Canadian Acoustics / Acoustique canadienne, 1988, 16(2): 9-23

THE EFFECT OF VARIOUS PARAMETERS ON THE SOUND ISOLATION BETWEEN OFFICES WITH SUSPENDED CEILINGS

K. Kruger, Building Sciences Branch
Alberta Public Works, Supply & Services
12th Floor, 8215 - 112 Street
Edmonton, Alberta T6G 5A9

ABSTRACT

There is very little practical information available on the acoustical performance of suspended ceilings used in an office environment. It is very difficult to determine the influence of specific elements through a comparison of field measurements since there are many unknown conditions that change from one site to the next. The purpose of this study was to evaluate the importance of various common parameters associated with suspended ceilings in a realistic but controlled manner. Effects of ceiling panel STC, return air openings, plenum absorption, plenum barriers and ceiling sandwich construction were measured.

SOMMAIRE

Peu d'information pratique de l'isolation acoustique des plafonds rapportés dans le local des bureaux existe. Puisque les conditions, d'un bâtiment à l'autre, sont très variables, il est difficile de déterminer l'influence d'éléments spécifiques a partir d'essais sur place. Le but de cette étude est d'évaluer plusieurs parametres associés aux plafonds rapportés dans une situation réaliste mais contrôlé. L'effet de la perte de transmission sonore de differents panneaux, des grilles de ventilation, de l'absorbtion et des barrières dans l'espace interstitielle du plafond, ansi que des panneaux sandwich ont été mesuré.

INTRODUCTION

Office construction in modern buildings typically consists of drywall partitions terminated at the underside of a continuous suspended ceiling. A large and open space above the ceiling is usually provided to create a return air plenum and to conceal mechanical and electrical equipment. Although there are only two primary building components separating offices, the prediction of sound isolation is nevertheless complex. The theory of plenum transmitted sound, as developed by Mariner[1], describes the effect of several important variables such as plenum depth, ceiling transmission coefficient and absorption coefficients for the various ceiling and plenum surfaces. The theory has been found to agree reasonably well with measurement where the acoustic properties of all the surfaces are homogeneous and readily defined. More realistic ceilings cannot be described in such explicit terms. Ceilings are often penetrated by numerous ventilation openings and light troffers making the transmission loss difficult to determine. Acoustic conditions above the ceiling can also be somewhat nebulous if a plenum contains a barrier or if absorptive material is unevenly distributed. To gain an insight on the importance of various parameters that are routinely encountered in designing offices for speech privacy, an extensive test program has been undertaken.

TEST FACILITY AND PROCEDURE

A reverberation chamber was modified to create two offices and an adjacent corridor. This provided a convenient and controlled environment to systematically investigate various ceiling configurations. Initially, a heavy gypsum board and plaster surface was installed at 3400 mm above the floor to represent a roof or upper floor structure. A conventional T-bar suspension grid was hung from this ceiling at 2400 mm above the floor leaving a 1 m plenum depth. A plan view and section through the test chamber are shown on Figure 1.

Three of the plenum walls were lined with 150 mm thick rigid glass fibre. The fourth surface, adjacent to both offices, was the untreated reverberation chamber wall. The intent of the absorption was to simulate a plenum which was open in three directions. This condition would be found above offices located along the perimeter of a building and away from any corners. Lining the plenum walls also tends to leave the ceiling performance substantially independent of plenum depth.[2]

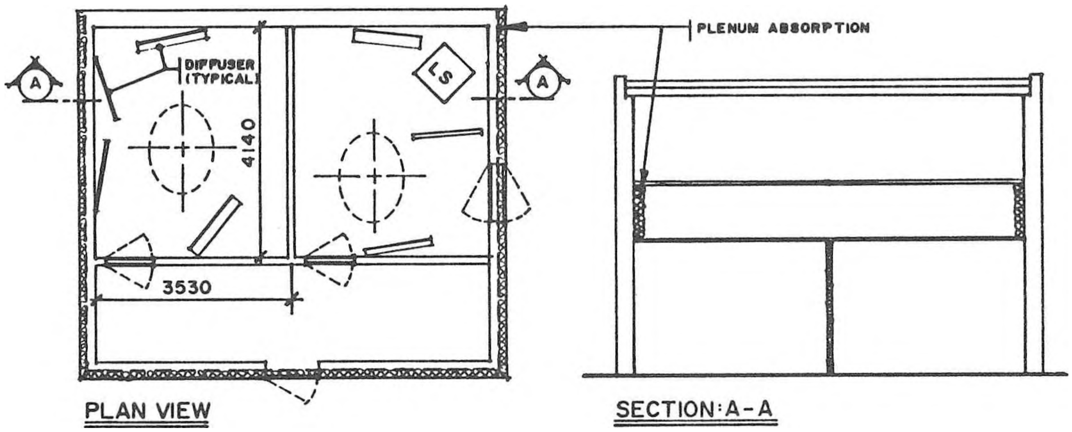


fig.1

The office partitions were constructed of 92 mm steel studs with 12 mm drywall applied to each side and insulated with 50 mm thick glass fibre batt. The transmission loss of the dividing wall was very similar to that of a good quality demountable partition. A 3 mm thick closed cell foam tape was used to seal the junction between the top plate of the wall and the suspended ceiling. The partitions were sealed to the chamber floor and walls with caulking. The rooms did not contain any absorptive material except the ceiling. Several plywood panels were placed in each room to create a more diffuse sound field.

The test procedure generally followed ISO 140/IV.[3] A single loudspeaker was placed in a corner opposite to the common office partition and directed toward the corner. The loudspeaker was fed broad band pink noise. A rotating microphone with a sweep time of 16 seconds and a sweep radius of 865 mm was positioned so that the traverse was not nearer than 500 mm to room boundaries. The boom was inclined approximately 40 degrees from horizontal and positioned as far from the source as possible. Space average levels for one complete revolution were determined using the mean squared pressure.

Level difference values were standardized to a reverberation time of 0.5 seconds. The equivalent absorption area was determined from an ensemble average of fifteen reverberation time analyses with a moving microphone.

Results are expressed in terms of the Derived Articulation Index (DAI) which is defined as follows:[4]

$$DAI = 30 \times \sum_{f_i} A(f_i)\ W(f_i)$$

where f_i is the centre frequency of the bands from 200 to 5000 Hz, $A(f_i)$ is the standardized level difference measured in the one third octave band with centre frequency f_i, $W(f_i)$ is the standard Articulation Index[5] weighting for that band given in ANSI S3.5. Conversion to the recently adopted Articulation Class[6] (A.C.) can be obtained by simply multiplying DAI by 10.

The DAI was chosen over the conventional measure of field sound isolation, the Normalized Noise Isolation Class (NNIC), because it was found to correlate much more closely to the Articulation Index. No attempt was made to measure the actual sound insulation of the ceiling. Since the intent of this investigation was to simulate field conditions as closely as possible, a typical dividing wall was used. Under some conditions and at certain frequencies, the overall isolation was dictated by the wall.

SPEECH PRIVACY

Neither the DAI or the AC are yet commonly used to describe sound isolation between cellular offices, so a comparison to the NNIC may be helpful. Approximately 400 tests were conducted on different ceiling and wall conditions. The level difference spectra are thought to be quite realistic for a wide range of office construction methods. Figure 2 shows the comparison between the NNIC and DAI for all of the data; the bars indicate one standard deviation. The best fit line is given by the following expression:

$$DAI = 1.26 + 1.06 * (NNIC)$$

The relationship between DAI and speech privacy is shown more specifically on Figure 3. Articulation Index values were calculated for every test at each of the background noise levels indicated on the graph. The resulting curves are best fit polynomials. Male speech at a normal voice effort was used as the source. The assumed spectral distribution of the background noise is that of the standard NC curve. Although this noise characteristic is not too common for real building mechanical noise sources, the graph does indicate the sensitivity of the DAI to privacy. A change in DAI of 5 can be quite significant. Confidential privacy is achieved when the sum of the DAI and the NC exceeds 70.

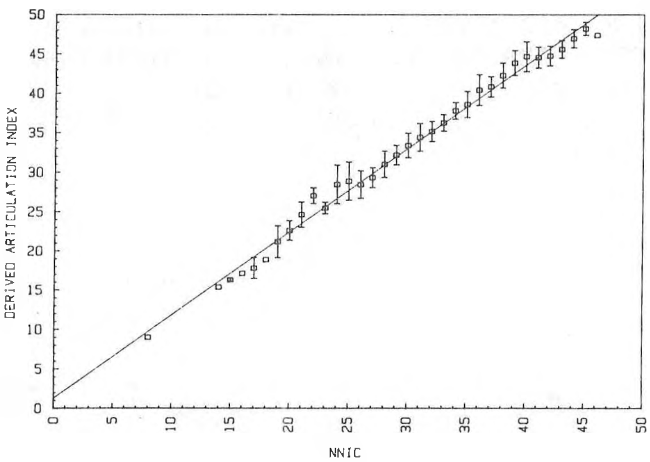


fig.2 relationship between DAI and NNIC for all tests in the study

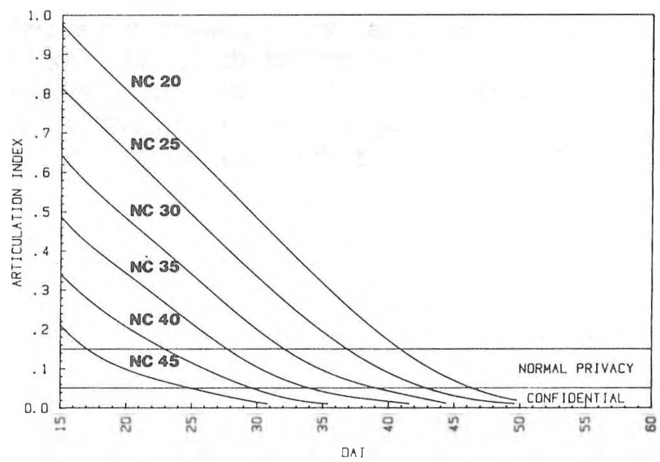


fig.3 speech privacy as a function of background noise and sound isolation

CEILING BOARD STC

The two-pass STC, measured according to AMA 1-II[7], is commonly used to establish the performance of ceiling panels. Manufacturers often publish the results quoting the appropriate STC range. The laboratory standard allows for the evaluation of ceiling systems representing field conditions, but typically samples are tested using a more ideal configuration consisting of an exposed suspension system that is continuous, well sealed over the common partition, and is without penetrations except those inherent to the product's design.

Table I indicates the ceiling panels that were tested in this study. Panel #9 is not actually a manufactured product although comparable products are available. The list includes panels intended for a wide range of applications. Specific products were selected on the basis of their popularity in commercial office space familiar to the author.

TABLE I CEILING PANEL CHARACTERISTICS

PANEL NO.	PANEL COMPOSITION	NOMINAL THICKNESS (mm)	SURFACE DENSITY (kg/m^2)	ADVERTISED STC RANGE
1	Glass Fibre	25	2.2	15 - 19 *
2	Glass Fibre & Foil Back	25	1.5	20 - 24
3	Glass Fibre & Foil Back	38	2.3	25 - 29
4	Mineral Wool & Backing	25	2.9	25 - 29
5	Mineral Fibre	22	6.6	30 - 34
6	Mineral Fibre	16	3.8	35 - 39
7	Mineral Fibre	16	3.1	35 - 39
8	Mineral Fibre	16	3.8	40 - 44
9	Drywall	6	5.8	40 - 44 *

* estimate

The sound isolation measured with the various ceilings is shown on Figure 4, where the DAI is plotted against the STC range for each product. Measurements were made using the typical ceiling configuration as described previously. The line drawn through the measured points indicates the best fit linear relationship between DAI and NNIC obtained from the entire body of data in this study. In order to plot the line, the NNIC was simply substituted with the median STC value for each range. This substitution is not strictly valid because the measurement standard used to obtain the NNIC (ISO 140-IV) is quite different from that used for the STC (AMA 1-II). However, many designers assume that the STC is representative of field performance and so the line gives an approximate indication of the isolation that might be anticipated when the ceiling is the dominant transmission path.

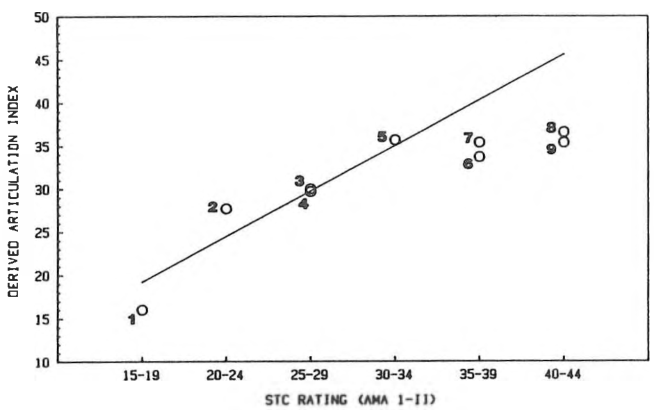


fig.4 comparison between transmission loss rating for various ceiling panels and sound isolation between offices

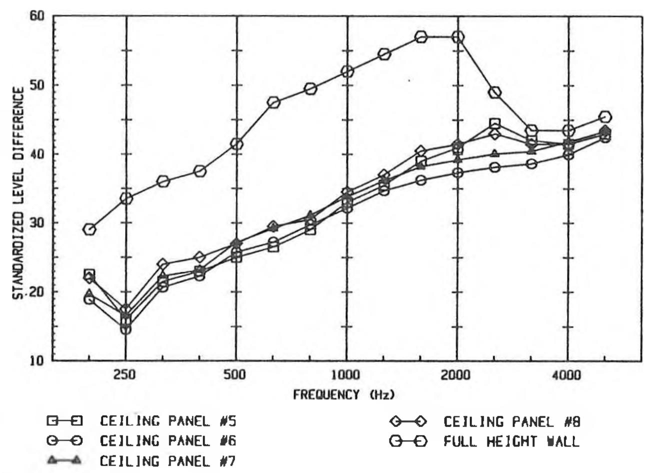


fig.5 level difference between offices with various mineral fibre ceiling panels

The glass fibre panels (1-4) perform as expected. These products have a low transmission loss and thereby minimize any differences that might occur when comparing measurements performed to different standards and conditions. A distinct plateau is found at approximately DAI 35 corresponding to all of the mineral fibre composition products. Since these panels have a relatively high transmission loss, it is not surprising that specific differences between test procedures become much more significant and lead to different results. For example, the AMA standard requires the plenum to be lined on all four sides. Removing absorption from one wall, as in this test facility, can reduce the isolation provided by a high transmission loss panel by as much as 4 dB at 1 KHz.[8] In addition, the transmission loss of the common wall, according to the AMA standard, must be at least 10 dB greater than the ceiling for all frequency bands. The more typical wall, used in these tests, does not meet this criterion for the mineral fibre panels and contributes to limiting the performance of the overall construction.

The similarity between the mineral fibre panels is further indicated by the level difference curves shown on Figure 5. Again, there does not appear to be a consistent correlation between the STC rating and the isolation over any part of the frequency range. In fact, panel #5, which has the lowest STC of this group, exhibits the best performance around the critical 2000 Hz region. Variation between products diminishes even more when openings through the ceiling or less than perfect seals are introduced. Influence of the wall begins to be seen for frequency bands above 2500 Hz where coincidence effects dominate.

The implication here is that, for typical office construction, there is little to be gained by selecting a ceiling panel with an STC above approximately 33 (Panel #5). This conclusion is probably somewhat tenuous considering that this test series is far from a comprehensive evaluation of the total number of products available. None the less, the variation in performance is remarkably small considering that the mineral fibre panels all have quite distinct physical characteristics and are produced by three different manufacturers.

Because of the similarity between the mineral fibre panels under relatively ideal conditions, it was decided that the behavior of many other ceiling configurations could be reasonably well represented by just one of the products. Even if the results of a specific test cannot be applied absolutely to the performance of other panels, at least the trends are expected to remain the same. Ceiling panel #7 was chosen as the standard.

RETURN AIR OPENINGS

Suspended acoustic ceilings are rarely installed without any penetrations. The most common unobstructed openings are those created to allow for return air to pass into the plenum. Two types of openings are typically found in offices; several long narrow slots which are integral to the light fixtures or a larger rectangular opening cut into a ceiling panel. The minimum area required to provide adequate ventilation varies approximately between 0.032 m^2 for an average size office located in an interior zone to 0.064 m^2 for an office on the building perimeter. This open area is typically equivalent to 3 return air slots and 6 slots respectively. Larger openings and especially more slots, are common.

The effect of return air slots was investigated by progressively increasing the number of slots in both rooms. The first two slots were part of a light fixture installed in each room. Additional slots were formed by leaving a gap between two closely spaced tees resulting in a free opening of 12 mm x 1025 mm. The slots were distributed evenly throughout the ceiling plane and placed symmetrically about the common office partition. A comparison between slots formed by the fixture and those created by the tees showed no difference outside the limits of repeatability. Similarly, there was no measurable effect of the fixture (with the slots blocked) compared to a ceiling without any fixtures.

Single return air openings were formed by cutting a 600 mm wide hole in a ceiling panel located near the center of each office and gradually increasing the length of the opening. The openings were spaced 3600 mm apart at the nearest edges.

Figure 6 shows the result of this series where return air open area in each office is plotted against the DAI. Several narrow slotted aperatures distributed over the ceiling have a significantly greater influence on sound isolation than a single aperature with an aspect ratio much closer to 1. From a practical perspective, consider that a DAI reduction of 5 can result in a significant change in speech privacy. Only 8 return air slots would be necessary for this to occur, whereas a single rectangular opening would have to be approximately 600 mm x 750 mm to have the same effect. An opening of this size is six to seven times larger than necessary for ventilation requirements.

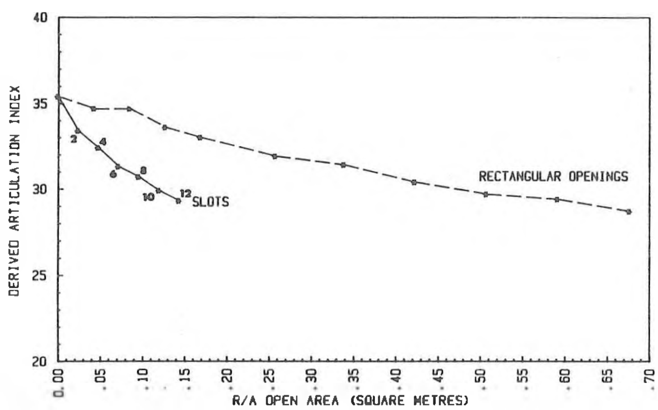


fig.6 effect of return air open area on sound isolation for two types of openings

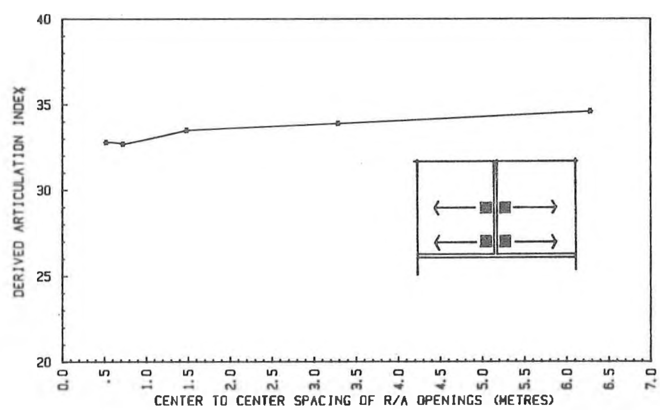


fig.7 effect of separation between square return air openings on sound isolation

Reducing sound propogation through a single large opening is a straight forward procedure requiring only a short section of lined duct on the back of the grill. But even this measure does not seem worthwhile in the case of a suspended lay-in ceiling since a typical opening of .09 m^2 only reduces the DAI by approximately 1.

The surprisingly small effect of a large return air opening was at first thought to be influenced by the room to room distance between openings. Proximity of the opening to the sound source could also have been a factor, since a diffuse sound field could not be established in such small rooms. Some indication of the importance of these parameters was determined by positioning return air openings on three different grid lines and gradually increasing the separation. Openings were located in a line directly above the source, along the office centre line and along the wall opposite from the source. Results indicate that proximity to the source does have a small influence. When the openings are in a line on the source side, isolation is reduced by an average of 2dB compared to a corresponding location on the opposite side of the room. Another factor that may have contributed to the poorer performance along the source grid line was the influence of the adjacent reflective plenum wall.

Figure 7 shows the effect of distance between 300 mm x 300 mm return air openings versus the DAI averaged for the two grid lines remote from the source. Generally, it appears that increased separation is beneficial but the improvement for practical purposes is minimal. In situations where there may be a row of offices, the separation would be maximized by locating the openings near the center of each office. However, this spacing (approximately 4 m), improves the DAI by less than 1 compared to when the openings are placed back-to-back with only the width of the partition separating them.

Of much greater concern, is the sound propogation through return air slots. A very simple method of controlling this flanking path was investigated. An open ended hood was placed above a light fixture, straddling the return air slots. The hoods were constructed from mineral fibre ceiling panels with the fissured surface facing the fixture.

Figure 8 shows the effect of the hood on level difference. For this test, three actual fixtures were used in each office, resulting in a total of 6 slots per room. Interestingly, the hoods not only eliminate flanking through the openings but also offer an additional improvement over the unpenetrated ceiling. This excess gain is thought to be caused by the increased absorption in the plenum provided by the exposed hoods.

Another, somewhat less common but more problematic, method of accommodating for return air near windows is through a continuous slot (typically 75 - 150 mm wide) which runs along the building perimeter. The slot is formed by terminating the suspended ceiling short of the exterior wall. When interior partitions are installed in this situation, a large opening between two offices is created.

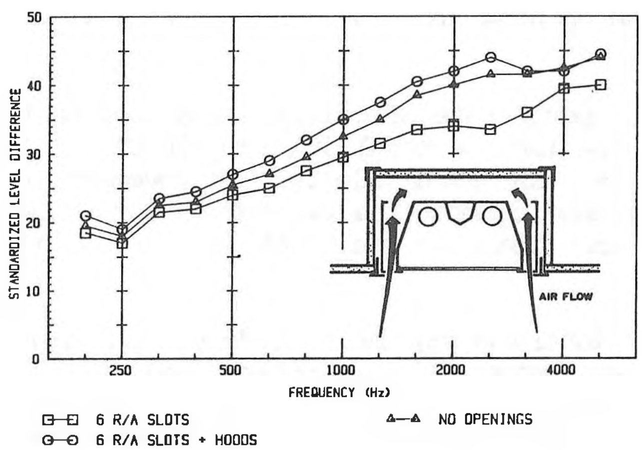


fig.8 level difference between offices indicating the effect of hoods placed above slotted light fixtures

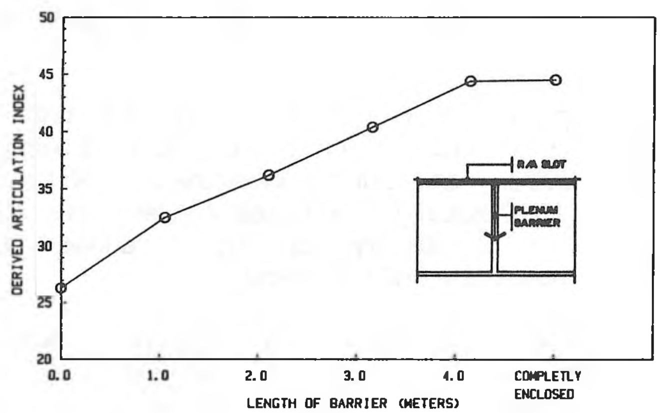


fig.9 effect of plenum barrier length on sound flanking through perimeter return air slot

One means of dealing with this flanking path is to introduce a partial barrier in the plenum starting at the exterior wall. The effect of such a barrier as a function of length is shown on Figure 9. Initially, a low value of isolation occurs because of the perimeter slot. The DAI decreases from 35 for an unpenetrated ceiling to 26 with the introduction of the slot. This type of return air opening has the most detrimental effect on sound isolation of all those investigated. However, a significant improvement takes place as a barrier is installed and extended along the wall.

Diffraction losses around the barrier are great enough at approximately the 2 m length to completely eliminate the effect of the return air slot. Sound isolation continues to increase as the barrier is carried across the entire length of the common partition. A negligible improvement is found when the barrier is further extended so as to enclose the entire plenum space of the receiving room.

PLENUM ABSORPTION

The addition of sound absorptive material to the plenum is a common method of reducing sound transmission between offices. Typically, batt insulation is laid directly on top of the suspended ceiling. It is improbable that this additional layer has a significant effect on the actual transmission loss of the ceiling panels. More likely, the presence of absorption helps to attenuate sound propogating along the plenum and controls flanking through cracks between the ceiling panels and the T-bar grid.

Plenum spaces that are crowded with ducting and other mechanical components may exhibit a somewhat similar effect by virtue of the diffusion and absorption that is present. Because the density and nature of the equipment differs tremendously, even within the same building, this variable was not investigated. Instead, a worst case situation was simulated where the plenum space was virtually empty.

The effect of absorption located directly above a suspended ceiling was determined by systematically increasing the number of batts placed symmetrically about the common partition. Standard RSI 2.1 insulation batts, 89 mm thick, were used. Measurements were made with and without return air slots in the ceiling. When slots were present, the batts were kept approximately 50 mm from the edge of the opening creating a 100 mm wide tunnel for the return air path.

Figure 10 plots the DAI against the percentage of ceiling area covered by absorption. For a ceiling without penetrations, a total increase in DAI of 10 occurs at 100% coverage. With slots, an even greater improvement of approximately 13 takes place. The difference between the two curves diminishes as more absorption is a added but the flanking due to the slots is still evident at full coverage.

Figure 11 shows an alternate way of interpreting the same data. The graph compares the change in DAI per square meter of absorption against the percentage of the ceiling area covered. This more directly relates to the cost effectiveness of this technique. As might be expected, for an unpenetrated ceiling, the effectiveness is greatest for the initial quantity of absorption and it continually diminishes as the coverage increases. When return air slots are present, plenum absorption is generally more effective than is the case for the unpenetrated ceiling and there appears to be an optimum coverage at approximately 40% - 60% of the ceiling area.

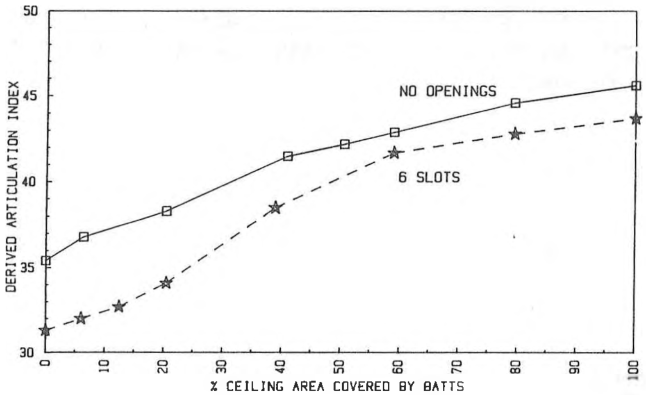


fig.10 sound isolation of mineral fibre ceiling versus area of batt insulation placed above panels

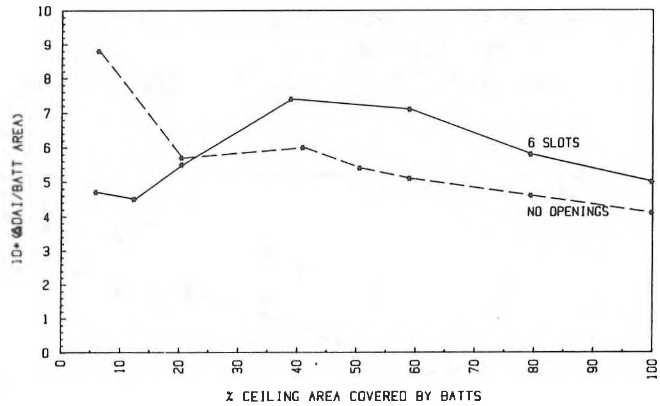
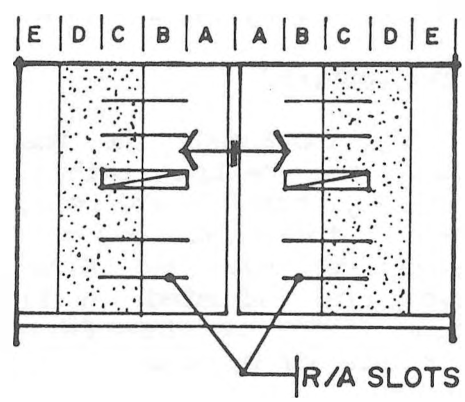


fig.11 effectiveness of absorption placed above suspended ceiling as a function of the quantity

Further testing, the results of which are summarized on Table II, revealed that the maximum effectiveness was actually more closely related to the relative location of the absorption with respect to the return air slots and the common wall rather than an optimum quantity. Initially, $10m^2$ of batt, representing approximately 40% ceiling coverage, was placed in a close array centered over the partition. The area of absorption was held constant but it was split into two equal sections and gradually separated. In the case with no slots there is a clear relationship between performance and location of absorption. Concentrating the absorption near the common partition appears to be the optimum arrangement. A similar trend occurs when return air slots are added to the ceiling, but the effect of placement is more pronounced. The DAI can vary by as much as 6 depending on location of the absorption. Figure 12 shows the level difference for two extremes in placement when slots are present.

TABLE II EFFECT OF BATT LOCATION

SLOT LOCATION	BATT LOCATION	DAI
-	-	35.4
-	AB (close array)	41.5
-	CD	38.6
-	DE	37.5
BC	-	31.2
BC	AB (close array)	38.5
BC	BC (2 areas)	38.5
BC	CD (2 areas)	34.1
BC	DE (2 areas)	32.2



A related test series, where the position of the slots was varied and absorption remained centered, showed that slot location is not very important. Although there was a slight improvement noted when the separation between return air slots in each room was maximized, the differences were typically less than 1dB in the critical frequency bands.

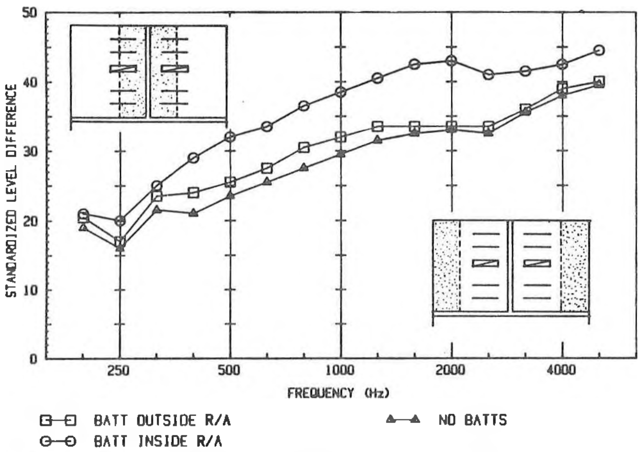


fig.12 level difference between offices indicating effect of extremes in batt location relative to position of return air slots

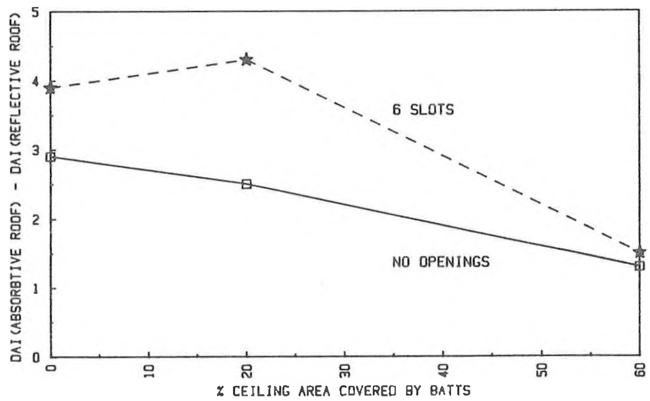


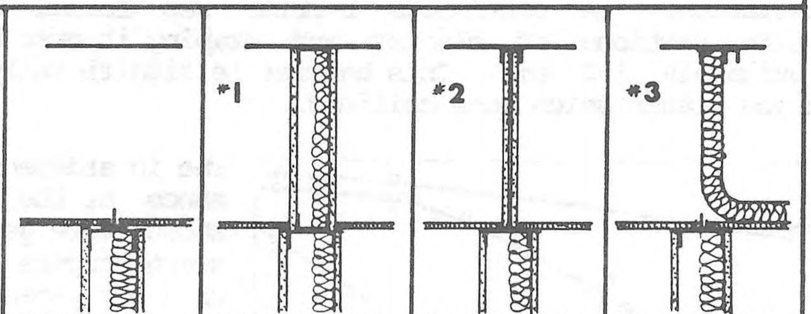
fig.13 improvement in sound isolation due to an absorptive plenum ceiling

Absorption in the plenum can also be found on the underside of a roof or floor slab in the form of a spray-on fireproofing material. Many of these products have reasonably good mid and high frequency sound absorption coefficients. A spray-on was simulated by attaching 25mm thick rigid insulation directly to the plenum ceiling. For some tests, batt insulation was also placed on top of the suspended ceiling to determine the combined effect of absorption at both locations. Results shown on Figure 13 indicate the direct improvement due to the addition of roof deck absorption for two ceiling configurations. Absorption applied to the upper surface of the plenum was not as effective as when it was placed on top of the suspended ceiling. Complete coverage of the plenum ceiling increased the DAI by a maximum of approximately 4. As indicated on Figure 10, this same increase can be achieved by covering only 25% of the ceiling panels with batt insulation. However, since the spray-on is likely to be installed for reasons other than sound isolation, any acoustic benefits derived from it are without cost. Combining absorption from the spray-on with a batt insulation overlay can give very substantial improvements, especially when the ceiling is ventilated.

PLENUM BARRIERS

In many instances, the most effective method of reducing sound transmission through the ceiling path, is to introduce a barrier into the plenum. This is especially helpful for ceilings with a very low transmission loss. DAI values obtained for three common types of barrier construction in combination with various ceilings are shown on Table III. The corresponding level difference curves are indicated on Figure 14 for the mineral fibre ceiling panels and Figure 15 for the glass fibre panels. Test results shown were obtained without any return air openings.

TABLE: III



EFFECT OF VARIOUS PLENUM BARRIERS.	NO BARRIER	91mm INSULATED DRYWALL	25mm DRYWALL	25mm FOIL BACKED INSULATION
CEILING PANEL TYPE.	DAI	DAI	DAI	DAI
MINERAL FIBRE PANEL # 7	35.4	48.3	46.5	39.8
GLASS FIBRE PANEL # 1	16.0	—	39.6	23.7
GLASS FIBRE PANEL #2	27.7	—	45.2	—

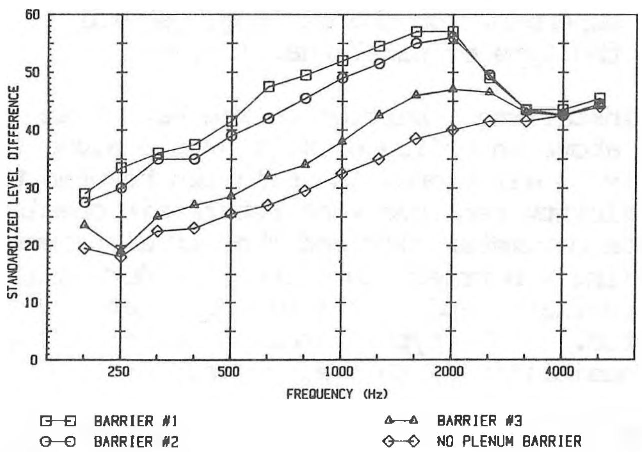


fig. 14 level difference between offices for various plenum barriers and mineral fibre ceiling panel #7

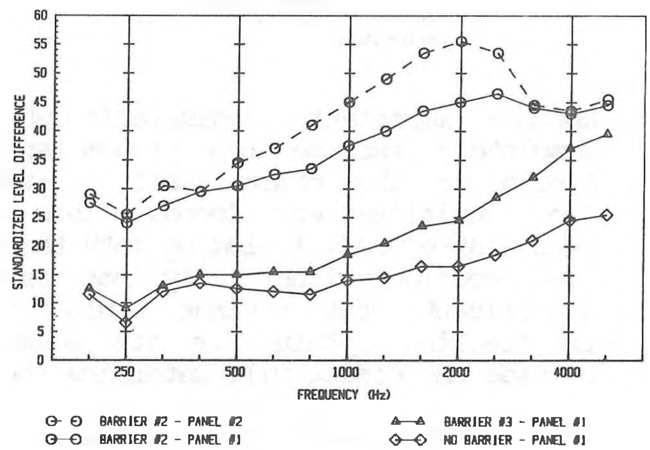


fig. 15 level difference between offices for various plenum barriers and glass fibre ceiling panels

Barrier #1 essentially transformed the dividing partition into a full height wall. The performance of this construction defined the upper limit of sound isolation for all test series. The prominent coincidence dip is typical of many offices but is not usually too serious since ambient noise levels in buildings are usually adequate to mask transmitted speech in these frequency bands.

Barrier #2, consisting of two layers of drywall placed back-to-back, is a more practical design where there may be a moderate amount of mechanical equipment to contend with. Joints can be offset and smaller pieces of drywall can be used for patching and fitting tightly up to ducts and conduit that penetrate the barrier. The drywall rested directly on the top track of the partition in order to avoid flanking through the ceiling panel or suspension system. Strips of insulation batt were used to caulk cracks between the barrier and abutting surfaces. This barrier was only slightly less effective than a full height wall when used in conjunction with the mineral fibre ceiling. With a glass fibre ceiling, the improvement afforded by the barrier is substantial but the poor performance of the ceiling panel limits the isolation over most of the frequency range. The slightly higher transmission loss of the foil backed glass fibre panel is beneficial and approximately defines the point at which further increases in ceiling performance have a minimal effect on overall isolation.

Foil faced insulation, used as Barrier #3, is desirable due to its ease of installation. A continuous barrier was formed by taping joints between separate sections of blanket and draping it over the top of the ceiling for approximately 300 mm. This barrier is significantly more effective when used with low transmission loss ceilings.

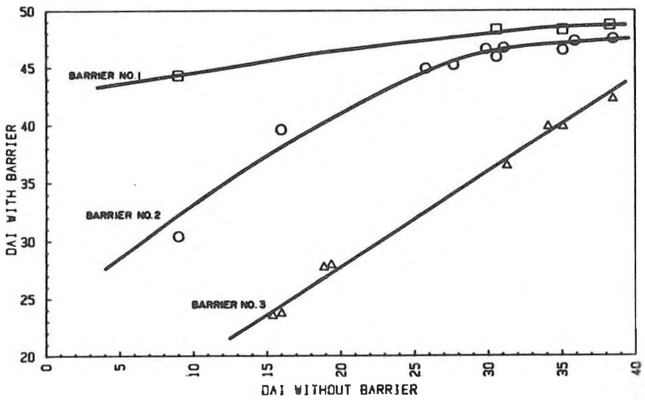


fig. 16 sound isolation obtained with various plenum barriers as a function of the ceiling performance

The interdependance between the performance of the ceiling and the barrier is shown more generally on Figure 16. The graph compares numerous ceiling configurations measured with and without a barrier. It can be seen that the sound isolation with Barrier #1 is nearly independent of the ceiling. Isolation with Barrier #2 is reasonably constant when used in conjunction with a ceiling that provides a DAI of approximately 28 or more. This includes most of the mineral fibre ceiling configurations. The low transmission loss of Barrier #3 makes the overall isolation very dependent on the ceiling, regardless of the type of panel that is used.

Another important consideration when installing a barrier is whether it should completely enclose the plenum space above an office or just extend along the length of the common wall. Virtually no difference in isolation between the two conditions was found. This similarity remained when return air openings were introduced, including both the wide perimeter slot and the six distributed slot configurations. By not installing a barrier above the corridor wall, a significant cost savings would be realized and problems associated with transferring return air are eliminated. The type of occupancy immediately outside the office will determine the feasibility of this approach.

All of the above tests were performed with well-sealed plenum barriers. In practise, achieving a tight barrier is often a problem, particularly in buildings with open web joists and metal decking. Numerous openings occur when a barrier butts up to the metal deck and runs perpendicular to the direction of the flutes. The importance of flanking at this joint was measured using Barrier #2 and the mineral fibre ceiling. Six return air slots were introduced into the ceiling to make the effect of barrier flanking more sensitive. As shown on Figure 17, a substantial reduction of 5 - 10 dB over much of the frequency range is noted as a result of the unblocked openings.

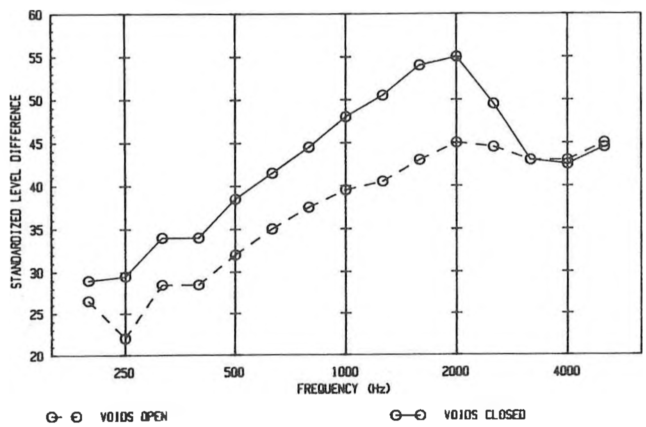
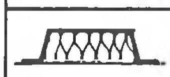
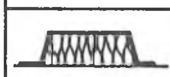
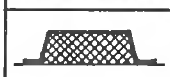
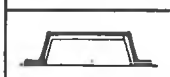
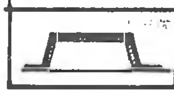


fig. 17 level difference between offices indicating importance of flanking through deck flutes above plenum barrier

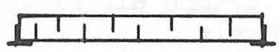
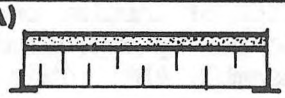
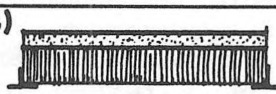
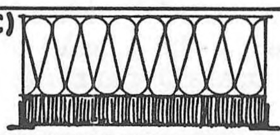
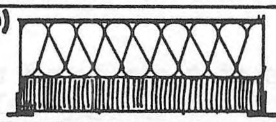
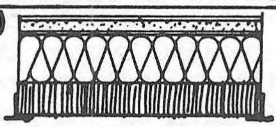
TABLE IV	EFFECT OF FLUTE FILLERS	
	FILLER	DAI
	NONE	39.8
	LOOSE BATT	42.7
	PACKED BATT	45.6
	FOAM CLOSURE	45.5
	SHEET METAL	41.0
	SHEET METAL (CAULKED)	45.6

Many materials can be used to fill these voids. The effectiveness of several common ones is indicated on Table IV. Low density glass fibre loosely fitted into the voids increased the DAI by approximately 3 but the voids were still a weak point. The same type of insulation, tightly compressed, nearly eliminated sound flanking. More elaborate fillers, actually intended to be used as air seals for this location, are comprised of preformed sheet steel or closed cell foam strips matching the profile of the metal decking. Insertion of the foam closures requires some compression thereby ensuring a good seal. This material proved to be very effective. The sheet steel closures were initially simply butted up to the metal decking, but small continuous cracks between closures and decking remained and consequently prevented an improvement in DAI. Caulking the joint along the entire profile of the decking restored full performance to the barrier.

SANDWICH CEILINGS

In a very crowded plenum, the construction of any kind of barrier becomes extremely difficult and time consuming. In these instances, it may be more practical to apply a backing to the suspended ceiling. Results for several sandwich assemblies are shown on Table V. DAI values are given for each assembly measured without any return air openings as well as with six return air slots.

TABLE V EFFECT OF VARIOUS SANDWICH CEILINGS

SANDWICH ASSEMBLIES		NO OPENINGS	6 R/A SLOTS
		DAI	DAI
	GLASS FIBRE PANEL #1.	16.0	15.4
	MINERAL FIBRE PANEL #7.	35.4	30.6
A) 	6mm DRYWALL GLASS FIBRE PANEL	36.9	32.6
B) 	6mm DRYWALL MINERAL FIBRE PANEL	40.6	33.1
C) 	89mm BATT MINERAL FIBRE PANEL	45.6	43.7
D) 	50mm BATT WITH FOIL BACK MINERAL FIBRE PANEL	46.9	40.2
E) 	6mm DRYWALL 25 mm BATT MINERAL FIBRE PANEL	44.3	36.6

The least expensive backing considered here was drywall. Full sheets were cut to size and placed on top of the ceiling panels. A 6 mm thick drywall was chosen so that the weight restriction for the suspended ceiling grid was not exceeded. The drywall increased the surface density of assembly "B", threefold. The corresponding increase in performance of 5 dB was not nearly the improvement that might be expected from the mass law. This shortfall was in part due to the fact that the drywall did not form a tight continuous backing leaving numerous small cracks between the ceiling panels and the T-bar. Some loss of plenum absorption also occurs since drywall is more reflective than the back side of the ceiling board. The effect of reduced back absorption is substantial, as indicated by a reduction in DAI of 7.5 when return air slots were introduced.

When drywall is used to back a glass fibre panel, as in assembly "A", the improvement is dramatic. The additional mass and flow resistance provided by the drywall accounts for an increase in DAI of approximately 21. Lack of absorption in the plenum is again evident from the results of the test with return air slots, although the improvement due to the backing is still substantial.

Results for assembly "C" indicate that glass fibre insulation is a much more effective backing for mineral fibre panels than is the drywall. Although the insulation batts do not significantly increase the mass of the ceiling, their benefit is derived from the substantial absorption that is added to the plenum. An absorptive backing is also beneficial in minimizing the effect of flanking through return air openings since the introduction of return air slots only reduced the DAI by about 2.

Foil faced insulation with the foil towards the plenum, as in assembly "D", provides a small further improvement in DAI compared to ordinary batt. Like the drywall backing, the foil also reduces absorption in the plenum, especially for frequency bands above 500 Hz and the effect of return air slots now becomes significant, causing a reduction in DAI of approximately 7.

Sandwich "E" combines batt insulation and drywall as backing materials. The transmission loss of this assembly is quite high, but because of a more reverberant plenum and the inevitable gaps which remain between drywall panels, the overall performance is actually slightly worse than assemby "C" which uses only insulation as a backing. However, the insertion of insulation between the ceiling board and the drywall does improve the DAI by approximately 4 when compared to the drywall-backed ceiling shown as assembly "B". This improvement is maintained even when return air openings are present.

Many of these sandwiches offer a substantial improvement over the basic suspended ceiling and perform nearly as well as a plenum barrier. The importance of avoiding even moderately reflective backing materials is quite obvious, especially if the ceiling is ventilated. The simple addition of a batt insulation backing appears to provide the best overall performance.

CONCLUSIONS

Suspended ceilings are often selected on the basis of their sound transmission loss rating. Attempting to simply match the STC of a ceiling panel to that of a wall system can lead to disappointing results. It is important to know the combined effect of the wall, plenum conditions and ceiling system including any flanking that might be introduced because of ventilation requirements. Return air slots, in particular, can impose a severe limitation on the performance of a ceiling. Practical methods of eliminating their effect have been described. Performance of the ceiling transmission path can be further improved by adding sound absorptive material to the plenum. Absorption was found to be most effective when placed directly on the back of the ceiling panels and centered about the common partition. This placement is especially important when return air slots are present. Various other backing materials can also be used to increase sound isolation when applied over the entire ceiling. The performance of these sandwich assemblies exhibited a marked dependence on their absorptive properties, as seen from the plenum, in order to minimize the effect of flanking through return air slots. Plenum barriers offer the greatest potential for increasing sound isolation especially when used in conjunction with low transmission loss ceilings. Barriers must be reasonably massive and well-sealed to realize their full benefit but they do not necessarily need to completely enclose the plenum space above an office.

ACKNOWLEDGMENTS

The considerable participation of Mr. Martin F. Fayers in initiating this study and assisting with the planning and execution of the testing, is gratefully acknowledged.

REFERENCES

1. Mariner, T. "Theory of Sound Transmission Through Suspended Ceilings Over Partitions", Noise Control, Nov. 1959.

2. Hamme, R.N., "Laboratory Measurements of Sound Transmission Through Suspended Ceiling Systems; J. Acoust. Soc. Am. Vol 33, No. 11, Nov. 1961, pp. 1523 - 1530.

3. ISO 140/IV, (1978), Measurement of Sound Insulation in Buildings and of Building Elements - Field Measurements of Airborne Sound Insulation Between Rooms.

4. Warnock, A.C.C. "Studies of Acoustical Parameters In Open Plan Offices." J. Acoust. Soc. Am. 63, 1978, pp. 832-840.

5. ANSI S3.5 (1969), American National Standard Method for the Calculation of the Articulation Index.

6. ASTM E 1110-86, Determination of Articulation Class.

7. AMA 1-II (1967), Ceiling Sound Transmission Test by Two Room Method.

8. Jonasson, H. "The Sound Insulation of Suspended Ceilings - Theory, Methods of Measurement and Interpretation of Results" Byggmastaren, 1973, 52 (1) (Jan), pp. 17 - 20. Translation No. 530 Property Services Agency, London.

BRÜEL & KJAER SEMINAR CALENDAR FOR 1988

Brüel & Kjaer not only produces some of the finest measurement devices in the world, the company also keeps abreast of the latest scientific developments in each of the fields where those instruments are used. Whether it be acoustics, vibration, luminance, or modal analysis or any other area in which our systems apply, we hold seminars each year to inform potential and present users of our equipment as to the current state of the art.

DATE	PLACE	TITLE
Jan. 18-20	Vancouver, B.C.	Machine Health Monitoring
Jan. 20-21	Toronto, Ont.	Noise Measurements
Jan. 27-28	Ottawa, Ont.	Noise Measurements
Feb. 9-10	St. John's, Nfld.	Machine Health Monitoring
Feb. 10-11	Thunder Bay, Ont.	Noise Measurements
Feb. 17-19	Edmonton, Alta.	Machine Health Monitoring
Feb. 24-25	Toronto, Ont.	Intensity Measurements
Feb. 24-25	Sherbrooke, Qué.	Mesures de vibration pour la maintenance prévisionnelle
Mar. 9-10	Cambridge, Ont.	Noise Measurements
Mar. 10-11	Prince George, B.C.	Noise Measurements
Mar. 15-16	Winnipeg, Man.	Noise Measurements
Mar. 22-24	Toronto, Ont.	Vibration Testing/Structural Analysis
Apr. 5-6	Vancouver, B.C.	Paper Machine Monitoring/Structural Analysis
Apr. 6-7	Ottawa, Ont.	Machine Health Monitoring
Apr. 6-7	St. John, N.B.	Machine Health Monitoring
Apr. 13-14	Timmins, Ont.	Machine Health Monitoring
Apr. 19-20	Montréal, Qué.	Essai aux vibrations et analyse modale
Apr. 21-22	Montréal, Qué.	Vibration Testing/Modal Analysis
Apr. 21-22	Edmonton, Alta.	Human Environment
Apr. 27-28	Toronto, Ont.	Advanced Acoustics
Apr. 28-29	Trois-Rivières, Qué.	Mesures de vibration pour la maintenance prévisionnelle
May 4-5	Ottawa, Ont.	Advanced Acoustics
May 4-5	Edmonton, Alta.	Noise Measurements
May 4-5	Val d'Or, Qué.	Mesures de vibration pour la maintenance prévisionnelle
May 10	Baie Comeau, Qué.	Mesures des nuisances de l'environnement
May 11	Québec, Qué.	Mesures des nuisances de l'environnement
May 13	Jonquière, Qué.	Mesures des nuisances de l'environnement
May 11-12	Thunder Bay, Ont.	Machine Health Monitoring

DATE	PLACE	TITLE
May 24-25	Montréal, Qué.	Intensity Measurements
May 26-27	St. John's, Nfld.	Intensity Measurements
May 25-26	Toronto, Ont.	Signal Processing
May 31 – June 2	Winnipeg, Man.	Machine Health Monitoring
June 1-2	Ottawa, Ont.	Signal Processing
July 6-8	Fort St. John, B.C.	Machine Health Monitoring
July 18-19	Vancouver, B.C.	Noise Measurements
Aug. 10-12	Edmonton, Alta.	Intensity Measurements
Aug. 25-26	Jonquière, Qué.	Mesures de vibration pour la maintenance prévisionnelle
Aug. 30-31	Montréal, Qué.	Mesures de vibration pour la maintenance prévisionnelle
Sept. 7-8	Toronto, Ont.	Electroacoustics
Sept. 7-9	Québec, Qué.	Mesures de vibration pour la maintenance prévisionnelle (séminaire avancé)
Sept. 14-16	Saskatoon, Sask.	Machine Health Monitoring
Sept. 21-22	Thunder Bay, Ont.	Machine Health Monitoring (Advanced)
Oct. 19-20	Ottawa, Ont.	Machine Health Monitoring (Advanced)
Oct. 24-25	Winnipeg, Man.	Noise Measurements
Oct. 26-27	Windsor, Ont.	Machine Health Monitoring
Nov. 8-10	Winnipeg, Man.	Machine Health Monitoring
Nov. 16-17	Baie Comeau, Qué.	Mesures de vibration pour la maintenance prévisionnelle
Nov. 23-24	Toronto, Ont.	Machine Health Monitoring
Nov. 29-30	Halifax, N.S.	Machine Health Monitoring
Dec. 1	Winnipeg, Man.	Human Environment

Please contact any of our offices listed below for further information on the course you are interested in.

Should you require a special seminar on any subject within our area of expertise, we will work with you to meet the needs of your organization.

Brüel & Kjaer Canada Ltd.

Montréal: (514) 695-8225
Toronto: (416) 677-5472
Edmonton: (403) 484-4228
Ottawa: (613) 225-7648
Winnipeg: (204) 694-2884
Vancouver: (604) 278-4257