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Passive noise control techniques for a diesel engine power-generation facility

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ABSTRACT

This paper presents passive noise control techniques investigated in order to reduce the sound output of a diesel engine power-generation facility in Heber, Utah. Sound pressure measurements made near the building that houses the generators exceeded 95 dBA, and property line measurements were 70 dBA. Noise complaints from neighbors prompted the facility management to investigate passive sound attenuation techniques. Traditional attenuation techniques such as barriers, enclosures, mufflers, louvers, and linings were researched in order to provide a solution to the problem. A cost per dB of attenuation analysis of these techniques relative to this specific facility was presented to the facility management. The analysis results and specific facility challenges are presented in this paper.

1 INTRODUCTION

Industrial diesel engine power-generators can be used as a primary or secondary source of electricity for small cities. These generators can range in size from small (10 kW) to extremely large (2.5 MW). A power-generation facility in Heber, Utah has a power-generation building that can simultaneously house up to six diesel generators. Large garage doors on the north side of the building are left open during operating hours to accommodate the large volumetric airflow requirement of each generator. The openings provide the necessary intake air for both engine combustion and radiator cooling. The engine exhaust air is vented through a muffler located on the top of the building, while the cooling air is exhausted through large rectangular flues on the south side of the building. The open garage doors, engine and cooling air exhaust flues, and one radiator unit mounted outside of the building all contributed significantly to the overall sound level. The facility management was interested in implementing passive noise control techniques to these noise sources because of the high sound output of this particular building.

This research had four main objectives. The first objective was to identify the major noise sources near the power generation building. Second, an analysis was performed to anticipate the community response to the measured sound level. Third, an analysis was performed to determine the effects of different acoustic treatments (the use of acoustic barriers, duct linings, enclosures, silencers, and louvers were considered). The last objective of this research was to propose a step-by-step set of recommendations to reduce the noise emission of the power generation building.

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2 MAJOR NOISE SOURCES

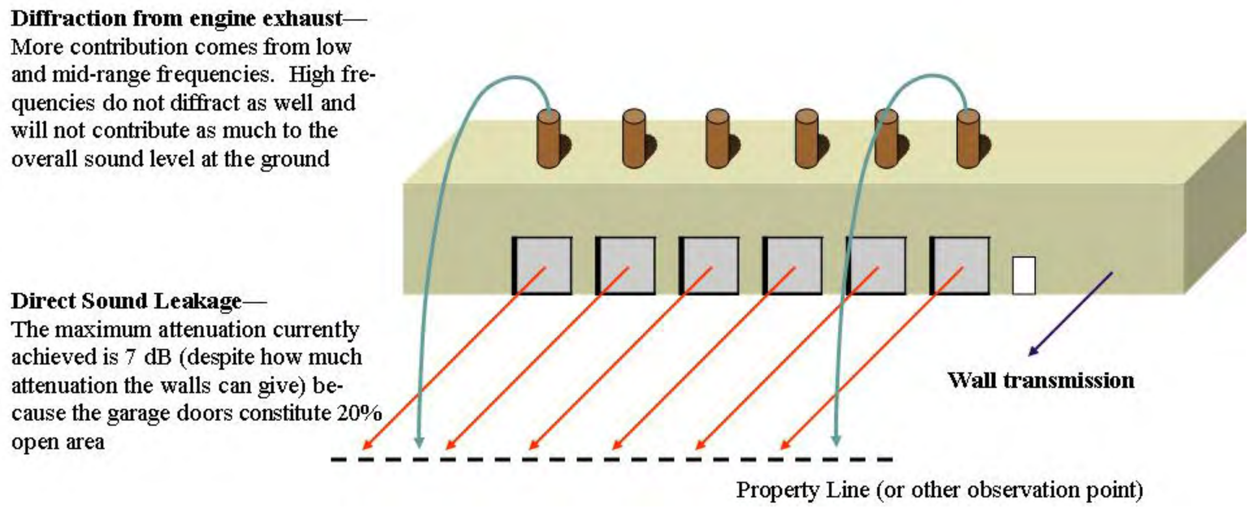
After reviewing sound level readings taken in and around the power generation building, it was concluded that there were five distinct noise source possibilities:

1. Noise transmitted through the walls of the test facility
2. Direct noise produced by a radiator system located outside the building
3. Direct noise resulting from open areas in the walls of the building (called acoustic leakage)
4. Diffraction noise from the cooling air exhaust and engine exhaust flues
5. Duct break out noise from the cooling air exhaust flues

The presence and relative significance of these noise sources depended on which side of the power generation building (north, south, east, or west) the observer was located. The noise sources of the northern and southern facades are discussed below.

2.1 Northern Façade

The northern façade had three of the five major noise sources: Noise transmitted through the walls of the test facility, direct noise resulting from open areas in the walls of the building, and diffraction noise from the engine exhaust flues. These sources are shown in Figure 1.



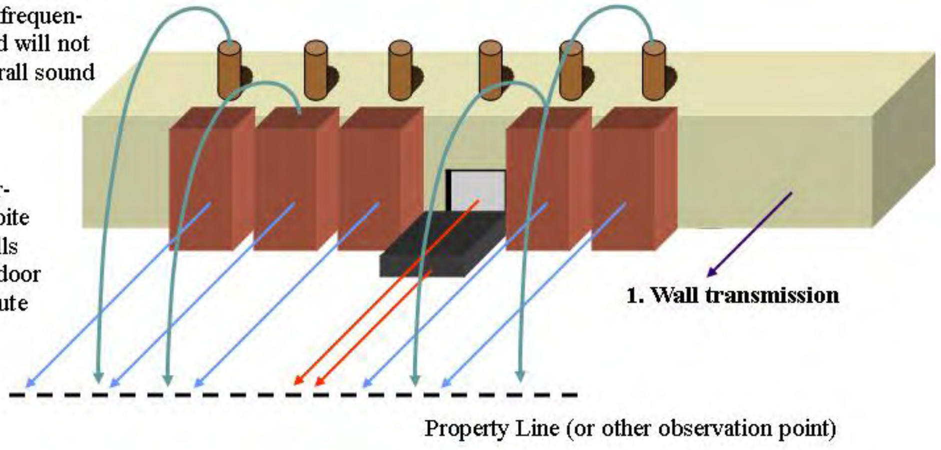
Diffraction from engine exhaust—
More contribution comes from low and mid-range frequencies. High frequencies do not diffract as well and will not contribute as much to the overall sound level at the ground

Direct Sound Leakage—
The maximum attenuation currently achieved is 7 dB (despite how much attenuation the walls can give) because the garage doors constitute 20% open area

Figure 1. Major sound sources on the northern facade of a diesel engine power-generation facility.

2.2 Southern Facade

The southern façade had all five major noise sources present. These sources are shown in Figure 2.



Duct break out noise—
The amount of sound transmitted through the walls of the duct

Diffraction from engine exhaust and cooling exhaust—
More contribution comes from low and mid-range frequencies. High frequencies do not diffract as well and will not contribute as much to the overall sound level at the ground

Direct Sound Leakage—
The maximum attenuation currently achieved is 14 dB (despite how much attenuation the walls can give) because the garage door and areas around flues constitute 5% open area

Direct Sound—
The externally mounted radiator produces between 85 and 105 dBA (measured 3 ft away from radiator)

Figure 2. Major sound sources on the southern façade of a diesel engine power-generation facility.

3 ANALYSIS OF COMMUNITY RESPONSE TO MEASURED NOISE LEVELS

Most cities have zoning regulations that limit the amount of noise a business can produce based upon geographic location in the city. The city of Heber, however, does not have a noise ordinance in the municipal code. The code for the nearby city of Provo says the following (excerpts from Chapter 9.06. Public Disturbances):

"Continuous noises described in 9.0.6.010 (2)* and 9.06.010 (3)** shall not exceed":

DISTRICT	DAY	NIGHT
Residential/agricultural	65 dBA	55 dBA
Commercial	70 dBA	65 dBA
Industrial	75 dBA	75 dBA

The measurements taken on the property line of the test facility were 70 dBA with only two of the six possible diesel engines in operation. However, since the city of Heber does not have a noise ordinance, another method for determining community annoyance was used.

The community response to noise consists of a list of decibel rewards and penalties for certain types of operating procedures. These rewards and penalties are used to adjust the measured sound level and make a "corrected" sound level. The corrected sound level is then correlated to an expected community response. Kinsler et al[1] gives tables outlining these correction factors and correlations.

Table 1. Correlation between corrected sound level and expected community response.

Corrected Level (dBA)	Expected Community Response
< 45	None
45-55	Sporadic complaints
55-60	Widespread complaints
55-65	Threats of community action
> 65	Vigorous community action

Table 2. Corrections to be added to the A-weighted sound level to produce a measure of community reaction.

Noise Characteristics	Correction in dBA
Pure tone present	+5
Intermittent or impulsive	+5
Noise only during work hours	-5
Total duration of noise each day	
Continuous	0
Less than 30 min	-5
Less than 10 min	-10
Less than 5 min	-15
Less than 1 min	-20
Less than 15 sec	-25
Neighborhood	
Quiet suburban	+5
Suburban	0
Residential Urban	-5
Urban near some industry	-10
Heavy industry	-15

An application of these principles to the power-generation facility is given below:

The maximum southern property line sound level measured with two generators in the power-generation building running was 70 dBA. If the area of the city where the facility is located was considered to be "Urban near some industry," 10 decibels would be subtracted from the measured sound level. The corrected sound level would then be 60 dBA. From Table 1, this level would correspond to a community response that bordered on widespread complaints to threats of community action.

The ideal acoustic solution for the power-generation facility would bring the corrected decibel level below 45 dBA. However, if the city of Heber continues to allow residential construction near the facility, the "Residential Urban" correction of –5 dB might need to be used instead of the "Urban near some industry" correction of –10 dB. If the management would like to operate the generators outside of work hours, the –5 dB correction for “Noise only during working hours” could not be used. With these factors considered, the corrected sound level would be 70 - 5 (residential urban correction) = 65 dBA. This level would correspond to a community response that bordered on widespread complaints to threats of community action. Therefore, the ideal acoustic noise control application for the power-generation facility would reduce the current sound level on the property line by 20 dB, allowing for a corrected level of 45 dBA and no expected community response.

4 ANALYSIS OF ACOUSTIC TREATMENTS

Passive noise control treatments were considered for each of the major noise sources. A table showing which treatments were considered for each noise source is shown in Table 3 below. Each of these treatments will be discussed further.

Table 3. Passive acoustic treatments that were considered for diesel engine power-generation noise sources.

Noise Source	Passive Acoustic Treatment
All	Acoustic barrier
External radiator, generators	Acoustic enclosures
Engine exhaust flues	Absorptive mufflers
Cooling air exhaust flues	Acoustic louvers
Cooling air exhaust flues	Acoustic lining

4.1 Acoustic Barriers

Acoustic barriers placed in the path of free field sound propagation will block part of the sound energy and will create an acoustic shadow where noise attenuation can be significant.[2] Although favorable circumstances may provide 15 dB attenuation, it is unlikely to realize more than 10 dB in most cases. A favorable circumstance is defined as one that meets the following criteria:

- The barrier is large with respect to the size of the source and the wavelength of the lowest frequency
- The barrier is as close to either the source or observer as possible
- The barrier wraps around the source or observer
- The barrier is distant from any reflecting surfaces
- The reverberation time of the surroundings is low

These conditions were not met for the power-generation building. The wall would need to be over 50 meters long and 6 meters high to be large with respect to the size of the building. In addition, the only possible physical location for the wall was 50 meters away on the property line. This location was not in accordance with the criteria that the barrier is close to the source or observer. A computer analysis was performed to predict the overall insertion loss of an acoustic barrier located on the southern property line of the facility. The wall was 150 m long, 3 m high, 50 m from the source, and 30 m from the observer. The overall insertion loss was estimated at 4 dB. This is not enough attenuation to justify the cost of such a large wall.

4.2 Acoustic Enclosures

An ideal acoustic enclosure completely encapsulates the noise source, forcing the sound to travel through the walls of the enclosure. Because the walls have an associated transmission loss, the sound level outside of the enclosure is lower than the sound level inside. Any aperture in the enclosure will permit acoustic leakage and will downgrade the performance of the enclosure.[2] However, most applications require openings to allow for the movement of air, stock materials, end products, and waste products into and out of the enclosure. In Figure 3, Bell[3] shows the effect of sound leaks on the potential noise reduction for walls.

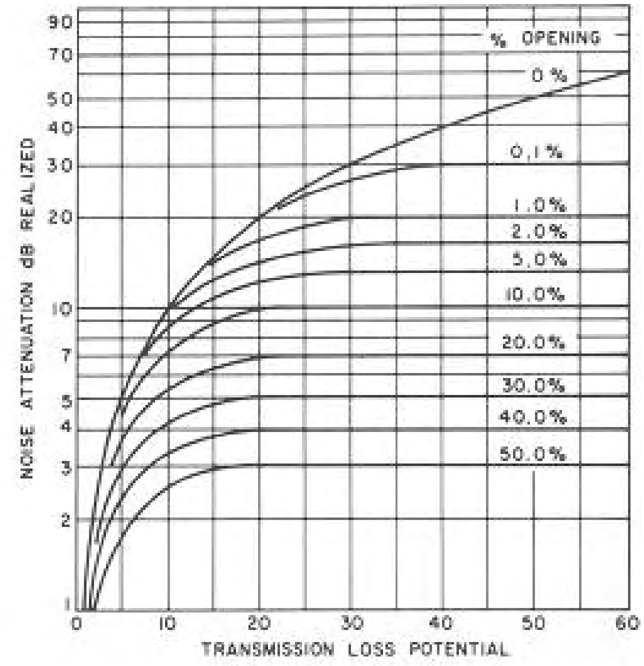


Figure 3. Effect of sound leaks on potential noise reduction for walls.

The walls of the power-generation building had a reasonable transmission loss potential of about 25 dB. However, due to high ventilation requirements of the diesel engines, the garage doors on the north side of the building were kept open, constituting a 20% open area on the north façade. From Figure 3 it is seen that the maximum noise attenuation realized with this operating configuration is 7 dB. This amount of attenuation was verified by measurement data. Because of the large amount of open area in the walls of the building, 18 dB of potential attenuation were not being utilized.

The southern façade of the power-generation building had less than 5% open area. However, Figure 3 shows that only 13 out of a possible 25 dB were utilized. Additionally, a radiator system (as shown instead of an exhaust flue in Figure 2) used to cool one of the diesel engines was located outside the southern wall of the building. The radiator system produced sound levels upwards of 100 dBA during full load operation but had no passive sound attenuation. An acoustic enclosure could be built around the radiator system to provide 25-30 dB of attenuation while allowing adequate ventilation over the radiator coils.

4.3 Absorptive Mufflers

Another major noise source was the engine exhaust flues. Although the flue openings were located on top of the building, some 10 m above ground level, the diffraction of the exhaust noise contributed to the overall sound level at the ground. The current engine exhaust system contained a reactive type muffler that was tuned to attenuate the engine firing frequency. Measurement data taken at the top of the engine exhaust flue showed that the reactive muffler was effective in attenuating low frequency noise, but did little to attenuate mid to high-frequency noise.

A secondary muffler of the absorptive type could be added in-line with the current reactive type muffler. This absorptive muffler would provide an additional 5 dB attenuation at low frequencies and 25-30 dB attenuation at mid to high frequencies. Figure 4 shows the 1/3 octave band levels with the current muffler (circle) and the predicted 1/3 octave band levels if a secondary muffler was added to the engine exhaust system (triangle).

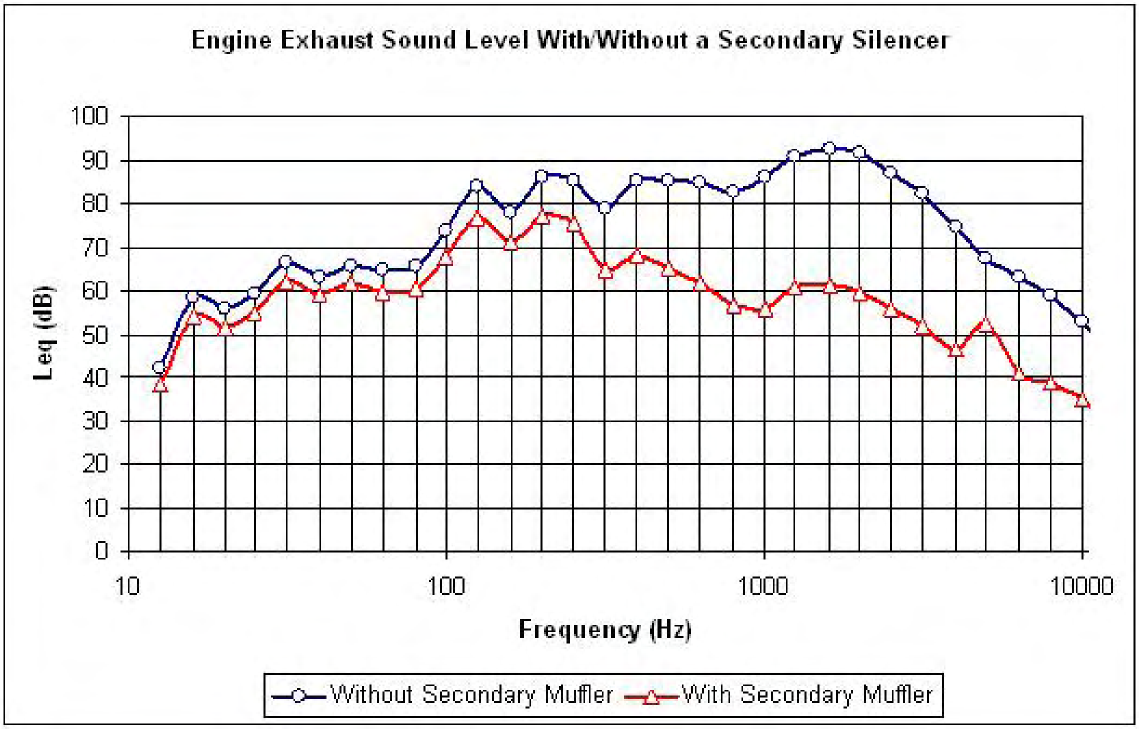


Figure 4. Measured 1/3 octave band sound levels of current engine exhaust (circle) and predicted 1/3 octave band sound levels with a secondary absorptive type muffler added (triangle).

It was calculated from the 1/3 octave sound levels that the overall sound level could be reduced from the current value of 99 dBA to 73 dBA by adding a secondary muffler.

4.4 Acoustic Louvers

Acoustic louvers allow for openings in the walls of acoustic enclosures while providing some attenuation. Absorptive material is placed on the underside of the louver slats. This allows for relatively large airflows and reasonable sound transmission loss. The power-generation building has five large cooling air exhaust flues located outside the southern wall. These flues are 3 m square, 7 m high, and are made of 3 mm steel. The cooling air that is drawn over the radiator coils of each diesel engine is exhausted through these flues. The sound level at the top of the flue was measured at 100 dBA. Similar to the engine exhaust flues, this sound diffracts back to the ground and contributes to the overall sound level. A roof/louver system was conceived to fit on the top of each cooling air exhaust flue as shown in Figure 5. From 1/3 octave band data it was calculated that the acoustic louver would provide 10 dB overall attenuation. In addition, the roof/louver system was designed to direct the sound to the west, away from neighbors.

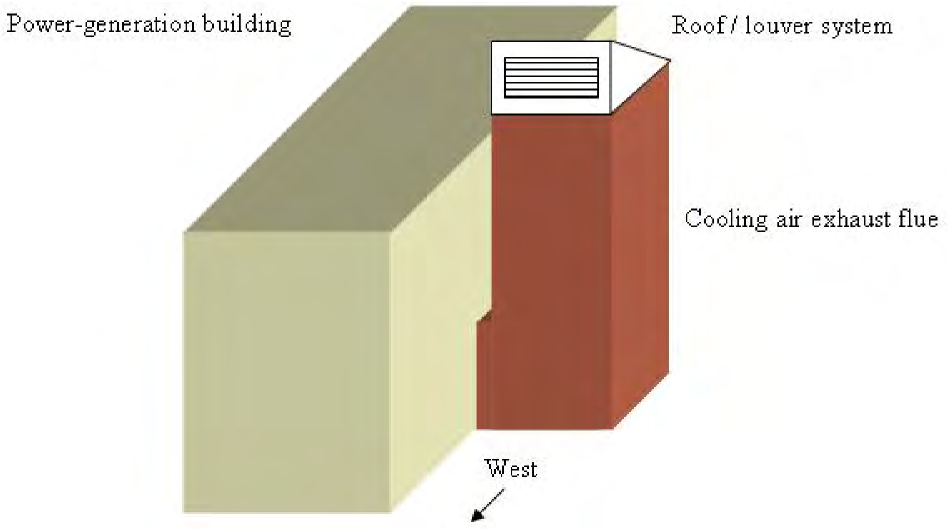


Figure 5. A roof/louver system was conceived to fit on the top of each cooling air exhaust flue to provide sound attenuation. The system was also designed to direct the sound to the west, away from neighbors.

4.5 Acoustic Linings

Acoustic linings were investigated to reduce the duct break out noise of the cooling air exhaust flues. Lining ducts with acoustic material is a viable passive sound reduction technique for ducts of small cross sectional area. The cooling air exhaust flues have a cross sectional area of 9 m^2. Computer modeling was used to predict the amount of attenuation possible if a 2 cm thick lining was applied on all four sides of the duct along the entire length. It was found that the overall attenuation was less than 2 dB. This amount of attenuation would not justify the cost such large amounts of acoustic lining.

5 STEP BY STEP RECOMMENDATIONS

The sequence for implementing the aforementioned passive noise control techniques to the power-generation building depended on several factors. These factors included the predominance of the noise source, cost vs. predicted attenuation, and ease of implementation. Taking these factors into consideration, the step by step recommendations shown in Table 4 were given to the facility management.

Table 4. Step by step recommendations to reduce the sound output of the power-generation building.

Step	Description	Estimated Attenuation	Estimated Cost	Limiting Factors
1. Reduce acoustic leakage on south wall	Seal up gaps between cooling air exhaust flue and test facility walls. Close the southern facing garage door where there isn't a cooling air exhaust flue.	5-10 dB	Total $500	At some point, the diffracted noise from the top of the exhaust flues will dominate the break out noise from the building and duct walls.
2. Add a roof/louver system	This addition to the cooling air exhaust flue will protect the inside of the flue from the weather, will attenuate some noise, and will point the remaining sound to the west.	5-7 dB	1 36"x72"x4" louver is $825 Total $5000	At some point, the diffracted noise from the top of the exhaust flues will dominate the break out noise from the building and duct walls.
3. Modify the current engine exhaust	Move the primary muffler (reactive type to control low frequency engine noise) inside the test facility building and add a secondary muffler (absorptive to control mid to high frequency attenuation) outside the test facility building.	15-20 dB	1 absorptive muffler is $3500 Total $25,000	The noise on the north side of the test facility building will still be dominated by the open garage doors. Adding mufflers at this point would only help on the southern property line.
4. Close the garage doors on the north side of the building	Introduce a forced air ventilation system to the building.	10-15 dB	~ $90,000	Care should be taken during the design of the ventilation system in order to meet both air flow and acoustic requirements.

6 SUMMARY

Passive noise control techniques were investigated for a power-generation facility in Heber, Utah. The major noise sources around the building were identified. An analysis was performed to predict the expected community response to the measured noise levels around the facility. An analysis was then performed to determine the effects of different acoustic treatments (the use of acoustic barriers, duct linings, enclosures, silencers, and louvers was considered). A step by step procedure, the sequence of which depended on the predominance of the noise source, cost vs. predicted attenuation, and ease of implementation was prepared for the facility management.

7 REFERENCES

[1] Lawerence E. Kinsler, Austin R. Frey, Alan B. Coppens and James V. Sanders, “Environmental Acoustics,” Chap 13 in *Fundamentals of Acoustics, 4th Edition,* (Wiley, New York, 2000).

[2] Sound Research Laboratories, *Noise Control in Industry, 3rd Edition*, (E. & F.N. Spon, New York, 1991).

[3] Lewis H. Bell, *Industrial Noise Control: Fundamentals and Applications, 2nd Edition,* (Marcel Dekker, Inc., New York, 1991).