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SOLUTION OF NOISE TRANSMISSION PROBLEMS BY IN-SITU SEGREGATION OF COMPOSITE TRANSMISSION FACTORS OF COMPLEX PARTITIONS USING SOUND INTENSITY

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In order to make the best decisions for reducing noise transmission through a complex partition, it is necessary to differentiate and determine the relative contribution of the partition elements to the transmitted noise. A “complex partition” is here defined as a partition with multiple elements in the plane perpendicular to the impinging noise, such as various wall materials, doors, windows, etc., as, for example, would make up the façade of a building. A noise source is placed on one side of the composite partition, and the transmitted sound intensity is measured over the surface of the various partition elements. The technique described specifically focuses on determination of building façade transmission loss, using reciprocity with a noise source inside the building. A typical case study is included in the essay.

1. Introduction

The degree to which external noise breaks into composite building structures (e.g., composed of walls, doors, windows, vents, cracks, etc.) depends on the amplitude and frequency characteristics of the noise, and on the ability of the various parts of the composite to resist the transmission of noise. Each of the architectural components has its own sound transmission loss characteristics, which also vary as a function of frequency.

Use of sound intensity as a technique for determining transmission loss, and associated error analysis and comparison with other techniques, is well established and documented.[1-4] It follows that, as intensity techniques are relatively insensitive to field conditions (compared to standardized methods using sound pressure), it is particularly useful in identifying the relative transmission characteristics of the various components in a multi-element barrier or building façade.

Given the considerations established in the literature, the goal of the method described in this essay is to isolate the various components of a room partition or façade to resolve their individual sound transmission characteristics. With this information, we can then verify which element or elements of the façade can be improved to provide a reduction in the transmitted noise, and the approximate degree of noise reduction to be expected from these improvements, with respect to noise of a particular spectrum.

The method is presented as a case study involving noise impact to the façade of a hotel room (Figure 1) that contains windows, a door, louvred vents, an air conditioning unit, various seals and joining elements, and other panels. The technique has been used by the author in other situations, such as to separate the individual transmission losses of elements associated with a conventional timber single-family dwelling (i.e., composed of insulated walls, windows, roof, and junctions between these elements), and to distinguish the relative transmission losses in the multielement partition between rooms in a high-rise office building (gypsum wall board, a glass element in the partition, a mullion, and the path over the partial-height wall through the lay-in ceiling).

Figure 1. **Photograph of the hotel façade discussed in the case study.**

2. Description of method

Especially when the noise is transient in nature (e.g., due to transportation sources), it is a particular challenge to evaluate the relative quantity of transmission through the various components of the room façade, since a stable source is required to obtain a true picture of the relative transmission loss. We therefore use another method to evaluate the structure: a broadband noise at high acoustic pressure is generated in the room enclosed by the façade of interest, and the sound transmission loss of the various façade components is determined by measuring the sound intensity outside of each component (as a linear system, the transmission loss is essentially the same in either direction through the building components).

The total radiated power from each element can then be calculated by multiplying the measured (surface-averaged) sound intensity by the surface area of the element. Though useful, it is not necessary to know the power or pressure incident on the composite surface, as long as it is uniform. However, location and diffusion of the test noise source is of great importance, and the uniformity of the noise over the interior surface should be verified.

3. Case Study

The hotel room façade used in the case study was impacted by noise from nearby passing trains. Before the study was carried out, the hotel management replaced the windows in one of the rooms with a dual-pane window having better sound isolation properties than the single-pane glass ubiquitously installed in the hotel. The analytical study was carried out later because this initial upgrade of the glass did not perceptibly reduce train noise transmission into the room.

3.1 Noise source

Each time a train passes on tracks running along the property line of the hotel, noise produced by the train carriage, bells on the crossing gates, and the train’s horn, is audible in the room. Figure 2 shows the noise level measured outside the test room with and without a passing train, in a plot of amplitude versus frequency. These are “maximum RMS” data, to capture the highest noise levels due to the passing train. “A” frequency weighting is used, because this approximates the sensitivity of the human ear with regard to the frequency of the sound, and audibility is particularly important in this case. The train increases the noise level at all frequencies, with the greatest increase in the 500 Hz to 4000 Hz range. Figure 3 shows space-averaged noise data collected inside the room without and with the passage of two trains. There is clearly a significant increase in the room noise levels while the train is passing. The noise will appear to be most intrusive in the range where the difference between train noise and ambient condition (without train noise) is greatest. The largest differences in level between the passing train and ambient are in the 500 Hz to 4000 Hz range.

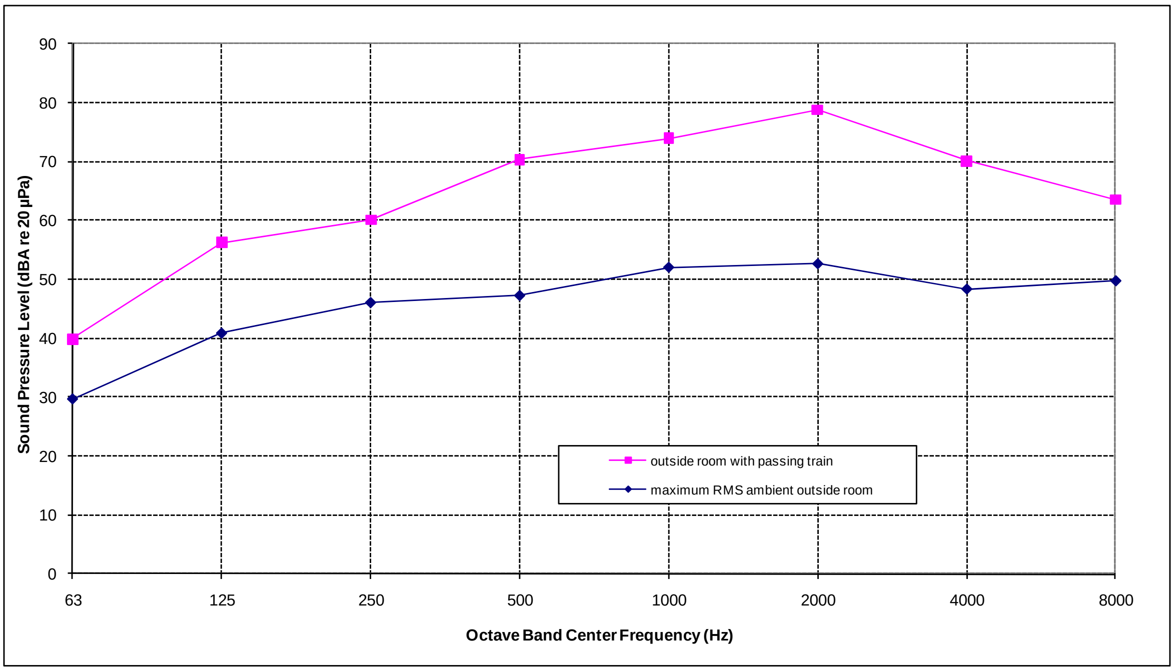

Figure 2. **Ambient noise levels outside hotel room (1m from façade) due to train; maximum RMS level, "slow" time weighting, "A" frequency weighting.**

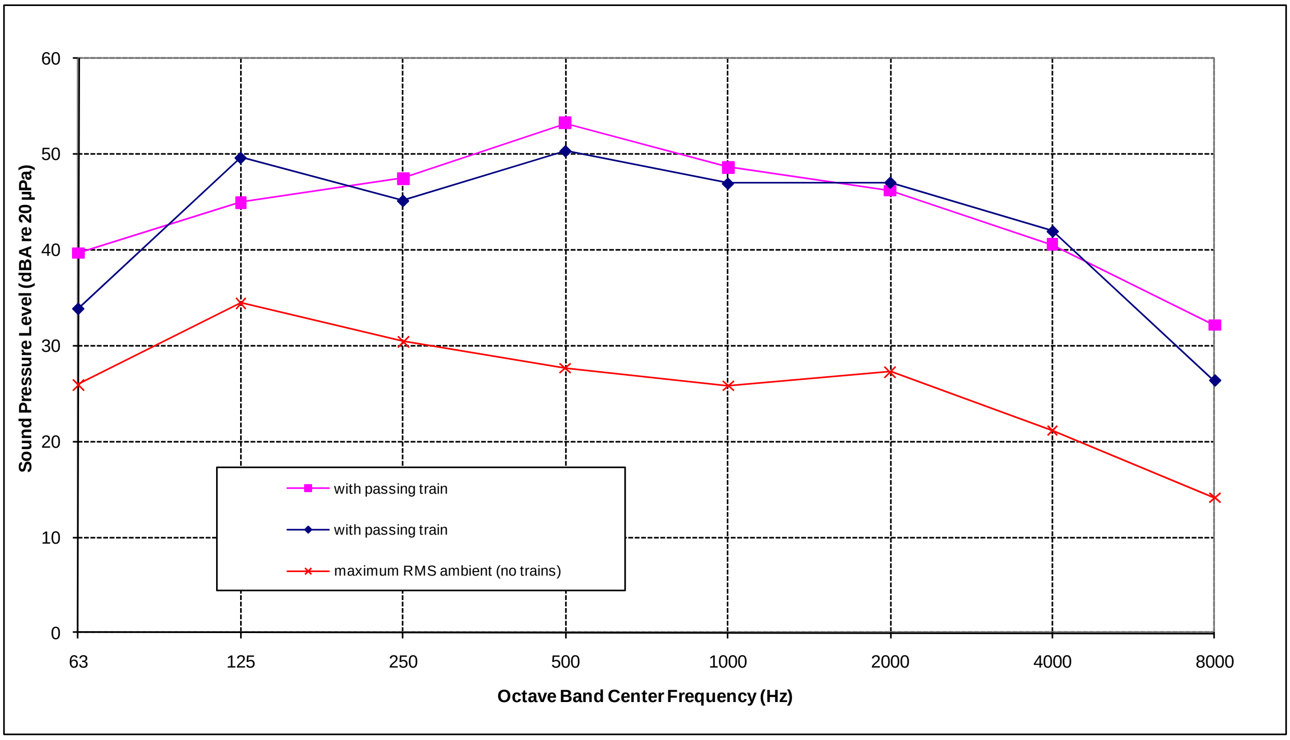

Figure 3. **Ambient noise levels inside hotel room, and noise levels inside room with train passages; maximum RMS level, "slow" time weighting, "A" frequency weighting.**

3.2 Façade description

Five basic components compose the hotel façade:

Windows - There are two 6mm thick safety tempered single-glazed windows with elastomeric seals. The total area of both windows is 4.5 m^2.

Door - The door is constructed of hollow metal. There is a stationary panel above the door that appears to be made of the same material. There are felt seals on the sides of the door, a simple elastomeric seal strip at the bottom, and a metal flange to cover the gap at the top (without a resilient seal). In this study, the door, the door frame, and the seal area (or any gaps without sealing—see the references[5-7] for discussion of the transmission loss though gaps around poorly-sealed doors and elsewhere), were measured as a unit, since it is good acoustical design practice to supply these as a unit (it is also possible to isolate the contribution from these various components of the assembly). The total door assembly area is 1.8 m^2. The area of the panel over the door is 0.3 m^2.

Air-conditioning (AC) unit inlet – The AC unit is located below the windows. There is a permanent opening into the unit from outside. A thin aluminum panel fills the space under the unit. The total area of the AC unit inlet is 0.4 m^2. The total area of the aluminum panel under the AC unit is 0.1 m^2.

Louvres - There are two sets of ventilation louvres, one located on each side of the AC unit, below the windows. There are elastomeric seals at the top, bottom, and sides of the louvres, but not between the louvre blades. The total area of both louvres is 0.7 m^2.

Aluminum channeling - All of the above components are connected with aluminum channeling. The quality of the caulking at connections varies from acoustically functional (soft and resilient) around the louvres, to non-functional (hardened and cracking) around the AC unit and at the brickwork between rooms. The total area of all of the aluminum channels is 0.6 m^2.

3.3 Results of noise transmission test

Table 1 lists each element tested, along with the measured radiated sound power as a function of frequency. The total given at the end of the table represents the logarithmic sum of the individual element sound power levels, and is thus the total sound power radiated from the façade of the hotel room with the test noise source inside the room.

Table 1: Measured sound power level of each façade element

	Sound power level (dB re 1 pW) versus octave band center frequency (Hz)								
architectural element	**31.5**	**63**	**125**	**250**	**500**	**1000**	**2000**	**4000**	**8000**
door, seals, and frame	80	77	76	72	66	70	71	66	52
panel over door	71	68	69	68	64	64	64	56	42
window, left pane	79	76	77	74	61	62	66	60	44
window, right pane	79	73	76	72	59	60	65	58	36
ventillation louvres, left	73	72	74	70	62	62	61	59	42
ventillation louvres, right	70	75	78	71	62	63	60	57	39
AC unit inlet	75	73	79	70	56	56	56	49	32
Al channel at door, left edge	68	64	66	63	54	57	55	52	37
Al channel at door, right edge	68	66	63	63	55	56	62	55	37
Al channel at brickwork, left edge	66	60	62	61	47	47	53	43	19
Al channel at top edge	72	65	68	67	53	56	59	48	29
Al channel between windows	66	61	61	56	43	46	51	44	23
Al panel under AC unit	68	66	68	63	52	47	45	40	25
total	**86**	**83**	**85**	**80**	**71**	**73**	**75**	**69**	**54**

This list can be greatly simplified by summing the sound power radiated from each type of element, as shown in Table 2.

Table 2: Measured sound power level of each façade element (summation by type)

	Sound power level (dB re 1 pW) versus octave band center frequency (Hz)								
architectural element	**31.5**	**63**	**125**	**250**	**500**	**1000**	**2000**	**4000**	**8000**
door, seals, and frame	80	77	76	72	66	70	71	66	52
panel over door	71	68	69	68	64	64	64	56	42
windows	82	77	80	76	63	64	69	62	44
ventilation louvres	75	77	79	74	65	65	64	61	43
AC unit inlet	75	73	79	70	56	56	56	49	32
Al channels + Al panel	76	72	73	71	60	62	65	58	40
total	**86**	**83**	**85**	**80**	**71**	**73**	**75**	**69**	**54**

We are interested in knowing the percentage of noise propagated through each type of element, as a function of frequency. This is simply the individual sound power for each element, divided by the total sound power for the whole façade. The percentage of noise contributed to the total noise in the room through each of the façade elements is shown in Table 3.

Table 3: Percentage of total radiated sound power level through each façade element

	Percent of total radiated sound power measured versus octave band center frequency (Hz)								
architectural element	**31.5**	**63**	**125**	**250**	**500**	**1000**	**2000**	**4000**	**8000**
door, seals, and frame	28	27	13	15	32	46	47	48	66
panel over door	3	3	3	5	18	14	8	5	7
windows	43	27	29	38	16	13	25	21	12
ventilation louvres	7	24	26	21	25	18	8	17	9
AC unit inlet	7	10	23	9	3	2	1	1	1
Al channels + Al panel	11	8	7	11	8	7	11	7	5

These data are plotted in Figure 4. Some conclusions that may be drawn from the data tables are as follows:

- Half of the noise is transmitted through the door in the most critical frequency range (the principle range of noise produced by the train): 500 to 8000 Hz. The door also admits low frequency noise, although in this range, admittance is dominated by the windows, the ventilation louvres, and the AC unit inlet.
- The windows admit approximately one third of the low frequency noise (250 Hz and below). The low frequency transmission is less critical with regard to the noise characteristic of the train.
- One quarter of the low frequency noise (63 to 250 Hz) comes in through the ventilation louvres.
- The AC unit inlet primarily admits noise in the 125 Hz band, but this is only one quarter of the total noise admitted in this frequency band.

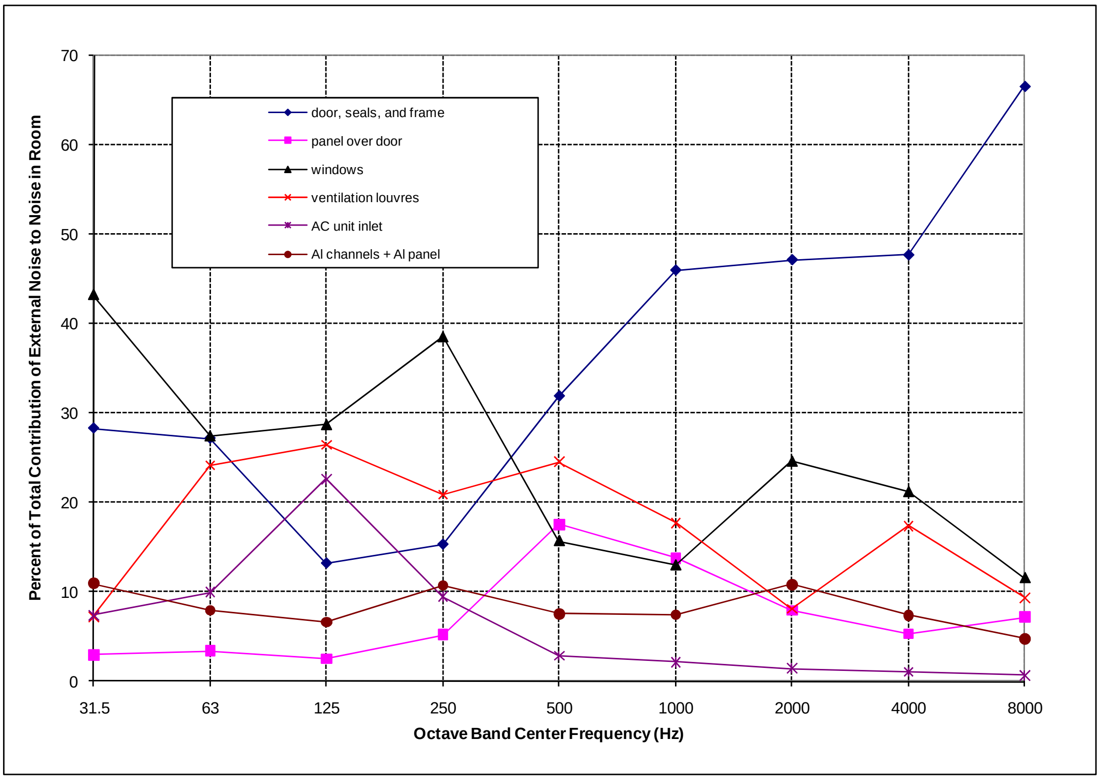

Figure 4. Relative contribution of paths by which external noise is transmitted into hotel room.

Given the noise level generated in the room, and the sound power radiated from each element, we can calculate the sound transmission loss of selected elements. This index is useful because it can be compared directly with published values of the same index for proposed component replacements. In Figure 5 we plot the measured transmission loss values for the door assembly (and over-door panel) and for the windows. It is notable that the windows significantly outperform the door in the critical 500 to 4000 Hz range.

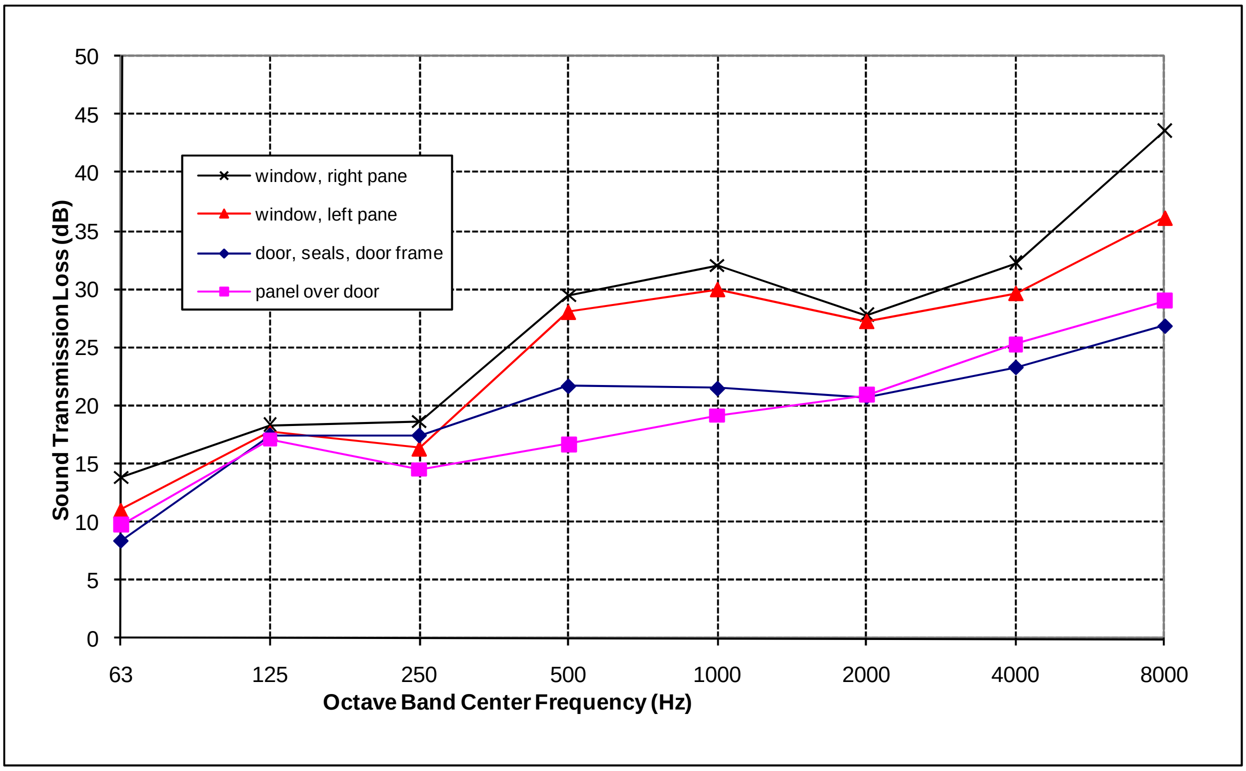

Figure 5. Measured sound transmission loss of hotel room door assembly and windows.

The measured sound transmission loss for the windows in the tested hotel room is similar to what one would expect for typical 6mm-thick single-glazed window. However, the door performance is relatively poor in comparison with the available population of standard and acoustical door assemblies. Further investigation showed that this is mostly due to the quality of the door itself (exacerbated by its relatively large area), and to a slightly lesser degree, to the seals around the door.

The measurement data show that it is the door that admits the most significant portion of the train noise. This is why the pre-study improvement of the windows by the building manager did not produce a perceivable difference in transmitted train noise. The hotel room door (including some contribution from the seals and framing) has a measured sound transmission class (STC) of STC 23. With the application of a well-sealed door rated at STC 35 or better, we calculate that the room noise levels due to external noise in the 500 to 4000 Hz bands will be reduced approximately 3 dB. Perceptually, it would appear that the train noise is just slightly quieter.

The foregoing analysis has allowed us to determine that no improvement beyond 3 dB can be gained by the use of a door with an STC rating greater than 35. This is because, with the improved door, the noise levels in the critical frequency range would then be controlled by the windows, ventilation louvres, and the over-door panel. If these are improved along with the door (e.g., using dual-pane windows, sealed or gasketed louvres, adding mass to the panel, improved acoustic caulking, etc.), the overall improvement could approach 10 dB, a perceptual halving of the transmitted noise.

4. Conclusions

The analysis method and case study discussed is shown to be useful in the identification of weak points in a multi-element partition. The numerical results of this type of study may be used to determine the necessary order of the replacement of elements (starting with the weakest), and what replacement of elements of various performance would result in from a perceptual standpoint, adding more certainty to the noise control process.

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