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Acoustical analysis methodology for urban rooftop playgrounds in New York City

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ABSTRACT

School playgrounds are a significant source of noise. In New York City, school playgrounds are often located in proximity to noise-sensitive locations (i.e., residences, hospitals, etc.) and typically contain a large amount of students simultaneously using the playground. As a result of space limitations in urban areas, rooftop playgrounds are common in New York City. These rooftop playgrounds are often located immediately adjacent to taller buildings that contain noise-sensitive uses. Consequently, it is necessary to examine the potential adverse noise effects associated with rooftop playgrounds. This paper presents a methodology developed by AKRF, Inc. for the acoustical analysis of urban rooftop playgrounds. The methodology includes noise measurements at an existing rooftop playground, street-level and rooftop measurements at the site of a proposed playground, and computer modeling using CadnaA. Where potential impacts are predicted, the analysis results are used to develop and design mitigation solutions. Specific case studies using this methodology and the New York City impact evaluation criteria are also presented in this paper.

1. INTRODUCTION

Numerous groups of students simultaneously utilize school playgrounds for active recreation before, during, and after the school day, and inherently generate noise. In New York City, a combination of the population density, variety of land use types, and urban architecture results in school playgrounds located adjacent to or in proximity to noise-sensitive land uses (i.e., residences, hospitals, etc.). As a result of space limitations in urban areas, it is common for a New York City school to locate their playground on the building's rooftop. When a school is immediately adjacent to taller buildings with noise-sensitive uses, not only is there typically a small distance between the rooftop playground and the adjacent buildings but there is also a direct line-of-site from the rooftop playground to the adjacent buildings'

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windows. Adjacent building facades also generate sound reflections increasing playground noise levels at the noise-sensitive uses. Consequently, it is important to analyze the noise effects of school rooftop playgrounds in New York City.

A. The New York City Environmental Quality Review Process

In New York City, when a project requires discretionary action it must go through the City Environmental Quality Review (CEQR) process. The CEQR process examines a project's potential for adverse environmental impacts including vehicular traffic and public transportation, air quality, hazardous materials, historic preservation, natural resources, shadows, economics and noise among other areas. Some examples of a discretionary action that may require CEQR approval would be the use of City, State, or Federal funds, the purchase or leasing of city-owned property, or when a proposed project does not conform to existing zoning regulations.

New York City schools often require CEQR approval since they are commonly funded by the New York City School Construction Authority (SCA). The SCA provides funding and manages all NYC Department of Education capital projects. This includes the construction of new schools, renovation of existing schools, and the conversion of existing buildings into schools. All SCA projects undergo CEQR environmental review. In New York City, private schools not funded or managed by the SCA often undergo CEQR environmental review for zoning nonconformity or other reasons.

B. Impact Criteria for School Evaluations

SCA projects are typically subject to their own noise impact criteria, and non-SCA projects are subject to the noise criteria set forth in the *CEQR Technical Manual*. The SCA criteria considers project-related noise increases to be an impact, when comparing the future with the proposed project to the future without the proposed project, greater than or equal to a 5 dBA $L_{eq(1)}$. The 5 dBA relative impact criteria correlates well with the average human ability to perceive changes in sound levels (see Table 1) and community response to changes in sound levels (see Table 2).

Table 1: Average Ability to Perceive Changes in Sound Levels

Change (dBA)	Human Perception of Sound
2-3	Barely perceptible
5	Readily noticeable
10	A doubling or halving of the loudness of sound
20	A "dramatic change"
40	Difference between a faintly audible sound and a very loud sound

Bolt Beranek and Newman, Inc., *Fundamentals and Abatement of Highway traffic Noise*, Report No. PB-222-703. Prepared for Federal Highway Administration, June 1973.

Table 2: Community Response to Increases in Noise Levels

Change (dBA)	Category	Description
0	None	No observed reaction
5	Little	Sporadic complaints
10	Medium	Widespread complaints
15	Strong	Threats of community action
20	Very strong	Vigorous community action

International Standards Organization, Noise Assessment with Respect to Community Responses, ISO/TC 43 (New York: United Nations, November 1969).

CEQR noise impact criteria are based on No Build noise levels and are shown in Table 3.

Table 3: CEQR Noise Level Impact Thresholds (in dBA)

Time Period	No Build $L_{eq(1)}$	Impact Threshold $L_{eq(1)}$
7AM – 10PM	Less than or equal to 60	No Build + 5
	61 – 62	65
	Greater than 62	No Build + 3
10PM – 7AM	Anything	No Build + 3
Source: New York City CEQR Technical Manual		

To uniformly analyze the noise effects of school rooftop playgrounds, AKRF has developed a methodology to predict rooftop playground generated noise levels in a complex urban environment, identify locations with the potential for significant noise impacts, and evaluate various mitigation measures. This methodology involves sound measurements of playground users at an existing rooftop playground and ambient noise levels at the proposed project site, and modeling with CadnaA to assess a project's noise effects.

This paper details the AKRF methodology, provides three case studies that use the AKRF methodology, presents some analysis results, and concludes with summary and closing remarks.

2. AKRF ACOUSTICAL ANALYSIS METHODOLOGY

The AKRF methodology has several steps: 1) perform sound measurements at an comparable existing facility to determine the average sound power level per playground user (when feasible), 2) perform sound measurements at the proposed project study area to determine an appropriate base of ambient noise levels, 3) computer modeling using the CadnaA, and 4) analyze the results for impacts. For projects where an impact is predicted to occur, the AKRF methodology can also be used to evaluate the acoustical effectiveness of mitigation options.

A. Determination of Playground User Source Levels

Sound measurements were performed to determine an average sound power level per playground user. This involved continuous measurements at an existing rooftop playground during its hours of operation on two separate days. The specifics of the sound measurement program are discussed later in this paper as Case Study 1. The measurement data was reviewed and atypical events (ex: ambulance siren, etc.) were identified using the L_{max} values. Hourly $L_{eq(1)}$ values were adjusted to not include any atypical events. Using these average $L_{eq(1)}$ values, the worst case $L_{eq(1)}$ scenario was selected, which was 74.0 dBA, in order to determine an average sound power level per playground user.

During these sound measurements, the number of children simultaneously using the playground and the average distance between the microphone and the center of the rooftop playground area was recorded. A literature search determined that 80 dBA at 5 feet (1.52 meters) was an appropriate sound pressure level to assume for one child shouting. This information was used along with sound measurement data collected to determine that each playground user spent approximately 30% of the time shouting. This assumption seemed reasonable based on qualitative observations that were made during the measurements.

B. Determination of Proposed Project Site Ambient Noise Levels

At the site of a proposed school rooftop playground, ambient sound levels are measured throughout the day. When feasible, elevated measurements are performed. When elevated measurements are not feasible, ground level measurements, acoustical fundamentals, and the CadnaA model are used to determine an appropriate base of ambient noise levels. An appropriate base of ambient noise levels is important for the assessment since noise levels associated with the proposed rooftop playground are compared to a “no rooftop playground” condition for impact assessment purposes.

In many cases, the existing baseline noise level is used in place of a calculated future noise level without the rooftop playground. This results in a lower baseline level and therefore a conservative analysis. However, if substantial changes to the noise levels, unrelated to the proposed project, are predicted in the project study area, future baseline noise level may need to be calculated.

C. Computer Acoustical Modeling with CadnaA

The CadnaA model is used to predict the sound generated by the proposed rooftop playgrounds. The CadnaA model is a computerized model developed by DataKustik for sound prediction and assessment. The model takes into account the sound power levels of the noise sources, attenuation with distance, ground contours, reflections from barriers and structures, attenuation due to shielding, etc. The CadnaA model is based on the acoustic propagation standards promulgated in International Standard ISO 9613-2. This standard is currently under review for adoption by the American National Standards Institute as an American standard. The CadnaA model is a state-of-the-art tool for acoustical analysis.

In a complex environment such as New York City, an important advantage of using CadnaA is that Geographic Information Systems (GIS) data can be directly imported creating a three-dimensional model with detailed geometry including ground contours, roadways, building locations, building footprints, and building heights. With this type of detailed model, the effects of shielding, reflections and distance attenuation are more accurately accounted for which results in a more accurate analysis.

CadnaA allows the user to model several different sound source types, including point sources, line sources, and area sources. The AKRF methodology uses an area source made of moving point sources to model a rooftop playground. The area source is geographically located where the proposed playground’s active recreation would occur. The number of moving point sources is determined by the maximum number of users expected to be simultaneously using the proposed rooftop playground at any given time.

D. Determining Sound Power Level for Each Playground User

The sound power level for an average playground user was determined in CadnaA by modeling the rooftop playground, where the sound measurements discussed above in “A. Determination of Playground User Source Levels” were performed, as an area source. A receiver point was created in CadnaA where the measurement microphone position was located. The average number of simultaneous playground users during the measurements was 30 children, and consequently the CadnaA area source was programmed to contain 30 moving point sources. The sound power level for each of the moving point sources (i.e., each playground user) was adjusted until the sound pressure level at the receiver point corresponded with the measurement results. A sound power level of 86.7 dBA for each playground user replicated the measurement results.

E. Modeling Proposed Playgrounds

In CadnaA it is easy to create an area source of any size or shape. Using the area source that contains the moving point sources, a proposed playground with any number of users can be modeled using the AKRF methodology. To create a proposed project's geometry into CadnaA, AKRF uses the architect's CAD files which can be imported directly into CadnaA. Using CAD files results in the most precise CadnaA model. Information regarding playground usage is also provided to determine the worst-case playground scenario and a conservative analysis. Receivers are created in CadnaA at window and balcony locations of nearby noise-sensitive uses. Receivers are located at multiple elevations for each building to determine the variation of playground noise levels above and below the elevation of the proposed playground. Using CadnaA, noise levels generated by a proposed rooftop playground are calculated at each receiver. These worst-case noise levels are combined with the measured ambient noise levels to determine the "future with the proposed project" noise level at each receiver location. To examine the temporal distribution of the proposed playground noise effects, the analysis examines several time periods through the day, typically including the AM, midday (MD), and PM. The calculated "future with the proposed project" noise levels are compared to existing noise levels to identify potential noise level increases caused by the proposed playground. The SCA or CEQR impact criteria are used to determine the significance of the predicted noise level increases. If the analysis indicates the potential for a noise impact, CadnaA is used to examine the acoustical effectiveness of mitigation measures. Mitigation measures may include a noise barrier, playground/building reconfiguration, or time of day restrictions for playground use. The CadnaA model is a fast and ergonomic tool to examine multiple scenarios and evaluate the effectiveness of mitigation options.

3. CASE STUDIES

Detailed below are three case studies that utilized the acoustical analysis methodology for rooftop playgrounds developed by AKRF. Due to real life limitations, compromises are often required regarding the AKRF methodology. Each of the three examples discussed below exemplifies a key point of the AKRF methodology.

A. Case Study 1- Determination of Source Sound Power Level

As previously discussed, the sound power level data used to model a rooftop playground was determined through measurements at an existing elementary school in New York City. Specifically, a continuous sound measurement was performed at the school's rooftop playground. The sound monitoring location was at the northern boundary of the rooftop playground which was located approximately 90 feet (27.43 meters) above street level. The microphone was secured along the perimeter fence approximately 30 feet (9.14 meters) from the center of playground activities. Measurements were performed on March 29 and April 18, 2007 from approximately 8:30 AM to 4:00 PM on both days. The continuous sound measurements were used to identify the temporal distribution of the playground noise levels throughout a typical school day. Observations and field notes, such as the number of children utilizing the rooftop playground at a single time, were recorded.

The sound level monitoring system consisted of a Brüel & Kjær Sound Level Meter Type 2260, a Brüel & Kjær Sound Level Calibrator Type 4231, and a Brüel & Kjær ½-inch microphone Type 4189. The microphone was mounted at a height of 6 feet (1.82 meters) above the playground surface to make it less accessible to playground users (i.e., harder for the children to tamper with the microphone) and the remaining instrumentation was located in a locked and secure Storm Case. The B&K 2260 was calibrated before and after readings with a Brüel & Kjær Type 4231 sound level calibrator using the appropriate adaptor. The data were digitally recorded by the sound meter and displayed at the end of the measurement period in units of dBA. Measured quantities included L_{eq}, L_1, L_{10}, L_{50}, L_{90}, L_{min}, and L_{max}. A windscreen was used during all sound measurements except for calibration. Weather conditions were noted to ensure a true reading as follows: wind speed under 12 mph; relative humidity under 90 percent; and temperature above 14°F and below 122°F. All measurement procedures were based on the guidelines outlined in ANSI Standard S1.13-2005. The sound measurement results are shown below in Table 4; the dominant source of noise was attributable to activity at the rooftop playground.

Table 4: Existing $L_{eq(1)}$ Values 9th Floor Rooftop Playground

Date	Start Time	L_{eq} (dBA)
3/29/07	8:30 AM	67.9
3/29/07	9:00 AM	69.0
3/29/07	10:00 AM	70.0
3/29/07	11:00 AM	74.0
3/29/07	12:00 PM	67.7
3/29/07	1:00 PM	69.3
3/29/07	2:00 PM	72.3
3/29/07	3:00 PM	67.9
4/18/07	8:30 AM	66.6
4/18/07	9:00 AM	67.9
4/18/07	10:00 AM	70.2
4/18/07	11:00 AM	72.3
4/18/07	12:00 PM	71.4
4/18/07	1:00 PM	71.6
4/18/07	2:00 PM	71.1
4/18/07	3:00 PM	69.3
Note: Field measurements were performed by ARKF, Inc. on March 29 and April 18, 2007.		

Examination of the temporal distribution and statistical descriptors of the sound data collected identified the worst case scenario: $L_{eq(1\text{-hour})}$ of 74.0 dBA. This occurred on March 29, 2007 from 11 AM to noon. The worst case $L_{eq(1\text{-hour})}$ of 74.0 dBA was used to calculate, as was described earlier in the methodology section, the representative sound power level for one rooftop playground user. This provided a basis for a conservative approach for modeling a rooftop playground and assessing the noise effects at adjacent noise-sensitive uses.

B. Case Study 2 – Extensive Elevated/Rooftop Ambient Measurements for Impact Assessment

This proposed school would be constructed on a site that currently contains a four story parking garage for a utility company. The proposed school would use the parking garage's building shell and add a fifth story expansion. The rooftop playground would be located at an elevation of approximately 72 feet (21.94 meters) and would be designed to accommodate up to 30 children simultaneously using the playground. There are several noise-sensitive uses immediately adjacent to the proposed rooftop playground. Since access to the parking garage's rooftop was obtainable, ambient sound measurements were performed in several locations as part of the rooftop playground acoustical analysis. In total six locations at the project site were selected for noise monitoring. Site 1 was located on the sidewalk immediately in front of the proposed school. Sites 2 through 5 were located on the northeast, southeast, southwest, and northwest corner of the parking garage roof, respectively. Site 6 was located on the southern side of the parking garage roof. Figure 1 shows the receptor site locations.

Short-term (i.e., 20-minute) spot measurements were performed at Sites 1 through 5 during the weekday AM, midday, and PM peak periods. A continuous long-term measurement was performed at Site 6 during the hours that the proposed rooftop playground would be in use (i.e., weekday daytime hours). The results of the sound measurements at Site 1 were used to determine current ambient noise level conditions at street level. Sites 1 through 5 were used to determine how ambient sound levels varied at different locations on the parking garage's rooftop. Site 6 was used to determine the temporal distribution of the ambient sound levels at elevations similar to that of the parking garage rooftop.

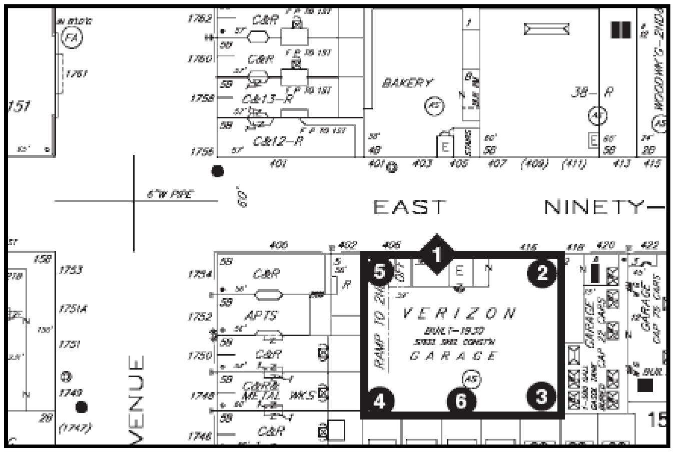

Figure 1: Noise Monitoring Locations

The Site 1 measurement results were used for the window/wall attenuation analysis and the measurement results all six sites were used to assess potential impacts related to the proposed rooftop playground at noise-sensitive uses located adjacent and in close proximity to the proposed rooftop playground. Using the results of the extensive rooftop measurements resulted in a more refined impact analysis since this measurement data was more representative of the ambient sound levels at adjacent elevated noise-sensitive locations.

C. Case Study 3 – Rooftop Noise Barriers and Window/Wall Attenuation Measures

Case Study 3 was for a multi-tier school building with a rooftop playground to be located on the lower section of the building approximately 40 feet (12.19 meters) above street level. The adjacent section of the school is taller at eight stories and has classrooms that overlook the rooftop playground. Additionally, there were several residential locations immediately adjacent to the proposed rooftop playground. Figure 2 is a 3D screenshot of the CadnaA model (the blue rectangle is the rooftop playground area source; the white and black spheres are receiver locations) that was set up to assess the noise effects of the proposed rooftop playground at adjacent residential locations and at the school's classrooms that would have a direct line of site to the rooftop playground.

Due to the high source levels and short distances between the proposed rooftop playground and adjacent noise-sensitive locations, initial review of the architectural plans lead to concern about the noise effects of the proposed rooftop playground on both the adjacent residential buildings and the proposed school's classrooms that overlook the proposed rooftop playground. Preliminary CadnaA modeling confirmed these concerns. Consequently, the CadnaA model was used to design a Lucite/Plexiglas-type perimeter noise barrier. The perimeter noise barrier would be approximately 8 feet (2.44 meters) tall and surround the rooftop playground on three sides (see Figure 2). The CadnaA model is a valuable tool for calculating reflections and shielding due to adjacent/intervening buildings in a geometrically complex urban environment such as New York City. Using the CadnaA model, AKRF was able to quickly analyze the noise levels due to playground activities at multiple window elevations of all the adjacent buildings. The results of the acoustical analysis using the final design of the Lucite/Plexiglass-type perimeter noise barrier demonstrated that at adjacent residential locations, which have a direct line-of-sight to the proposed rooftop playground and are at approximately the same or higher elevations than the rooftop playground, exterior noise levels at the building facades would increase by less than 3 dBA during the hours when the proposed rooftop playground is producing its maximum expected noise levels. Consequently, noise from the proposed rooftop playground would not be expected to result in significant noise impacts at adjacent noise-sensitive receptor locations.

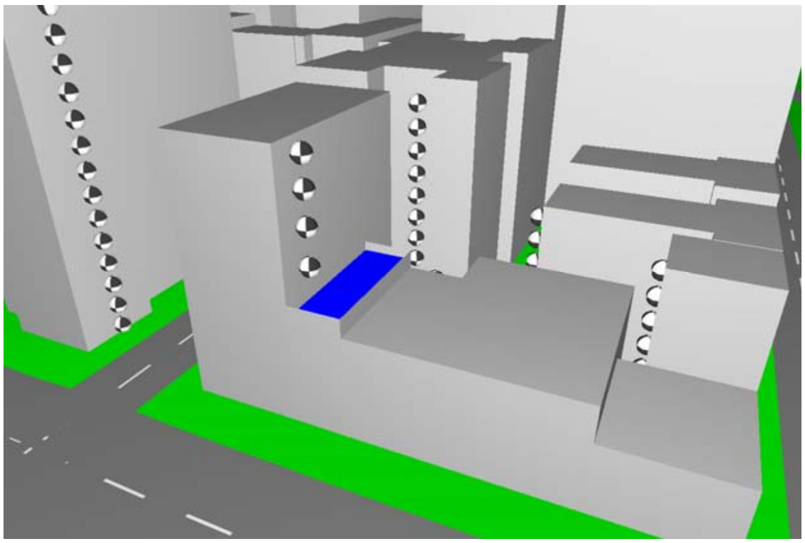

Figure 2: 3D Screenshot of CadnaA Model

The New York City *CEQR Technical Manual* has set window/wall attenuation quantities for buildings, based on exterior $L_{10(1)}$ noise levels, and in order to maintain interior noise levels of 45 dBA $L_{10(1)}$ or lower for school uses. Based on the results of the street level noise monitoring program and the CadnaA modeling, the proposed school's building facades were designed to achieve desirable interior noise levels. The south façade of the proposed school would require 26 dBA of attenuation and the east façade of the propose school would require 31 dBA of attenuation. AKRF worked with the architect on the design of the proposed school such that the composite Outdoor-Indoor Transmission Class (OITC) of the south and east facades meets these attenuation requirements. Additionally, for the façade of the proposed building that is immediately adjacent to the proposed rooftop play area, the building design would include windows that have an OITC sufficient enough to achieve at least 39 dBA of composite window/wall attenuation for the fifth floor (there are no classrooms with windows adjacent to the rooftop play area on the fourth floor). With these architectural design measures, noise levels within the proposed building would satisfy CEQR interior noise level requirements and result in interior ambient noise levels that are conducive to a desirable learning environment.

4. CONCLUSIONS

A. Confidence in Rooftop Playground Noise Level Predications

The AKRF study determined that a sound power level of 86.7 dBA per child could be used to conservatively assess the noise effects of a rooftop playground. This determination of source sound power level agreed well with a previous study called, “Noise Emission of Sporting Facilities and Quantification for Noise Prediction” by Wolfgang Probst[1]. The Probst study determined that the sound power level of one child shouting in a schoolyard or in a crowded swimming pool was 87 dBA. Both the AKRF study and the Probst study conclude that the accurate modeling of a school playground can be done using an area source, containing N number of children, with the following equation:

$$\text{Sound Power Level of Area Source (dBA)} = [\text{PWL of one child} + 10 \cdot \text{LOG}(N)] \quad (1)$$

B. Advantages to the AKRF Developed Approach

The AKRF developed approach using the CadnaA for modeling a rooftop playground and examining the noise effects has several advantages:

- The CadnaA model is a valuable tool for calculating reflections and shielding due to adjacent/intervening buildings in a geometrically complex urban environment such as New York City;
- Sound level predictions can be made quickly at a large number of analysis locations;
- Allows the user to quickly and ergonomically explore the acoustical effectiveness of various mitigation options; and
- Helps with communicating analysis results to the public since CadnaA is a visual tool (i.e., 3D view, colorful contour maps, etc.).

C. Next Steps

The AKRF methodology described in this paper is a good foundation for creating a guideline method for assessing the noise effects of a rooftop playground in an urban environment such as New York City. Currently, the areas where further refinement is desired are:

- Perform additional measurements at existing rooftop playgrounds to further refine the sound power level used to represent each child. Based on previous AKRF acoustical studies for outdoor school playgrounds (Wu, Weixiong, *Development of Noise Assessment Method for School Playground Noise*, INTER-NOISE, 2006), the playground user sound power level may differ depending on the age of the children utilizing the playground (i.e., early education, elementary school, middle school, etc.). Additional measurements would also aid in establishing average octave band sound power levels for a playground user;
- Validation of CadnaA results. As the proposed schools that AKRF used the methodology outlined above to analyze the noise effects of their rooftop playgrounds are built and the playgrounds become active, it would be a wonderful opportunity for AKRF to perform on-site sound measurements to examine the agreement between the actual sound levels and the predicated sound levels.

Currently, AKRF’s methodology for analyzing rooftop playgrounds in New York City is a good foundation for creating a guideline for assessing the noise effects of a rooftop playground in an urban environment. We look forward to work that will allow us to further develop and refine our methodology and we welcome input from our fellow acousticians.

REFERENCES

[1]Probst, W.: "Geräuschentwicklung von Sportanlagen und deren Quantifizierung für immissionsschutztechnische Prognosen", Annex 4, page 70, Report B2/94, Bundesinstitut für Sportwissenschaft, ISBN 3-921896-84-3