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Study on the Effect of Acoustic Material Placement on Speech Iintelligibility in College Classrooms

Shujie Li[a], and Mengxuan Xu[b]

School of Architectural and Artistic Design, Henan Polytechnic University, Jiaozuo 454000, China

[a]767819391@qq.com, [b]1447612519@qq.com

Abstract

Indoor sound quality, as the primary environment for teaching and learning in higher education, has a direct impact on teaching quality and is an important component of acoustical research in campus buildings. The key acoustic parameters of a classroom at Henan University of Technology are measured on site to analyze the quality of the acoustic environment in the classroom and the real sound quality effect in the room in this study. And the EASE sound quality simulation software was also used to ensure that the total amount of sound absorption in the classroom remained constant by controlling variables and placing sound absorbing materials in various locations in the classroom to simulate and calculate the best arrangement of sound absorbing materials by analyzing the results of the STI values in various options. This research can be used to help with the design of sound quality in university classes.

Keywords

Classroom Sound Environment; Sound Quality Design; Acoustic Absorption Materials; EASE Acoustic Simulation Software.

1. Introduction

The classroom is the primary location for students to learn and communicate, and the acoustic environment can have a direct impact on teachers' and students' physical and mental health, as well as their work efficiency, which in turn influences the overall quality of instruction. Multimedia classroom is a common classroom form in colleges and universities. Due to the vast volume of space, it is easy to generate problems such as excessive reverberation time and diminished clarity, which cannot match the standards of normal multimedia classroom use [1]. As related research advances, classroom sound quality evaluation and improvement solutions continue to grow [2]. It is possible to accurately understand the current condition of the indoor acoustic environment, analyze existing difficulties, and provide appropriate acoustic design solutions or restoration plans by combining the findings of acoustic parameter measurements and software simulations. EASE, a simulation software based on geometric acoustics theory, is highly renowned in the field of interior acoustic design and research, and is one of the most widely used professional acoustic simulation software [3]. This study uses the acoustic software EASE to simulate and calculate the sound pressure level, C50 clarity, reverberation time, speech transmission index, and other objective parameters of the multimedia classroom at Henan University of Technology to analyze the sound quality of the room under the existing acoustic design scheme. Sound level meters were used to measure characteristics in university classrooms in order to analyze the actual interior sound environment and ensure that software simulations and actual circumstances were consistent. The final simulation investigates the impact of acoustic materials on the classroom sound environment at various points across the space, providing useful information for university multimedia classroom design.

2. Exoerimental Site

This building acoustics experiment took place in a typical classroom on the 5th floor of Henan University of Technology's North Campus's 2nd teaching building in Jiaozuo City's Jiefang District. The huge multimedia classroom, as shown in Fig. 1, is 16.9 m long, 10.9 m wide, and 4.62 m high, with a construction area of 180.4 m2, a total surface area of 594.69 m2, and a total volume of 739.27 m3. It can accommodate 187 pupils at once. Fig. 2 depicts the inside finish of the existing acoustic design concept. The classrooms have no suspended ceilings and are surrounded by white emulsion painted concrete walls, terrazzo floor tiles, yellow fabric curtains hanging from the windows, and multi-layer plywood tables and chairs.

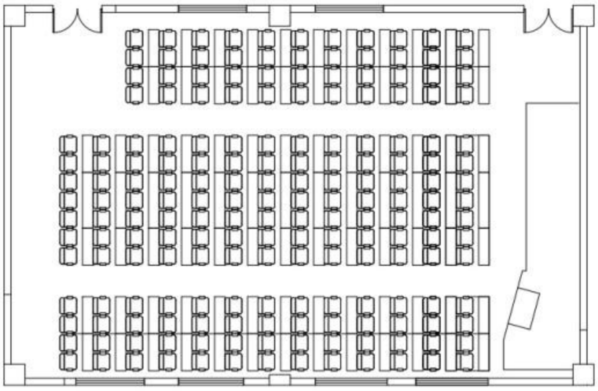

Fig. 1 Classroom floor plan illustration

Fig. 2 Actual classroom view

3. Acoustic Environment Simulation

The acoustic software EASE is used to simulate the acoustic environment of a multimedia classroom, to evaluate the classroom acoustic environment indicators in conjunction with appropriate codes, and to determine whether they can meet the requirements of normal classroom operation.

3.1 Software Modelling

A 3D model of the multimedia classroom is created in SketchUp and imported into the EASE software. To input the classroom material specifications, simulate the real sound environment of the multimedia classroom full field, and calculate the relevant acoustic parameters, the EASE software is utilized. Fig.3 illustrates this.

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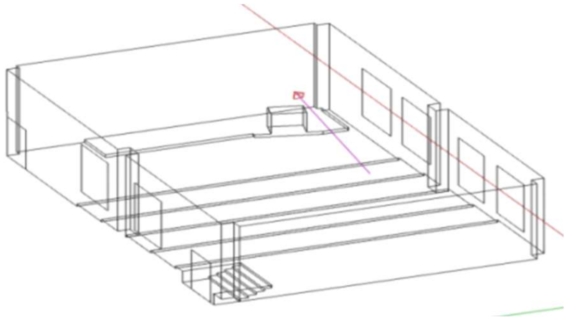

Fig. 3 Software model illustration

The airtightness of the imported model is checked using the sound tracing principle in EASE software; the loudspeaker and listening area in the model are set, as well as the properties of the various surfaces and room parameters; and acoustic parameters such as reverberation time, sound pressure level, C50 clarity, and speech transmission index are obtained from simulations. Table 1 shows the material coefficients of the room surfaces.

Table 1. Material coefficients for all sectors of the interior at different frequencies

Location	Material	125Hz	250Hz	500Hz	1000Hz	2000Hz	4000Hz
Windows	Double glazing	0.25	0.10	0.07	0.06	0.4	0.02
Flooring	Timber	0.20	0.15	0.10	0.08	0.08	0.05
Ground	Terrazzo	0.01	0.01	0.01	0.02	0.02	0.02
Walls	Plastered brick walls	0.01	0.05	0.06	0.07	0.09	0.08
Doors	Timber	0.15	0.11	0.10	0.07	0.06	0.07
Other	Full students	0.30	0.41	0.49	0.84	0.87	0.84

3.2 Simulation Results

The multimedia classroom's reverberation duration, sound pressure level, speech intelligibility, and speech intelligibility, as well as other objective acoustic characteristics relevant to room sound quality, were all simulated using EASE. Fig. 4 shows the results of each parameter's 1 kHz simulation. The reverberation time T0 of the multimedia classroom at 500-2000 Hz is greater than 1.0 s, which does not meet the requirements of the recommended reverberation time of not more than 1.0 s in the classroom as stipulated in the specification, and the frequency characteristics tend to be flat, as can be seen from the simulation results. It demonstrates that the indoor reverberation time is not within an acceptable range and therefore language sound halls cannot meet the reasonable requirements.

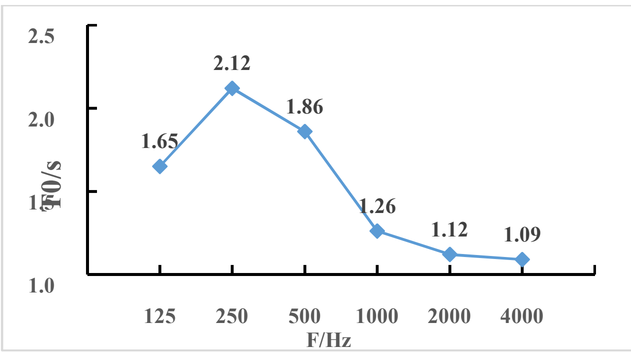

Fig. 4 Multimedia classroom reverberation time simulation values

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SPL stands for sound pressure level; sound pressure is the most commonly used physical quantity for sound measurement, but the magnitude of sound pressure is usually described in terms of sound pressure level, because the human ear can normally receive sound pressure levels in the 40 to 120 dB range [4]. The classroom sound pressure levels are dispersed between 58 and 66 decibels in Fig. 5, and the simulation results in Fig. 6 show that the sound pressure levels do not surpass 70 decibels at all frequencies. However, the space has strong acoustic characteristics, needing sound pressure levels between 70 and 75 dB, so the multimedia classroom indoor loudness cannot match the teaching needs in the event of pure human voice without auxiliary equipment.

Fig. 5 Multimedia classroom total SPL isobaric map

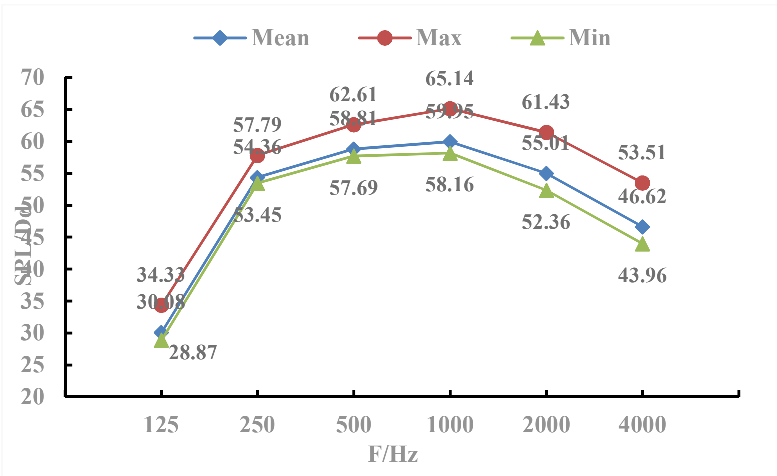

Fig. 6 Total SPL simulation for multimedia classrooms

C50 is a linguistic clarity metric that measures intelligibility. The ratio of sound energy before and after the 50 ms division point of sound energy is expressed as a dB value. Good clarity is defined as being above 0 dB in rooms with normal reverberation; if the classroom has a long reverberation period, it must be above -5 dB [5]. Only the right quarter of the classroom is over 0 dB, as shown in Fig. 7, and the rest of the range fails to meet the standards. Fig. 8 shows that the measured average speech intelligibility across all frequency bands was less than 0dB, indicating that the classroom failed in speech intelligibility.

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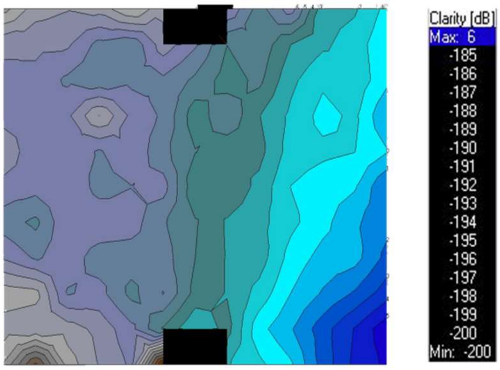

Fig. 7 Multimedia classroom C50 clarity isobar graph

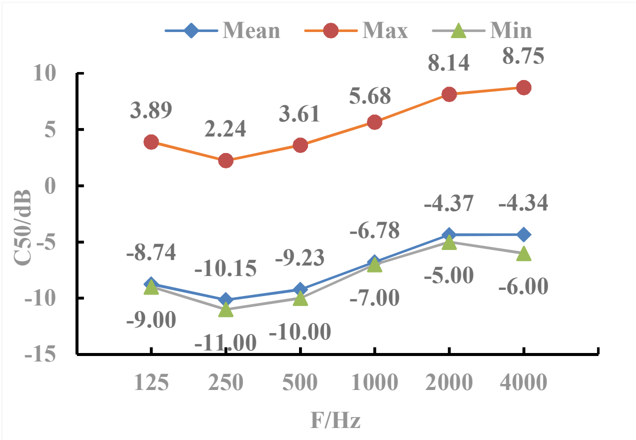

Fig. 8 Simulated C50 clarity values for multimedia classrooms

The Rapid Speech Transmission Index, also known as STI speech intelligibility, has a physical basis in communication technology's signal modulation concept, where the signal-to-noise ratio Lsn in each frequency band is related to the transmission system's reduction in amplitude modulation [6]. The signal-to-noise ratio, the reverberation time, and the speech's sound pressure level all affect speech intelligibility in a room, according to numerous studies.The Speech Transmission Index (STI) goes from 0 to 1, with 0 being the worst and 1 being the greatest, and a STI of greater than 0.6 indicating a better listening experience.Fig. 9 demonstrates that the vast majority of the room's range is less than 0.6, indicating low speech intelligibility; Fig. 10 shows that the mean STI value is between 0.45 and 0.6, indicating that the classroom's STI index is of basic quality with space for development.

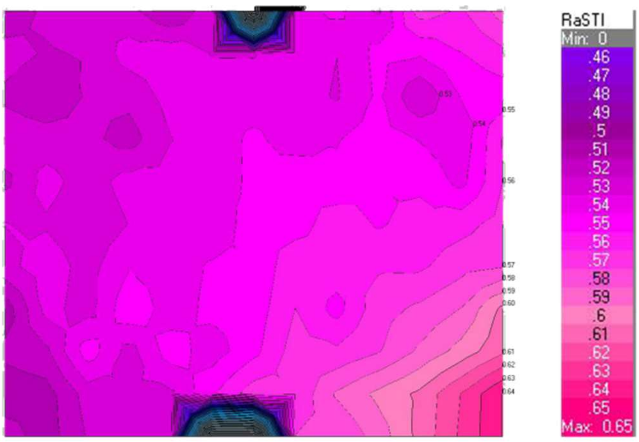

Fig. 9 Software simulation of classroom RASTI isobars

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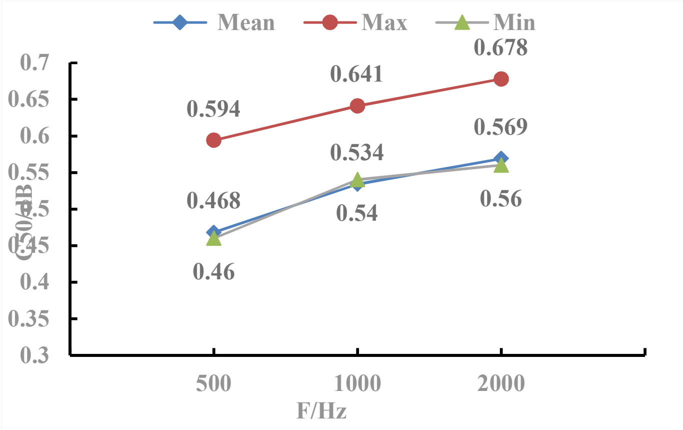

Fig. 10 Multimedia classroom RASTI simulation values

4. Sound Environment Mesurement

4.1 Field Measurement

On a 1.2 m height plane, the measurement points are uniformly distributed over the listening region. Each row has four measurement sites, for a total of 16 points in four rows, all of which are greater than 1 m from the reflective surface.The multimedia classroom was set up for normal use, that is, between the hours of 8:00 and 17:00 on weekdays, with the doors and windows closed and the field empty. The sound source was a mobile phone recording, and the source's sound power was set at 75 decibels. Using a sound level meter, multiple measurements were taken at the measurement places, and the objective acoustic characteristics at each measurement point were recorded. Table 2 shows the results of the measurements.

Table 2. Measured data sheets

Point 1	Point 2	Point 3	Point 4
54.6 dB	55.1 dB	57.0 dB	59.5 dB
Point 5	Point 6	Point 7	Point 8
54.6 dB	55.4 dB	57.1 dB	60.3 dB
Point 9	Point 10	Point 11	Point 12
53.5 dB	55.6 dB	57.7 dB	62.4 dB
Point 13	Point 14	Point 15	Point 16
53.8 dB	55.1 dB	58.7 dB	63.8 dB

4.2 Data Comparison

Fig. 11 shows the results of the acoustic simulation software EASE simulating the multimedia classroom's indoor sound environment and Fig. 12 shows the findings of the actual sound pressure level data measured in the multimedia classroom on site. When the software simulation was compared to the measured results, it was discovered that the trend of growth and reduction was nearly identical, with the exception of some of the measured data that contained mistakes. The differences in acoustic parameter values between simulated and measured values are modest, and the experimental simulations are slightly greater, but the data is usually consistent. This demonstrates that the EASE software simulation findings more precisely reflect the actual sound field of the classroom and can be used as a guide for the design of multimedia classrooms in institutions.

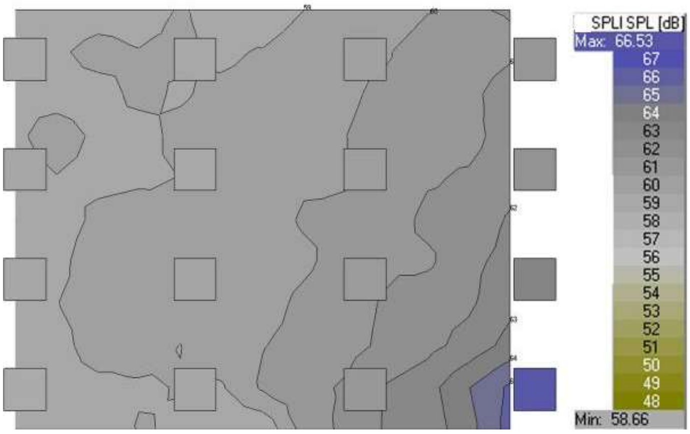

Fig. 11 Classroom simulated measurement point data plot

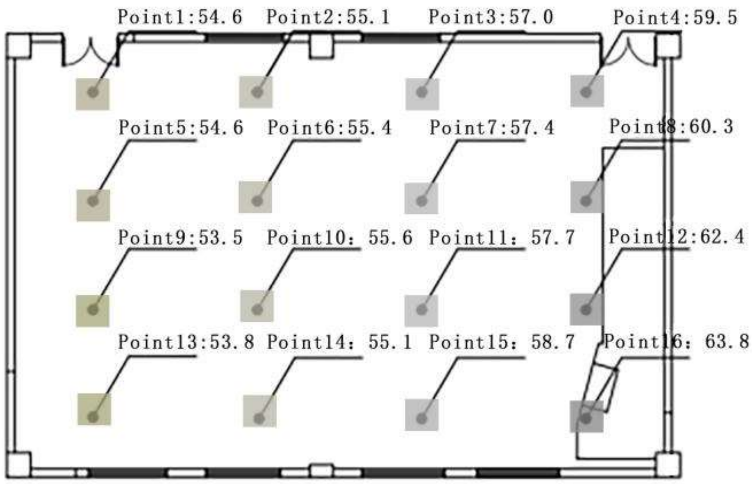

Fig. 12 Classroom field measurement point data map

5. Simulation Data Analysis

5.1 Basic Theory

Although there is a weak relationship between reverberation time and speech intelligibility evaluation, room sound absorption is still a significant factor affecting speech intelligibility, and increasing room sound absorption in multimedia classrooms can improve speech intelligibility to some extent. Adding acoustic materials can increase a room's absorption coefficient, for example, the average absorption coefficient of a classroom without acoustic materials is around 0.02, whereas arranging some materials with a relatively large absorption coefficient can increase a room's average sound absorption. Many studies, on the other hand, focus just on the amount of sound absorption in the room and ignore the impact of how the sound absorbing materials are placed [7]. As a result, the location of the acoustic material in the classroom can have an impact on voice quality.

5.2 Programme Strategy

The reverberation time of the classroom was simulated without the use of sound absorbing materials, and the analysis of the reverberation time of each frequency band revealed that the amount of low and medium frequency sound absorption in the classroom is minimal, indicating that the absorption coefficient of low and medium frequency should be chosen for the arrangement of high sound absorbing materials. Six distinct arrangements of acoustic materials were simulated and developed in Table 3 to study the influence of acoustic material arrangement on speech intelligibility in multimedia classrooms.

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Table 3. Arrangement of sound absorbing materials

Option	Arrangement of sound absorbing materials	Calculation of total sound absorption (m^2)	Sound absorption coefficient of newly added materials	Area of new acoustic material added (m^2)
1	No treatment	33.13	0	0
2	Back wall tiled	56.35	0.600	43.81
3	Ceiling covered	56.35	0.196	170.19
4	Side walls covered	56.35	0.300	100.7
5	Ceiling spacing	56.35	0.550	48
6	Ceiling back wall spacing	56.35	0.800	40.8

This article focuses on how acoustic materials are placed, namely the position and arrangement (concentrated or distributed), with a total area of 473.28 m2 estimated using the wall and ceiling range. The total amount of sound absorption in the room is calculated by calculating the area of sound absorbing materials for each option, controlling the absorption coefficient of the newly added materials so that the total amount of sound absorption in the room is the same for each optimised option, and then determining the absorption coefficients of the sound absorbing materials for each frequency band based on the area of sound absorbing materials for each option, as shown in Fig. 13. Table 4 shows the STI language clarity simulation values and grille plots for the six arrangement options.

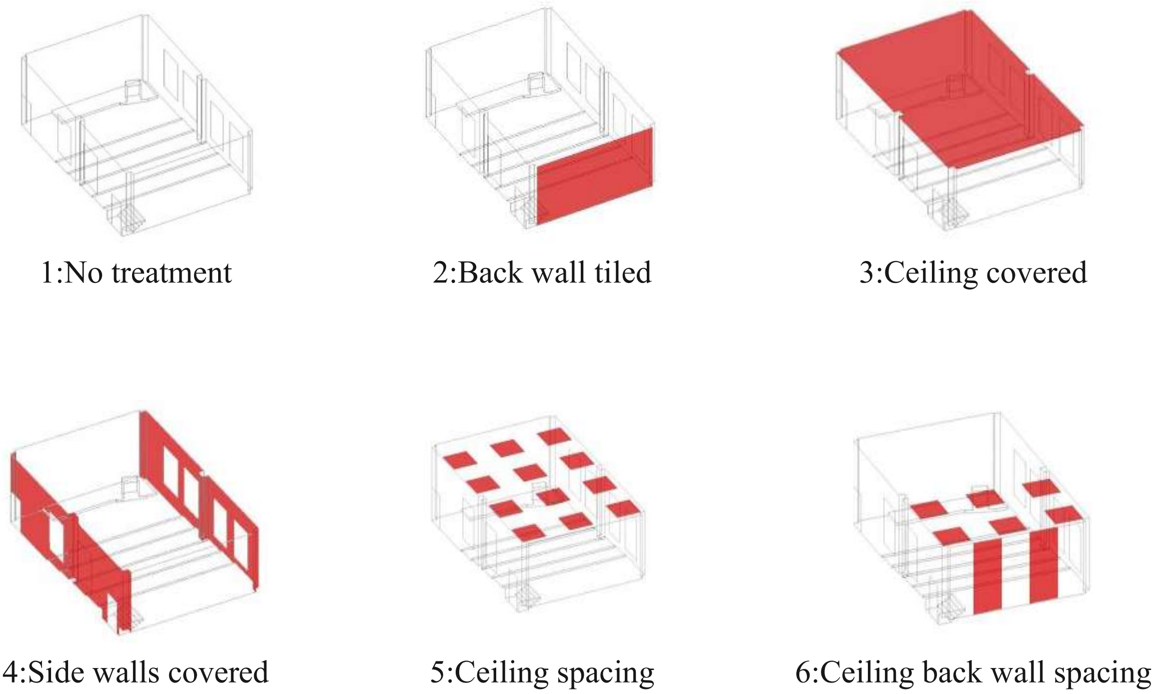

Fig. 13 Layout of multimedia sound absorbing materials

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Table 4. STI simulation results for different arrangements

Option	Arrangement of sound absorbing materials	Max	Min	Mean
1	No treatment	0.641	0.524	0.534
2	Back wall tiled	0.668	0.551	0.567
3	Ceiling covered	0.668	0.561	0.568
4	Side walls covered	0.673	0.573	0.573
5	Ceiling spacing	0.668	0.553	0.567
6	Ceiling back wall spacing	0.675	0.562	0.579

The simulated grille diagram of the classroom without sound absorption treatment is shown in Fig. 14. The average STI of the classroom is 0.534, the STI is not uniformly distributed, the isobaric values vary widely, the STI values at the back of the classroom are low, the STI values in the area close to the sound source in the listening area are high, and more than half of the area within the listening area is less than 6.0, indicating a low speech intelligibility area.

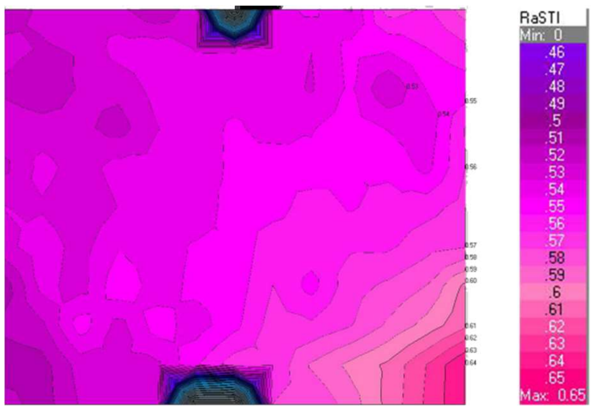

Fig. 14 Option 1: No treatment

Fig. 15 is a simulated grille diagram of a classroom with the treatment applied to the back wall. The average STI at each measurement point is 0.567, which is 0.033 higher than that of the classroom without sound absorbing treatment, the overall level of speech intelligibility has increased, and the STI at the back of the classroom rises by 0.03, which corresponds to a threshold at which the change can be felt by humans.

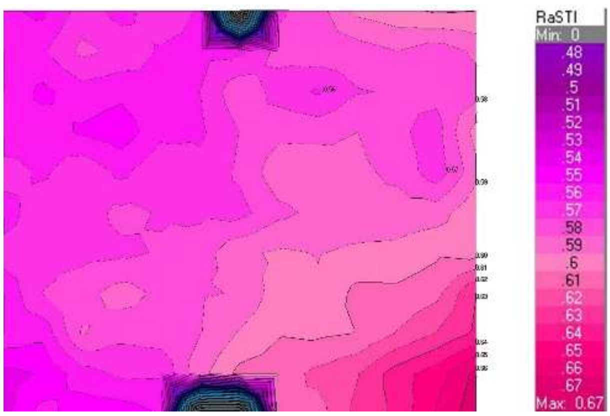

Fig. 15 Option 2: Back wall tiled

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Option 3 has a mean STI of 0.568, which is 0.034 higher than option 1. Fig. 16 shows a simulated grille diagram of the classroom ceiling with full treatment, which shows that when the acoustic materials are arranged on the ceiling, the uniformity of the distribution of STI values is not greatly improved, and there are still cases of lower STI values in the back areas.

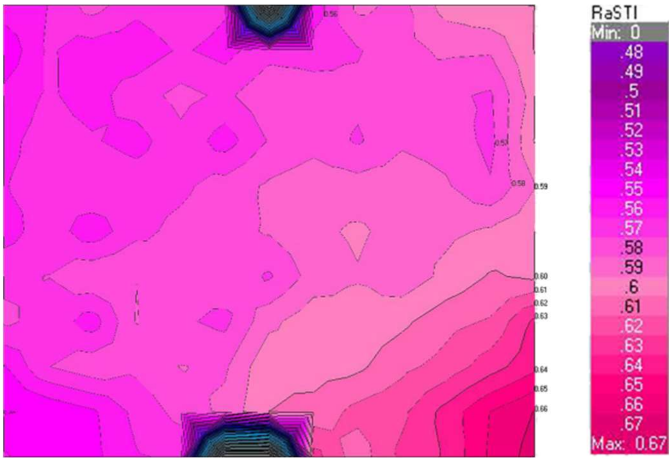

Fig. 16 Option 3: Ceiling covered

Option 4 had a mean STI of 0.573, which was 0.039 higher than option 1. Fig. 17 depicts a simulated grille diagram of the classroom ceiling tiled treatment. It can be seen that for rectangular classrooms, parallel side walls can cause flutter echoes, resulting in a reduction in speech intelligibility. Based on studies of classroom body shapes, adequate reflected sound has a significant impact on improving speech intelligibility, indicating that there may be some flutter echoes in the classroom. The clarity of voice in the classroom is much improved by Option 4, which reduces reflected sound from the side walls.

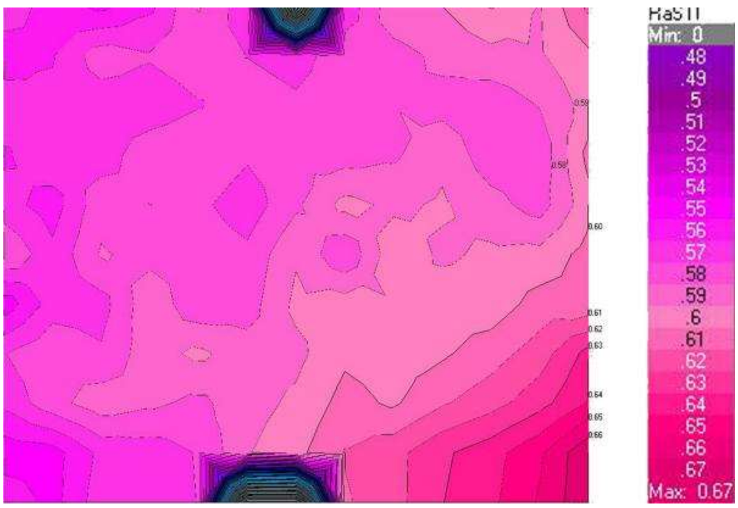

Fig. 17 Option 4: Side walls covered

Option 5 has the same mean STI value as option 2, which is 0.567. Fig. 18 depicts a grid representation of the treated classroom ceiling. The overall STI values of the multimedia classroom have improved, but the STI values in the back area remain low, indicating that the decentralized layout can enhance the STI distribution in the classroom to some extent.

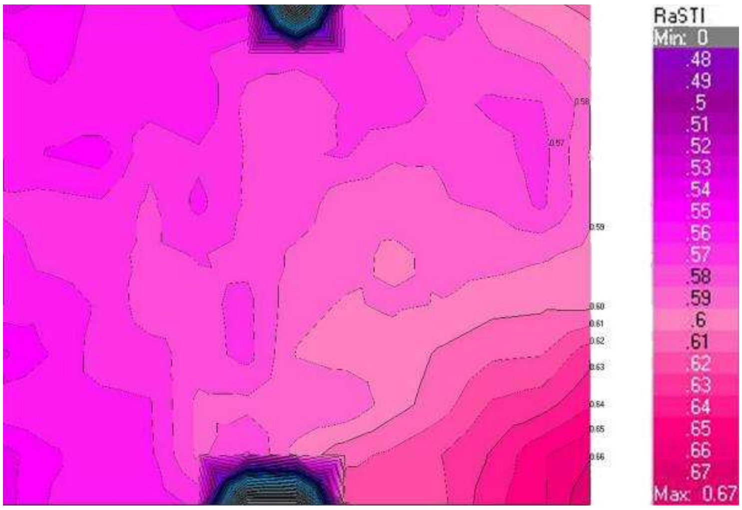

Fig. 18 Option 5: Ceiling spacing

Option 6 is to arrange the sound absorbing materials on the rear wall and ceiling with the same amount of sound absorption and in a spaced arrangement. The mean value of STI is 0.579, which is 0.045 higher than Option 1. Fig. 19 shows the simulated grille diagram for the classroom ceiling tiling treatment, which shows that the overall uniformity of the room is less uniform, but still the most impressive result of all the options, and also shows that reflected sound from the back of the classroom affects average speech intelligibility in the room, and that reducing the transmission of reflected sound from the back of the classroom can improve the level of speech intelligibility in the room. The STI value distribution is similar to that of the previous choices, with the exception that the rear seat has a higher STI value boost.

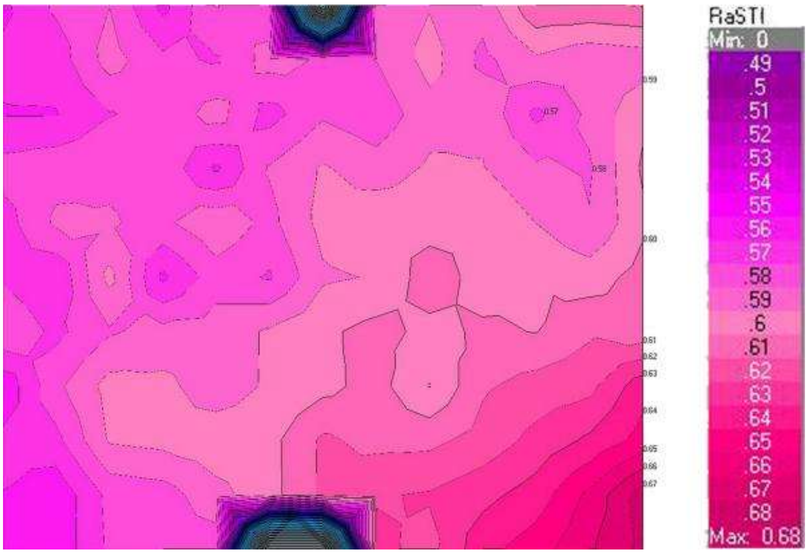

Fig. 19 Option 7: Ceiling back wall spacing

6. Conclusion

The simulation results of the EASE software can more accurately reflect the actual sound field of the classroom, and the arrangement of the acoustic materials has a certain influence on the speech intelligibility of the classroom, as shown by the simulation and analysis of the five layout options, and increasing the overall total amount of sound absorption can improve the STI value of about 0.03 perceptible in the entire classroom.

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The placement of sound-absorbing materials on the side walls or scattered on the back of the ceiling and the back wall has a greater effect on improving speech intelligibility in the classroom, and also shows that limiting the transmission of reflected sound from the side walls and the back of the classroom helps to improve the overall level of speech intelligibility in the classroom, assuming that the amount of sound absorption in the room remains constant. Furthermore, while sound-absorbing materials can increase the mean value of STI, the uniformity of STI distribution in the classroom does not improve significantly.

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