# Investigating The Effect Of Educational Equipment Noise On Smart Classroom Acoustics

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## ABSTRACT

Numerous studies have been carried out highlighting and investigating the acoustics of conventional classrooms for good Speech Intelligibility (SI). However, with the rapid advances in education and instructional technology a new generation of high-tech classrooms referred to as "smart classrooms" is emerging and becoming a necessity at educational institutions. This paper describes the features of smart classrooms which make them different from traditional ones, focusing particularly on the Background Noise (BN) generated by instructional equipment. Measurements were conducted in similar classrooms to assess the magnitude and characteristics of generated noise. With the instructional equipment in operation, acoustical measurements revealed an appreciable increase in the ambient noise level. A computer model of a typical smart classroom is developed to investigate the appropriateness of the classroom layout and surface finishes as recommended by the Acoustical Society of America (ASA) [8]. To determine the impact of the resulting BN on SI in such specialized enclosures, simulations of a classroom model with the recommended surface finishes under various BN conditions were carried out. Results showed that it is necessary to restrict the overall BN level to NC-25 (35 dBA), and emphasized the need to select quiet operating instructional equipment.

## SOMMAIRE

De nombreuses études ont été faites ayant pour but d'exposer et d'examiner les conditions acoustiques des classes conventionnelles en vue d'y assurer une bonne clarté de la parole. Cependant, avec les avancements rapides dans le domaine de la technologie éducative et didactique, une nouvelle génération de classes dotées de technologie de pointe, et nommées "classes intelligentes", commencent à émerger et devenir une nécessité pour les établissements éducatifs. Cette étude décrit les traits des classes intelligentes qui les rendent différentes des classes traditionnelles, en concentrant particulièrement sur le bruit de fond produit par les équipements didactiques. Des mesures ont été prises dans des classes semblables afin de déterminer le niveau et les caractéristiques du bruit ainsi produit. Avec les équipements didactiques en cours d'usage, les mesures acoustiques ont révélé un accroissement notable du niveau du bruit ambiant. Un modèle d'ordinateur représentant une classe intelligente typique a été établi pour étudier la convenance du plan de la classe et du poli des surfaces en conformité avec les recommandations de la Société Acoustique de l'Amérique (ASA) (8). En vue de déterminer l'effet du bruit de fond causé par le bruit des équipements didactiques sur la clarté de la parole dans de tels espaces fermés, des simulations du modèle de classe susmentionné avec de différents polis de surfaces sous différentes conditions de bruit de fond ont été menées. Les résultats ont révélé qu'il est nécessaire de limiter le niveau global du bruit de fond à NC-25 (35 dBA). Ils ont de même souligné le besoin de choisir des équipements didactiques silencieux.

## 1. INTRODUCTION

In spite of the development in the knowledge exchange media and educational setup, classrooms still continue to play a vital role in academic exchanges and learning. For effective learning and enhanced comprehension in classrooms, an adequate matrix of indoor environmental quality in terms of visual, acoustical and thermal conditions is required. Acoustics is one of the major criteria that dictate the functionality of a classroom, as vocal communication is the basic medium of instruction. Not only does poor acoustics affect student comprehension of the instructor's speech but it is also responsible for causing vocal fatigue to the teacher trying to instruct and conduct a dialogue with the students resulting in health problems and teacher absenteeism. In the last two decades, numerous studies have been carried out in this field highlighting the importance of good acoustical ambience and SI in classrooms. Studies by Bradley [1-3], Hodgson [4, 5], Lubman and Sutherland [6, 7] and so many more have studied the characteristics of classroom acoustics in detail.

Various organizations such as the (ASA) have described guidelines in the form of a resource book for creating better hearing environments for students [8], while the American National Standards Institute (ANSI) has prepared a universal standard for the acoustical features of places for learning. Many acousticians agree with the ANSI standard S12.60-2002 [9] specifications of reverberance and noise levels in conventional classrooms. However, emergence of a new type of classrooms has been seen in recent years which is gradually taking over the conventional classrooms.

The new classroom, suitably called as ‘Smart Classrooms’ have considerably different acoustic characteristics as compart to the conventional classrooms. The aim of this study is, therefore, to assess the impact of noise in smart classrooms.

## 2. COMPONENTS OF SMART CLASSROOM

The idea of a conventional classroom is changing from isolated units to more connected places with improved visual communications. A new generation of high technology classrooms referred to, as “smart classrooms” is becoming a necessity at universities. A smart classroom may be defined as “an interactive multimedia electronic classroom networked to the Internet and housing a video/audio, and broadcast-on-demand system” [10]. These classrooms integrate computer education with the latest presentation and multimedia facilities to make the classrooms more interactive and thus enhance the learning process. Classrooms with interconnected computers at each student station create a collaborative learning environment with the instructor as a mentor, making classroom technology as simple and non-intimidating as possible. FIG. 1 illustrates different layouts of university smart classrooms and their interior views [11-13].

Major components of smart classrooms that make them different from conventional classrooms are computer workstations, electronic interactive white board, presenter’s or instructor’s workstation/lectern equipped with control panels for VCR and video projector, video data projector/overhead projector/slide projector, and sound reinforcement system (if needed) [12]. Low acoustical ambience is highly recommended for comprehension of speech and instructions along with controlled artificial lighting and good air quality. It is essential to treat the classroom surfaces with optimum layout of sound-absorbing material and at the same time restrict the Background Noise (BN). Due to the presence of a large amount of instructional equipment constantly generating noise, smart classrooms are inherently nosier environments than traditional classrooms.

## 3. IMPACT OF EQUIPMENT NOISE IN CLASSROOMS

The recent ANSI standard (ANSI S12.60-2002) [9] on classroom acoustics does not elaborate on the noise generated by instructional equipment in a classroom. The standard simply specifies that the average BN in a classroom with educational equipment should not exceed 35 dBA while HVAC systems and other building services are operating. It is therefore necessary to study and verify the impact of noise generated by the educational equipment which would permit formulating "ANSI standard" recommendations for smart classrooms as well.

Two smart classrooms at King Fahd University of Petroleum and Minerals (KFUPM) Dhahran, SA were selected to investigate the spectra and magnitude of the. These centrally Air-Conditioned (A/C) classrooms were equipped with contemporary educational equipment such as data projectors, personal computers, overhead projectors and networking equipment.

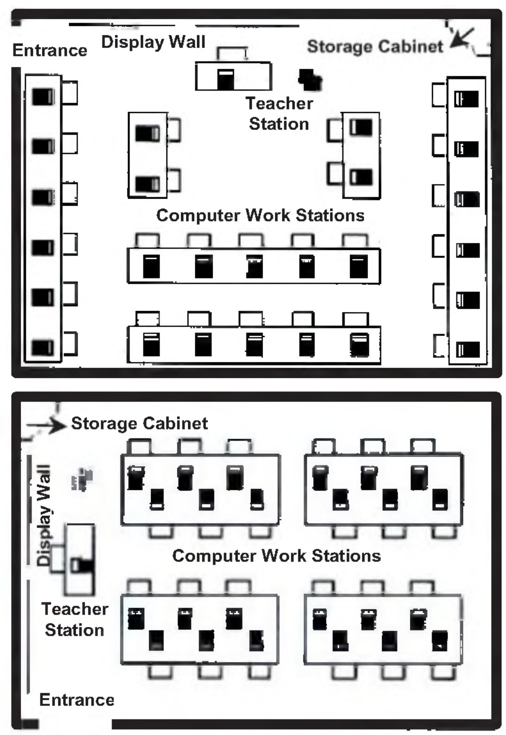
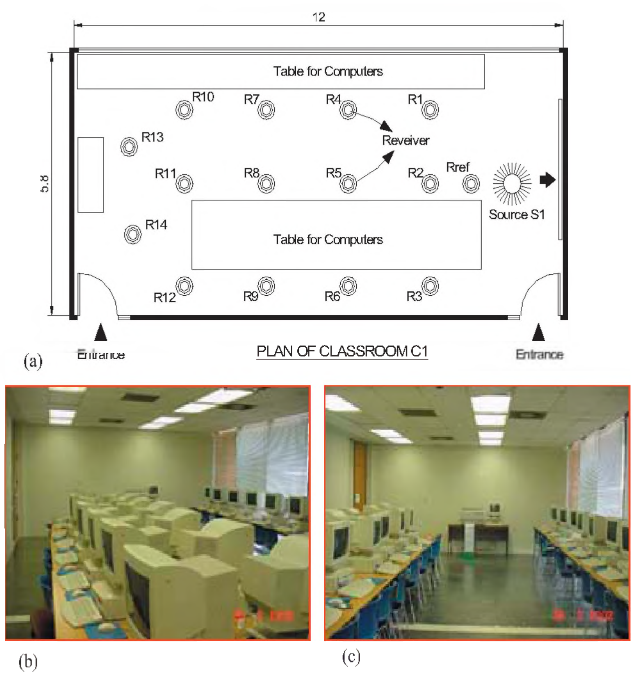



**FIG. 1 (a) Alternative layouts of proposed smart classrooms for universities, (adapted from [11])**

**FIG. 1 (b) Interior views of example university smart classrooms (adapted from [12])**

Measurements were conducted to assess the effect of the existing instructional equipment on the BN by quantifying the noise when all the equipment are turned 'On' compared to the 'Off' condition while the HVAC system is operational. The architectural and spatial characteristics of one classroom are shown in FIG. 2. For the purpose of measurements, Maximum Length Sequence System Analysis (MLSSA) [14], a PC-based audio and acoustical measurement system, was used. MLSSA was configured to measure the Sound Pressure Level (SPL) of ambient noise in the standard octave bands along with the A-weighted noise level and the corresponding Noise Criteria (NC) ratings. The ambient noise levels were measured in the selected locations utilizing a calibrated ½" condenser microphone positioned at a height of 1.2 m to mimic the human ear of seated students. As shown in FIG. 2(a), 14 receivers (i.e. R1-R14) are distributed along the classroom. These locations were near the noise generating equipment and A/C outlets.




**General Information:-**

| | |
|---|---|
| Classroom reference number: | C1 |
| Dimensions (L x W x H) m³: | 12.0 x 5.8 x 2.65 |
| Area: | 69.6 m² |
| Room aspect ratio: | 2.0 |
| Volume (m³): | 184 |
| Capacity (persons): | 30 |

**Surface Finishes:**

| | |
|---|---|
| Walls: | Three walls Painted on Gypsum Plastered One wall Glazed. |
| Floor: | Hard Floor of Polished Mosaic Tiles. |
| Ceiling: | Porous Acoustical Panels. |
| Tables: | Hard Wood Table Tops. |
| Chairs: | Plastic/ Metal Chairs. |

**FIG. 2 (a) Plan of measured classroom C1, (b) and (c)Interior views of the classroom. General information of the room along with its surface finishes are also described.**

Table 1 illustrates the average spectrum of the BN measured in the classroom referred to as 'C1' with the instructional equipment turned 'Off' and 'On'. The average values in various mid frequency ranges are described in the lower rows of the table along with the NC ratings and Room Criteria Mark II (RC Mark II) ratings. The variation in the mean spectra can be noticed. The BN level in this classroom exceeds the recommended value for educational facilities. An increase in the NC rating from a mean of NC-43 to NC-46 is noticed when the equipment is switched 'On'. The second classroom, 'C2,' shows a profound increase in the BN level when equipment is turned 'On'.

**Table 1 BN spectra measured in classrooms C1 and C2 with equipment 'Off' and 'On'.**

| | Classroom C1 | | | Classroom C2 | | |
|---|---|---|---|---|---|---|
| | Equipment Condition | | | Equipment Condition | | |
| Octave-band frequencies | Off | On | Difference | Off | On | Difference |
| 31.5 | 63.7 | 65.9 | 2.2 | 57.7 | 58.5 | 0.2 |
| 63 | 60.1 | 61.7 | 1.6 | 51.9 | 53.9 | 2.0 |
| 125 | 55.1 | 55.6 | 0.5 | 46.9 | 51.4 | 4.5 |
| 250 | 45.1 | 49.8 | 4.7 | 40.1 | 47.1 | 7.0 |
| 500 | 44.4 | 47.2 | 2.8 | 34.3 | 43.6 | 9.3 |
| 1000 | 43.8 | 46.7 | 2.9 | 29.3 | 39.3 | 10.0 |
| 2000 | 39.5 | 41.7 | 2.2 | 27.1 | 37.1 | 10.0 |
| 4000 | 32.2 | 34.9 | 2.7 | 22.8 | 36.5 | 13.7 |
| 8000 | 23.7 | 26 | 2.3 | 22.9 | 29 | 6.1 |
| **500-2000** | **43** | **46** | **3.0** | **30** | **40** | **10.0** |
| **dBA** | **48** | **51** | **3.0** | **38** | **48** | **10.0** |
| **NC** | **43** | **46** | **3.0** | **30** | **39** | **9.0** |
| **RC Mark II** | **43 HF** | **46 HF** | | **30 N** | **39 HF** | |

FIG. 3 depicts the mean noise spectrum in the equipment 'Off' and 'On' conditions. A low existing average BN of NC-30 was measured in classroom C2 (when equipment is off), but a considerable BN increase was noticed when the equipment was operational especially in the mid-frequency range. A large increase in the NC rating (NC-30 to NC-39) can be also observed. Similar increase was noticed in the RC Mark II rating. This rating adds another dimension to the BN characteristics in the measured classrooms by providing a sound quality descriptor, namely, Quality Assessment Index (QAI) [15]. In classroom C1, the BN is associated with a QAI of "HF" which suggests that the noise is dominant at high frequency range (i.e. hissy noise). In classroom C2, the BN has a QAI of "N" which is descriptive of a "Neutral" and balanced noise spectrum with no particular frequency dominance. However, as the instructional equipment is turned on, an increase in sound level associated with a 'Hiss' is perceptible.

The increase in the mean BN spectra when equipment is 'On' is distinct in classroom 'C2' as seen in FIG. 4 compared to classroom 'C1' is due to the presence of high A/C noise in classroom 'C1'. However, it is clear from measurements that there is a perceptible impact on the ambient noise of a classroom when equipment is operational. This increase is mainly occurring in the frequency range where most of the speech sound energy exists. High BN can create unintelligible speech conditions in a smart classroom. This fact renders a smart classroom highly vulnerable to poor Speech Intelligibility (SI) as they are equipped with a large amount of instructional equipment. The BN and the SI in a classroom are also influenced by room enclosure, proximity of a listener to the sound source (Instructor), the boundaries of the room and the locations of noise sources.

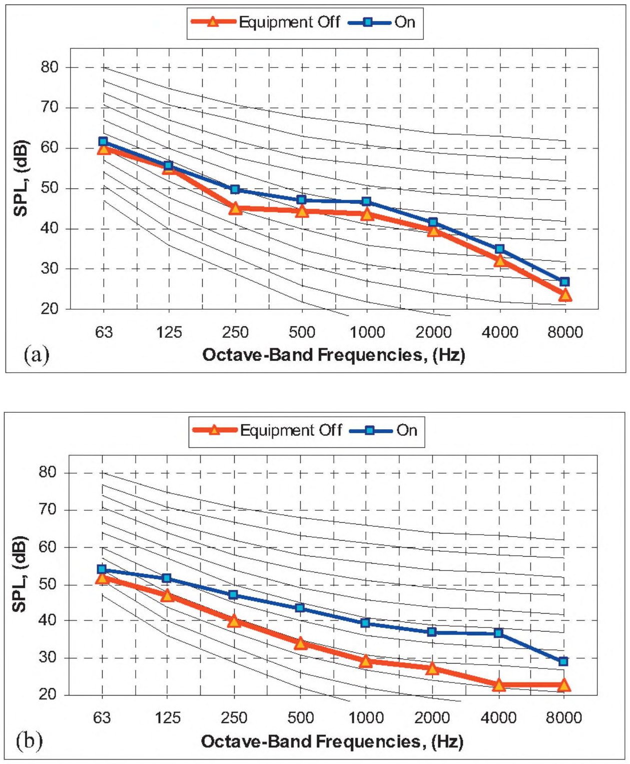



**FIG. 3 BN measured in room (a) C1 and (b) C2 with instructional equipment 'OFF' and 'ON'.**

## 4. SIMULATION OF AN IDEAL SMART CLASSROOM MODEL

A typical smart classroom model is developed with a simple layout similar to the example shown in FIG. 1 (b), to investigate the impact of varying BN in a smart classroom. The classroom is assumed to accommodate 24 students with an average area utilization of 4.2 $m^2$ per student. FIG. 4 shows the plan and details of the model along with a 3D view. Four tables are symmetrically arranged each housing 6 desktop computers. The instructor is equipped with a computer at the lectern that houses all display controls. The display wall is used both as a screen as well as an electronic white board. Storage units for networking equipment, video display equipment, and un-interrupted power supply system etc. are housed at the corner of the display wall.

The model is simulated by ODEON 5.0, the acoustical modeling and simulation software [16]. The model boundaries are assigned surface finishes as recommended by the (ASA) resource for "creating learning environment with desirable listening conditions" [8]. FIG. 5 shows three alternatives of surface finish and placement, with alternative C being the best solution for a traditional classroom. Similar alternative is assumed in this study but without sloping the ceiling reflector above the instructor area. The lower one-meter portion of the walls and the display wall behind the instructor area are kept reflective and assigned absorption of 10% while the remaining upper portion of the walls has 30% absorption. The ceiling above the instructor area is allocated reflective surface treatment while the periphery of the ceiling is made absorptive with 50% sound absorption.

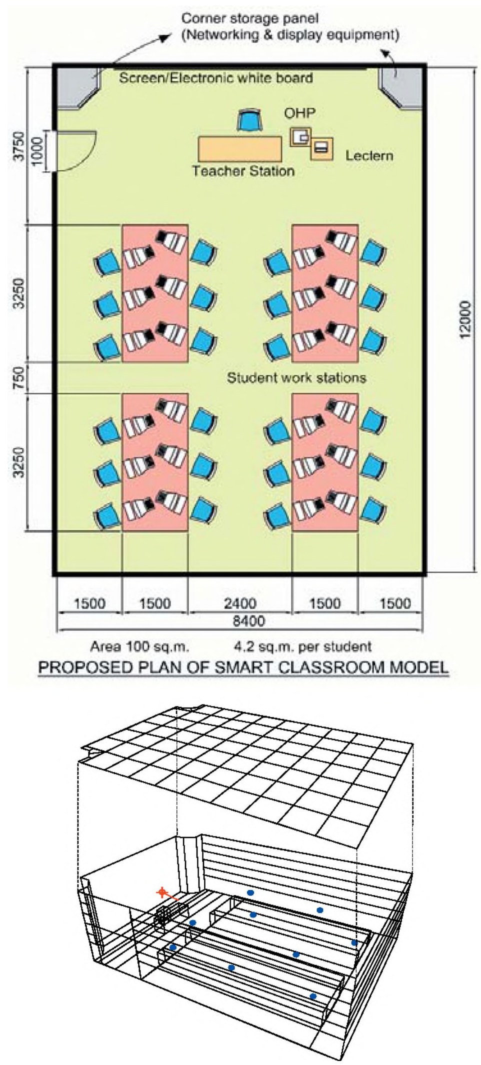



**FIG. 4. Plan and 3D view of the smart classroom model.**

The floor is laid with 6mm pile carpet bonded to closed cell foam underlay. Table 2 describes the finishing of the modeled classroom surfaces. To represent irregularities due to PC's on the table; the tabletop surface is assigned a scattering of 30% with hard wood polished material and kept constant throughout the simulation runs. Thus an ideal room for speech performance as suggested by the ASA [8] is modeled.

The model is simulated under various BN conditions as obtained in the measured classrooms using two types of directional sound sources, “Talk Normal” and “Talk Raised” to mimic an instructor speaking in a normal voice and raised voice respectively. The ‘Talk Normal’ sound source corresponds to a male talker with normal voice effort while a ‘Talk Raised’ sound source simulates a talker addressing an audience in raised voice [17]. The impact of different BN noise levels on SI is evaluated and the results are presented graphically in FIG. 6.

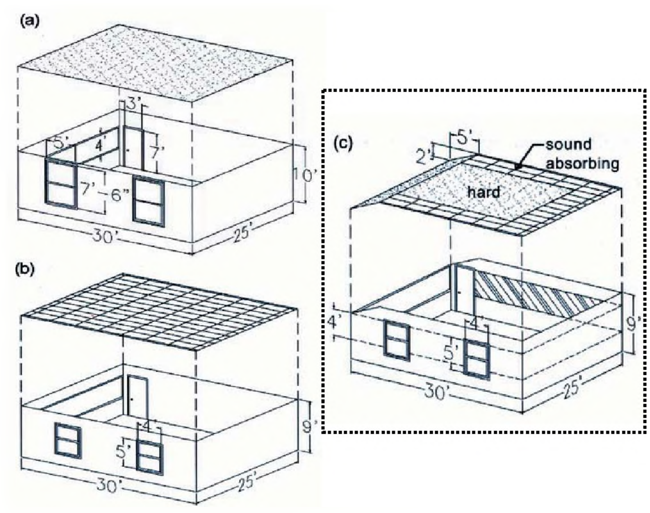



**FIG. 5. The three layouts of sound absorption material placement. Classroom (a) is a typical undesirable room with no sound absorbing material and no useful reflection patterns. Classroom (b) is better with an acoustical lay-in, sound absorbing ceiling and thin carpet. Classroom (c) is a desirable room with sound absorbing wall treatment on three walls, thin carpet, sloped ceiling reflector at the front and a ceiling with reflective surface in the center and sound absorbing surface around the perimeters. (adapted from [8])**

The floor is laid with 6mm pile carpet bonded to closed cell foam underlay. Table 2 describes the finishing of the modeled classroom surfaces. To represent irregularities due to PC’s on the table; the tabletop surface is assigned a scattering of 30% with hard wood polished material and kept constant throughout the simulation runs. Thus an ideal room for speech performance as suggested by the ASA [8] is modeled. The model is simulated under various BN conditions as obtained in the measured classrooms using two types of directional sound sources, “Talk Normal” and “Talk Raised” to mimic an instructor speaking in a normal voice and raised voice respectively. The ‘Talk Normal’ sound source corresponds to a male talker with normal voice effort while a ‘Talk Raised’ sound source simulates a talker addressing an audience in raised voice [17]. The impact of different BN noise levels on SI is evaluated and the results are presented graphically in FIG. 6.

**Table 2. Surface finishing data of the developed model that coincides with the ASA recommendation described in Figure 5(c).**

| **Room Surface** | **Material Assignment** | **ODEON Material Ref. # [17]** |
|---|---|---|
| Tables | Hard wood polished | 603 |
| Occupant seats | Lightly upholstered seats (un-occupied) | 906 |
| Door and Corner panels | Hard wood | 603 |
| Front wall | 10% absorption | - |
| Floor | Lightweight carpet | 506 |
| Lower 1.0 m portion of walls | 10% absorption | - |
| Side and back walls | 30 % absorption | - |
| Ceiling tiles | 10 % central portion and 50 % absorption on periphery | - |

## 5. SIMULATION RESULTS

The simulation results, which are the mean values of the frequency range of interest, that is from 500 to 2000 Hz, reveal the detrimental impact of high BN on the SI in the modeled classroom. FIG. 6 which should be examined from bottom towards the top, shows the results of the simulations under various BN conditions in terms of the variations of the calculated acoustical indicators at nine sound receivers that are distributed along the model. A wider value range is suggestive of an uneven distribution of sound in the model while a shorter range indicates spatial uniformity. Hence, in the base case (shown at the bottom of the figure) 3 bars are used to represent data under a particular BN level, lower bar represents RT value range and the upper two bars depict Speech Transmission Index (STI) values using a Talk-normal and Talk-raised sound sources respectively. STI is an SI indicator that takes into account the enclosure reverberance as well as the prevailing noise characteristics. As seen in the base case the average RT value and Clarity ($C_{50}$) levels are within the acceptable range, however RT values exceed the recommended limit of 0.6 seconds at more than 60% of the receiver locations.

Since the same model is simulated under various BN levels represented by NC values as well as dBA levels, RT and $C_{50}$ values remain unchanged. STI results confirm the suitability of the smart classroom model configuration and surface finishes as recommended by the ASA resource book [8]. BN of NC-40 (i.e. 49 dBA) or less are found to exist in smart classrooms when instructional equipment are operational.

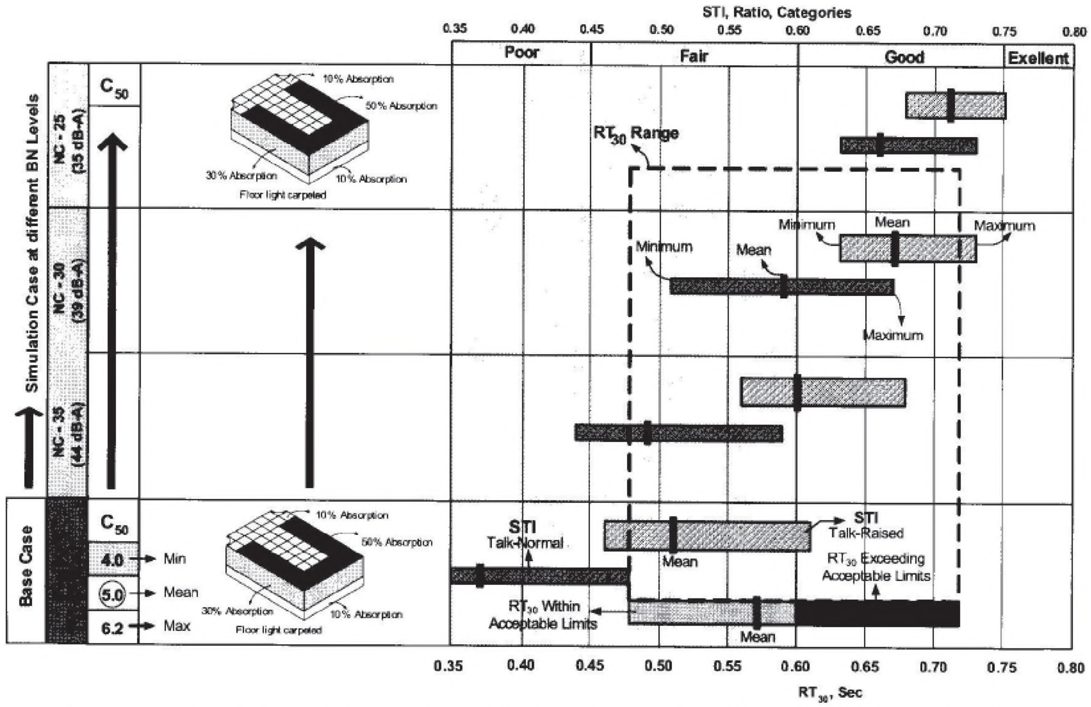



**FIG 6. Results of the model cases simulated at different BN conditions. STI values are used.**

Simulation results indicate an average "Fair" SI rating when the instructor is only assumed to talk in a raised voice, while it is unfavorable "Poor" rating when the instructor talks with normal voice effort. The impact of BN increase on the SI once the computers and instructional equipment are operational can also be assessed from FIG. 6. If, for example, one limits the BN to NC-30 or less results in "Fair" and "Good" SI rating with "Talk-Normal" and "Talk Raised" instructor's voice efforts respectively. SI is found to be within the "Good" rating range when the BN in the classroom is limited to NC-25 (i.e. 35 dBA).

## 6. CONCLUSIONS

Measurements in smart classrooms with computers and othetr instructional equipment indicate appreciable increase on the overall BN. The simulation of a typical smart classroom model with ideal surface finishing characteristics as recommended in reference [8] under various BN conditions highlights the detrimental impact of the BN increase on the SI in such specialized enclosures. The results of this study suggest that even if the BN in a traditional classroom is restricted to 35 dBA (NC-25) as specified by the ANSI standard [6], once computers and the instructional equipment are included and put to operation, a BN increase of about 6 to 10 dBA, notably degrades the SI in the classroom. Therefore it is necessary to select quiet operating equipment that would on an average increase the ambient background noise by not more than a NC-5 rating.

It should be noted that the overall classroom noise generated by noise sources, which radiate with constant power (e.g. computers) would be influenced by the room acoustical conditions, particularly the surface sound absorption. A more accurate modeling in this case requires detailed knowledge of the octave-band sound power levels and directivity of each noise source. Furthermore, the possibility of improving SI conditions in such enclosures by investigating alternative surface treatment needs to be explored. An attempt to investigate ideal surface finish characteristics is the next step leading towards optimizing acoustics in such evolving smart classroom.

## ACKNOWLEDGMENT

The authors would like to express their gratitude and thanks to *King Fahd University of Petroleum and Minerals* (KFUPM) for its continuous support.

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