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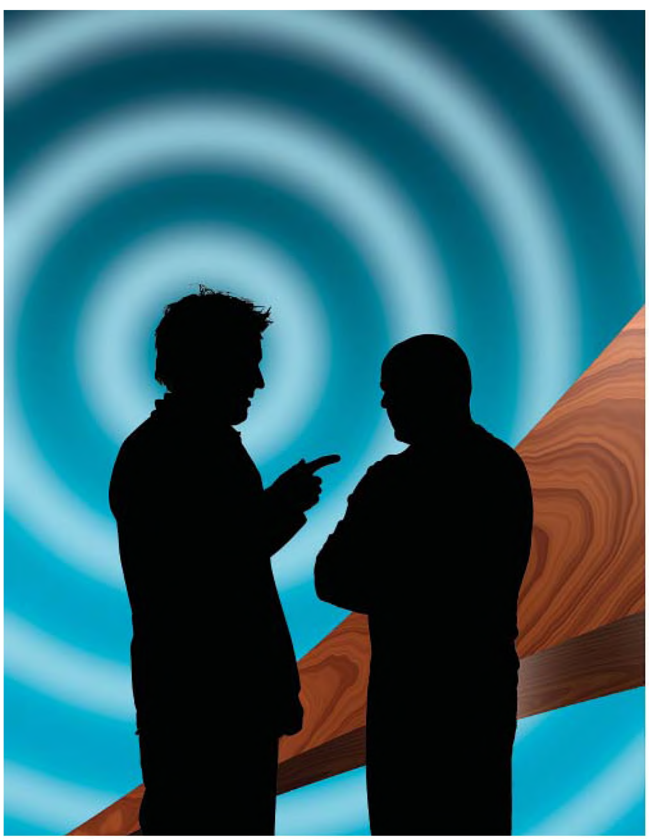

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THE CANADIAN ACOUSTICAL ASSOCIATION
P.O. BOX 1351, STATION "F"
TORONTO, ONTARIO M4Y 2V9

L'ASSOCIATION CANADIENNE D'ACOUSTIQUE
C.P. 1351, SUCCURSALE "F"
TORONTO, ONTARIO M4Y 2V9

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EDITORIAL / ÉDITORIAL

Once again, it is your Editor-in-Chief's turn to present the March 2011 issue of the Canadian Acoustics Journal. The last time I wrote the editorial was for the Proceedings of the Acoustic Week in Canada 2009 conference that was held in bucolic Niagara-on-the-lake, Ontario, as I was the Conference Chair.

It is a pleasure to introduce the March 2011 issue as it pertains to the special area of Building Acoustics. Canada has a vibrant acoustical community that works in diverse areas of acoustics. Building Acoustics is no exception. From major research institutions to private firms and universities, the output of the research in Building Acoustics has travelled beyond Canada and won international recognition. The researchers from the National Research Council of Canada serve on international associations as editors and preparers of standards. Consultants from private firms work on international projects such as concert halls and building design. The diverse nature of the five papers, all from Canada, speak to the vibrant activity in Building Acoustics in Canada – three are from Universities, one from the National Research Council of Canada and the final paper is from a consulting company in Alberta.

Murray Hodgson of the University of British Columbia will present his work on the aspect (or lack of it) of acoustics in sustainable buildings. John Bradley and Brad Gover of the National Research Council of Canada will present his results on speech security/privacy of closed rooms. Novak and his students from the University of Windsor will discuss the results, both simulation and experimental, of the acoustics of a lecture theatre. Ben Gaum and Ramani Ramakrishnan of Ryerson University discuss the formal exploration of the impact of sound on form. Kevin Packer and Clifford Faszer of FFA Consultants in Acoustics and Noise Control Ltd. Of Calgary will present the results of the study conducted of a gymnasium in Alberta. Finally, the impact of the location of sources in test chamber is presented by Ryerson University's Ramani Ramakrishnan.

I will be stepping down as Editor-in-Chief in 2012. A new Editor will be elected during the Annual General Meeting (AGM) in October 2012 and will become the new Editor-in-Chief from 2013 onwards. CAA is looking for an Assistant Editor who will work with Ramani Ramakrishnan and will be trained to be the next Editor. He or she will be nominated during the 2012 AGM and it is hoped that the membership will vote him/her to be the Editor-in-Chief. This will aid in the smooth transition from Ramani Ramakrishnan to the new Editor. Interested person should contact either the president, Christian Giguère or Ramani Ramakrishnan.

Ramani Ramakrishnan
Editor-in-Chief

Une nouvelle fois, c'est au tour de votre rédacteur en chef de présenter la parution du journal de l'association canadienne d'acoustique de mars 2011. La dernière fois que j'écrivais l'éditorial, c'était pour les comptes rendus de la semaine de l'acoustique canadienne de 2009 dont la conférence s'est tenu dans la bucolique ville de Niagara-on-the-Lake en Ontario et en tant que président de la conférence.

C'est un plaisir de vous présenter la parution de mars 2011 étant donné qu'il a trait au domaine de l'acoustique du bâtiment. Le Canada possède une communauté acoustique dynamique qui œuvre dans les divers domaines de l'acoustique ; L'acoustique du bâtiment n'est pas une exception. Des principaux centres de recherches aux entreprises privées et universités, les travaux de recherche en acoustique du bâtiment se sont répandu au-delà du Canada et ont gagné une reconnaissance internationale. Les chercheurs du Conseil National de Recherches Canada interviennent dans la préparation et la rédaction de normes pour des associations internationales. Des conseillers de compagnies privées travaillent sur des projets internationaux tels que la conception de salles de concert et de bâtiments. La diversité des cinq articles, tous canadiens, témoigne du dynamisme de l'acoustique du bâtiment au Canada; trois proviennent d'universités, un du Conseil National de Recherches Canada et le dernier article d'une entreprise de consultation en Alberta.

Murray Hodgson de l'université de Colombie Britannique présentera son travail portant sur la partie « acoustique » (ou l'absence de celle-ci) dans les bâtiments dits « durables ». John Bradley et Brad Gover du Conseil National de Recherches Canada présenteront leurs résultats sur l'intimité acoustique et la confidentialité dans les lieux clos. Novak et ses étudiants de l'université de Windsor discuteront des résultats des simulations et expérimentations de l'acoustique d'un amphithéâtre universitaire. Ben Gaum et Ramani Ramakrishnan de l'université Ryerson discuteront de l'exploration formelle de l'effet du son sur la forme. Kevin Packer et Clifford Faszer de FFA Consultants in Acoustics and Noise Control Ltd. à Calgary présenteront les résultats de l'étude d'un gymnase en Alberta. Enfin, l'effet de l'emplacement des sources dans une chambre d'essai sera présenté par Ramani Ramakrishnan de l'université de Ryerson.

Je me retirerai de la fonction de rédacteur en chef en 2012. Un nouveau rédacteur sera élu pendant l'assemblée générale annuelle en octobre 2012 et deviendra le nouveau rédacteur en chef à partir de 2013. L'ACA est à la recherche d'un(e) rédacteur(trice) en chef adjoint qui travaillera avec Ramani Ramakrishnan et sera formé(e) pour être le(la) prochain(e) rédacteur(trice). Il ou elle sera nommé(e) lors l'assemblée générale annuelle de 2012 et il est à espérer que les membres l'éliront comme le(la) rédacteur(trice) en chef. Cela facilitera la transition en douceur entre Ramani Ramakrishnan et le(la) nouvel(le) rédacteur(trice).

Les personnes intéressées sont invitées à contacter le président, Christian Giguère ou Ramani Ramakrishnan.

Ramani Ramakrishnan, Rédacteur en chef

POSITION OPEN - Assistant Editor, Canadian Acoustics Journal

The current Editor-in-Chief, Ramani Ramakrishnan, will be stepping down in 2012. A new Editor will be elected during the Annual General Meeting (AGM) in October 2012 and will become the new Editor-in-Chief from 2013 onwards. CAA is looking for an Assistant Editor who will work with Ramani Ramakrishnan and will be trained to be the next Editor. He or she will be nominated during the 2012 AGM and it is hoped that the membership will vote him/her to be the Editor-in-Chief.

The current proposal is to aid in the smooth transition from Ramani Ramakrishnan to the new Editor.

Interested person should contact either the president, Christian Giguère or Ramani Ramakrishnan.

SPEECH PRIVACY CRITERIA FOR CLOSED ROOMS IN TERMS OF SPEECH PRIVACY CLASS (SPC) VALUES

J.S. Bradley and B.N. Gover

Institute for Research in Construction, National Research Council, Montreal Rd. Ottawa, K1A 0R6

ABSTRACT

This paper describes a new set of speech privacy criteria in terms of Speech Privacy Class (SPC) values. SPC values can be used to specify the required speech privacy for new construction or to assess the speech privacy of existing closed rooms. The ASTM E2638 measurement standard defines SPC as the sum of the measured average noise level at the position of a potential eavesdropper outside the room, and the measured average level difference between a source room average and the transmitted levels at the same location. With a given combination of level difference and ambient noise level, the likelihood of transmitted speech being audible or intelligible can be related to the probability of higher speech levels occurring in the meeting room, based on the statistics of speech levels from a large number of meetings. For a particular SPC, there is a speech level for which transmitted speech would be at the threshold of intelligibility. The probability of higher speech levels occurring is the probability of a speech privacy lapse at that SPC value. A set of increasing SPC values corresponding to increasing speech privacy are proposed and for each SPC value, one can give the probability of transmitted speech being either audible or intelligible. This makes it possible to accurately specify speech privacy criteria for meeting rooms and offices, varying from conditions of quite minimal to extremely high speech privacy, with an associated risk of a speech privacy lapse which is acceptable for each situation.

RÉSUMÉ

Cet article décrit un nouvel ensemble de critères de confidentialité des entretiens relié au degré de confidentialité verbale (*Speech Privacy Class - SPC)*. Cette échelle de confidentialité peut servir à définir le niveau de confidentialité requis des nouvelles constructions ou d'évaluer la confidentialité de pièces fermées déjà existantes. La norme ASTM E2638 définit le SPC comme étant la somme du niveau de bruit moyen mesuré à l'emplacement d'une éventuelle écoute clandestine à l'extérieur de la pièce avec la différence de niveau moyen mesuré entre la moyenne d'une pièce source et les niveaux transmis au même emplacement. Pour une combinaison donnée de différence de niveau et de niveau de bruit ambiant, la probabilité d'audibilité ou d'intelligibilité du discours transmis peut être reliée à la probabilité de niveaux de discours plus élevés, ce qui se passe dans les salles de réunion, basé sur les statistiques de niveaux de discours d'un grand nombre de réunions. Pour une valeur du SPC, il existe un niveau de discours pour lequel le discours transmis serait au seuil de l'intelligibilité. La probabilité qu'un niveau de discours plus élevé se produise est égale à la probabilité d'une déchéance de confidentialité pour cette valeur du SPC. Un ensemble de valeurs plus élevées du SPC correspondant à une confidentialité accrue est proposé et pour chaque valeur, on peut donner la probabilité d'audibilité ou d'intelligibilité du discours transmis. Ceci permet de déterminer de façon précise des critères de confidentialité du discours pour les salles de réunion et les bureaux, allant des conditions minimales aux conditions extrêmes de confidentialité, avec un risque associé de perte de confidentialité acceptable pour telle ou telle situation.

1. INTRODUCTION

This paper describes a new set of criteria for rating the speech privacy of closed rooms. A closed room provides speech privacy when it is difficult for eavesdroppers outside the room to understand or in some cases to even hear speech from the room. The degree of speech privacy can vary from being able to understand some but not all of the words spoken in the room at positions outside the room, to cases where it is very rarely possible to understand any of the words. It is also possible to have even higher privacy where it is difficult, or even impossible, to hear any speech sounds from the adjacent closed room. Very high speech privacy is often referred to as speech security.

Although it is often desirable to have some degree of speech privacy, achieving very high privacy can be costly. Consequently, the amount of speech privacy should be designed to meet the needs of each particular situation. Usually the required degree of speech privacy is determined by how sensitive the information is that is to be discussed in the room.

The likelihood of a speech privacy lapse can be described statistically and for a particular construction can be related to the probability of higher speech levels occurring in the closed room. Where more sensitive information is to be discussed, higher privacy is required to minimize the risk of the loss of more critical information.

In this paper, a set of speech privacy criteria is described that makes it possible to match the probability of a privacy lapse to the severity of the consequences of the loss of information in each situation.

2. SPEECH PRIVACY BASICS

The intelligibility of speech decreases with decreasing speech-to-noise ratios at the position of the listener. Thus constructions that better attenuate the transmission of speech sounds will lead to reduced signal-to-noise ratios at positions of potential eavesdroppers and hence to increased speech privacy. The question is how to weight the importance of the attenuation of speech sounds and the reslting signal-to-noise ratios as a function of frequency. There are many different ways to combine the influence of different frequencies in calculating signal-to-noise ratios, but our research [1] has shown that values of uniform-weighted, frequency-averaged, signal-to-noise ratios over speech frequencies (SNR_{uni32}) best predict the audibility and intelligibility of speech transmitted through various walls. SNR_{uni32} at the position of the listener is given by,

$$SNR_{uni32} = \frac{1}{16}\sum_{f=160}^{5000}\{L_{ts}(f) - L_n(f)\}_{-32} \qquad (1)$$

Where in each ⅓-octave band centred at frequency f,

L_{ts} = transmitted speech level,

L_n = ambient noise level,

-32 indicates that all $\{L_{ts}(f) – L_n(f)\}$ differences are clipped to never be less than -32, at which point speech would be inaudible.

Figure 1 illustrates a plot of average speech intelligibility scores (over 19 listeners) versus SNR_{uni32} values from the previous work [1]. The previous work also found SNR_{uni32} values corresponding to the thresholds of audibility and of intelligibility of transmitted speech sounds which are given in Table 1. These are the SNR_{uni32} values at which 50% of a panel of attentive listeners could just detect speech sounds or could just understand at least one word of short low predictability test sentences. These threshold values can be used to set design goals for particular situations.

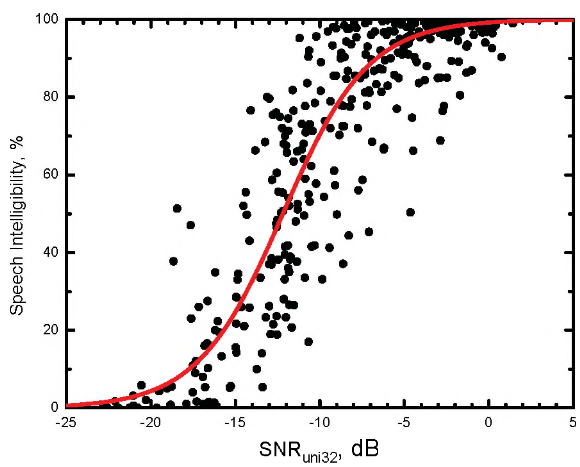

***Figure 1**. Mean speech intelligibility scores versus SNR_{uni32} values for speech sounds modified to simulate transmission through walls,* (R^2 = 0.750, n=500) [1].

SNR_{uni32}	Threshold
-16 dB	Intelligibility
-22 dB	Audibility

***Table 1.** Thresholds of Intelligibility and of Audibility of transmitted speech sounds [1].*

Subsequent work showed that although the threshold of audibility was not affected, reflected sounds in rooms could affect the threshold of intelligibility [2]. However, these effects would not be significant for most meeting room type spaces with reverberation times of no more than about 0.5 s. In more reverberant situations, the threshold of intelligibility can be increased a few dB.

In earlier speech privacy studies, the Articulation Index (AI) was used to rate the speech privacy of closed rooms [3]. Recently various speech privacy measures were compared [4], and the comparison of AI and SNR_{uni32} values is shown in Figure 2. These results suggest *Confidential Privacy* (AI ≤ 0.05) is equivalent to an SNR_{uni32} value of about -14 dB. This would approximate the threshold of intelligibility in a slightly reverberant environment [2]. This illustrates approximate agreement between the old and the new approaches for rating speech privacy, However, Figure 2 also illustrates the limitation of AI values in that they approach asymptotically to 0 for low values indicative of high speech privacy. That is, AI values do not differentiate well among cases of high privacy and cannot be used to describe very high privacy where AI would be essentially zero.

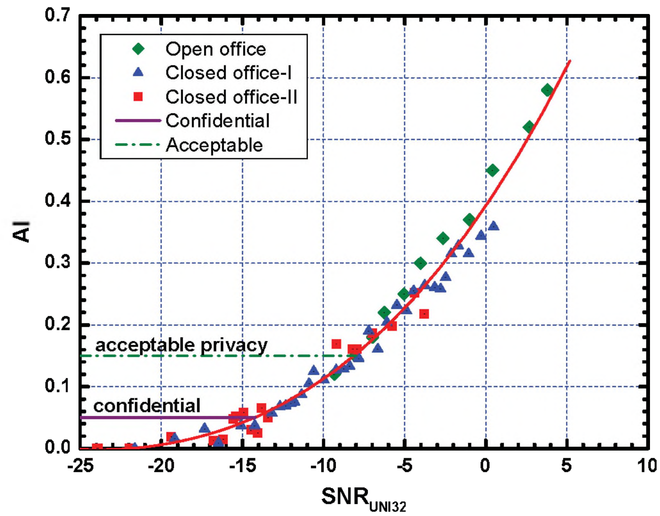

***Figure 2.** Plot of AI values versus SNR_{uni32} values for data from 3 previous studies. The horizontal solid and dash-dot lines indicate the confidential (AI = 0.05) and acceptable (AI = 0.15) speech privacy criteria respectively [4].*

Acceptable privacy in Figure 2 refers to acceptable conditions in open plan offices [5,6].

3. ASTM E2638 MEASUREMENT STANDARD

To evaluate the speech privacy of a room we need to be able to estimate SNR_{uni32} values at locations outside the room. A new procedure has been developed to do this and is described in the ASTM E2638 measurement standard [7]. The standard describes how to measure sound transmission from room average levels in the closed room to point receiver positions, usually 0.25 m from the outside of the room, in terms of frequency-averaged level differences (LD(avg)). Ambient noise levels are also measured at the same points outside the room in terms of frequency-averaged noise levels (L_n(avg)). In both cases '(avg)' indicates an arithmetic average over the speech frequency ⅓-octave band levels from 160 to 5000 Hz inclusive.

The speech privacy of a closed room will increase as either LD(avg) or L_n(avg) increases. The sum of these two quantities is defined as the Speech Privacy Class (SPC) which can be used to rate the speech privacy of closed rooms.

$$SPC = LD(avg) + L_n(avg) \quad (2)$$

Conventional sound transmission measurements between rooms (e.g. ASTM E336, ISO140 Part V) assume diffuse sound fields in both spaces and measure the average transmission characteristics of the separating partition. Conventional transmission loss tests (illustrated in the upper part of Figure 3) are based on the measurement of room average levels in both adjacent spaces.

The new ASTM E2638 procedure measures level differences from room average levels in the source room to spot receiver positions, usually 0.25 m from the outside of the meeting room (see lower part of Figure 3). A room average source level is used to represent the possibility of the talker being at any point in the meeting room. This is achieved by measuring average test sound levels in the room using a combination of multiple source and microphone positions.

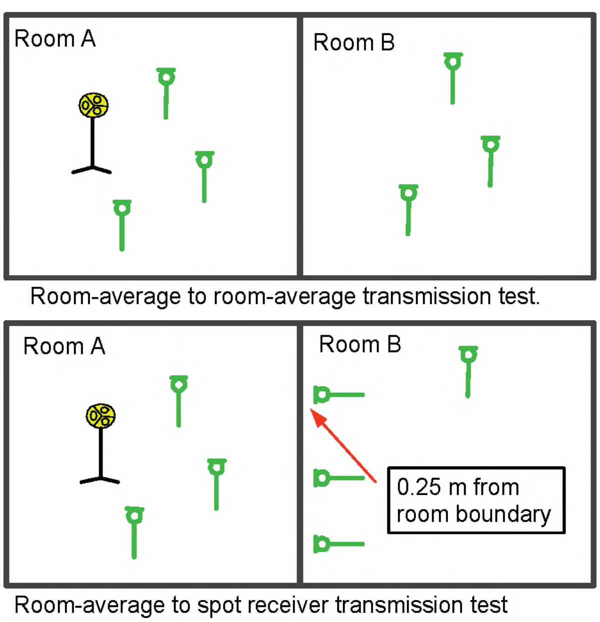

Figure 3*. Comparison of ASTM E2638 method (lower) to that of conventional sound transmission measurements (upper). In both cases room average levels are measured in the source room (Room A). Although room average levels are also measured in the receiving space for conventional transmission tests (upper), the received levels are measured at spot receiver positions usually 0.25 m from the separating wall for the ASTM E2638 procedure (lower).*

Spot receiver positions in the adjacent space 0.25 m from the wall represent a worst case scenario for speech privacy where an eavesdropper would be most effective if positioned close to the outside of the room. The ASTM E2638 procedure does not assume a diffuse field in the receiving space and produces measured level differences that will vary from one point to another to indicate the likely variations in the speech privacy of the room boundary. The measurements at spot receiver positions close to the outer wall of the room are little influenced by the acoustical properties of the adjacent space making it possible to measure into almost any adjacent space.

4. Speech Level Statistics and the Probability of a Speech Privacy Lapse

For a given situation (i.e. for a particular combination of LD(avg) and L_n(avg) values), the likelihood of a speech privacy problem is related to the probability of higher speech levels occurring in the meeting room. If we can describe the statistical distribution of speech levels in typical meetings and meeting rooms, we can determine the probability of a speech privacy lapse in terms of the likelihood of speech levels exceeding either the threshold of audibility or the threshold of intelligibility at receiver positions in an adjacent space.

Information to describe the statistics of speech levels in meetings was obtained by placing data loggers around the periphery of meeting rooms for 24 hour periods. The data loggers recorded 10 s L_{eq} values throughout 24 hour periods. The 10 s L_{eq} values recorded during meetings were used to investigate speech levels in meeting rooms [8]. Table 2 gives a summary of the meetings and rooms measured. Few systematic effects of the variations in speech levels with the properties of the rooms and their occupants were found.

In rooms with sound reinforcement systems, average levels were only about 2 dB higher than in rooms without sound amplification. The effect of sound reinforcement systems was minimal because speech levels were measured around the periphery of the rooms to represent speech levels incident on the room boundaries. This suggests that the sound reinforcement systems were adjusted to provide levels, at more distant locations in the larger rooms, that were similar to the speech levels found in smaller rooms without sound amplification.

Spot receiver positions in the adjacent space 0.25 m from the wall represent a worst case scenario for speech privacy where an eavesdropper would be most effective if positioned close to the outside of the room. The ASTM E2638 procedure does not assume a diffuse field in the receiving space and produces measured level differences that will vary from one point to another to indicate the likely variations in the speech privacy of the room boundary. The measurements at spot receiver positions close to the outer wall of the room are little influenced by the acoustical

properties of the adjacent space making it possible to measure into almost any adjacent space.

Meeting and room parameters	**Values**
Number of meeting room cases* measured	32
Number of meetings measured	79
Number of people in each meeting	2 to 300 people
Range of room volumes	39 to 16,000 m^3
Range of room floor areas	15 to 570 m^2

Table 2. *Summary of meetings and meeting rooms measured (*includes 30 different rooms, 2 of which were measured with and without sound amplification systems).*

Average meeting speech levels were found to increase systematically with ambient noise levels. Ambient noise levels were measured in terms of L_{eq} values when the rooms were unoccupied and as L_{90} values when the rooms were occupied. The two approaches gave very similar values [8]. The plot of increasing speech levels with increasing ambient noise levels (in terms of L_{90} values in this case) in Figure 4 is an example of the Lombard effect [9]. Low ambient noise levels in meeting rooms are important for good intelligibility in the room, but also so that speech levels are lower and less likely to cause speech privacy problems at points outside the room. This is a very important result indicating why it is so important to have very low ambient levels in meeting rooms. Consequently the practice of adding masking sound to meeting rooms is particularly problematic because it will decrease speech intelligibility within the room and decrease speech privacy to positions outside the room.

The statistical characteristics of speech levels in meeting rooms were determined by creating a cumulative probability distribution plot of the 10 s L_{eq} values of speech levels during all meetings. The distribution of all 110 773 L_{eq} values is shown in Figure 5.

From the probabilities of the occurrence of various speech levels in Figure 5, one can calculate the corresponding average time interval between occurrences of particular speech levels taking into account the 10 s duration of each L_{eq} measurement of speech levels. Each probability indicates the frequency of occurrence of all speech levels up to and including the corresponding speech level on the x-axis. For example, a 90% probability corresponds to a speech level of 64.5 dBA, indicating that 90% of the time 10 s speech L_{eq} values would be no higher than 64.5 dBA. Hence, 10% of the time this speech level would be exceeded. There are 360 intervals of 10 s duration in one hour and this would correspond to speech levels exceeding 64.5 dB in 36 of them. On average there would be a 60 min / 36 = 1.67 minute interval between times when the 64.5 dBA speech level is exceeded.

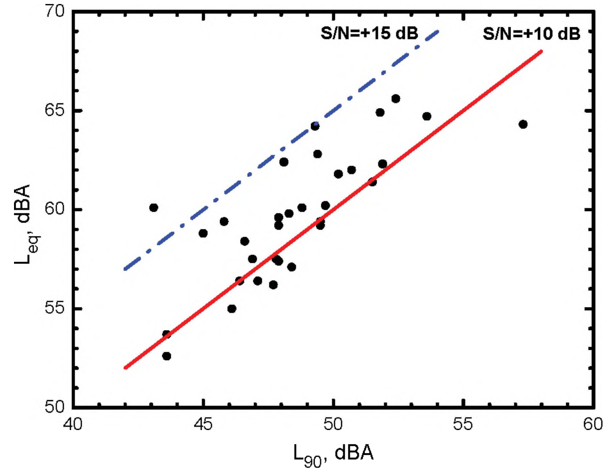

Figure 4. *Meeting-average speech levels (L_{eq}) versus ambient noise levels in the meeting rooms (L_{90}). The solid diagonal line shows situations with a +10 dB speech-to-noise ratio and the dash-dotted line shows the more ideal conditions for good intelligibility of a +15 dB speech-to-noise ratio [8].*

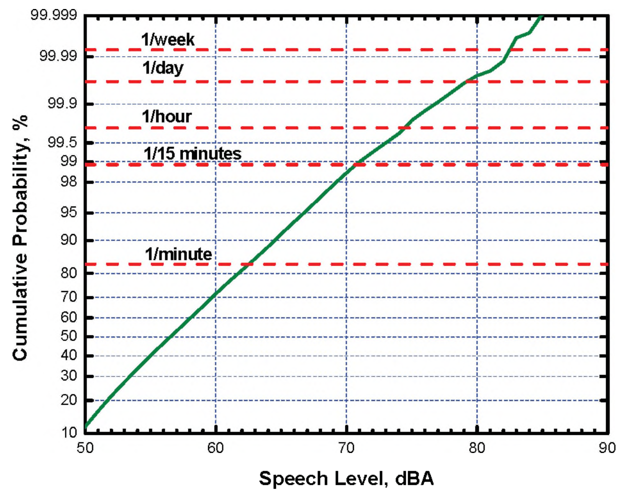

Figure 5. *Cumulative probability distribution of 10 s speech L_{eq} values for the combined data from 79 meetings. The labels on the horizontal dashed lines (1/minute to 1/week) indicate the frequency of occurrence of the particular 10 s speech L_{eq} values.*

5. Speech Privacy Class (SPC) Criteria

Speech privacy criteria can be given in terms of Speech Privacy Class (SPC) values (equation (2)). For each SPC value the probability of transmitted speech exceeding either the threshold of audibility or the threshold of intelligibility can be determined to describe the related likelihood of a privacy lapse. The audibility or intelligibility of speech can be related to the uniformly-weighted, frequency-averaged, signal-to-noise ratios (SNR_{uni32}), defined in equation (1). Table 1 gives SNR_{uni32} values for the thresholds of audibility and intelligibility of transmitted speech.

First we re-write equation (1) by replacing $L_{ts}(f)$ (the transmitted speech level) by, $L_{sp}(f)$-LD(f), (the source room speech level less the measured level difference from the average level in the room to the level at a receiver outside the room).

$$SNR_{uni32} = \frac{1}{16}\sum_{f=160}^{5000}\{L_{sp}(f) - LD(f) - L_n(f)\}_{-32} \quad (3)$$

If we assume that the -32 dB clipping of the quantity in the curly brackets is usually not very important and can be neglected, then equation (3) can be simplified to equation (4).

$$SNR_{uni32} \approx L_{sp}(avg) - LD(avg) - L_n(avg) \quad (4)$$

In equation (4) '(avg)' indicates arithmetic averaging of the ⅓-octave band values over the speech frequencies from 160 to 5000 Hz inclusive. This can be rearranged to the following,

$$LD(avg) + L_n(avg) \approx L_{sp} - SNR_{uni32} \quad (5)$$

Finally, we usually want to design so that conditions meet or are below the threshold of intelligibility. From Table 1, this corresponds to an SNR_{uni32} of -16 dB or lower. The left side of equation (5), ($LD(avg) + L_n(avg)$) is the Speech Privacy Class (SPC). Substituting SNR_{uni32} = -16, we then have,

$$L_{sp} \leq SPC - 16 \quad (6)$$

This tells us that for each situation (i.e. SPC value) there is a corresponding meeting room speech level that when exceeded will lead to intelligible speech at points immediately outside the room. Lower speech levels would not be expected to be intelligible at points outside the room. If the corresponding meeting room speech level in equation (6) is quite high, it will not occur very often and the room will have a reasonably high degree of speech privacy. Using Figure 5 we can say how often a particular speech level will occur and hence from equation (6) and knowledge of the SPC value, we can say how often speech transmitted from the room is likely to be intelligible. We could alternatively use the more stringent criterion for the threshold of audibility (SNR_{uni32} = -22 dB) and describe how often speech from the room would be just audible to an eavesdropper even though not intelligible.

SPC	Time between intelligibility lapses	Time between audibility lapses
60	0.32 min	-
65	0.76 min	-
70	2.87 min	0.62 min
75	18.03 min	2.09 min
80	2.28 hours	12.54 min
85	15.30 hours	1.53 hours
90	-	11.22 hours

Table 3. *Summary of expected average time intervals between intelligibility and audibility lapses for Speech Privacy Class, SPC, values from 60 to 90.*

Average expected intervals between intelligibility and audibility lapses were calculated for a range of SPC values [8] and are included in Table 3. To help the reader estimate other intervals between various speech levels occurring, Figure 5 includes horizontal dashed lines to indicate various reference intervals (e.g. 1/minute to 1/week).

6. SPC Values and Their Application

Using the procedure described above, the risks of exceeding the thresholds of audibility and of intelligibility were determined for a range of SPC values. These are given for 5 different SPC values at 5 point intervals in Table 4. How often transmitted speech would be audible or intelligible is described in words that are explained in the legend below the table. It is seen that the 5 SPC values correspond to a wide range of conditions from quite minimal speech privacy to extremely high speech privacy.

In practice the 3 SPC values 75, 80 and 85 are probably of most practical use for closed rooms. Values of 90 and higher would correspond to essentially inaudible speech and values of 70 and lower would suggest very little privacy for a closed room. The 5 point SPC intervals represent a suitable perceptually small but significant interval.

Speech privacy criteria would usually be determined by the most sensitive type of information to be discussed in the room. Proposed speech security criteria for use in Canadian federal government buildings would specify minimum SPC values of 75, 80 and 85 for rooms where Protected, Secret and Top Secret information is to be discussed respectively. For more sensitive information, unique analyses would be required for each case.

Category	SPC	Description
Minimal speech privacy	70	Frequently intelligible
Speech privacy	75	Occasionally intelligible, and frequently audible
Speech security	80	Very rarely intelligible, and occasionally audible
High speech security	85	Essentially not intelligible, and very rarely audible
Very high speech security	90	Unintelligible and essentially inaudible

Legend	
Frequently:	about 1 per 2 minutes
Occasionally:	about 1 per 15 minutes
Very rarely:	about 4 per 8 hours
Essentially not:	about 1 per 16 hours

Table 4. *Speech Privacy Categories (SPC) and the related risk of speech being audible or intelligible.*

To rate the privacy of existing rooms one can measure $LD(avg)$ and $L_n(avg)$ to determine the SPC of the room at particular locations [10]. The resulting SPC value can be interpreted in terms of the SPC categories in Table 4.

7. DESIGNING TO ACHIEVE A SPECIFIC SPC RATING

This section describes how one can design to achieve specific SPC ratings from TL(avg) values and lowest likely L_n(avg) values. Table 5 shows how the intermediate levels of privacy (SPC = 75, 80 and 85) relate to combinations of LD(avg) and L_n(avg). The three columns to the left of Table 5 give results for 3 different ambient noise levels referred to as "very quiet", "quiet" and "moderate noise". Ambient noise levels are given in terms of L_n(avg) values and are also converted to approximate A-weighted levels (L_n(A)). The conversion assumed a neutral noise spectrum decreasing at 5 dB per octave with increasing frequency. Below the ambient noise levels in Table 5, there are 3 rows of TL(avg) values (i.e. frequency-averaged transmission loss values). These have been empirically related to LD(avg) values [11],

$$TL(avg) \approx LD(avg) - 1 \qquad (7)$$

This relationship makes it possible to estimate the sound isolation of particular building elements from laboratory sound transmission loss test results. Finally, to the right of the TL(avg) values are the SPC values corresponding to the combination of the L_n(avg) values and the corresponding TL(avg) values in each row (as per equation (7)).

The highlighted cells in Table 5 show the values of L_n(avg) = 24 dB and an as-built TL(avg) = 55 combining to give an SPC = 80 which provides a high degree of speech privacy described as "Speech security". In Table 4 this SPC value is described as corresponding to conditions where transmitted speech would be "Very rarely intelligible, and occasionally audible". From an analysis of the relationship between TL(avg) and STC values obtained from laboratory measurements of wood and light weight steel stud wall constructions, TL(avg) = 55 is approximately equal to an STC rating of 51. However, this is only a very approximate relationship, and the STC values are included in Table 5 only to help readers relate to the new TL(avg) values. These results suggest that with an as-built SPC rating of 80, quite high speech privacy can be achieved using relatively common constructions.

Of course the degree of speech privacy is also influenced by the ambient noise levels at the receiver position. In the above example a little higher noise level could provide very high speech privacy, but much quieter conditions would make it very difficult to achieve high speech privacy.

For existing buildings it is usually possible to measure the actual ambient noise levels in spaces adjacent to meeting rooms. Such measurements should be over a long enough time interval to be able to indicate the lowest likely ambient levels when the room is in use. When lowest likely ambient noise levels cannot be measured, we can estimate them from previous measurements of noise levels in spaces adjacent to meeting rooms over 24 hour periods. When the lowest likely ambient noise level is taken to be the lowest 1 percentile level, the values shown in Table 6 were found for the day, evening and night periods [12].

Ambient noise levels				
Very quiet	Quiet	Moderate noise		
14	24	34	⇦ L_n(av)	
25	35	45	⇦ L_n(A)	
TL(avg) ≈ LD(avg)-1			SPC	Description
60	50	40	75	Speech privacy
65	55	45	80	Speech security
70	60	50	85	High speech security

Table 5. *Combinations of TL(avg) and L_n(avg) for some SPC values of 75, 80 and 85.*

Period	Level, dBA	Level, L_n(avg)
Day (8:00 to 17:00)	35	24
Evening (17:00 to 24:00)	30	19
Night (24:00 to 8:00)	25	14

Table 6. *Estimates of lowest likely ambient noise levels in spaces adjacent to meeting rooms for 3 different time-of-day periods [12].*

8. WHY NOT USE STC RATINGS?

The SNR_{uni32} measure was developed from listening tests in which subjects rated the audibility and intelligibility of speech modified to represent transmission through walls [1]. Equations (3), (4) and (5) show that this leads to the recommendation to use LD(avg) values to rate the attenuation of speech sounds from meeting rooms to adjacent spaces. Equation (7) shows the approximate conversion from LD(avg) values to TL(avg) making it possible to predict privacy at the design stage. The success of the TL(avg) measure can be confirmed from the results of a second series of listening tests in which the speech was modified to simulate transmission through 20 different walls [13]. The walls included STC ratings from 34 to 58 representing a wide range of sound insulation conditions. In the experiment, ambient noise levels were held constant and the only source of variation was the varied transmission loss, TL(f), of the 20 simulated walls. With noise levels, L_n(avg), and speech source levels, L_{sp}(avg), held constant, equation (5) indicates that variations in transmitted speech levels are related only to LD(avg) values and consequently, according to equation (7), also to TL(avg) values.

Figures 6 and 7, from the results of [13], compare how well speech intelligibility scores were related to STC and TL(avg) values. Figure 6 shows that the intelligibility of transmitted speech was not well related to the STC ratings of the walls (R^2 = 0.510). By comparison, Figure 7 shows that the same speech intelligibility scores were much better predicted by TL(avg) values ($R^2 = 0.853$).

TL(avg) values are more accurate predictors of the assessed speech privacy provided by a wall. Using STC values to predict speech privacy could easily lead to costly over design of the sound attenuating properties of the wall, or perhaps to even more costly outcomes due to failure to achieve adequate speech privacy.

When TL(avg) values were plotted versus STC values for 74 types of stud walls, the resulting plot in Figure 8 shows a statistically significant relationship ($R^2 = 0.720$, n = 74) but with substantial scatter (RMS variation in TL(avg) values about the mean trend of ±3.05 dB). That is, for a given STC value there is a substantial range of possible TL(avg) values.

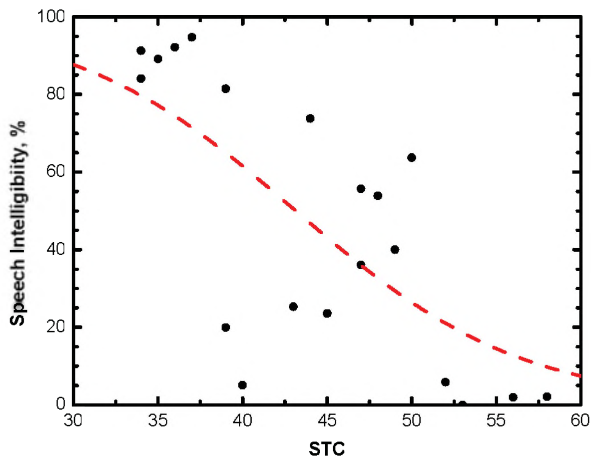

Figure 6. *Mean speech intelligibility scores versus STC ratings of 20 walls ($R^2 = 0.510$) [13].*

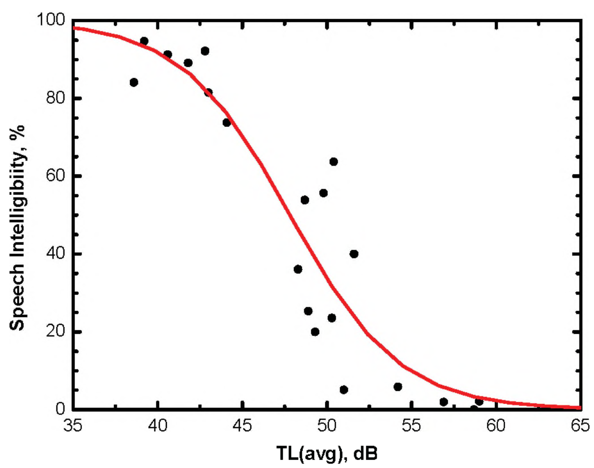

Figure 7. *Mean speech intelligibility scores versus* TL(avg) *ratings of 20 walls ($R^2 = 0.853$) [13].*

The solid lines on the graph represent possible speech privacy requirements in terms of either STC or TL(avg). The vertical line corresponds to conditions with STC 52, which has been a commonly used STC requirement for adequate speech privacy. The horizontal line, corresponding to TL(avg) values of 57 dB, represents a possible speech privacy recommendation using the new approach. The 11 data points that are plotted as open circles, or in one case as an 'X', are the conditions with TL(avg) values within 1 dB of 57 dB. It is seen that they correspond to STC values varying from 46 to 57. In some cases an STC 52 wall might provide adequate speech privacy, but in many cases it would not. It is important to select walls in terms of a desired TL(avg) value because it is much more likely to provide the expected degree of speech privacy.

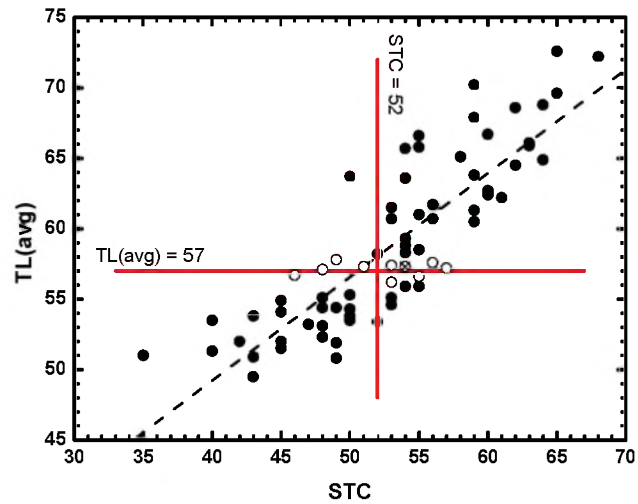

Figure 8. *Plot of mean TL(avg) versus mean STC for each of the 74 types of gypsum board walls.*

One can similarly more accurately assess speech privacy using ambient noise levels in terms of L_n(avg) values rather than A-weighted ambient noise levels. In previous research, [1,13] A-weighted signal-to-noise ratios have been found to be much less accurate predictors of the intelligibility of speech than SNR_{uni32} values based on L_n(avg) values.

9. Conclusions

The new SPC values provide a uniform system for rating all categories of speech privacy from very minimal privacy to extremely high speech security. SPC values can be measured to evaluate existing facilities or can be predicted for new facilities from laboratory tests of building elements. Of course to accurately predict the sound transmission from a meeting room to adjacent spaces in a real building, all sound paths must be considered. Flanking sound transmission via paths such as a common floor slab can severely limit the maximum possible sound isolation of a meeting room.

Although the procedures were developed for rating the speech privacy of meeting rooms, they could also be applied to other situations such as in health care facilities where speech privacy is often desired. To describe the risk of privacy problems in other situations such as health care facilities, it would be necessary to assess the probability of various speech levels occurring in those environments.

ACKNOWLEDGMENTS

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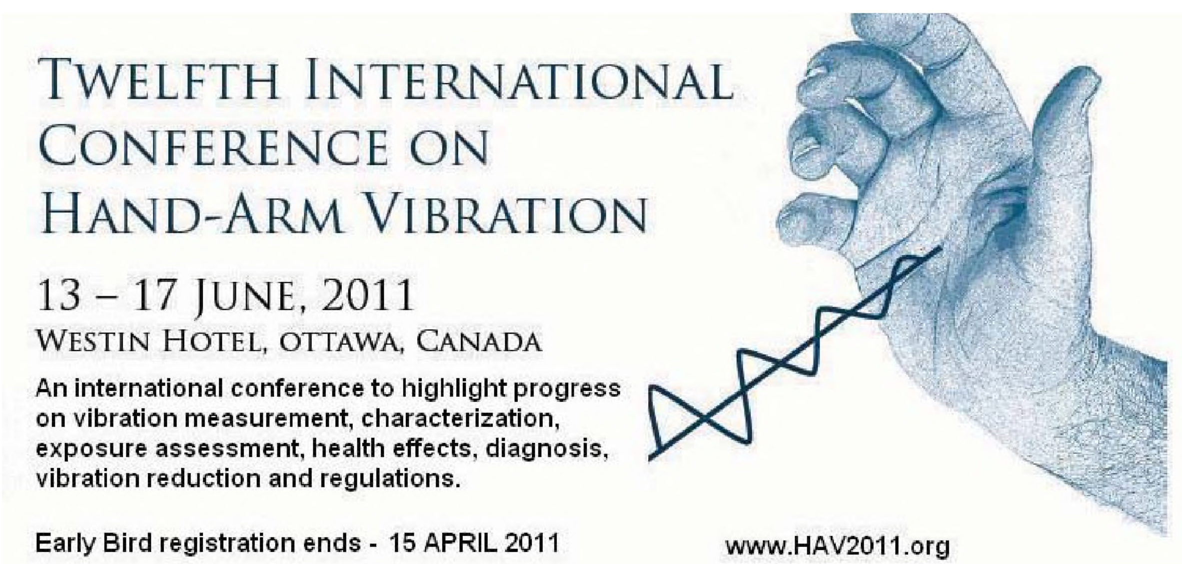


EVALUATION AND CONTROL OF ACOUSTICAL ENVIRONMENTS IN 'GREEN' (SUSTAINABLE) OFFICE BUILDINGS

Murray Hodgson
Acoustics & Noise Research Group, SOEH-MECH, University of British Columbia, Vancouver, BC, Canada

ABSTRACT

This paper discusses the increasing important issue of the acoustical design of 'green' (sustainable) buildings. Many 'green' buildings have unsatisfactory acoustical environments, according to their occupants. Work done at UBC to evaluate acoustical quality in 'green' office buildings and improve it by engineering control measures is reviewed. The problem of 'green'-building acoustics is introduced and its importance discussed. Details of the acoustical evaluation of six 'green' office buildings by occupant-satisfaction surveys and acoustical measurements are presented, and their implications for the design of 'green' buildings considered. A detailed study of one naturally-ventilated 'green' building is discussed. Pre-treatment survey and measurement evaluation results are presented. It is concluded that inadequate noise isolation due to natural-ventilation openings is a big problem. The design and post-treatment evaluation of noise-control measures to improve the noise isolation in two situations is discussed. Finally, other 'green'-building acoustical issues are noted, and conclusions are drawn as to where future work should be directed.

SOMMAIRE

Cet article présente une question hautement importante qu'est le design acoustique des bâtiments « verts » ou encore durables. De nombreux bâtiments verts possèdent un environnement acoustique insatisfaisant tels que rapportés par leurs occupants. Ici, nous rapportons une revue du programme de recherche accompli à UBC autour de ses bâtiments verts allant de leur évaluation acoustique à la proposition de solutions de contrôle en vue d'améliorer les environnements de travail. Le problème de l'acoustique des bâtiments verts est discuté ainsi que son amplitude. Des précisions sur l'évaluation de six bâtiments verts par des questionnaires et par des mesures sont rapportées suivi d'une discussion sur les implications quant au design de tels bâtiments. L'étude détaillée d'un bâtiment vert ventilé naturellement est discutée. Une enquête prétraitement et les mesures d'évaluation sont présentées. Il est conclu que l'isolation inadéquate du bruit due aux ouvertures créées par les ouvertures des ventilations naturelles pose un réel problème. Le design et l'évaluation post-traitement des mesures mises en place pour le contrôle du bruit sont discutés. Pour conclure, d'autres aspects autour de l'acoustique des bâtiments verts sont notés, et des indications ayant trait aux possibles directions que la recherche dans ce domaine devrait prendre sont suggérées.

1 INTRODUCTION

What does acoustics have to do with sustainable building? Surely, creating acoustical environments in 'green' buildings that the occupants find unsatisfactory *is not sustainable*!

The aim of sustainable ('green') architecture is to create buildings that preserve the environment and conserve natural resources, as well as provide a 'healthy' environment for its occupants. A 'healthy' environment is one that does not cause disease, that promotes well-being and, in the case of workplaces, that enhances productivity. An important aspect of the built environment—often overlooked or undervalued in design—is the acoustical environment. Recent papers [1, 8, 10, 14-16, 22, 23, 25, 26, 30], mainly at acoustical conferences with special sessions on 'green' building, have pointed out that 'green' buildings are often less than satisfactory acoustically, and have reported work devoted to the design, control and/or optimization of their acoustical environments [11, 13-15, 19, 24, 27-29]. The work discussed here was an attempt to investigate this issue more fully, with a focus on 'green' office buildings, and to increase awareness of 'green'-building acoustical issues in the non-acoustical design community.

So, who cares about the acoustical environments in their 'green' buildings? Well…apparently, for example, the occupants of a significant number of recent 'green' buildings at the University of British Columbia (UBC—which aims to be a world leader in sustainability research and practice), who have expressed concerns to the author about the acoustical environment. Of course, poor acoustical environments are not restricted to 'green' buildings; the occupants of numerous conventionally designed, non-'green' UBC buildings have contacted him with acoustical concerns. Acoustical consultants say that they increasingly are asked to resolve acoustical problems in 'green' buildings. In summary, there seem to be a lot of poor acoustical environments in 'green' (and non-'green') buildings; maybe we should do something about it!

To begin to do so has been the objective of recent work at UBC, much of it done in collaboration with Stantec Engineering/Architecture, Vancouver [www.stantec.com]. This paper presents details of the acoustical evaluation of six 'green' office buildings, the acoustical evaluation of one naturally-ventilated 'green' building (Liu) on the UBC campus, and the design and evaluation of engineered noise-control measures to improve the acoustical performance of Liu natural-ventilation openings. It then discusses other 'green'-building acoustical issues, draws conclusions and discusses where we should go from here.

2. ACOUSTICAL EVALUATION OF SIX 'GREEN' OFFICE BUILDINGS

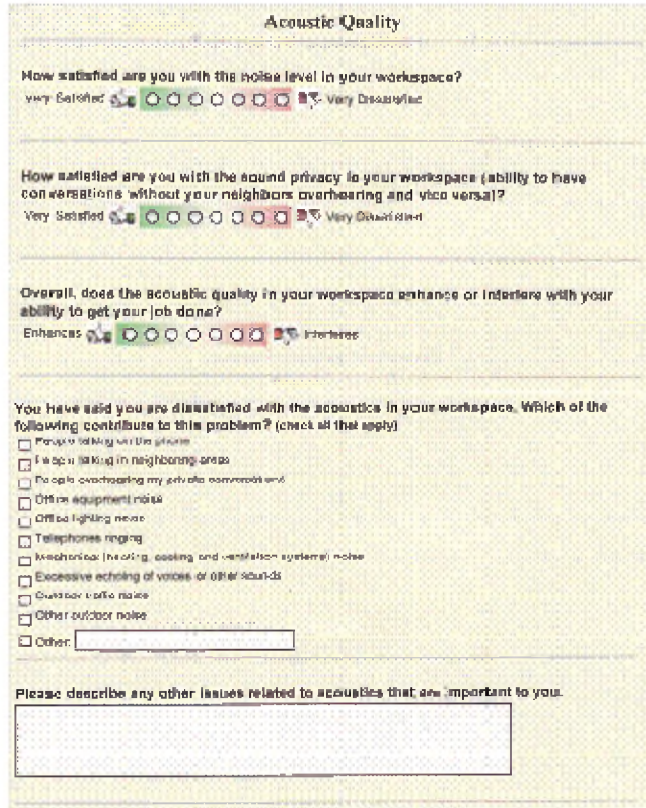
2.1 Objectives, Methodology and Study Buildings

The objective of this work was to evaluate six 'green' office buildings acoustically, to learn design lessons. It involved meetings with the designers, performing an occupant-satisfaction survey (using a web-based survey developed by the Center for the Built Environment at the University of California at Berkeley (www.cbe.berkeley.edu—Figure 1 shows the questions pertaining to the acoustical environment), analyzing the acoustical responses, walking through the building, planning acoustical measurements, performing and analyzing the acoustical measurements, and considering the design implications of the results.

The study involved six very different nominally-'green' office buildings, all designed to prevailing sustainable-development principles, evaluated 1-5 years after occupancy. Descriptions can be found elsewhere [www.ecosmart.ca/index.cfm?bd=kbdet.cfm&id=58]. All buildings had mainly glass façades for day-lighting, with sun shades and operable windows, and contained a mix of private and shared offices, and open-office cubicles.

2.2 Measurements and Acceptability Criteria

The objective here was to use physical-acoustical measurements to evaluate the acoustical environment, to explain the survey results, which identified situations (workplaces and building conditions) of high and low occupant satisfaction. Workplaces at which measurements were performed were chosen to correspond to high and low occupant satisfaction. In general, these included desks in open-plan, shared and private offices, which were located in quiet and noisy areas, near and far from operable windows. Furthermore, measurements were made under building conditions expected to correspond to high and low satisfaction (windows or doors closed or open, quiet or noisy external source). Table 1 shows the four acoustical parameters that were measured. Of particular interest is Speech Intelligibility Index [2] which quantifies speech intelligibility and privacy. Also shown are the acceptability criteria used to evaluate each aspect of the acoustical environments in these office buildings, chosen from information in various sources [3-5, 7].


Acoustic Quality

How satisfied are you with the noise level in your workspace?
Very Satisfied ○ ○ ○ ○ ○ ○ ○ Very Dissatisfied

How satisfied are you with the sound privacy in your workspace (ability to have conversations without your neighbors overhearing and vice versa)?
Very Satisfied ○ ○ ○ ○ ○ ○ ○ Very Dissatisfied

Overall, does the acoustic quality in your workspace enhance or interfere with your ability to get your job done?
Enhances ○ ○ ○ ○ ○ ○ ○ Interferes

You have said you are dissatisfied with the acoustics in your workspace. Which of the following contribute to this problem? (check all that apply)
- ☐ People talking on the phone
- ☐ People talking in neighboring areas
- ☐ People overhearing my private conversations
- ☐ Office equipment noise
- ☐ Office lighting noise
- ☐ Telephones ringing
- ☐ Mechanical (heating, cooling and ventilation systems) noise
- ☐ Excessive echoing of voices or other sounds
- ☐ Outdoor traffic noise
- ☐ Other outdoor noise
- ☐ Other:

Please describe any other issues related to acoustics that are important to you.

Figure 1: Occupant-satisfaction survey, CBE, UC Berkeley: acoustical quality.

2.3 Results

Designer meetings

Following are the main points relevant to acoustics learned from the designers at the meetings with them: LEED® certification is often a goal that influences design; design often does not involve specialized acoustical expertise—acoustical consultants deal with 'special cases'; quantitative acoustical design targets are never set; designers are aware

Table 1: Acoustical measurement parameters and acceptability criteria.

Measurement parameter	Acceptability criterion
Background noise level, NC in dB	NC 30-35 in meeting, conference rooms NC 35-40 in workspaces
Reverberation time (mid-frequency), RT_{mid} in s	< 0.75 s for comfort, verbal communication
Speech Intelligibility Index, SII	> 0.75 for high speech intelligibility < 0.2 for high speech privacy
Noise Isolation, NIC in dB	NIC 35-40 for executive offices, conference rooms NIC 30-35 for general offices, meeting rooms

of acoustical issues; external noise (and pollution) concerns may rule out a fully-natural ventilation concept; 'green' buildings often have operable windows, which causes noise concerns if there's an external noise source; low noise levels resulting from absence of a forced-air system result in low speech privacy; client's wishes (e.g. for open-office design) may affect design; budget short-falls at the end of the project may affect acoustical quality; obtaining good noise isolation involves lined return-air ducts, upholstered furniture, acoustical ceilings, carpet, open-office partitions; some buildings are designed for any occupant—the internal 'fit-up' (e.g. acoustical treatments) is done later by contractors for tenants (often on limited budgets); designers often believe their building is well designed, and is successful with its occupants.

Occupant-satisfaction surveys

The Berkeley survey asks occupants to rate their general satisfaction with the building and with their workspace, with the office layout, with the office furnishings, with thermal comfort, air quality, lighting, acoustical quality and with the washrooms. Occupants rated quality on a scale of -3 (maximum dissatisfaction) to +3 (maximum satisfaction).

Figure 2 shows the results of the occupant-satisfaction surveys done in five of the six buildings. Also shown (Ref) are the average scores from all buildings ('green' and non-'green') surveyed using the CBE survey. In general, satisfaction ratings were positive indicating satisfaction. Occupants were very satisfied with their buildings and workspaces, with the furnishings, office layouts, cleanliness and maintenance and with the washrooms. They were gener ally very satisfied with the lighting, and somewhat satisfied with air quality. Satisfaction with thermal comfort varied from somewhat satisfied to somewhat dissatisfied. Occupants were generally dissatisfied with the acoustical environment, which often received the lowest rating. Speech privacy was found to the biggest acoustical issue. The main sources of dissatisfaction with acoustical quality were: lack of privacy; HVAC noise; phone ringing; external noise; people moving and talking; office equipment; reverberation. Concerns were least in private offices, and greatest in open-plan and shared offices. They were greatest near (external) walls, and least far from walls.

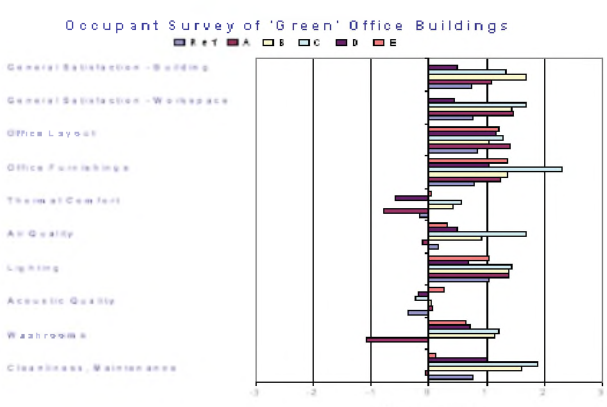


Figure 2: Occupant-satisfaction-survey results for 'green' office buildings.

Acoustical measurements

Following are the main results of the acoustical measurements:

- Background Noise Level: NC 26-34 (unoccupied, natural ventilation); NC 35-42 (unoccupied, forced-air ventilation); NC 45-60 (external noise, windows open); NC 40-60 (occupied);
- Reverberation Time: open-office areas: 0.6-1.0 s (low absorption); 0.2-0.4 s (high absorption); private offices: 0.4-0.7 s (low absorption); 0.2-0.4 s (high absorption); hallways, atriums: 0.9-2.4 s;
- Speech Intelligibility (private office, across desk, casual voice): 0.3-0.6 (forced-air ventilation, low absorption); 0.7-0.8 (natural ventilation, high absorption);
- Speech Privacy. Between open-office cubicles, casual voice): 0.3-0.6 (forced-air ventilation, low absorption); 0.7-0.8 (natural ventilation, high absorption). Outside-inside private office (door open, casual voice) = 0.7;
- Noise Isolation: into closed offices = NIC 25-30 (door closed), = NIC 9-15 (door open); between work areas = NIC 7-20.

Design implications

The main acoustical design implications of the results related to low background-noise levels, inadequate speech privacy, excessive reverberation, inadequate noise isolation between workplaces in open and shared work areas, and inadequate internal and external wall isolation. Following are details, divided into 'universal' issues applicable to any building, and specific 'green'-building issues:

'Universal' design issues:

- a design approach that assumes that acoustical issues are minimal and can be dealt with using the non-specialist knowledge of the design team, may not result in occupant satisfaction with the acoustical environment;
- locating an office building next to an external noise source makes noise complaints likely;
- operable windows significantly reduce the sound isolation provided by the building envelope, resulting in noise complaints;
- adequate sound isolation from outside to inside offices requires good acoustical design;
- shared offices inevitably lead to speech-privacy concerns. Private offices readily provide adequate speech privacy;
- open-plan office areas are acoustical challenges that require good acoustical design; the required speech privacy depends partly on the expectation and activities of the occupants;
- buildings with insufficient sound-absorbing materials have excessive reverberation, resulting in an acoustical environment which feels 'noisy', in which intermittent sounds (e.g., telephone ringing, door slams) are distracting, and which impairs verbal communication; it also results in low sound isolation between different work areas, allowing sound to propagate with little attenuation between them, causing noise problems;

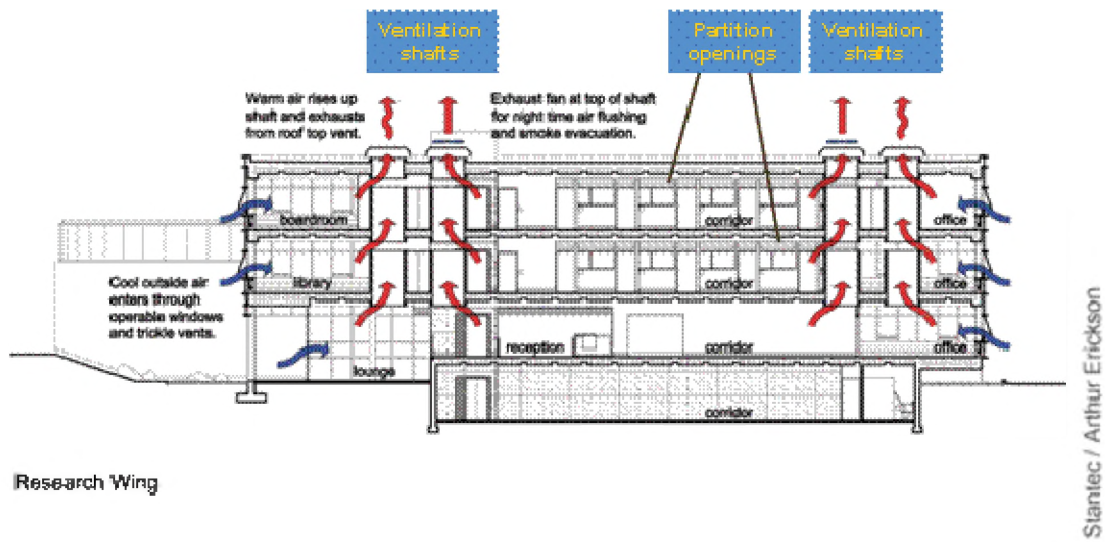


Figure 3: Elevation of the Liu building, showing components of its natural-ventilation system.

- one of the buildings housed an elementary school; school classrooms are acoustically critical spaces that require careful attention to the acoustical design—in particular, with respect to building, school and classroom layout, HVAC and equipment noise levels, noise isolation to adjacent spaces and reverberation times (consult ANSI Standard S12.60-2002 for more details).

'Green'-building design issues:

- since LEED® virtually ignores acoustics, a building designed to obtain LEED® certification is unlikely to have adequate attention paid to the acoustical environment;
- 'green' buildings often are designed to have natural/displacement ventilation systems. These can affect the acoustical environment beneficially or detrimentally, resulting in low background-noise levels and low noise isolation. However, forced-air ventilation *can* figure in 'green'-building design;
- many 'green' buildings have few sound-absorbing materials. This affects the acoustical environment detrimentally, resulting in excessive reverberation, low acoustical privacy and inadequate attenuation of sound propagating through the building. However, beneficial sound-absorbing materials *can* figure in 'green'-building design;
- since LEED® virtually ignores acoustics, a building designed to obtain LEED® certification is unlikely to have adequate attention paid to the acoustical environment;
- if a 'green' building, designed with a ventilation system relying on operable windows, is located next to significant noise source, noise problems are likely, especially if the windows open on the source side;
- a 'green' building designed to rely on a natural or displacement ventilation system, and with a transparent envelope for day-lighting, may overheat on hot, sunny days, forcing occupants to open windows and doors, causing excessive noise and low speech privacy;
- background-noise levels in a 'green' building with ful or partial natural-ventilation system may be lower tha as expected in a conventional building with a forced-ai system; these low levels may make it more difficult t achieve adequate speech privacy;
- a 'green' building designed to rely on a natural ventilation system usually involves air-transfe openings and/or ducts in partitions; these reduce nois isolation between areas, even when treated acoustically

3. ACOUSTICAL EVALUATION OF THI UBC LIU BUILDING

A detailed study was next made of one particular 'green office building—the naturally-ventilated, three-storey offic block of the Liu building on the UBC campus—no involved in the original study. Figure 3 is an elevatio drawing showing components of the natural-ventilatio system. Liu was again evaluated by occupant survey an acoustical measurement.

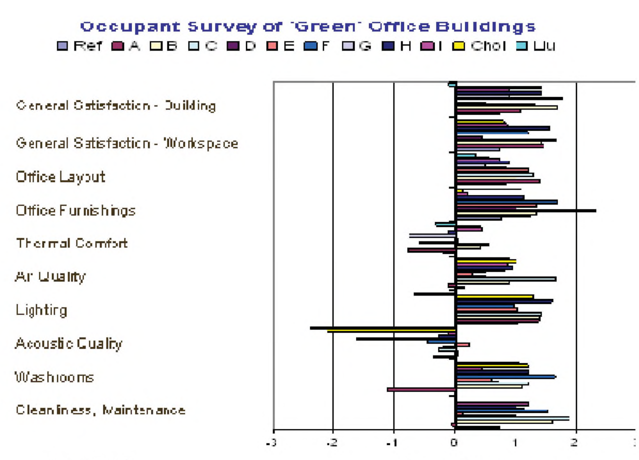


Figure 4: Occupant-satisfaction survey results for eleven 'green' office buildings, including Liu (and Choi).

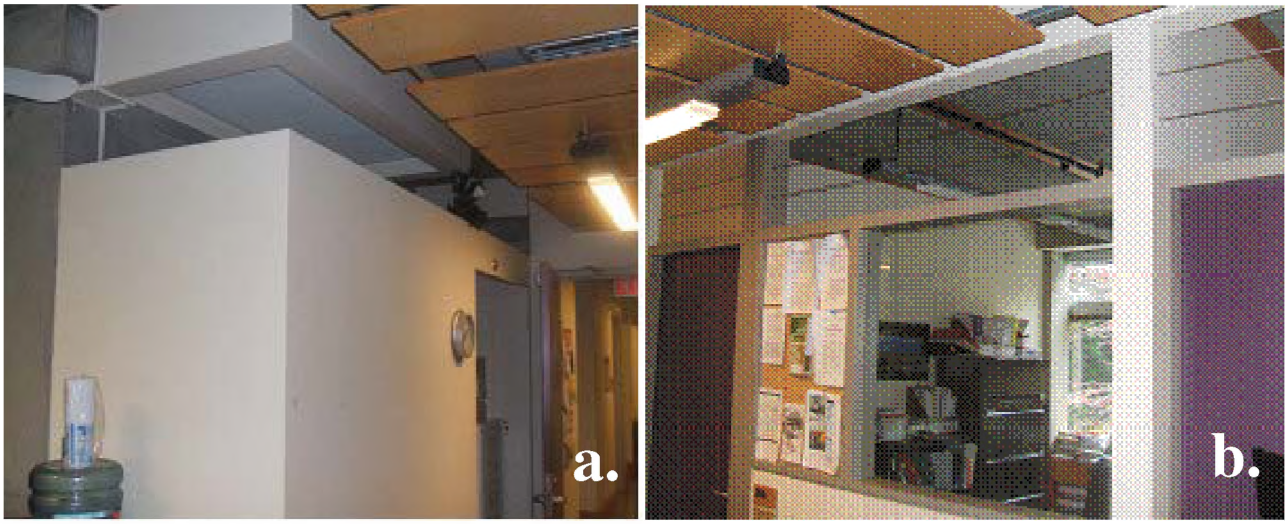


Figure 5: Liu building natural-ventilation system: (a) shafts and floor openings; (b) office/corridor openings.

3.1 Occupant-Satisfaction Survey

Figure 4 shows the occupant-satisfaction results of Figure 2, with those for the Liu building—and for the adjacent, similarly naturally-ventilated Choi building and several othr 'green' buildings—added. Of particular note is the extremely low satisfaction with acoustical quality in these two buildings.

The results of the occupant-satisfaction survey and preliminary acoustical measurements showed that two main acoustical problems in the Liu building, which are main sources of dissatisfaction with the acoustical quality, are:

- poor sound isolation between building floors due to sound transmission through ventilation shafts and natural-ventilation openings in the floor/ceiling slabs (see Figure 5a);
- poor sound isolation between offices and corridors on the 2nd and 3rd floors due to 45-cm-high natural-ventilation openings in the separating partitions (see Figure 5b).

Thus, more detailed acoustical measurements were made between floors in the vicinity of the north-end pair of ventilation shafts and floor/ceiling openings, and between a third-floor office and the adjacent corridor.

3.2 Acoustical-Parameter Measurements

The acoustical parameters described in Table 1 were again measured in various locations at the north end of the Liu building before treatment, and the results were compared with the same acceptability criteria. Table 2 shows the NIC and SII values measured between floors at the Liu north end. Table 3 shows the NIC and SII values measured between an office and the adjacent corridor (with door closed).

The noise isolation between offices on the first and second floors was an inadequate NIC 22-25; that between offices on the first and third floors was an adequate NIC 34-46. It was concluded, not surprisingly, that the ventilation shafts and floor/ceiling natural-ventilation openings have a significant effect on the transmission of sound energ between floors. The exact noise isolation obtained depend on the relative source and the receiver positions, and thos relative to the ventilation shafts.

Measured values of Speech Intelligibility Index ar presented in Table 2. Between adjacent floors, SII wa borderline acceptable with a normal voice, but unacceptabl with a raised voice. When the source and receiver wer separated by two floors, SII was quite acceptable.

Table 3 shows the analogous NIC and SII result between the office and the adjacent corridor. The nois isolation is a very inadequate NIC 10. Even with a casua voice, speech privacy is very low; in fact, with normal voic the SII corresponds to acceptable speech intelligibility!

In summary, the measured NIC and speech privac values for offices on the north end of the corridors wer lower than desirable in key cases and acceptable in others Those between the office and corridor were unacceptable.

4. DESIGN AND EVALUATION OF NOISE CONTROL MEASURES FOR NATURAL-VENTILATION OPENINGS IN THE LIU BUILDING

4.1 Objectives

Following the acoustical evaluation of the Liu building, project was initiated to find engineered noise-contro solutions to the identified problems. Given the NIC and SI results, and the available budget, it was decided to target th pair of north-end ventilation shafts, and one office partition The objective was to design and install noise-contro devices with adequate acoustical performance, subject t ventilation constraints, and then evaluate the performanc by acoustical measurement.

4.2 Noise-Control Concepts, Constraints, Criteria

Preliminary meetings held to discuss feasible design con

Table 2: NIC and SII measured between floors at the Liu north end, before treatment.

Source	Receiver	Noise Isolation Class, NIC (dB)	Speech Intelligibility Index (SII)		
			Casual voice	Normal voice	Raised voice
First-floor office	Office, second floor	25	0.03	0.20	0.42
	Office 1, third floor	37	0.00	0.08	0.30
	Office 2, third floor	41	0.00	0.07	0.29
	Corridor, third floor	27	0.01	0.14	0.36
Second-floor office	Office 1, first floor	22	0.04	0.20	0.42
	Office 2, first floor	25	0.06	0.22	0.43
	Office 1, third floor	34	0.00	0.07	0.28
	Office 2, third floor	46	0.00	0.03	0.24
	Corridor, third floor	23	0.01	0.12	0.33

Table 3: NIC and SII measured between Office 310 and the corridor, before treatment.

Source	Receiver	Noise Isolation Class, NIC (dB)	Speech Intelligibility Index (SII)		
			Casual voice	Normal voice	Raised voice
Office 310	Corridor	10	0.44	0.57	0.67

cepts, the constraints on the design, and design evaluation criteria, came to the following conclusions:

- Ventilation shafts—feasible acoustical treatments could involve lining the internal surfaces of the ventilation shafts, and/or suspending sound-absorbing baffles in them; of course, these treatments are reminiscent of ventilation-duct linings and acoustical louvers;
- Office partition—the noise-control concept that was chosen was to create an acoustically-lined,, Z-shaped silencer in the natural-ventilation opening; this is similar to the concept of the transfer silencer, already used in naturally-ventilated 'green' buildings;
- Constraints—it was, of course, not acceptable in this 'green' building to excessively compromise natural-ventilation airflows through the silencers; preliminary airflow modelling imposed the design constraint that the treatment of the ventilation shafts could not reduce their cross-sectional area by more than 25%; as for the partition opening and lined, Z-shaped silencer, a minimum airflow-path dimension of 125 mm had to be maintained;
- Acceptability/design criteria—the noise isolation design target was again NIC 30-35 for general offices and 35-40 for private office; as for speech privacy, SII < 0.2 was deemed acceptable.

4.3 Ray-Tracing Prediction

A ray-tracing room-prediction tool was used to create a virtual model of the three floors of the north end of the Liu building with its ventilation shafts and floor/ceiling ventilation openings (see Figure 6), and to predict the noise isolation between floors. Note that this was an energy-based model intended for rooms with dimensions much greater than the sound wavelength; in the case of sound propagation through shafts and openings with dimensions which are not large compared to the wavelength, high prediction accuracy is not guaranteed.

The building model was validated by comparing the predicted noise isolation with that measured in the untreated building. Figure 7 shows the results, which are generally within 5 dB, suggesting the model is reasonable.

Ray tracing was then used to predict the noise isolation between floors for various engineered noise-control measures involving acoustical lining of the ventilation shafts, or a combination of lining and various configurations of absorbent baffles suspended in the shafts. Figure 8 shows the results for various control measures and source and receiver positions.

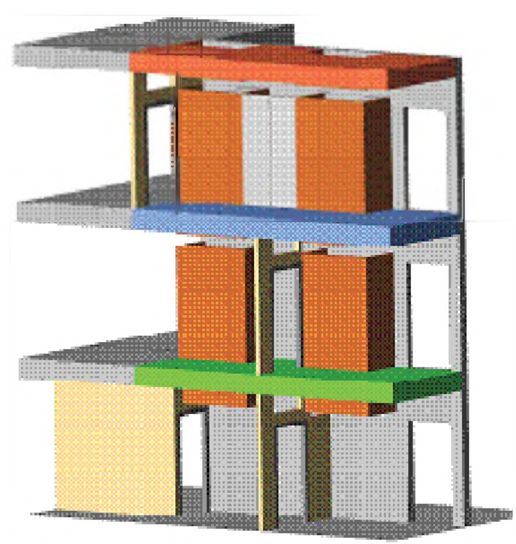


Figure 6: The ray-tracing virtual building model with (front and side walls removed).

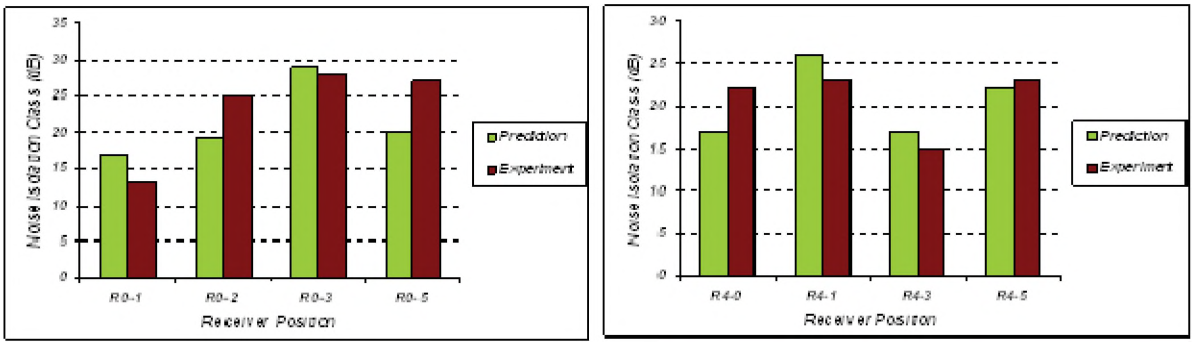


Figure 7: Measured and predicted noise isolation (NIC) between floors of the Liu building: (left) source on first floor, (right) source on second floor.

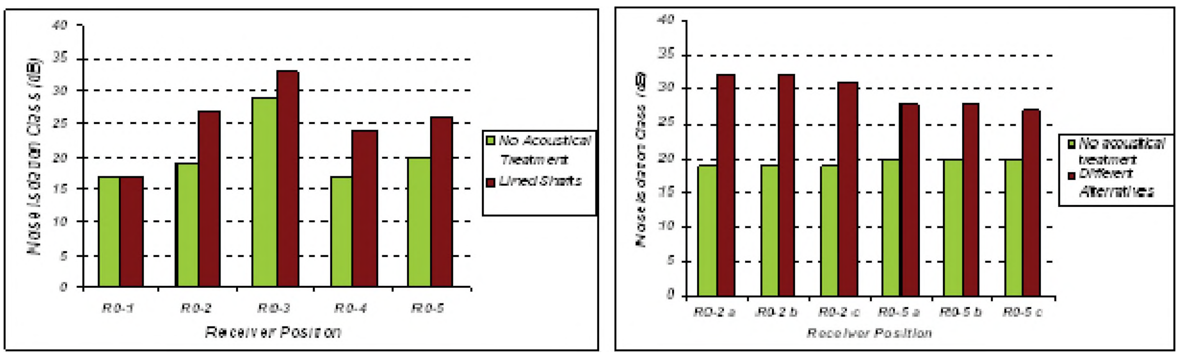


Figure 8: Ray-tracing predicted noise isolation (NIC) between floors of the Liu building without and with engineering-control measures: (left) ventilation shaft absorbent lining; (right) lining plus suspended baffles; a. 32 baffles (high α) in the opening between floors; b. 32 baffles (high α) located at the top of the ventilation shafts; c. 32 baffles (typical α) located at the top of the ventilation boxes).

Prediction modelling was also used by Stantec to optimize the design of the office-partition lined, Z-shaped silencer; the results are presented elsewhere [31].

4.4 Control Measures Implemented

Considering the results of the predictions, the final design of the noise-isolation system for ventilation shafts chosen for implementation was as follows:

1- Lining the inner surfaces of the lower boxes on the second and third floor shafts with 50-mm-thick acoustical liner;
2- Lining the inner surface of the upper boxes on the first and second floor shafts with 25-mm-thick acoustical liner;

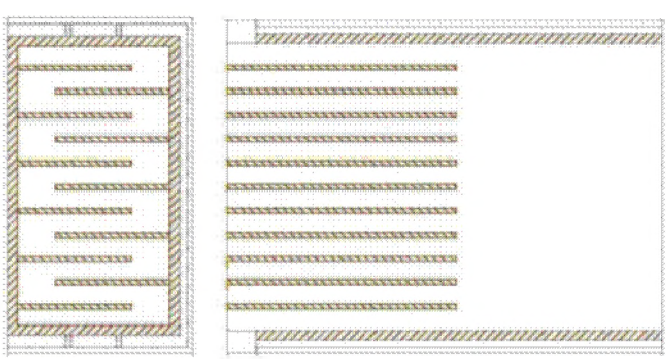


Figure 9: Drawing of the lining and baffle configurations that were installed in two pairs of ventilation shafts in the Liu building.

3- Locating baffles in the second and third floor ventilation shafts as follows: number of baffles: 11; baffle dimensions: 25 x 400 x800 mm^3.

Figure 9 shows a drawing of the linings and baffles that were installed in the two pairs of north-end ventilation shafts on the second and third floors. Lining alone was installed in one of each pair, and lining and baffles in the other (to allow their independent evaluation). Figure 10 is a drawing and photographs of the lined, Z-shaped silencer installed in the Liu office-partition opening.

4.5 Results

The noise isolation and Speech Intelligibility Index were re-measured after treatment. The results are shown in Tables 4 and 5, along with the changes due to the treatments. The ventilation-shaft lining and baffles increased the noise isolation to NIC 39-56 (increase of NIC 15-23). The lined, Z-shaped silencer in the partition opening increased the noise isolation to about NIC 25 (increase of NIC 15).

4.6 Airflow and Air-Quality Measurement

To investigate the effect of the office-partition silencer on airflows and air quality, the following quantities were measured (by Dr. Karen Bartlett, UBC) before and after treatment:

- room volume, temperature and relative humidity;
- air changes (ACH)/hour, windows closed/open => calculate air flow (cfm)/person;

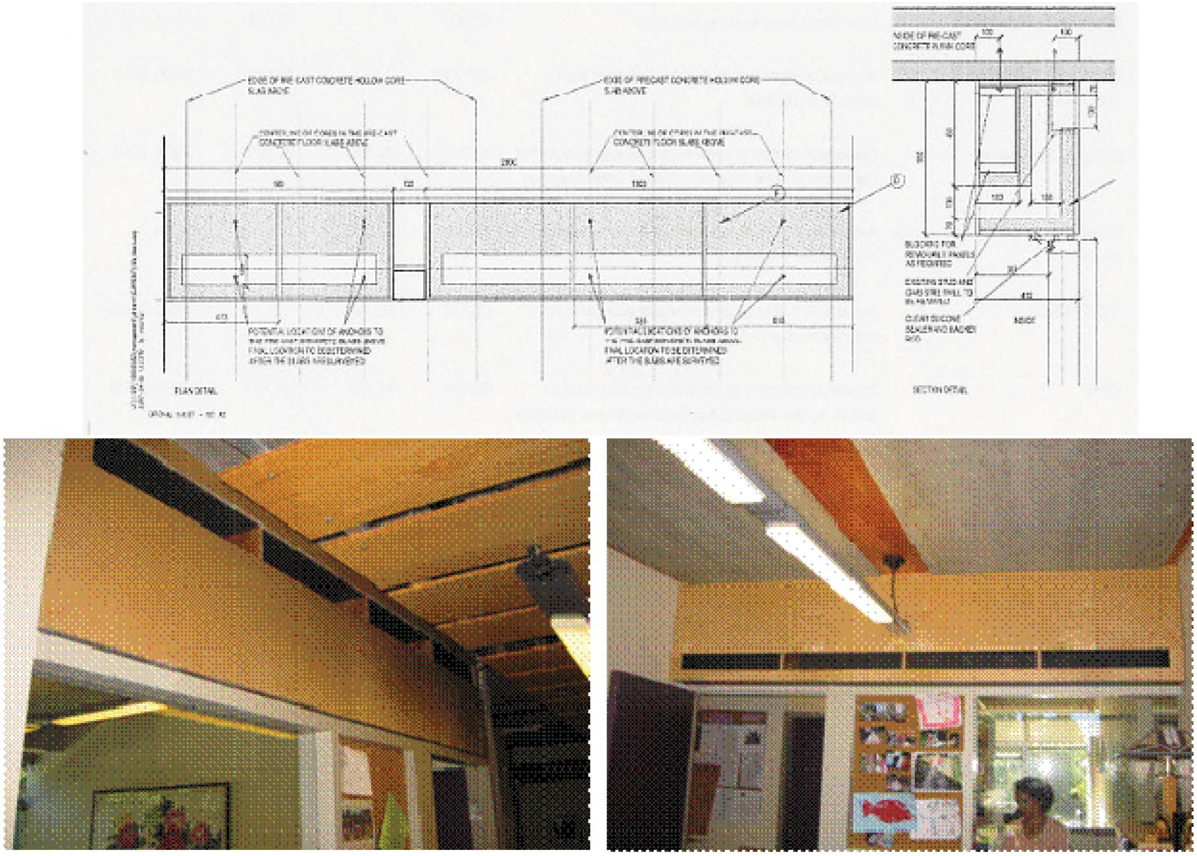


Figure 10: Drawing and photographs of the lined, Z-shaped silencer installed in the Liu office-partition opening.

- fibre concentration (fibres/ml);
- ratio of indoor-to-outdoor fungal-spore concentration (CFU/m^3).

The results are shown in Table 6. To determine the acceptability of the results, they were compared with the following values recommended by ASHRAE: ACH > 10–15 (depending on situation); cfm/person > 17.

It was concluded that no deterioration of air flows or air quality due to the acoustical treatment was measured. However, this may be explained at least in part by the fact that airflows in the untreated building were very low and could not be reduced much by treatment.

4.7 Summary

Following is a summary of the main conclusions of the study of the effectiveness of the engineering-control measures:

- Ventilation-shaft lining and baffles—the noise isolation increased to NIC 39-56 (increase of NIC 15-23); lining

Table 4: NIC and SII measured between floors at the Liu north end, after treatment, and changes.

Source	Receiver	Noise Isolation Class, NIC (dB)	ΔNIC (dB)	Speech Intelligibility Index (SII)					
				Casual voice	ΔSII	Normal voice	ΔSII	Raised voice	ΔSII
First-floor office	Office, second floor	40	+15	0.00	-0.03	0.05	-0.15	0.12	-0.30
	Office 1, third floor	56	+19	0.00	0.00	0.02	-0.06	0.05	-0.25
	Office 2, third floor	56	+15	0.00	0.00	0.01	-0.08	0.02	-0.27
	Corridor, third floor	50	+23	0.00	-0.01	0.01	-0.13	0.05	-0.31
Second-floor office	Office 1, first floor	39	+17	0.00	-0.04	0.02	-0.18	0.05	-0.37
	Office 2, first floor	45	+20	0.00	-0.06	0.02	-0.20	0.06	-0.37
	Office 1, third floor	46	+12	0.00	0.00	0.01	-0.06	0.04	-0.24
	Office 2, third floor	52	+ 6	0.00	0.00	0.01	-0.02	0.05	-0.19
	Corridor, third floor	43	+20	0.00	-0.01	0.01	-0.11	0.15	-0.28

Table 5: NIC and SII measured between Office 310 and the corridor, after treatment, and changes (Δ).

Source	Receiver	Noise Isolation Class, NIC (dB)	Δ NIC (dB)	Speech Intelligibility Index (SII)					
				Casual voice	ΔSII	Normal voice	Δ SII	Raised voice	Δ SII
Office 310	Corridor	24	+14	0.04	-0.40	0.18	-0.39	0.38	-0.29

Table 6: Results of air-flow and air-quality measurements in the Liu building before and after treatment (K. Bartlett).

Case	Room	Volume (ft^3)	Temp (deg C)	RH (%)	ACH closed	ACH open	cfm/person (closed)	fibres/ ml	CFU/m^3 (in/out)
Before treatment	302	1683.8	22.4	46.2	0.55	0.92	15.6	0.004	0.85
	309	1288.9	36.5	36.5	0.63	7.20	13.5	0.009	1.09
	312	864.3	41.1	41.1	0.88	3.20	11.6	0.007	1.04
After treatment	302	1683.8	22.0	57.0	0.16	1.43	4.5	0.007	0.65
	309	1288.9	22.6	57.1	0.99	5.00	21.3	0.005	0.46
	310	1149.0	23.4	56.5	0.47	6.90	9.0	0.008	0.61

and baffles together are too effective; further investtigations suggest that baffles alone might be the most cost-effective treatment;

- Partition-opening lined, Z-shaped silencers—the noise isolation increased to about NIC 25 (increase of NIC 15); the design criteria was not met; the Z-shaped silencer is apparently too short (due to space limitations?);
- Air flow, quality—no significant effect was measured (due to inadequate ventilation before treatment?).

5. DISCUSSION

The acoustical evaluation of 'green' office buildings has shown that occupants are often highly dissatisfied with the acoustical environment—in particular, with low speech privacy resulting from inadequate sound isolation between work areas. This results, for example, from the open-office design, inadequate sound absorption, and natural-ventilation openings in walls, floors and ceilings. Prioritizing obtaining 'green'-building ratings (e.g., LEED® ratings), and inadequate budget allocations for acoustical treatment, exacerbate the problems.

Detailed study showed that low sound isolation because of natural-ventilation openings is the main source of acoustical problems in the UBC Liu building (and Choi next door), leading to very low occupant satisfaction with the acoustical quality. Devices—essentially specially designed silencers with linings and/or baffles—were designed, installed and evaluated, and found to be effective, but not optimal. This demonstrates that engineered noise-control solutions can resolve acoustical problems in 'green' buildings. However, the desire, expertise and financial resources must be available for the benefits of these solutions to be realized.

'Green' buildings have other acoustical issues that were not specifically involved in the buildings discussed here. One is inadequate sound absorption due to thermal ceiling slabs (which cannot be obstructed by suspended acoustical ceilings) [32]. This problem also occurs because of the perception that many sound-absorbing materials are not 'green'. There is a great need to develop 'green' sound-absorbing materials, and work to do so is already underway [6, 12, 18, 21]. Life-cycle analysis can be used to determine the sustainability of building designs, and of their construction materials, including sound absorption [33].

Designers must remember that the various components of a building—thermal, ventilation, structural, acoustical, lighting, etc.—affect one another. Using extensive glazing in the envelope enhances natural day-lighting, but may cause glare, can negatively affect the thermal environment, and can reduce sound isolation and cause noise problems, especially if operable windows, or enclosed-office doors, are opened for ventilation. A recent pilot study [20] investigated the relationship between ventilation, air and acoustical qualities in 'green' and non-'green' buildings, finding that forced-air ventilation gives better indoor-air quality (IAQ), but higher ventilation-system noise levels, that IAQ and noise level are directly related, that in naturally-ventilated spaces with radiant ceiling slabs, lack of acoustical treatment gives lower fibre concentrations, but worse acoustical conditions, that naturally-ventilated spaces have unsatisfactory ventilation quality but acceptable noise levels with the windows closed, and satisfactory ventilation quality but excessive noise levels with the windows open (even without significant external noise sources), that naturally-ventilated spaces with few furnishings or sound-absorbing materials have higher IAQ, and that acoustical treatment can enhance acoustical quality, but worsens IAQ. 'Green'-building design must take an integrated, holistic approach.

As acousticians, we have a responsibility to help designers create buildings with acoustical environments which satisfy the occupants, and promote their health, well-being and productivity. Unfortunately, our advice is not always requested or followed due to ignorance, other priorities and financial constraints. So, what more can we do to achieve occupant satisfaction with acoustical quality in 'green' buildings? Here are a few ideas:

- make acoustics a mandatory component of the education of students who may become building designers;
- raise awareness of acoustical issues in 'green' buildings;
- educate 'green'-building designers in acoustical issues;
- ensure good acoustics is a priority in 'green'-building design;
- ensure that acoustical quality is valued in LEED® and similar 'green'-building rating schemes [9, 17, 22];
- include acoustical expertise at the design stage of all 'green' buildings;
- do research to investigate and resolve acoustical issues (e.g. perform more occupant-satisfaction surveys, develop better prediction tools, better design criteria, optimal noise-control measures);
- start focused programs on 'green'-building design for engineers, architects, teachers, policy-makers and others.

6. CONCLUSION

The aim of sustainable ('green') building is to create buildings that preserve the environ-ment and conserve natural resources, as well as to provide a 'healthy' environment for its occupants. Designing a building to preserve the environment and conserve resources is admirable and essential, but it must not be done to the detriment of the occupants, who will live and work in the building.

The acoustical environment is often judged the least satisfactory aspect of 'green' office buildings by the occupants. They are dissatisfied with excessive noise and poor speech privacy, and consider that the acoustical environment does not enhance their ability to work (i.e. productivity). Speech privacy is often the biggest concern.

The results of this work suggest that improving acoustical environments in 'green' buildings fundamentally requires good acoustical design—that is, the application in design of existing knowledge, with input from an acoustical specialist from the beginning of the design process. This knowledge relates to site selection and building orientation, to the design of the external envelope and penetrations in it, to the building layout and internal partitions, to the design of the HVAC system, to the appropriate dimensioning of spaces, and to the amount and location of sound-absorbing treatments. For a satisfactory acoustical environment, the advice of the acoustical specialist must be followed, and the budgetary resources made available for it to be realized.

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Sound Created Form: Exploring The Influence Of Sound On Architectural Form

Ben Gaum[1,2] and Ramani Ramakrishnan[1]
1 - Department of Architectural Science, Ryerson University, Toronto, Ontario
2- Kirkor Architects, Toronto, Ontario

ABSTRACT

The Montreal Jazz Festival is one of the largest and the most important jazz festivals in the world. The festival lacks a proper central location for operations. The current project has explored the influence of sound on architectural form and the aural quality of spaces it can create, by designing a new "Maison du Festival." The original schematic design of the building called for two "amphitheatred" sections of the plan allowing for performances on the two main stages to be projected onto the building itself, essentially acting in the same way as the back of a traditional amphitheatre. The overall form of the building was mainly derived from taking various wav file recordings of the streets surrounding the proposed site and then converting those files into a three dimensional representation. This was achieved by using a software called soundplot 1.0 ™ to capture the wav files that were then generated into 3D form in Rhino. Several recordings of each street were taken at various times of the day both during and after the festival to obtain a visual representation of the types of sounds that were directly affecting the proposed site. Three dimensional 'strips' were then selected from the hundreds of forms generated that would most accurately match the proposed schematic formal design and provide the "amphitheatred" sections required. A uniform building envelope was created from the wav file strips. This building envelope was then analyzed using CATT Acoustics to test the acoustic properties of the buildings form. The results of CATT Acoustics as well as the information gathered from previous studies of outdoor performance spaces were used to alter that the form of the original building in order to satisfy desired acoustical parameters that were required for the musical performances. The CATT Acoustics software proved instrumental in providing the acoustical analysis information that would help accurately transform the buildings form to properly satisfy the acoustical requirements of the festival organizers.

RÉSUMÉ

Le festival de jazz de Montréal est l'un des plus grands et importants festivals de jazz dans le monde. Le festival n'a pas d'emplacement central approprié pour ses activités. Avec la conception d'une nouvelle « Maison du Festival », le projet actuel a exploré l'influence du sonore sur la forme architecturale et la qualité sonore des espaces qu'il peut créer. La conception préliminaire originale du bâtiment exigeait deux sections du plan en forme d'amphithéâtre permettant aux spectacles sur les deux scènes principales d'être projetés sur le bâtiment lui-même, agissant essentiellement de la même manière que l'arrière d'un amphithéâtre traditionnel. La forme globale du bâtiment provient principalement de divers enregistrements en fichier wav pris dans des rues entourant le site proposé et convertis en une représentation en trois dimensions. Ceci a été réalisé en utilisant un logiciel appelé Soundplot 1,0 ™ afin de capter les fichiers wav, qui ont été ensuite générés sous forme 3D dans Rhino. Plusieurs enregistrements pour chaque rue ont été pris à différents moments de la journée à la fois pendant et après le festival afin d'obtenir une représentation visuelle des types de sons qui affectaient directement le site proposé. Des «bandes» en 3 dimensions ont ensuite été sélectionnées parmi les centaines de formes générées qui correspondaient le mieux aux formes de la conception préliminaire proposée et qui fournissaient les sections en forme d'amphithéâtre requises. Une enveloppe du bâtiment uniforme a été créée à partir des « bandes » de fichier wav. Cette enveloppe du bâtiment a ensuite été analysée à l'aide de CATT Acoustics, pour tester les propriétés acoustiques de la forme du bâtiment. Les résultats de CATT Acoustics, ainsi que les informations recueillies des études antérieures sur les espaces dédiés aux spectacles en plein air ont été utilisés pour modifier la forme du bâtiment original afin de satisfaire aux paramètres acoustiques désirés qui étaient requis pour les concerts. Le logiciel CATT Acoustics s'est avéré utile en fournissant les informations de l'analyse acoustique qui permettront de transformer avec précision la forme des bâtiments pour répondre correctement aux exigences acoustiques des organisateurs du festival.

1. INTRODUCTION

The relationship between music or sound and architecture dates back as far as Vitruvius, and possibly further. In his book The Ten Books of Architecture, Vitruvius devotes as much text to "sound, music and acoustics as he did to site design, materials and color; a level of attention unheard of in current architectural writing [1]. Although they have always displayed strikingly similar attributes in terms of balance, structure and emotional interpretations, architecture and music have come so close, but have never fully been able to bridge the gap that lay between them. It was always a question of sensory differences that found it impossible for architecture to be "heard" and for music to be "drawn" [2]. Sound offers a rich medium for exploration: it is an essential element of how we understand and relate to space, and its properties and behavior are intimately linked to the physical experience of an environment [3]. In more recent years it has been the trend in movements such as Acoustic Ecology and Soundscape Study to try and understand the effects of sound and music in our built environment. Based on more subjective qualities, these areas of study have proved to be more interpretational or conceptual ways of thinking of sound to shape the experience of space rather than results based in a more scientific, engineering reality that could actually be proven or shown in a physical architectural model.

This paper has focused on scientific and engineering practices and has applied quantitative and numeric data to the analysis of both architectural form and the interpretations of the people who use them in the hope of finding a connection between the two and address the main problem statement of the research by asking how sound affects form. The Montreal Jazz Festival's main venue was used in this study to understand the relationship between sound, music and architecture.

The Montreal Jazz Festival is currently the largest and arguably one of the most important jazz festivals in the world. For 30 years this festival has been drawing massive crowds and continuously attracting the biggest names in the music world despite never really having a proper central location for operations. The current research project explored the influence of sound on architectural form and the aural quality of spaces it can create and was part of a Masters of Architecture thesis [4]. The main focus of the research was the design of a new "Maison du Festival" that will act as the main welcome center, archive/museum and operations center for the Montreal Jazz Festival of the future.

The growth of the festival over the last five or so years, according to the director of the festival, has been seen as a true double edged sword. Although the increase in festival goers and popularity has been great for the festival in general, it has also caused them many technical problems with regards to proper outdoor venue locations and sizes as well as surrounding acoustic conditions.

The approach to the design element was to see how sound influences architecture in three basic conditions: environmental acoustic design, formal exploration and program-experiential considerations.

The environmental acoustic design looked at the design of the building on a large urban scale. The design focus was the integration of the building form into both the overall festival site and the city as a whole. The program for the building is based on the idea of sound vs. noise. Sound is an audible experience to be embraced and enjoyed such as music and natural sounds whereas noise can be described as unwanted or undesirable sounds such as traffic or construction. The placement of the program took into consideration the proper controlling of both sound and noise in the buildings plan as well as the buildings orientation on the site. Sound was also used in the formal exploration of the building. Various sound wave samples along the length of the surrounding streets of the proposed site were taken at various times of the day, both during and after the festival. They were then converted into a three dimensionally generated form that was then used to create the overall form of the building [5]

Acoustic simulation, using CATT Acoustics Software was also undertaken to evaluate the building form's influence on the noise as well as jazz programs' acoustic responses [6]. Preliminary results of the research were presented in a conference in Niagara-on-the-Lake in 2009 [7]. Complete details of the research are presented in this paper.

The paper is divided into the following subsections. Section 2 provides details of the background to the research. Existing environmental noise at the proposed site and its impact on the formal exploration are described in Section 3. The conceptual design of the building's form and its subsequent exploration are detailed in Sections 4 and 5. The acoustic analysis of the building form using CATT Acoustics is presented in Section 6. Section 7 describes the final details of the building such as its structure, materiality and uses.

2 BACKGROUND

The program of the design of "Maison du Festival", will be a 54000 sq. ft., 3 storeys building that will act as the main welcome center, archive/museum and operations center for the Montreal Jazz Festival of the future. It will include:

- 20000 sq. ft. of gallery space for museum and festival display;
- 3500 sq. ft. café;
- 4500 sq. ft. festival operations office space;
- 5000 sq. ft. recording studio and rehearsal space;
- 2500 sq. ft. multipurpose spaces.

The site, shown in Figure 1, is located just west of the existing festival site at Place des Arts in the central downtown core of Montreal. Currently, the site is an open park site with no existing buildings on it. Focus was on designing a building with as much green space on the site to be used throughout the year.

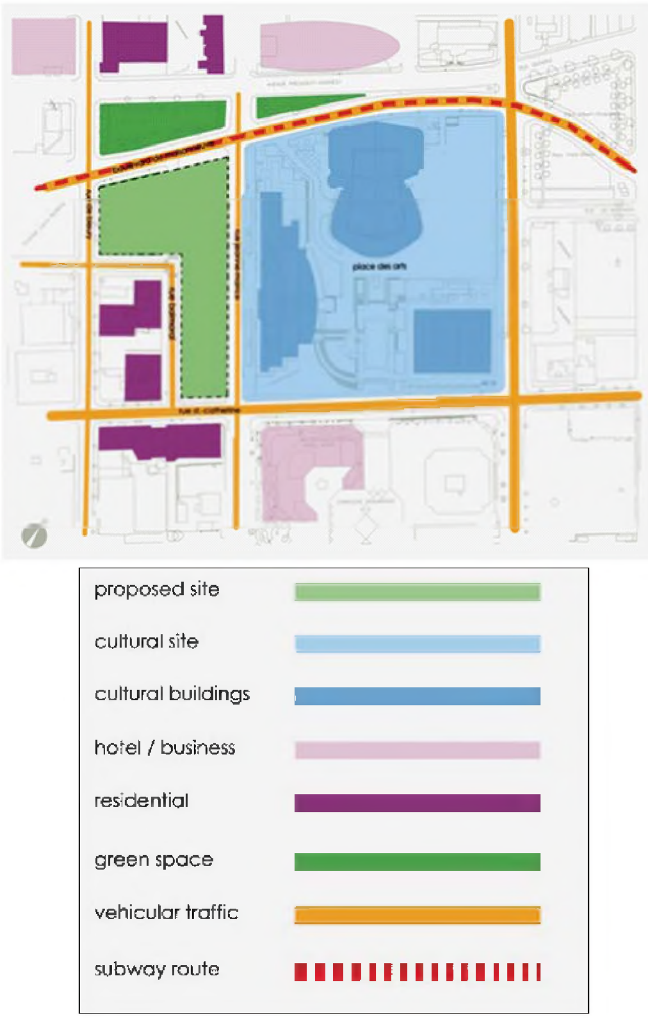

Figure 1. Site Plan of the Montreal Jazz Festival's "Maison du Festival".

3 SITE ACOUSTIC CONDITIONS

Before the design of the building itself can begin, an analysis of all the surrounding environmental acoustic and site conditions were considered. Conditions that have to be addressed include:

- Proposed site in relation to the existing site at Place des Arts;
- Building types, sizes and orientations on the Place des Arts site;
- Building types, sizes and orientations surrounding proposed site;
- Green spaces surrounding proposed site;
- Vehicular traffic surrounding proposed site;
- Existing subway conditions surrounding sit;.
- Existing and proposed festival stage locations and the size of spectators they service.

The existing Place des Arts site is a full city block that consists of two large indoor performance spaces and a large art gallery, all of which are roughly 40-50 feet in height. By having a new building on the proposed site to the west, it would solidify this entire area as a strong cultural hub of the city of Montreal as a whole. The buildings surrounding the proposed site are quite different and have to be addressed with regards to their acoustic properties. On the west side of the proposed site there are two residential brick buildings of 7 and 14 storey's high. These will have to be protected against any unwanted sounds or noise being produced during the festival. On the south side of the site, there are commercial properties that include a 20 storey hotel on the south east corner. This will also have to be considered in terms of protection of unwanted noise as well as sound reflections off the hotel back onto the outdoor performance areas. Two open green spaces with enough vegetation are to the north of the site that provide enough shielding to the residential buildings beyond them of unwanted noise from the festival. The vehicular traffic, although fairly heavy at times, both to the north (Rue de Maisoneuve) and south (Rue St. Catherine) of the site are blocked off from vehicular traffic during the festival. The subway that runs below Rue de Maisoneuve to the north shouldn't pose any serious acoustic problems as long as no part of the proposed building is placed below grade at the north end of the site.

An analysis of the current location, crowd capacity and sound projection directions of the existing outdoor venues shows that at present, an intricate choreography of different show times must be used in order for the performances to go on and not to cancel out or interfere with each other acoustically. The current venue locations in the existing festival site is shown in Figure 2. By redirecting the two large main venue positions and creating two amphitheater sections of the proposed building by projecting sound onto the new Maison du Festival, it would allow for more flexibility of the other outdoor venues around the festival site being used. The proposed modifications are highlighted in Figure 3. This design

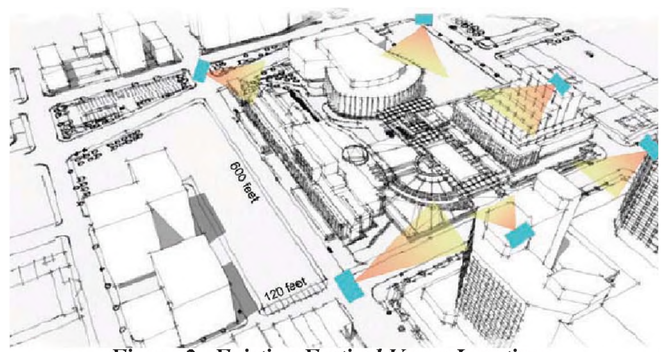

Figure 2. Existing Festival Venue Locations.

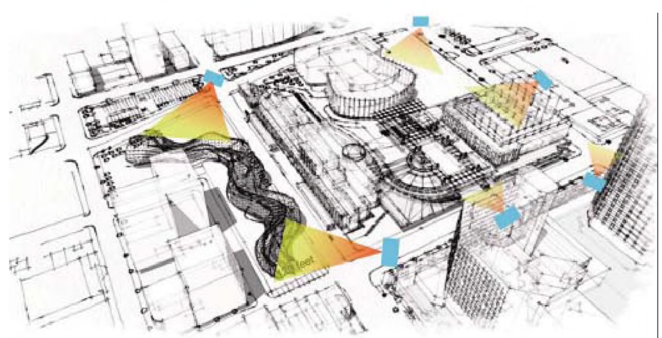

Figure 3. Proposed Festival Venue Locations.

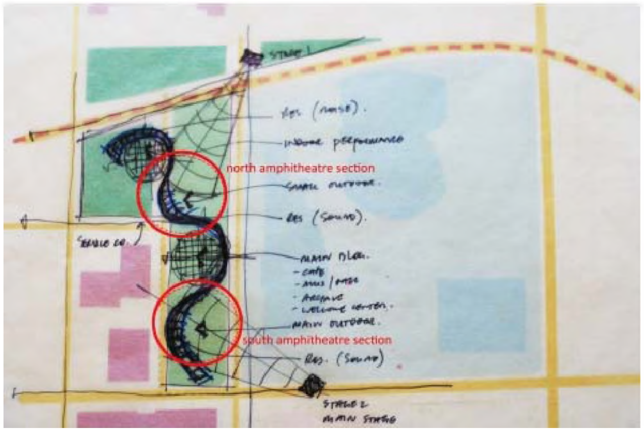

Figure 4. Conceptual sketch of the proposed building.

approach used the new building as a backdrop for the festival itself by engaging the entire festival site as well as the surrounding city. It gave organizers much more flexibility over visual considerations and circulation throughout the site as well as far more control and containment of the sound being projected from the two main event stages themselves for optimal acoustical conditions.

4 CONCEPTUAL DESIGN

The two outdoor amphitheater sections would be the strongest element in the conceptual design and will allow for performances from two outdoor stages to be projected onto the building itself. Initial sketches show how the introduction of the amphitheatre sections aim to accommodate and replace the existing performances stages being used by the festival. The conceptual sketch is shown in Figure 4. The north amphitheater section will replace the festival's largest performance area by allowing approx. 50,000 spectators and the south amphitheater will allow for performances with close to 25,000 spectators. Early diagrams of Figure 5 show the curved form of the design taking shape as theoretical sound sources from the north and south performance stages are projected onto a flat plane. Figure 5 sketches are the conceptual exploration of the form for the proposed building. Although the outdoor amphitheater sections will be mainly seasonal, the indoor program of the building will be useable all year round.

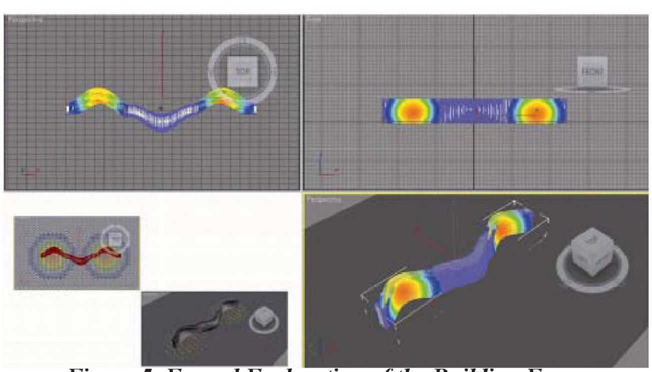

Figure 5. Formal Exploration of the Building Form.

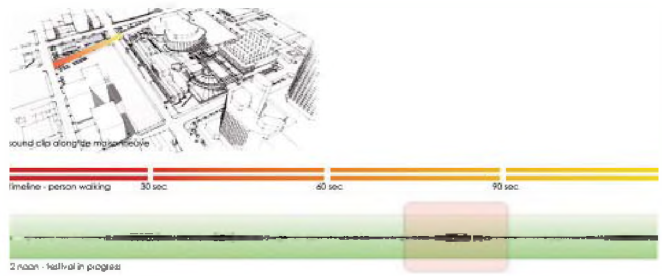

Figure 6. Recorded Sound Wav along Rue De Maisoneuve.

Figure 7. SoundPlot manipulation of Rue de Maisoneuve sounds.

5 FORMAL EXPLORATION

In order to explore and examine the possibilities that could inspire the formal outcome of the building, an interpretational approach to a scientifically acoustic process was taken to generate the buildings organic form. Audio recordings were taken along the length of the three streets that directly border the proposed site. Rue de Maisoneuve to the north, Rue Jeanne-Mance to the east, and Rue Balmoral to the west. The recordings were taken at three different times of day both while the festival was in full swing as well as when the festival was over. A sample recording of the Rue de Maisoneuve sound is shown in Figure 6. A multitude of interesting sounds and noises were recorded, from people walking, car traffic, truck traffic, children yelling, crowds cheering and music playing. The recordings of each street were then compiled together in bands to create an entire grouping of the possible sounds that could be heard along that street. These recordings, in wav file format, were then plugged into a 3D generation program called SoundPlot that was developed by Michael B Pliam of PliaTech Software [5]. The program served one very basic purpose. It converted sound waves into 2 and 3 dimensional surfaces which can subsequently be edited using standard engineering design tools (Soundplot). The desired sound bite is then generated and exported into a Rhino file that can be altered and manipulated to suit. One such manipulation of the Rue de Maisoneuve sounds is shown in Figure 7.

For this project, close to 200 different 3D wav file forms were generated. From this large number of series of wav files generated, a select few were chosen that would most ac-

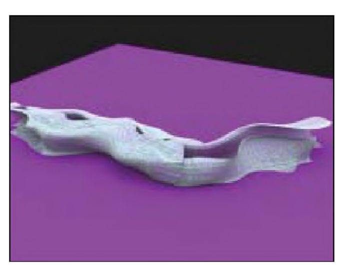

Figure 8. Rough Building Form – North East View.

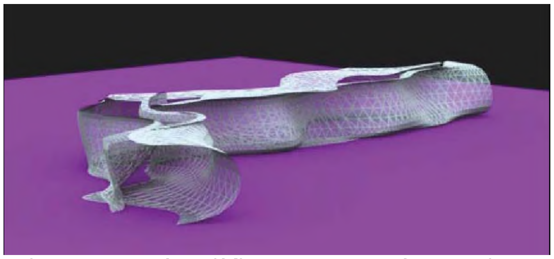

Figure 9. Rough Building Form – North West View.

curately match the desired program, form and orientation of the building required. In this case, the major forms that were trying to be matched were the amphitheater areas of both the north and south sections of the building.

The early forms of these amphitheater sections can be clearly seen in the 3D generated wav files shown in Figures 8 and 9. After selecting 'strips' that would best fit the desired form from each group, the 'strips' were put together to form a uniform building envelope. A great deal of tweaking and altering of the forms were undertaken in order to mould them into their desired shape. Over 20 different renditions were generated before the final building envelope took its final form.

6 ACOUSTICAL ANALYSIS OF BUILDING FORM

After a final general form was worked out, it had to be analyzed acoustically to determine its effectiveness on the surrounding site. Again, the two main areas that were to be analyzed were the north and south amphitheater sections. Each section was analyzed separately using CATT Acoustic. To perform the CATT Acoustics analysis, an acoustic 3D model of each section were created that included the detailed geometry file, a material's file and sound source and receiver files. The geometry file consisted of a computer generated 3D model and its general massing. The materials file identified the proper materials that were used on the final design along with its properly calculated absorption coefficients. The sound files located the source and receiver areas in relation to each amphitheatre section. By using the CATT Acoustics software as well as information gathered from previous studies of outdoor performance spaces, it was determined that the form of the original building had to be altered in order to satisfy desired acoustical parameters required for the musical performances. The results from the CATT Acoustics LEAK analysis showed that the north amphitheater section ended up being too small and was not able to contain or control enough of the projected sound to satisfy the festivals requirements. The LEAK analysis was new step undertaken in the current study and it evaluates the amount of sound that leaks out of the amphitheatre. The LEAK analysis thus calculates the amount lost to the audience space. The initial design showed that 7104 LEAKS were recorded during the analysis. The required solution consisted of: the width of the section to be enlarged drastically as well as an increase in height. The analysis of this revised version, shown in Figure 10, resulted in a drastic decrease in the number of LEAKS recorded at 1436, a much more acceptable level. The overall width of the section was increased to allow for a full 15 degrees on either side of the performances center stage. The south amphitheater section although smaller in overall size, proved to satisfy its requirements due to its slightly curved roof section that had been generated in the original 3D wav form. This slightly curved roof section essentially helped project the sound back down onto the spectators watching the performance. It was also determined that the original steel material being suggested for the outer skin layer of the building in the conceptual design proved to be too highly reflective and hence caused a large amount of unwanted reflected noise. Another solution was evaluated and is discussed in the next section. The CATT Acoustics software proved instrumental in providing the acoustical analysis information that would help accurately transform the buildings form and materiality to properly satisfy the acoustical requirements of the festival organizers. The acoustic results are evaluated in terms C-80, RT60, G and SPL distribution. The acoustic results for one frequency, at 500 Hz, are shown in Figure 11. The results for the revised design are seen to be in the acceptable range for the two open air amphitheatres. It should also be noted that the proper design of the two sections proved instrumental in providing enough environmental acoustic protection to the two residential structures to the west of the proposed building site.

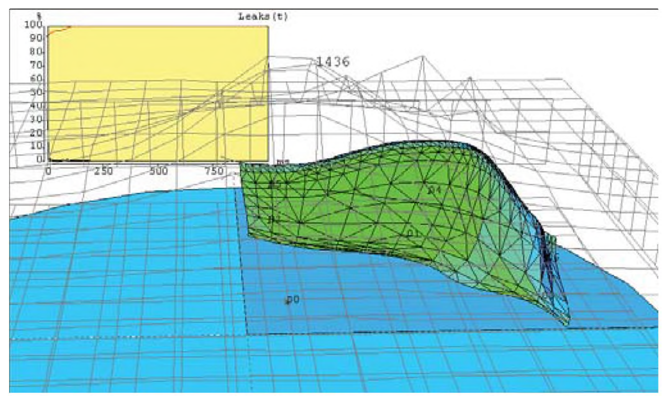

Figure 10. Revised North Amphitheatre LEAK Analysis from CATT Acoustic simulation – p0 marks the stage.

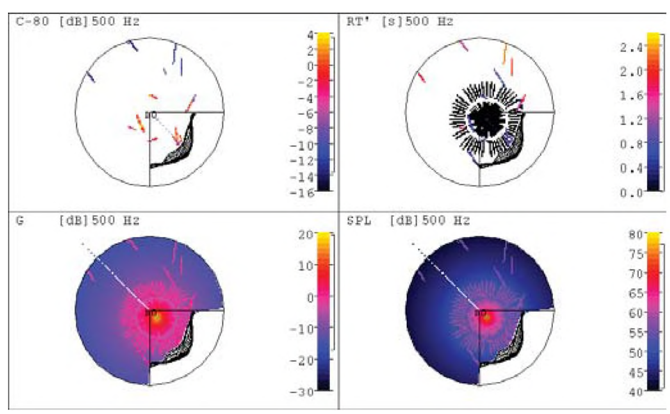

Figure 11. Revised North Amphitheatre Acoustic analysis from CATT Acoustic simulation – p0 marks the stage.

7 BUILDING DESIGN / LAYOUT

The overall layout of the building was divided into three main sections. The north section would house all of the festival offices, the central section would house the galleries and the south section would house the sound recording, rehearsal rooms and archival space. This grouping of program was done for obvious cohesive layout as well as acoustical considerations. The overall organic form of the design provided a multitude of interesting visual as well as acoustic changes throughout the building. A constant changing, opening and closing, widening and narrowing of the overall form gave a living, breathing feel to the architectural experience.

The first floor plan is shown in Figure 12. There are three entrances to the building at this level. Both the north and south ends of the building are entrances for the offices and studio spaces respectively. They are specifically acoustically separated and placed at either end of the building. During the festival these entrances would not be as directly connected to the action and large crowds entering through the eastern, main public festival entrance that is located off of Rue Jeanne Mance. This entrance is set 5 feet below grade, located at the bottom of a ramp that is gently sloped down from the street level. Acoustically, this allows visitors to gently be

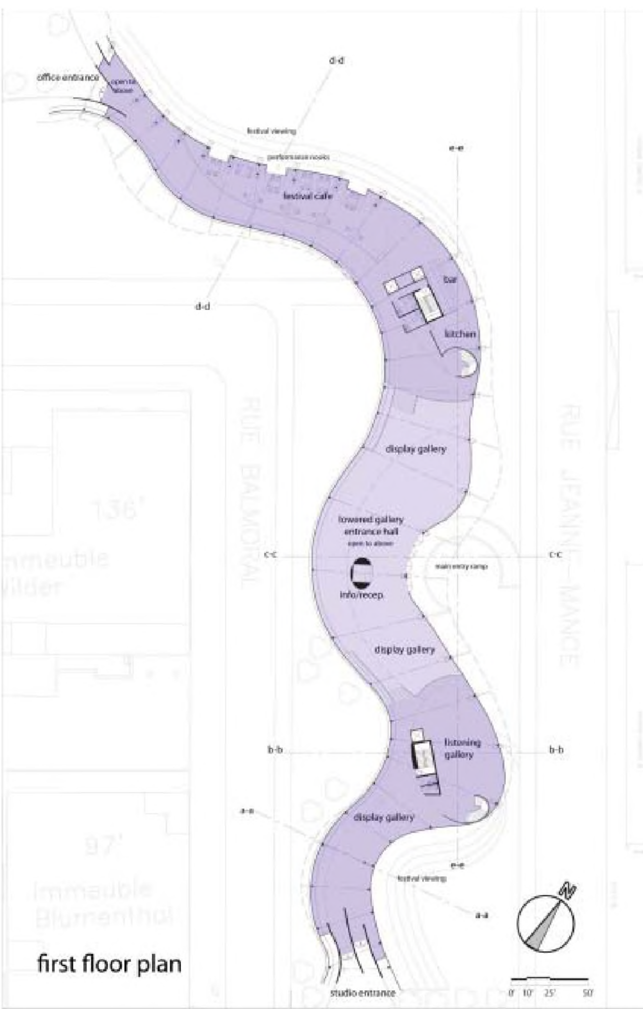

Figure 12. First Floor Plan.

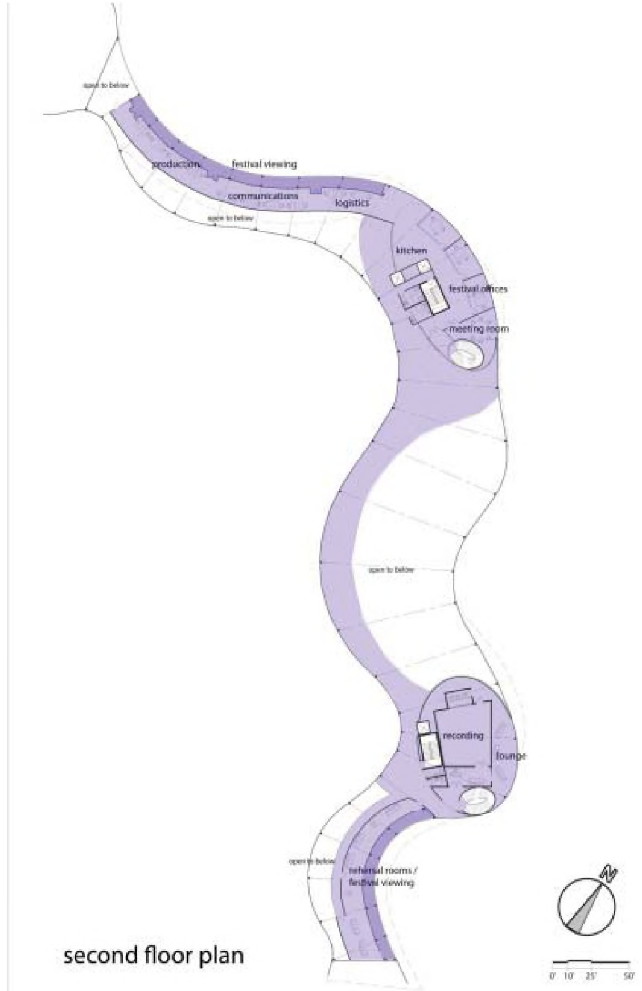

Figure 13. Second Floor Plan.

pulled out of the everyday sounds of the surrounding city and directly into the 3 storey entrance hall atrium and main display gallery spaces. These gallery spaces will house current exhibits that would highlight the current jazz festival musicians, participants and characters. The info/reception booth, an oval outer shell surrounding an inner rectilinear shape, sets a formal tone of “form within a form” that can be seen throughout the building. Primarily, this can be seen in the two large egg shaped masses that hang above the south end first floor listening gallery and north end café. These work to compliment the non linear, overall organic form of the building but were also designed specifically for acoustic purposes. In the first floor listening gallery, the resulting convex form of the ceiling helps to diffuse sounds in order to make for a more enjoyable listening experience. Individual listening pods are provided for visitors as well to help isolate and control the listening experience visitors will have in the gallery. In the north café, the convex form of the ceiling provides the same diffusion of sound for a quieter, less intrusive dining experience. Performance nooks are available for individual, random performances from musicians to come and play for patrons of the café further enhancing the musical, friendly, openly expressive nature of the jazz festival. In one nook performers might be strumming some bluegrass, while at the

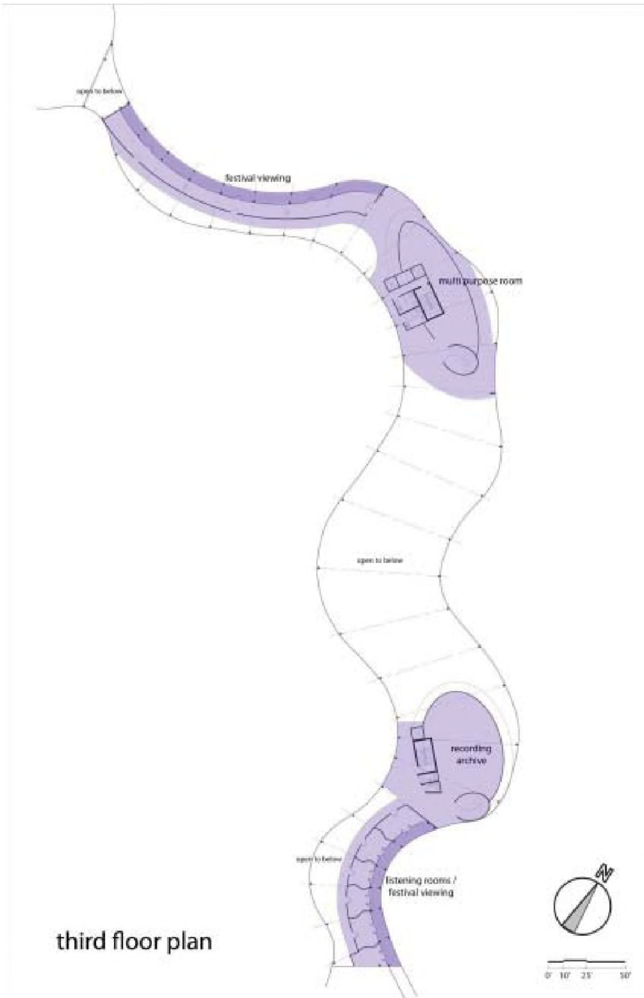

Figure 14. Third Floor Plan.

same time; in another nook separate performers might be offering acoustic blues. Exterior festival viewing or seating is also provided at both amphitheater sections. The festival viewing areas are designed in much the same way the seating was designed in traditional amphitheatres but also provide a continuity between the building form and the ground plane.

Each large egg shaped mass is offset by a central, solid rectilinear circulation core that rises up through the form and includes: elevators, emergency stairs and washrooms. As well, visitors are offered a more introspective audible ascent into the masses themselves as one leaves the openness of the first floor up into the vertical tube like effect of the circular formal staircase provided in each of the two masses.

The second floor plan is shown in Figure 13. One begins to fully experience the "form within a form" design. The south end mass houses the irregular, polygon shaped recording studio and lounge that are consistent with proper conventional, contemporary studio design. The offset or difference between the egg shape and the polygon interior produces a pochet effect that creates essentially an outer and inner shell, allowing for an inhabitable space between the two shells for acoustic separation as well as placement of services. The north end egg shaped mass houses the main festival offices that overlook the entire north side of the festival site. Both the rehearsal rooms and common festival offices double as festival viewing rooms that overlook each of the south and north amphitheatre sections respectively. Here, VIP festival onlookers can have optimal, "luxury box" like seating in which to enjoy the festival with specially designed balconies that are incorporated into the structural design of the building. This experience continues up the festival viewing areas on the third floor, shown in Figure14, as well as a recording archive room and a large multi-purpose room.

7.1 Building Details

The structural frame of the building is a triangulated steel truss system that flares out to create an inner and outer truss section at the second and third floors. This flare creates a space between the two sections of truss that can again be inhabited and is used to create the festival viewing balconies (See Figure 15). Where as in traditional design, the balconies are an added appendage that cantilever out from the main wall of the building exterior, in this design the overall flow and form of the building are never compromised or interrupted in order to accommodate the balconies. The triangulation of the truss allows for added structural strength while also allowing for maximum flexibility to achieve the desired form.

The materiality for this design was seriously considered with regards to the acoustic nature and effects the materials would have on the final design. Materials for the design had to be aesthetically pleasing as well as satisfy all required acoustic parameters. The envelope of the building is a double glazed insulated glass panel wall system. On the south/west side of the building, this double glazing allowed for the incorporation of a passive heating system that can then be distributed to the rest of the building. On the north/east side of the building, primarily on the non-amphitheatre sections of the entire façade, the outer layer of the double glazed system will be perforated with 2" diameter perforations. This will help with the absorption and diffusion of unwanted environmental noise into the cavity provided. To replace the original outer steel skin proposed in the conceptual design of the building, a green wall or living wall system will be incorporated onto the amphitheatre sections to help with the proper absorption of projected sounds from performances much the same way diffuser and absorption panels are used to line the interior walls of recording studios. The perspective view (from the south) of the final building design is shown in Figure 16.

8 CONCLUSIONS

The ever popular and successful Montreal Jazz Festival required a central operational building. The results presented in this paper resulted from a master's thesis. The building was designed so that the form conformed to the sounds that would be created at the proposed site. The form's original exploration was based on the street sounds near the jazz festival site. The street sound were manipulated into 3-D wave forms that created the building. The building's form was then simulated in an acoustic software to refine and retune. The

Figure 15. Section Showing Balcony System.

final design produced a design that satisfied both the environmental acoustical consideration as well as the required acoustics of the two amphitheatres.

ACKNOWLEDGEMENTS

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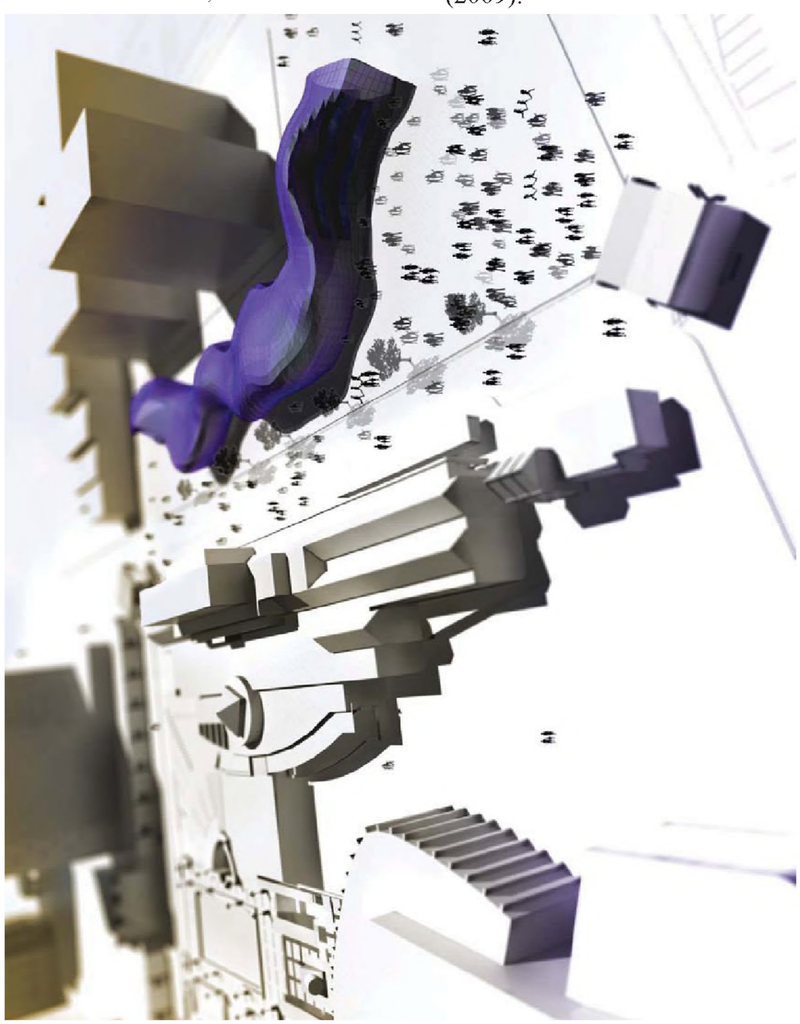

Figure 15. Perspective View looking South.

REVERBERATION MEASUREMENT AND PREDICTION IN GYMNASIA WITH NON-UNIFORMLY DISTRIBUTED ABSORPTION; THE IMPORTANCE OF DIFFUSION

Kevin Packer and Clifford Faszer
FFA Consultants in Acoustics and Noise Control Ltd., 304, 605 1st Street SW, Calgary, Alberta, Canada, T2P 3S9,
info@ffaacoustics.com

ABSTRACT

As part of a performance verification exercise reverberation times (RT) were measured in several newly constructed school gymnasia, rectangular in plan with two variations in room size, all with similar finishes and constructions. Due to architectural constraints, the rooms have acoustically hard finishes below a height of 3 m. The room finishes are primarily acoustically reflective with the exception of continuous bands of absorptive upper wall paneling around the full perimeter of the rooms (exposed unpainted Tectum over mineral fibre insulation) and painted acoustic metal deck ceilings (fiberglass insulation in the perforated deck flutes). The initial RT measurements exceeded the design targets. Modeling using ODEON room acoustics prediction software was conducted to determine the quantity and placement of additional absorption required to bring the RT into compliance. After installation of an additional continuous band of absorptive paneling in the rooms at a height below the existing panels, the RT were re-measured. The mid-band average RT increased, with a 0.5 sec RT increase at 1000 Hz in one room and a 1 sec RT increase at 1000 Hz in another. Further investigation lead to the hypothesis of an insufficiently diffuse sound field and uninterrupted standing wave modes in the lower untreated portion of the room contributing to the unexpected results. RT were subsequently re-measured under 5 different conditions; an empty gym, addition of 5 people, and 3 levels of diffusion. Diffusion was varied by adding sheets of plywood (5, 10, 15 sheets) leaned against posts or each other. The addition of as few as 5 people or 5 plywood sheets was found to significantly reduce the measured RT, closer to the modeled predictions, with between a 0.6 sec and 1 sec reduction observed in the mid-band average RT from the empty condition.

RÉSUMÉ

Dans le cadre d'un exercice de vérification des performances, les temps de réverbération (RT) ont été mesurés dans plusieurs gymnases d'école nouvellement construits d'un plan rectangulaire, avec deux variations de taille de pièce, mais tous avec des finitions et de construction semblables. En raison de contraintes architecturales, les salles n'ont aucune finition acoustiquement absorbante au-dessous d'une taille de 3 M. Les finitions de pièce sont principalement acoustiquement réfléchissantes, à l'exception des bandes continues du panneautage absorbant de mur supérieur autour du périmètre complet des salles (Tectum exposé non peint sur l'isolation de fibre minérale) et des plafonds peints de plate-forme en métal acoustique (isolation de fibre de verre dans les cannelures perforées de plate-forme). Les mesures RT initiales ont excédé les exigences de performance. La modélisation en utilisant le logiciel de prévision d'acoustique des locaux d'ODEON a été fait afin de déterminer la quantité et le placement d'absorption supplémentaire exigés pour introduire le RT dans la conformité. Après l'installation d'une autre bande continue du panneautage absorbant au-dessous des panneaux existants, les RT ont été remesurés et se sont trouvés plus hauts de 0.5 sec à la bande 1000 Hz dans une salle et 1 sec plus haute dans l'autre. Plus de recherche a mené à l'hypothèse qu'un champ acoustique insuffisamment diffus et des modes d'onde stationnaire non interrompus dans la partie non traitée au bas de la salle ont contribué aux résultats inattendus. Les RT ont été remesurés dans 5 conditions différentes; un gymnase vide, avec l'addition de 5 personnes et avec 3 niveaux de diffusion. La diffusion a été variée en ajoutant des feuilles de contreplaqué (5, 10 et 15 feuilles) appuyé contre les poteaux ou l'un à l'autre. L'addition de seulement 5 personnes ou de 5 feuilles de contreplaqué a réduit les RT mesurés, entre 0.6 sec et 1 sec dans la moyenne des mi-fréquences en comparaison de la salle vide, un résultat plus près des predictions modélisées.

1. INTRODUCTION

School gymnasia present several acoustical challenges as the rooms must support variety of uses, mainly athletic instruction, practice and competition, school and community gatherings, as well as both drama and music performances. Excess noise levels and reverberation are common concerns for these facilities. However considerations such as user safety, surface durability and impact resistance, ease of maintenance and clean-ability often dictate the application of acoustically reflective finishes in the occupied portion of the room. Further, the room contain parallel and acoustically reflective floors, ceilings, and lower wall surfaces.

Previous research [1] has indicated that reverberation times (RT) between 1.5 and 2 seconds across the speech frequency range are favourable for gymnasia in order to preserve a sense of excitement for sporting activities and liveliness for musical performances while not significantly compromising speech intelligibility which is strongly dependent on reverberation time and background noise levels.

This paper documents the results of RT measurements conducted in several newly constructed school gymnasia as part of a performance verification exercise for the builder. These gymnasia are located in Alberta where current government design standards [2] stipulate that RT in a typical unoccupied gym not exceed 2.0 sec averaged over the frequency range of 500 to 2000 Hz.

The gymnasia were built with acoustical finishes described as acceptable in the Alberta Infrastructure design guidelines [2], however the initial RT measurements did not meet the design target. Furthermore, the mid-band average RT measured after the installation of additional acoustically absorptive treatment were found to be higher, with a 0.5 sec RT increase at 1000 Hz in one room and a 1 sec RT increase at 1000 Hz in another, contrary to intuition and the predictions from geometric room acoustical modeling.

It was noted that the presence of a minimal amount of solid objects on the floor during some of the measurement sessions appeared to significantly influence the measured RT, with a 1.2 sec RT decrease at 1000 Hz in one room and a 1.4 sec RT decrease at 1000 Hz in another. This led to the hypothesis of an insufficiently diffuse sound field and uninterrupted standing wave modes in the lower untreated portion of the room contributing to the unexpected results.

RT were subsequently re-measured under 5 different conditions; an empty gym, addition of 5 people, and 3 levels of diffusion. Diffusion was varied in a simple manner by adding sheets of plywood (5, 10, 15 sheets) leaned against posts or each other. The addition of as few as 5 people or 5 plywood sheets was found to significantly reduce the measured RT, closer to the modeled predictions. The results of the above investigations are presented in this paper.

2. ROOM DESCRIPTIONS

Eighteen new elementary schools, nine in Calgary and nine in Edmonton, were constructed for the Alberta Government in a Public Private Partnership P3 arrangement. Two of the seven basic school designs were chosen by the builder for acoustical testing. Two of the schools were in Calgary and the other two were in Edmonton.

The measured gymnasia were rectangular in plan with two different room sizes: Type A, 27.8 m x 18.5 m, slightly sloped ceilings 9.3 m to 9.6 m above finished floor (AFF); Type B 24.0 m x 18.0 m, ceilings 9.1 to 9.5 m AFF. The finishes were painted concrete block walls to 3 m above a cushioned wood floor and painted 2-layer 16 mm thick abuse-resistant gypsum board walls to the underside of a painted acoustic metal deck ceiling. According to an acoustical lab test report provided by the metal roof deck manufacturer, the acoustic deck has a Noise Reduction Coefficient (NRC) of 0.75 with a pronounced peak in the mid-band absorption.

Initially, two 1.2 m high continuous bands of exposed unpainted Tectum/mineral fibre paneling (38 mm mineral fibre behind 25 mm Tectum, edges concealed with wood trim) extended around the full perimeter of the rooms on the upper walls, approximately 222 m^2 and 202 m^2 in the Type A and B gymnasia respectively, providing roughly 25% wall coverage. The bottoms of the panels were approximately 4.5 m AFF in the Type B gyms and approximately 5.5 m AFF in the Type A gyms. According to the panel supplier the tectum/mineral fibre panels have an NRC rating of 0.85 with significant mid-frequency absorption.

3. METHODOLOGY AND LIMITATIONS

A tripod-mounted Brüel & Kjaer 2270 Precision Real Time Sound Level Analyzer equipped with a Brüel & Kjaer 4189 microphone and Brüel & Kjaer UA 1650 windscreen and version 3.2 of the BZ7227 Reverberation Time software was used to record, archive and evaluate the RT measurements. Microphone height was approximately 1.8 m AFF.

Sound decays were measured at a minimum of 5 locations in the rooms with the exception of the first set of measurements in Gym A-1 and Gym B-1. During these initial survey measurements decays were measured at 3 positions in Gym A-1 and at 4 positions in Gym B-2. Measurement positions were consistent (within ~0.5 m) between repeated measurement sessions in the same gymnasium. Standard deviation in RT between measurement positions did not generally exceed 0.1 sec in the 250 Hz to 4000 Hz range. However the standard deviation in RT between measurement positions was as high as 0.14 sec at 125 Hz and 0.12 sec at 1000 Hz in some instances.

Sound impulses were generated from large diameter balloon bursts and the decays measured. In some instances the measurements were repeated with decays generated with interrupted pink noise played over a JBL Eon Power 15 amplified speaker. Good agreement was found between the two methods with the measured mid-band average RT generally within 0.1 sec for the same room using the two methods. During the final measurement session with added diffusion only large diameter balloon burst impulses were used. Reported RT are those measured with large diameter balloon burst impulses.

Background noise measurements were taken during each measurement session and found to not exceed RC 35 (N) with the exception of the initial measurements in Gym A-1 which were taken before the HVAC system air-balancing was completed and met an RC 46 (HF). In all cases sufficient sound energy was generated in the frequencies of concern for the decays that the background sound levels were not a factor in the RT measurements.

4. RESULTS & MODELLING

The initial RT measurements (see Figure 1) did not meet the design target and were surprising in that the mid-band average RT in the slightly smaller Type B gym were 1.2 sec higher than those measured in the Type A gym. These measured times were higher than expected considering the extent of and the manufacturer-claimed mid-band sound absorption of the acoustic deck and acoustic panels.

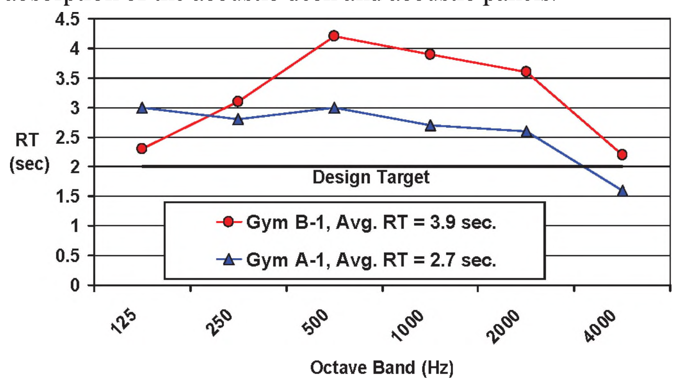

Figure 1. Initial measured gymnasia RT with ~25% wall panel coverage.

The acoustical treatments in this Type B gym were inspected and no problems or defects were apparent. The acoustic deck perforations were not sealed with paint and the flutes had fibrous batt insulation in them. The Tectum appeared to be installed as per the manufacturer's recommendations; the Tectum was porous and mineral fibre was present behind the Tectum.

The RT were re-measured in this room. With the room empty (except for the scissor lift used for the acoustic treatment inspection) the re-measured RT were lower than the initial measurements yet still above the performance requirement (see Figure 2).

A lack of adequate absorption was presumed and the two basic variations of gymnasia (Type A & B) were modelled using ODEON room acoustics prediction software to determine the quantity and placement of additional absorption required to bring the RT into compliance. ODEON is based on prediction algorithms (image-source method, ray-tracing and ray-radiosity) that account for scattering due to surface roughness and diffraction. A reflection-based scattering method is used that accounts for frequency-dependent scattering [3]. Scattering coefficients were chosen according to ODEON guidelines [4].

Air temperature and humidity readings recorded during the gymnasia RT measurements were used in the modelling (Type A Gym: 20 °C, 37% RH, Type B Gym: 20 °C, 38% RH).

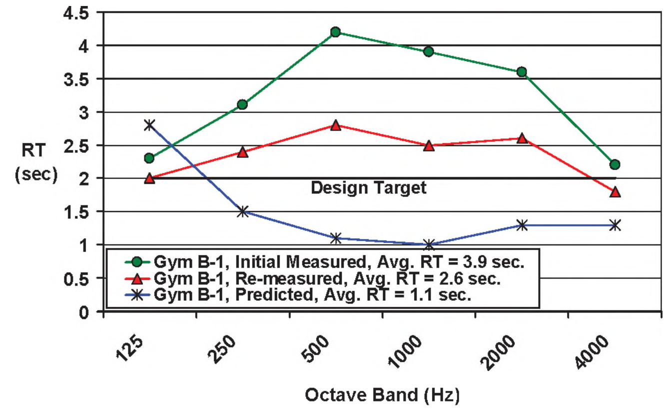

Figure 2. Initial (circles) and re-measured (triangles) RT in Gym B-1 with ~25% wall panel coverage. Predicted RT (asterisks) also shown.

As explained by Cox and D'Antonio [5], the accuracy of geometric room acoustic modelling software is limited by the validity of the input data, namely the accuracy of the modelled room geometry, surface sound absorption and scattering coefficients. In this case the geometry for the gymnasia is not complex. Furthermore, with the exception of the acoustic deck and Tectum panels the absorption coefficients for the various room materials are fairly well established in literature. This does not mean these values are infallible.

Recent literature by Cox and D'Antonio [5] and Sauro and Mange [6] describe how there can be significant uncertainty in absorption coefficients even for common materials due to factors such as sample size, edge effect (sound diffraction at sample edges), and variations in diffusion and sample mounting conditions between various testing labs. Cox and D'Antonio recognize that with practice experienced acoustical modellers gain an understanding of how absorption coefficients vary between lab test data and real rooms. Uncertainties in absorption coefficients are dealt with by adjusting absorption coefficients used in the modelling based on measured RT with repeated use of surface treatments on various projects over time. This is relevant to this study in that both acoustic deck and Tectum panels have been used in enough projects to establish that they provide at least some absorption in the critical mid frequency bands.

As the predicted RT with the acoustic treatment manufacturers' absorption data were significantly below the measured values, the absorption coefficients in the models were 'calibrated' so that the predictions better matched the measured RT. The calculations indicated that an additional 148 m^2 of panels were required in the Type A gyms and an additional 96 m^2 of panels were required in Type B gyms.
A third continuous 1.2 m high band of panels approximately 111 m^2 in area was installed in the Type A gymnasia at a height below the existing panels (bottom of panels constrained to a height approximately 3.4 m AFF). The resulting wall panel coverage in the Type A gymnasia was approximately 40%. In the Type B gymnasia a third

limitations with regards to non-uniform distribution of absorption and refer to the extensive work by Hodgson [10][11] in this field. In their study of RT in an unoccupied simulated classroom they found it necessary to add gypsum board diffuser panels to the room to increase diffuseness and that increasing the number of panels resulted in lower reverberation times.

The requirement for a sufficiently diffuse sound field is established for laboratory measurements in ASTM C423 - 09a [12]. This is typically achieved with fixed and/or rotating sound-reflective panels hung or distributed with random orientations about the volume of the reverberation room to interrupt standing wave modes. ASTM C423 states that it has been found that in rectangular rooms the area (both sides) of diffusers required to achieve satisfactory diffusion is 15 to 25% of the total surface area of the room.

In this study all of the gymnasia except for the two following cases were measured completely empty (neglecting the measurement equipment and operator): As mentioned previously, for one measurement session in Gym B-1, a scissor lift was located at one end of the room and a 1.2 m by 2.4 m Tectum board was leaning against a wall (see Figure 6). During a measurement session in Gym B-2, a few boxes of construction materials were present on the floor (see Figures 7, 8 & 9).

Figure 6. Scissor lift and Tectum panel in Gym B-1.

In both cases, these objects were judged at the time not to be large enough in area or volume to make a significant difference in the RT. However, the diffusion that they may have provided was not considered. In both cases lower RT were measured with the most dramatic difference in the later case: a mid-frequency average RT of 2.1 seconds, reasonably close to the ODEON predictions and significantly lower than measurements in the same room conducted roughly one week later by an independent 3rd party with the room empty (see Figure 5).

The third band of wall panels appeared to be having some effect in the Type B gymnasia measured with the additional objects but not in the other (empty) gyms. Further investigation finally lead to the hypothesis of an insufficiently diffuse sound field and uninterrupted standing wave modes in the lower untreated portion of the room contributing to the unexpected results. It was suggested that providing some diffusive objects to break up these reflections might provide results closer to a minimally occupied condition and to the predictions. This hypothesis was tested and the RT re-measured in Gym B-1 with some plywood panels and also with a few people.

Figure 7. Construction materials in Gym B-2 (view 1).

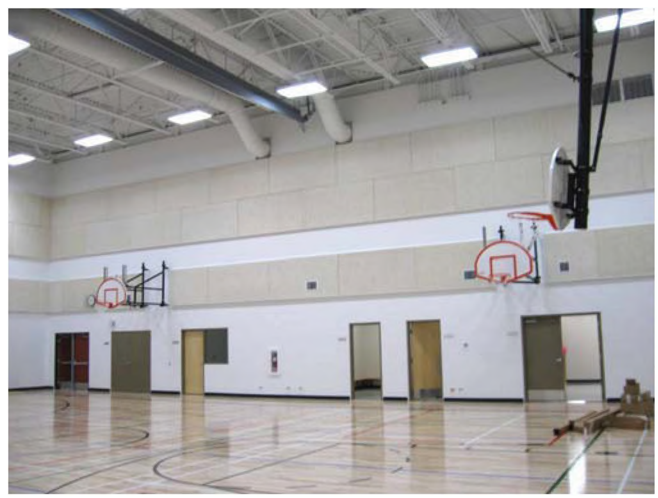

Figure 8. Construction materials in Gym B-2 (view 2).

The third band of wall panels appeared to be having some effect in the Type B gymnasia measured with the additional objects but not in the other (empty) gyms. Further investigation finally lead to the hypothesis of an insufficiently diffuse sound field and uninterrupted standing wave modes in the lower untreated portion of the room contributing to the unexpected results. It was suggested that providing some diffusive objects to break up these reflections might provide results closer to a minimally occupied condition and to the predictions. This hypothesis was tested and the RT re-measured in Gym B-1 with some plywood panels and also with a few people.

Figure 9. Construction materials in Gym B-2 (view 3).

Five different conditions were measured; an empty gym, addition of people, and three levels of diffusion. Diffusion was varied with plywood sheets, 1.2 m x 2.4 m x 12.7 mm thick, stood on end at various locations throughout the gym. Ten of these plywood sheets were fastened together at one end to form five self-supporting A-frame units. The remaining five plywood sheets were leaned against the volleyball net and supporting end poles at the mid point of the gym (see Figure 10). Sheets were removed and the measurements repeated. The measurements were also repeated with the room empty and again with the equipment operator plus four other adults.

Figure 10. Plywood sheets in Gym B-1

6. RESULTS WITH ADDED DIFFUSION

The results for the re-measured Gym B-1 with approximately 35% wall panel coverage and with and without the plywood panels (totalling between 2% and 5% of the room surface area) to increase sound diffusion in the room are presented in Figure 11. All plotted measurements were conducted with the room empty except for the noted fittings or occupants plus the measurement equipment and operator. For the RT measurements with plywood sheets two stepladders were also present. The predicted RT are for the empty room (i.e. no people or plywood panels).

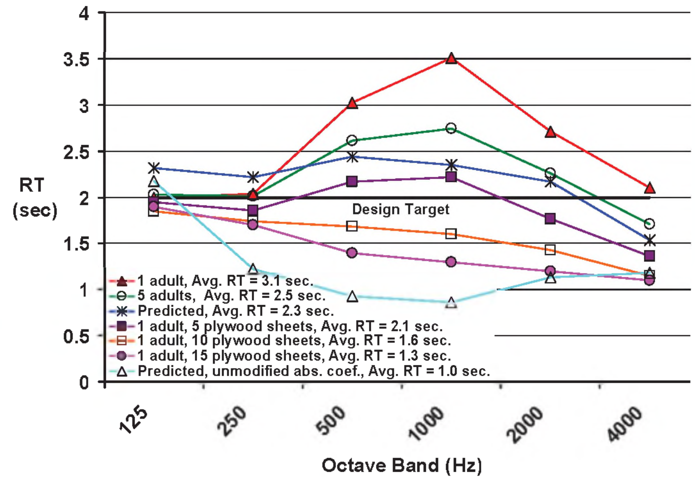

Figure 11. Comparison of measured and predicted RT in Gym B-1 with ~35% wall panel coverage showing the effect of the addition of people and plywood sheets. Triangles: room empty (except for 1 adult). Open circles: 5 adults. Asterisks: predicted RT with modified acoustic treatment absorption coefficients. Solid squares: 1 adult, 5 plywood sheets. Open squares: 1 adult, 10 plywood sheets. Solid circles: 1 adult, 15 plywood sheets. Open triangles: predicted RT with unmodified acoustic treatment absorption coefficients.

The addition of as few as four people or five plywood sheets was found to significantly reduce the measured RT, closer to the modeled predictions, with between a 0.6 sec and 1 sec reduction observed in the mid-band average RT from the empty condition. This decrease in the measured reverberation times is more than can be accounted for by the sound absorption provided by four additional adult bodies alone.

The low frequency RT did not appear to be particularly sensitive to the addition of the plywood however the times in the 500 to 4000 Hz bands were significantly reduced. With the addition of the plywood panels, between a 1.3 sec and 2.2 sec reduction in the RT at 1000 Hz from the empty condition was observed resulting in a mid-band average RT of between 1.3 sec and 2.1 sec compared to 3.1 sec for the empty room.

Similar measurements were repeated by Alberta Infrastructure in Gym A-2 and Gym B-2. Their findings (not yet published) were similar with regards to the effect of diffusive elements on the measured RT (see Figure 12).
During their measurements the importance of plywood placement was not extensively evaluated, however some variations were deliberately introduced to help evaluate any effect this may have. Generally it appeared that the RT were not particularly sensitive to the location of the plywood.
They also reported that the physical variations between the two types of gymnasia did not result in any major

differences in RT. Eight (8) and 18 adults were also randomly distributed throughout the gymnasia while reverberation testing took place. Using body surface areas calculated with the DuBois formula as suggested by ASHRAE and height and weight determined using Standard Pediatric Data from the National Centre for Health Statistics, they deduced that the equivalent of 15 (K-6) students (9 year old males) results in the same reverberant characteristics as approximately four sheets of plywood and that increasing the number of student equivalents to 34, lowers the reverberation to the same degree as approximately ten sheets of plywood.

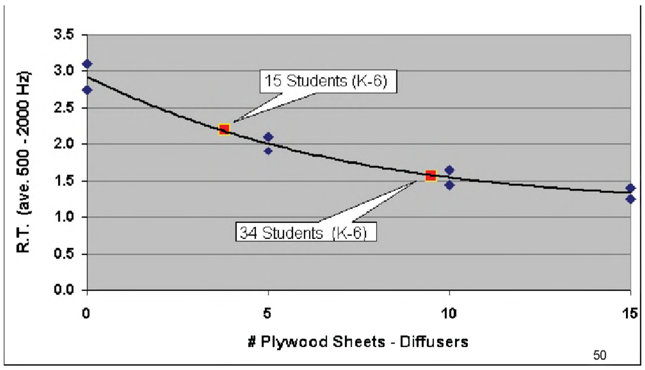

Figure 12. Alberta Infrastructure measured RT in Gym A-2 (upper diamonds) and Gym B-2 (lower diamonds) with ~40% wall panel coverage.

As a result of these measurements Alberta Infrastructure decided that to more fairly and accurately assess the RT criterion applicable to the project, it was important to add diffusion in an appropriate amount to emulate the diffusion that would be provided by a typical class size of 25 (K-6) students and one teacher.

They prescribed that this could be accomplished by adding seven, 1.2 m x 2.4 m sheets of 16 mm to 19 mm thick plywood distributed throughout the gym as described above.

7. ADDITIONAL COMMENTS

It could be argued that plywood sheets are not 'diffusers' per say as they are generally flat and smooth and reflections from them would be predominantly specular. Sound reflectors or re-directors may be a more accurate description of these panels although they were found to increase the level of diffusion or sound mixing in the room.

It has been suggested that the plywood panels change the propagation and reflection of the sound waves in the lower portion of the room and thus of the reflected sound incident on the acoustically absorptive wall panels and acoustic deck, resulting in more effective absorption by the acoustic treatments.

RT measurements in the upper (treated) portion of the room were not conducted during this study but may have yielded some interesting results. One possible explanation for the increase in measured mid-band average RT in the empty rooms with the addition of additional absorptive wall panels could be that by adding absorption in the upper portion of the room while leaving the lower portion of the room (where the measurements were conducted) acoustically reflective actually made the sound field in the room less diffuse. This hypothesis requires further study.

ACKNOWLEDGEMENTS

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Location of Horn Speakers in a Reverberation Room

Ramani Ramakrishnan
Department of Architectural Science, Ryerson University, Toronto, Ontario

ABSTRACT

Considerable theoretical research has been conducted in understanding the design constraints of horn speakers. Further, the locations of horn speakers in reverberation rooms had been well researched. However, most of the research methods applied simple sinusoidal source functions (tones) to evaluate the design criteria of horn speakers. The understanding of the horn speaker behaviour, when band limited random noise signatures such as pink noise and white noise are used as input sources, is still not clear. A hyperbolic horn with cut off frequency of 70 Hz was used in a medium sized reverberation room to study the horn behaviour. Some of the basic questions to be studied were the influence of horn location on the cut-off frequency, as well as the influence of the horn location on the diffuse sound field in the reverberation room. In addition, the influence of the input sound source on the room sound levels was also studied. The results of the experiment are presented in this paper.

RÉSUMÉ

D'importantes recherches théoriques ont été menées pour comprendre les contraintes de conception des enceintes à pavillon. De même, l'emplacement des enceintes à pavillon dans les salles réverbérantes a été bien étudié. Cependant, la plupart des méthodes de recherche appliquaient de simples fonctions sinusoïdales (son pur) comme source pour évaluer les critères de conception d'enceintes à pavillon. La compréhension du comportement des enceintes à pavillon quand des bruits aléatoires à bande limitée tels que le bruit rose ou le bruit blanc sont utilisés comme sources d'entrée n'est pas encore clair. Un pavillon hyperbolique avec une fréquence de coupure de 70 Hz a été utilisé dans une salle réverbérante de taille moyenne afin d'en étudier le comportement. Quelques-unes des questions fondamentales à étudier étaient l'influence de l'emplacement du pavillon sur la fréquence de coupure, ainsi que l'influence de l'emplacement du pavillon sur le champ acoustique diffus dans la salle réverbérante. Par ailleurs, l'influence de la source sonore d'entrée sur les niveaux sonores dans la salle a également été étudiée. Les résultats de l'expérimentation sont présentés dans cet article.

1 INTRODUCTION

Horn speaker design, such as the pioneering work of Beranek [1], has been well studied and reported in the literature. However all of the early research applied simple sinusoidal source functions (tones) to evaluate the design criteria of horn speakers [1,2]. In addition, the location of a source in a room is very much dependant on the expected sound field. Typical effects of locating the source in corners were highlighted in Bell [3] and Beranek [4]. The diffused sound in a reverberation room is supposed to be amplified by the factors based on source's location in the room. Waterhouse evaluated the sound power output of sources when placed against reflecting surfaces and showed that the 'Q' factors are 1, 2, 4, and 8 for the centre, single corner, double corner, and triple corner location of the source respectively [5]. However, his results, for sinusoidal sources as well as a few band-filtered random noises, were valid only when the reflecting surfaces were infinite in extent. Waterhouse concluded that the above results would hold for very large chambers even though no experimental results were provided in Reference 5. Glyn Adams, through theoretical evaluation showed that for steady sound sources, the impact of far walls, away from the reflecting surfaces near the sources, influenced the sound output of the sources [6]. Wright conducted an FEM (Finite Element Method) analysis and showed the importance of room modes on the radiated sound in enclosed spaces [7].

In addition, Cox et.al. [8] and Welti and Devantier [9] studied the relationship between low-frequency sounds, source locations, number of sources as well as the room sizes on the resulting sound level in enclosed spaces. Sevastiadis et.al., in a recent study, applied both numerical and experimental methods to evaluate the prevention of sound colouration inside rooms at low frequencies [10]. Once again, the results of References 8, 9 and 10, applied sinusoidal source functions to understand the behaviour of room sound levels. The extension of the above results, to broad-band and/or band-filtered sounds, is not clear.

The sinusoidal source functions analysis of the early research indicated that, if horn (exponential, conical or hyperbolic) speakers were used in a reverberation room as the main source, the operating frequencies can be modified based on the location of the horn. It was also hypothesized, for example, that if the horn is located in a triple corner, the cut off frequency can be reduced or the mouth size can be reduced [11]. The current investigation was undertaken to test the above hypothesis.

The main concerns with efficient horn designs are the large dimensions of the horn such as its length and mouth cross-sectional area. The understanding of the behaviour of horn speakers, when band limited random noise signatures such as pink noise and white noise are used as input sources, would aid in efficient horn designs with manageable horn mouth size as well as its length.

A hyperbolic horn with cut off frequency of 70 Hz was used in a medium sized reverberation room to study the horn behaviour. Some of the basic questions to be studied were the influence of horn location on the cut-off frequency, as well as the influence of the horn location on the diffuse sound field in the reverberation room. In addition, the influence of the input sound source on the room sound levels was also studied. The results of the above simple experiment are presented in this paper.

2 THE REVERBERATION CHAMBER

The reverberation chamber at Concordia University was used to conduct the experiment. Basic acoustic and geometrical details of the reverberation chamber are presented below. The results of the chamber evaluation can be found in Ramakrishnan and Grewal [12].

2.1 Chamber details

The reverberation chamber is located in the engineering building of Concordia University, Montreal and is used by the Building, Civil and Environmental Engineering Department (BCEE). The characteristics of the chamber are: Length, L = 6.13 m; Width = 6.96 m; Height = 3.56 m; Chamber Volume = 152.3 cu.m. The RT60 varied between 0.8 sec to 3 sec. across the frequency band.

2.2 Chamber characteristics

Reverberation rooms are special test rooms used to evaluate the sound power level of sources as well as to qualify space bound hardware such as antennae and satellites to a high intensity noise environment with levels and spectral content representative of the acoustic environment present during launch. Combinations of reverberation rooms are used to evaluate transmission properties of building materials as well as absorption characteristics of noise control products. A number of standards are available that prescribe minimum requirements of reverberation rooms [13, 14].

The main characteristics of the reverberation rooms are: i) Adequate volume; ii) Suitable shape or diffusing elements or both; iii) Suitably small sound absorption over the frequency of interest; and iv) Sufficiently low background noise levels. [13, 14].

The volume of the chamber needs to be adequate as it determines the low-frequency limit of the room. Above the low-frequency limit, the room responds to bands of noise uniformly thus assuring spatial constancy of the sound levels. There are different methods to determine the low-frequency limit. One such limit is the Schroeder frequency and is given by [15],

$$f_c = 2000\sqrt{\frac{T_{60}}{V}} \qquad (1)$$

where, T60 is the chamber's reverberation time, sec. and V is the volume of the chamber in cubic meters.

The above limit is quite restrictive and when the sound levels are bands of noise, the volume can be lower and one can still maintain adequate spatial uniformity. The results of sound levels, from both single sinusoidal tones as well as bands of noise, measured in the Concordia reverberation chamber are presented below to determine the adequacy of chamber volume.

Eq. (1) has provided a low-frequency limit which has been adopted by many standards and based on that requirement, the volume of the chamber has to be determined. As mentioned earlier, Schroeder requirement is quite restrictive.

Another empirical approach is to impose a norm of at least 20 modes per octave for acceptable uniformity. Slingerland, Elfstorm and Grün applied 20 modes/octave criterion and derived the following relationship for the cut-off frequency [16],

$$f_c = \frac{c}{\sqrt[3]{V}} \qquad (2)$$

where, c is the speed of sound.

The two different approaches produce different limits and the most commonly used Schroeder limit is too restrictive. Field measurements were conducted in the chamber to determine the most reasonable limit that is practical and can be easily implemented. The cut-off frequency as per Eq. (1) is 188 Hz and as per Eq. 2 is 64 Hz.

The chamber is rectangular in shape and the standing wave frequencies can easily be determined from basic descriptions [17] and are given by,

$$f_n = \frac{c}{2}\sqrt{\left[\frac{n_x}{L_x}\right]^2 + \left[\frac{n_y}{L_y}\right]^2 + \left[\frac{n_z}{L_z}\right]^2} \qquad (3)$$

The number of modes in each octave band was enumerated from the above equation and the results for the chamber are given in Table 1.

The results of Table 1 show that that the Chamber can be comfortably used from the 125 Hz octave band to achieve acceptable spatial uniformity. This is borne out by the cut-off frequency of 64 Hz calculated from Eq. 2. The Schroeder limit for the Chamber is 188 Hz (from Eq. 1) which is very restrictive.

Table 1. Modal Composition of the Chamber

Band No.	Lower Limit	Centre Frequency	Upper Limit	Number of Modes
1	22	31.5	44	5
2	44	63	88	38
3	88	125	177	210
4	177	250	355	340

The validity of these limiting frequencies is confirmed through measurements and is presented next.

A simple experiment was used to determine the spatial uniformity of the chamber as well as the low-frequency cut-off limit of the chamber. Simple speakers (both low-frequency speakers and a bank of high frequency tweeters) were used to generate the sound. Both pink noise and sinusoidal tones (100, 150, 200, 250, 300, 400, 500 Hz) were generated and the resulting noise levels were measured at a number of locations, - between 48 and 54. The locations were chosen randomly at two different heights. The results of the measured SPLs are presented in Tables 2 and 3.

Table 2. Sound Levels in the chamber (Broadband, 28 Samples)

1/3 Octave Band Centre Frequency, Hz	Average SPL, dB	Range, dB	Standard Deviation, dB
50	145.4	10.0	3.8
63	146.1	8.3	2.6
80	144.9	7.1	2.6
100	144.2	3.9	1.4
125	144.2	4.0	1.4

The results of Table 2 show that for a broadband signal, the chamber had good spatial uniformity from 100 Hz (1/3 octave band) and above. However, the same cannot be inferred for tones. Even for frequencies above the Schroeder frequency limit of 188 Hz, the chamber's spatial uniformity, as seen in the results of Table 3, is poor.

Table 3. Sound Levels in the chamber

Tonal Frequency Hz	Average SPL, dB	Range dB	Number of Samples	Standard Deviation, dB
100	102.5	37.1	37	9.5
150	100.1	29.3	47	7.1
200	98.0	28.6	48	8.8
250	97.6	35.1	48	7.6
300	94.4	31.1	48	7.4
400	96.3	29.8	48	7.8
500	100.7	32.6	48	8.4

The ISO Standard 3741 [14] requires a minimum of 200 cu. m. as per the Schroeder limit of 125 Hz Octave band and the maximum allowable standard deviation is 1.5 dB. The results of Table 2 show that even if one cannot meet the minimum volume requirement, the spatial uniformity of the chamber sound levels can be satisfied for broadband sound levels. For pure sinusoids, even though the volume requirements are satisfied, the results of Reference 12 indicated that the spatial uniformity cannot be assured.

3 THE HYPERBOLIC HORN

A hyperbolic horn speaker was used for the tests. The horn in a triple corner is shown in Figure 1. The horn details are: the horn length is 92.1"; the throat area is 2.1 sq. in; the mouth area 397.5 sq. in.; band width is from 68 to 219 Hz; and the horn volume is 3.7 cu. ft.

The horn was connected to an AURA NS3-193-8A speaker with frequency response from 50 Hz to 7000 Hz (±3 dB). The microphone boom that was used in the sound levels measurements is in the background.

Figure 1. The Hyperbolic horn at a triple corner (The microphone boom is in the background).

4 THE EXPERIMENT

The experiment basically consisted of driving the speaker-horn combination with single sinusoids or band filleted random noise. The diffused sound field was measured by using a microphone boom at two different heights. The equivalent sound level over a 30 second traverse of the boom was calculated. The measurements were conducted for three locations of the horn – the horn speaker in triple corner (as shown in Figure 1); the horn speaker was moved diagonally by 2 feet; and the horn speaker was moved diagonally by 4 feet. The last location would represent a double corner somewhat. Different combinations of the horn speaker locations were also tested. The results for the above triple corner and a single corner are presented in this paper. As mentioned earlier, the operating frequency of the hyperbolic horn is from 68 Hz to 219 Hz. The above band width was determined by the

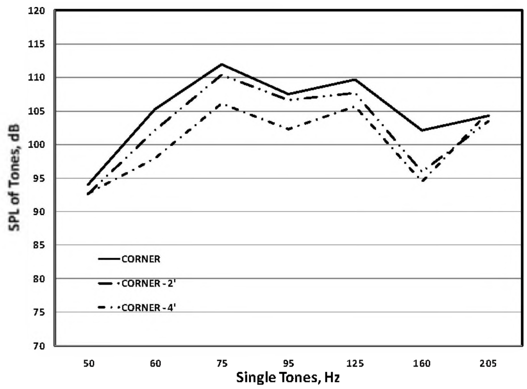

Figure 2. Room SPL variation – single tones.

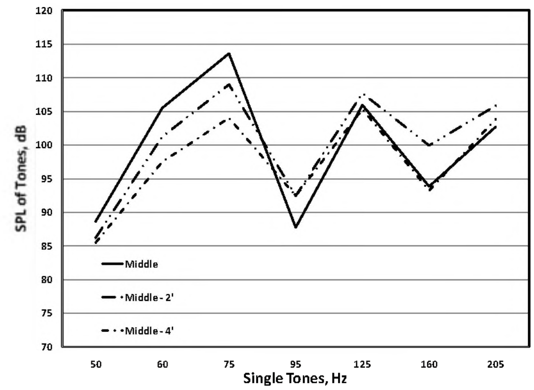

Figure 5. Room SPL variation – single tones.

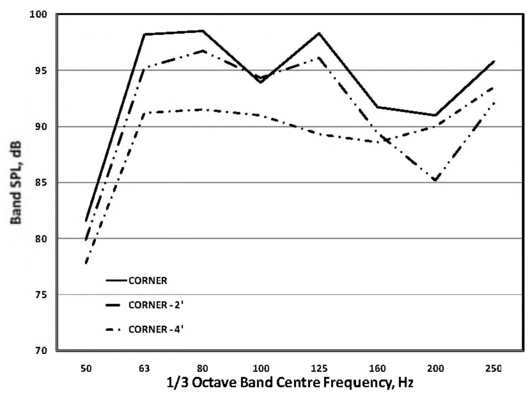

Figure 3. Room SPL variation – Band filtered noise.

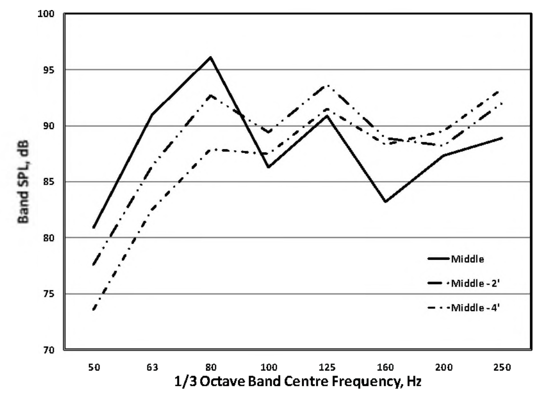

Figure 6. Room SPL variation – Band filtered noise.

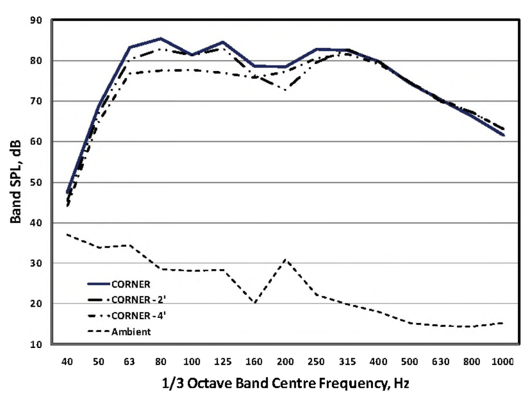

Figure 4. Room SPL variation – Pink noise (40 to 10 kHz).

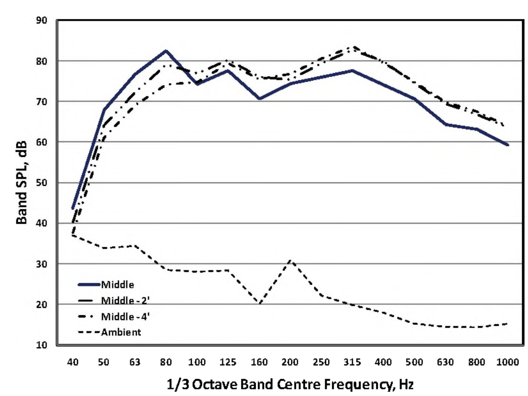

Figure 7. Room SPL variation – Pink noise (40 to 10 kHz).

manufacturer from the design of hyperbolic horn. The length and the mouth area were evaluated after fixing the cut-off frequency and the upper limit frequency of the horn design.

5 RESULTS AND DISCUSSION

The room sound pressure levels (SPL) for various conditions are shown in Figures 2, 3 and 4 below for the triple corner location. The operating condition changes from a triple corner to a somewhat pseudo-double corner.

The SPL variations in the room for sinusoidal sources are shown in Figure 2. The room SPLs between 60 Hz and 160 Hz are seen to follow the typical 'Q' factor variation of 3 to 4 dB differences. The behaviour below 60 Hz and above 200 Hz is seen to be indifferent to the speaker location. Even though a strong signal was generated at 50 Hz, the triple corner effect is non-existent. The results for band-filtered random noise are shown in Figure 3 and much broader pink noise results are shown in Figure 4. The speaker location's effect is unpredictable for the band-filtered random noise within the operating range of the horn. The speaker location had absolutely no effect when the broader pink noise was generated. No consistent 'Q' factor effect was evident in the results of Figures 3 and 4. Strong room modes may have an impact in the 100 to 200 Hz frequency range, even though there are a few modes, at least 10 in each third-octave.

The results for a single corner location, slowly changing onto a non-reflecting location, are shown in Figures 5 thru' 7.

Somewhat similar behavior to the early results can be seen. In addition, the room mode impact, particularly the coupling between the source and the room, is seen to be strong in the 100 to 200 Hz frequency range.

6 CONCLUSIONS

The effect of the location of a horn speaker in a reverberation room was tested. The effect was evident in the sinusoidal input signals. When random noise and/or broad band signals were used as input, the preliminary results show that the speaker location had no impact on the diffused sound levels of the reverberation chamber. The current work is on-going and the above experiment needs to be expanded to include higher frequency bands to test the validity of the questions that were posed.

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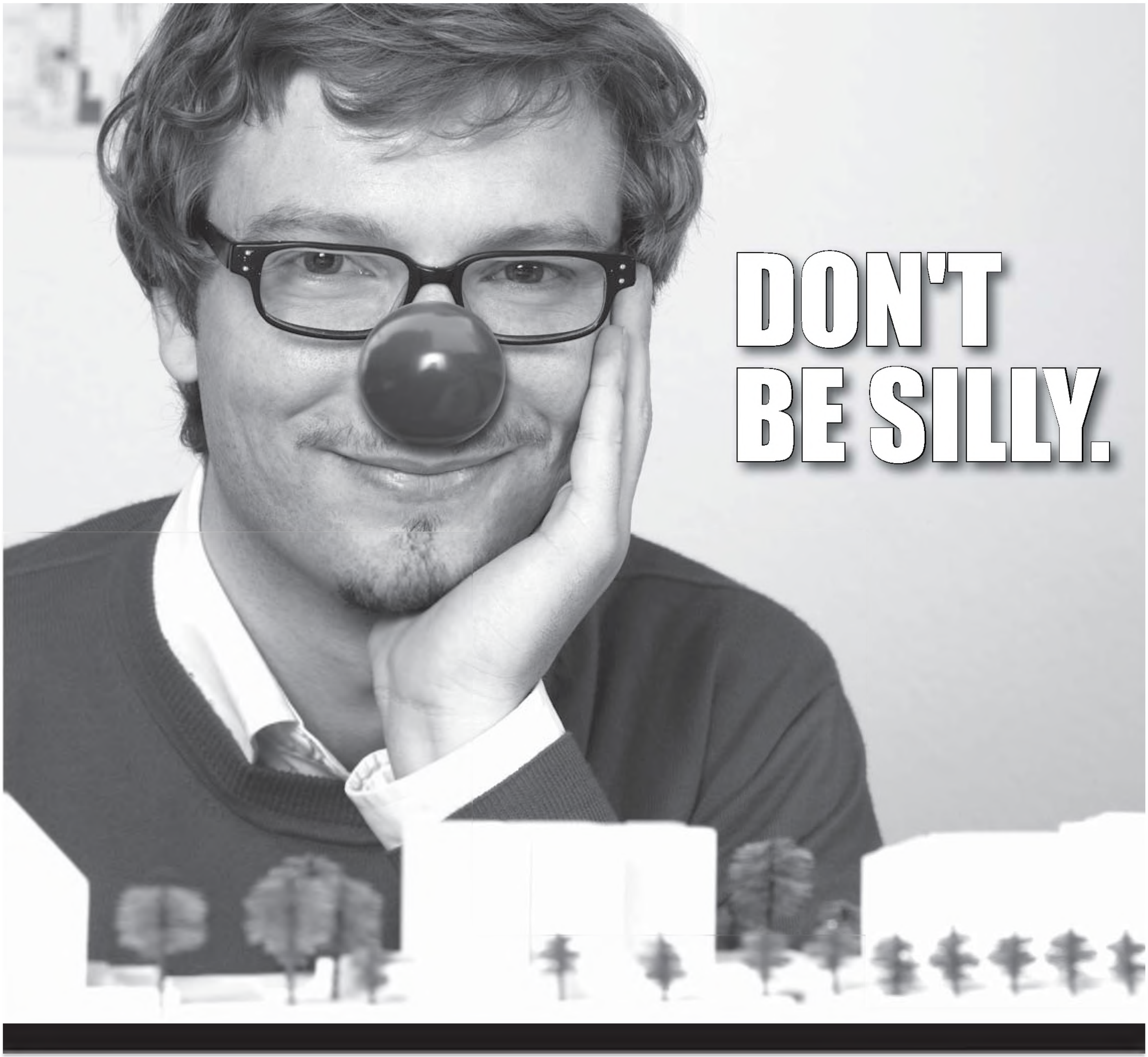
DON'T
BE SILLY.

Acoustic Enhancement of Proposed Grand Lecture Hall using Computer Simulation

Chris DiMarino, Dillon Fuerth, Devin Gignac, Adam Lunardi, Colin Novak, Robert Pikul and Anthony Simone
University of Windsor, Mechanical, Automotive and Materials Engineering,
401 Sunset Ave.; Windsor, ON; N9B 3P4; Canada

ABSTRACT

The presented research deals with the acoustical performance of a proposed grand lecture hall using experimental and modeling techniques. The primary challenge for the senior undergraduate engineering group was that the room has yet to be fully designed or constructed. The secondary goal was to optimize the design of the room using the computer software ODEON in the early design stage rather than after it has been built as is often the case. Reverberation time, early decay time, clarity and STI were the four acoustical parameters considered. The modeling software was also validated using test measurements conducted in a similar lecture room. The results of the present room design demonstrated less than ideal reverberation time and early decay times for the proposed room use but above average clarity and STI values. Design suggestions are given to increase the acoustical performance of the proposed lecture hall.

RÉSUMÉ

La recherche présentée est une étude des conceptions pour optimiser les propriétés acoustiques d'un amphithéâtre par méthodes expérimentales et avec les modèles informatiques. Le principal défi pour le groupe d'étudiantes de quatrième année en génie était que la salle n'a pas été encore complètement conçue ou construit. L'objectif secondaire était l'optimisation de l'amphithéâtre en utilisant le logiciel ODEON au stade de la conception, plutôt qu'après que la salle a été construit, comme c'est souvent le cas. Les quatre paramètres du son en considération étaient: le temps de réverbération, le temps de décroissance, la clarté et le STI. Plusieurs expérimentes ont été mené dans un amphithéâtre similaire pour corroborer le modèle en ODEON. Les résultats du présent amphithéâtre conceptuel ont démontré des niveaux de temps de réverbération et temps de décroissance moins que ceux qui seraient idéales pour ce type de salle de classe, mais ils ont aussi indiqué des valeurs de la clarté et de STI au dessus de la moyenne. Les suggestions sont données pour augmenter la performance acoustique des paramètres sous-performants.

1. INTRODUCTION

The primary purpose of this undergraduate research project was to evaluate the University of Windsor's Centre for Engineering Innovation (CEI) grand lecture hall. The challenge associated with this was that the CEI building has not yet been constructed which eliminates the possibility of using conventional evaluation methods. For this reason, a computer modeling program was used to analyze the lecture hall. The software chosen for this task was ODEON and the metrics analyzed were: reverberation time, early decay time (EDT), clarity (C80), and speech transmission index (STI) [1-4]. These four acoustical parameters were chosen to provide a thorough room evaluation.

The secondary goal was to acoustically optimize the design of this proposed lecture hall. Since construction had already begun, it was impossible to make drastic changes. However, new acoustical technologies can be implemented into a completed room such as better wall materials and sound traps. The results were used to gauge the necessity of the design upgrades.

ODEON is simulation software used to evaluate the acoustical properties of spaces. This investigation was unique because the room which was evaluated is the size of a concert theatre, but must have the acoustics of a classroom. To ensure the results were accurate, a few different room sets were evaluated. Simple and detailed room models were used with the original and upgraded materials. This diversity of test conditions helped validate the results received from ODEON. The results of the investigation confirmed the importance of evaluating the acoustics of a room during the design phase. The results of the current undergraduate group project are presented in this paper.

Section 2 presents the results of the acoustical investigation of an existing lecture theatre. The simulation process and preliminary results of the simulation are described in Section 3. The modeling details as well as the details of the design upgrades are shown in Section 4. Section 5 contains the results of the simulation. Potential errors of the simulation are described in Section 6. Design recommendations are discussed in Section 7 and the conclusions of the current investigation are presented in Section 8.

2. VALIDATION OF SIMULATIONS

Prior to evaluating the acoustics of the grand lecture hall based on design drawings alone, a validation exercise of the software's ability to predict reverberation time and STI was carried out. To do this, a simulation model of an existing 155 seat lecture hall was created and the results were compared to physical measurements for these metrics.

The measurements of reverberation time and STI for the existing hall were performed using DIRAC software, a PC program designed for determining various acoustical parameters based on the measurement and analysis of the impulse response.

Reverberation time of the lecture hall was measured following the procedure of ISO 3382 standard [5]. For this, the reverberation time was measured in 1/1 octave frequency bands and averaged at the most significant bands (500 Hz and 1000 Hz) at a receiver height of 1.2 meters which is representative of the height of a seated listener's ear and at a source height of 1.5 meters. A total of 20 reverberation times were measured in the lecture hall using alternating source and receiver positions around the room. To ensure that the reverberation times obtained were of good quality, the impulse to noise ratio (INR) values were verified to be within acceptable values over the measurement frequency range.

STI measurements were obtained by placing the source at the front and centre of the room to represents the position and source of a lecturer. A total of 15 receiver locations were situated at various positions throughout the hall at a height of 1.2 metres. An ESweep signal and a male filter using DIRAC were used to obtain the impulse response for the speech intelligibility metrics. The ESweeps signals are frequencies that increase exponentially over time and are often said to provide better quality results [6].

Next, the physical dimensions of the room were carefully measured, drawn into CAD software and imported into ODEON. Material surface properties including absorption and scattering coefficients were estimated using an extensive library of typical surface types. From this, a simulation model was created with source and receiver locations similar to those used in the experimental exercise. Predictions of the reverberation time and STI were then calculated using ODEON and compared to the experimental measurements.

Using ODEON, the unoccupied room had a predicted global reverberation time of 1.01s. This is comparable to the measured reverberation time of 1.03s. Upon closer examination, the results of the modeled and experimental measurements within the mid frequency band of 250Hz – 2000Hz were within a 5% agreement. The results at frequencies below 250Hz though did not agree as well which are assumed to be the result of poorly estimated absorption coefficients for some of the room surface materials.

The majority of the predicted STI values calculated at the 15 listener positions were within 5% of the measured STI results which is considered acceptable. However, there were very few STI values that were marginally outside of the 5% range.

Given the favourably comparative results from the validation exercise, it was concluded that the ODEON software is capable of predicting the common room acoustic metrics. This is conditional that the computer model is dimensionally and geometrically correct and that representative material surface properties are chosen.

3. SIMULATION PROCESS

The simulation process using ODEON began with the creation of geometrical representation of the space using AutoCAD software which is capable of exporting a drawing exchange format (dxf) file. While ODEON does have a drawing editor, this option should be used only for the creation of very simple structures. The importation of the geometry file requires the specification of key parameters including tolerance level, connection specification between surfaces and the position of the coordinate system. For this study, two models of the lecture hall were created. The first is referred to as the "detailed model" which is an accurate representation of the room geometry. A second "simplified model" was also created which had a more uniform representation of the surfaces with less architectural detail. The specific differences between the two models are described in Section 4.

The specification in the model of the surface connection type, in this case glued, is important to ensure that the enclosed space is without gaps where there should be none. The specified dimensions were given in millimetres with the tolerances selected to be medium to ensure efficient use of computational resources. A debugger option was used to ensure that no surface overlaps or unwanted irregularities were present. The software also allows the control of other conditions including temperature, humidity and background sound power levels. Standard values for these were used.

The next task in the modeling process was to assign material properties to the room surfaces based on the bill of material for the building design. These include absorption at select frequencies and scatter, or diffusion coefficient. The software has an extensive library of values which can be chosen by the user for these. While many of the room materials are common, such as tile and concrete floors, gypsum board, wooden desks and vinyl covered seats, other surfaces including the side walls and ceiling were made from newer and more innovative acoustic and thermal materials. Some information was found on the manufacturer's websites [7]. For others, the software did provide some guidance by providing a general range for these coefficients taken from similar applications and materials. These recommendations were used to estimate the unknown coefficients.

The next step in the process is to identify source and receiver locations representing where talkers and listeners would normally be located. For the sources, both position and directivity of the sources required specification. The analysis is done through the aid of specific jobs. This option allows the user to specify an analysis to a single job which can involve either one source-receiver combination or multiple source-receivers combination. The setting of the job entirely depends on the set of circumstances and the requirements of the user. The software requires that each job has only one active point source. In the end the user can set up multiple jobs so as to analyze different scenarios. Once the setup is complete and all the parameters are fixed, all the jobs are run simultaneously to complete the analysis which can take considerable time and processing power.

The goal of a good design for the lecture hall is to have a space with uniform acoustic performance throughout the space. For this, an initial analysis was performed for which sound intensity maps were generated which are very similar to colour spectrograms. The sound source was a simulated lecturer at the front of the room and the seat represented the receivers. From these plots, location of low sound pressure levels can be identified. The initial analysis identified a problem with inadequate sound pressure levels at the rear third of the lecture hall. This result suggested that the decay times at some locations within the hall were too low. To solve this, an alternative design with alternative material selections having more diffuse properties [7] was evaluated to increase the decay times with the hope to also increase the sound pressure levels at the rear of the hall. Specifically, this revised model removed the presence of cloth covered architectural panels from the side walls and replaced them instead with smooth drywall. Further, the pyramidal shaped details in the ceiling were removed and again replaced with simple flat drywall surfaces. The seating in the auditorium in the first model incorporated cloth covered cushioned seats. To increase the diffusivity of the space these were replaced with a harder industrialized fiberglass chair. Other surfaces, such as linoleium flooring was replaced with painted concrete. The goal of these changes was to increase reverberation times in the space particularly in the hope of increasing sound levels at the rear of the auditorium.

It was also recognized that a simple increase in reverberation does not necessarily mean an overall improved soundscape within the space. Too much reverberation can result in poor speech recognition. One only needs to imagine listening to a lecture in an empty gymnasium to appreciate this. Because of this, other metrics were also predicted to evaluate the sound quality of the space including EDT, C80 and STI. An attempt to improve remaining problem areas was with the addition of sound traps [8].

4. DETAILS OF THE MODEL

It was stated in the previous section that a detailed and simplified model was generated to represent the space of the lecture hall. There were essentially four fundamental design simplifications which were incorporated into the two models.

The first major difference between the detailed and simplified model was the way that the ceiling surfaces were detailed. The ceiling, as it was designed by the architect, was very irregular in shape. The transition surfaces are not perpendicular to each other with some of these having pyramid shaped diffusers. These differences are illustrated in the plan view of the ceiling for both the detailed and simplified models as given in Figures 1 and 2 respectively.

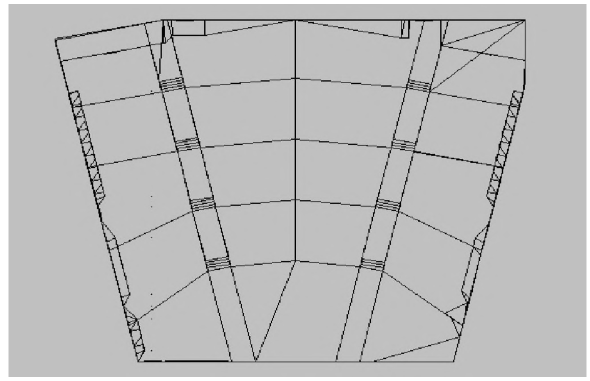

Figure 1: Plan view of Lecture Hall Ceiling for the Detailed Model

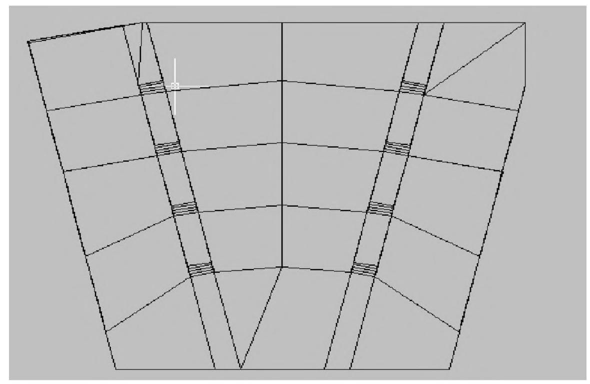

Figure 2: Plan view of Lecture Hall Ceiling for the Simplified Model

A second significant difference between the way that the detailed and simplified models were constructed is the position and shape of the lecture hall seating. The detailed model included shapes with relatively accurate dimensions and shape of the proposed seating for the hall. The simplified model instead represented the seating by box shapes having similar dimensions. The fundamental difference here is that the box shapes are totally enclosed compared to the more open style of the details seats. These differences are illustrated in Figures 3 and 4.

The last major difference between the detailed and simplified model was the way that the wall surfaces and internal

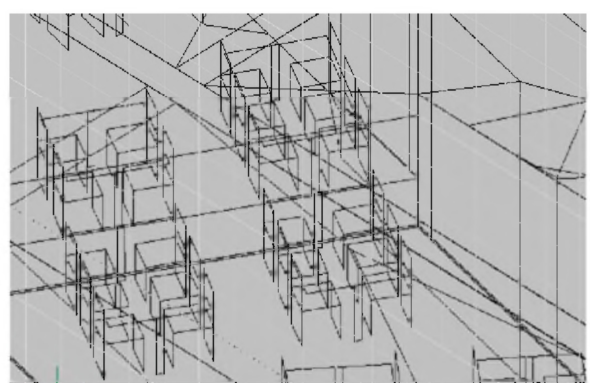

Figure 3: Seating for the Detailed Model

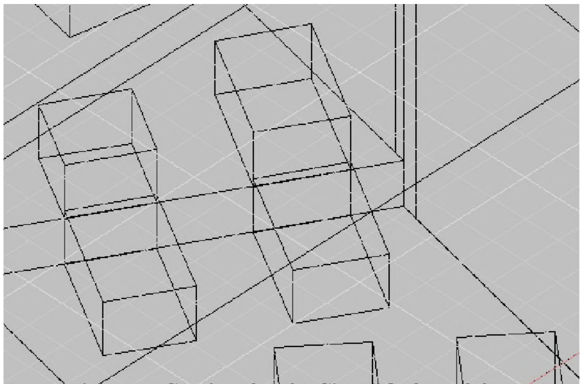

Figure 4: Seating for the Simplified Model

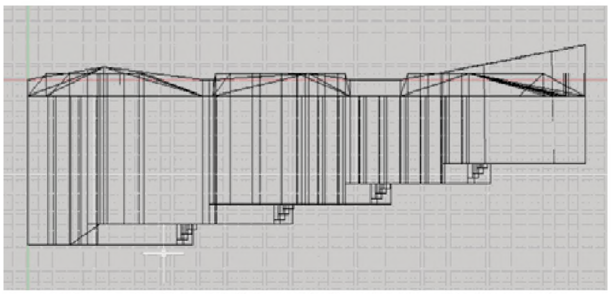

Figure 5: Side Wall Details for the Detailed Model

Figure 6: Side Wall Details for the Simplified Model

structures were modeled. Similar to the case of the ceiling, the architects design of the wall surfaces were very irregular with much surface detail. The internal structures were also hollow at some locations and solid at others. The simplified model had much smother surfaces without the detail and was created without any hollow spaces behind the walls. These are illustrated in Figures 5 and 6 for the detailed and simplified models.

5. RESULTS AND DISCUSSION

The primary purpose of this research was to evaluate the acoustics for the yet to be constructed grand lecture hall to be located in the University of Windsor's new engineering building. The secondary goal was to acoustically optimize the design of this proposed lecture hall. The modeling included the use of both the proposed building surface materials as well as upgraded materials. The results of both a detailed and simplified geometry were also examined. For each of these, the metrics of reverberation time, early decay time (EDT), clarity (C80), and speech transmission index (STI) were predicted. The predicted results for each of these are detailed below.

The results for the original materials showed low values for the reverberation time and EDT but higher than average clarity and STI values. The simple room design performed better than the detailed in all parameters except STI. The upgraded materials increased the reverberation time and EDT, but lowered the clarity and STI.

Each graph shows the results for both the original and upgraded materials. Since there were two room models (detailed and simplified) evaluated, each sound parameter had two graphs. Therefore, there were four sets of results for each parameter. For all of the graphs except STI, the sound parameter was graphed against the frequency on a logarithmic range from 63 to 8000 Hz. Special notice was given to the 1000 to 4000 Hz range because this is where speech primarily resides. Performance in this frequency range was critically important since the room will be used as a lecture hall.

These sound metrics were all dependent on room size and shape, not sound loudness. For example, the results should be the same whether the room is tested with one speaker or 10. For this research, the results generated with 32 speakers in the room were active, were the same if just one source was active. This provides validity to the results. This issue is important because it will be discussed in depth for this room. Whether the lecturer will use the speaker system, or speak without amplification will affect the evaluation of the room.

5.1 Reverberation Time (RT60)

The desired reverberation time for a room of this size and intended use is between 1 and 1.2 seconds [9]. The predicted reverberation times for the detailed and simplified models are illustrated in Figures 7 and 8 respectively, each for the design and upgraded surface materials. The simple model with upgraded materials was the only room designed with reverberation times within the ideal range with all other models predicting lower times. The reverberation times between the original and upgraded materials for both models were fairly consistent over most of the frequency range with a decrease in the 1000 Hz to 4000 Hz range. The overall difference between the highest and lowest cases was approximately 40%. The low reverberation times may be due to the pyramid shaped ceiling details and absorptive materials. This assumption is reinforced by the results for the simplified room with upgraded materials which had neither pyramid ceilings nor absorptive materials and performed at a more desired re-

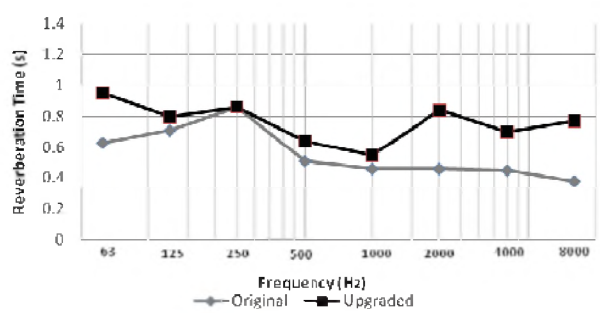

Figure 7: RT60 vs. Frequency for Detailed Model

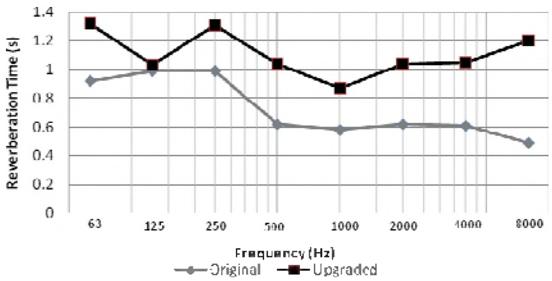

Figure 8: RT60 vs. Frequency for Simplified Model

verberation time.

5.2 Early Decay Time (EDT)

The results for the EDT are in Figures 9 and 10. The ideal early decay times should be similar to reverberation time, or 1 to 1.2 seconds. The EDT results should also correlate closely to the reverberation time results. In general, the results did correlate with 90% of the reverberation times. The EDT results gauge how diffusive the room was [10]. Similar to the results of the reverberation time, only the simple room with upgraded materials performed at the ideal range. However, this was the data set which least correlated with its respective reverberation time (78%).

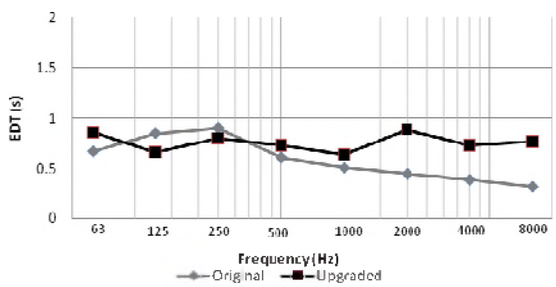

Figure 9: Early Decay Time vs. Frequency for Detailed Model

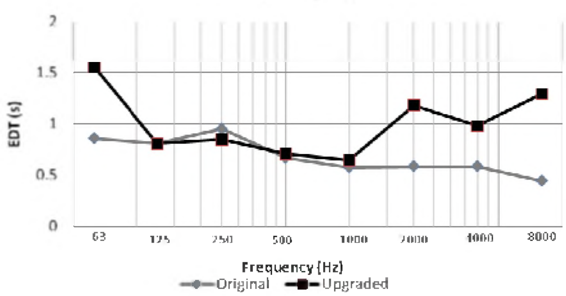

Figure 10: Early Decay Time vs. Frequency for Simplified Model

5.3 Clarity (C80)

It is generally accepted that clarity values above one are acceptable [11]. The results for clarity for each of the modeled cases are given in Figures 11 and 12. All four room scenarios performed well above the standard. The original room material cases performed noticeably better, particularly in the 1000 to 4000 Hz range. The detailed rooms had higher clarity values than the simple rooms. Given that clarity is a comparison of constructive to destructive sound waves, it is suggested that the sound trapping effects of the detailed room and original materials may have led to higher clarities because destructive interference was not as prevalent.

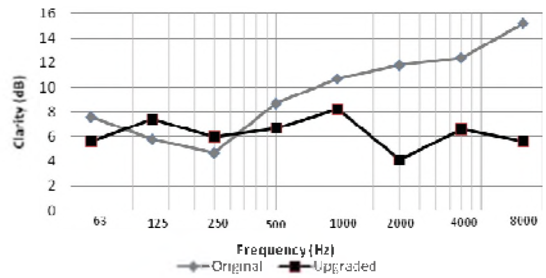

Figure 11: Clarity vs. Frequency for Detailed Model

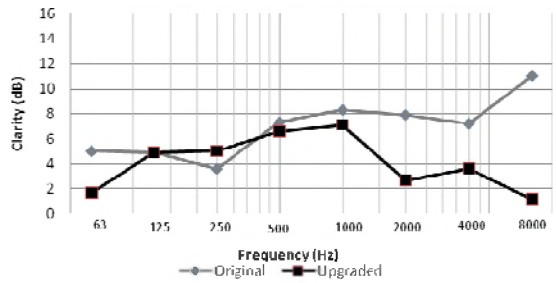

Figure 12: Clarity vs. Frequency for Simplified Model

5.4 Speech Transmission Index (STI)

It should be noted that the details of the HVAC system was not incorporated in any of the models. The effects of the presence of the HVAC system can be a major influence to the STI value. The proposed space in this building is intended to have an innovative type of HVAC system which would be difficult to simulate.

However, the authors have been informed by the architects that this new HVAC system design is expected to be very quiet and should not drastically alter the results. The STI results are illustrated in Figures 13 and 14. The generally accepted ideal range for STI with the given purpose of this space is 0.5 to 0.75 [9]. The results for this parameter were similar to those for clarity except that they differed from each other by only approximately 10%. The room modeled

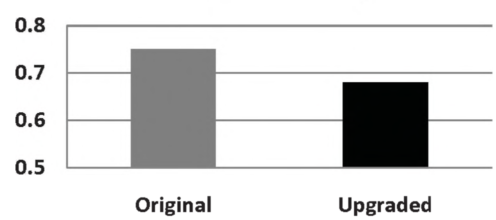

Figure 13: STI Results for Detailed Model

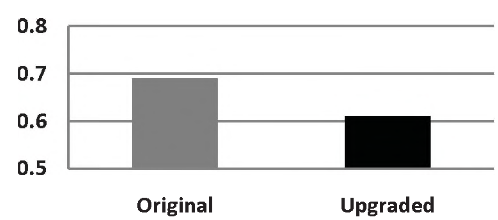

Figure 14: STI Results for Simplified Model

with the original materials performed better with the detailed room model having the best results. All four room designs performed within the range of acceptable values.

While the modeled results for the lecture hall were reasonable, the decay times were lower than expected and the clarity and STI values were above average. It was found that the upgraded materials resulted in an increase in the predicted decay times as anticipated. However, the upgraded surface materials also resulted in lower clarity and STI results.

Given the large margin of variability in most of the results, questions toward the validity of the software are raised. On average, the parameters varied by approximatly36%. However, in consideration of the different modeled input designs, some variation is to be expected.

6. DISCUSSION OF ERRORS

The decay time results presented in the previous section were considerably lower than ideal and also differed depending on the materials used and level of model detail. These can be attributed to a number of sources of error associated with the model input and computation.

As stated in an earlier section, the choice of material property input is important as an inappropriate choice of absorption or scattering coefficient can greatly affect the accuracy of the modeled results. This was regarded as the largest source of error due to the newer style of surface materials used for this building which was not included in ODEON's material data bank. It is assumed that some of the assumed values used for these materials may have influenced the accuracy of the results.

It was also found that some of the calculation approximations used by the ODEON led to truncation errors. Although these errors were small, they may have carried an additive effect throughout the series of calculations. This can be especially so for a complicated space as large as the lecture hall in this study. Other assumptions regarding the modeling of the rooms complicated geometry is another possible source for error. As the amount of approximations increased, so did the chance for error. Finally, the assumption associated with neglecting the impact of the HVAC on the STI prediction may have also resulted in error in this metric's results.

7. DESIGN RECOMMENDATIONS

The secondary objective of this project was to suggest design improvements for the grand lecture hall. It was found that the upgraded materials used did provide greater reverberation and early decay times [7]. However, these upgrades also decreased the clarity and speech transmission indexes. The changes in the clarity and STI were not significant enough though to greatly impact the room, the increase in reverberation time and EDT would improve the sound quality of this space. The early decay time values for the frequency range of 1000Hz to 4000Hz, where speech naturally occurs, was a key parameter to consider.

A live room concept, which can monitor the room acoustics and display the results, is also recommended, especially considering that the room is an engineering teaching hall. This way, the room could be used for demonstration tutorials to assist students in the understanding of room acoustics and architectural material properties. By this, the instructor would be able to demonstrate acoustic experiments for the students.

8. CONCLUSIONS

The primary focus of this research was to evaluate a lecture hall in a preconstruction condition. The secondary goal was to determine how to acoustically optimize the lecture hall's design. This was accomplished through implementation of the ODEON software to predict several different acoustical parameters. Several combinations of materials, wall construction and ceiling designs were modeled to provide evidence of which combinations offered the best acoustical results.

The reverberation time of the detailed grand lecture hall was relatively low for a room of its size. This was due to the pyramid ceilings and absorptive surfaces. This may cause problems for lecturers without the aid of speaker amplification. It is a common trend in room design to design the space to be absorptive and lessen sound propagation, however, this can cause both speaker and listener fatigue.

If anything, this study showed the importance of designing and optimizing the acoustics of a room intended for a learning environment. The merit of using design software like ODEON was also demonstrated.

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The Acoustics of Performance Halls
J. Christopher Jaffe
W. W. Norton and Company, 2010
List price: Cd$62.50 (Hardcover)
208 pp., ISBN: 978-0-393-73255-9

Quick! Name that acoustician who designed the Toronto Opera House and the new auditorium for the Royal Conservatory of Music in Toronto. I am sure, the name of the architect is at the tip of your tongue, but alas the acoustician is difficult to name. Of course, most of us familiar are with the giants such as Leo Beranek, Ted Schultz and Russell Johnson who have contributed not only to auditorium acoustics, but to the overall field of engineering acoustics in general. [Note: The acoustician for the two brilliant auditoria is Bob Essert of Sound Space Design Ltd., London, UK]. Architects seem to take centre stage (perhaps rightfully so), but many of them do not even mention the name of the acoustician in their press releases. If the acoustics of the auditorium is not up to snuff, the blame is placed squarely on the poor, non-descript acoustician. It is such a joy, therefore, to receive a book where the acoustician seems to have played a major role in making sure the auditorium satisfies the demands of the different stakeholders and at the same time seems to have collaborated well with architects. Christopher Jaffe's book The Acoustics of Performance Halls provides a wonderful backdrop to the oft-difficult collaborative relationship between the architect and the acoustician.

Jaffe's book is not a 'Text Book' in the conventional sense of the term. It is a personalized journey of Jaffe over the course of 50 years of acoustical consulting work related to auditorium acoustics. Jaffe begins his journey with an overview of the limitations faced by designers, till the end of the 19th century of performance spaces: hall width restrictions (19 m of less) and lack of acoustical information such as quantification of surface reflections. With steel and concrete structures available from the late 19th century, the hall width could be drastically increased thereby resulting in different shapes. In addition, acoustical descriptions and measurement abilities became feasible with Wallace Sabine's classical reverberation time representation. Jaffe terms the above two developments as "Design Revolution" and presents in his first chapter, through examples, the various hall designs that could be designed as compared to the conventional shoe-box design. Similar ideas were expanded in Chapter 2, titled "Breaking Away." The third chapter is recognition of the seminal work undertaken by Dr. Beranek in the 1960s, who tried to bridge the gap between musicians, architects and acousticians by quantifying the subjective perceptions to meaningful acoustic descriptors. Jaffe concludes Chapter 3 by providing appropriate design goals to satisfy the needs of the listening area.

Chapter 4 turns its attention to the acoustical aspects of the orchestra platform where the requirements of the musicians are paramount. Since Jaffe's early work focused on orchestra shells, his knowledge and experience on providing good acoustics to the musicians takes centre stage in this chapter. The use of binaural mannequins to measure the response on the orchestra stage without disturbing the musicians is also described in Chapter 4. The preparation and application of a survey questionnaire for the musicians is also highlighted in Chapter 4. Jaffe turns his attention to the design requirements of a 'shoe-box' concert hall in Chapter 5. The chapter is divided into succinct parts that include listening area acoustics, stage acoustics as well as variable acoustical elements that can be implemented in the concert hall. Jaffe captions his Chapter 6 as 'Musical Memory.' He postulates that one of the reasons a particular hall is deemed poor acoustically, may be due to the inability of the orchestra and/or the music directors to adjust to the acoustics of a new hall. The Kennedy Center for the Performing Arts in Washington DC is used as a case study when the new hall was designed to satisfy the ever-changing needs and the intended good acoustical design practices were sacrificed. Jaffe showed how he, as the replacement acoustician, was able to overcome the 'Musical Memory' to produce a acoustically satisfactory concert hall.

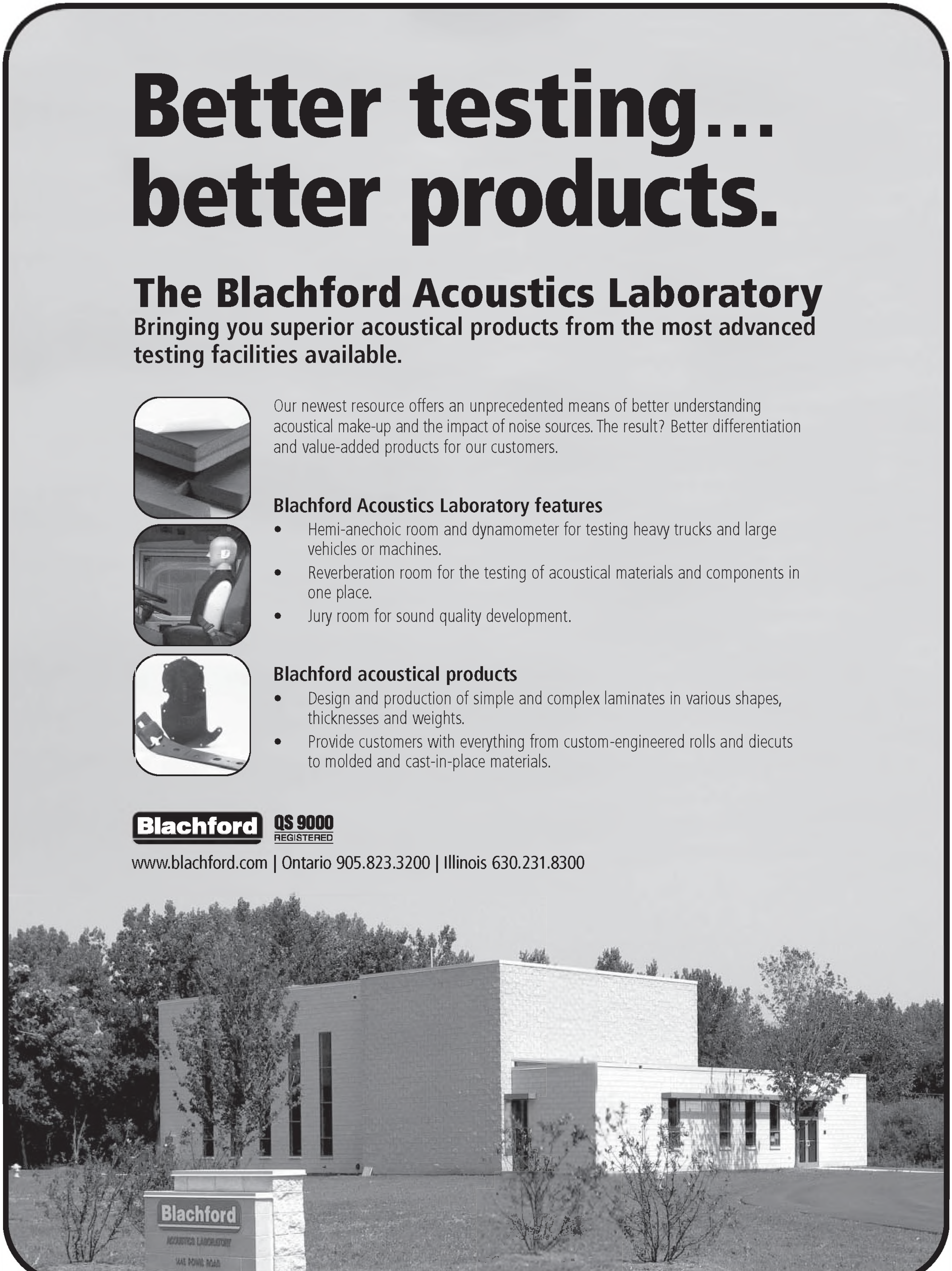
Chapter 7 discusses the design problems faced by "Recital Halls." These are usually small auditoria connected with music departments of universities. Occasionally, main concert venues will have recital halls for small ensemble performances. By the aid of his design studies for recital halls, Jaffe presents the process of achieving satisfactory acoustics of these small theatres. He also shows us the way he designed the Zankel Hall, the 600 seat auditoria located below the famous Carnegie Hall in New York City. The new surround hall evolution and the design details required for good acoustic are highlighted in Chapter 8. Chapters 9, 10 and 11 are similar to earlier design chapters, but they focus on multipurpose performance halls, summer music pavilions and mobile concert stages respectively.

Chapter 12 is titled, "Concert Hall Shapers," where Jaffe describes his expertise in modifying the acoustics of coupled concert hall stage areas so that a multipurpose hall can provide the required acoustical performances. In many contemporary halls, the orchestra is usually brought forward to the front of the proscenium arch to provide a sense of intimacy with the audience space. The acoustical problems and the methods to overcome them are discussed in Chapter 13, aptly titled, "Cab Forward," named for a particular car model manufactured by Chrysler Corporation. Chapter 14 is in the realm of modern acoustical techniques where electronics is used not for just amplification, but for the modification of the acoustics of listening spaces. Jaffe presents examples of his design called ERES (Electronic Reflected Energy Systems).

Chapter 15 is a plea for the current disconnect that exists between architecture, musicians and acousticians to be properly bridged. This disconnect that seem to plague concert hall industry was highlighted in the opening sentences of this review. Dr. Jaffe's caption of the chapter, "Art and Architecture: Will the Twain Meet?" reminds one of the immense hurdles acousticians face while designing the acoustics of a listening space and let us hope that we will meet the challenges head-on.

Many of the chapters end with lessons learned section, which are highlights of the book. The book is full of wonderful colour images of halls around the world. The acoustician for most of the presented examples is, of course, Christopher Jaffe. There is, however, a minor criticism of the book in that Jaffe presents a number of concepts and results in a tabular form. These tables have a bright blue background with the text in small fonts and hence very difficult to read. In conclusion we quote Dr. Beranek's forward, "This personal account of acoustical accomplishments in a wide variety of performance spaces is recommended to architects, managers, owners, musicians, music lovers, and of course all acousticians." This reviewer heartily endorses Dr. Beranek's recommendations. Of course, we also have a wish list. Now that, Dr. Jaffe has presented his overall concepts, it would be very helpful to novice and apprentice acousticians if Dr. Jaffe were to prepare a good design book, with calculations, design approaches and procedures for the proper realization of good acoustics of auditoria.

Prof. Ramani Ramakrishnan
Department of Architectural Science
Ryerson University, Toronto
rramakri@ryerson.ca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Porte (Gate) Saint-Louis
(Photo: Yves Tessier, Tessima)

— SECOND ANNOUNCEMENT —

ACOUSTICS WEEK IN CANADA

Quebec City, October 12-14, 2011

Acoustics Week in Canada 2011, the annual conference of the Canadian Acoustical Association, will be held in Quebec City from October 12 to 14. This premier Canadian symposium in acoustics and vibration will take place in beautiful Old Quebec, a UNESCO world heritage treasure with European appeal. You surely will not want to miss this event. The conference will include three days of plenary lectures and technical sessions on all areas of acoustics, a meeting of the Acoustical Standards Committee, the CAA Annual General Meeting, an Exhibition of acoustical equipment, materials and services, the Conference Banquet, an Award ceremony and other social events.

Venue and Accommodation – The conference will be held at **Hôtel Château Laurier Québec**. The hotel is conveniently located on the Plains of Abraham at the heart of all major attractions of Old Québec. It is only a few steps from Grande Allée Historic Street, well-known for its restaurants, boutiques and nightlife. The Parliament Buildings, the Old City walls and Porte (Gate) Saint-Louis are only a five-minute walk from the hotel. The Hôtel Château Laurier Québec boasts 289 rooms and suites, modern conference facilities with 17 meeting rooms and banquet services, a fitness room, an indoor pool and landscaped outdoor garden with spas, and an inner courtyard. You will enjoy four-star bilingual services rooted in a rich francophone tradition.

A block of Standard ($134/night + taxes) and European ($114/night + taxes) style rooms is being offered at special conference rates based on single or double occupancy. Additional adults will be an extra $20/night. Wireless internet access is complimentary with each room. Indoor parking is available for an overnight charge of $19/day. Hotel reservations must made by congress participants no later than September 11, either by phone (1-800-463-4453), by fax (1-418-524-8768) or by email (reservation@vieuxquebec.com). It is important to quote the event reservation number # 5007 when booking. Availability of rooms in the conference room block is on a first come first serve basis. Do not delay booking your room!

Participants are strongly encouraged to stay at Hôtel Château Laurier Québec. Staying at the conference hotel will place you near your colleagues and all conference activities, and help make the meeting a financial success to the benefit of future activities of the Canadian Acoustical Association.

Hôtel Château Laurier Québec

Plenary Lectures and Technical Sessions – Three plenary lectures are planned in areas of broad and relevant appeal to the acoustical community, highlighting the regional expertise and distinctiveness. Technical sessions will be organized in all major areas of acoustics, including the following topics:

- Architectural Acoustics
- Physical Acoustics and Ultrasound
- Psycho- and Physio-Acoustics
- Hearing and Speech Sciences
- Underwater Acoustics
- Bio-Acoustics and Biomedical Acoustics
- Engineering Acoustics and Noise Control
- Musical Acoustics and Electro acoustics
- Shock and Vibration
- Hearing Loss Prevention
- Signal Processing and Numerical Methods
- Acoustical Standards

If you would like to propose and/or organize a special session on a specific topic, you are invited to contact the Technical Co-Chairs as soon as possible.

Exhibition and Sponsorship – The conference will show case an exhibition of acoustical equipment, products and services on Thursday October 13, 2011. If you or your company are interested in participating in the Exhibition or in sponsoring conference social events, technical sessions, coffee breaks or student prizes, all of which being excellent promotional opportunities, please contact the Exhibition Coordinator.

Courses/Workshops – If you would like to offer a course/seminar in association with Acoustics Week in Canada, please contact the Conference Chair. Assistance can be provided in accommodating such an event, but it must be financially independent of the conference.

Student Participation – Student participation is strongly encouraged. Travel subsidies and reduced registration fees will be available. Student presenters are eligible to win prizes for the best presentations.

Paper Submission – The abstract deadline is June 15, 2011. The two-page summaries for publication in the proceedings issue of *Canadian Acoustics* are due by August 1st, 2011. Details will be given on the conference website.

Rue (Street) Saint-Louis (Photo: Luc-Antoine Couturier)

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Conference Chair: **Christian Giguère**
cgiguere@uottawa.ca

Technical Co-Chairs: **JérémieVoix**
jeremie.voix@etsmtl.ca
Hugues Nelisse
hugues.nelisse@irsst.qc.ca

Exhibition Coordinator: **André L'Espérance**
a.lesperance@softdb.com

Logistics: **François Bergeron**
francois.bergeron@rea.ulaval.ca
Jean-Philippe Migneron
jean-philippe.migneron.1@ulaval.ca

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nellaham@uottawa.ca

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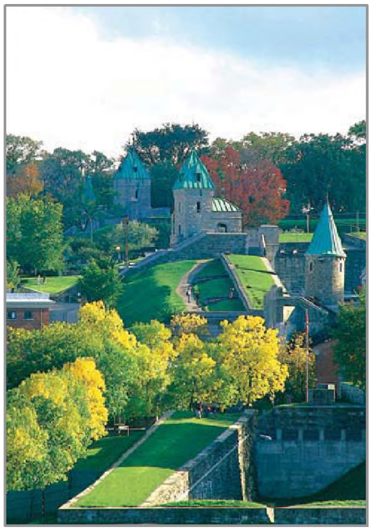

Murs (Walls)
(Photo: Brigitte Ostiguy)

— DEUXIÈME ANNONCE —

SEMAINE CANADIENNE D'ACOUSTIQUE

Québec, 12 au 14 octobre 2011

La Semaine canadienne d'acoustique 2011, le congrès annuel de l'Association canadienne d'acoustique, se tiendra à Québec du 12 au 14 octobre prochain. Cet événement de premier plan dans le domaine de l'acoustique et des vibrations, tenu au cœur d'une ville si pittoresque et joyau du patrimoine mondial de l'UNESCO, en fera encore cette année un colloque à ne pas manquer. Il comprendra trois jours de séances plénières et sessions scientifiques, une réunion du Comité de normalisation en acoustique, l'Assemblée générale annuelle de l'ACA, une exposition d'équipement, produits et services en acoustique, un banquet, la remise annuelle des prix et d'autres activités sociales.

Lieu du congrès et Hébergement – Le congrès se tiendra à l'**Hôtel Château Laurier Québec**, exceptionnellement situé sur les plaines d'Abraham et au cœur de tout ce qui fait le charme de Québec pour votre plus grand plaisir. L'hôtel n'est qu'à quelques pas de la rue Grande-Allée, bien connue pour ses restaurants, boutiques et boîtes de nuit. La colline parlementaire, la porte Saint-Louis et l'enceinte du Vieux-Québec ne sont qu'à 5 minutes à pied. L'Hôtel Château Laurier Québec compte 289 chambres et suites, un ensemble de 17 salles de réunion et de banquet, une salle de conditionnement physique, une piscine intérieure, un jardin extérieur avec spas et une cour intérieure.

Un bloc de chambres en style standard (134$/nuit + taxes) et européen ($114/nuit + taxes) est offert à des taux préférentiels en occupation simple ou double. Des frais de 20$/nuit sont applicables pour tout adulte supplémentaire. L'accès Internet haute vitesse sans fil est gratuit dans les chambres. Le stationnement intérieur est offert au tarif de 19$ par jour. Les réservations devront être effectuées individuellement par les congressistes au plus tard le 11 septembre par téléphone (1-800-463-4453), par télécopieur (1-418-524-8768) ou par courriel (reservation@vieuxquebec.com). Il est important de préciser le numéro de confirmation d'événement # 5007 lors de votre réservation.

Hôtel Château Laurier Québec

La disponibilité des chambres du bloc à taux préférentiels est sur le principe du premier arrivé, premier servi. Ne tardez donc pas à réserver votre chambre !

Les congressistes sont vivement encouragés à héberger à l'Hôtel Château Laurier Québec. Cela vous permettra de mieux côtoyer vos collègues durant votre séjour et de bénéficier pleinement de toutes les activités du congrès. Demeurer à l'hôtel du congrès contribue aussi au succès financier de l'événement et profitera aux prochaines activités de l'Association canadienne d'acoustique.

Fontaine de Tourny (Photo: La Maison Simons)

Séances plénières et sessions scientifiques – Trois présentations plénières dans des domaines d'intérêt général en acoustique sont prévues, mettant en évidence l'expertise régionale. Des sessions scientifiques seront organisées dans tous les domaines principaux de l'acoustique et des vibrations, dont les thèmes suivants:

- Acoustique architecturale
- Physique acoustique et Ultrasons
- Physio et Psychoacoustique
- Sciences de la parole et Audition
- Acoustique sous-marine
- Bioacoustique et Acoustique biomédicale
- Génie acoustique et Contrôle du bruit
- Acoustique musicale et Électroacoustique
- Chocs et Vibrations
- Prévention de la perte audition
- Traitement des signaux et Méthodes numériques
- Normalisation

Si vous désirez suggérer ou organiser une session spéciale, svp contactez le comité scientifique dès maintenant.

Exposition technique et Commandite – Le congrès comprendra une exposition d'équipement, produits et services en acoustique le jeudi 13 octobre 2011. Si vous ou votre entreprise êtes intéressés à réserver un table pour cette exposition technique ou commanditer des événements sociaux, sessions scientifiques, pauses-cafés ou prix étudiants, lesquels présenteront tous d'excellentes occasions promotionnelles, veuillez communiquer avec le coordinateur de l'exposition technique.

Cours/Ateliers – Si vous souhaitez offrir un cours ou atelier dans le cadre de la Semaine canadienne d'acoustique, veuillez contacter le Président du congrès. Le comité de congrès vous prêtera assistance pour organiser votre événement, mais il doit être financièrement indépendant du congrès.

Participation étudiante – La participation étudiante est fortement encouragée. Des subventions de voyages et des frais d'inscription réduits seront offerts. Des prix seront décernés pour les meilleures présentations étudiantes lors du congrès.

Soumissions – La date d'échéance pour la soumission des résumés de présentation est le 15 juin 2011. Les articles de deux pages pour publication dans le numéro spécial des actes de congrès dans l'*Acoustique canadienne* sont dus le 1 août 2011. Plus de renseignements suivront sur le site internet de la conférence.

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Comité organisateur:

Président: **Christian Giguère**
cgiguere@uottawa.ca

Comité scientifique: **Jérémie Voix**
jeremie.voix@etsmtl.ca
Hugues Nelisse
hugues.nelisse@irsst.qc.ca

Exposition technique: **André L'Espérance**
a.lesperance@softdb.com

Logistique: **François Bergeron**
francois.bergeron@rea.ulaval.ca
Jean-Philippe Migneron
jean-philippe.migneron.1@ulaval.ca

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INSTRUCTIONS TO AUTHORS FOR THE PREPARATION OF MANUSCRIPTS

Submissions: The original manuscript and two copies should be sent to the Editor-in-Chief. The manuscript can also be submitted electronically.

General Presentation: Papers should be submitted in camera-ready format. Paper size 8.5" x 11". If you have access to a word processor, copy as closely as possible the format of the articles in Canadian Acoustics 39(1) 2011. All text in Times-Roman 10 pt font, with single (12 pt) spacing. Main body of text in two columns separated by 0.25". One line space between paragraphs.

Margins: Top - 0.75"; bottom - 0.75" minimum; sides - 0.75".

Title: Bold, Times New Roman 14 pt with 14 pt spacing, upper case, centered.

Authors/addresses: Names and full mailing addresses, 10 pt with single (12 pt) spacing, upper and lower case, centered. Names in bold text.

Abstracts: English and French versions. Headings, 12 pt bold, upper case, centered. Indent text 0.5" on both sides.

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Equations: Minimize. Place in text if short. Numbered.

Figures/Tables: Keep small. Insert in text at top or bottom of page. Name as "Figure 1, 2, ..." Caption in 9 pt with single (12 pt) spacing. Leave 0.5" between text.

Line Widths: Line widths in technical drawings, figures and tables should be a minimum of 0.5 pt.

Photographs: Submit original glossy, black and white photograph.

Scans: Should be between 225 dpi and 300 dpi. Scan: Line art as bitmap tiffs; Black and white as grayscale tiffs and colour as CMYK tiffs;

References: Cite in text and list at end in any consistent format, 9 pt with single (12 pt) spacing.

Page numbers: In light pencil at the bottom of each page. For electronic submissions, do not number pages.

Reprints: Can be ordered at time of acceptance of paper.

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