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COMPARATIVE ANALYSIS OF RETROFIT WINDOWS FOR NOISE CONTROL AT A HOTEL

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Abstract

Guest rooms in a historic landmark luxury hotel suffered excessive environmental mechanical equipment noise intrusion through windows. Measurements of outdoor-indoor sound transmission loss have been carried out to compare the performance of four retrofit sound control window fixtures with performance of existing fixtures. The hotel originally opened in 1924 and reopened in 2000, after a multi-million dollar renovation in which original window fixtures were replaced. Several guest rooms overlook the roof of the hotel's adjacent banquet and meetings wing, with rooftop mechanical equipment that includes air-cooled chillers, air handlers, exhaust fans, and cooling tower. Hotel management desired to reduce mechanical noise in guest rooms, and some window fixtures were again replaced or augmented with various retrofit sound control glazing fixtures. Sound transmission loss measurements using outdoor amplified broadband noise source and, separately, mechanical equipment noise sources were conducted on one existing, single-pane guest room window type and four multi-pane sound control glazing fixtures to compare effectiveness. Analysed window types included single-pane, double-pane, and triple-pane systems, and glazing types included laminated glass and plate glass. No specific noise reduction criterion was used, but analyses were conducted to determine which glazing fixture's noise reduction spectrum best matched the tonal noise spectra of the existing mechanical equipment. Noise reduction spectra were also analysed with respect to ASTM (OITC and STC) and ISO (Rw) curve fitting techniques. Noise reduction with amplified broadband noise source was compared to noise reduction with mechanical equipment noise and vibration sources to evaluate possible contributions from equipment vibration. This paper presents photographs and details of the existing and retrofit window conditions with tabular and graphical results from measurement of outdoor-indoor sound transmission through windows and existing interior ambient conditions.

1. INTRODUCTION

A historic hotel underwent a major renovation in May 2000 in which original wood-frame window fixtures with single layer glass were replaced with metal frame fixtures, also with single layer glass. Upon completion, the owner determined that the replaced windows permitted excessive building mechanical equipment noise intrusion into some guest rooms.

Through a series of retrofit window installations, several windows were again replaced with metal or wood frame windows with double layer glass, and some windows were also retrofitted with interior single layer sashes. Hotel owners desired to compare sound transmission performance of the replacement and retrofit assemblies with hard data for cost-benefit analysis. On-site evaluation of the existing installations provided greater reliability than predictive theoretical analyses, because the test automatically included flanking paths and other difficult to predict variances from theory.

The replacement and retrofit systems included a variety of glazing thicknesses, glazing types, and frame and sash types. Two of the systems included laminated (Lam) glazing. Two of the systems included a fixed removable sash installed as a secondary window on the guest room side of the existing window. These removable panes fit into a separate frame with a gasket sealing system that required no bolts or screws to secure glass.

Table 1. Tested windows and window construction (thicknesses in mm).

No.	Room	Manufacturer	Frame	Type	Construction from Inside to Outside				
					Glass	Space	Glass	Space	Glass
1	313	Kolbe & Kolbe	wood	fixed	---	---	Lam-9	18	6
2	314	Binswanger	alum.	fixed	Lam-9	64	6	13	6
3	414	Maine Glass	alum.	fixed	5	64	6	13	6
4	415	unknown	alum.	slider	---	---	6	13	6
5	715	unknown	alum.	slider	---	---	---	---	3

JEAcoustics was retained to determine (a) the effectiveness of each of the windows, and (b) which would be acceptable for normal hotel suite occupancy. Based on findings, the hotel would order replacement windows for other hotel rooms or seek alternatives. Outside to inside noise reduction performance was determined for each of the windows. Performance was then compared with source noise levels and allowable tolerance for noise received indoors to determine optimum selections.

2. PERFORMANCE CRITERIA

No objective acoustical performance criterion for windows was established by the hotel owners. To establish a performance standard, we relied upon our own acoustical consultation experience with intrusive noise and reviews of noise research,[1,2] which generally indicate a tolerance for tonal intrusive noise about equal to continuous ambient noise levels, but annoyance when above ambient.

2.1 Equipment Noise

Equipment noise levels were measured on the rooftop adjacent to guest rooms. Primary external noise sources for rooms that have a view over rooftop equipment included two air cooled rotary screw type chillers closest to the guest rooms. Secondary external noise sources included other rooftop equipment, including a third chiller, a cooling tower, a kitchen make-up air handler, and kitchen exhaust fans, plus bus, truck, and auto street traffic at grade.

Outdoor noise from chillers exhibits prominent tonal peaks around low frequencies at 56 Hz, 115 Hz, and 171 Hz, and at higher frequencies around 234 Hz, 287 Hz, 415 Hz, 593 Hz, and 890 Hz.[3] During normal occupancy, hotel windows are closed and indoor air conditioning is on, providing a moderate amount of masking sound from the indoor fan. In each room, the air conditioning fan coil unit is in a ceiling furring, at opposite side of the room from the window. Chiller noise intrusion through the windows is audible above the background fan noise. Measurements of equipment noise through windows were conducted in guest rooms on the third, fourth, and seventh floors, in rooms 313, 314, 414, 415, 715, and the third floor service lobby (near exit stairs; Figure 1, left, bottom).

Figure 1. Floor plans of Levels 3, 4, and 7, with equipment and measurement locations.

2.2 Allowable Equipment Noise Intrusion

ASHRAE guidelines[4] for continuous background mechanical system noise in hotel rooms suggest a balanced noise spectrum between RC 25 and 35 (32-37 dB(A)).

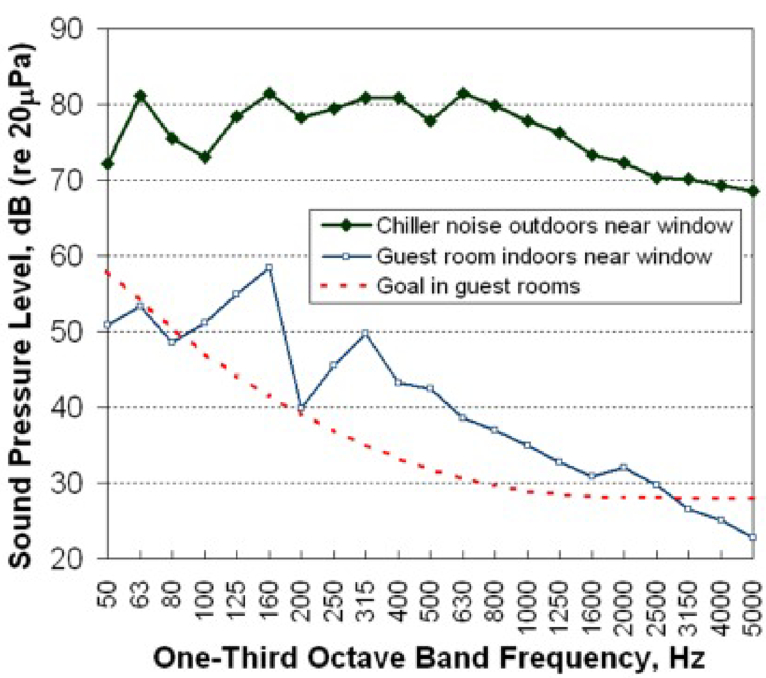

Figure 2. Chiller noise outdoors compared to indoor noise and indoor goal spectrum.

Balanced (non-tonal) indoor air conditioner fan noise could actually be allowed between RC 35 and 50 (42-57 dB(A)), since room occupants would be able to control the operation of the equipment in their own rooms. However, elevated indoor fan noise tends not to be balanced and would not be appropriate for masking of intrusive tonal equipment noise from outdoors. Additionally, not all guests could be expected to keep their ventilation fans on full time for sound masking purposes.

2.3 Glazing Performance Criteria

With regard to rating standards, full spectrum results over a broad frequency span are relevant to hotel occupancy, since occupants might be disturbed by a variety of noise sources. Furthermore, chiller noise was measured to have tonal noise peaks at low, mid, and high frequencies. Sound Transmission Class (STC) is an industry standard for rating glass performance, but the field testing procedure is intended for interior partitions, not exterior building shell/façade elements, and the frequency span is limited to 125 Hz to 4000 Hz one-third octaves. The Outdoor-Indoor Transmission Class (OITC) rating[5] as defined in ASTM E 1332[6] is specially suited for evaluating the sound isolation performance of exterior building facades and components, and it extends to include one lower octave. However, currently, OITC information is not often provided by window manufacturers. The STC rating, along with the associated field-tested Normalized Noise Isolation Class (NNIC) rating,[7,8] is the more widely used method for evaluating sound isolation of all building components. Therefore, both STC and OITC ratings were relied on for tests and evaluations.

Based on the goals established for allowable equipment noise intrusion and balanced indoor noise spectrum, glazing performance for window fixtures should achieve noise reduction consistent with a minimum of STC 48 and OITC 41.

Small room volumes in guest rooms (37-53 cu. m) make lower frequency results less reliable. However, since most of the guest rooms in the facility have similar volumes, the test room measurement results can be expected to be comparable to each other. Therefore, one-third octave test results are reported over a range of 80 Hz to 5000 Hz.

3. FIELD TRANSMISSION LOSS TESTS

The tests consisted of measurements of continuous outdoor noise source and indoor receiver noise levels, plus measurements of continuous background (ambient) noise levels within each unit. Measurement procedures were conducted in general accordance (not strict conformance) with ASTM standards[5] using the "moving microphones" method. Exceptions included identification and elimination of flanking paths and determination of confidence limits. Outdoor source and indoor receiver levels were measured with separate analysers, Larson-Davis 2900 and 824 real-time analysers, with ANSI Type I[9] precision microphones and pre-amps. Analyser operators attempted to start and stop measurements simultaneously; however, there may be slight differences (a fraction of a second) in start and stop times. Measurements were typically 1 minute in duration.

For comparison, tests were conducted three times, twice using an amplified sound source, and once using the collective rooftop mechanical equipment as test noise source. The amplified sound source used was random pink noise, balanced through a 7-band equalizer, and amplified through a 450 watt amplifier and passive loudspeaker. For tests at the seventh floor, use of loudspeaker as test noise source proved to be impractical; therefore, the test of the window at room 715 was conducted using only rooftop mechanical equipment noise as the test noise source.

The loudspeaker was placed on the roof, below the test room windows, and tilted up toward the window at an angle similar to the roof equipment noise propagation path. The two chillers nearest the guest rooms were turned off. The outdoor sound source was equalized and set to approximately 105 dB(A) outside the window (much louder than roof equipment and traffic noise) in order to minimize the variability of noise due to alternating equipment and traffic conditions.

Data was analysed to determine OILR and Apparent OITL values, which were used as the basis to determine a Normalized Noise Isolation Class (NNIC) rating and Field Outside-Inside Transmission Class (FOITC) rating.

4. THEORETICAL SOUND TRANSMISSION LOSS

Window noise transmission performance variations were estimated using predictive analyses discussed by Quirt[10] and Sharp.[11] It is difficult to predict the effects of flanking paths, equipment vibration effects on radiated noise, and effects of unsealed glazing cavities.

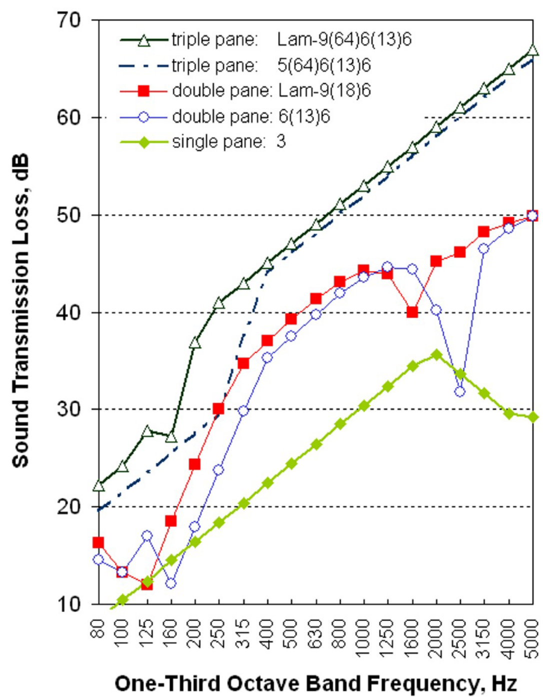

Figure 3. Predicted window transmission loss performance.

5. RESULTS

Results indicate two of the window assemblies marginally achieve the desired sound reduction performance. Measured values are presented in Figure 4, below. Better sound transmission loss performance among all the tested units was measured in Rooms 314 and 414, where window assemblies include fixed double-pane windows with a third interior pane of glass installed in a separate frame. Figure 4 shows that the unit in Room 414 performs best in the mid-frequency range between 200 Hz and 2000 Hz, but also has 'dips' or weaknesses around 160 Hz and 2500 Hz.

Sound transmission performance results for the non-laminated double-pane windows as found in Room 415 (and at the outside faces of Rooms 314 and 414) indicates a measured coincidence dip centered on the 2500 Hz one-third octave band. This dip at 2500 Hz, shown in Figure 4, is consistent with performance of windows with 6 mm thick plate glass panes separated by a 9 mm to 13 mm air space.

The amplified loudspeaker noise source could be made much louder than chiller noise outdoors. Test results with the louder, amplified noise source were much less affected by indoor background noise levels and transient noise events, and are more accurate than results with chiller noise source, with one exception at the third floor service lobby.

Table 2. Field tested window acoustical performance results.

No.	Room	Type	Glass	Space	Glass	Space	Glass	**NNIC**	**Rw**	**FOITC**
1	313	fixed	---	---	Lam-9	18	6	**39**	**38**	**32**
2	314	fixed	Lam-9	64	6	13	6	**47**	**47**	**40**
3	414	fixed	5	64	6	13	6	**48**	**48**	**40**
4	415	slider	---	---	6	13	6	**35**	**35**	**28**
5	715	slider	---	---	---	---	3	**27**	**27**	**25**

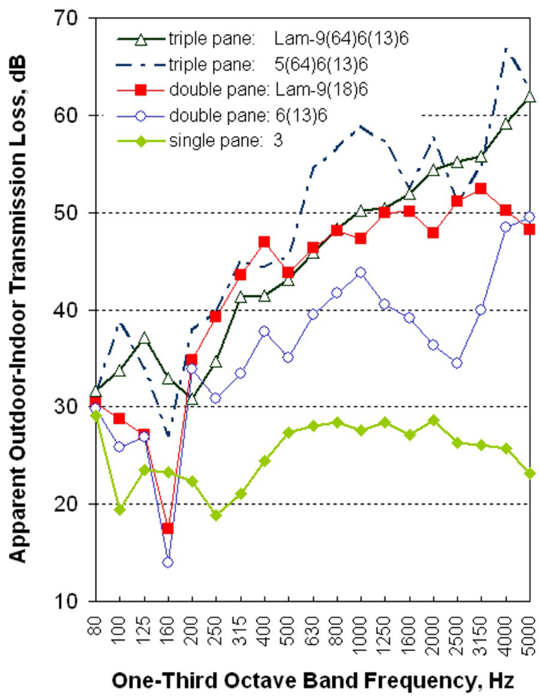

Figure 4. Comparison of measured sound transmission loss.

Measured performance in the test with amplified loudspeaker noise transmitted through the single-pane window at third floor service lobby included significant flanking noise transmission through unsealed gaps around nearby emergency exit door. The result for that test was NNIC 21 and does not accurately represent window performance. Performance in the test with chiller and cooling tower noise transmitted through a similar window at Room 715 did not include such flanking noise. The result for that test was NNIC 27, and spectral noise reduction appears to match well with lab-tested performance of similar window units (3 mm plate glass in operable aluminum frames).

Comparison of chiller sound transmission loss (including airborne noise and potential structure borne vibration/noise contributions) with sound transmission loss measured using amplified loudspeaker noise source (without significant structure borne vibration contributions) indicates there is generally not a significant level of noise induced by structure borne vibration from chillers; however, there is some evidence that structure borne equipment vibration and noise may contribute 3 to 4 dB to indoor noise levels on the third floor. Nevertheless, results indicate that such structure borne noise from equipment did not affect test results when amplified loudspeaker noise source was used.

5. CONCLUSIONS

Predicted values roughly coincide with measured values, except below 200 Hz and between 1250 Hz and 4000 Hz. Variations from predictions at low frequencies may be a result of small receiver room sizes (37-53 cu. m) and variations at high frequencies may be a result of difficulty to predict window resonance with unsealed cavities and sound flanking through window seals. Among the tested windows, the systems that have better sound transmission loss performance are the triple-pane units, No.2 (NNIC 47) and No.3 (NNIC 48), both of which have interior retrofit panes installed about 64 mm from a double-pane plate glass unit.

Figure 5. Interior views of triple-pane systems No.2 (left) and No.3 (right).

The perimeter frame and gasket assembly for the interior pane of system No.3 had visible gaps, while system No.2 appeared to have more airtight seals. Although this could allow high frequency sound transmission, it would also allow the 64 mm cavity to 'breath' and to be decoupled from the building wall and outer window frame, which could explain its overall better performance than system No. 2. Although the result for unit No.3 is better than No.2, which has laminated glass, it actually exhibits some weaknesses at low frequencies, compared to the laminated unit. Weaknesses can be seen in Figure 4 as 'dips' in performance at 160 Hz and 2500 Hz one-third octave bands. Unit No.3 appears to exacerbate low frequency 171-Hz chiller tonal effects and impact on guest room occupants.

One would expect a laminated unit not to have as much of the particular low frequency tonal weaknesses exhibited by the plate glass unit. Regardless, the plate glass triple-pane unit performs about 3-6 dB better than the laminated triple-pane unit across middle and high frequencies, including the most prominent chiller tones at 584-594 Hz. It is this mid-frequency range that tends to be more important for guest room noise criteria (RC) and chiller noise impact on room occupants. Therefore, based on the measurement results and the choices available at the time, the Maine Glass plate glass retrofit unit No.3 in Room 414 was identified as the preferred system to implement at other guest rooms. However, it remained desirable to find an alternative laminated unit to reduce low frequency tonality effects and effects of measured weaknesses at 160 Hz and 2500 Hz.

In spite of vibration isolation mounts used to support rooftop chillers, there is a possibility that structure-borne vibration from chillers and other rooftop mechanical equipment may be transmitted to the roof structure and then to the hotel tower structure, and may then radiate as airborne noise from drywall and glazing surfaces in guest rooms. With glazing that achieves performance greater than NNIC 35, this radiated structure-borne equipment noise may add to the airborne noise transmitted directly through windows. Measurement results indicate that this could limit the benefit achieved by existing and proposed retrofit noise control windows on the third floor, reducing effective chiller noise isolation in some third floor guest rooms by 3 to 4 dB at prominent chiller and equipment tonal frequencies. It was not evident that structure-borne chiller noise contributes to airborne noise on the fourth floor and above; however, with retrofit glazing units that achieve performance greater than NNIC 48, it is possible that radiated structure-borne equipment noise could become perceptible on upper floors as well.

6. ACKNOWLEDGEMENTS

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