specific sound power level of the elbow, f_D is the octave band low limit frequency, $f_D = f_z / \sqrt{2}$, f_z is the octave band center frequency, d is the diameter or equivalent diameter of the duct, v is the wind speed in the elbow.

The regenerative noise of the tee, the airflow noise sound power level of the tee L_w is:

$$L_w = L_{WC} + 10\lg f_D + 30\lg d + 50\lg v_a \tag{16}$$

where L_{WC} for the specific sound power level, according to the v_i / v_a value can be found, v_i for the wind speed into the tee, v_a for the wind speed out of the tee.

Valve regeneration noise, airflow noise generated by the valve on the pipeline sound power level can be calculated using the following formula:

$$L_w = L_\theta + 10\lg s + 55\lg v \tag{17}$$

where, L_θ is a constant determined by the valve blade angle θ, v is the airflow velocity in the duct, and s is the duct cross-sectional area.

The regenerative noise of the air outlet, for the airflow noise sound power level L_w of the constant air velocity diffusion type air outlet is:

$$L_w = L_{wC} + 10\lg f_D + 30\lg(d \cdot v) \tag{18}$$

where L_w is the value of the specific sound power level, d is the diameter of the diffuser neck, and v is the flow velocity at the diffuser neck.

IV. Characterization of acoustic optimization of teaching spaces in higher education institutions

With the development of the times, multimedia classrooms in the teaching space of colleges and universities are more and more favored by university campuses, but in the process of building multimedia classrooms, the creation of acoustic environment is often overlooked. Sound information is not well transmitted, so that the music performance did not achieve the desired effect. Therefore, the multimedia classroom should ensure that the performer's voice can be clearly transmitted, but also to ensure that the music and sound effects of the music performance are not distorted and have a certain infectious force. In the construction of multimedia classroom, its acoustic environment should not be underestimated. This study takes the multimedia classroom of University H as the research object of this acoustic environment analysis, and explores the changes of its acoustic characteristics from the perspectives of users and designers, respectively, based on the acoustic environment optimization design method of university teaching space proposed in the previous section.

IV. A. Calculation of acoustic objective evaluation parameters

IV. A. 1) Early vocal support and teaching space

For the acoustic environment optimization method proposed in this paper, the multimedia classroom of University H is optimized, and the early acoustic support calculation method given in the previous paper is used to explore the correlation between the early acoustic support and the volume of university teaching space. Figure 1 shows the results of the correlation analysis between the early acoustic support degree and the volume of university teaching space.

As can be seen from the figure, the degree of early acoustic support tends to decrease as the volume of the teaching space increases. Combined with the subjective opinions of performers of different music performances, it can be seen that the objective support degree is generally considered to be the most appropriate between [-14dB,-10dB], but there may be a few decibels difference for different types of music performers. Combined with the actual situation of the multimedia classroom in University H, whose teaching space volume is between 45~55m3, the objective support is mainly between -14.5dB~-12.8dB, which is in line with the requirement of the optimal objective support. In addition, under the ISO standard, a specification proposes to use the reflected sound energy early acoustic support degree after 110ms as an index of the reverberation of the teaching space perceived by the music performer, so as to better describe the parameter of the teaching space's support degree for the music performer.

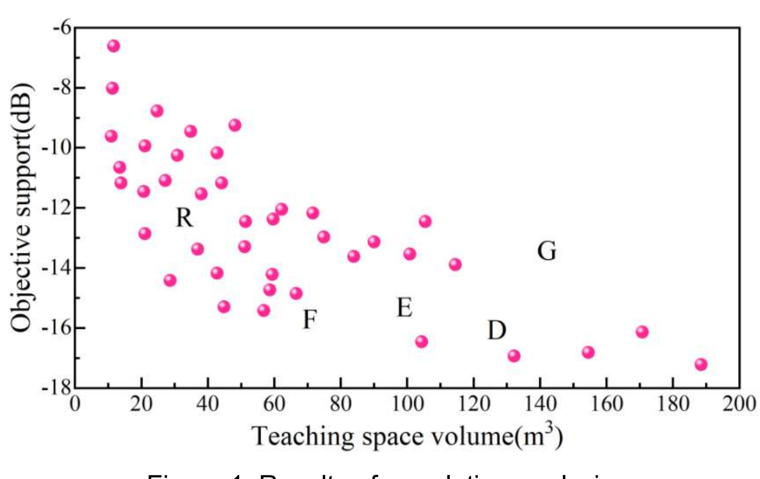

Figure 1: Results of correlation analysis

IV. A. 2) Experimental results of acoustic sound quality parameters

The listening experiment required subjects to compare the difference in subjective ratings of two sound quality indicators, reverberation and ASW, between a multi-source and a single-source convoluted musical performance signal, respectively, with and without a visual signal. Reverberation refers to the effect that the reflections from all surfaces of the room enhance and accentuate the direct sound when the music is performed in the room, and ASW represents the range of the width of the sound source as perceived by the human ear, i.e., the width of the sound emitted from the sound source propagated through the space by the binaural action and felt by the listener, and the perceived width of the sound source may be different from the width of the real musical instrument. The subjective listening experiments were rated on a scale of 1 to 10 for each experimental signal, with the rating range divided into five equal grades: excellent, good, fair, poor, and bad. Subjects referred to the rating scale and gave the corresponding scores. The subjects were all between the ages of 25 and 35, with some background in music study and professional training in subjective evaluation of sound quality, totaling 40.

This listening simulation experiment was divided into two experiments, i.e., the following experiments were conducted under the conditions of no visual signals and visual signals, and each experiment had four pairs of combinations, i.e., four typical reception point locations (S1~S4), and each combination contained two music clips (A and B), which were used to evaluate the two metrics, respectively. The subjective evaluation of the reverberation sense of the teaching space under single-source and multiple-source conditions was carried out, and the duration of each segment was 30 s, which contained two music segments of single-source and multiple-source each for 14 s (the order of randomization), with an interval of 2 s. Table 2 shows the mean values of the subjective evaluation results under the listening simulation experiments.

As can be seen from the mean values of the reverberation sense of reception points S1~S4 and the scores of each option in the four cases of ASW, for the reverberation sense evaluation metrics, the mean values of the subjective ratings of the subjects for the single sources ranged from 8.21 to 8.76, with the highest mean rating of the reception point S4 (8.70), and the relatively lowest mean rating of the reception point S1 (8.49). For multiple sources, the mean subjective ratings ranged from 8.45 to 8.93, with the highest mean rating at reception point S3 (8.79) and the relatively lowest mean rating at reception point S1 (8.69), and there was no significant difference in listening ratings between the visual and no visual conditions for single sources. For the ASW evaluation metrics, the mean subjective ratings of subjects for single sound sources ranged from 8.46 to 8.81, with the highest ratings for reception point S1 and the relatively lowest ratings for reception point S3. For multiple sources, the mean subjective scores ranged from 8.43 to 8.89, with the highest score at reception point S1 and the lowest score at reception point S2, and there was no significant difference in the listening scores between the visual and non-visual conditions. On the whole, the subjective scores of listening sound in the teaching space of the university after the optimized design of this paper are all above 8 points, which is in a good grade. This also shows the feasibility and practicability of the relevant building structure acoustic optimization design method given through this paper, which provides an improved solution for the comfort of music performance in college teaching space.

Table 2: Playback sound pressure level

Evaluation index	Music snippet	Sound pressure level / dBA			
		S1	S2	S3	S4
Reverb sensation	A-Left	8.21	8.43	8.59	8.69
	A-Right	8.76	8.65	8.62	8.71
	B-Left	8.45	8.76	8.75	8.66
	B-Right	8.93	8.87	8.83	8.79
ASW	A-Left	8.62	8.59	8.46	8.62
	A-Right	8.81	8.65	8.57	8.53
	B-Left	8.74	8.43	8.65	8.75
	B-Right	8.89	8.62	8.62	8.87

IV. B. Analysis of the effect of air-conditioning anechoic control

IV. B. 1) Muffler Acoustic Characterization Test Results

Experimental measurement of muffler acoustic performance is a very important part of the muffler design and selection process, and is also the final evaluation means of whether the muffler can meet the work requirements before delivery. In this paper, when carrying out the muffling design of the air conditioning system in the teaching space of colleges and universities, the original muffler is reset to a super muffler, and in order to verify the application of this muffler, this section is aimed at the measurement of its acoustic performance.

Insertion loss of muffler refers to the difference of average sound pressure level measured at a given point outside the system before and after installing the muffler in the system. Since most of the transition pipe sections in laboratories do not consider the muffling elbow processing and placement, the “pipe mouth method” is often used to obtain an approximate insertion loss value, i.e., before installing the muffler, measure the value 1 at a position away from the mouth of the pipe (e.g. In the installation of the muffler before a position from the pipe mouth (such as 50 ° angle with the pipe axis orientation, from the center of the pipe mouth 1.2m away from the position) to measure the value of 1, after the installation of the muffler from the muffler pipe mouth to maintain the same relative position to measure the value of 2, to the difference between the two as the insertion loss. Practice has proved that the measurement data of “orifice method” is reliable and theoretically meets the requirement of evaluating the noise reduction effect at the site.

The test data acquisition equipment using multi-channel analyzers and microphones, the arrangement of four measurement points were located in the half anechoic chamber outlet left, right 50 ° angle and the center of the outlet, the distance from the center of the outlet are 1.2 m, the distance between the measurement point and the reflective surface is greater than 1.8 m. The muffler size of the test for the auditorium design number of pieces of muffler and muffling elbow. The muffler flange interface size of 1200mm × 900mm, expansion section effective length of 1100mm, plus both ends of the total length of the reducer is 1500mm, muffling insert thickness of 120mm, the spacing of inserts for 120mm. muffling elbow flange interface size of 1200mm × 900mm, muffling insert thickness of 60mm, set up a number of pieces of the pipe guide sheet. Muffler sound-absorbing material adopts 35kg/m^3 ultrafine glass wool, surface protection structure for 1 layer of glass fiber cloth and perforated metal plate, hole diameter of 5mm, perforation rate of 25%.

According to the Calibration Specification for Pipe Muffler Test System, set the wind speed, turn on the machine and wait for the wind speed to stabilize, measure the wind speed in the profile near the end pipe and the muffler connection, and the sensor is more than 20mm away from the pipe wall. test the insertion loss of the muffler under the static state and the wind speed of 2, 5, 8m/s respectively, and measure the wind speed of each measurement point under different wind speeds for five times, and take the average of the results, and the insertion loss and muffling elbow insertion loss are shown in Table 3 and Table 4 respectively. The muffler insertion loss and muffling elbow insertion loss are shown in Table 3 and Table 4 respectively.

As can be seen from the table, under different octave center frequencies and different air-conditioning wind speed changes, the insertion loss of the super silencer designed in this paper changes less, and the insertion loss of the muffling elbow also changes less. This shows that the super silencer designed in this paper is conducive to controlling the noise performance of the air conditioning system in the teaching space of colleges and universities, so as to better ensure that the acoustic environment of the teaching space of colleges and universities is more in line with the needs of music performance.

Table 3: Muffler insertion loss

Frequency /Hz	v=0m/s Loss=21.5dB	v=2m/s Loss=22.5dB	v=5m/s Loss=22.5dB	v=8m/s Loss=20.5dB
60	3.15	3.28	1.15	4.42
120	3.24	7.46	6.42	4.45
240	17.63	17.51	20.28	14.37
480	26.08	26.14	29.04	24.51
960	33.14	33.06	34.07	32.35
1920	24.15	25.78	27.59	26.79
3840	20.28	22.39	20.25	19.38
7680	16.91	20.24	15.78	13.25

Table 4: Insertion loss of silencing elbow

Frequency /Hz	v=0m/s Loss=21.5dB	v=2m/s Loss=22.5dB	v=5m/s Loss=22.5dB	v=8m/s Loss=20.5dB
60	4.45	16.38	2.64	4.45
120	12.17	14.26	10.24	7.53
240	12.28	13.57	11.35	13.26
480	12.35	13.06	10.72	13.07
960	11.24	12.74	10.48	12.63
1920	11.08	14.32	11.06	12.15

3840	7.51	13.59	8.72	9.48
7680	7.29	11.78	5.35	8.27

IV. B. 2) Analysis of the effect of auditorium noise control

In this paper, the University of H multimedia classroom acoustic optimization, in the audience hall pool seat selection of air volume of 35,000m^3 / h, static pressure outside the machine for the 460Pa inverter air conditioning box, when the frequency of 60Hz operation more than the design of the air volume, the noise is larger, air conditioning box frequency is reduced to 50Hz, air conditioning box measured air volume and the design of the air volume is basically the same. In order to ensure the balance of the theater wind, multimedia classrooms on top of the exhaust fan needs to be turned on at the same time to track the air conditioning box of the new air volume. The following test results are frequency 50Hz, the design air volume under the operation of the test value of the multimedia classroom auditorium pool seat uniformly choose 3 points for testing, pool seat location A, B, C were near the return air outlet seat area, pool seat front seat area, pool seat back seat area, pool seat in the middle of the area (VIP area), the auditorium pool seat before the commissioning of the noise test results as shown in Figure 2. Test results show that the audience hall pool seat before commissioning operation noise test value of 60Hz, 960Hz, 1920Hz, did not meet the requirements of NR25.

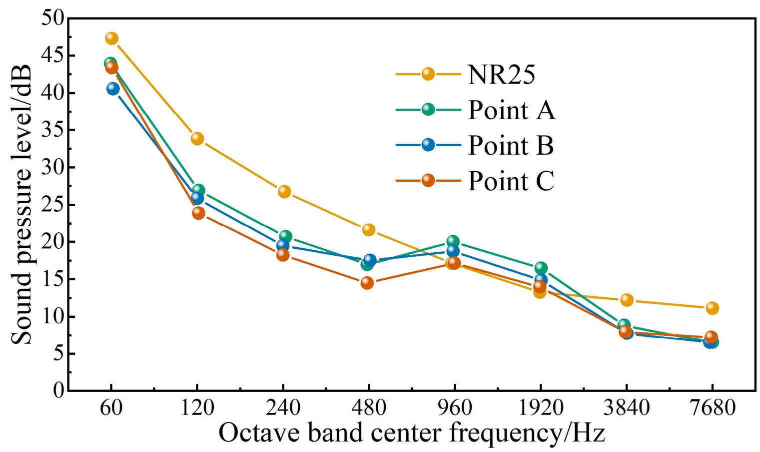

Figure 2: Noise test values before debugging

Through the scene of item-by-item inspection and testing, make the following adjustments:

(1) for the test point A return air outlet seating area, the original design of the return air outlet in the audience hall side wall set two return air louvers, the construction unit debugging, did not adjust the air volume of the two return air louvers, a large number of return air from the resistance of small louvers back to the air conditioning box. Resulting in one of the return air outlet speed is larger, up to 2.5m / s, a return air outlet only 1.0m / s, by adjusting the air volume, the test point A position noise decreased significantly.

(2) For test points B and C, the noise mainly comes from the pool seat static pressure box below the seat of the air supply outlet, the pool seat static pressure box in the original design of the uniform arrangement of five 7000m3 / h air supply flare, the construction unit for the first time when the commissioning, and did not regulate the airflow of the five air supply flare, resulting in one of the air supply flare speed to 3.0m / s, and four other air supply flare speed less than 1.0m / s. The air supply ducts and air supply flares to increase the sound-deadening cotton inside. Through on-site adjustment of the airflow to reach the design value, and at the same time in the air supply pipe and the air supply flare to increase the internal muffler, the noise of the test points B and C has been reduced, but the noise in the 60Hz frequency band still does not meet the design requirements. Considering that there are already 3 mufflers and 2 muffling elbows set up in the air conditioning room and 2 mufflers set up in the civil static pressure box, the noise at this time is not caused by insufficient number of mufflers, and finally, by replacing the pulleys inside the air conditioning box, the noise of the test points A, B and C meets the requirements of NR25 at the center frequency of different octave bands. Figure 3 shows the test results after the commissioning of the pool seat in the audience hall.

Through the Auditorium pool seat commissioning process can be seen, for the noise requirements of higher regional service air conditioning box need to ensure the quality of the factory is recommended to carry out acoustic testing, test results need to meet the design requirements. Air conditioning system is often more difficult to eliminate noise in the low-frequency band, for the noise requirements of higher places in the design of the proposed use of mufflers and anechoic static pressure box combined, not because of the resistance of the anechoic static pressure box is larger than the choice. Multimedia classroom in the audience hall floor seat muffling calculation method with the audience hall pool seat, the final noise test results to meet the NR25 curve.

The air conditioning box serving the area with higher noise requirement is recommended to take frequency conversion measures. Auditorium Block unit in 60Hz operation exceeds the design air volume, if the air conditioning box air volume is adjusted by closing the small valve to increase the system resistance, not only waste of energy, the air conditioning box noise volume will not be reduced, and it is difficult to meet the requirements of NR25. The auditorium block eventually reaches the design airflow at about 50Hz.

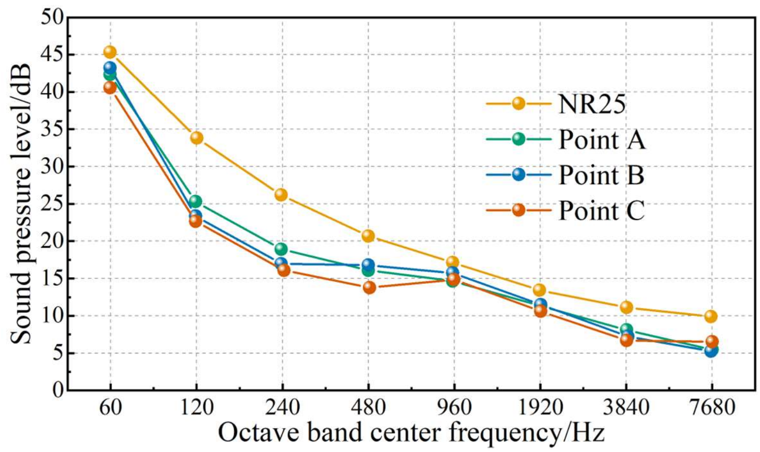

Figure 3: Noise test values after debugging

V. Conclusion

The optimized multimedia classroom of University H achieves the desired effect of music performance through the improvement of acoustic design. The experimental results show that there is a negative correlation between the early acoustic support (ST) and the volume of the teaching space, and the optimized objective support is maintained between -14.5dB and -12.8dB, which meets the requirements of the optimal music performance environment. The anechoic design of the air-conditioning system reduces the interference of noise to the music performance, resulting in a significant improvement in the sound quality of the teaching space.

In the implementation process, for the optimization of the air-conditioning system, more efficient mufflers were used, and the fan and piping system were optimally adjusted to reduce the impact of low-frequency noise. The experimental results show that the noise of the commissioned teaching space meets the NR25 standard, which satisfies the demanding teaching and performance needs. This study proves the effectiveness of acoustic optimization design in college teaching space, and provides a useful reference for further improving the acoustic quality of music education space.

In summary, this study provides a theoretical basis and practical basis for acoustic optimization of college teaching spaces, and the proposed optimization design scheme not only improves sound quality, but also has wide applicability to the acoustic design of future college teaching spaces.

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