



A Study on the Impact of Acoustic Design Optimization in Music Education Spaces on Students' Music Learning Outcomes

Nan Meng^{1,*}

¹ The Music Academy of Qiongtai Normal University, Haikou, Hainan, 570000, China

SUMMARY: *The acoustic environment is an important component of music education and teaching spaces. This study takes university music classrooms as its research object, conducting a correlation analysis of subjective data from a questionnaire survey using stepwise regression. Based on measured data, the acoustic environment is simulated using a computer model across three dimensions: reverberation time, sound pressure level, and speech transmission index. Subsequently, an optimized design scheme for music teaching spaces is proposed. Finally, 100 students were selected as empirical research subjects to explore the effectiveness of the optimized teaching space. In terms of teaching methods, students using the optimized teaching space reported feeling highly adapted to the teaching methods. Thus, the music education teaching space designed in this study has a positive impact on students' music learning outcomes.*

KEYWORDS: *computer simulation; stepwise regression; teaching space; acoustic environment; correlation analysis*

1 Introduction

Music is a form of expression for the human soul and a comprehensive manifestation of intellectual and emotional qualities. As an essential component of fostering students' all-round development, the acoustic design of music education spaces has garnered significant attention [1-3]. Music teaching spaces serve as vital venues for music instruction, rehearsals, and performances. Optimizing acoustic design plays a crucial role in enhancing music learning outcomes, protecting the hearing of teachers and students, and improving the experience of music appreciation and creation [4-7].

In the process of improving the acoustic design of music teaching classrooms, various elements need to be considered [8]. Spatial planning is a necessary stage [9]. The form and size of teaching space affect sound transmission [10]. The best classroom form will be the rectangular one, with suitable length-to-width ratio, without excessive narrowing or square [11]. Moreover, the proper classroom height is a significant factor, since high ceilings will decrease sound reflection and reverberation [12-14]. Regarding materials, their acoustic capabilities will be essential [15]. Walls can be covered with sound-absorbing materials, such as acoustic panels or acoustic foam, allowing to absorb sounds and to minimize reflection [16-18]. Also, carpets can be used for the floor, which will help both decrease noise due to the steps and sound reflection [19]. The acoustic ceiling can also be used to improve the sound absorption effect [20]. The arrangement of furniture and equipment has an impact on the acoustic effect [21].

*18727053340@163.com

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Furniture and equipment, like desks and chairs, need to be arranged in an orderly fashion to prevent unnecessary mess [22]. The choice of furniture is also crucial. Wood material furniture will reflect less sound than other types [23]. Window installation cannot be ignored [24]. With double-glazed windows, outdoor sounds can be completely blocked, and the sound insulation effect of the classroom will be improved [25]. Windows must be located at a reasonable location and size so that enough natural light can be obtained and sound reflection is avoided [26, 27]. The arrangement of the sound system is another way to optimize classroom acoustics [28]. In addition to the design of classroom acoustics, professional sound testing must also be done [29]. Using professional acoustic equipment, indicators such as reverberation time and sound clarity will be tested and then the design will be optimized [30, 31].

According to the literature [32], the importance of acoustic environments in influencing the learning outcome of students is discussed. On that basis, the research examines the different common cases of acoustic correction designs in school classrooms as well as the acoustic measurement verification outcome after the intervention of the measures. In conclusion, the findings give guidance to the acoustic engineer working in the area. The literature [33] explains the significance of classroom acoustic environments and the difficulties encountered. From the simulation of the study, it analyzes the acoustic environment optimization and verification in multimedia classrooms, and finds out that many factors affect the efficacy of classroom acoustic environments control, and the proper method could result in the best outcome. According to literature [34], the effect of learning spaces on learning outcomes is discussed. By using the data collected from several visits to high schools, it finds out that acoustic comfort plays an important role in education. The literature [35] seeks to enhance classroom acoustic quality for effective learning processes. In conducting a survey by considering two different classrooms and using a questionnaire to assess students' levels of depression, anxiety, and stress, it was realized that there was reverberation time greater than 1 second in both the classrooms, and 34% of students had suffered from severe symptoms of anxiety. The literature suggested use of high absorption materials in enhancing classroom acoustic quality. In the literature [36], emphasis is placed on the significance of indoor acoustic environment on speech intelligibility, learning performance of the learners, and teachers' vocal performance in the teaching process. Literature [37] is designed to study the influence of sound environments on the behavior of special education students and stress the significance of sound quality as an essential feature of educational facilities. Literature [38] discusses the problems associated with implementing acoustic design approaches in architectural design education systems. This work illustrates, using a number of cases, how architectural acoustics and landscape architectural design techniques have been combined within architectural design education. This literature shows the importance of certain design contexts and auditory training techniques in learning environments. The above-mentioned literature proves the significance of acoustic design optimization for increasing teaching efficiency, reveals some difficulties in optimizing acoustic designs, and suggests some effective ways to solve these problems.

First, taking university classrooms as the research object, the acoustic environment of 25 classrooms in five comprehensive universities was measured, including background noise, lecture sound pressure level, reverberation time, STI value, and EDT value. A questionnaire survey was conducted to assess students' satisfaction with the classroom acoustic environment, and factors influencing satisfaction were analyzed. Additionally, students' learning efficiency was surveyed, and factors influencing learning efficiency were analyzed. Second, based on the experimental survey data, computer simulations were conducted to analyze the reverberation time, sound pressure level, and speech transmission index of the classrooms. Design proposals for music teaching spaces were then developed based on the simulation results. Finally, 100

students were selected as subjects for empirical research, and the effectiveness of the optimized teaching spaces was explored from three aspects: teaching compatibility, teaching interactivity, and teaching effectiveness.

2 Evaluation of the acoustic environment in music education teaching spaces

2.1 Selection of classrooms and placement of measurement points

This paper selected 30 music classrooms in 12 teaching buildings across 9 campuses of 7 comprehensive universities to conduct acoustic testing and questionnaire surveys on the tested classrooms.

2.2 Learning Efficiency Evaluation Analysis

This study conducted a questionnaire survey on 30 classrooms in 12 schools, with the students attending classes in these classrooms as the research subjects. The participants included students from various subjects and grades. A total of 500 questionnaires were distributed, with 495 completed questionnaires returned. Student perceptions of classroom learning experiences were quantified using a 1-5 point scale across six items. Higher scores indicate greater comfort and higher learning efficiency. The average scores for different factors influencing learning efficiency are shown in Table 1. As shown in the table, the average scores for the six items ranged from 2.81 to 3.83, with little variation.

Table 1: The average score of different school efficiency factors

Factor	Max	Min	Ave
Unfret	5	1	3.83
Unweary	5	1	3.45
Undress	5	1	3.7
Focus	5	1	2.81
Motivated	5	1	2.9
Be able to understand	5	1	3.59

The correlations among the factors influencing learning efficiency are shown in Table 2. According to SPSS analysis, the three factors “did not cause irritability,” “did not cause fatigue,” and “did not cause discomfort” had $P < 0.01$ in pairwise comparisons, with R values of 0.29, 0.3, and 0.36, respectively. This indicates that there is a connection between the three emotions, and that irritability, fatigue, and discomfort may occur simultaneously during lectures and influence each other.

Table 2: The correlation among the factors influencing learning efficiency

Project	Unfret	Not exhausted	No discomfort
Unfret	1	0.29	0.33
Unweary	0.29	1	0.36
Undress	0.33	0.36	1

The correlation coefficients between comprehension and the other three items are shown in Table 3. According to SPSS analysis, “being able to understand the content” was significantly correlated with “not causing irritability,” “providing motivation,” and “promoting concentration”

at the 0.01 level, with correlation coefficients of 0.2 (1), 0.2 (6), and 0.2, respectively. This indicates that focus, lack of irritability, and feeling motivated are interconnected in terms of understanding classroom content and improving learning efficiency, with their correlation coefficients being very close.

Table 3: Understand the correlation coefficient of the three

Project	Did not cause restlessness	Make it have power	Make focus
Understand content	0.21	0.26	0.2

In terms of the analysis of differences in learning efficiency and subjective clarity across demographic variables, a single-factor ANOVA analysis using SPSS revealed no significant differences in school efficiency and subjective clarity evaluations among students of different genders, grades, and majors. The results of the variance test for gender, major, and grade across the six items of learning efficiency are shown in Table 4. In the “concentration” item, significant differences were observed among grades for fourth-year university students.

Table 4: Variance test results

		Not agitated	Not tired	Concentration	Be motivated	Not unwell	Understand.	Subjective clarity
Gender	F	0.303	3.489	0.095	0.082	0.008	2.419	1.421
	P	0.843	0.068	0.759	0.774	0.938	0.117	0.242
Professional	F	3.116	1.299	3.703	0.835	0.749	3.349	0.608
	P	0.051	0.277	0.046	0.435	0.494	0.036	0.558
Grade	F	0.505	1.067	3.846	0.55	0.34	2.723	1.712
	P	0.734	0.379	0.002	0.693	0.865	0.021	0.192

2.3 Correlation analysis between objective data and subjective evaluation

To investigate the relationship between the objective acoustic data of classrooms measured in actual tests and students' subjective evaluations, the questions in the questionnaire regarding sound field satisfaction and learning efficiency were quantified on a scale of 1 to 5. There were a total of nine questions regarding learning efficiency, with higher scores indicating higher evaluations of learning efficiency by students.

1) The correlation analysis between background noise and subjective data is shown in Table 5. The correlation analysis between background noise and learning efficiency indicates that the significance coefficient $P = 0.0005 < 0.05$ for background noise and learning motivation, indicating a significant correlation between the two. Similarly, the significance coefficient $P = 0.040 < 0.05$ for background noise and comprehension indicates a significant correlation between the two. This indicates that background noise in the classroom affects students' learning efficiency by influencing their learning motivation and comprehension, but the correlation coefficients are low at -0.334 and 0.245, respectively.

Table 5: Correlation analysis between background noise and subjective data

	Subjects	Not agitated	Not tired	Focus	Be motivated	Not uncomfortable	Understood
R	0.134	-0.06	0.178	-0.003	-0.334	0.055	0.245
P	0.308	0.603	0.151	0.881	0.0005	0.591	0.04

2) The correlation analysis between the sound pressure level of lectures and subjective data is shown in Table 6. The sound pressure level of lectures has no effect on subjective clarity. The P value of the learning motivation item is 0.000, and $R = 0.394$, indicating a significant positive

correlation between the two, which suggests that the sound pressure level of lectures has an impact on students' learning motivation.

Table 6: Correlation analysis between Lecture sound pressure level and subjective data

	Subjects	Not agitated	Not tired	Focus	Be motivated	Not uncomfortable	Understood
R	-0.016	0.086	-0.193	0.173	0.394	0.102	0.194
P	0.685	0.514	-0.075	0.141	0	0.386	0.48

3) The correlation between reverberation time and subjective data is shown in Table 7. There is a highly significant correlation between reverberation time and subjective clarity evaluation in music subjects, with a correlation coefficient of 0.332. There are also significant correlations between reverberation time and irritability, discomfort, and comprehension, indicating that reverberation time affects learning efficiency by influencing students' irritability, discomfort, and comprehension.

Table 7: The correlation between reverberation time and subjective data

	subjects	Not agitated	Not tired	Focus	Be motivated	Not uncomfortable	Understood
R	0.332	0.431	0.092	-0.094	0.23	0.339	0.339
P	0.003	0.009	0.435	0.472	0.057	0.006	0.007

4) The correlation analysis between STI values and subjective data is shown in Table 8. There is a highly significant correlation between classroom STI and subjective clarity in music subjects. This is because music subjects are taught in a more abstract language that emphasizes mathematical logic rather than linguistic logic, so students need to hear the teacher clearly and have higher requirements for classroom sound clarity.

Table 8: Analysis of the correlation between STI values and subjective data

	Subjects	Not agitated	Not tired	Focus	Be motivated	Not uncomfortable	Understood
R	0.341	-0.191	0.175	0.231	0.063	-0.3	-0.267
P	0.002	0.103	0.101	0.067	0.493	0.006	0.019

5) The correlation analysis between EDT values and subjective data is shown in Table 9. There is a significant correlation between EDT and subjective clarity perception. Among the five objective factors, EDT is the only factor that is significantly correlated with both music subject and subjective clarity, indicating that EDT has a significant impact on clarity perception.

Table 9: Analysis of the correlation between EDT values and subjective data

	Subjects	Not agitated	Not tired	Focus	Be motivated	Not uncomfortable	Understood
R	0.426	0.199	0.17	-0.099	0.25	0.266	0.421
P	0.000	0.054	0.242	0.452	0.014	0.026	0.000

To further investigate the extent to which several objective factors influence subjective factors, a regression analysis was conducted, with the resulting regression coefficients serving as indicators of the magnitude of the influence of objective factors on subjective factors.

1) Regarding the impact of objective factors on the clarity of music subjects, a stepwise regression analysis was conducted to analyze both objective and subjective factors. The regression analysis results for the impact of objective factors on the clarity of music subjects are shown in Table 10, and the equation between the three factors can be derived as $y = 0.479x_1 - 0.416x_2 + 5.795$, where y represents the clarity of music subjects and x_1 represents the classroom EDT.

Table 10: The regression analysis results of objective factors on the clarity

				Collinearity statistics	
Objective project	Standardization coefficient	t	Significance	Tolerance	VIF
constant	5.795	8.548	0	-	-
EDT	0.479	3.808	0	0.705	1.412
Lecture level	-0.416	-3.224	0.003	0.705	1.412

2) Regarding the impact of objective factors on the clarity of music subjects, a stepwise regression analysis method was used to analyze both objective and subjective factors. The significance of the excluded variables is shown in Table 11. After excluding irrelevant factors, the regression coefficients for EDT and teaching sound pressure level on the perceived clarity of music subjects were obtained. The regression analysis results for objective factors on the clarity of music subjects are shown in Table 12, and the equation between the three can be derived: $y = 0.638x_1 - 0.401x_2 + 5.422$, where y represents the clarity of music subjects, x_1 represents the classroom EDT, and x_2 represents the lecture sound pressure level. The adjusted R-squared value is 0.266, the model tolerance is >0.2 , and the variance inflation factor (VIF) is <10 , indicating that multicollinearity among the independent variables has been ruled out. The software excluded the independent variables background noise, STI, and T30, as their significance P-values for the dependent variable were all greater than 0.05. The significance of the excluded variables is shown in Table 13.

Table 11: The significance of the excluded variable

Objective project	t	Significance
Background noise	-0.303	0.79
T30	-0.263	0.805
STI	-1.303	0.182

Table 12: Regression analysis results of objective projects on the clarity

				Collinearity statistics	
Objective project	Standardization coefficient	t	Significance	Tolerance	VIF
constant	5.422	9.102	0	-	-
EDT	0.638	5.311	0	0.703	1.413
Lecture level	-0.401	-3.27	0.003	0.703	1.413

Table 13: The significance of the excluded variable

Objective project	t	Significance
T30	0.208	0.837
STI	-1.533	0.111
Background noise	-0.431	0.674

3) The influence of objective factors on irritability. The regression equation for irritability, reverberation time, and EDT is $y = 0.756x_1 - 0.406x_2 + 3.265$, with an adjusted R^2 of 0.202. The results of the regression analysis of objective factors on irritability are shown in Table 14. Where y represents the irritability score, x_1 represents reverberation time, and x_2 represents EDT. The variables excluded from the model do not exhibit a significant regression trend on the dependent variable (irritability). The significance of the excluded variables is shown in Table 15.

Table 14: The objective project is a regression analysis of the feeling of irritable

				Collinearity statistics	
Objective project	Standardization coefficient	t	Significance	Tolerance	VIF
constant	3.265	39.546	0	-	-
T ₃₀	0.756	4.266	0	0.336	3.003
EDT	-0.406	-2.251	0.022	0.336	3.003

Table 15: The significance of the excluded variable

Objective project	t	Significance
T ₃₀	0.193	0.855
STI	-1.531	0.116
Background noise	-0.439	0.679

4) The impact of objective factors on fatigue was analyzed using stepwise regression. No regression model was established. The remaining three variables were excluded from the model because their p-values were greater than 0.05. Additionally, the DW value between STI and EDT was $2.88 > 2$, indicating that the residuals were not independent, leading to their automatic exclusion from the model. Therefore, none of the five independent variables were included in the model, and the regression model was not established.

5) Regarding the impact of objective factors on learning motivation, the equation obtained is $y = 0.614x_1 + 0.471x_2 + 0.553x_3 + 0.08$, where y represents student learning motivation, x_1 represents classroom STI, x_2 represents classroom reverberation time T30, and x_3 represents teaching sound pressure level. The regression analysis results for objective factors on learning motivation are shown in Table 16, and the variables excluded by the software are shown in Table 17. Similarly, it was found that although EDT and background noise were significantly correlated with “motivated” in pairwise comparisons, the regression was not significant.

Table 16: The regression analysis results of objective projects on learning motivation

Objective project	Standardization coefficient	t	Significance	Collinearity statistics	
				Tolerance	VIF
constant	0.08	0.153	0	-	-
Lecture sound pressure level	0.553	4.843	0	1.736	1.404
STI	0.614	4.837	0	0.442	2.213
T30	0.471	3.361	0.001	0.33	2.076

Table 17: The significance of the excluded variable

Objective project	t	Significance
EDT	1.211	0.210
Background noise	-1.775	0.093

6) The regression analysis of objective factors on discomfort is shown in Table 18. The equation for reverberation time and discomfort is $y = 0.312x + 3.293$, with an adjusted R-squared value of 0.098, where y represents students' discomfort and x represents the reverberation time T30 of the classroom. Objective factors significantly associated with discomfort include reverberation time, STI, and EDT. However, the latter two do not show a significant regression with discomfort and were excluded. The significance of the excluded variables is shown in Table 19. This indicates that the latter two factors indirectly influence students' discomfort by affecting reverberation time.

Table 18: Regression analysis of discomfort in objective projects

Project	Normalization factor	t	Significance
Constant	3.293	35.620	0
T30	0.312	3.021	0.003

Table 19: The significance of the excluded variable

Objective project	t	Significance
STI	-0.633	0.522
EDT	-0.093	0.95
Background noise	0.079	0.951
Lecture sound pressure level	-0.518	0.628

7) As far as the effect of the objective factor on the “understanding” score is concerned, the output of the regression analysis between the objective variables and understanding is provided in Table 20 below, wherein y stands for the “understanding” score and x stands for classroom EDT. Variables eliminated by the software have been indicated in Table 21 below. It can thus be seen that the STI and T30 variables do not exhibit regression effect on “understanding,” and thus, their effects are indirect through the classroom EDT.

Table 20: Objective project regression analysis results that are understandable

Project	Normalization factor	t	Significance
Constant	3.106	54.625	0
T30	0.426	3.895	0

Table 21: The significance of the excluded variable

Objective project	t	Significance
T30	-0.113	0.887
STI	0.2	0.845
Background noise	1.57	0.112
Lecture sound pressure level	-0.435	0.638

3 Sound environment renovation and simulation analysis

3.1 Sound Environment Renovation

According to the current inner construction of the building, the principle of designing is that there will be local adjustment made to the building's shape, and the use of acoustic materials is introduced between these interfaces. Through designing, the optimal shape of the classroom is achieved by changing the shape of its ceiling to the form of a folded plate, and therefore the direct sound reflected from the sound source of the lectern could be reflected back to the audience space, which will improve the clarity and volume of the speech sound. Also, for the purpose of solving such problems as echo from the rear wall, sound focusing on side walls, and room noise, acoustic materials can be used along with interior decorations. PVC flooring material is used for the seating floor whereas wooden flooring along with a suspended joist system is used in the podium floor. The ceiling will have perforated dual layer gypsum board ceiling supported by a metal joist suspended folding panel system. The doors and windows will be soundproof doors, thermal break aluminum alloy framed doors, and insulated glass windows. Four major phases are considered for the construction of the acoustic renovation, namely floor, rear wall, side wall, and ceiling.

3.2 Reverberation Time Analysis

The modified reverberation time is shown in Figure 1. Simulation results indicate that the mid-frequency reverberation times for the five acoustic modification stages G1 to G5 are 1.92 s, 1.87 s, 2.05 s, 0.55 s, and 0.99 s, respectively. The reverberation time characteristics for different modification stages are summarized in Table 22. The G4 and G5 stages have a significant effect on reducing reverberation time, while the G2 stage has a relatively weak effect. The G3 stage has a negative effect on reducing reverberation time, indicating that the acoustic renovation of the side walls plays a dominant role in reducing reverberation time. However, the sound absorption effect of the currently used felt panels is inferior to that of the perforated panels before renovation.

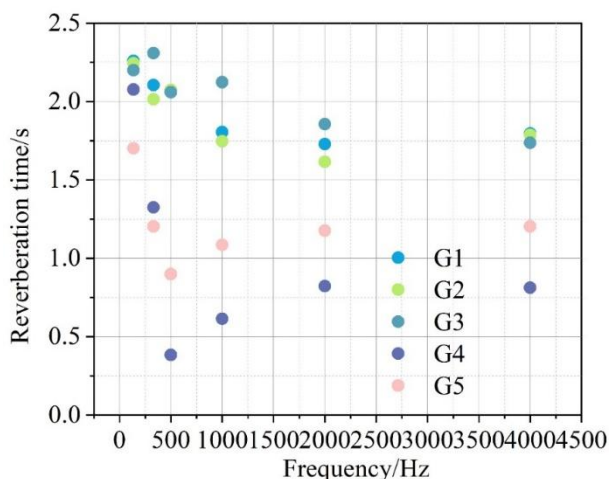


Figure 1: The reverberation time after the transformation

Table 22: The reverberation time of different changes

Renovation stage	Low frequency(125 ~ 250 hz)		Medium frequency (500 ~ 1000Hz)		High frequency(2000 ~ 4000Hz)	
	RT/s	Percentage decline/%	RT/s	Percentage decline/%	RT/s	Percentage decline/%
G1	2.27	--	1.87	--	1.81	--
G2	2	11.89	1.66	11.23	1.74	3.87
G3	2.01	11.45	2.04	-9.09	1.8	0.55
G4	1.71	24.67	0.59	68.45	0.89	50.83
G5	1.49	34.36	1	46.52	1.21	33.15

To further compare the effects of different acoustic materials on reverberation time in renovated areas, acoustic simulations were conducted on changes to materials in a single area and compared with the pre-renovation state. The results of changing the position of sound-absorbing materials on reverberation time are shown in Table 23. The results indicate that replacing the perforated acoustic panels on the side walls plays a dominant role in reducing mid-frequency reverberation time. The felt panels on the rear wall and the double-layer gypsum board ceiling have only a minor effect on reducing mid-frequency reverberation time, suggesting that the perforated sound-absorbing materials used before the renovation had better performance.

Table 23: The situation where the reverberation time is changed at a single position

Layout area	Low frequency(125 ~ 250 hz)		Medium frequency (500 ~ 1000Hz)		High frequency (2000 ~ 4000Hz)	
	RT/s	Percentage decline/%	RT/s	Percentage decline/%	RT/s	Percentage decline/%
Before the renovation	2.18	--	1.88	--	1.76	--
Floor (PVC)	2.1	3.67	1.86	1.06	1.7	3.41
Rear wall (felt)	2.26	-3.67	2.06	-9.57	1.82	-3.41
Side wall (slit sound-absorbing board)	1.52	30.28	0.57	69.68	0.89	49.43
Ceiling (folded gypsum board)	2.22	-1.83	1.96	-4.26	1.93	-9.66
Ceiling (gypsum board)	2.29	-5.05	2.01	-6.91	1.79	-1.70

3.3 Sound pressure level analysis

The sound pressure level after modification is shown in Figure 2. The sound pressure level decreased by 0.16 dB, -1.14 dB, 2.88 dB, and 5.24 dB in stages G2 to G5, respectively. The sound pressure level attenuation was mainly concentrated in the mid-frequency range, with no significant attenuation in the high-frequency and low-frequency ranges. This trend was similar to the overall change in reverberation time. Additionally, the sound pressure level in each stage was between 40 and 60 dB, meeting the requirements for indoor teaching. The sound pressure level attenuation at each measurement point is shown in Figure 3. The attenuation curves at each measurement point in stages G2 to G4 are relatively smooth, with the maximum differences in sound pressure level attenuation at each measurement point being 0.14 dB, 0.29 dB, and 0.42 dB, respectively. In the G5 stage, the curves show a stepwise increase in groups of three test points, with this increase gradually slowing down. The maximum difference in sound pressure level attenuation among the test points is less than 3 dB, at 2.14 dB. The sound field uniformity in the G5 stage is slightly worse than in the G2 to G4 stages but remains within an acceptable range. For indoor sound fields, the magnitude of sound pressure levels at each point is influenced by both direct sound and reflected sound. The G5 stage uses segmented folded-plate double-layer gypsum board. The folded-plate design provides early reflected sound for the audience. However, due to the difficulty of moving existing equipment, the exposed local structure of the ceiling results in insufficient folded-plate reflective surfaces, reducing the early reflected sound reaching the audience area. Therefore, in acoustic renovations, the installation location, angle, and density of sound-absorbing materials should be fully considered for their impact on sound pressure levels in the audience area.

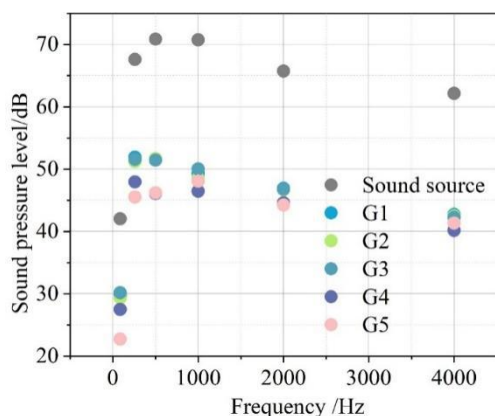


Figure 2: Modified sound pressure level

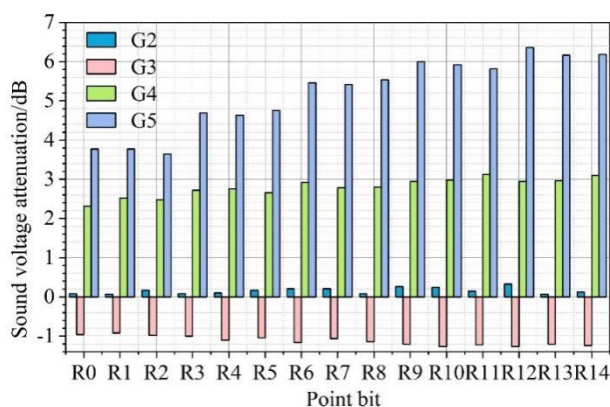


Figure 3: The sound pressure level at each point attenuates

3.4 Language Transmission Index Analysis

The modified speech transmission index is shown in Figure 4. The acoustic modifications to the floor and rear wall had little effect on the speech transmission index, while the acoustic modifications to the side walls and ceiling significantly improved the speech transmission index, increasing it by 0.3 and 0.16, respectively, from an original moderate level to an above-average level. However, G5 has lower speech intelligibility than G4, indicating that the original integrated flat-ceiling-type micro-perforated double-layer gypsum board ceiling is more effective in improving speech intelligibility than the renovated divided-panel-type double-layer gypsum board ceiling. The language transmission quality of the classroom is influenced by both reverberation time and sound pressure level. The mid-frequency reverberation time of G4 is 0.55 seconds, which does not meet the standard requirements.

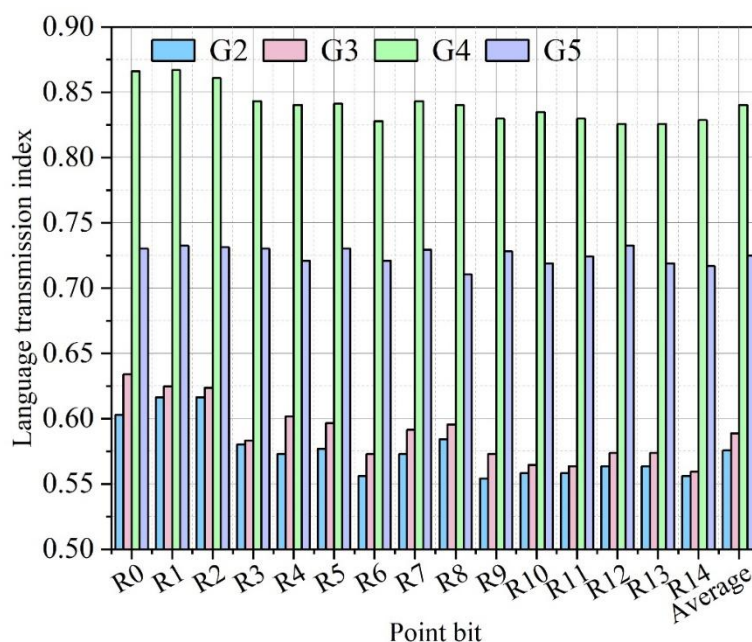


Figure 4: Modified language transfer index

4 Optimized design of music teaching spaces

4.1 Music Teaching Space

Due to their different functions, music teaching spaces vary significantly in terms of classroom size, shape, and acoustic requirements. Large spaces primarily accommodate various music-related teaching activities conducted on a class-by-class basis, while small spaces refer to practice rooms where students engage in independent practice. Different functional rooms adopt their own concentrated layout arrangements, and except for performance spaces, all are enclosed spaces [39]. This is primarily to prevent mutual interference between music classrooms, so music classrooms have special soundproofing requirements during design. Music education spaces are illustrated in Figure 5.

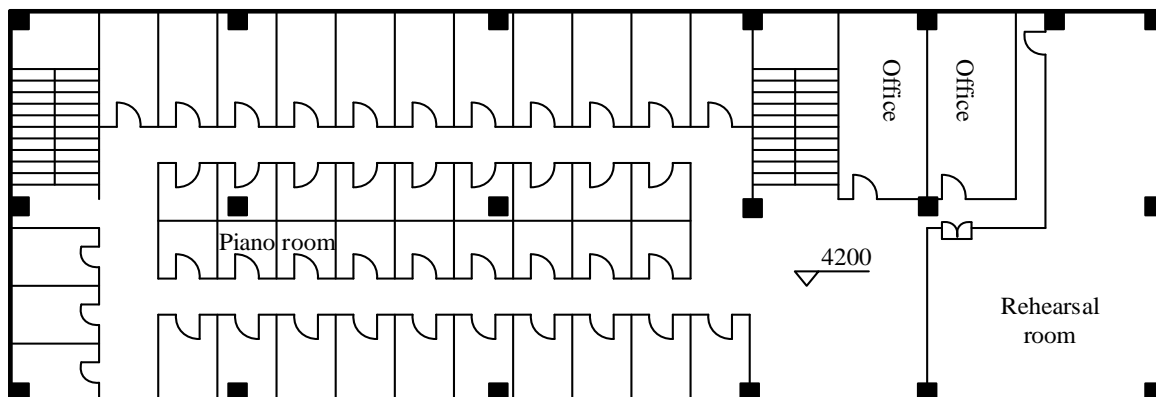


Figure 5: Music Teaching Space

4.2 Design of Specialized Music Classrooms

1) Classification of specialized music classrooms

Music classrooms can be categorized by specialty into singing and dance classrooms (which can also be used as dance classrooms), vocal music classrooms, instrumental music classrooms, piano classrooms, guzheng classrooms, etc. For specialized art examination schools, there should also be music appreciation rooms, practice rooms, etc.

2) Design of Music Specialized Classrooms

(1) Location Requirements

The location of music classrooms must be carefully considered to minimize the impact of noise on the teaching building while ensuring that the surrounding environment is sufficiently quiet to facilitate smooth course operations. Therefore, music classrooms should ideally be located away from general teaching areas and noisy locations. If they must be located within the teaching building, they should preferably be placed at the end or top floor. Special attention should be paid to the direction of window openings, and soundproof corridors, antechambers, or soundproof doors should be installed in connecting corridors. The ceilings and walls of music classrooms should have high-performance sound-absorbing treatments. Elevators should be installed within the academic building to facilitate the transportation of musical instruments or the movement of large instruments by faculty and students.

(2) Basic Design Requirements for Specialized Music Classrooms

The podium in music classrooms should be equipped with a projection screen. Students need to practice frequently, and teachers also need to provide frequent guidance. The floor area per student should not be less than 2.8 square meters. In some choir classrooms, provided that relevant requirements are met, several rows of choir platforms can be installed on the rear wall to accommodate students' choir needs. The height of each step of the tiered choir platform should ideally be 0.20 meters, and the width should ideally be 0.60 meters. Installing choir platforms in choir classrooms allows teachers and students to clearly see each other's mouth movements while singing and also facilitates ensemble instrument practice.

(3) Room Dimensions

Music classrooms are an indispensable type of specialized classroom for students preparing for art exams. Music classrooms are equipped with preparation rooms, and those with better conditions also have instrument rooms. During design, both acoustic quality requirements and the distance between rear-row student seats and the teacher must be considered. Music classrooms can be designed in shapes such as rectangles, triangles, or pentagons, with rectangular layouts being the most advantageous.

(4) Facilities and Equipment

In the storage room, infrequently used percussion instruments should be neatly organized

in transparent cabinets. The waiting room is used for teacher or lecturer preparation and group practice sessions. The choir room is located near the auditorium on the street, with a flat floor to facilitate piano movement, and includes features such as a five-line blackboard, screen notice board, movable desks and chairs, sheet music room, recording, and sound playback systems. In the instrumental music room, storage space is recommended for small instruments, and wheeled carts are installed for the transportation of large instruments, connecting to the practice room. The practice room is located near the instrumental music room and performance room, but soundproofing and instrument stands are required in practice rooms of various sizes. The teacher's room and music score library are arranged between the choir room and instrumental music room to increase space utilization.

(5) Piano Room Design Requirements

Piano rooms are specialized classrooms used for music instruction and practice in art education. They are typically small spaces with high requirements for acoustic factors such as sound field, noise, and reverberation time. The internal space should adopt an irregular room shape to meet acoustic requirements while creating rich indoor and outdoor spaces.

3) Acoustic Environment Analysis of Music Specialized Classrooms

(1) Requirements for the acoustic environment

Noisy environments can distract students and may affect their learning outcomes. Research indicates that noise levels exceeding 55 dB(A) can disrupt normal learning, and levels exceeding 75 dB(A) can cause students to become irritable. Prolonged exposure to poor acoustic environments in classrooms can lead to inattention, impaired sound discrimination abilities, and reduced language comprehension. The sound levels in music classrooms typically reach approximately 85 dB. Sound from music classrooms can interfere with one another and also affect surrounding classrooms. Therefore, doors, windows, and other soundproofing and noise-reduction measures with good sound insulation performance should be adopted.

(2) Sound Environment Control in Music Classrooms

1) Planning and Layout

Music practice rooms play a significant role in any art school. Music rooms require a quiet environment with minimal noise, but the sounds they produce during use can disrupt the normal operation of surrounding classrooms. Therefore, music rooms should be located away from other important teaching spaces. New music rooms may have varying levels of sound intensity, so they can be categorized into three different grades. High-grade music rooms should be separated from other teaching areas to prevent the noise they generate from affecting others' learning. If they must be located in the same building, the three levels of sound-proofed rooms should be placed on different floors and preferably in end rooms. High-level instrument rooms should be located on lower floors to reduce their impact on the surrounding areas and minimize noise transmission downward. For instruments that produce significant noise, such as percussion and pianos, measures like installing sound-dampening floors should be considered to reduce noise. Music-specific classrooms should be arranged along the perimeter of the site, with an outdoor courtyard enclosed in the center of the building. The outdoor courtyard can serve as an outdoor performance space, providing students with a venue for musical exchange. When combined with a hall, it can form a semi-outdoor performance area.

2) Soundproofing of the building envelope

(1) Wall treatment methods

a. Structural design: Music-specific classrooms should have appropriately increased floor thickness, preferably with sound-absorbing suspended ceilings installed below, combined with increased roof panel thickness in conjunction with the roof insulation layer. Internal sound-absorbing materials should be installed to prevent noise intrusion and provide as quiet an indoor environment as possible. b. Sound absorption treatment: Music classrooms can use sound-

absorbing materials combined with various perforated panels, with the panels fixed to the joists. The air layer between them also helps reduce noise. Plastered ceilings and raised wooden floors can also reduce noise transmission. c. Equipment soundproofing and noise reduction: Music classrooms should preferably use a central air conditioning system to minimize noise. Low-noise equipment should be selected, with equipment rooms located on the ground floor, and other equipment should also be designed to minimize noise generation.

(2) Soundproofing of doors and windows

The exterior windows of music classrooms should use high-seal insulated glass, and the doors should have multi-layer composite structures with good soundproofing properties. For music classroom doors and windows, window soundproofing is more challenging because windows need to be opened for ventilation, allowing sound to escape and propagate outward.

3) Acoustic treatment of practice rooms medium-sized practice rooms are used for individual instruction or group teaching, with an area of approximately 13-18 square meters, and large practice rooms are used for simulated exams, sectional practice, and exam rehearsals, with an area of approximately 20-25 square meters.

4) Optimized design of practice rooms

(1) Material selection: Functional spaces are divided by changing the flooring materials. These primarily include a rest area, a piano training area, and a vocal training area. The rest area features carpeted flooring, while the piano training area and vocal training area are fitted with soundproof wooden floors without cavities. Sound absorption acoustic panels made of glass fibers are attached to the walls, effectively addressing the noise issue. As a result, each practice room is separated and will not affect other practice rooms.

(2) Design Modifications: The rooms near the corridor are poorly lit; therefore, they are designed as resting rooms. The judge's chairs are situated along the walls, where teachers can guide their students from there. The interior design of each piano room is uniform, and all electric pianos are positioned on one wall, guaranteeing sufficient distance between the pianos without interfering with each other's playing.

(3) Arrangement of Teaching Materials: This practice room can be used to conduct piano classes and vocal lessons. The essential teaching materials for piano class are electric pianos, whereas those required for vocal lessons are the stand and a full-length mirror. Seating for teachers or judges is provided for teachers to guide students during training or for judges to evaluate students' performances.

(4) Control of reverberation time: Excessively long reverberation times hinder teachers from identifying issues during performances. Conversely, overly short reverberation times may result in insufficiently full-bodied sound, which can dampen learning enthusiasm. Control standards for reverberation time vary depending on the teaching content and sound frequency. For instruments like the erhu and pipa, which have lower sound levels, reverberation time targets are higher, typically around 0.5 seconds. For instruments like the flute, trumpet, and vocal performances, which have higher sound levels, the reverberation time should be controlled around 0.35 seconds. The greater the total sound absorption of the room, the shorter the reverberation time. In the case of a relatively fixed-sized practice room, the sound absorption treatment of various surfaces becomes an important measure for controlling reverberation time. Typically, the ceiling is treated with sound-absorbing materials, which also have noise-reduction effects.

5) Noise control

Different types of practice rooms have different permissible noise levels. For example, the permissible noise level for violins is 35–40 dB, for pianos and male voices it is 45 dB, and for flutes it is 50 dB. The permissible noise level should be determined based on the room's intended use, or the minimum value for the most likely use should be selected for noise control.

When conditions permit, high-noise and low-noise practice rooms should be zoned to avoid interference. Noise control within practice rooms primarily involves addressing the room's various interfaces, doors, windows, openings, and equipment.

6) Music Rehearsal Hall

Music rehearsal halls are venues for music rehearsals, professional exchanges, and other activities. Some institutions also use rehearsal halls as combined classrooms. Rehearsal halls are generally small in scale, and institutions with high acoustic quality requirements often have dedicated concert halls. This article focuses solely on rehearsal halls located within educational buildings. Among various types of rehearsal halls, music rehearsal halls have the highest acoustic quality requirements, and the unique acoustic demands of music rehearsal halls are the key consideration in their design.

(1) Plan Form

Music rehearsal halls located within art teaching buildings are predominantly rectangular in plan form. This plan form facilitates coordination with the overall column grid and, compared to fan-shaped plans, is advantageous for providing strong early lateral reflections. To accommodate activities such as exchanges, observations, lectures, and small-scale assembly performances, rehearsal halls are also equipped with a certain number of seats. The appropriate placement of seats should be considered when determining the plan shape. When compared with common classrooms and practice rooms, rehearsal rooms for music have large areas on the floor. In order to achieve proper proportions between space sizes and a bigger volume of space, they always have ceilings which are double the height of common classrooms.

(2) Acoustic Design

The acoustic design principles of rehearsal halls are comparable to those of concert halls, but there are some specific features. Rehearsal halls are of smaller sizes than concert halls, and in order to help teachers find any problems in their pupils' performance, the reverberation time of a rehearsal hall can be a little bit lower than that of a concert hall. In order to provide a warm and rich sound, the reverberation time of middle and high frequencies can be set at one second and low frequencies at 1.3 seconds. To create an atmosphere of concert performance in a rehearsal hall, devices capable of adjusting reverberation time must be provided with an adjustment time of about half a second. Utilization of reflections during the initial stage in generating the intimacy and loudness effect should be fully exploited. Diffusion systems should be used in renovations for good sound diffusion. By facilitating the lateral interaction between the performers using sound reflection and sound refraction and providing for equal sound field distribution in the audience area, the design should satisfy the acoustic design criteria. Sound-absorbing panels can be used in the back of the seats to eliminate echo effects. Figure 6 shows the front elevation of the rehearsal hall. The indoor noise level in the music rehearsal hall should be controlled between 35 and 40 dB. In addition to using walls that meet sound insulation requirements, attention should also be paid to the treatment of weak points such as doors and windows. The selection of air conditioning units and lighting fixtures should also consider noise control.

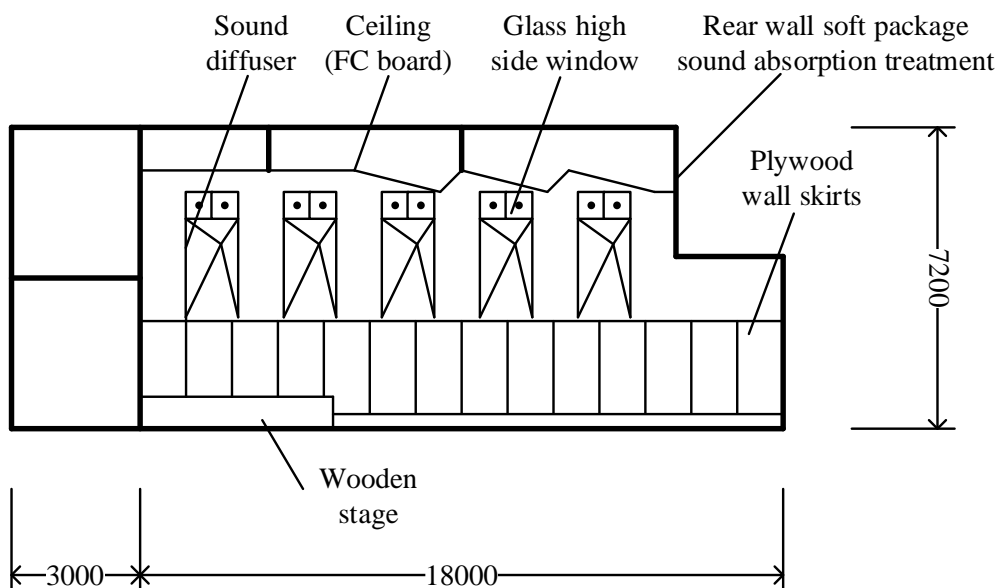


Figure 6: Elevation drawing of the rehearsal hall

(3) Furniture and auxiliary rooms

The floor of the music rehearsal hall does not need to be sloped, allowing for flexible arrangement of the various sections and providing good adaptability. Movable wooden steps can be installed to accommodate choir rehearsals, and lightweight movable seats should be used to enhance spatial flexibility and meet the layout requirements for different rehearsal activities and combined classes. Formal rehearsals and observation activities require changing rooms, which should be located near the rehearsal hall. Storage rooms should also be located nearby to accommodate furniture and musical instruments.

5 The impact of teaching space design optimization on learning outcomes

This experiment explores the impact of optimized teaching space design on students' music learning outcomes. With 100 students as the research subjects, it examines the effectiveness of students' use of the optimized music classroom from three aspects: teaching compatibility, teaching interactivity, and teaching effectiveness.

5.1 Teaching compatibility

The author used descriptive statistical methods in SPSS to determine the extent to which teaching spaces align with students' learning needs. The mean and standard deviation of the teaching alignment indicators are shown in Table 24. As indicated by the data in the table, students using the pre-optimized teaching space felt less adapted to the teaching methods of their courses, while those using the optimized teaching space reported feeling highly adapted to the teaching methods. In terms of teaching objectives, students using the pre-optimized teaching space felt that the teaching objectives and tasks of the music course were very clear, while students in offline teaching felt that their understanding of the teaching objectives and tasks of the music course was average and not particularly good. In terms of teaching content, students using the pre-optimized teaching space did not feel that the online music course content was particularly rich, but students in offline teaching felt that the traditional offline music classroom had very rich and diverse teaching content. In terms of learning needs, there was no

significant difference between students using the pre-optimized teaching space and those in offline classes. Both groups felt that both the pre-optimized teaching space model and the optimized teaching space were relatively effective in meeting their learning needs for music courses.

Table 24: The basic indicators of mean and standard deviation on the teaching matching index

Indicator	Optimize	Sample size	Minimum value	Maximum value	Mean	Standard deviation
Course teaching	Before	100	1	6	2.4976	1.02556
	After	100			4.1135	0.69714
Teaching target	Before	100	1	6	4.6506	0.86887
	After	100			3.2271	1.13548
Teaching content	Before	100	1	6	3.0856	1.23339
	After	100			4.7187	2.13514
Learning demand	Before	100	1	6	3.792	1.29617
	After	100			3.8044	1.21745

5.2 Interactive teaching

Teaching interactivity is divided into three indicators: teacher-student interaction, student-student interaction, and diversification of interaction methods. Descriptive statistics were conducted using imported data, and the mean and standard deviation of the teaching interactivity indicators are shown in Table 25. Based on the data in the table, it is possible to make a simple inference about the teaching interaction in the pre-optimized teaching space and the post-optimized teaching space. In terms of teacher-student interaction, the pre-optimized teaching space had poor interaction between students and teachers, with students being reluctant to discuss music-related issues with teachers and showing low initiative. In contrast, in the post-optimized teaching space, students were very willing to discuss music-related issues in the music classroom and demonstrated high initiative.

Table 25: The mean and standard deviation of the teaching interactivity index

Indicator	Optimize	Sample size	Minimum value	Maximum value	Mean	Standard deviation
Interaction between teachers and students	Before	100	1	6	3.0535	1.20953
	After	100			4.0978	1.02969
Sexual interaction	Before	100	1	6	3.5858	1.18094
	After	100			4.5381	1.23337
Interaction method	Before	100	1	6	3.888	1.11835
	After	100			3.6529	2.0428

5.3 Teaching Effectiveness

Teaching effectiveness is assessed based on four indicators: self-assessment of learning outcomes, classroom performance, learning stress, and evaluation of teaching methods. The mean and standard deviation of the teaching effectiveness indicators are shown in Table 26. Analysis of the data table reveals that students using the pre-optimized teaching space perceive their learning outcomes to be slightly weaker than those using the post-optimized teaching

space. In terms of classroom performance, students using the optimized teaching space perceived their classroom participation as highly active and their attention as relatively more focused. However, students using the pre-optimized teaching space perceived themselves as not particularly active in class and their attention as not notably focused.

Table 26: The mean and standard deviation of teaching effect indicators

Indicator	Optimize	Sample size	Minimum value	Maximum value	Mean	Standard deviation
Self-assessment of learning outcomes	Before	100	1	6	3.8758	1.249
	After	100			3.9789	2.04829
Classroom performance	Before	100	1	6	6.9624	1.16585
	After	100			8.2645	1.19386
Study pressure	Before	100	1	6	3.9075	1.33056
	After	100			3.5018	2.69757
Evaluation of Teaching methods	Before	100	1	6	7.1231	1.2052
	After	100			7.9942	1.42445

6 Conclusion

The acoustic environment, as an important factor influencing the dining experience, is increasingly gaining attention. This paper explores methods for optimizing the acoustic environment in music education spaces and proposes an optimized design scheme. Through empirical research, it demonstrates that the optimized design of teaching spaces has a positive impact on learning outcomes, providing references and insights for the design and research of music education spaces. The experimental conclusions drawn in this paper are as follows:

The maximum difference in sound pressure level attenuation across all test points is less than 3 dB, with a value of 2.14 dB. The sound field uniformity in the G5 stage is slightly poorer compared to the G2 to G4 stages. Therefore, to maintain indoor sound field uniformity, the installation location, angle, and density of acoustic materials must be carefully considered.

In the experiment on the impact of optimized teaching space design on learning outcomes, students using the optimized teaching space reported feeling more active in class and having greater concentration. This indicates that the teaching space design optimized in this study has a positive effect on students' music learning outcomes.

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About the Author

Nan Meng was born in Mudanjiang City, Heilongjiang Province, China, in 1985. She obtained a doctorate from the Novosibirsk Conservatory of Music (Glinka) in Russia. Currently, she works at the Music College of Qiongtai Normal University. Her main research interests are music education and music research.

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