University of Hartford Acoustics

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Contribution of Floor Treatment Characteristics to Background Noise Levels in Elementary School Classrooms Part 2

by

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ABSTRACT

Phase 1 of this study determined the effects of hard versus soft flooring on overall speech and activity noise levels in elementary classrooms. A significant decrease in overall levels was found in carpeted rooms compared with those with vinyl composition tile. This phase sought to investigate a range of floor materials and their pertinent properties. Nine different floor materials were mounted to 3” concrete slabs and evaluated using a battery of acoustic, impact and chair scrape tests. Tested materials included vinyl composition tile (VCT), resilient rubber athletic flooring (virgin, blended/ synthetic, and recycled), polyurethane, vinyl cushion tufted textile (VCTT) carpet, and rubber-backed commercial nylon carpet (RBC). Impedance tube measurements of sound absorption were made using ISO 10534-2, while sound power measurements according to ISO 3741 were made while either (a) tapping on each mounted sample with a standard tapping machine, or (b) while reciprocating an elementary classroom chair back and forth to produce repeatable scraping sounds. In general, the two carpet samples (VCTT & RBC) demonstrated in the lowest sound power levels during tapping and chair scrapes, and the highest sound absorption coefficients. The relative performance of each material was compared by spectral composition and overall A-weighted sound power levels. A discussion of additional usability factors, such as maintenance, cost and installation is also presented.

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1.0 PURPOSE

The purpose of this study was to evaluate the acoustical performance of different flooring materials, with regards to their suitability for classroom use. It sought to determine what features might aid in the reduction of the generation and build-up of noise in occupied learning areas, called classroom activity noise. The materials were rated based on their performance in sound absorption testing, and sound power level tests conducted while the materials were subjected to automated chair scraping device and a standard floor tapping machine.

2.0 BACKGROUND

This study was born out of the recognition of current teacher-student interaction patterns in modern elementary school classroom environments, and how such activities could be addressed in future updates of classroom acoustic standards. While ANSI Standard S12.60-2002 has provided important criteria for reverberation time and background noise levels for classrooms, the standard stipulates performance values for those criteria in unoccupied spaces and for stationary sound sources, such as HVAC noise [1]. Three main factors contribute to classroom sound levels: speech sounds, classroom activity noise, and background noise (due to HVAC, traffic, computer projectors, lights, etc.). Many schools no longer employ the classical lecture-teaching format. Instead, an increased level of interactive and collaborative work by students in small groups is being done in today's schools. This type of pedagogy can generate more classroom activity noise compared to the classic lecture format, and beyond that produced by the ventilation system and/or lights. This raises the issue of compliance with ANSI 12.60's signal-to-noise requirement of +15 dB, and whether classroom activity noise itself may be disruptive to a learning environment.

Note that the floor is where a significant amount of classroom activity noise is generated (i.e. footfalls, chair and desk scrapes, dropped objects). The selection of flooring in schools, however, is often based on features such as low maintenance, (i.e., vinyl composition tile, VCT) or for aesthetic reasons, such as rubber-backed commercial-grade carpeting. The unintentional or intentional consequence of choosing one material over another has often meant a trade-off between acoustic performances versus ongoing maintenance issues. Ideally, the existence of a low maintenance flooring material that could also reduce the noise generated during classroom activities would be a combination of desirable characteristics.

2.1 Previous Studies

Phase 1 of this study was conducted during spring 2010 by Giacomoni, Hornecker, Vigeant, and Celmer at the University of Harford [2]. That study investigated the effect of two different floor types on the classroom activity noise levels at the University of Hartford's K–5 Magnet School. Two groups, a 2nd and 5th grade class, were recorded in two rooms of similar size, layout, and composition, but different flooring; one contained vinyl composition tile (VCT), the other a short-pile rubber-backed commercial carpet. Extended recordings of entire class periods in each room were parsed to separate speech, background noise and classroom activity noise. The average sound levels of the parsed components were compared for each grade level between rooms with different floor materials. It was found that the 2nd grade classroom with VCT had 10 dBA higher activity noise levels as compared to the carpeted room. The 5th grade comparison provided less of a difference, but still showed levels 6 dBA higher between the two rooms. Thus, the study demonstrated a relationship between a room's flooring material and measured activity noise levels in classrooms.

2.2 Sound Absorption

A large consideration in classroom acoustics is the amount of reflectivity of surfaces within the learning environment. This, in turn, affects reverberation time and compliance with ANSI S12.60 Classroom Acoustics requirements mandated to achieve high speech intelligibility Phase 1 of this study found the VCT classrooms had a lower Room Constant compared to the carpeted rooms, despite their nearly identical floor plan layouts [2]. Thus, sound absorption values were evaluated in this study for each evaluated floor material. Absorption values for each material were found in one-third octave bands, as well as a computation of the Noise Reduction Coefficient, defined as the average of the values at 250, 500, 1000 and 2000 Hz [17].

2.3 Classroom Noise Sources & Sound Power Levels

Detailed analyses of the parsed classroom activity noise recordings in Phase 1 revealed two types of noises that predominated. The first was related to impact noises, including footfalls and objects dropped onto the floor. These sounds had the common element of striking the floor surface at or near a perpendicular angle. The second type was related to noise generated due to friction as objects interacted with the floor’s surface, usually due to chairs being pushed or dragged across the floor. In these cases, the motion was parallel with the floor’s surface.

Sound power was the chosen parameter for comparative analysis of these two types of noises, since values of energy per unit time are irrespective of distance and acoustic environment. Moreover, sound power values can used to predict spatial distributions of sound pressure levels caused by noise sources within a particular acoustic space. Thus, quantifying sound power of impact sounds as well as those caused by chair scraping on different floor surfaces would enable direct study of their potential effect on classroom activity noise, as well as on ANSI S12.60 signal-to-noise ratio goal of +15 dB within a classroom environment.

2.4 MATERIALS

For this study, a total of nine different flooring types were tested, see Figure 1:

- Vinyl cushion tufted textile (VCTT) Tandus Corporation;
- Vinyl composition tile (VCT), Armstrong;
- Rubber-backed commercial-grade nylon carpet (RBC);
- Resilient rubber (virgin) (RRV), TruSport;
- Resilient rubber (blended/ synthetic) (RRs), Mondo Contract Floors;
- 2 samples of resilient rubber (recycled), Gerbert (RRr) & Ecosurfaces (RRr B);
- Polyurethane (Poly), Gerbert Polyflor;
- High-density polypropylene (HDP), Flex-Court International;

Figure 1. Flooring Sample Reference Key

Floor types were chosen to provide a variety of surface textures related to impact, friction and potential sound absorption (impedance) properties. They were also chosen to provide a variety of floor types that are either already widely used in classroom or athletic flooring, or that have the potential for easier maintenance and not typically used in classroom floors.

3.0 PROCEDURE

The evaluation of the flooring was conducted by comparing each sample's response to three different tests: sound absorption via impedance tube, as well as sound power via automated impact tapping and chair scraping.

Materials for the impedance tube tests were cored into 100mm and 30mm diameter samples using a hydraulic press and a custom hole punch; the larger and smaller samples were used for low and high frequency testing, respectively.

For the sound power tests, flooring materials were cut and attached directly to 24" x 18" x 3" concrete slabs using construction adhesive (see pictures in Appendix, Figures 10–18). The slabs were formed during a previous sound power study of footfalls at the University of Hartford [3]. The weight of each slab was approximately 105 pounds, which resulted in a weight density for each slab of 11.7 lb/ (ft^2-in). Note that this number is within the concrete weight density range for typical commercial floors of 9 to 12 lb/ (ft^2-in) [5].

3.1 SOUND ABSORPTION TESTING

Using a **Brüel & Kjær** *Type 4206* Impedance Tube, sound absorption coefficients for normal incidence was determined for each flooring material (Figure 2 below).

Figure 2. Brüel & Kjær Type 4206 Impedance Tube

This was accomplished using a **Brüel & Kjær** *PULSE* data acquisition system in accordance with the procedures described in ISO 10534-2, *Determination of Sound*

Absorption Coefficient and Impedance in Impedance Tubes [6]. The random incidence coefficients were extrapolated from the normal incidence coefficients at frequencies of 500 Hz and above, and used in determining the Noise Reduction Coefficient (NRC) for comparative analysis.

3.2 SOUND POWER TESTING

The sound power level measurements were carried out in the University's reverberation room, as ISO 3741 stipulates that measurements be taken in a diffuse field, controlling for the effects of arrival direction of the incident sound waves. Measurements were conducted as outlined in ISO 3741, *Determination of Sound Power Levels of Noise Sources using Sound Pressure-Precision Methods for Reverb Rooms* [7]. It should be noted that the University of Hartford's reverberation room underwent independent ISO qualification for diffuse fields. Utilizing the procedures described in ISO 3741 Annex E, the chamber qualified for diffuse field testing in all 1/ 3 octave bands from 100 – 10,000 Hz.

The University's **Brüel & Kjær** *Type 3923* boom microphone was configured to traverse a maximum circumferential path while traveling no closer than 1 meter to any surface within the reverberation room, so as to comply with ISO 3741. The boom was set to a 32-second rotation period for each circumference. Each test sample was situated in the reverberation room greater than 2 m from each wall.

At the start of each testing procedure, the reverberation room's ventilation system was turned off to achieve the lowest possible background noise levels. The procedures of ISO 3741 were executed as part of a standard **Brüel & Kjær** *Pulse Labshop* project. The current temperature and atmospheric pressure in the reverberation room were recorded at the start of each test. The **Brüel & Kjær** *Type 4942* microphone was calibrated using a **Brüel & Kjær** *Type 4213* calibrator, and placed on a rotating boom that measured a spatial average of the sound pressure level in the room for each measurement.

The ISO 3741 comparison method uses a reference source. A **Brüel & Kjær** *Type 4204* Reference Sound Source (RSS) was used for this purpose. At the start of each measurement procedure, the sound power of the reference source is measured. Any differences between the measured and the manufacturer's reference calibration levels are used to produce a *measurement* correction factor applied to subsequent sound power measurements of each unknown source. To ensure calibrated use of the RSS's sound power levels, that day's atmospheric pressure and temperature measurements were used to compute *environmental* corrections factors using the relationships:

$$\Delta L_p = 10Log_{10}(\frac{B}{B_{Cal}}) \quad \text{(Equation 1)}$$

Where:

B = Barometric Pressure in *m*Bars;
B_{cal} = Barometric Pressure in *m*Bars given on the RSS calibration report;

$$\Delta L_p = 5Log_{10}(\frac{T}{T_{Cal}}) \quad \text{(Equation 2)}$$

Where:

T = Ambient Temperature in Kelvin;
T_{cal} = Temperature in Kelvin given on the RSS calibration report;

In addition to environmental conditions, the rotation speed of the RSS was checked each testing day to be sure it was rotating at 3256 RPM, the calibration speed of the Lab's noise source. A **Variac** variable transformer was used along with a **Shimpo** *Model # DT-315AEB* Stroboscope in order to be certain that the reference sound source rotated at its calibrated speed.

Sound power level reference measurements were carried out with the RSS before the testing was conducted on each sample using the tapper and chair scraper mechanisms described below. The reference measurements consisted of calibrating the microphone, measurement of background noise levels in the reverberation room and then the radiated sound levels of the RSS using the same

32-second traversing period. Once these results were obtained, the actual test measurements were carried out. The background noise levels were compared to measured values to ensure the source had sufficient signal strength in all measured frequency bands.

3.3 FLOOR TAPPING

The noise generated from footfalls and other impacts was simulated using a **Brüel & Kjær** *Type 3207* Tapping machine, as seen in Figure 3. Each floor sample was tested using the sound power procedure described in section 3.2.

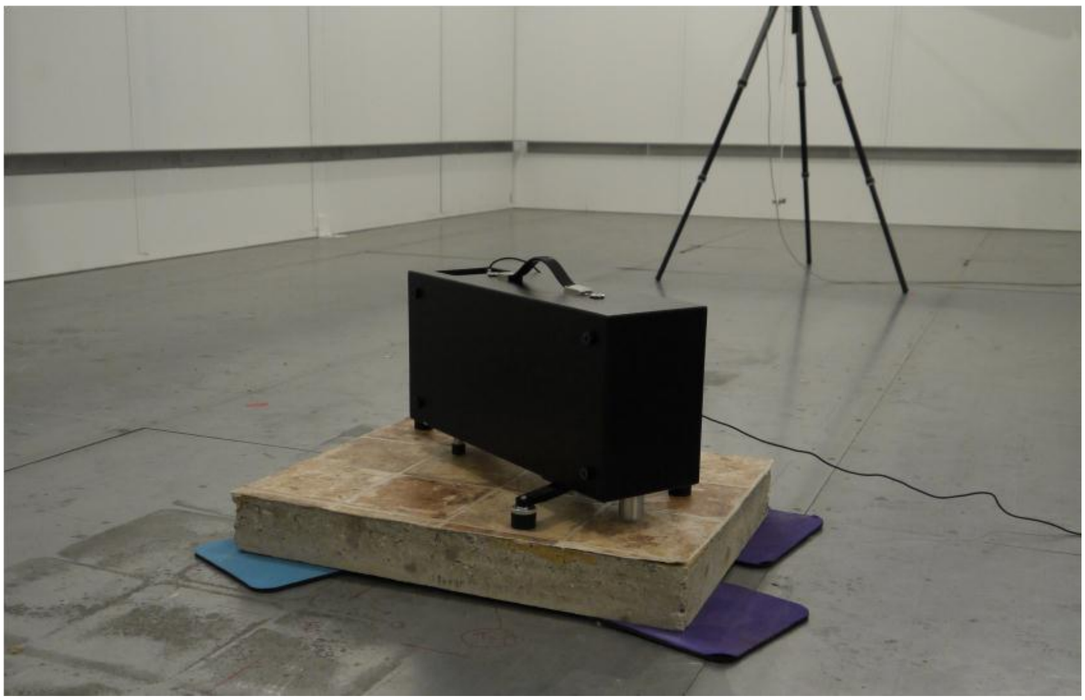

Figure 3. B&K 3207 Used in Floor Tapping Simulation, Shown in Test Setup.

To consolidate materials and space, both sides of each concrete slab were used to attach flooring samples. To isolate the amount of energy transmitted through the slab, rubber pads were inserted if the attached material on the slab's backside did not have comparable thickness and/or compliance. A PULSE sound power project was used to determine the spectral and overall A-weighted sound power levels, which was used for subsequent comparative analysis.

3.4 CHAIR SCRAPING

A reciprocating scraping device was devised, as depicted in Figure 4.

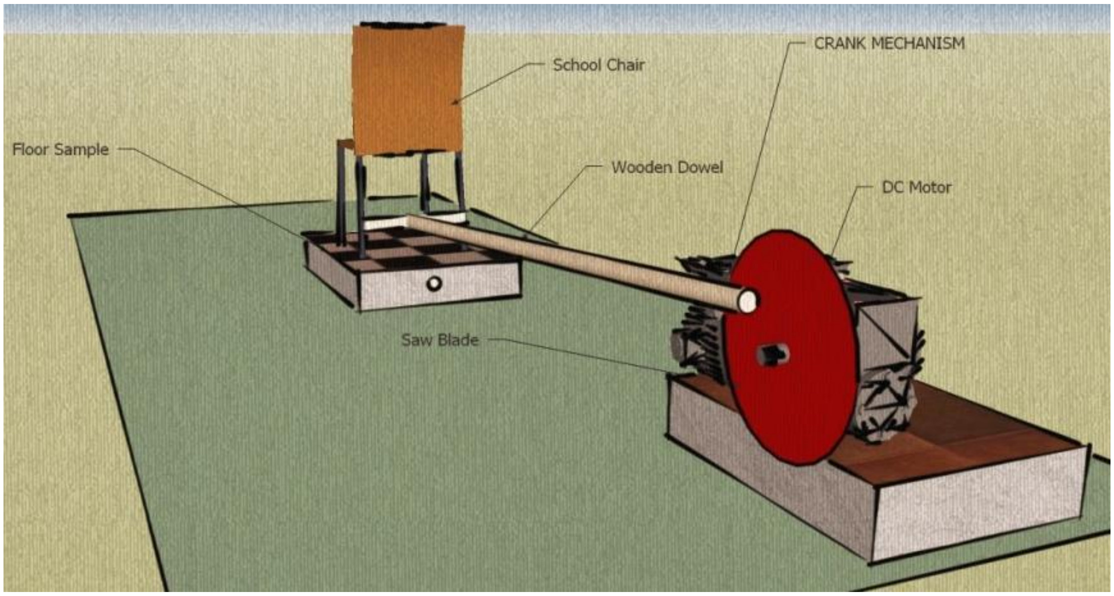

Figure 4 – Visualization of Reciprocating Chair Scraping Device

The device consisted of a DC electric elevator-door motor, a 10-inch diameter metal disk as a cranking mechanism, a wooden dowel as a connecting rod, fastened to child-size wooden classroom chair on loan from the University's Magnet School, see Figure 5 below.

Figure 5. Actual Device Used in Scraping Simulation. Shown in Test Setup

A **BK Precision Corp.** *Model 1672* DC power supply was used to power the device from outside the reverberation chamber at a reciprocating speed of approximately 2 Hz. The metal disc, PVC fittings, and dowel rod were combined to form a crank and actuator arm. The constructed device enabled the chair, mounted on each tested sample to move in a forward and backward scraping pattern, with a stroke length between 6 and 8 inches. Wedges were used to level the surface and ensure the chair remained on the sample during the test's entirety. Each sound power test was repeated three times and averaged, using the procedures of ISO 3741 described in section 3.3. Thus, the PULSE sound power project was used to determine the spectral and overall A-weighted sound power levels, which was used for subsequent comparative analysis.

4.0 RESULTS

4.1 Sound Absorption Results

The average Noise Reduction Coefficient (NRC) was plotted *vs.* floor type, see Figure 6 below. Individual spectral results are shown in the Appendix, Figure 19.

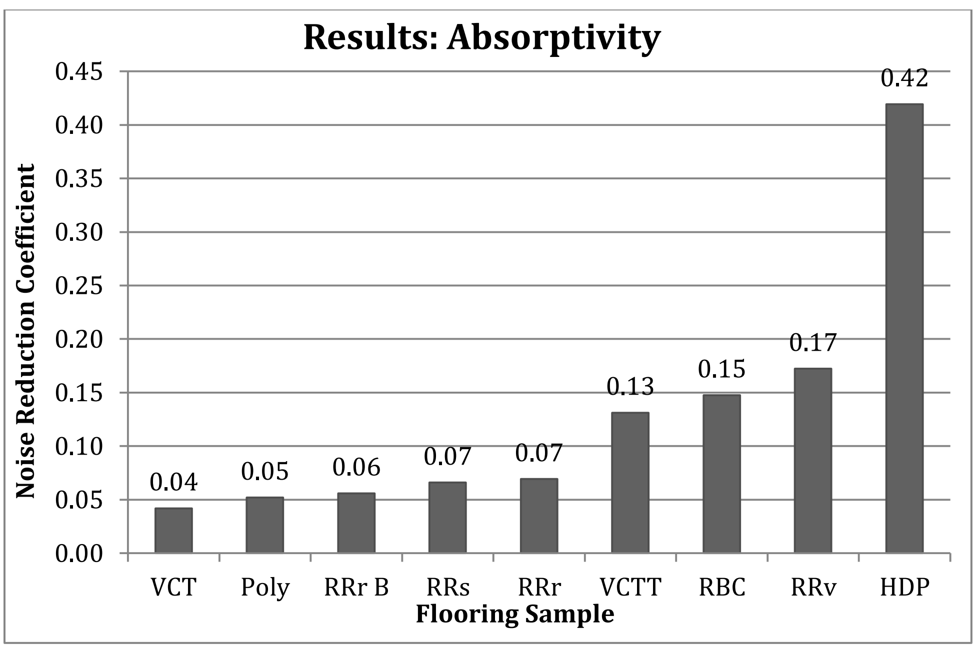

Figure 6. NRC Data from Impedance Tube Testing

All samples except for HDP exhibited relatively low average absorption coefficient values. The materials exhibited absorption coefficients that are typical of materials with similar density, thickness and surface texture. As such, both carpet samples exhibited higher NRC values (13% & 15%) compared to harder surfaces, such as VCT (4%).

However, in order to investigate the anomalous high NRC value of the High Density Polypropylene (HDP), an additional test was conducted to determine if the mounting condition of the sample affected the material's performance. The waffled back of the sample was filled with putty and compared against the unfilled sample results. The filled sample yielded a 17% smaller NRC value of 0.35, while exhibiting a similar spectral contour, as shown in Figure 7, It was further suspected that the increase in absorptivity around the 1250 Hz band for both filled and unfilled samples was still caused by the gap produced from the flooring's waffled backing, and thus was discounted as to its performance in full scale applications.

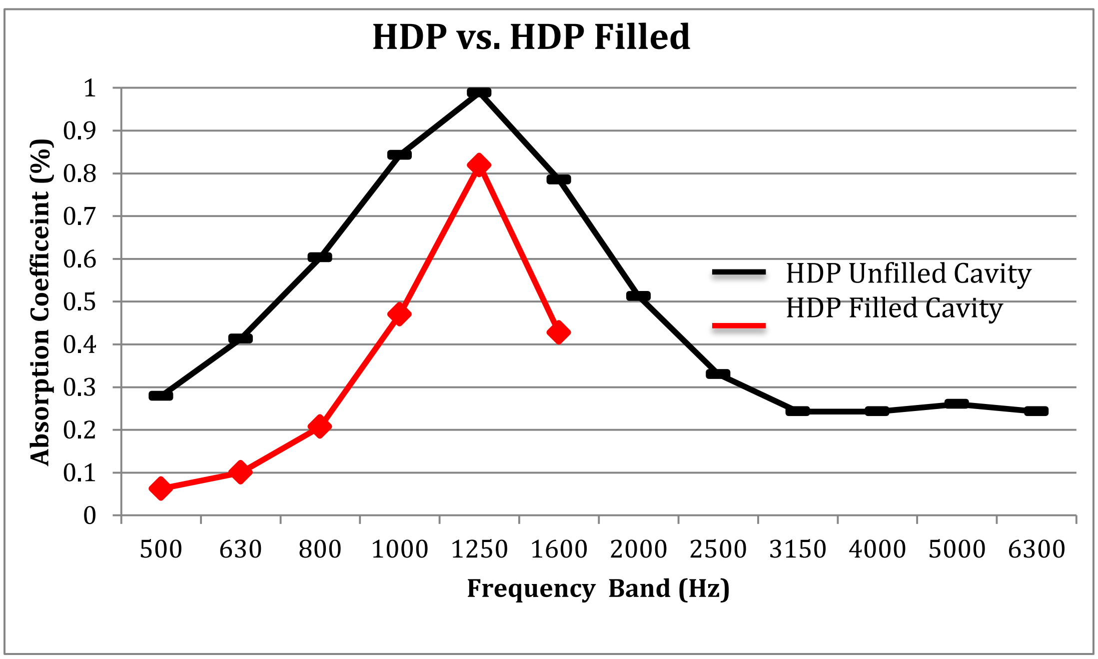

Figure 7. HDP Mounting Investigation Results

4.2 FLOOR TAPPING SOUND POWER RESULTS

The overall A-weighted sound power levels (re: 10^{-12} W) measured in the simulated footfall test are shown in Figure 8. Individual spectral results are shown in the Appendix, Figure 20.

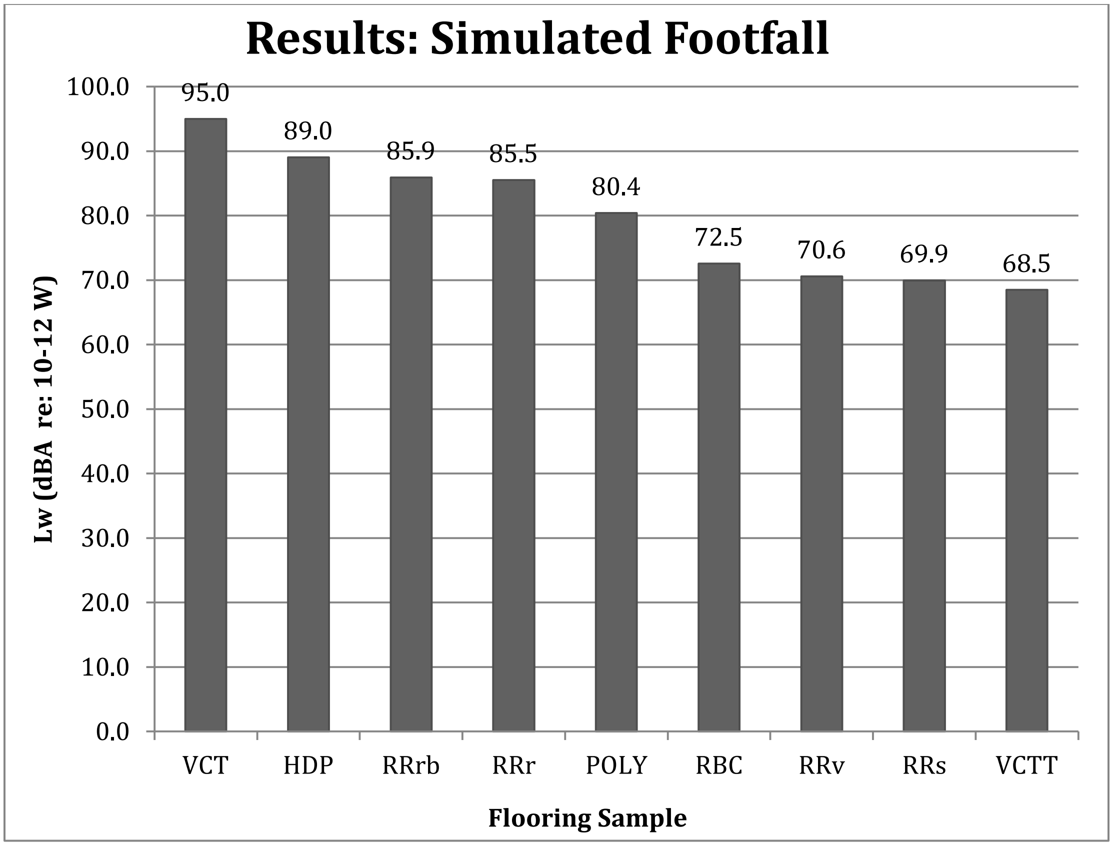

Figure 8. Average A-weighted Overall Sound Power Level for Simulated Footfall Test

It was found that that the vinyl cushioned tufted textile (VCTT) produced the least radiated sound power of the tested materials when impacted by the tapping machine, which generated a sound power level of 68.5 dBA (re: 10^{-12} W). The synthetically blended and virgin rubber flooring (RRs and RRv) also demonstrated relatively low sound power levels, as did the rubber-backed commercial-grade nylon carpet (RBC).

4.3 CHAIR SCRAPING SOUND POWER RESULTS

The overall A-weighted sound power levels (re: 10^{-12} W) measured during the reciprocating chair scraping test are shown in Figure 9. Individual spectral results are shown in the Appendix, Figure 21.

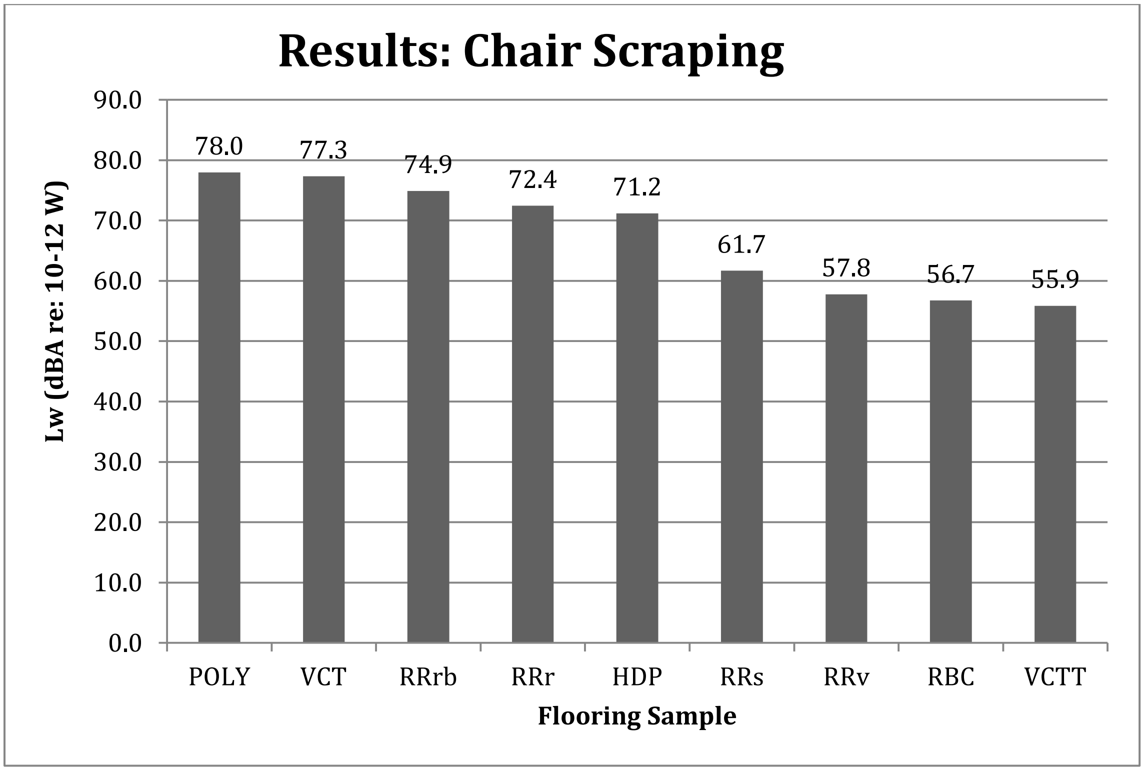

Figure 9. Average A-Weighted Overall Sound Power Level for Chair Scraping Test

It was found that that the vinyl cushioned tufted textile (VCTT) produced the lowest radiated sound power of the tested materials as stimulated by the scraping device, which generated a sound power level of 55.9 dBA (re: 10^{-12} W). The rubber-backed commercial-grade carpet also generated relatively low sound power levels, as did the virgin and synthetic/ blended rubber flooring (RRv and RRs). The VCT and polyurethane flooring produced the highest scraping noise of the tested samples. Both exhibited a classic 'stick-slip' interaction between the wooden chair leg bottoms and the floor surface. The periodicity of this skidding was evident in the spectral peaks at 400 Hz for the polyurethane and at 315 Hz-400 Hz for the VCT.

5.0 ADDITIONAL MATERIAL PROPERTY COMPARISONS

Given the acoustic performance ratings of VCTT on this study's sound absorption tests and the sound power tapping & chair scrape tests, a table has been generated to compare other aspects of VCTT to commercial nylon carpet and less expensive indoor/ outdoor carpet. See Table 1, next page. It covers such issues as material properties, installation methods, LEED/ green points and costs. The table is not intended to be an exhaustive review, but rather an appraisal of some issues pertinent to a current-day flooring selection process.

Note, for example, that many carpet manufacturers have certifications for low volatile organic compound (VOC) emissions, but a significant source of VOC's appears to be in the adhesives used for their installation. Similarly, bacteria growth appears to be a stronger function of sealing the seams and prevention of moisture buildup below the installed surface, rather than a material's properties themselves.

Table 1. ADDITIONAL MATERIAL PROPERTY COMPARISONS [8] – [16]			
Material Property	**Material**		
	VCTT **Vinyl-Cushion Tufted Textile** ***Powerbond RS* (Tandus)**	**RBC** **Rubber-Backed Commercial Nylon Carpet (Shaw, Mohawk)**	**Indoor/Outdoor Carpeting** **(Foss, TrafficMaster)**
Cost per square foot	\$4.00 – \$5.00	\$3.00 – \$6.00	\$0.70 – \$2.00
VOC Output	Complies with chronic VOC emissions requirements per Section 1350. Complies with product requirements of the California Department of Health Services' *Standard Practice for the Testing of Volatile Organic Emissions from Various Sources Using Small-Scale Environmental Chambers.*	All carpet products pass the CRI Green Label plus certification for VOC emissions (Mohawk); Nu Broadlok adhesive contains anti-microbial agents and is solvent free. Passes the CRI Green Label plus for VOC emissions (Mohawk). Meets the industry's highest VOC standard, the CRI Green Label Plus program (Shaw).	No stated VOC data for indoor/outdoor; adhesive emissions depend on brand used. (Foss, TrafficMaster)
Pile Height Ranges	0.117” (Powerbond Cushion) 0.187” (Abrasive Action)	0.113” (Mohawk Bigelow) 0.195” (Shaw Prosper Classicbac)	0.25” (Foss Ozite) 0.25” (TrafficMaster)
LEED Points Green Features	Environmentally Preferable Product (EPP) Certification. Carpet & Rug Institute (CRI) Green Label Plus CRI Certification GLP9744 (PwrBond Cushion)	CRI Green Label Plus Certified GLP8216 (Mohawk Bigelow) CRI Green Label Plus Certified GLP8472, Contrib. LEED pts (Shaw Prosper Classicbac)	Contributes LEED points for 100% recycled polyester fiber materials (Foss, TrafficMaster)
Installation Methods	Tandus RS Adhesive System (Full Coverage Peel & Stick) Tandus Flooring C-XL Seam Sealer	Nu Broadlok adhesive (Mohawk). Shaw 1000/1200 premium multipurpose adhesive or Shaw 2057/2100 Patterned Carpet Adhesive. Shaw 4000 or 8300 Seam Sealer	Adhesive or double-sided tape (Foss) Peel & Stick (TrafficMaster)
Styles roll *vs.* squares	6-foot roll goods; 24” x 24” squares	12-foot roll goods; (Mohawk, Shaw) 24” x 24” squares (Mohawk, Shaw)	6 and 12-foot roll goods (Foss); 18” x 18” (TrafficMaster)
Bacteria/mold	Backing conforms to the requirements AATCC 174 for Anti-Microbial Assessment of Carpets, Carpet Moisture Penetration by Dynamic Impact and by Spillage and ASTM Z8114 Accelerated Soil Test. No antimicrobials added to product (ASTM E2471-05). Minimized due to non-flow-through vinyl backing and chemically welded seams.	Nu Broadlok adhesive contains anti-microbial agents (Mohawk). Prolonged dampness more than 24 hours may promote growth of mold and bacteria in the carpet or cause separation of the backing (Shaw).	Mold and mildew resistant; also available with patented Fosshield’s anti-microbial technology (Foss). Mold and mildew resistant, not made with antimicrobial agents (TrafficMaster);

6.0 CONCLUSIONS

The vinyl cushioned tufted textile (VCTT) samples produced the lowest sound levels in the chair scraping and simulated footfall tests, with average sound power level measurements of 55.9 dBA and 68.5 dBA (re: 10^{-12} W), respectively. These values were significantly lower than the tested hard tile surfaces such as vinyl composition tile (VCT), which produced sound power levels for the chair scraping and tapping of 77.3 dBA and 95.0 dBA (re: 10^{-12} W), respectively. The absorption coefficients of the VCTT were relatively low (NRC = 13%), but note that they were similar to those measured for the rubber-backed commercial nylon carpet (NRC = 15%), and were two to three times higher than VCT in speech frequency range of 500 – 3150 Hz. The absorption, tapper, and chair scraping results for the two carpet samples (VTCC + RBC) are consistent with the classroom activity noise measurements made in phase 1 of this study [2].

The use of flooring materials that more effectively damp impact sounds/ footfalls, reduces scraping sounds from chair movements, and exhibits less reflectivity to sound incidence can have a more comprehensive effect on providing acoustically appropriate classroom learning environments. Together, these impact, friction and absorptive features directly address classroom activity noise, by increasing the Room Constant, increasing signal-to-noise ratio and consequently reducing the Lombard effect. Reductions in activity noise create a quieter learning environment, making it more likely that students will adapt their behavior to be quieter.

Ultimately, a given school district will have to weigh the pros and cons of each material's acoustic performance, costs, and upkeep. While VCTT reportedly has low maintenance and high durability properties, a recommendation for possible improvement by manufacturers would involve determining optimal pile height for level loop materials, by plotting pile height versus sound absorption values.

7.0 REFERENCES

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8.0 APPENDICIES

Figure 10. Vinyl Cushion Tufted Textile (VCTT)

Figure 11. Vinyl Composition Tile (VCT)

Figure 12. Rubber-backed Nylon Carpet (RBC)

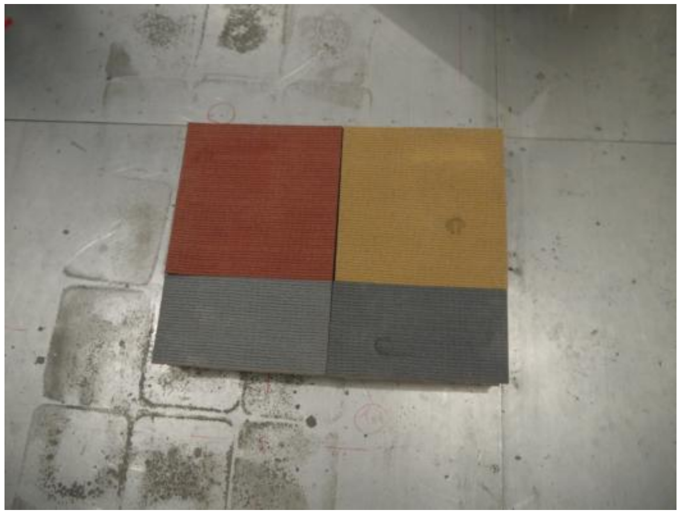
Figure 13. Resilient rubber (virgin) (RRV)

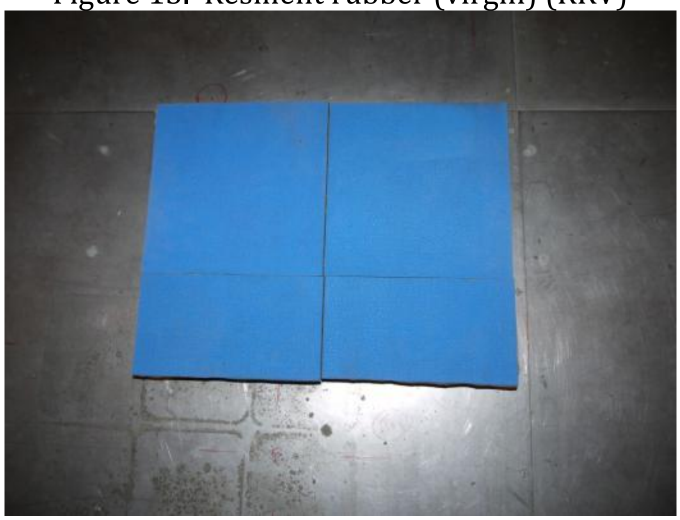
Figure 14. Resilient rubber (blended/synthetic) (RRs)


Figure15. Resilient rubber (recycled) (RRR)

Figure16. Resilient rubber (recycled) (RRR) (B)

Figure 17. Polyurethane (POLY)

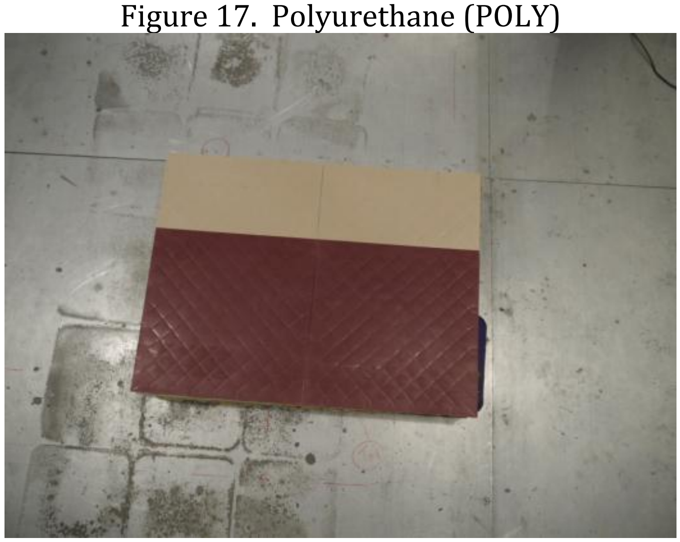

Figure 18. High-density polypropylene (HDP)

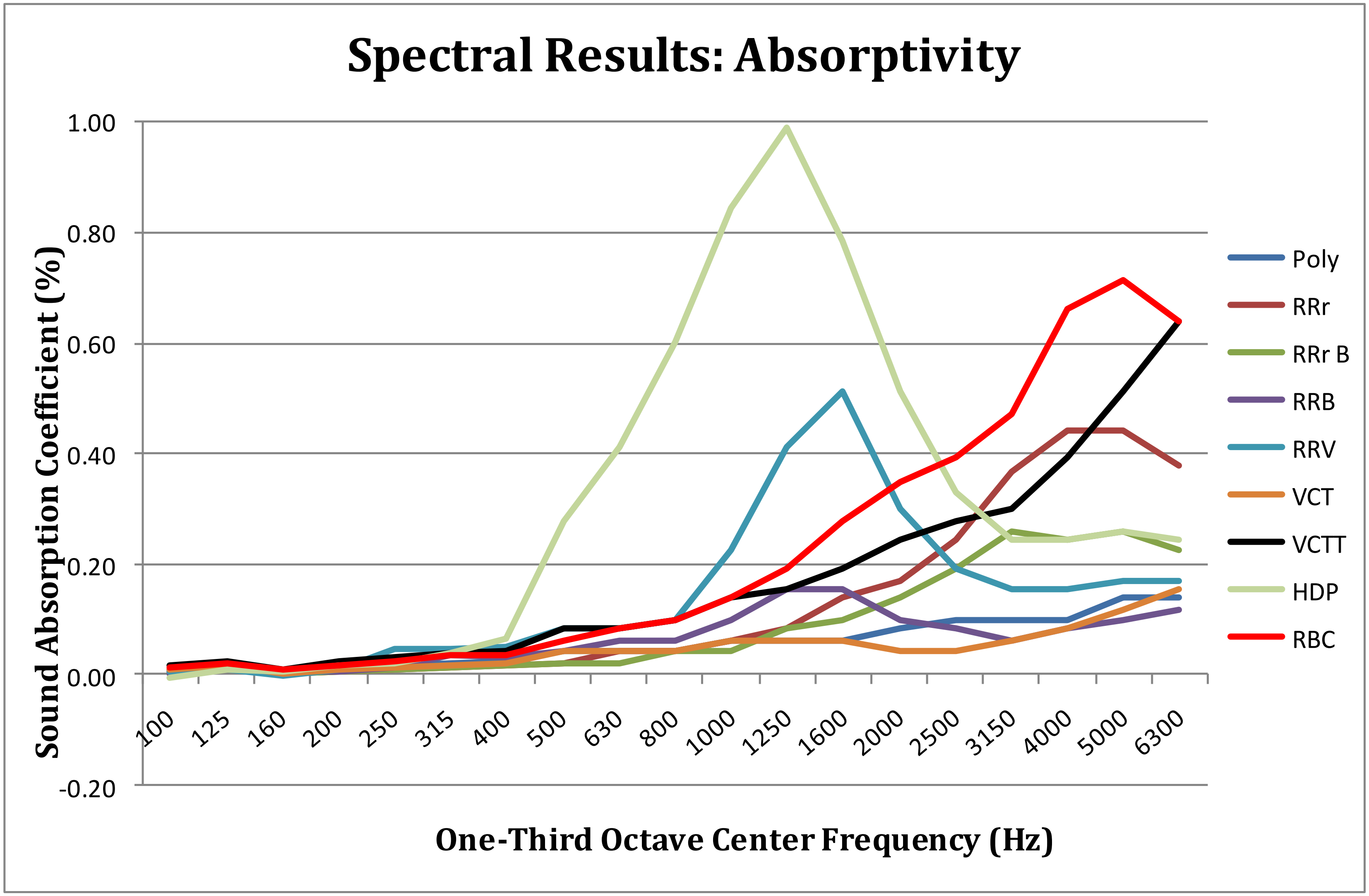

Figure 19. Spectral Results of Absorptivity

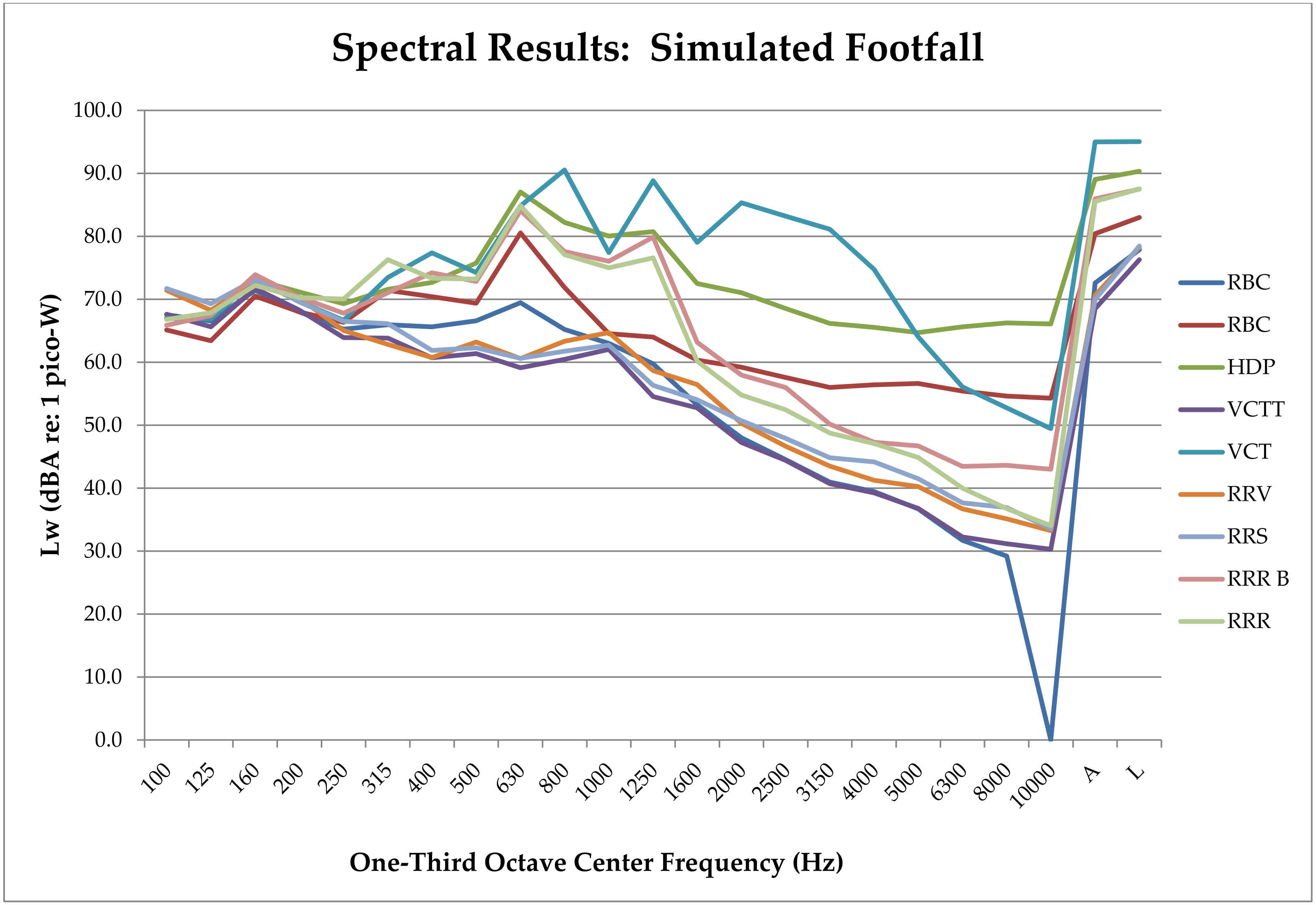

Figure 20. Spectral Results of Simulated Footfall Noise

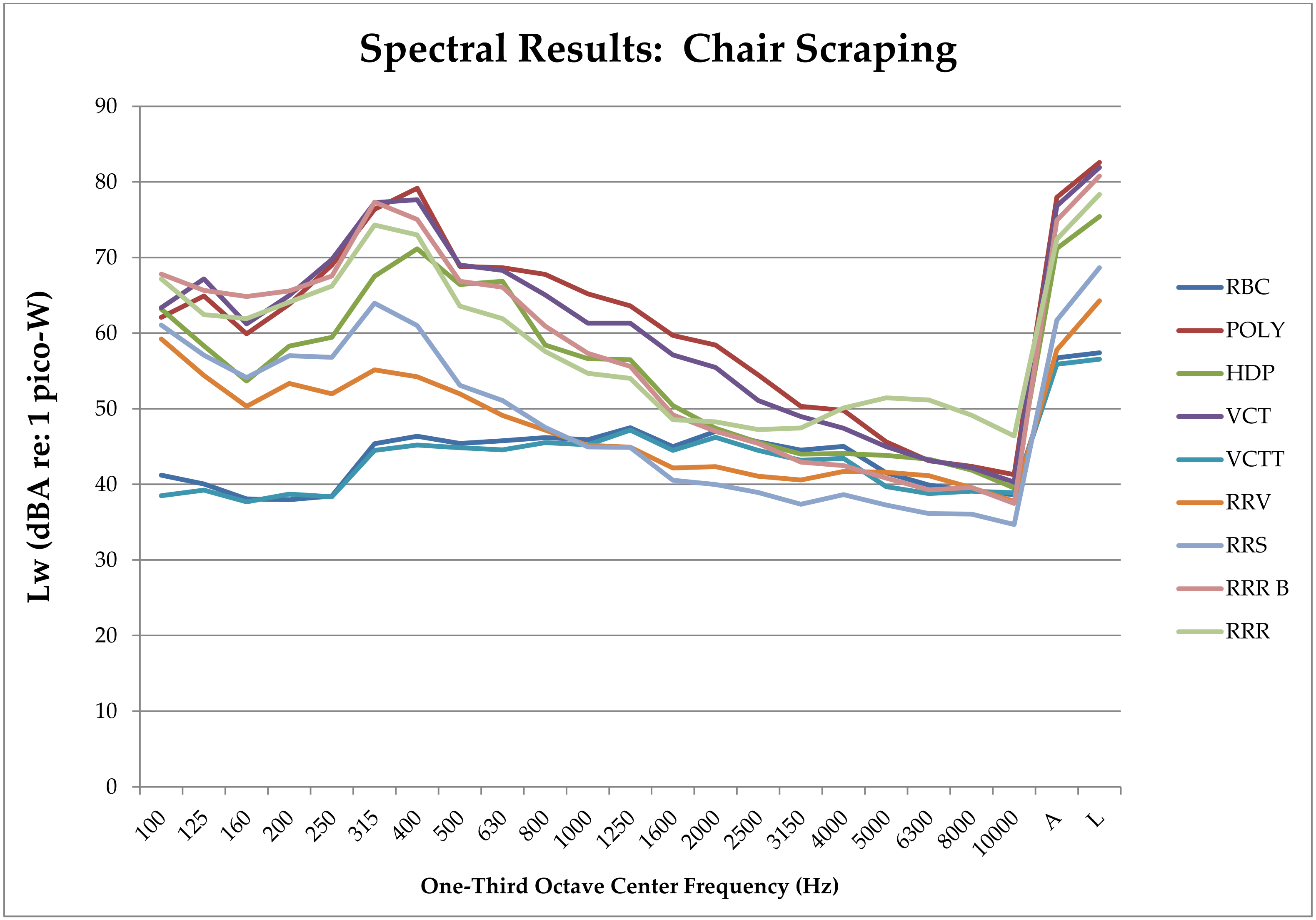

Figure 21. Spectral Results – Chair Scraping Test