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Developing Statistical Acoustics Model for Lecture Auditorium using Application of Reverberation Time

Mohammed Ogab, Siti Noor Asyikin Mohd Razali, Djamal Hissein Didane

Abstract:*This article focusses on the findings of a research project into the acoustic characteristics of University Tun Hussein Onn Malaysia (UTHM) classrooms. The listening ability of the students in different sitting positions with different classrooms design was conducted. Physical measurements were taken from 10 sample rooms of lecture halls and normal classrooms in four different conditions; when occupied, unoccupied, with and without air-conditioning. For an optimal learning environment in terms of Speech intelligibility of selected theatre halls and normal classrooms, academic building block G3 of UTHM have been analyzed experimentally and analytically using survey questionnaires, direct measurements of classroom noise levels and reverberation time. Thus, a statistical approach was performed to estimate the reverberation time in a room. Reverberation time and sound pressure level were correlated and the linear regression analysis was executed. The analysis was carried out using SPSS software. The survey identified the lecture auditoriums that were acoustically rated by both lecturers and students as either good or bad. The result obtained from direct measurements shows that the 'good' classrooms when occupied typically had a mid-frequency (average of 500 Hz & 1 kHz) reverberation time (RT) of 0.42 seconds. The mid-frequency reverberation time in the "poor rooms" ranged from 0.53 to 0.63 seconds, while when unoccupied the 'good' classrooms typically had a mid-frequency reverberation time (RT) of 0.47 seconds. The mid-frequency reverberation time in the "poor rooms" ranged from 0.59 to 0.67 seconds. It's obvious that theatre halls are having better acoustic properties and there was a good agreement with the result obtained from the survey. The result from the statistical models shows that the predicted reverberation time was reliable with an average percentage of errors of less than 18% compared to the measured reverberation time.*

Keywords: *Classroom acoustics; reverberation time; sound pressure level; speech intelligibility.*

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* Correspondence Author

Mohammed Ogab*, Department of Energy and Thermofluid Engineering, Faculty of Mechanical and Manufacturing Engineering, University Tun Hussein Onn Malaysia, Johor, Malaysia (UTHM). Email: ogabfils@gmail.com

Siti Noor Asyikin Mohd Razali, Department of Mathematics and Statistics, Faculty of Applied Sciences and Technology, University Tun Hussein Onn Malaysia (UTHM), Pagoh Education Hub, Johor, Malaysia. Email: asyikinr@uthm.edu.my

Djamal Hissein Didane, Department of Energy and Thermofluid Engineering Faculty of Mechanical and Manufacturing Engineering, University Tun Hussein Onn Malaysia (UTHM), Johor, Malaysia. Email: djamal@uthm.edu.my

I. INTRODUCTION

The recent architectural surroundings necessitated an effective acoustic design in facilitating the learning process in any educational environment. However, the acoustics features in many educational facilities are less than acceptable due to many hindrances especially noise interference.

The research of lecture auditorium acoustic is vital since creating a conducive environment for learning to facilitate learning [1]. Optimizing the learning environment inside of a lecture hall especially that involves sound is definitely a crucial consideration. Classroom and lecture hall acoustics have long been studied in an effort to achieve a regularly hearing-friendly class session [2]. Regulations have been implemented and alleviative measures have indeed been taken – resulting in an improved modern classroom for the listening student's ability [3]. Furthermore, nowadays, the modern classroom is fused with technology and built with careful engineering, challenges the old wisdom that calls students to "sit in the front of the classroom" or "get to class early if a seat in the front is desired" [4].

At the initial stage, a conducive environment would involve a range of noise projections. Lately, the acoustic arrangement is compulsory to be incorporated into every design in any educational environment. The absence of constructive designed spaces and even the whole physical environment will be subjected to a disturbing level of noise [5]. The lecture theatre is an example of a single performance space. However, since few people have any real knowledge of what factors affect the acoustics of a space or what to take into account when designing a space where people listen, we often miss out on the benefits from a good acoustic environment [6].

In order to measure the acoustic characteristic of the classroom, acoustical parameters such as reverberation time and echoes, noise criterion and acoustical rating Systems, etc. are and background noise level is considered measured for unoccupied classrooms and thus investigate the consequence of occupants [7]. Reverberation time is a significant parameter that measures the acoustic features of an enclosed space after the sound source has been removed or the sound to be inaudible after turning off the sound source [8]. The volume of sound in the hall is also assessed by the ceiling height which determines the reverberation time of sound. This will affect in terms of regulating speech intelligibility.

Thus, It is recommended that heights be kept between in limit as the volume of the classroom also with limit [9] and [10].

The interference of sound in the various types of rooms should not exceed the Noise Criterion limits. It is recommended that for general classrooms to be effective the Noise Criterion limit should be between 30 to 40 dB [11].

The recommended noise level of a learning space should in range of 35-40 dB and 0.6-0.7 s for Maximum background noise levels and maximum reverberation times respectively [12] and (Bies, Hansen et al., 2017). Many acoustical rating systems and criteria have been developed to quantify and describe HVAC system noise in buildings and occupied spaces [14]. Most commonly, engineers and consultants, today are using the NC rating system in specifications and when evaluating noise situations (Marino et al., 2012) &[16].

For an optimal learning environment in terms of Speech intelligibility, this focus of the study is to identify the acoustic characteristics of University Tun Hussein Onn Malaysia (UTHM) classrooms where the listening ability of the students in different sitting positions with different classrooms design were investigated, where the academic building block (G)3 of UTHM have been analyzed experimentally and analytically using survey questionnaires, direct measurements of classroom noise levels and reverberation time.

II. METHODOLOGY

This research utilized two approaches in assessing the noise level in a specific space. The first method was using a direct measurement of sound- measuring instrument. Where measurements were conducted in the five octaves band frequencies.

The second method utilized the statistical models developed by means of correlation analysis with related parameters to predict the reverberation time. The later method was completed by using the SPPS software.

The outcomes of the reverberation time from the method stated above were then compared to the actual measurement

A. The Plan View of Auditorium Hall

The university site consists of a range of classrooms with different building designs, usually more than one room of each design type. The study area of the project was concentrated at Block G3 of UTHM, comprising three levels, while measurements were based on their design, theatre halls and normal classroom with dimensions of 20 m long, 9.1m width and height of 4.25 m. This auditorium has two front doors and six windows as shown in Figure 1. As shown in Table 1 below, five samples of each room style were studied.

Table- I: Classrooms Rooms samples

Blok G3 Building	
Group A: Theatre halls	
Room 1	DK1 – (Dewan Kuliah 1)
Room 2	DK2 – (Dewan Kuliah C)
Room 3	DKE – (Dewan Kuliah D)
Room 4	DKG – (Dewan Kuliah G)
Room 5	DKF – (Dewan Kuliah F)
Group B: Normal classrooms	
Room 6	BKE 3 – (Bilik Kuliah B 3)
Room 7	BKE 7 – (Bilik Kuliah E 7)
Room 8	BKB10 – (Bilik Kuliah B10)
Room 9	BP2 – (Bilik perbincangan1)
Room 10	BP2 – (Bilik perbincangan1)

The seating, dimensions, surface finishes, and construction materials were recorded and analysed, in addition to photographic records of the interior and exterior. The questionnaires in conjunction with the building surveys were used to identify 'test' rooms for further detailed investigation.

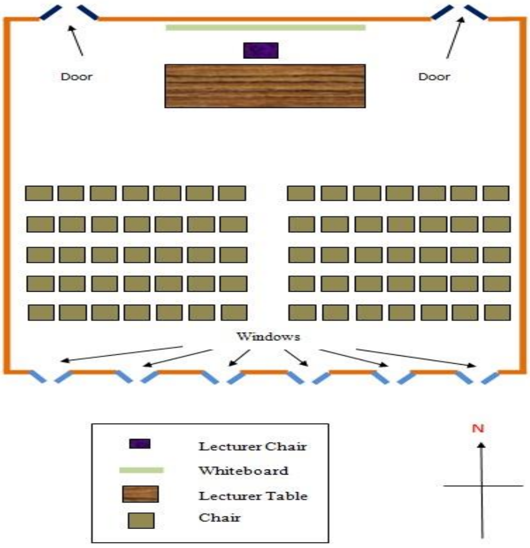

Fig. 1.The layout of the classroom and theatre hall.

B. The Measuring Instruments and Technique

The sound measurement and its features play a significant role in the development of a systematic approach to noise estimation to check whether the theory established was accurate and applicable. The instrument used in this study comprises the sound level meter (SLM), Sound source and the calibrator.

The sound level meter is the primary apparatus utilized for field sound measurement. The sound meter employed is of Model 1358 with a microphone Model 4155 manufactured by Bruel & Kajaer. Also attached to the sound level meter is the 1/1 – 1/3 octave filter set Type 1625, which was used for the frequency band analysis. In this study, five different frequencies of the sound bands were applied. All the measurements made are on the weighted level.

C. The Measuring Technique

The sound level meter was calibrated before and after the measurement and was taken to ensure the accuracy of the measurement. Therefore, a calibrator type 4231 of 94 dB SPL in the 1000 Hertz frequency was used to calibrate the sound level meter [17].

The calibration is done by attaching the calibrator to the microphone and the sound power level measured should be 94 dB in the 1000 Hertz frequency band. If calibration is not performed beforehand the k-factor of the sound level meter should be adjusted until it read 94 dB in 1000 Hertz frequency band.The device is placed to a level of 0.75 m above the ground when the sound measurement is engaged from 5 different sitting positions. Furthermore, it has to ensured that there is no other source of noise other than the noise from the standard speaker device. When measuring the sound level in a room with the air conditioning unit on, and when the sound level meter placed near to the air conditioning unit, a windscreen is also attached to the microphone to avoid measuring the sound generated by the air velocity. However, the windscreen has sound attenuations of 0.3 dB.

D. Statistical Analysis Method

This method encompassed data collection and information obtained using the direct measurement method discussed in the previous section. Then statistical analysis was first conducted to compare the mean of all results of direct measurements to verify the difference using (T-Test) for both room designs (theatre hall and classroom). The second was to correlate the reverberation time which defines the speech intelligibility with a sound pressure level in a room in order to obtain the statistical model that can satisfy the condition of parameters. The statistical analysis was carried out using the statistical package for Social Science (SPSS) version 21.0 software.

In this method, the statistical models were obtained through the linear regression analysis and equations. These equations were used as a design tool to estimate the noise level in a particular space with varied conditions of occupancy. These equations will save a lot of manual calculation time in estimating the noise level in the room.

III. RESULT AND DISCUSSION

A. Reverberation Time

Figure 2 and Figure 3 illustrate the average of the above 10 samples which are five theatre halls (Group-A) and an average of five poor classrooms (Group-B) were taken in each frequency band and the average reverberation time for each frequency band when occupied and unoccupied was deduced. The result of comparisons between the average measured reverberation times for five theatre halls (Group-A) and five poor classrooms (Group-B) when occupied and unoccupied are depicted in Figure 2 and Figure 3. The ‘good’ classrooms when occupied typically had a mid-frequency (average of 500 Hz & 1 kHz) reverberation time (RT) of 0.42 seconds, with the exception of one room, which was a permanent classroom (acoustically hard). This classroom had a mid-frequency RT of 0.48 seconds. The mid-frequency reverberation time in the “poor rooms” ranged from 0.53 to 0.63 seconds, with an average value of 0.58 seconds which exceed the optimum reverberation time. While when unoccupied noted that the ‘good’ classrooms typically had a mid-frequency (average of 500 Hz & 1 kHz) reverberation time (RT) of 0.47 seconds. The mid-frequency reverberation time in the “poor rooms” ranged from 0.59 to 0.67 seconds, with an average value of 0.63 seconds.

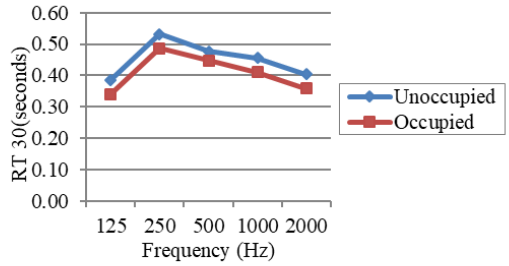

Fig. 2.Average Reverberation time measurements (RT30) for - Group A

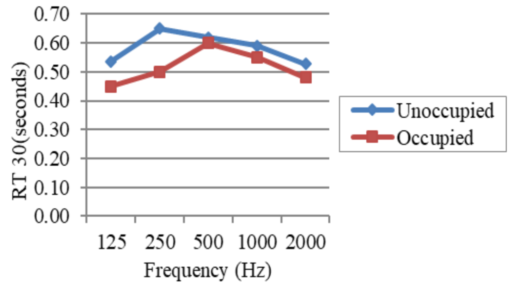

Fig. 3.Average Reverberation time measurements (RT30) for - Group B

B. Noise level (SPL)

When speech is uttered by the speaker, the acoustical energy is spread all over an increasingly massive area and the average decibel level decreases. To a first approximation, this effect follows the 6 dB rule and called Speaker-to-listener distance (SLD). This means that the average speech level falls by 6 dB for every doubling of distance from the source as indicated in Figure 5 which shows that there is a good agreement with the above rule for theatre hall that has acceptable noise level and good signal to noise ratio for most position from O to E.

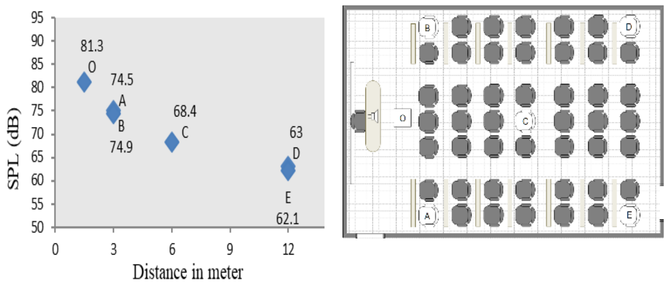

Fig. 4.The measured sound pressure level for theatre halls in different positions

The critical distance is defined as the distance at which the levels of the direct and reverberant sound are equal. At distances less than one-third of the critical distance, the direct sound is 10 dB or stronger than the reverberant sound as found in the normal classrooms that showed high noise levels and poor signal-to-noise (S/N) ratios as indicated in Figure 6 below. For normal classrooms, it shows the sound pressure level in different sitting position, it's obvious from the data measured that there is a great discrepancy between the sound pressure level and the rule of 6 dB of (SLD)for each doubling of distance, as shown in Figure 6, where the total sound level as a function of distance for normal classrooms. In these rooms, most of the listeners are receiving a mixture of direct and reverberant speech.

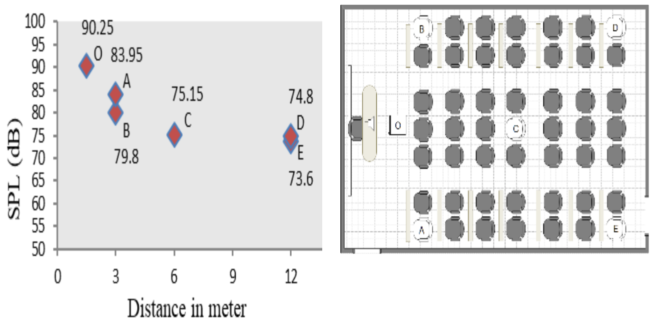

Fig. 5.The measured sound pressure level for normal classrooms in different positions

C. Background Noise Level

The background noise was assessed in the rooms using a sound level meter, B&K type 1358. Possible noise sources contributing to the recorded levels include the ventilation systems, traffic, and the activity in the neighboring areas. -All the measured background noise levels for theatre halls were below 45 dB in all conditions as shown in Figure 6 in accordance with recommended criteria for steady background sound in this building the produced voice levels were not affected by the background noise.

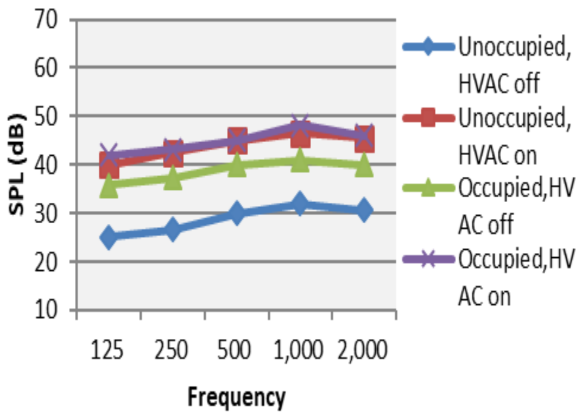

Fig. 6.The average background noise level for theatre halls in different conditions

The unoccupied background noise level was utilized as a benchmark to measure and this is important for rooms that have constant background noise from ventilation or A/C. For rooms when occupied and HVAC on, it was noted that high background noise levels from air-conditioning/mechanical ventilation were the main problem. This is a critical element in room design as the speaker's voice needs to be clearly heard above the background noise. This will assist with not only the speech intelligibility but also prevent undue strain to the speakers and minimize distraction.

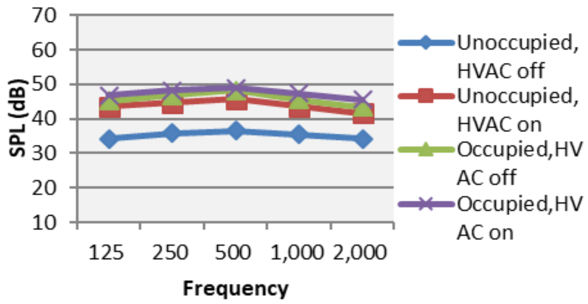

Fig. 7.The average background noise level for theatre halls in different conditions

The carpeted theatre halls typically have lower levels of reverberation than many normal classrooms, surrounding areas in block G3 building. This is due to improper shielding between classes for normal classrooms compared to theatre halls. The results of the average background noise level vs. frequency in four different conditions for normal classrooms are shown in Figure 7.

D. Establishing A Statistical Model

Using the method discussed in previous section, a statistical model can be developed by means of correlation the appropriate parameters in order to produce a linear equation that predict or estimate the reverberation time in a particular space in four different conditions, which were when occupied, unoccupied, with and without air-condition using the SPSS version 20.0 software.

- **Correlation Analysis**

The correlation analysis was conducted to check the level of dependency or correlation among the parameters stated to measure the reverberation time. Since different frequency bands have different variables, the analysis was conducted for the 5 different frequency bands.

To summarize, the parameter sound pressure level (SPL) had a strong negative linear relationship with the reverberation time (RT60) for all model 1 and model 2. This means that the higher the sound pressure level, the higher the reverberation time. While for model 3 and model 4, the sound pressure level has a significant correlation with reverberation time only in the 125Hz, 250Hz, and 500Hz. In conclusion, the reverberation time in a room depends on many factors, including those that were not mentioned above like the volume, the room construction and furniture, layout, level of occupancy and many more factors that were difficult to be determined. These parameters may correlate to the reverberation time but the relationship may not be linear.

- **Linear Regression Analysis**

Linear regression analysis was performed to obtain the statistical model to predict the RT60 in a particular space in four different conditions, which were when occupied, unoccupied, with and without air-conditioning. The statistical models derived in the form of equation correlating the reverberation time with the sound pressure level (SPL). The statistical models obtained were shown in Table 2.

Table- II: Statistical model obtained from the linear regression analysis

F (Hz)	Measured Reverberation Time (RT60)	R^2
125	Predicted RT60 = -1.139 + 0.028 SPL	0.608
250	Predicted RT60 = - 0.0191+0.011 SPL	0.884
500	Predicted RT60 = - 0.325+0.011 SPL	0.949
1000	Predicted RT60 = - 1.204+0.023 SPL	0.900
2000	Predicted RT60 = - 1.236+0.0255 SPL	0.784

E. Relationship between the Measured and Predicted Reverberation Time

Using the statistical models developed in the linear regression analysis, the predicted reverberation time can be computed by referring to noise level (SPL) as specified in the noise criteria NC for the learning environment. The summary of the results of comparisons between the measured reverberation time and the predicted reverberation time was shown in Table 3.

Table- II: Comparisons between measured RT and predicted RT

	Frequency				
	125	250	500	1000	2000
Mean (%)	23.24	7.97	11.36	12.95	11.16
Median (%)	23.5	6.25	11.23	12.05	8.57
Std.Deviation(%)	8.15	4.62	3.19	3.0734	6.78
Skewness	0.136	1.106	1.885	1.663	1.276
Std. Error of Skewness	0.913	0.913	0.913	0.913	0.913
Minimum (%)	13.51	4.26	11.36	10.0	5.88
Maximum (%)	31.25	15.09	17.75	18.18	21.95

Referring to Table 4, the highest mean percentage of errors occurred in the 125Hz frequency with 23.24% and its median was at 23.5%. This error was relatively big compared to other frequencies, which were in a range of less than 13% in mean and less than 12% in the median. The high positive skewness in all the frequencies shows that most errors occurred were actually less than 2 %. the average median percentage of errors obtained was only 9.6%, which was acceptable. In conclusion, the statistical model obtained from the linear regression analysis was quite accurate and can be used for predicting the reverberation time which defines the speech intelligibility in a particular room. These results also indicate that the sound pressure level used in the linear regression analysis has a linear relationship with the reverberation time.

Comparison between the two sets of reverberation time in a particular space, it was possible to visualize how they deviate from each other. Figure 9 shows the mean values of measured and predicted reverberation time plotted against the five frequency bands. As seen in Figure 8, the predicted reverberation time is very close to the measured reverberation time. The predicted reverberation time can be used to evaluate the acoustic characteristics of a particular room.

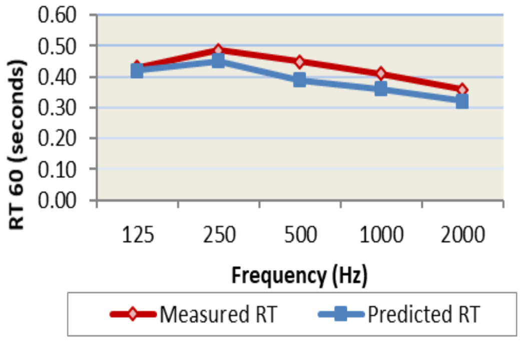

Fig. 8.Comparisons between the measured and predicted reverberation time

IV. CONCLUSION

The present paper has measured and provided a reference set for noise level and reverberation time values under various room acoustic conditions, which are important parameters to assess the vocal effort required for speech in a room in terms of speech intelligibility for both theatre hall and normal classrooms in any building.

From the result obtained, it can be concluded that the statistical model established was quite accurate in estimating the reverberation time in a particular space. The reverberation time in a room depends on many factors, including those like the volume, the room construction and furniture, layout, level of occupancy and many more were rather unknown as it is difficult to determine their relationship with the reverberation time. And these factors may correlate to the reverberation time but the relationship may not be linear. The statistical model established showed that the sound pressure level has a strong relationship with the reverberation time and has been considered to predict the reverberation time.

Regarding the result obtained from the survey, we summarize that the teaching experience seemed to be an important factor in the interaction with the acoustics of classrooms. It may seem reasonable that teachers learn from their own experience to adjust their voices according to the acoustics of the classrooms. Therefore, we take into account that teachers are one of the professional groups with the highest risk of suffering from voice disorders. Among the causes, they claim classroom acoustics, and not only background noise, to be one of the potential hazards affecting their vocal health.

The investigation that was carried out on the acoustic properties of university classrooms, the results obtained were in good agreement with the results obtained from the survey. It's obvious that university theatre halls are having the best acoustic provision through the shape with which the ceiling and the walls were constructed. Moreover, it should be noted that the acoustic management of a building is to be taken into consideration before the implementation of the project since it is so costly to amend the construction after the building has been completed. If we discover that the acoustic effect of a

building is not up to an appreciable level, the wall surface may be acoustically treated with sound-absorbing materials.

SUMMARY OF THE STUDY

From the result we obtained, it can be concluded that big reverberation time (RT) is the "common cold" of bad classroom acoustics. And the noise level in the particular space, as well as the background noise level, depends on many factors, ranging from directly noise transmission from the air conditioning unit to the construction of the room itself. Some of the factors are rather unknown as it is difficult to determine their relationship with the acoustic properties and it was found that the air conditioning systems were producing excessive noise, resulting in some of the rooms with the high sound level exceeding the permissible value compared to the assigned NC. The obvious implication of the foregoing is that the effective speech-to-noise ratio in classrooms must be high if the occupants are to have adequate access to acoustic information in the speech of teachers and classmates. In other words, the combination of direct speech and the early components of reverberation should be high in relation to the combination of noise and the late component of reverberation. Nonetheless, recommendations to reduce RT might include the two ways in a normal classroom: either the volume must be decreased or the sound absorption must be increased. Increasing the absorption in a room is accomplished by adding more "soft" materials such as fabric faced glass fiber wall panels, carpet, or acoustical ceiling tiles. Simply including a sound-absorbing lay-in ceiling and thin carpet on the floor can usually result in good classroom acoustics and low reverberation time. The carpet adds some high-frequency absorption, but primarily serves to reduce self-noise from the students. The solution is inexpensive for new construction and is also an affordable way to renovate existing classrooms.

Lecture halls should be designed according to the latest knowledge concerning acoustical requirements. This can be accomplished with reasonable constructive and instrumental expenditure. In the case of renovations, for various reasons, the room acoustics of lecture halls often do not meet the requirements. The reverberation time for normal classrooms is much too long. The sound system must then be especially carefully designed. For most of the seats fairly good speech intelligibility can be achieved. However, if the acoustical design of the room is poor then today's requirements for speech intelligibility often cannot be met for all positions of the seat, even with a very sound good system.

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AUTHORS PROFILE

Mohammed Ogab, PhD Candidate, Department of Energy and Thermofluid Engineering, Faculty of Mechanical and Manufacturing Engineering, Universtity Tun Hussein Onn Malaysia (UTHM), Johor, Malaysia.

Siti Noor Asyikin Mohd Razali, Senior Lecturer, Department of Mathematics and Statistics, Faculty of Applied Sciences and Technology, University Tun Hussein Onn Malaysia (UTHM), Pagoh Education Hub, Johor, Malaysia

DJAMAL HISSEIN DIDANE, Lecturer, Department of Energy and Thermofluid Engineering, Faculty of Mechanical and Manufacturing Engineering, Universtity Tun Hussein Onn Malaysia (UTHM), Johor, Malaysia.

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