Sound Transmission Through Ceilings from Air Terminal Devices in the Plenum

A.C.C. Warnock
Institute for Research in Construction, National Research Council Canada.

Introduction.

HVAC sources in ceiling plenums are often major contributors to the noise level in occupied spaces below. This paper presents results from ASHRAE RP-755 [1, 2, 3, 4] and discusses primarily the sound attenuation through ceiling systems and the sound pressure levels in the room below. The focus of RP-755 was on the interactions between terminal units (positioned above and close to a lay-in ceiling), the ceiling panels, the plenum and the room below. The intent was to evaluate the calculation methods used in ARI 885-90 [5] and suggest improvements where necessary.

At the beginning of the project it was known that transmission loss results obtained in reverberation room tests did not apply to this situation because of the close coupling between the source and the ceiling panels and the absence of a diffuse sound field in typical plenums. As well, the information used to prepare ARI 885 was provided by a few manufacturers, but it did not form a consistent set based on a standard test procedure or accepted method of measurement.

Summary of the investigation.

Test Room. The room acoustics test (RAT) room, where the measurements were made, is a rectangular parallelepiped 4.71 m wide and 3.6 m high. One end wall can be moved but for most of the experiments, the length was set at 9.2 m giving a room volume of 156 m^3. The T-bar system for supporting tiles was installed so the distance from the face of the supporting surface of the T-bar to the true ceiling of the room was 740 mm. To provide some scattering, 8 sheets of 16 mm gypsum board measuring 1.22 x 1.22 m were hung on the walls or placed on the floor and inclined against the walls.

Sound Sources. The four terminal types used in the project were an air-to-air ceiling induction unit, a VAV shutoff unit, a series flow fan-powered VAV unit, and a parallel flow fan-powered VAV unit. To provide more convenient reference sources with good repeatability, two metal boxes each containing two loudspeakers radiating random noise were also used as sources above the ceiling. One was positioned near the middle of the room, close to the devices being tested. The second was placed in one corner of the plenum.

Ceiling Types. Six ceiling panel types laid on a standard T-bar grid were tested. No clips or other devices were used to hold the panels down. The types of panel and the coded identifiers used for brevity are given in Table 1. Sound transmission loss (ASTM E90) and sound absorption (ASTM C423) with the specimen mounted on an E400 frame (ASTM E795) were measured for each ceiling type in NRC's reverberation rooms.

Table 1: Ceiling types and codes used for identification.

Code	Ceiling panel type
A895	16 mm thick mineral fiber tiles
A755B	16 mm thick lightweight mineral fiber tiles
G13	13 mm vinyl-faced gypsum board
FGvin	50 mm thick glass fiber tile with perforated vinyl face
FGTL	50 mm thick glass fiber tile with perforated vinyl face and metal foil backing
A2910	16 mm thick glass fiber tiles with vinyl face randomly perforated with fissures

Measurements. Sound pressure levels were measured in the RAT room for each source in combination with each ceiling type. As well, for each ceiling the reverberation times and sound pressure level as a function of distance from a nominally omni-directional source were measured in the room.

Major Results.

The difference between the sound power, L_w, of a given device placed in the plenum and the average sound pressure level, $<L_p>$, in the room below measures the combination of the "plenum/ceiling effect" and the average "space effect". These terms are defined in ARI 885 as

Plenum/Ceiling Effect: The difference between the octave band sound power level from the source located in the plenum/ceiling cavity and the sound power level transmitted to the occupied space.

Space Effect: The difference between the octave band sound power level entering the occupied space and the resulting octave band sound pressure level at a specific point in the space.

Ceiling attenuations. The attenuations for all the sources used were averaged to get the average $L_w - <L_p>$ for each type of ceiling tile (See Fig. 1). The interesting feature of this graph is the small differences among tile types with the exception of the G13 and A2910 tiles.

One might have expected that the heavier G13 tiles would have given much lower levels in the room than the lighter tiles. The conclusion drawn from this result was that for most of the tiles used, the dominant path through the ceiling is the leakage between the edges of the tiles and the T-bars. For the mineral fiber and glass fiber tiles there will be different relative amounts of sound power transmitted due to leakage, absorption on the rear face and at the edges, and transmission through the body of the tile.

The light A2910 tiles provide little attenuation through the body of the tile at high frequencies and for the gypsum board tiles, there is no sound absorbing material to offset the effects of the leaks around the edges of the tiles. These two types of tiles are quite different from the others but are perhaps not typical of products used below air terminal units.

One conclusion that can be drawn from this figure is that since most normal tiles give about the same result, there is little point in creating a test procedure to rate the effectiveness of ceiling tiles as attenuators of sound from air terminal units. The sound powers of the devices tested all decreased fairly rapidly as frequency increased. So, even the poor attenuation of the G13 and A2910 tiles at high frequencies is not likely to be important. On the other hand, mounting systems for the tiles other than standard T-bars, give more attenuation [6] so it may still be deemed advisable to create a test procedure.

The attenuations measured for the different ceiling types, did not agree well with those predicted from values given in ARI 885.

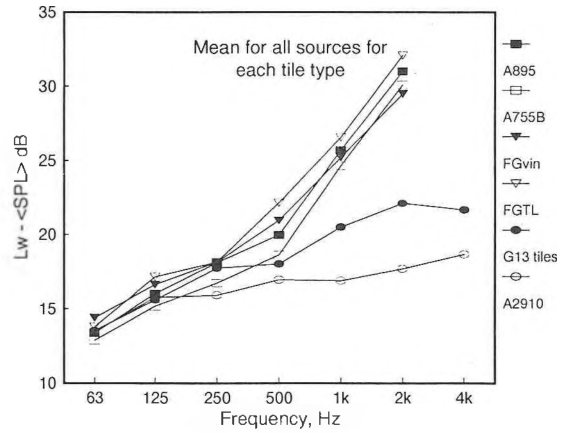

Figure 1: Average of L_w - $<L_p>$ for all sources for each type of ceiling tile.

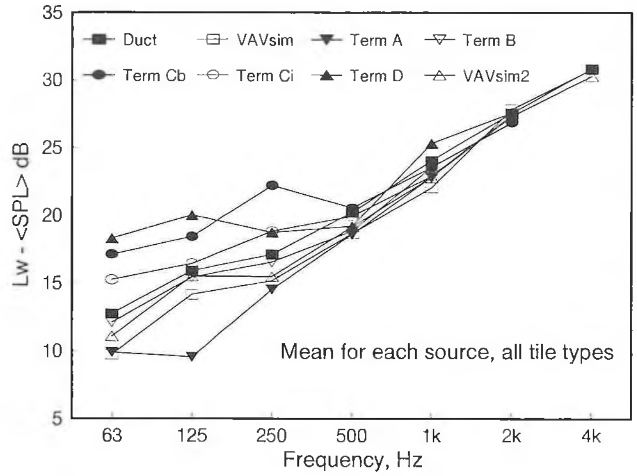

Figure 2: Average of L_w - $<L_p>$ for all ceilings for each type of source.

Differences among sources. Figure 2 shows for each source the average attenuation for all the ceiling types used. If the sound power emitted by the device were not altered by the presence of the ceiling, if the attenuation provided by the ceiling were constant, and if there were no interaction between the device and the ceiling, then all of these curves would be approximately the same. There are, however, quite significant differences at and below 250 Hz among the devices. The conclusion drawn from this graph is that the coupling between the ceiling tiles and the source influences the sound power radiated into the room below the ceiling. This makes it difficult to accurately predict the sound pressure level in the room below using only sound power levels for the device measured according to standards and some fixed insertion loss values for the ceiling tiles.

Dependence of ceiling attenuation on source area. Examination of the data revealed a fairly strong correlation between the effective ceiling attenuation and the area of the surface of the source closest to the ceiling. As the area increased, so did the ceiling attenuation. This correlation explains much of the scatter at low frequencies in Fig. 2. No physical model or analytical expression has been found to explain this dependence. The empirical model developed is:

$$SPL(f) = P(f) - A(f) + m(f) \times (S - 0.83).$$

where

- f is the mid-band frequency of the octave band, Hz,
- $SPL(f)$ is the average sound pressure level in the room, dB,
- $P(f)$ is the power emitted by the terminal unit when tested according to standards [7], dB,
- $A(f)$ is the nominal attenuation of the ceiling tiles, dB,
- $m(f)$ is the slope of the regression of attenuation on area, dB/m^2,
- S is the area of the lower face of the terminal unit, m^2, and
- 0.83 is an empirical constant determined from the measured data.

The values of m found from experiment are given in Table 2.

Table 2: Values of coefficient m.

f, Hz	63	125	250	500	1k	2k	4k
m, dB/m^2	4.4	4.1	2.5	0	0	0	0

Spatial attenuation. For a source placed in the room *below* each ceiling the Schultz [8] formula predicts an attenuation of 3 dB/distance doubling independent of room absorption. In this work, however, the attenuation depended on the reciprocal of the room reverberation time according to

$$\text{Attenuation} \approx (0.9/RT + 0.5)\ \text{dB/dd}.$$

The dependence on RT, while quite clear, is not very important in practice in typical rooms.

When the source was *above* the ceiling in the plenum, the sound field in the room below varied very little with distance from the source. Except at 2000 and 4000 Hz, the attenuation is less than 1 dB/dd. ARI 885 specifies the use of the Schultz formula and so was inaccurate in this respect.

This work showed that insertion losses for ceiling systems cannot readily be obtained from standard measurements in reverberation rooms. Based on the project new procedures for calculating the sound pressure level in a room below a terminal unit were recommended to ARI and ASHRAE.

References.

[1] Warnock, A.C.C., "Sound Transmission Through Ceilings from Air Terminal Devices in the Plenum", Final report ASHRAE RP755. January 1997.

[2] Warnock, A.C.C., "Sound pressure level versus distance from sources in rooms," ASHRAE Transactions 1998, V.104, Pt.1.

[3] Warnock, A.C.C., "Environmental correction factors for predicting room sound pressure levels", ASHRAE Transactions 1998, V.104, Pt.1.

[4] Warnock, A.C.C., "Transmission of sound from air terminal devices through ceiling systems", ASHRAE Transactions 1998, V.104, Pt.1.

[5] ARI Standard 885-90, Air-Conditioning & Refrigeration Institute, Arlington, Virginia, 1990.

[6] F.P. Mechel, "Theory of Suspended Ceilings", Acustica, **81**, p491, 1995

[7] ARI Standard 880, "Air terminals", Air-Conditioning & Refrigeration Institute, Arlington, Virginia, 1990.

[8] Schultz, T., 'Relationship between sound power level and sound pressure level in dwellings and offices', RP-339, ASHRAE Transactions 1985, V. 91, Pt. 1.