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QUIET IN AUDITORIA: WHY AND HOW TO STRIVE FOR IT ON BUDGET- AND SITE-CONSTRAINED PROJECTS

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1 INTRODUCTION

Quiet background noise conditions are an essential feature of high quality performance spaces, and achieving quiet conditions is a central goal of the design of all performance rooms. However, many designers reserve the lowest noise goals for well-funded projects, and accept higher noise as inevitable for lower cost projects.

This paper presents conclusions from a series of research studies that highlight the importance and benefit of very low levels of background noise in performance spaces; these studies have been reported previously in greater detail.[1,2] This paper presents two new cases studies of performance venues designed and built with modest budgets and achieving very low noise.

Two sets of research studies are reported:

a. Structured listening to music played in two unoccupied music performance rooms while manipulating electronically the levels of background noise.
b. Measurements of sound pressure levels in a music performance room during concerts with audience.

Two project case studies are presented:

a. Seton Hill University Performing Arts Center in Greenberg, Pennsylvania.
b. Hess Center for the Arts at Deerfield Academy in Deerfield, Massachusetts.

These studies and the discussion in this paper focus on music performance. It is our expectation that the basic findings apply equally to speech-based theatre and other sound-critical forms of live performance.

2 PREVIOUS RESEARCH STUDIES ON PERCEPTION OF LOW LEVELS OF BACKGROUND NOISE IN MUSIC ROOMS

2.1 Structured listening with varied background noise

On two occasions, in two different quiet music performance halls, we have made studies of listening to music while electronically manipulating background noise levels in the hall using a large number of loudspeakers placed at the perimeter and upper levels of the halls, surrounding the listening area. We began by making each hall as quiet as it could be, by switching off HVAC serving the hall and quieting other apparent noise sources. Then we added small amounts of filtered broadband noise to the hall to achieve slightly elevated noise levels, the loudest of which were approximately NC-15[3] and the quietest of which were close to or below the threshold of hearing in most frequency bands. (In both halls, residual noise in the 125 Hz region limited our study to some degree.) Music was played through a loudspeaker placed on the performance platform at a level realistic for a quieter solo instrumental performance, and listeners heard the same music played over different background noise spectra. Live music performance (piano, soprano voice, and cello) was also used, and subjective responses from listeners were similar between live and recorded music.

Figure 1 shows measured background noise spectra for several “samples” presented blind to subjects at the Experimental Media and Performing Arts Center (EMPAC) Concert Hall at Rensselaer Polytechnic Institute (RPI) in Troy, NY on July 17, 2011. Listeners evaluated the noise samples for subjective loudness without music playing, and then evaluated them for annoyance or intrusiveness while listening to music. Both evaluations correlated strongly with objectively measured loudness of the noise samples: see Figure 2.

In a similar study performed at Jordan Hall at New England Conservatory in Boston, Massachusetts on June 24, 2010, listeners reported that music changed character when noise levels were slightly elevated, becoming less spatial and more frontal, less warm, and drier. These effects were not reported during the study at EMPAC Concert Hall, which is a highly reverberant room as configured for the study (curtains retracted, hall mostly unoccupied).

2.2 Measured levels during concerts with audience

We attended a series of five concerts at Distler Hall at the Granoff Music Center at Tufts University and recorded sound pressure levels during these concerts. The hall is a rectangular recital hall with approximately 300 seats on one level. The aim of this study was to learn how closely the quietest moments during concerts approach the background noise levels of the unoccupied hall, and whether the background noise floor is set by audience noise rather than building mechanical noise. This topic has been studied previously by Newton and James[4] and by Jeong, Marie, and Brunskog,[5] and our findings are consistent with these previous studies.

Figure 3 on the next page presents the sound spectra measured during the loudest and quietest moments (15-second L_{99}) of two concerts, April 18 and 22, 2012, compared with background sound levels measured in the unoccupied hall following each of these concerts. At both concerts, the quietest moments exceeded the background sound of the hall by only between 3 and 5 dB in the 1,000 Hz octave band, and by less than this amount in other octave bands. At these quietest moments, the background sound of the hall contributes significantly to the overall sound pressure levels at all frequency bands and may control the overall sound pressure level.

The concert on April 18 was a student chamber music concert, with an audience of about 80 people. The concert on April 22 featured a concert choir with orchestra and soloists. The performers and audience together numbered over 300. During both concerts, audiences were well-behaved, and there were many quiet points when we were able to hear the background sound of the hall. This occurred most frequently at the conclusion of musical movements, and occasionally during a particularly quiet musical note.

3 CASE STUDIES

3.1 Seton Hill University Performing Arts Center

A new performing arts building at Seton Hill University in Greenburg, Pennsylvania opened in 2010, designed by MacLachlan, Cornelius & Filoni Architects with Acentech. The approximately $20 million building includes the 400-seat multi-purpose Reichgut Concert Hall, the 200-seat flexible Ryan Theatre, a large rehearsal room, art gallery, and various support spaces. To accommodate the program within the limited budget, the university and project team set certain priorities at the outset. Quiet background noise conditions in the concert hall and flexible theatre were among the highest priorities. For budgetary reasons, the HVAC system was designed around packaged rooftop units, each of which included compressor and condenser sections in addition to air distribution fans. Each of the performance spaces was equipped with its own dedicated rooftop unit, and rooftop units were located over non-sensitive spaces, such as the scene shop, lobby, and corridors.

Rooftop units were properly isolated from the building structure using spring and neoprene isolation mounts. The roof assembly included concrete to reduce transmission of noise into the building. No building structural separation was included between the rooftop equipment and the concert hall.

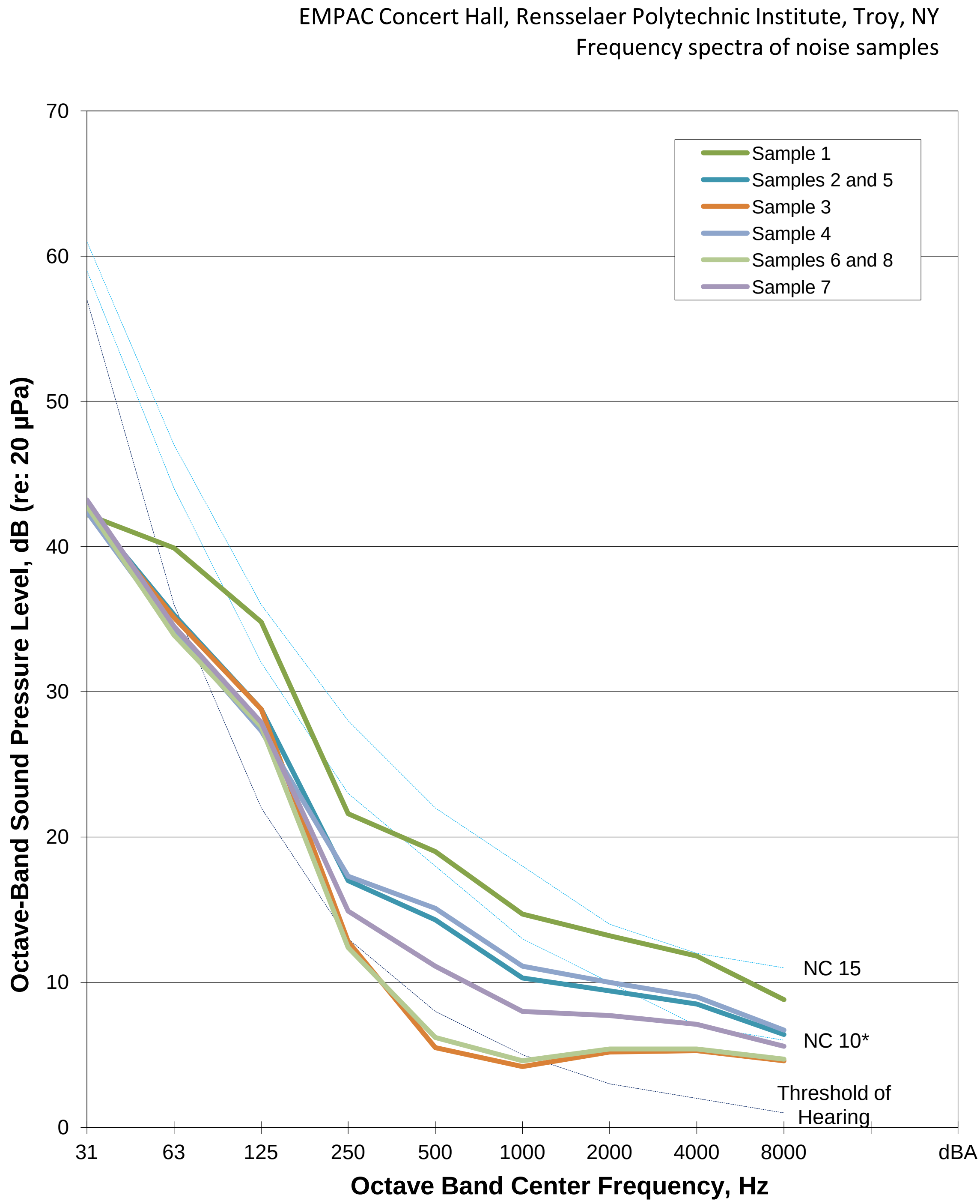

Figure 1: Frequency spectra of noise samples at EMPAC Concert Hall structured listening session. At high frequencies, measured levels of some samples were likely controlled by instrument noise. (* NC-10 curve calculated relative to NC-15 curve.)

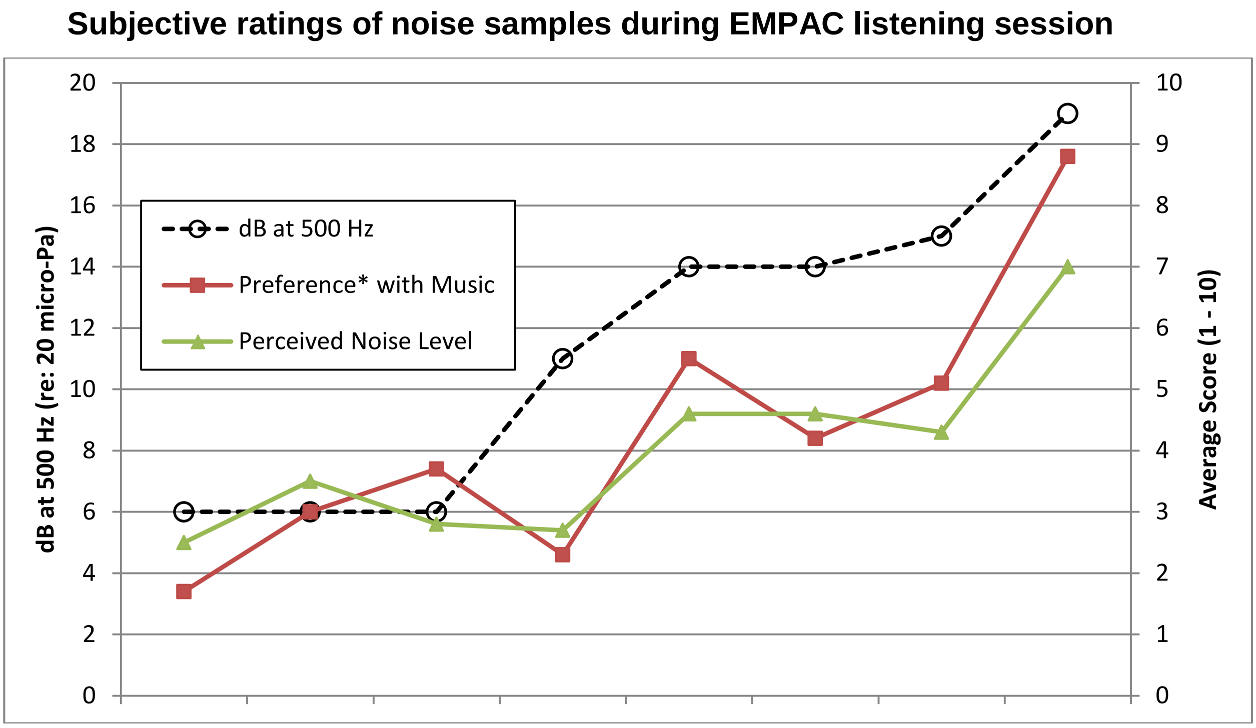

Figure 2: Subjective rankings of noise samples at EMPAC Concert Hall structured listening session. Listeners' preferred lower background noise during music listening, and this apparent correlation occurred at levels as low as NC-10 (calculated relative to NC-15 curve).

Ductwork serving the concert hall is sized for low airflow velocity, and is configured to be somewhat self-balancing and to provide significant length of duct to each supply diffuser. Ductwork was lined with sound absorbing material. The duct layout is less than perfect, aerodynamically, and requires use of dampers; however, the low airflow velocities and duct lining control aerodynamic noise sufficiently.

Sound attenuators were included in supply and return ductwork, and these were selected according to calculations of noise propagation from selected rooftop unit fans and their manufacturer noise levels.

The resulting background noise level in the concert hall from HVAC operation is NC-15.

The noise control design features described above are all in common practice in design of low-cost auditoria, and this approach has been used successfully in many multi-purpose auditorium spaces in public high schools. This approach does not guarantee very low noise, but it allows low-cost projects to design toward a very low noise goal and to achieve the best possible result within constraints and without costly overdesign. It is quite within reach of most budget-constrained projects to design toward and achieve background levels in performance spaces of NC-15 or lower.

3.2 Deerfield Academy Hess Center for the Arts

The Hess Center for the Arts at Deerfield Academy, an independent boarding school in Massachusetts, received a major renovation and addition that was completed in 2014. The project included the new 175-seat Wachsman Concert Hall, a major renovation and expansion to 800 seats of the existing multi-purpose auditorium, 12 new music practice rooms and two renovated large rehearsal rooms, a new dance room, and new art studios and gallery. The project cost was $24 million. The project was designed by Architectural Resources Cambridge with Acentech.

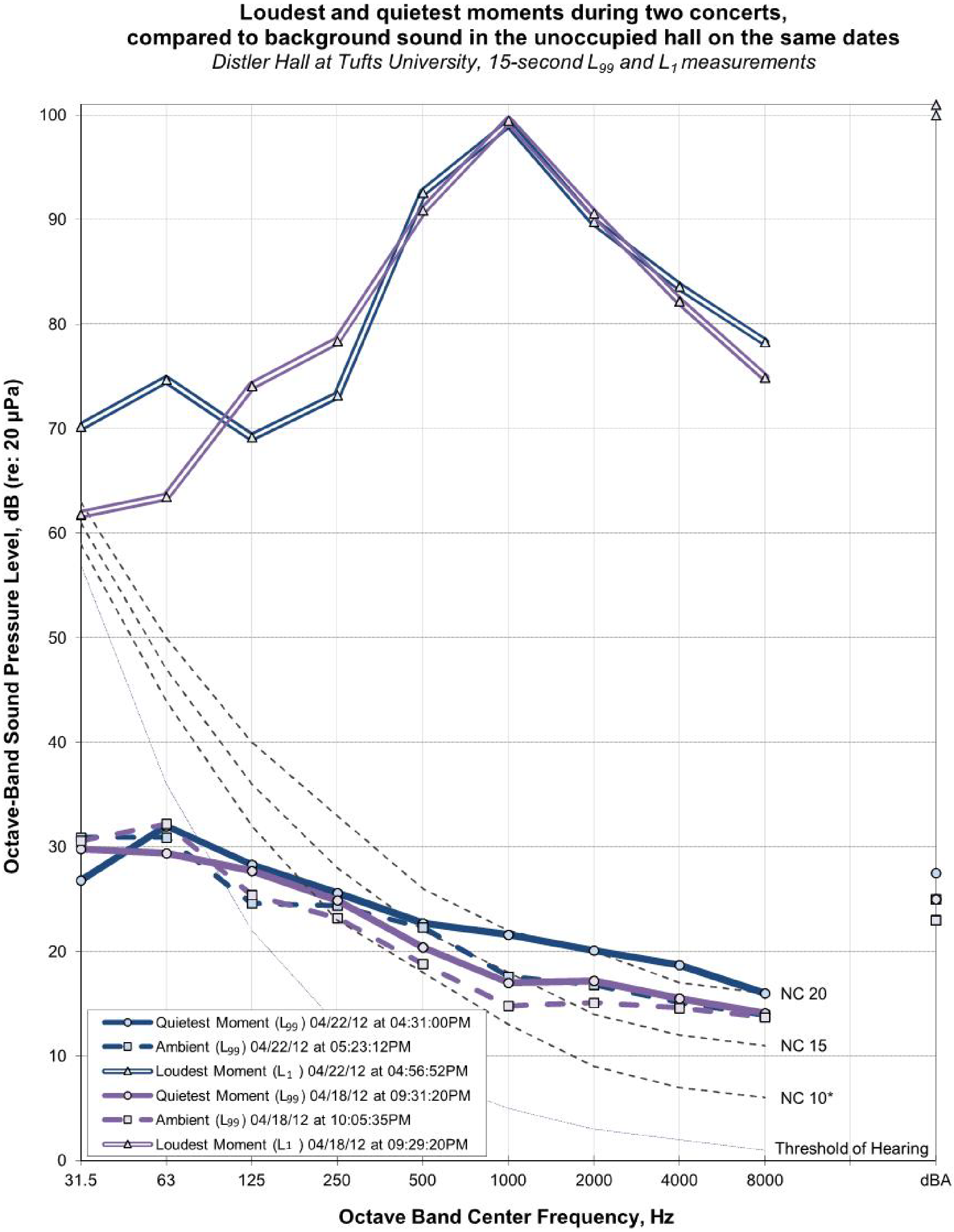

Figure 3: Loudest and quietest moments during two concerts, compared to background sound measured post-concert in the unoccupied hall. At frequency bands above 1,000 Hz, the noise floor of the measuring device was significant. (***** NC-10 curve calculated relative to NC-15 curve.)

From the start, the school's desire for excellent acoustics, including very low background noise, drove the design of the concert hall. Again, cost considerations required air handling units to be located on the roof, over an adjacent storage room and corridor. Fortunately, hot and chilled water are provided from a remote source, and the rooftop equipment contains fans and coils only.

A dedicated rooftop air handling unit serves the concert hall. It was selected for very low noise characteristics, with a discharge Lw of 84 dBA and inlet Lw of 71 dBA. The unit is isolated on spring and neoprene mounts on a concrete roof.

Supply air is delivered to the hall at floor level, and the supply air path includes long duct runs with several splits well upstream of supply diffusers and minimal use of dampers. All ductwork serving the concert hall is lined with acoustically absorptive material. Supply and return duct sound attenuators were selected according to calculations of noise propagation from selected rooftop unit fans and their manufacturer noise levels.

Return air is collected through an array of linear slot grilles backed with lined plenum boxes, which feed air into a single large lined plenum box. Airflow velocities through the grilles are very low: 200 feet per minute (1.0 meters per second).

The resulting noise level in the concert hall from HVAC operation is well under NC-10 and was not audible to us in the empty room, even after allowing our ears to adjust for at least 30 minutes. See Figure 4 below.

4 CONCLUSIONS

The importance of very low levels of background noise in performance spaces, at or near the threshold of hearing, is well established, and the studies discussed in this paper add to that body of knowledge. Recent project experience shows that very low noise environments can be achieved even in low cost performance spaces by employing common and reasonable noise control design techniques.

ACKNOWLEDGMENTS

We gratefully acknowledge all those who participated in and supported this work.

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2. J. Sacks, R.W. Wolff, and A.M. Jaramillo, "Investigation into Background Noise Conditions During Music Performance", presented at the International Symposium on Room Acoustics, Toronto, Canada, June 9-11, 2013.
3. For convenience and clarity, we have chosen in this paper to refer to background sound levels in terms of Noise Criteria (NC), determined by the tangent method, as defined by ANSI S12.2-2008. Values below NC-15 are calculated relative to the NC-15 curve. The authors do not intend to endorse any particular metric.
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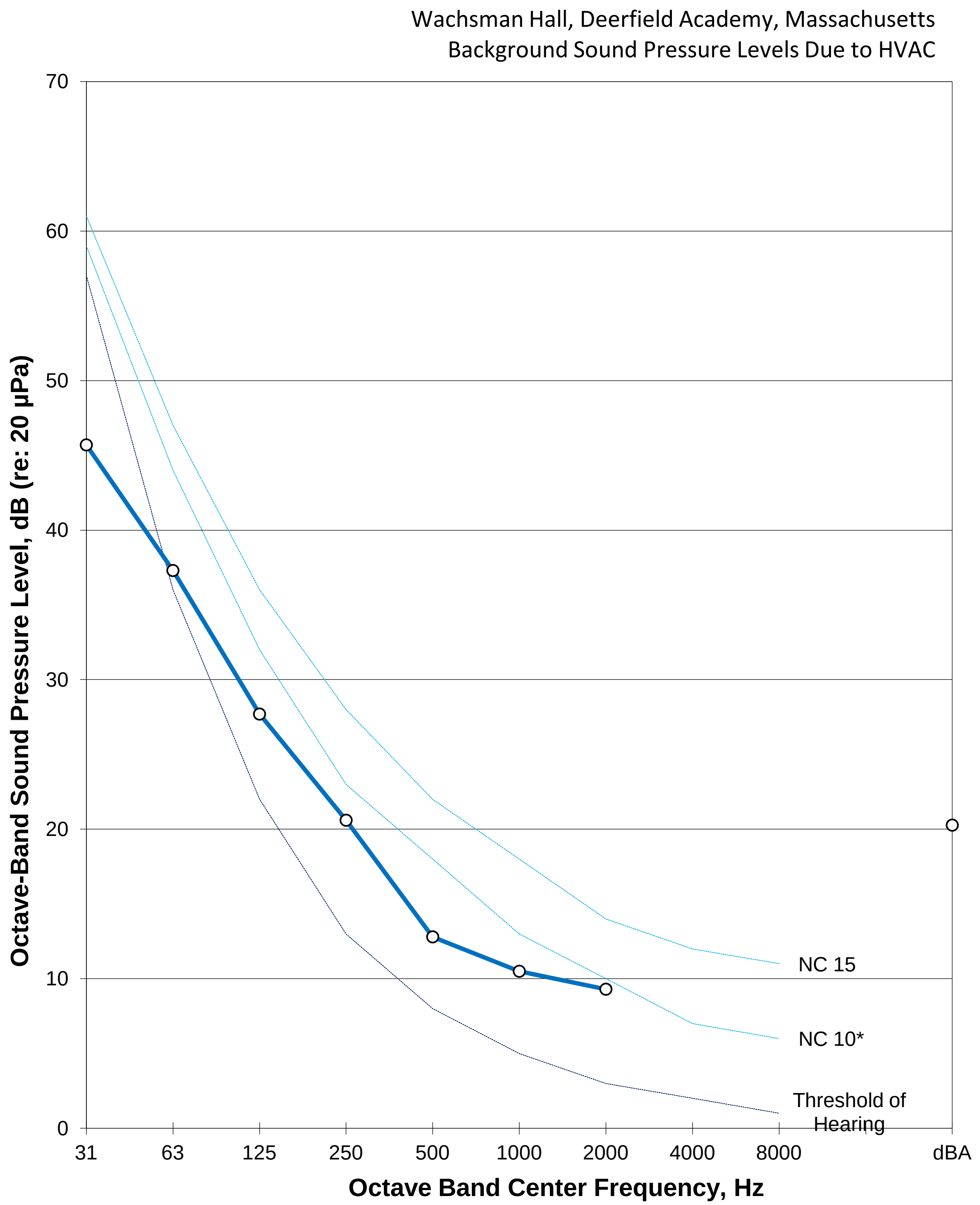

Figure 4: Background sound level due to HVAC operation in Wachsman Concert Hall at Deerfield Academy, measured August 22, 2014. At frequency bands above 1,000 Hz, the noise floor of the measuring device was significant, and data at 4,000 Hz and above have been omitted. (***** NC-10 curve calculated relative to NC-15 curve.)