

UBC-CLASSROOM ACOUSTICAL SURVEY

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SUMMARY

Acoustical measurements were made in 46 randomly-chosen, unoccupied University of British Columbia (UBC) classrooms. Further tests were done in 10 UBC classrooms when both unoccupied and occupied by students, in order to determine the effect of people and to correct the 'unoccupied' results. The objective of the work was to determine the acoustical quality of the UBC classroom stock and how this depends on the classroom design. The results showed that the UBC classroom stock is of far from optimum acoustical quality. This was found to be because many classrooms have excessive reverberation and result in low speech levels, especially at the back of the rooms; in addition, some have noisy ventilation systems. Further work is in progress to determine user reaction to the acoustical conditions, typical student-generated noise levels and the effect of speech-reinforcement systems.

SOMMAIRE

Des mesures acoustiques ont été réalisées à l'intérieur de 46 salles de classe inoccupées de l'Université de la Colombie Britannique (UBC), sélectionnées au hasard. Des relevés supplémentaires ont été faits dans 10 autres classes de l'UBC alors qu'elles étaient inoccupées ou occupées par des étudiants, dans le but de déterminer la contribution des gens et de corriger les résultats "inoccupés". L'objectif de l'étude était de déterminer la qualité acoustique de l'inventaire de classes de l'UBC et comment celle-ci dépend du design de la classe. Les résultats démontrent que l'inventaire de classes est loin d'atteindre des qualités acoustiques optimales. Ceci serait attribuable au fait que plusieurs salles de classe ont une durée de réverbération excessive, ce qui engendre des niveaux faibles de parole, surtout à l'arrière des salles de classe; de plus, quelques unes des salles sont équipées de systèmes de ventilation bruyants. D'autres projets sont en cours afin de déterminer la réaction des usagers aux conditions acoustiques, aux niveaux de bruit typiques générés par les étudiants et à l'effet de systèmes de renforcement de la parole.

1. INTRODUCTION

During summer 1993 an acoustical survey of the classrooms on the University of British Columbia (UBC) campus was undertaken. The general objective was to determine the acoustical quality of the UBC classroom stock and how this depends on the classroom design. This work was carried out under the auspices of the UBC Ad Hoc Committee on Hearing Accessibility.

This paper summarizes work accomplished to date. That work did not allow a final conclusion regarding all aspects of classroom quality to be determined. Further work, aimed at resolving these questions, is in progress.

2. SPEECH INTELLIGIBILITY

In university classrooms, the major acoustical concern is that of verbal communication. Inadequate acoustical conditions, resulting in poor verbal communication, cause two main problems. First, they lead to reduced learning efficiency. Second, they can lead to fatigue, stress and health problems (headaches, sore throats) amongst lecturers, who are forced to compensate for poor acoustical conditions by raising their voices, for example.

The quality of verbal communication can be quantified by the "speech intelligibility". This quantity is the percentage of speech material which is correctly understood by the average listener. It has been suggested that, in the case of

normal-hearing adults working in their first language, the speech intelligibility should exceed 97% [1]. In the case of acoustically-challenged people, such as hard-of-hearing students, students working in a second language and children, the requirements are undoubtedly more stringent; Bradley suggests aiming for 100% [2].

In the present study, speech intelligibility was assumed only to be due to the following two factors:

1. Signal-to-noise ratio, S/N - this is equal to the level of speech, SL, in dBA minus the level of background noise, BGN, in dBA, both at the listener position. The speech level depends on the speaker's voice level, the distance between the speaker and the listener, and on the acoustical conditions in the classroom. The background-noise level results from noise from the ventilation system, projectors, in-class student activity and sources outside the classroom. The levels of these depend on the acoustical conditions in the classroom;
2. Reverberation time - the reverberation time in a room generally increases with room size, and decreases with the amount of sound absorption in the room.

The higher is the speech level and the lower is the background noise level, the higher is the signal to noise ratio and, thus, the speech intelligibility. Too much reverberation is bad, since it results in an effective increase in the background-noise level.

Research has shown that to obtain a speech intelligibility of 100% for normal-hearing people the reverberation time must not exceed 0.7 s; with this reverberation time, the signal to noise ratio must exceed 15 dBA [2]. Given typical speech levels [3], this implies that the background-noise level must not exceed about 35 dBA. As mentioned, the requirements are even more stringent in the case of more acoustically-challenged persons; an optimum reverberation time of 0.4-0.5 s, a minimum signal-to-noise ratio of 20 dBA and a maximum background-noise level of 30 dBA have been suggested [2].

The acoustical conditions in a classroom depends on three main factors: room geometry (size and shape); the sound-absorptive properties of the internal room surfaces; the number of people in the room. All three factors affect speech and background-noise levels, as well as reverberation time.

3. CLASSROOMS TESTED

Measurements were done in two categories of classroom:

- a. Randomly-selected, unoccupied classrooms - in order to evaluate the quality of the UBC classroom stock and determine how room design affects it, tests were done in 46 unoccupied classrooms, chosen randomly from the UBC classroom list. Note that this represents about 10% of the UBC classrooms. Of course, the results of tests in unoccupied classrooms are not typical of the acoustical conditions in a classroom when in use for lectures, since they do not account for the presence of students. However, tests in unoccupied classrooms are much easier to do than in occupied classrooms. The classrooms varied from small seminar rooms with volumes under 100 m³ and less than 10 seats, to large auditoria with volumes over 3000 m³ and over 400 seats; the volume-to-surface-area ratios varied from 0.6-2.4 m. The largest proportion of rooms had 40-60 seats, volumes from 250-500 m³ and volume-to-surface-area ratios of about 1.0 m;
- b. Unoccupied / occupied classrooms - in order to determine the effect of the presence of students on speech intelligibility and, thus, to correct the results from the unoccupied classrooms for the presence of students, tests were done in 10 classrooms when both unoccupied and occupied by a number of students.

In all tests the ventilation systems were in operation. However, overhead or slide projectors, common sources of background noise in a classroom, were not in operation. Since the tests were done during the summer, noise from outside the classrooms was not a factor as it can be during term. Speech-reinforcement systems, installed in some larger classrooms, were also not in operation. In the case of the occupied classroom tests, the students were asked to remain quiet; thus the effect of background noise due to in-class student activity was not measured.

4. EXPERIMENTATION AND ANALYSIS

In each classroom, measurements were made of the impulse responses between a source and each of 4 to 10 microphone positions, distributed throughout the room, using the Maximum Length Sequence System Analyzer (MLSSA). The source was an omnidirectional loudspeaker array located at a typical lecturing position and at 1.5 m high. It radiated white noise filtered according to the spectrum of typical speech. The output level was adjusted to one standard deviation below that typical of average male and female speakers, speaking at between normal and raised voice level (ie 56 dBA at 1 m in a free field [3]). From each of the impulse responses the following quantities were calculated:

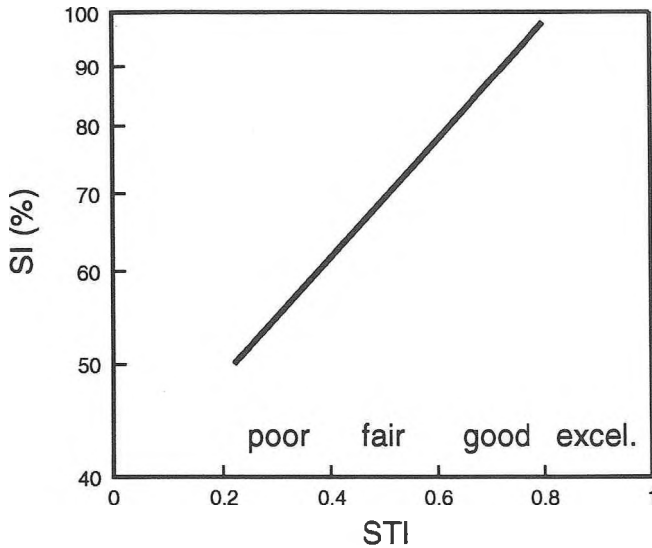


Figure 1. Assumed relationship between STI and SI (derived from Figure 2 of [4] under the assumption that $SI=1-AL_{cons}$).

- a. Speech Transmission Index (STI) [4] - the relation between this measure, which varies between 0 and 1, and speech intelligibility (SI) is shown in Figure 1 (derived from Figure 2 of [4] under the assumption that $SI=1-AL_{cons}$). Note that ranges of STI values can also be associated with subjective acoustical-quality descriptors as follows [4]:

STI range	Quality descriptor
0.2-0.4	Poor
0.4-0.6	Fair
0.6-0.8	Good
0.8-1.0	Excellent

- b. Early decay time (EDT) - this is a measure of reverberation time based on the initial sound decay.

The STI and EDT results were averaged over all of the measurement positions in each room. All quantities were determined in octave bands from 125-4000 Hz. Single-number ('Global') values were, for want of a better method, then determined by weighting the octave-band values according to their relative importance to speech intelligibility [4].

- c. Sound propagation (SP) - this is the variation of level with distance from the source (expressed in terms of level minus the source power level, resulting in a negative value in decibels). All quantities were determined in octave bands from 125-4000 Hz.

In addition, measurements were made of background-noise levels in dBA at a number of positions in each classroom using a sound-level meter.

It is important from a design point of view to determine to what extent typical classroom surfaces absorb sound. Therefore, diffuse-field theory and the octave-band EDTs measured in the 46 unoccupied classrooms were used to determine the average octave-band and Global absorption coefficients of the classroom surfaces.

It was also important to determine to what extent people absorb sound. Therefore, diffuse-field theory and the octave-band EDTs measured in the 10 unoccupied/occupied classrooms were used to determine the average absorption per person, in m^2 .

In order to get an estimate of the background-noise levels generated by student activity while attending a lecture, a further test was performed. Noise levels generated by 51 students during a final exam in Classroom A (see below) were measured in octave bands and in dBA.

5. RESULTS AND DISCUSSION

Test results will be illustrated using those from three classrooms, whose main characteristics are shown in Table 1. Note that Classroom A was regularly shaped, moderately sized and had low absorption. Classroom B was regularly shaped, moderately sized and had high absorption; in terms of average Global STI it was the best classroom measured. Classroom C was a large, irregularly shaped auditorium with moderate absorption; it was the worst room measured.

5.1 Unoccupied classrooms

Figure 2 shows the variation of octave-band STI with source / receiver distance in Classrooms B and C. This figure

Table 1. Details of three classrooms for which results are presented.

Room	Seating Type	No. of seats	Length (m)	Width (m)	Height (m)	Global avg. abs ¹ coeff.	# students (occupied)
A	Raked	113	9.0	12.1	3.7	0.09	51
B	Flat	120	10.6	11.6	3.1	0.27	14
C	Raked	451	25.2	21.5	6.1	0.16	350

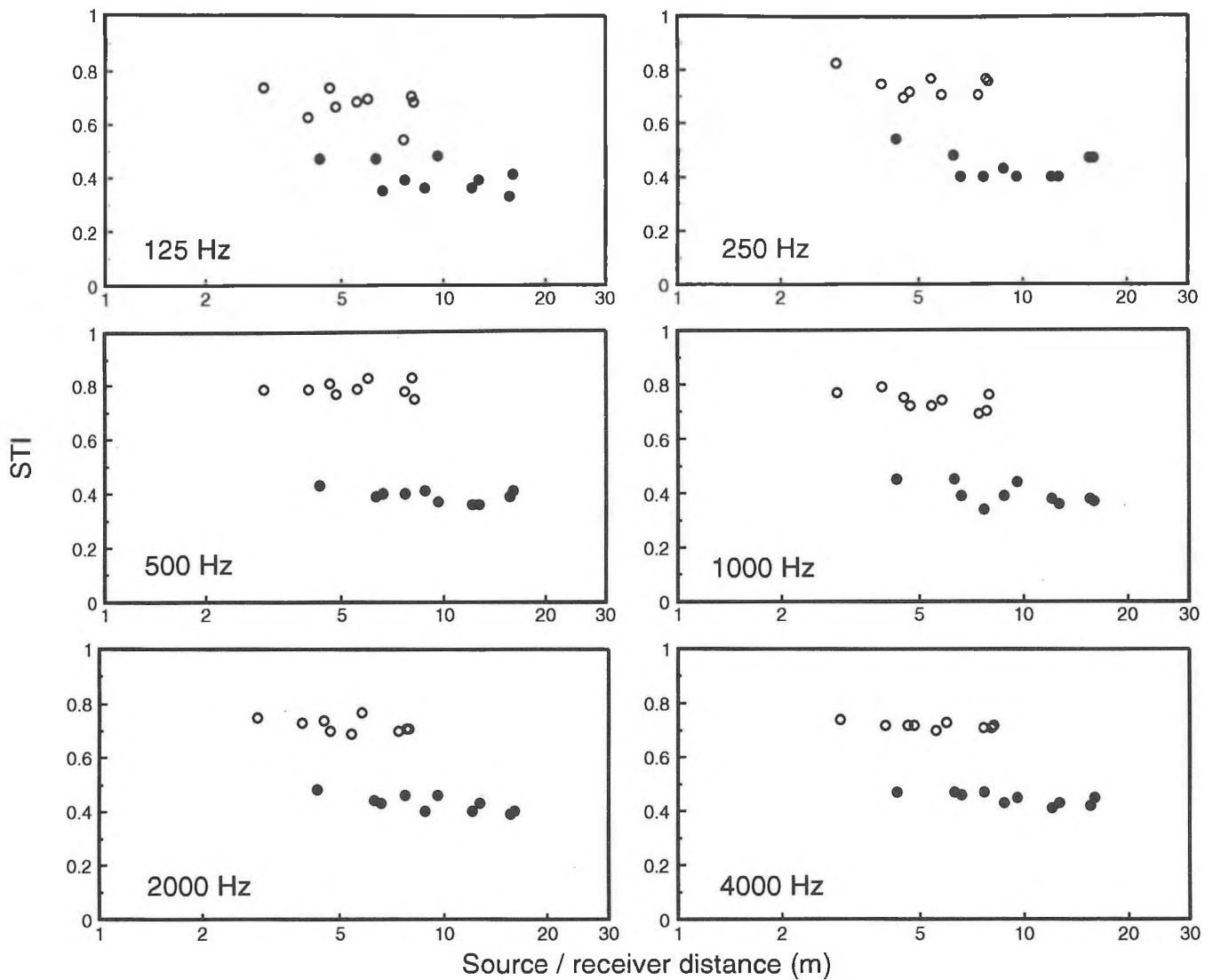


Figure 2. Measured octave-band STI's in unoccupied (○) Classroom B and (●) Classroom C.

shows the range of STI values measured. Though STI's tended to decrease with source/receiver distance as expected, surprisingly the variation was never strong. Figure 3 shows the frequency distribution of the average Global STIs measured. None of the classrooms had average Global STIs above 0.8 (excellent) or below 0.4 (poor). However, some individual positions at the front of smaller classrooms has excellent ratings; similarly, some positions at the back of the largest and 'worst' rooms had Global STI values under 0.4 (see Figure 2). The classrooms were divided more-or-less equally between fair ($0.4 < \text{Global STI} < 0.6$) and good ($0.6 < \text{Global STI} < 0.8$). It appears that the acoustical quality of the UBC classroom stock when unoccupied is very mediocre. We will return later to the question of the quality when occupied.

By way of explanation of the STI results, Figures 4 and 5 show the frequency distributions of the measured Global

EDT and BGN values, respectively. Measured EDTs exceeded 0.7 s in most classrooms, and exceeded 2 s in some cases. Background-noise levels exceeded 35 dBA in most classrooms and 50 dBA in some.

Figure 6 shows the 1000-Hz octave-band sound propagation in Classrooms A, B and C. In the small, low-absorption Classroom A, the speech level varies little with position. In small but absorbent rooms (eg Classroom B), and in large rooms (eg Classroom C), the speech level decreases with distance from the source, leading to low speech levels at the back of the room.

Note also that the shape of these curves indicates that prediction by diffuse-field theory is often inaccurate. Levels generally decrease with distance, only showing constant reverberant levels in small, low-absorption rooms.

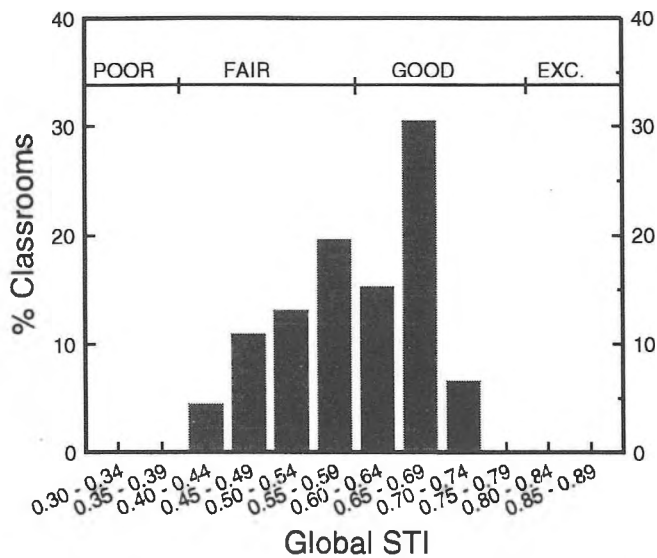


Figure 3. Frequency distribution of the room-averaged Global STI's measured in 46 unoccupied classrooms.

In the absence of special acoustical treatment, the main features found to significantly increase the amount of sound absorption above and beyond the ambient absorption in 'basic' rooms which did not have these features, were carpets, acoustical ceiling tiles (suspended or not) and upholstered seating. In order to determine the absorptive properties of typical classroom surfaces, the classrooms were divided into categories according to whether or not they had these features. Figure 7 shows the average octave-band and Global surface absorption coefficients which can thus be attributed to each type of surface in these classrooms. For example, classrooms without carpets, ceiling tiles and upholstered seating had, on average, a Global absorption coefficient of 0.09. The presence of a carpet, ceiling tiles or upholstered seating increased the Global coefficient by 0.05, 0.08 or 0.04, respectively.

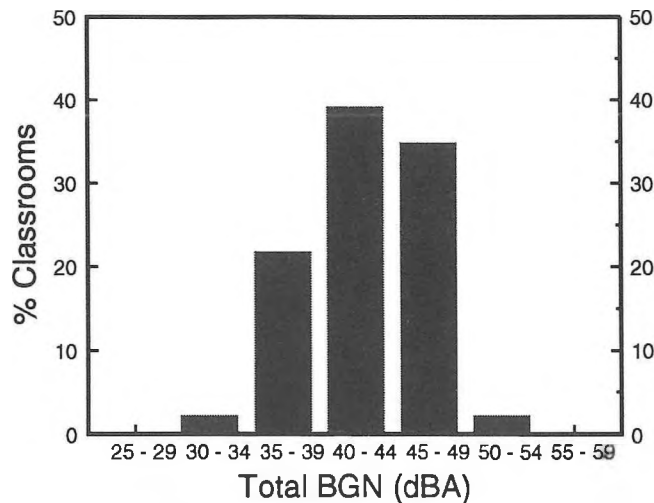


Figure 5. Frequency distribution of the room-averaged A-weighted BGN in 46 unoccupied classrooms.

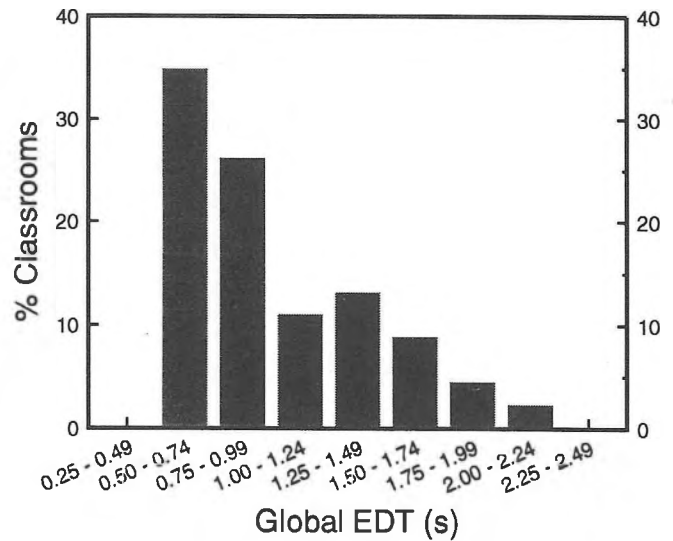


Figure 4. Frequency distribution of the room-averaged Global EDT in 46 unoccupied classrooms.

5.2 Occupied classrooms

Figure 8 shows the variation with distance of the change due to people in 1000-Hz octave-band STI in Classrooms B and C. The results show that the presence of students generally had little effect on STI in smaller classrooms (eg Classroom B), and increased the STI in larger rooms (eg Classroom C). As illustrated in Figure 9, this result is partly

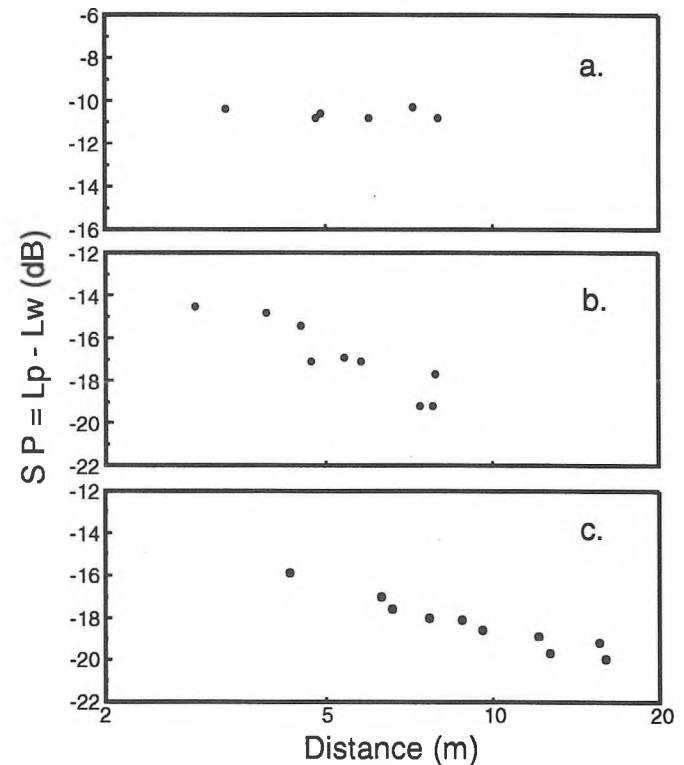


Figure 6. 1000-Hz octave-band SP measured in Classrooms a) A, b) B, and c) C when unoccupied.

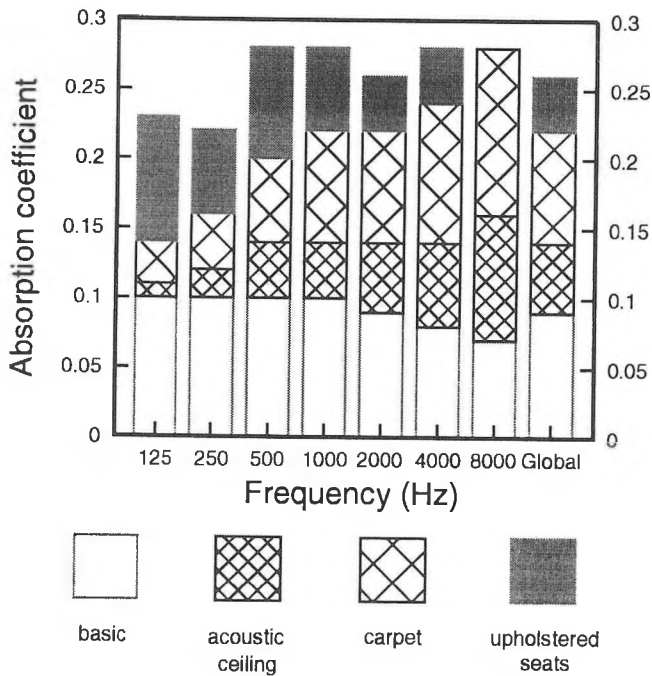


Figure 7. Average surface-absorption coefficients in classrooms with various classroom features.

explained by the fact that in small rooms - especially when absorbent - people had little effect on EDT (in Classroom B the Global EDT decreased by 8%), whereas in large rooms

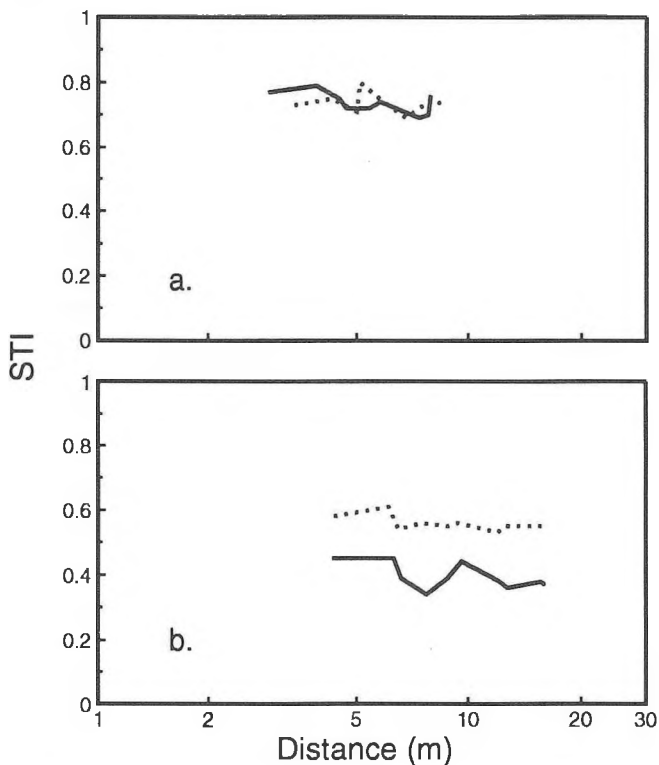


Figure 8. Measured 1000-Hz octave-band STI's in Classrooms a) B and b) C when (—) unoccupied and (.....) occupied.

they reduced the EDT significantly (in Classroom C the Global EDT decreased by 44%). Unfortunately, the positive effect of decreased reverberation is counterbalanced by the negative effect of a reduction in speech level resulting from the presence of people in large rooms. This is illustrated in Figure 10 showing the change due to people in the 1000-Hz octave-band SP in Classrooms B and C, respectively. Recall that the effect of noise due to in-class student activity is not included here.

Figure 11 shows the average and standard deviations of the octave-band and Global absorption-per-person results. The absorption introduced by a person in a classroom increases with frequency from about 0.4 to 1.1 m² (Global increase of 0.74 m²).

5.3 Background-noise test

Figure 12 shows the octave-band and A-weighted BGN levels in Classroom A when unoccupied (ventilation system only) and when occupied by 51 students writing a final exam. In this case noise is due to movement of chairs, papers etc., but not to voices. Background-noise levels increased by 21 dBA to 56 dBA due to the presence of the students. This result suggests that student-generated background noise is a significant factor negatively affecting speech intelligibility in classrooms.

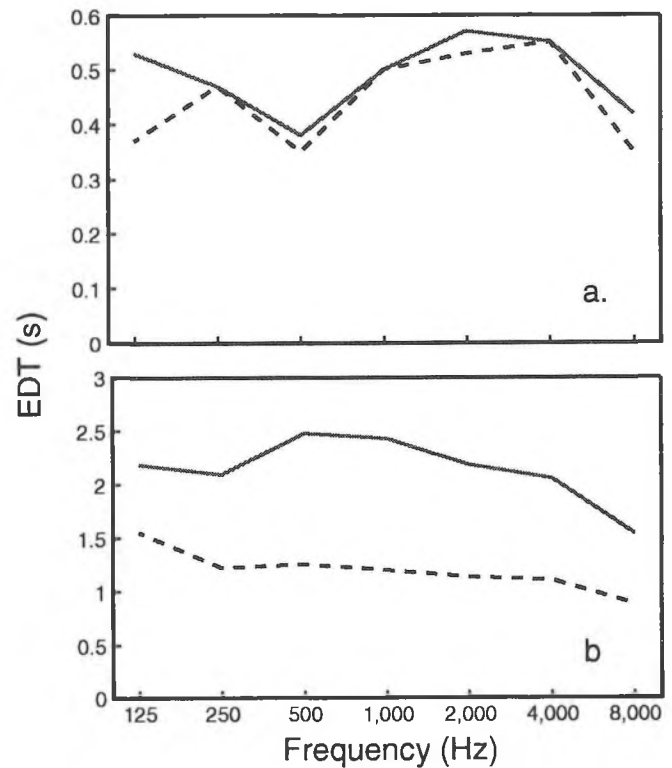


Figure 9. Measured octave-band EDT's in Classrooms a) B and b) C when (—) unoccupied and (- - -) occupied.

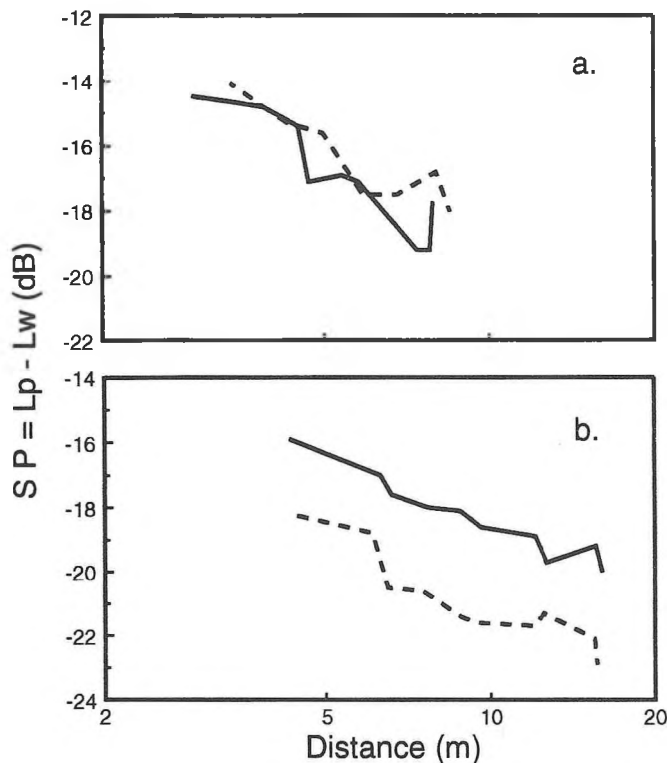


Figure 10. Measured 1000-Hz octave-band SP's in Classrooms a) B and b) C when (—) unoccupied and (---) occupied.

6. STI IN OCCUPIED CLASSROOMS

In order to estimate the acoustical quality in occupied UBC classrooms, the following procedure was followed for each of the 46 classrooms, assumed half and fully occupied,

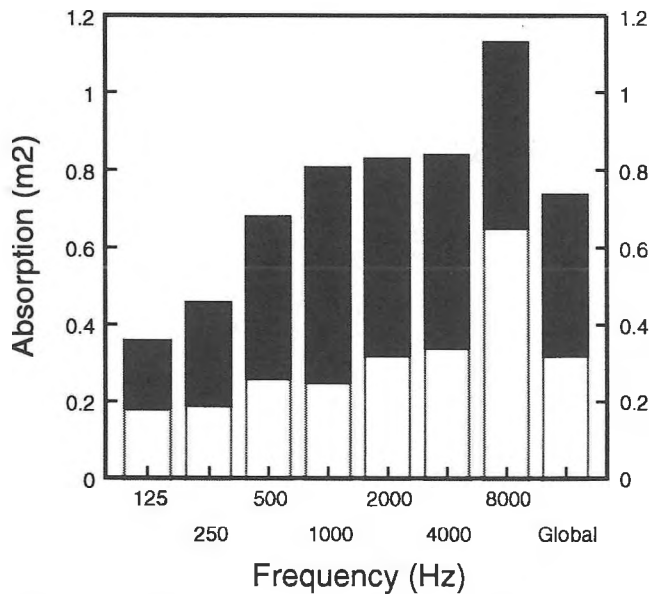


Figure 11. Average (complete bar) and standard deviations (white bar) of the average absorption per person measured in 10 classrooms

using the above results:

- using diffuse-field theory and the average absorption per person, the 1000-Hz unoccupied EDTs, and the SPs (ie signal levels) at the centre of the classroom, were corrected for the presence of students;
- based on the results of the background-noise test in Classroom A, the background-noise levels in the occupied classrooms were assumed to be 53 dBA (half occupied) and 56 dBA (fully occupied);
- the average Global STIs measured in the unoccupied classrooms were corrected.

Figure 13 compares the frequency distributions of the STI values for the 46 classrooms when unoccupied and half and fully occupied, respectively. In general, the presence of students decreased speech intelligibility (average Global STI decreased by as much as 0.3). Only in the case of 'basic' classrooms with low-absorption surfaces and, therefore, high EDTs when unoccupied, did the presence of students increase speech intelligibility (average Global STI increased by up to 0.1).

7. CONCLUSIONS

The results of the UBC-classroom acoustical survey show that the classrooms - even when fully occupied - have far from optimum acoustical quality. Most classrooms have excessive reverberation and provide inadequate speech

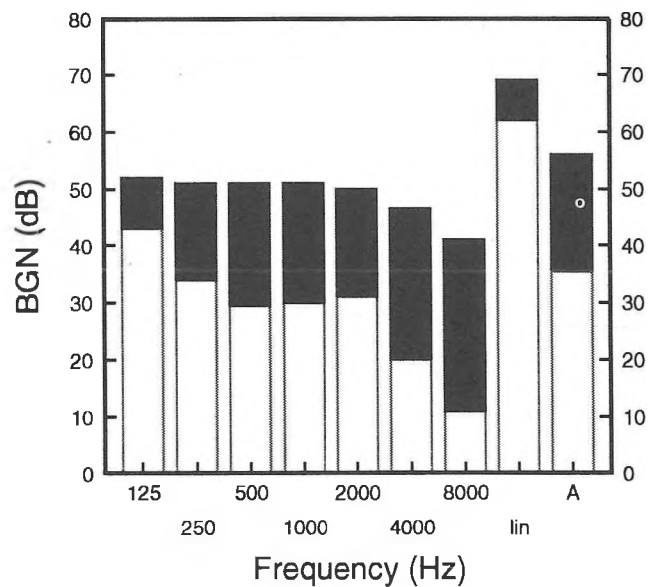


Figure 12. Measured room-averaged background noise levels in Classroom A when unoccupied (white bar) and occupied (complete bar) by students writing an exam.

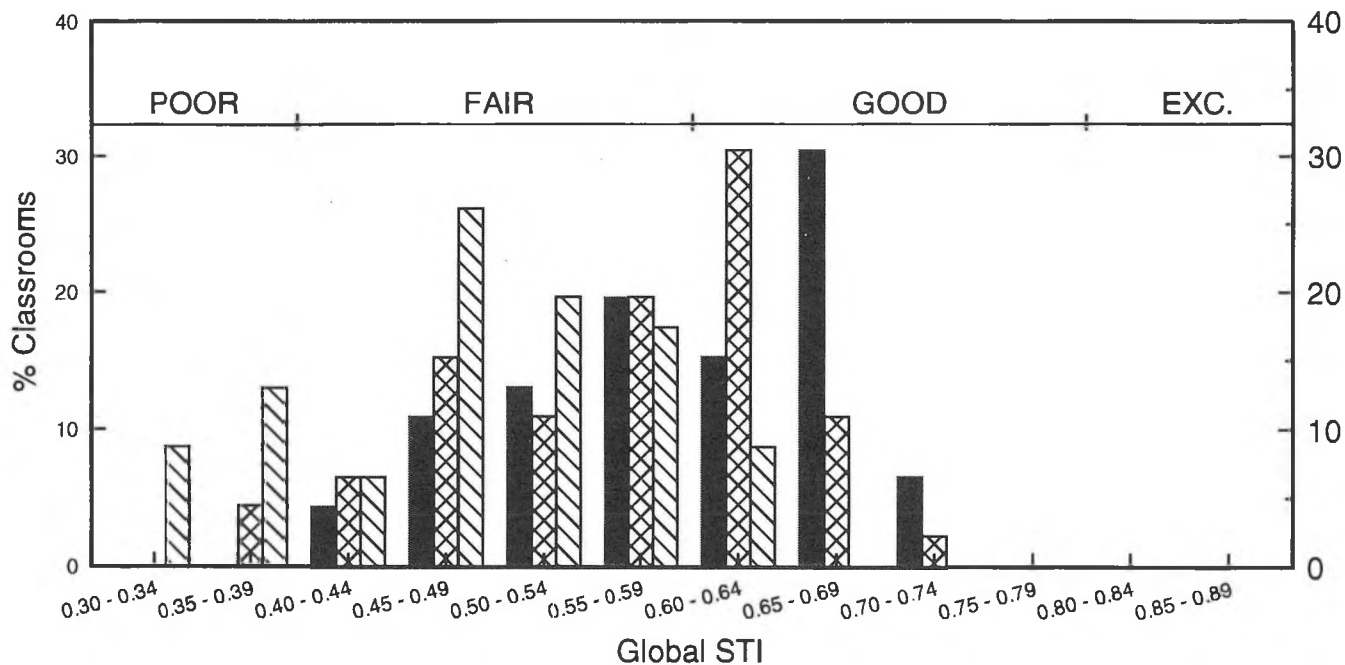


Figure 13. Frequency distributions of the Global STI in 46 classrooms: ■ unoccupied (measured); ☒ half occupied (predicted); ▨ fully occupied (predicted).

levels; some have high background-noise levels due to the ventilation system and other sources.

Several associated studies are on going at this time, involving further tests in UBC classrooms. They are as follows:

- a questionnaire has been developed to determine student and instructor reactions to the acoustical conditions in UBC classrooms. It has been administered to over 6000 people; the results are being analyzed;
- initial measurements of the effect of speech-reinforcement systems on classroom quality have been done. They suggest that such systems may improve or worsen quality;
- STI measurements for source positions in the audience, and for receiver positions in the audience and at the instructor position are planned. This is relevant to speech intelligibility when students ask questions;
- detailed measurements of speech levels, and of student-generated background noise levels are in progress.

ACKNOWLEDGEMENTS

The author would like to thank the professors who allowed us time during their classes to make measurements in the occupied classrooms. Thanks also to the students involved for putting up with the 'noise' and remaining quiet. Thanks also to the Disability Resource Centre which provided partial funding for project. Finally, thanks to Physics students John Kim and Tony Skrjanec for their hard work in completing the survey and associated analysis.

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Announcement and Call for Papers

INTER-NOISE 95 TO BE HELD IN NEWPORT BEACH, CALIFORNIA, USA

INTER-NOISE 95, the 1995 International Congress on Noise Control Engineering, will be held in Newport Beach, California, USA. Newport Beach is a business center and resort community on the Pacific Coast south of Los Angeles. The congress will be held at the Newport Beach Marriott hotel from 1995 July 10 to 12.

INTER-NOISE 95 will be the twenty-fourth in a series of international congresses on noise control engineering that have been held in the United States and in other countries since 1972. The theme of INTER-NOISE 95 is *Applications for Noise Control Engineering*. The congress is sponsored by the International Institute of Noise Control Engineering, and is being organized by the Institute of Noise Control Engineering of the USA (INCE/USA).

Alan H. Marsh, President of DyTec Engineering and Editor-in-Chief of *Noise Control Engineering Journal*, is the General Chairman. Robert J. Bernhard, Director of the Ray W. Herrick Laboratories at Purdue University, and J. Stuart Bolton, Professor of Mechanical Engineering at Purdue University, are co-chairmen of the Technical Program and will edit the congress proceedings.

Technical papers in all areas of noise control engineering will be considered for presentation at the congress.

CONTRIBUTIONS INVITED

Abstracts of papers proposed for presentation at INTER-NOISE 95 must be received by the Technical Program Chairmen no later than **1994 November 29**. The abstract should be approximately 250 words in length, and must be submitted in the format reproduced on the third page of this announcement.

If the paper is accepted for presentation at INTER-NOISE 95, it must be typed on the special manuscript paper which will be supplied by the Congress Secretariat. The completed manuscript will be printed in the Congress Proceedings, and must be received by the Technical Program Chairmen no later than **1995 April 04**.

EQUIPMENT EXHIBITION

A major acoustical equipment, materials and instrument exhibition will be held in conjunction with INTER-NOISE 95. The Exhibition will include materials and devices for noise control as well as instruments such as sound level meters, noise monitoring equipment, sound intensity measurement systems, acoustical signal processing systems, and equipment for active noise control.

OTHER MEETINGS IN NEWPORT BEACH

A noise control seminar and an international symposium will be held at the Newport Beach Marriott immediately before INTER-NOISE 95. The seminar will be held on 1995 July 07-08. The 1995 International Symposium on Active Control of Sound and Vibration will be held on July 06-08. This symposium is a continuation of the conferences on active control of sound and vibration which were held at Virginia Polytechnic Institute in Blacksburg, Virginia, USA in 1991 and 1993, and a continuation of an active noise symposium held in Japan in 1991.

Technical Papers in all areas of noise control engineering will be considered for presentation at the Congress. The following technical areas are of particular interest.

Aircraft Noise Control: Interior and Exterior

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Standards and Regulations for Noise Control

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CONGRESS VENUE

The site of the congress, the Newport Beach Marriott Hotel, is approximately 1 km from the Pacific Ocean on a hill with a view to the southwest of Newport Beach Harbor, Balboa Island and, on the horizon, Catalina Island about 40 km offshore. Newport Beach is located in Orange County, California, south of Los Angeles. Orange County Airport (John Wayne Airport [SNA]) is about 15 minutes to the north of the hotel by automobile. The airport was completely rebuilt in 1990–1991, and is an excellent final destination for delegates to INTER-NOISE 95. The Newport Beach Marriott hotel provides complimentary transportation to and from the Orange County Airport. Los Angeles International Airport (LAX) is about 60 km to the northwest. Scheduled air transportation service, scheduled bus service and frequent van service are also available from LAX to Orange County Airport.

The location of the hotel is very attractive; opportunities for recreational activities include sightseeing at *Disneyland* in Anaheim, a boat trip to Catalina Island, and the harbor and beaches in the Newport Beach and Laguna Beach areas (readily accessible by public transportation). The hotel is adjacent to one of Southern California's major shopping centers, Fashion Island, in the Newport Center, and is about 20 minutes by automobile from the well-known South Coast Plaza shopping center and the Orange County Center for the Performing Arts in Costa Mesa. Some of the best restaurants in California are within a 30-minute drive from the hotel.

The hotel has excellent meeting room and exhibition facilities for INTER-NOISE 95. It was the venue for INTER-NOISE 89. Attendees at that congress will recall the excellent meeting, living and dining facilities at the Newport Beach Marriott.

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