SCADM: A Developed Smart Classroom Acoustics Design Model for Enhancing Educational Environment

Abdul Hamid M. Ragab, Amin Y. Noaman, Ayman I. Madbouly

Faculty of Computing and Information Technology,
King Abdulaziz University,
P.O.Box. 80221, Jeddah 21589,
Kingdom of Saudi Arabia
aragab@kau.edu.sa

Abstract. The quality and efficiency of learning and teaching processes in academic universities depend on many important factors. Acoustic quality within the learning environment of the classroom and its surroundings is one of the most important factors that affect the quality of the learning process. Several studies and researches focused on the subject of acoustical comfort in university classrooms. In this paper we study smart classroom acoustics design issues required to achieve high quality acoustics conditions. These designing issues include inside and outside noise sources, designing for optimum reverberation time, selection of sound insulation and acoustical treatment materials, designing for speech intelligibility, and auralization inside the KAU classrooms. The aim is to suggest a developed smart classroom acoustics design model (SCADM) that can be used by architects, acoustics engineers and designers in an early stage of classroom design in order to achieve the acoustical conditions of KAU university classrooms. The goal of this research is to raise the quality and efficiency of the educational environment to reach an excellent learning environment, and hence increasing students learning outcomes.

Keywords: Smart classroom, education quality, Students learning outcomes, acoustical comfort in university classrooms.
1. Introduction

Formal education is conducted in classrooms, in which there is an intensive amount of verbal communication between students and teachers and among students themselves during this learning process. The existence of high levels noise in the classroom will affect the learning and teaching environment for both students and teachers, and will make students tired prematurely. This may result in consuming students' cognitive abilities that could be better employed to understand and pay more attention to the content of their classes. Building classroom with good acoustics is one of the important considerations while designing new classrooms. Decades of research have been devoted by architects, audiologists, acousticians, and speech language pathologists to document the educational value of acoustics quality and the detrimental effect of bad acoustics design on students’ learning and achievements.

Smart classrooms are technology based enhanced classrooms. Smart classrooms provide the opportunity to integrate new learning technologies to enhance the learning process for both teachers and students. Applying new technologies in learning help students to actively learn and inspire them to use technologies for learning throughout their lives. Smart classrooms present the learning environment with equipment such as interactive smart board, data projector, audio amplification system, media and video, smart tables, computers, document camera, and VCR/DVD players. Existence of such devices inside smart classroom increases the overall background noise (BN) by 6 to 10 dBA\textsuperscript{[1]}.

Many research studies have been carried out to highlight the importance of having good acoustic design conditions to achieve good sound intelligibility inside classrooms. Acoustical measures of classrooms, such as speech intelligibility\textsuperscript{[2]}, background noise levels\textsuperscript{[3,4]}, early decay times\textsuperscript{[5]}, reverberation times\textsuperscript{[6]}, as well as various early/late sound ratios have been the focus of these studies.\textsuperscript{[7]}

In this paper, interrelationships of these measures will be considered to evaluate the appropriate design model of smart classrooms. The suggested smart classroom acoustics design model can be used by architects, acoustics engineers and designers in an early stage of classroom design in order to achieve the optimal acoustical conditions of KAU university classrooms.
2. Literature Review

With the evolution of modern era, there were many aspects that affect the acoustic performance inside the classroom environment. In the past, the environment in the classrooms were pleasant, quiet, and enjoyable. Today, modern classrooms become more reverberant and have more noise. Such acoustic problems were existed because of the insufficient awareness and the shortage of perception of the problem on the part of the professionals involved. Although there is no lack of resources or funds, they had lack of solutions to such problems \[1\]. It showed that the best way to solve such problems is to avoid them in the design phase. Many researches proved negative impacts and effects of noise, the lack of clarity of talk, and the lack of speech intelligibility not only on the efficiency of learning and the quality of teaching but also on the well-being of students and teachers. Students are impaired by background noise and teachers suffer from raising their voice level to compensate for the high level of background noise and increase the signal to noise ratio (SNR) \[8, 9\]. On the other hand, if the classroom acoustics were well designed and the acoustical properties inside the classroom were improved, this will result in an improvement on learning and students' behavior, and these results are registered in numerous studies \[10, 11\].

Wróblewska et al.\[12\] studied the influence of acoustical adaptation on classroom's acoustical environment; they showed that acoustical adaptation in the classroom changed the values of acoustical parameters into the desired range. They showed that not only the amount of absorption plays a role, but also its placement is essential.

Dockrell and Shield\[13\], studied the effects of using sound field systems (SFS) in classrooms. They found that small and subtle effects could be noticed when SFS is used. Their study showed that using SFS in classrooms improved the speech to noise ratio (SNR) and caused a gain in the spoken comprehension measure. However, further studies are required to substantiate this effect, especially in poorly acoustics classrooms. They suggested that further work and studies for classroom acoustical parameters are needed to be considered as an additional variable while measuring the benefits of using SFS in classrooms.

In a study done by Rand\[14\], for the Heating, Ventilation, and Air Conditioning (HVAC) systems and classroom acoustics, they showed
that installation cost will not greatly increase if the acoustical standard is met by using standard HVAC equipment. They also mentioned that to meet the requirements, we need to do good design, selection and application practice as follow\[^{[14]}\]:

- Make sure that accurate sound power level (SPL) is obtained. This will help to reduce the need of a large factor of safety in the design.
- Predict classroom sound levels and make sure that adequate attenuation is achieved by performing the required acoustical analysis.
- Find good places to locate the equipment away from the classroom. A good place is in or above less critical places such as utility areas, corridors, or mechanical rooms.
- Appraise the trade-off between performing path attenuation and buying quieter equipment.
- Minimize regenerated noise by lowering the airflow velocity in the ductwork.
- Make sure that you follow the manufacturer’s design recommendations while designing and installing diffuser.

The subject of acoustical comfort (ambient noise, sound insulation, reverberation time, speech intelligibility, auralization, acoustical materials) in classrooms of primary and secondary schools, as well as in university classrooms has been the focus of several studies around the world \[^{[15–18]}\].

In all studies, the acoustic quality of the classrooms were analyzed based on measurements of the sound pressure level inside and outside the classrooms, the reverberation time, and sound insulation inside the classroom.

Zannin and Zwirtes\[^{[17]}\] evaluated the acoustic performance of classrooms in public schools. The acoustics quality of classrooms of three constructive designs has been evaluated. They analyzed the quality based on measurements of the reverberation time, sound pressure level inside and outside the classrooms, and sound insulation. Results revealed design errors in all the schools of this study which caused poor acoustical quality of the surveyed classrooms, for all three constructive designs studied. These errors involved both the architectural design and the materials used in the interior finish of the schools. They showed that the
surveyed designs do not meet the guidelines of either the Brazilian Standards or the International Standards employed as references.

Measurement of reverberation time and sound insulation usually follows the international Standards ISO 140-4, ISO 140-5, ISO 717-1, and ISO 3382. Also, the American National Standards Institute (ANSI) approved ANSI Standard S12.60 for Classroom Acoustics [18], titled “Acoustical Performance Criteria, Design Requirements, and Guidelines for Schools,” is widely used in such cases. This standard presents an enhanced learning environment for students and teachers alike by improving the classroom acoustics design conditions for good speech intelligibility. In our research, results (sound insulation and reverberation time) will be compared with reference values found in the ANSI Standards S12.60.

3. Noise Effect of Smart Classroom

In all researches, studying and analyzing the acoustic quality of the conventional classrooms depends on measuring the sound pressure levels inside and outside the classroom. Also, it depends on measuring the reverberation time, and sound insulation used inside the classroom. Usually, the international Standards ISO 140-4, ISO 140-5, ISO 717-1, and ISO 3382, are commonly used while measuring the reverberation time and sound insulation inside classrooms. Also, the American National Standards Institute (ANSI) has approved ANSI Standard S12.60-2002 for acoustical features of learning places and design requirements for classroom acoustics.

Thomas[19] has defined smart classroom as “an interactive multimedia electronic classroom networked to the Internet and housing a video/audio, and broadcast on demand system”. Smart classrooms equipped with interconnected computers for each student, allow for interactive and collaborative learning. Smart classrooms present collaborative and interactive learning environment equipped by new technology devices and equipment such as interactive electronic smart board, instructor's lectern equipped with data projector, audio amplification system, media and video projector, smart tables, networked computers, document camera, VCR/DVD player. The existence of such
additional components inside smart classrooms makes them different from conventional classrooms. The existence of such equipment increases the noise level inside smart classroom and this effect must be taken into consideration while designing a new classroom or make acoustical treatment for an existing classroom.

In the proposed model; explained in section V; different layouts of KAU smart classrooms will be investigated. Since, ANSI standard (ANSI S12.60-2002) doesn't include the effect of smart classroom instructional equipment, it is important to study this to see how this will affect the learning process.

4. Importance of the Study

Speech intelligibility usually degrades with the existence of excessive noise and reverberation inside classrooms. This degradation of speech intelligibility will result in reducing students' understanding and hence reduces students' learning and teaching quality. Speech intelligibility tests usually measure the percentage of words that a listeners with normal hearing can correctly understand from a list of spoken words. A speech intelligibility rating of 75% means that listeners with normal hearing could understand only 75% of the words read from a list [2, 20].

Although the need of good acoustically designed classrooms and the way to achieve this have been known for decades, unfortunately this information was not available for architects and planners engineers, as well as for administrators and decision makers. While solutions are not
prohibitively expensive the classroom acoustics problems seem to be endemic. Actually, the reason was the shortage of understanding of the problem and its solutions not the insufficient funds. The cost spent on school buildings nationwide was $7.9 billion\textsuperscript{[20]}. Good acoustic performance and listening conditions could be achieved with only a fraction of this amount if we take classroom acoustics design into considerations.

To achieve this, architects and planners should consider the classroom acoustics from the beginning of the design process. The optimum solution of many acoustics problems could be prevented beforehand not after it happened. Acoustics problems can be avoided during the design phase with low cost and by using different design arrangements of the same building materials. This is much better than renovation of a poorly designed classroom which may be more expensive.

Our research aimed to study and propose a developed classroom acoustics design software model of the acoustics characteristics of KAU existing classrooms and to suggest design recommendations to optimize the classroom acoustics of new KAU classrooms. The suggested model can be used by architects, acoustics engineers and designers in an early stage of classroom designs to evaluate the acoustical conditions of university classrooms. The study is suggested after complaints relating to the acoustics properties of the existing classrooms, since building classroom with good acoustics has to be one of the important design considerations for new classrooms.

5. Proposed Design Model (SCADM)

In this paper we propose different classroom's layout models that could be adequate for smart classrooms. In our model we considered the number of students in the classroom as a design factor. As shown in the proposed models below in Figure.1 (a, b) the number of students inside the classroom depends on the classroom dimensions. Researches\textsuperscript{[21, 22]} showed that the lower middle range for social distance as a mean for calculating minimum size of the classroom is 7 feet ($\approx 2.13$ m). However, for smart classrooms this distance is large. Practically, we found that a distance of (1.4 m) is adequate and gives reasonable classroom dimensions for large and small groups of students. As shown in Figure 1a, the dimensions of the classroom can be calculated by the following
equations that relate classroom dimensions with the number of students and hence the number of computers inside the classroom:

\[
L \text{ (Length)} = D \times \left[ \frac{N}{G} - 1 + R \right] \\
W \text{ (Width)} = D \times \left[ \frac{N}{G} + 1 \right]
\]

where:

- \( N \equiv \) Number of students
- \( G \equiv \) Number of groups of computers
- \( D \equiv \) Recommended Social Distance (\( \approx 1.4 \) m)
- \( R \equiv \) Difference between the numbers of computers in length and width.

Figure 1 (b) shows a different classroom layout with the same dimensions but with an increased number of students by \((N/G - 1) \times 3\). Of course, different classroom layouts could be arranged. However, there are other factors that may affect the maximum number of students inside classroom. First of these factors is the room length, since speaker's visual gestures can greatly improve the recognition of what he/she is saying. Benefit of this is not easily quantifiable but generally it is thought that the maximum distance from instructor to student should not be more than 20 m \([23]\). This is the maximum distance at which student can identify these visual prompts, and to also ensure that a good amount of direct sound level could be received by students. Second factor is the room volume; the ideal room volume per seat for classroom is "volume / seat 2 – 5 m\(^3\)."

In our previous research \([24]\) we have developed a classroom acoustic assessment model in which we found that noise sources inside the classroom ranked with 23% along other criteria that affect the learning quality. Smart classroom equipment was also identified as common source of noise generated within new classrooms with an importance level of 20%. And this represents a ratio of 4.6% weight related to the whole model of criteria that affect the learning process and its quality. These results showed that how noise emitted from smart classroom equipment could affect the enhancement of learning quality and how this noise source could reduce the speech intelligibility inside smart classrooms.

Adding more computers means adding more noise sources. It's known that by adding or combining levels of 'n' equal loud sound sources the total sound level will increase. The total level in dB is the level of one
sound source plus the increase of sound level in dB\textsuperscript{[25]}, as indicated in table 1. The total sound level is calculated using the following equation:

\[ L_\Sigma = \Delta L + L_1 = 10 \times \log_{10}(n) + L_1 \]

where,
- \( L_\Sigma \): total sound level
- \( \Delta L \): Level increase \( \Delta L \) for 'n' equal loud sound sources
- \( n \): number of equal loud sound sources
- \( L_1 \): level of one sound source

Figure 2 shows the relation between the number of equal loud incoherent sound sources "\( n \)" and the sound level difference \( \Delta L \). As shown in Figure 2, the sound level increases as the number of sources increases.

![Fig. 2. Relation between number of equal loud sources 'n' and the sound level difference \([19]\)](image)

<table>
<thead>
<tr>
<th>Number of 'n' equal loud sound sources</th>
<th>Level increase ( \Delta L ) in dB</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>3.0</td>
</tr>
<tr>
<td>3</td>
<td>4.8</td>
</tr>
<tr>
<td>4</td>
<td>6.0</td>
</tr>
<tr>
<td>5</td>
<td>7.0</td>
</tr>
<tr>
<td>6</td>
<td>7.8</td>
</tr>
<tr>
<td>7</td>
<td>8.5</td>
</tr>
<tr>
<td>8</td>
<td>9.0</td>
</tr>
<tr>
<td>9</td>
<td>9.5</td>
</tr>
<tr>
<td>10</td>
<td>10.0</td>
</tr>
<tr>
<td>12</td>
<td>10.8</td>
</tr>
<tr>
<td>16</td>
<td>12.0</td>
</tr>
<tr>
<td>20</td>
<td>13.0</td>
</tr>
</tbody>
</table>
6. Research Methodology

Our research investigations will be conducted in listening environments at KAU smart classroom models to identify good and poor classroom models. This will be investigated in details using the following methods:

- Speech perception tests in live and simulated background noise in classrooms
- Classroom noise levels daylong recordings [A-weighted Sound Level].
- Acoustical measurements of classroom acoustic parameters [Clarity, Signal to Noise Ratio (SNR), Reverberation Time (RT)].
- Applying some acoustical modifications/treatments to the classrooms that were identified by teachers as being poor acoustically (The addition of acoustic ceiling tiles and repeating the detailed measurements).
- Proposing a developed smart classroom acoustics design model that can be used by architects, acoustics engineers and designers in an early stage of classroom designs.

7. Classroom Acoustic Design Considerations and Standards

To design a classroom with optimum acoustical characteristics for a learning process, it is essential that both architectural and mechanical design should comply with the existing design standards and many important factors and considerations must be achieved. With the existence of excessive reverberation time or background noise in classrooms causing interference with speech communication and thus an acoustical impediment to learning will be present. In this section we present the acceptable standard level of reverberation time and the A-weighted and C-weighted sound level inside classrooms, see Table 2. Also, some considerations and guidelines that are intended to assist in achieving conformance to the reverberation time criteria and an acceptable noise level inside classrooms will be introduced.
Table 2. Limits on A- and C-weighted sound levels of background noise and reverberation time.

<table>
<thead>
<tr>
<th>Learning space</th>
<th>Greatest one-hour average A- and C-weighted sound level of exterior source background noise (dB)</th>
<th>Greatest one-hour average A- and C-weighted sound level of interior source background noise (dB)</th>
<th>Maximum permitted reverberation times for sound pressure levels in octave bands with mid-band frequencies of 500, 1000, and 2000 Hz (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Core learning space with enclosed volume ≤ 283 m³ (≤ 10 000 ft³)</td>
<td>35 / 55</td>
<td>35 / 55</td>
<td>0.6 s</td>
</tr>
<tr>
<td>Core learning space with enclosed volume &gt; 283 m³ and ≤ 566 m³ (&gt; 10 000 ft³ and ≤ 20 000 ft³)</td>
<td>35 / 55</td>
<td>35 / 55</td>
<td>0.7 s</td>
</tr>
<tr>
<td>Core learning spaces with enclosed volumes &gt; 566 m³ (&gt; 20 000 ft³) and all ancillary learning spaces</td>
<td>40 / 60</td>
<td>40 / 60</td>
<td>No requirement</td>
</tr>
</tbody>
</table>

7.1 Classroom Reverberation Time

Reverberation time (RT60) is defined as the time required in seconds for sound to decay 60 decibels from its initial level after a source stops generating sound. It was used to define the optimum RT for an auditorium or room, which depends upon its intended use. According to ANSI standard, classrooms should have reverberation times in the range of (0.4-0.8) seconds, but many existing classrooms have reverberation times of 1 second or more. Figure 3 shows the suitable reverberation time for various room usages. As shown in Figure 3, classrooms need a
shorter reverberation time for speech to be understood more clearly. If
the reflected sound from one syllable is still heard when the next syllable
is spoken, it may be difficult to understand what was said [26].
[27] has developed an empirical reverberation time equation that relates the
value of the reverberation time in a room to the room's volume, and the
total sound absorption inside that room, as follows:

$$RT_{60} = \frac{4 \ln 10^6 V}{C Sa}$$

where,
C: the speed of sound in the room
V: the room's volume in m³
S: the total surface area of room in m²
a: is the average absorption coefficient of room surfaces
Sa: total absorption in sabins.

Fig. 3. Suitable RT (in seconds) for various rooms typically found in educational facilities [26].
It must be noted that:
- Total absorption and reverberation time can be changed based on the frequency defined by the acoustic properties of the space.
- The shape of the room and sound losses are not taken into account in equation [27]. It must be noted that this is important for large spaces.
- In lower frequency ranges the sound energy absorbed will be less, causing longer reverberation times at these lower frequencies.

In learning spaces, we can control the reverberation time value by using sound absorption materials. Selecting the place to add such absorbing materials and the area of materials used for treatment are important factor in controlling the reverberation time and hence in achieving optimum acoustical characteristics in classrooms and learning spaces [28].

Understanding of spoken words will be affected and reduced if there is an excessive reverberation inside the lecture room. On the other side, if there are too much sound absorbing treatment materials inside the classroom beneficial early sound reflections will reduce speech intelligibility for distant listeners as a result of the rapid fall off of the

Fig. 4. Optimum RT –vs.- Room volume for different room usages [28].
speech levels from a talker with distance. Figure 4 shows the optimum reverberation time of mid frequency (500 Hz) in seconds of different room usages verses room volume.

7.2 Discrete Echoes

Reflected sound causes a special problem called discrete echoes. We are familiar with the echo phenomenon that is hearing one's voice answer a second late after shouting into a canyon. This kind of echoes can also happen in rooms, albeit more quickly \[29\]. If a teacher's voice is continuously echoing off the back wall of a classroom, the lecture will be difficult to understand because of each echo will interfere with the next word.

7.3 Early Reflections & Late Reflections

Sound reflections inside classrooms are important to increase speech intelligibility; however reflections arrived later are not desirable \[29\]. Sound reflections that continue to reflect and bounce inside classroom and arrive to the listener after (0.05) seconds of arriving of the direct sound cause one word to blur into the next word. This degrades the speech intelligibility inside the classroom. So, to design good acoustics classroom these later-arriving reflections must be acoustically treated, to increase speech intelligibility and to prevent additional sources of noise inside the classroom. Early arriving reflections are added to the direct sound while arriving to our hearing system. These early-arriving sound reflections are considered useful because they make the voice louder and hence increase speech intelligibility \[30\]. So, to achieve optimum speech intelligibility, classrooms must be acoustically designed to increase the amount of direct and early-arriving reflections of the speech sound to the listener. At the same time, the classrooms must be acoustically designed to decrease the amount of later-arriving speech sound reflections and decrease the amount of ambient noise as possible.

The ratio of direct and early arriving speech energy to later-arriving speech energy and ambient noise has been called a useful-to-detrimental sound ratio. These ratios are related to speech intelligibility scores \[30\], as well as to other more complex measures such as the Speech Transmission Index (STI) and the simplified version of it, Rapid Speech Transmission Index (RASTI) \[31\].
7.4 Flutter Echo

Another type of echo could happen when two flat, hard surfaces are parallel or between floor and ceiling. In these cases the sound rapidly bounces back and forth between these parallel surfaces and creates a ringing effect echo. This echo will interfere with hearing and this phenomenon is called flutter echo that can be dealt with as explained in [32].

7.5 Location of the Absorbing Material

In cases where there is no fixed lecture position for the teacher, we need to consider the following two cases for ceiling height:

- When ceiling heights $\leq 3$ m (10 ft.) place most, if not all, of the sound-absorption treatment material on the ceiling. This is the best design option [33].
- When ceiling heights $\geq 3$ m (10 ft.); in such case we need to place an increased amount of sound-absorption material on the walls. If almost all of sound-absorbing materials are installed on the ceiling, then it is prudent to use furnishings like bookshelves of sufficient height to ensure that the sound waves traveling across the room are spread and scattered in the direction of the sound-absorbing ceiling.

7.6 Mounting of Acoustical Treatment in Classrooms

The airspaces behind the wall or above the ceiling acoustic treatments are usually specified by the architect. These airspaces have a minimum value that is specified by the manufacturers of these acoustic treatment materials. As long as the minimum airspace required for installing treatment materials exist, the actual sound absorption coefficient of these material should not be less than the published values at frequencies of 500 Hz and higher [34]. Wall-mounted treatment materials should be installed using glue or clips to the wall surface as manufacturer recommends, or these can be fastened to added spacers to achieve sound absorption coefficients stated.

7.7 Carpeting in Classrooms

Using carpets in classrooms can help significantly to reduce background noise levels from chair and foot impacts, and can also reduce impact noise transmitted to room below [36]. What must be noticed is that
carpets alone cannot provide the required sound absorption for classrooms especially at low frequencies since its absorption is generally poor at these frequencies.

7.8 Absorption of Furnishings and Occupants

When calculating classroom reverberation time, sound absorption coefficients of typical furnishings such as tables, desks, chairs, and storage cabinets must be included. Experiments comparing the reverberation for furnished and unfurnished classrooms showed that a sound absorption equal to 5% of the floor area is a conservative approximation for the sound absorption of these furnishings [18]. The sound absorption of an occupant is approximately equal to 0.55 m² (6.0 ft²) for university students [32]. We should not include sound absorption of learning-space occupants again in any calculations because sound absorption of the occupants inside classrooms was already considered in the reverberation time values showed in Table 2 above.

7.9 Classroom Ambient Noise Levels

Classrooms are usually designed for speech communication. Unfortunately, classrooms are often not designed to optimally support this intended use. Ignoring acoustical design issues from the beginning will result in inaccurate speech communication. The cost of acoustical treatment needed after that will exceed the cost of doing the required optimal acoustical classroom design from the beginning. And of course, classrooms with poor acoustical designs will affect the learning process and the educational development.

Speech intelligibility in classrooms extensively degrades if there is an excessive ambient noise level and inadequate room acoustics design [24]. Usually listeners can guess correct spoken words in noisy environment without difficulty because of their quite remarkable abilities to guess. However, when the noise stops, a great difference in communication situation is noticed. Listeners with hearing impairment will face more difficulty in communicating in improbably acoustically designed places that have excessive noise. Table 3 shows the value of optimum reverberation times along with the maximum ambient noise levels to obtain optimum speech intelligibility conditions inside different classrooms. The louder the speech signals, compared to the level of interfering noise, i.e. high signal to noise ratio, the more intelligible the speech will be. Important sources of noise in classroom spaces are
heating, ventilating and air conditioning (HVAC) equipment. In smart classrooms, projectors and computer devices are another source of noise. Students inside classroom themselves, also add unwanted noise that will interfere with spoken words and hence decreases the ability to understand speech.

8. Evaluating Measuring and Classroom Noise

Usually we measure Sound Pressure Level (SPL) for the octave band which gives us a noise spectrum. This noise spectrum is used to obtain Noise Criterion (NC), common used in U.S., or Noise Rating (NR), commonly used in Europe, by plotting the measured octave band levels on a set of NC or NR curves.

8.1 Noise Criterion – NC

NC is a single numerical index commonly used to define design goals for the maximum allowable background noise in a given space. It was established in United States to rate indoor noise, heating, ventilating and air conditioning noise. The NC criteria curves consist of a family of curves that define the maximum allowable octave-band sound pressure level corresponding to a chosen NC design goal [32]. As an example, a private office space would require a lower NC rating than a lobby area. NC curves extend from 63Hz to 8000 Hz to define the limits of octave band spectra, must not be exceeded to achieve the acceptance level of certain space, as shown in Figure 5. The measured noise spectrum is plotted to represent the measured NC curve, the lowest NC curve which is not exceeded by the measured NC, is the NC rating of this measure.

Table 3. Maximum ambient noise levels and optimum reverberation times (RT) for good speech intelligibility [18].

<table>
<thead>
<tr>
<th>Example Situations</th>
<th>Maximum noise</th>
<th>RT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary school classroom</td>
<td>30 dB(A)</td>
<td>0.5</td>
</tr>
<tr>
<td>Boardroom for elderly adults</td>
<td>23 NC</td>
<td></td>
</tr>
<tr>
<td>High school classroom</td>
<td>35 dB(A)</td>
<td>0.7</td>
</tr>
<tr>
<td>General meeting room</td>
<td>28 NC</td>
<td></td>
</tr>
<tr>
<td>Large lecture hall theatre</td>
<td>30 dB(A)</td>
<td>0.7</td>
</tr>
</tbody>
</table>
8.2 Recommended NC For Classrooms

Recommended NC levels for different KAU room/space types should not exceed the NC limits listed in Table 4.

Table 4. Recommended NC levels for different KAU room/space types [32].

<table>
<thead>
<tr>
<th>Type of Room - Space Type</th>
<th>Recommended NC Level NC Curve</th>
<th>Equivalent Sound Level (dBA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lecture and classrooms</td>
<td>25-30</td>
<td>35-40</td>
</tr>
<tr>
<td>Open-plan classrooms</td>
<td>35-40</td>
<td>45-50</td>
</tr>
<tr>
<td>Movie motion picture theaters</td>
<td>30-35</td>
<td>40-45</td>
</tr>
<tr>
<td>Libraries</td>
<td>35-40</td>
<td>40-50</td>
</tr>
<tr>
<td>Legitimate theaters</td>
<td>20-25</td>
<td>30-65</td>
</tr>
<tr>
<td>Private Residences</td>
<td>25-35</td>
<td>35-45</td>
</tr>
<tr>
<td>Restaurants</td>
<td>40-45</td>
<td>50-55</td>
</tr>
<tr>
<td>TV Broadcast studies</td>
<td>15-25</td>
<td>25-35</td>
</tr>
<tr>
<td>Recording Studios</td>
<td>15-20</td>
<td>25-30</td>
</tr>
<tr>
<td>Concert and recital halls</td>
<td>15-20</td>
<td>25-30</td>
</tr>
<tr>
<td>Sport Coliseums</td>
<td>45-55</td>
<td>55-65</td>
</tr>
<tr>
<td>Sound broadcasting</td>
<td>15-20</td>
<td>25-30</td>
</tr>
</tbody>
</table>

8.3 Noise Rating (NR)

Noise level can also be measured using Noise Rating (NR) set of curves developed by the International Organization for Standardization
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These curves are used to find the acceptable indoor environment for hearing preservation, speech communication and annoyance. In Europe it is common to use the NR. Unlike NC curves, different NR curves are obtained for each room type usage(s). Each curve has an NR number that represents the acceptable sound pressure level based on the room usage. Figure 6 shows NR curves for different sound pressure levels plotted over the octave band spectra [27].

![NR curves](image)

Fig. 6. Noise rating curves for different sound pressure levels plotted over the octave band spectra [27].

8.4 **Recommended Noise Rating Levels**

Noise rating levels for different room/space usages must not exceed the NR values defined in Table 5.

<table>
<thead>
<tr>
<th>Noise rating curve</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>NR 25</td>
<td>Concert halls, broadcasting and recording studios, churches</td>
</tr>
<tr>
<td>NR 30</td>
<td>Private dwellings, hospitals, theatres, cinemas, <strong>conference rooms</strong></td>
</tr>
<tr>
<td>NR 35</td>
<td>Libraries, museums, court rooms, <strong>schools</strong>, hospitals operating theaters and wards, flats, hotels, executive offices</td>
</tr>
<tr>
<td>NR 40</td>
<td>Halls, corridors, cloakrooms, restaurants, night clubs, <strong>offices</strong>, shops</td>
</tr>
<tr>
<td>NR 45</td>
<td>Department stores, supermarkets, canteens, general offices</td>
</tr>
<tr>
<td>NR 50</td>
<td>Typing pools, offices with business machines</td>
</tr>
<tr>
<td>NR 60</td>
<td>Light engineering works</td>
</tr>
<tr>
<td>NR 70</td>
<td>Foundries, heavy engineering works</td>
</tr>
</tbody>
</table>
The noise rating graphs for different sound pressure levels are plotted at acceptable sound pressure levels at different frequencies \cite{27}. Acceptable sound pressure level varies with the room and its use. Different curves are obtained for each type of use. Each curve is obtained by an NR number.

\section{9. Personal Computer Noise Emissions}

As identified by the Basic Criteria for Award of the Environmental Label (the Blue Angel) \cite{34}, the evaluation of noise emissions is based on the indication of the declared A-weighted sound power level in dB to the first decimal place. A-weighted sound power levels $L_{WA(1...3)}$ are determined and calculated on the basis of ISO/FDIS 7779:2010\cite{35}. It must be made sure that in the case of different configurations of identically constructed units, the measurements are performed on the loudest individual components. Measurements shall be taken in the following operational modes:

1. The unit is in idle mode. The measurement of the $L_{WA(1)}$ shall be performed in accordance with ISO/FDIS 7779:2010\cite{35} in the operating mode according to ECMA-74:2008 \cite{30}, Annex C.15.3.1. The measurement can be dropped if no fans are installed (e.g. CPU fans, power supply fans, computer system fans).

2. The hard-disk drive is enabled. The measurement of the $L_{WA(2)}$ shall be performed in accordance with ISO/FDIS 7779:2010 \cite{35} in the operational mode according to ECMA-74:2008 \cite{36}, Annex C.9.3.2. The measurement can be dropped if no mechanical hard disk drive is installed.

3. An optical drive in a typical configuration is enabled. The measurement of the $L_{WA(3)}$ shall be performed in accordance with ISO/FDIS 7779:2010 in the operational mode according to ECMA-74:2008, Annex C.19.3.2. The measurement can be dropped if no optical drive is installed.

To make sure that the sound power level can be considered to declare as minimum of three devices need to be tested in each operational mode in accordance with ISO 9296:1988. The declared sound power levels $L_{WAd(1...3)}$ shall be determined on the basis of ISO 9296:1988 and given in dB to the first decimal place.
Alternatively, if the noise measurements can only be performed on one device the declared A-weighted sound power level $L_{WAd}$ may be determined using the following formula following ISO 9296:1988:

$$L_{WAd} = L_{WAe} + 3 \text{ dB}$$

($L_{WAe}$= sound power level determined by means of a single measurement in dB Measurement conditions)

The values of the declared A-weighted sound power level $L_{WAd(1...3)}$ recorded therein shall not exceed the following operational mode:

1. Hard disk drive enabled (HDD) $L_{WAd(1)}$ 42.0 dB
2. Idle mode $L_{WAd(2)}$ 38.0 dB
3. Optical drive enabled (ODD) $L_{WAd(3)}$ 50.0 dB

For measurement purposes, the Equipment Under Test (EUT) is placed on a test table according to DIN EN ISO 7779: 11-2002, arrangement with 9 measurement points as shown in Figure 7.

where:

- $I_1, I_2, I_3 \equiv \text{EUT dimensions}$
- $d \equiv \text{Measurement distance} = 1.0 \text{ m}$
- $a = 0.5 I_1 + d$
- $b = 0.5 I_2 + d$
- $c = I_3 + d$
- $S \equiv \text{Measuring surface} = 4(ab + bc + ca)$

$$\text{Surface sound value} = 10 \log \frac{S}{S_0}$$

$S \equiv \text{Measuring surface}$

$S_0 \equiv \text{Reference area} = 1.0 \text{ m}^2$

![Fig. 7. Test arrangement for measuring noise emission from PC.](image)
Measurements are done in anechoic chamber as shown in Figure 8, with the following measuring conditions:

- Background noise level 14, 0 dB
- Room correction K2 = 1, 33 dB
- Measurement uncertainty 3, 0 dB
- Absorption factor $\alpha = 0, 5$
- Length 10, 0 m
- Width 10, 0 m
- Height 5, 0 m
- Reference area $A = 200, 00 \text{ m}^2$

Noise emission values according to ISO 9296: 1988,

- ODD sound pressure level = 24.4 dB (A)
- HDD sound pressure level = 22.3 dB (A)
- Idle mode sound pressure level = 19.4 dB (A)

And according to RAL-UZ 78: 06-2006, "The Blue angel":

- ODD Measured $L_{WAd} = 39.9$ dB (A)
- HDD Measured $L_{WAd} = 37.8$ dB (A)
- Idle mode Measured $L_{WAd} = 34.9$ dB (A)

$L_{WAd} = L_{WAe} + 3$dB (Measurement uncertainty)

10. Conclusion

The work explained in this paper suggested a developed smart classroom acoustics design model (SCADM) that can be used by architects, acoustics engineers and designers in an early stage of classroom design in order to achieve the acoustical optimum conditions of KAU classrooms. The work tackled several important problems caused by the noise generated by students and instructional equipment in...
smart classroom that can seriously degrade communication and speech intelligibility and hence degrading learning quality. This type of interior noise source has been taken into consideration in the evaluation, to aid in the application of practical noise control measures. These measures may take the form of using neoprene chair-leg tips to minimize the sound of scuffling chairs and avoiding locating noisy projectors close to students. Excessive noise and reverberation are significant barriers to effective learning, particularly for students with special learning needs or hearing disabilities. A signal-to-noise ratio (SNR) of +15 dB is critical for an optimal learning environment. This can be addressed by increasing the sound quality inside the classroom by using sound field amplification but care must be taken here since this is not necessarily helpful if reverberation is excessive. Excessive noise in the classroom contributes to vocal strain in teachers and this can be managed if vocal and speech strategies for teachers are maintained. Classroom noise and acoustics need to be properly addressed during the design, building and retrofitting of the University classrooms. Increasing awareness of classroom acoustics and noise issues among architects, school officials and administrators is a must. New classroom must be located away from exterior noise sources, and design new classroom with the appropriate room size, ceiling height, and sound insulation material. Also, appropriate use of absorptive and reflective materials is important to keep reverberation times within optimal range for classrooms. By achieving the quality and efficiency of the smart classroom and educational environment, we can reach excellent speech intelligibility, and hence increasing students learning outcomes.

11. Acknowledgment

Authors would like to thank King Abdulaziz University in Jeddah, Saudi Arabia for offering the necessary facilities for accomplishing this research.

References


نموذج مطور لتصميم الصوتيات داخل الفصول الدراسية الذكية لتحسين البيئة التعليمية

عبدالحميد محمد رجب، وأمين يوسف نعمان، وأيمن إسماعيل مدبولي

كلية الحاسبات وتقنية المعلومات، جامعة الملك عبدالعزيز، جدة، المملكة العربية السعودية

aragab@kau.edu.sa

ال改良. تعتمد جودة وكفاءة عمليات التعليم والتدريس في الجامعات الأكاديمية على العديد من العوامل المهمة. إذ يعتبر جودة الصوت داخل بيئة التعلم في الفصول الدراسية ومحيطها، هي واحدة من أهم هذه العوامل التي تؤثر على جودة العملية التعليمية. وقد ركزت العديد من الدراسات والأبحاث حديثًا، على موضوع الراحة الصوتية في الفصول الدراسية الجامعية، ومدى تأثيرها على العملية التعليمية.

تدرس في هذا البحث خصائص تصميم الصوتيات داخل الفصول الدراسية الذكية، واللازمة لتحقيق شروط الصوتيات ذات الجودة العالمية. وتشمل هذه الخصائص على القضايا المتعلقة بالتصميم داخل وخارج مصادر الضوضاء، والتصميم الأمثل للصدى الزمني، واختيار مواد عزل الصوت ومواد المعالجة الصوتية، والتصميم لوضوح الكلام والاستماع داخل الفصول الدراسية بجامعة الملك عبدالعزيز.

حيث يقدم البحث اقتراح نموذج مطور لتصميم الصوتيات للفصول الدراسية الذكية، التي يمكن استخدامها من قبل المهندسين المعماريين، ومهندسين الصوتيات والمصممين في مرحلة مبكرة من تصميم الفصول الدراسية، من أجل تحقيق شروط الصوتيات داخل الفصول الدراسية الجامعية، بجامعة الملك عبدالعزيز. وذلك بهدف رفع مستوى جودة وكفاءة البيئة التعليمية الجامعية، للوصول إلى بيئة تعليمية ممتازة، تؤدي إلى تحسين مستوى مخرجات التعليم لدى الطلاب.