Acoustical Evaluation and Comparison Between Two Classroom Types in Erbil

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Abstract: In order to acquire an effective learning process in lecture halls with good speech intelligibility, good acoustical performance is essential. Inappropriate acoustic quality in classrooms reduces learning quality experience and can induce emotional disorders among students. The aim of this study is to evaluate and compare acoustic quality in two classrooms to determine their performance in terms of the learning process, at two types of theoretical halls at the Faculty of Engineering, Tishk International University. The calculation for the acoustical parameters of Reverberation Time (RT, T30), Speech Transmission Index (STI) and sound pressure level (SPL) for the selected educational spaces (classrooms) by simulation software (ODEON) were conducted, and the results were compared with acoustical requirements and guidelines for educational spaces. The results indicated that the closer the receiver (i.e., learner) is to the source (i.e., the lecturer), the lower the reverberation time; conversely, the further students (receivers) are from the teacher (source), the lower the STI and SPL values. This is mainly because of teacher's direct sound. It can be concluded that the acoustic quality of flat halls is better than raked halls for the learning process.

Keywords: Acoustical Parameters, Lecture Hall Acoustics, ODEON, Reverberation Time, Speech Transmission Index

1. Introduction

The acoustics of educational spaces (e.g., classrooms and lecture halls) have always attracted the interest of structural engineers, architects, sound engineers, and educators due to the fundamental requirement of high-quality sound for the educational process. Optimum acoustical conditions facilitate learning process effectiveness. Good classroom acoustics provide comprehensive verbal communication and speech intelligibility between the students and educators, as well as between students and their co-learners during the learning process, all of which has significant impacts on improving academic performance and the achievement of learning goals, and the quality of the teaching and learning environment (Pekkarinen & Viljancn, 1991). Conversely, poor acoustical conditions negatively affect the intelligibility of verbal communication among students and between them and teachers (Hodgson, 1999; Russotti, 2023).

The distance between instructors and pupils in the classroom is one of the elements that has an evident influence on speech intelligibility and awareness. Students sitting in the front rows of classrooms have better achievement and are generally able to hear the teacher very well due their proximity, and the reception of strong direct and early speech signals from the teacher.

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However, pupils sitting nearer the rear of the classroom receive commensurately weaker direct and early speech signals from the teacher, and they are also more affected by reverberation and late speech sound, even when sound systems are used with speakers at the rear of the room; indeed, this can induce additional problems in the interplay between secondary sound from speakers emanating from the rear of the hall and the primary sound from the speaker at the front (San et al., 2020).

Acoustic assessment and simulation are essential to determine acoustic performance and acoustic comfort in spaces. The development of new technologies for acoustic simulations and assessment had attracted increasing interest in recent years, predicting acoustical parameters with unprecedented good accuracy (Hodgson et al., 2008; Rezk et al., 2018). Among many acoustic software programs, ODEON is used in this paper, as it gives complete impression of acoustic performance in space. It provides the main acoustical criteria in space, which are: reverberation time (RT, T30), speech transmission index (STI), sound pressure level (SPL), and Early Decay Time (EDT) (Mahdavi et al., 2008).

Research in this field has been ongoing for decades, due to the constant need to optimally enhance acoustic performance in educational spaces in universities. Increasing importance has been attached to the importance of classroom designs that take speech intelligibility into consideration (Fuchs, 2019). Reverberation time is considered as a particularly influential factor in the quality of classroom acoustics. The length of reverberation time can cause a person to feel angry or uncomfortable, thereby possibly affecting the emotional status of the students and lecturer, creating an inherently negative experience for space users, and undermining the learning process (Evans et al., 1995; Hagen et al., 2004). Furthermore, the noise in the classroom can even lead to or exacerbate disorders such as depression, anxiety, and stress (Sarlati et al., 2014).

Reverberation time pertains to the sound volume and frequency, and the absorption coefficient of surface materials in the room. If reverberation time decreases, speech intelligibility commensurately increases. Reverberation time is particularly egregious in large rooms, such as lecture halls, where it is necessary to decrease reverberation time as much as possible (ISO 3382-1:2009, 2021). In the last decades, specific standards for classroom design have been used in many countries. The World Health Organization has also agreed some recommendations for classroom design in schools to reduce reverberation and noise through significant classroom acoustics standards, including the benchmark of less than 1.0 second as a good value of reverberation time; 0.4-0.5 seconds of reverberation time creates a high signal-to-noise ratio, which is an acceptable value for the learning process (Russotti, 2023).

This study calculated the acoustical parameters (Reverberation Time RT, T30; Speech Transmission Index STI; and sound pressure level SPL) for selected educational spaces (classrooms) using simulation software (ODEON), and the results were compared with acoustical requirements and guidelines for educational spaces. The aim of this study is to evaluate the acoustic performance of the university educational spaces, using the case of two main lecture halls in the Faculty of Engineering of Tishk International University (TIU) in Erbil. Both lecture halls are located on the second floor of the Main Building. The study has two main objectives: (i) to specify the acoustical quality of each flat and raked floors in the two different lecture halls at TIU; and (ii) to evaluate and compare the acoustical performance of two different classrooms in two cases – teacher to student (T2S), student to teacher (S2T), and student to student (S2S). A series of simulations were conducted using computer simulation in ODEON Room Acoustic Software, to evaluate the acoustical performance of three different cases. The results generated through the simulation are discussed and compared.

2. Materials and Methods

Two different types of classrooms were chosen as the case study in the Main Building of TIU, a private university recently built in 2010. The first chosen room is the lecture room with a raked floor (6.50 x 12.85 x 3.00 m), and the second lecture room is a regular box shaped room (6,60 x 9.20 x 3.00 m), as shown in Figure 3 and Figure 4. Overall, the room surfaces comprise walls of painted plaster, windows, ceramic tile floor, white boards, a smart board screen, a combination of regular plaster painted ceiling with suspended ceiling of high absorption. Furniture includes fixed wooden desks and light upholstered fixed seats. A description of the classrooms, and volumes found in Table 1 describes the geometrical, occupational, and furnishing data of the classrooms, including the furniture type.

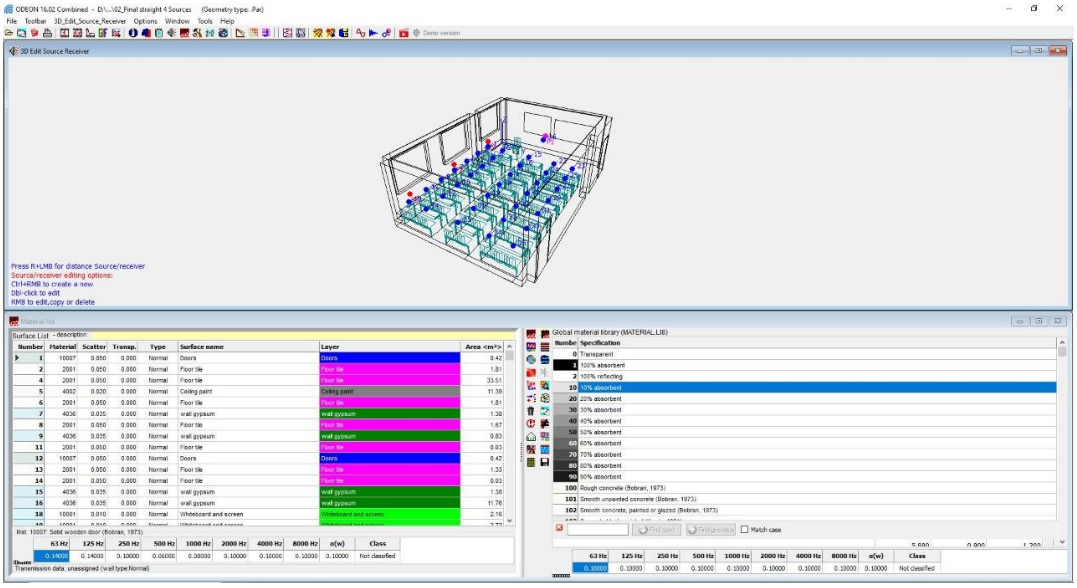


Figure 1: ODEON Software (print screen) for Material List

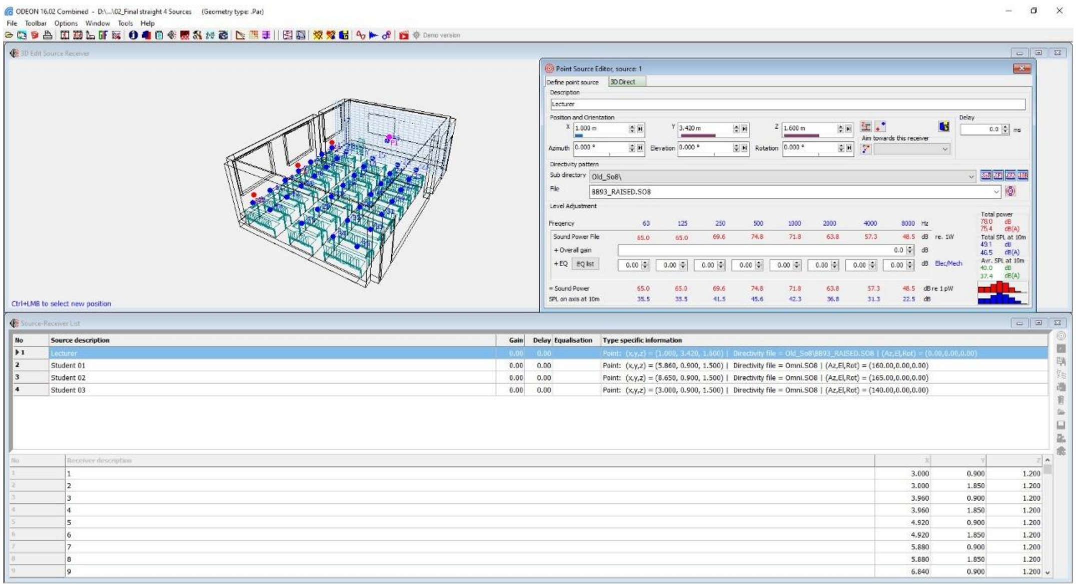


Figure 2: ODEON Software (print screen) for Source Description and Sound Specification

Figure 3: Drawing Plan of Flat and Raked Hall

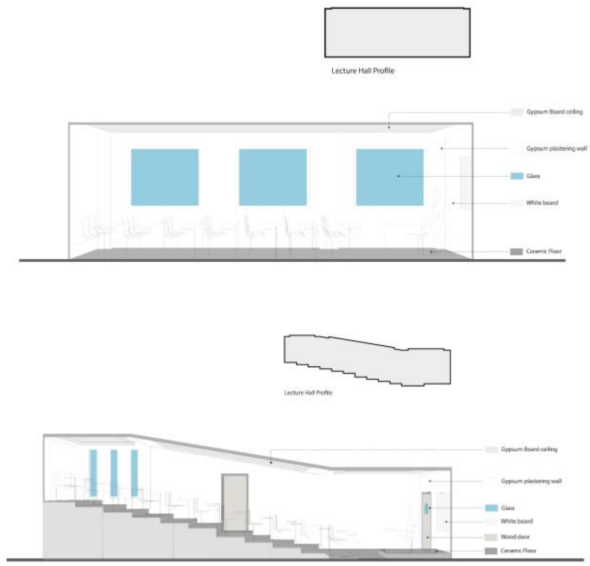


Figure 4: Section View of Flat and Raked Hall

Table 1: Description of Evaluated Lecture Halls: Dimensions, Area, Volume, Capacity and Furniture

Parameters	Units	Flat hall	Racked hall
Floor Area	Square meter	60.99	81.96
Length	M	9.2	12.85
Width	M	6.63	W1=6.25 W2= 6.85
Height	M	3.2	2.86
Volume	Cubic meter	195.16	209.56
Capacity	Persons	57	89
Furniture	Number	14 no. of three seats+ 7 no. of two seats	22 no. of four seats

Guidance on computer prediction models to calculate the acoustic parameters for Building Bulletin 93 (BB93) (Section 1.1.7) states that STI performance standard governs all speech transmissions, whether T2S, S2T, or S2S. Consequently, the following calculations are required:

(1) T2S, to ensure that oral presentations by the teacher, with a raised voice, are intelligible to the whole class. In this situation, the teacher is the source, and every student is a receiver.

(2) S2T, to ensure that responses made by students to the teacher, in a raised voice, are intelligible to the teacher. At least three separate calculations are required, one for each of three different student source locations. The student source locations should be chosen to represent students at the rear of the class.

(3) S2S, to ensure that responses made by students to the teacher, in a raised voice, are intelligible to other students in the class. At least three separate calculations are required, one for each of three different student source locations. All other student locations are receiver positions. The source locations should be distributed in the student area, with at least one at the front and another at the back of the class. (Agency, 2014).

Regarding the simulation procedure, firstly, the 3D model of both classroom type of TIU was modeled using Google Sketch up®. When modeling the chairs and tables, seat, back rest, and tabletop components were modeled out in a simplified manner, then simplified legs and other small details were added, and the resultant models were exported into ODEON Room Acoustic Software 16.0. The model validity was checked before the room model was assigned. Simulation accuracy was ensured by complete enclosure of the room model by doing the water tightness test, using 3D investigate ray tracing. The “Ray Tracing” is an important technique in computerization, and is a broadly used method in generating a realistic image in computer graphics by calculating the color and level of light at all points as a result of tracing the light path throughout image plane pixels as they engage with the optical surface. The algorithms of modern ray-tracing can easily simulate an extensive variety of optical effects, such as scattering, refraction and reflection. These capabilities could be utilized in simulating wave propagation in 2D and 3D virtual probes and virtual objects could be positioned on the surfaces of internes (Petrie & Mills, 2020).

The sound source and receivers were applied into the room after the materials were applied to all the surfaces in the model in ODEON. Initially the focus of this research was on sound sources, due to the availability of material databases of sound absorption characteristics; more specifically, the concentration was about mid-frequencies ranging between 250Hz to 2000Hz, but it was finally limited to 1000Hz, commensurate with typical human hearing and speech intelligibility.

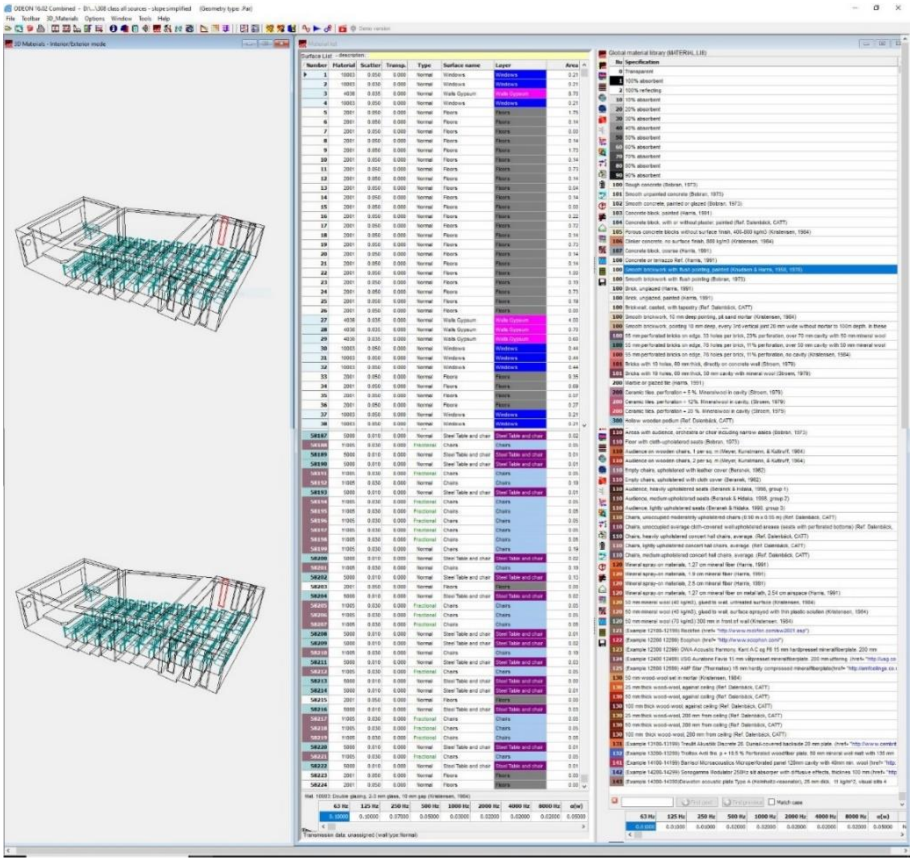


Figure 5: Material Selection Part in ODEON

Three points of natural raised sound (BB93_RAISED_NATURAL.SO8) were used as sound sources in this study. Raised natural sound source was applied instead of normal natural sound source, to represent more formal speaking to the class, because normal natural sound source is for normal conversation (e.g., between students). This sound source will represent the lecturer standing and teaching in the classroom. The source representing the lecturer was in the front center of the class, 1 m in front of the blackboard, and 1.5 m above the ground (standing position), while the receivers were placed 1.2 m above the ground (sitting position), and at least 1 m away from the wall, to provide a more accurate simulation (Rosenberg, 2010).

For the seating position of the students and the table arrangement in the classroom, there were 44 simulated points in the raked floor classroom, and 35 simulated points in the regular floor classroom. The distribution of sound sources (red dot) and receiver points' (blue dot) for each room model is shown in Figure 1. The simulation verification using 3D investigated ray tracing test was performed to ensure that the room model was completely enclosed. The materials were not exactly fitted, rather they were chosen from a library of 'standard materials', and therefore they reflect the properties of the real materials by more than 90%; however, the data have sufficient accuracy to illustrate the real context. For instance, the gypsum board in the ODEON library materials has the same properties and specifications of the real one but in some parts of the class's ceiling the perforated ceiling is used which the materiality of it cannot be specified in the ODEON software.

The relevant acoustical parameters such as reverberation time (T30), STI, and SPL were presented. To limit the presented data in the stated parameters, only the 1000 Hz octave band was considered. As explained previously, simulation programs such as ODEON can simulate sound sources of eight different octave band frequencies, ranging from 125Hz to 8000Hz, or ruralize the acoustics of a room. However, 1000 Hz octave band of each parameter illustrates the problem quite well (Rezk et al., 2018).

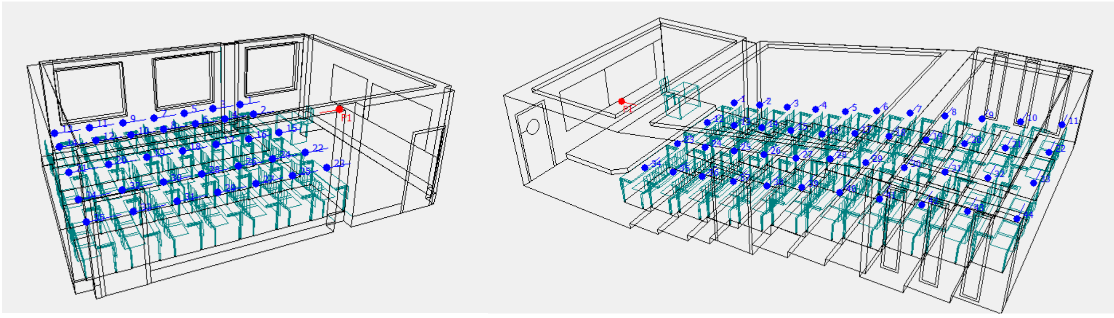


Figure 6: ODEON 3D Model of Flat and Raked Hall.

3. Results and Discussion

The acoustical parameter simulation results of both room models cover three different cases (i.e., T2S, S2T, and S2S), analyzed and presented in the form of 2D surfaces and figures for comparison purposes.

3.1 Reverberation Time (T30) – T2S

Figure 7 illustrates reverberation time (T30) in the frequency of 1000Hz in the flat and ranked halls when the teacher speaks to the students. There were 35 receiver points in the flat hall and 44 receiver points in the raked hall specified for the simulation purpose. Each of the receiver points represents an individual pupil. Simulated results show that in both halls the reverberation time differed between receivers near to or far from the source (i.e., the teacher), but there was no a significant difference in the value of reverberation time for flat and raked halls. In the flat hall the reverberation time increased gradually until the last row, while in the raked hall it was almost the same in the first and last rows due to its geometrical shape, as the utilized materials within the halls are almost the same (Bassuet et al., 2014) (Table 1).

By comparing flat and raked floor lecture halls, it is noticeable that the highest and lowest reverberation time (T30) values in both halls were 0.65 and 0.54 seconds (respectively), both of which were within the raked hall. Moreover, the T30 value of flat floor lecture hall is within this range (0.55 - 0.62 second), which manifests a marginal difference with the raked floor lecture hall. Compared to the standards (BB93), the reverberation time of all the receiver points (i.e., students) of both halls was within the recommended values of ANSI, thus the halls are acoustically suitable for educational purposes (Russotti, 2023).

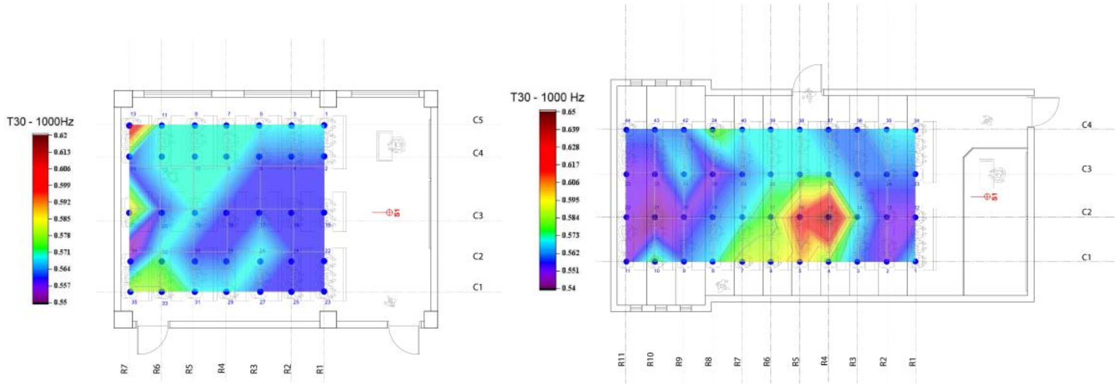


Figure 7: T30 at 1000Hz of Flat and Raked Hall – T2S

3.2 Speech Transmission Index (STI) - T2S

STI defines the speech intelligibility degree of the room. When speech intelligibility is more than 0.6 it can be considered as ‘good’, and when it is more 0.75 it is considered as ‘very good’ (Wróblewska, 2010). As shown in Figure 8, STI is gradually reduced from the first to the last row; in other words, the further students (receivers) are from the teacher (source), the lower the STI values, which is mainly attributable to the phenomena of the teacher’s direct sound. Figure 8 also shows that all students receive a good level of STI in the flat hall, ranging from 0.69 to 0.60 from the first to last row, correspondingly. On the other hand, In the raked hall, from the first to eighth row the STI was ‘good’, while the last three rows had average (‘fair’) STI (0.57). The number of receivers in the raked hall was greater as opposed to the flat hall, thus it can be expected that the value of STI decreased as the number of students increased.

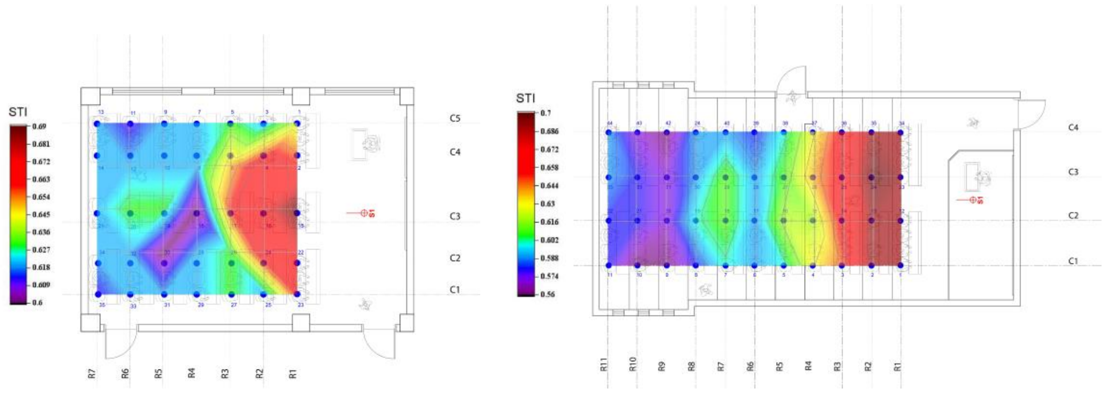


Figure 8: STI of Flat and Raked Hall – T2S

3.3 Sound Pressure Level (SPL) – T2S

The results show that the SPL values range between 56.7-60.5 dB in the flat hall which is higher than the raked hall when the minimum SPL is 53.78 dB, and the maximum is 60.4 dB. This could be because of the extended length of the raked floor lecture hall compared to the flat floor lecture hall. In both halls the results show that the value of SPL reduces steadily as we get farther away from the source (the teacher). Thus, the SPL values are higher in the front rows than in the rear rows. This is mainly because the direct sound energy is most prevailing at distances close to the teacher. Furthermore, the map consistency for both halls gradually changed color from the front to back because there are no major sound obstacles like columns or partitions to create acoustic shadows, as shown in the SPL contour maps (Figure 9).

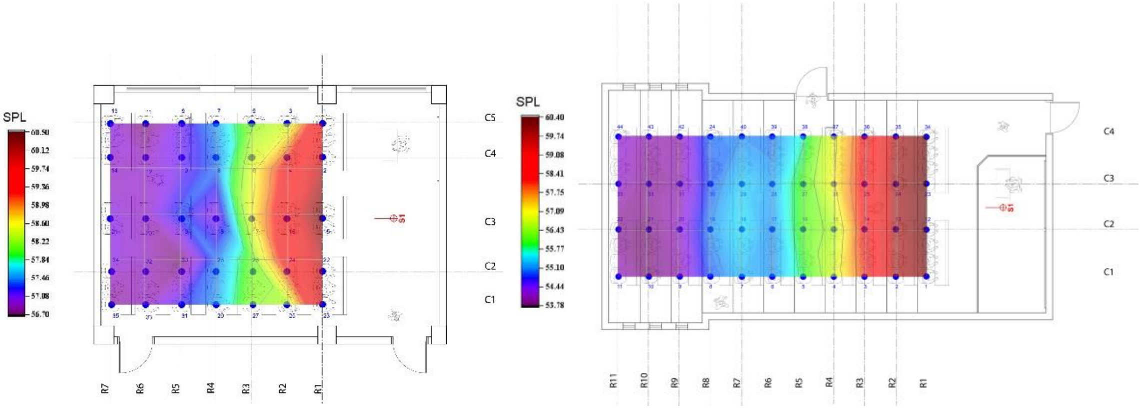
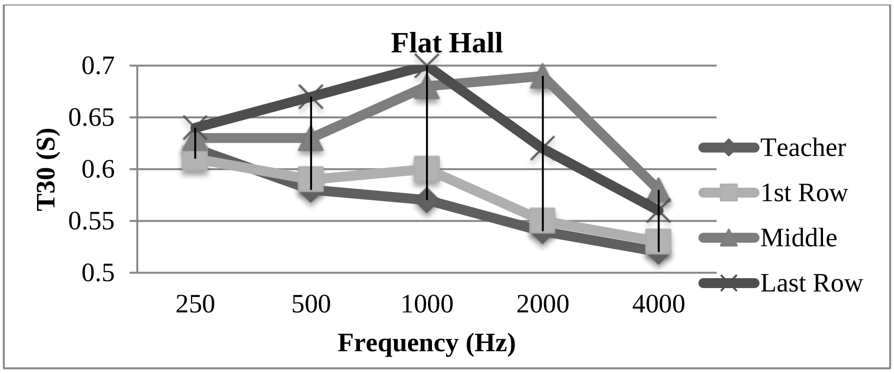


Figure 9: SPL of flat and raked hall – T2S

3.4 Reverberation Time (T30) – S2T and S2S

The reverberation times (T30) of the two classrooms were compared when a student in three different locations (front, middle, and rear) speaks to the teacher and other students, as shown in Figure 10. Charts show the simulated T30 values of frequency range of 250Hz to 4000Hz with respect to selection of four receiver points (three students and a teacher) of both lecture halls in TIU. It was observed that the flat hall had longer reverberation times (T30). Based on the figures, the reverberation time for the classroom decreases as the frequency increases from 250Hz to 4000Hz. This is because most materials do not absorb low frequency well, thus resulting in shorter reverberation at higher frequency and longer reverberation in lower frequency (TrombettaZanninPersonEnvelope & ZanardoZwirtes, 2008). The results also show that both classrooms have reverberation times between 0.43 and 0.7 seconds for all frequencies, which is smaller than 1.0 seconds, indicating acceptable reverberation time values. The T30 from the teacher and the first row is approximately the same, especially in the flat hall, with some small fluctuations in the raked hall. This is mainly because of the regularity of the surface geometry of the flat room and its smaller size (Bassuet et al., 2014). A student in the last row receives the lowest T30 because this location is closer to the rear wall, and the reflected sound needs less distance and consequently less time to reach them (Figure 11).



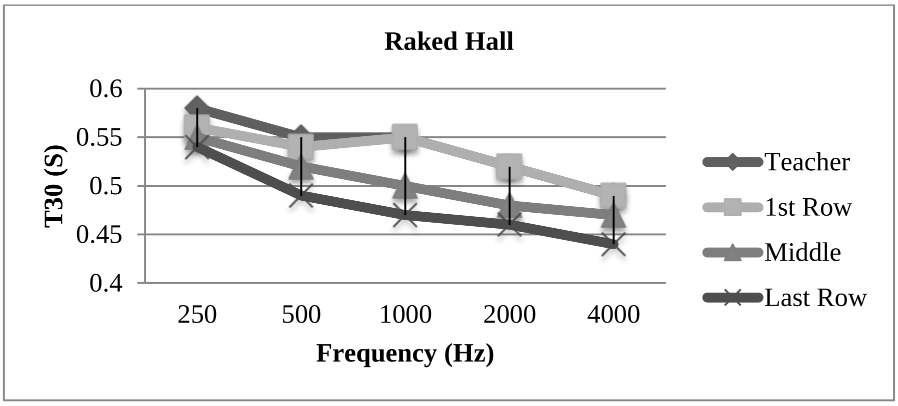


Figure 10: Reverberation Time (T30) of Flat and Raked – S2T and S2S

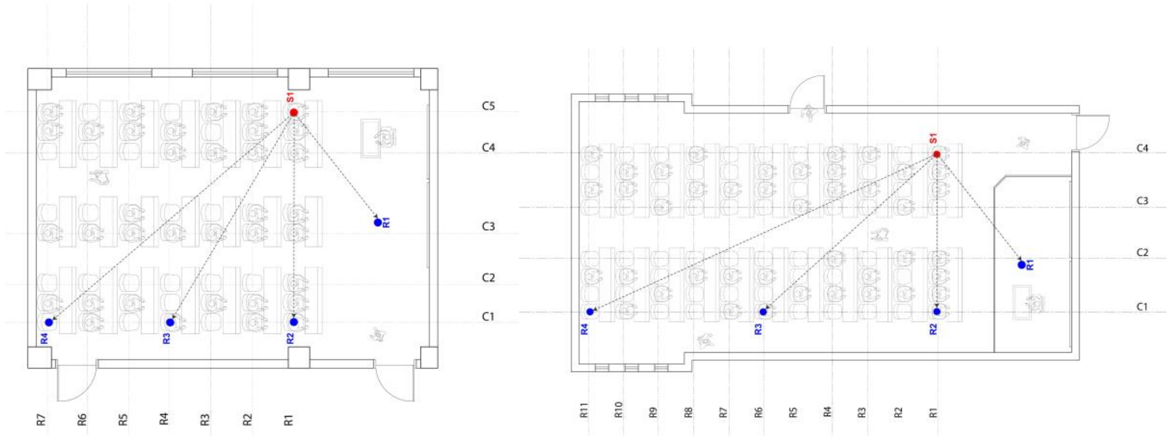


Figure 11: Source and Receivers Location of Flat and Raked – S2T and S2S

3.5 Speech Transmission Index (STI) - S2T and S2S

To reach 'good' speech intelligibility, the STI value of classroom must be 0.60 and above (Steeneken and Houtgast, 1980). The graph in Figure 12 illustrates the STI value from three sources in different locations at the left side to the teacher and three students in the right side for both flat and raked halls. It can easily be seen that STI is good from the teacher to the first row, and lower at the middle and last students, but in the third source it is completely different, because of the distance between the source and receivers. Based on the results, all students in the flat hall have STI values of more than 0.6 except the teacher in the third source, because of the greatest distance between them. In the raked hall, the teacher and the first-row student receive lower than 0.6 from the third source, and the middle and last students receive lower than 0.6 from the first source. The results are plotted in STI versus distance from the source (student).

From the graph, in the first source, all the receivers (teacher and students) in the flat hall fall above 'fair' STI rating (above 0.6). In both halls the teachers and students in the first row receive highest amount of STI, which is about 0.7; the value reduces with increasing distance from the source, and the last row students receive the lowest STI in both cases. For the second source the STI is almost the same in all receiver points, because the distance from the source and receivers is similar except for the last row, due the sound direction not being straight to the receiver. The STI of the third source is completely different from the first, because of their locations in the first and last rows (respectively).

From the simulation, the STI values of the raked hall in the teacher and first row position are higher than in the flat hall, but in the middle and last rows the STI of the flat hall is higher. This may because the raked hall distance from the last rows to the source is higher than in the flat hall, but for the first rows the relative location of the teacher is basically the same. Thus, it can be concluded that STI decreases in both cases as the receivers (teacher and students) are further away from the source (student) (Figure 13).

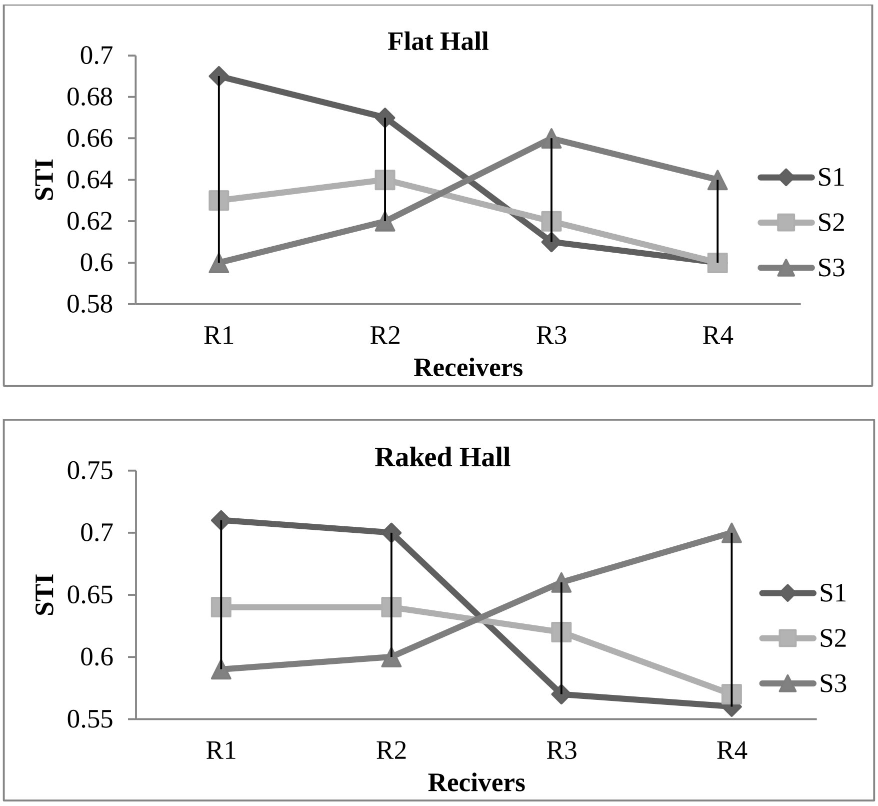


Figure 12: Speech Transmission Index (STI) of Flat and Raked – S2T and S2S

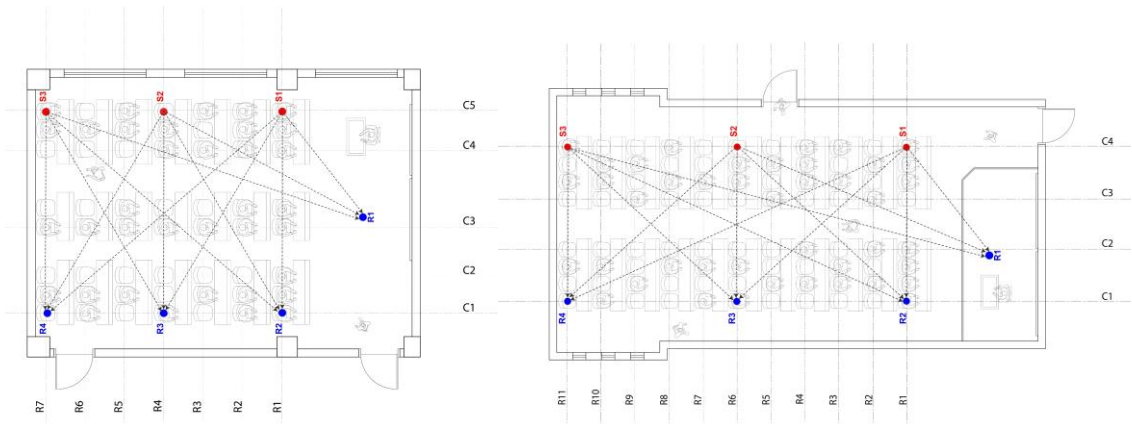


Figure 13: Source and Receivers Location of Flat and Raked – S2T and S2S

3.6 Sound Pressure Level (SPL) - S2T and Student

A-weighted SPL was simulated and measured in dBA, a weighted scale for judging loudness that corresponds to the hearing threshold of the human ear, while the dB scale is based only on sound intensity. The dBA scale is based on intensity and on how the human ear responds, as humans do not hear all frequencies equally (Gracey,n.d).

The results in Figure 14 indicate that the A-weighted SPL values of the flat hall is 55 and 60 dBA; the teacher position has the highest, while 42 to 56 dBA in the last row is the lowest value of the same frequency. From the chart it can also be seen that the SPL(A) value of the teacher and first row is almost the same, and the middle and last rows are also close to each other. On average the SPL(A) of the flat hall is higher than that of the raked hall by about 5dBA, especially in the farthest position from the sources. This is mainly because the length of the flat hall is shorter than that of the raked hall. Additionally, the figures show that the SPL(A) values of both halls gradually increased in fluctuation from the front to back due to the absence of sound obstacles (Figure 10).

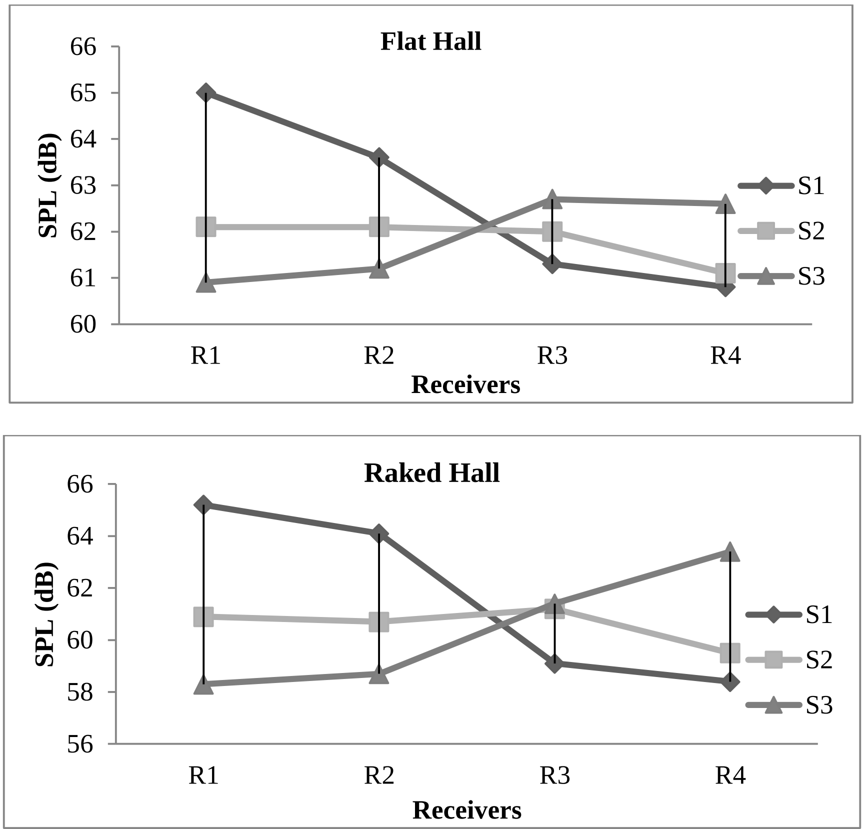


Figure 14: Sound Pressure Level (SPL) of Flat and Raked – S2T and S2S

4. Conclusions

This study compared and evaluated the acoustical characteristics of two cases of the most common types of lecture halls, flat floor and raked floor halls, at Tishk International University in Erbil, for three main scenarios: T2S, S2T, and S2Ss. ODEON room acoustical simulation was utilized to assess the degree of speech intelligibility in the studied lecture halls. The results compared between the halls relative to acoustical recommend criteria for lecture halls. The simulation results of two lecture halls indicated that the quality of sound was better when in T2S than in S2S. The acoustical properties of flat hall were better than raked hall, due to the regularity of its surface geometry and its smaller size.

In the flat hall, the reverberation time increased gradually until the last row, while in the sloped hall it was relatively homogenous in the first and last rows, due to its geometrical shape, given that the materials utilized within the halls basically the same. STI is gradually reduced from the first to the last row; in other words, the further students (receivers) are from the teacher (source), the lower the STI values, this is mainly because of the teacher's direct sound. On average, the STI of the flat hall is better than that of the raked hall, due to the number of receivers in the raked hall being greater as opposed to the flat hall, thus it can be expected that the value of STI is decreased as the number of students increased. The SPL values are higher in the front rows than in the rear rows due to direct sound energy being more prevalent at distances closer to the teacher. Moreover, for S2T and S2S the SPL(A) value of the teacher and first row is almost the same, and the middle and last row have similar values. The average SPL(A) of the flat hall is higher than that of the raked hall by about 5dBA, especially in the farthest position from the sources. This is mainly because the length of the flat hall is shorter than that of the raked hall. Additionally, the figures show that the SPL (A) values of both halls gradually increased in fluctuation from the front to back, due to the absence of sound obstacles.

It can be recommended that further research is required to enhance the acoustical performance of common lecture halls in Erbil by selecting more types of lecture halls and simulating other acoustical parameters of lecture halls that are limited in ODEON 16 Basics.

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