Fundamentals of Sound

Sound is a form of energy transmitted from a vibrating source. The vibrating matter creates small, repetitive pressure disturbances that are imparted to the air along a path and reach a receiver, the ear. Ear drums sense these small changes in the barometric pressure of the air, distinguishing sounds based on amplitude and pitch. Amplitude refers to the level of energy that reaches the ear which corresponds to how loud we perceive sound. Pitch is the relative quality or the frequency of the sound that reaches the ear, helping a person to identify the source of the sound.

In HVAC systems, the source of sound is a combination of different processes, such as turbulence from the fan(s) and mechanical sounds from the motor(s), etc. Frequency, measured in Hertz (Hz), is the number of oscillations (cycles) completed per second by a vibrating object. The sound that humans hear covers a frequency range of about 20 Hz to about 20,000 Hz. Sounds at different frequencies behave differently, causing humans ears to react to them differently as well. This audible range of frequencies is divided into eight octave bands, reproduced below in **Table 1.**

Table 1. Octave Band Frequencies

Band Number	Identifying Frequency (Hz)	Approximate Frequency Range (Hz)
1	63	44 - 88
2	125	88 - 176
3	250	176 - 353
4	500	353 - 707
5	1,000	707 - 1,414
6	2,000	1,414 - 2,828
7	4,000	2,828 - 5,656
8	8,000	5,656 - 11,312

Creating Sound Ratings

The human ear responds to a large range of sound pressures. Sound pressure is typically measured in Pascals (Pa), which creates a range of pressure values so wide that it is more convenient to use a logarithmic scale. Therefore, the decibel (dB) scale is preferred because it collapses a large range of pressure values to a more manageable, easier to analyze range. The sound pressure level is measured in dB above a standard reference level and given by:

$$L_p = 10 \log (p/_{pref})^2 = 20 \log (p/_{pref})$$

Here "p" represents the sound pressure being measured and "pref" is the reference sound pressure, typically 20 µPa, which is generally considered the threshold of human hearing.

Sound ratings are typically provided in terms of the sound power of a source, which is its rate of emission of acoustical energy and is expressed in watts. Sound power does not depend on the distance of observation location from the source but it does depend on operating conditions. The sound power level, Lw, is defined by:

$$L_w = 10 \log(w/10^{-12}) \text{ dB}$$

Here "w" is the sound power emitted by the source in watts and 10-12 is the reference power.

Mechanical equipment is rated in terms of sound power level in order to provide a common reference measurement that is independent of distance and the acoustical conditions of the environment. When attempting to measure sound power level ratings, an engineer will find that he cannot measure these ratings directly. Instead, sound power level ratings are calculated from several sound pressure measurements created by a source in a particular test environment using one of four common methods: free-field, reverberation room, progressive wave (in-duct), and sound intensity. Once the sound pressure level is measured, the sound power level can then be determined mathematically; this calculation is treated in greater detail in **Appendix A.** The sound pressure level can also be derived from published sound power levels, again using a complex mathematical process that can be studied using **Appendix B.**

Due to the logarithmic properties of sound levels, adding two equal noise sources yields a level 3 dB higher. The addition of decibels is mentioned in greater detail in **Appendix C.**

Analyzing Sound Ratings

The purpose of developing sound ratings is to help determine whether or not the evaporative cooling equipment will cause a sound problem. Sound becomes noise when it is too loud, unexpected, contains unwanted tones (e.g. a whine, whistle, or hum), or is unpleasant. Sound only has to be unwanted for it to be noise, not necessarily just loud. Humans respond differently to each particular frequency of sound, making the ear more receptive to certain frequencies than others. As mentioned before, sound is a combination of frequencies. This creates a problem for measuring the impact of each sound on human hearing since each frequency will be perceived differently by the ear. This has resulted in the development of the A-weighting factor, which simulates human response to sound at low sound levels by de-emphasizing low frequencies within the sound spectrum. The A-weighting factor accounts for the ear's reduced sensitivity to low frequency sounds and thus allows for a better comparison of sounds emanating from two different sources. Defining a noise problem is typically in terms of dBA, which is the A-weighting corrected value of a decibel. This weighting factor, reproduced in **Table 2** below, allows for a more accurate determination of when a sound becomes a noise. Other weighting factors exist for higher sound levels, but are not commonly used.

Table 2. A- Weighting Factors

Band Number	1	2	3	4	5	6	7	8
A- Weighting Factor	-25	-15	-8	-3	0	+1	+1	-1

HVAC Acoustical Design Goals

For any specific project, it is important how the design engineer decides to rate the background sound. This is not to say that all evaporative cooling equipment have a sound problem; in fact, most do not. The most common rating methods include the A-weighted sound level (dBA), noise criteria (NC) method, and room criterion (RC) method. Each method highlights different characteristics of sound. When selecting a rating method it is important to consider how the rating will be used. A-weighted sound levels are excellent predictors of human judgments of sound, but do not reveal the spectral balance of sound. Thus, a limitation of A-weighted sound levels is that the measurements do not correlate well with the annoyance caused by noises. Different sounds can receive the same rating but retain dissimilar subjective qualities. A-weighted sounds are best for a comparison between sounds that are similar but differ in level, such as comparing the loudness between two different makes of a fan. Therefore, the A-weighted sound level is not the best tool for measuring HVAC systems as a whole, but it is better used for measuring a single component like a fan.

When measuring evaporative cooling equipment as a whole, the NC or RC methods work best. These methods account for environmental noise, unlike the A-weighted sound level. The key difference between RC and NC methods is the emphasis on the lower frequencies (16 Hz, 31.5 Hz) and the higher frequencies (8 KHz), respectively. As of this publication, the predominant design criterion that HVAC engineers utilize is the NC method, chosen for its ease of use and widespread publication in HVAC resources. The RC method, considered to be the better measure of sound between the two methods, is slowly replacing the NC method as a means of analyzing sound.

The NC method plots sound pressure levels in the eight octave band levels. The method is composed of a family of criterion curves extending from 63 to 8000 Hz from which values are tangentially chosen. **Figure 1** illustrates an NC chart below.

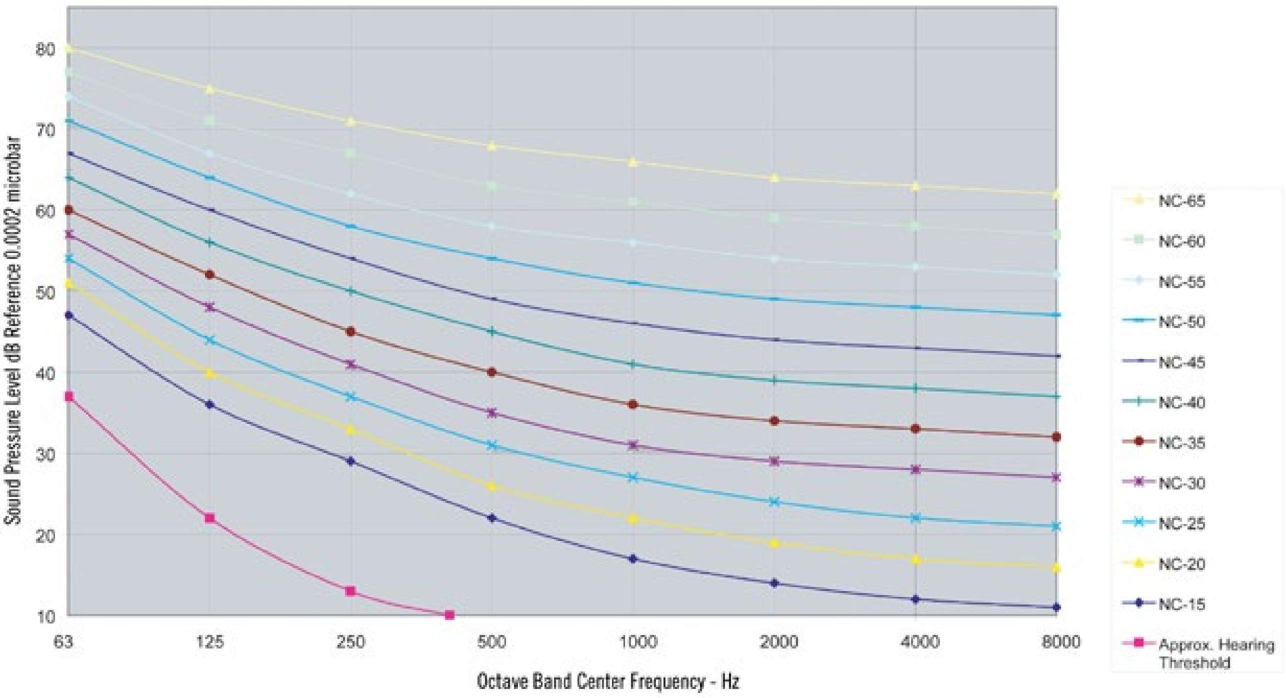


Figure 1. Noise Criterion (NC) Curves

Determining Sound Attenuation Requirements

The following thirteen step procedure can be used to determine the sound attenuation requirement for an evaporative cooling tower. The sidebar follows the procedure for a specific application.

Steps 1 and 2: Select NC Values and the Corresponding Sound Pressure Levels

The first step in the development of the evaporative cooling equipment's noise criterion is to select the particular activity that best describes what the indoor "neighbors" in the vicinity of the equipment will be doing when the equipment is operating as shown in **Table 3** on the following page. Where two or more neighbor conditions may be applicable, the one having the lowest NC value should be selected. The corresponding NC values of **Figure 1,** shown previously, or in **Table 4** on the following page give the eight octave band sound pressure levels, in decibels, for that selection. The goal is to keep the sound heard by the neighbor, inside his home or building, at or below these sound pressure levels.

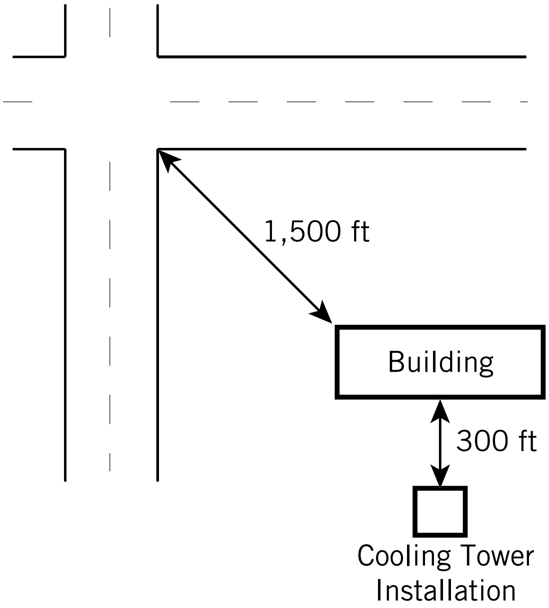


Figure 2. Example Scenario

Determining Sound Attenuation Requirements Example

The following example illustrates the process of choosing sound criteria for an application of a cooling tower. Once finished, an HVAC engineer will be able to determine what level of sound attenuation, if any, is necessary. The example refers to different "items" which are found in the BAC Sound Evaluation Worksheet (**Appendix F** on **page J72**). **Appendix F1** is a worksheet that follows the running example on the sidebar in this document. **Appendix F2** is left blank for your own use.

Example:

Consider a cooling tower installation located near the edge of a college campus, approximately 300 ft (91.4 m) from a classroom building. The college is located within a large city, and two main streets pass by one corner of the campus about 1,500 ft (457.2 m) from the classroom building. The cooling tower will be used both day and night during warm weather. The classroom must rely on open windows for air circulation (See **Figure 2**). Determine the noise criterion for the unit.

Step 1: **Determine the Neighbor Activity Condition.** Refer to **Table 3** on the following page**.** For "good listening conditions" inside a typical classroom, select NC-30 as the noise criterion.

Step 2: **List the Sound Pressure Levels.** In the indicated spaces under Item 2 of the Sound Evaluation Work Sheet, **Appendix F**, enter the sound pressure levels from **Table 4** on the following page for the octave frequency bands that correspond to the chosen NC-30 curve.

Table 3. Suggested Range of Noise Criteria for Indoor Neighbor Activities

Activity	Suggested Range of Noise Criteria
Sleeping, Resting, Relaxing	
Homes, Apartments, Hotels, Hospitals, etc.	NC-20 to NC-25
Suburban and Rural areas	NC-25 to NC-30
Excellent Listening Conditions Required	
Concert Halls, Recording Studios, etc.	NC-15 to NC-20
Very Good Listening Conditions Required	
Auditoriums, Theaters	NC-20 to NC-25
Large Meeting and Conference Rooms	NC-25 to NC-30
Good Listening Conditions Required	
Private Offices, School Classrooms, Libraries, Small Conference Rooms, Radio and Television Listening in the Home, etc.	NC-30 to NC-35
Fair Listening Conditions Desired	
Large Offices, Restaurants, Retail Shops and Stores, etc.	NC-35 to NC-40
Moderately Fair Listening Conditions Acceptable	
Business Machine Areas, Lobbies, Cafeterias, Laboratory Work Areas, Drafting Rooms, Satisfactory Telephone Use, etc.	NC-40 to NC-45
Acceptable Working Conditions with Minimum Speech Interference	
Light to heavy Machinery Spaces, Industrial Areas, Commercial Area such as Garages, Kitchens, Laundries, etc.	NC-45 to NC-55

Table 4. Octave Band Sound Pressure Levels (dB reference 0.0002 microbar) of Indoor Noise Criterion (NC) Curves in **Figure 1**

	Octave Band Center Frequency in Hz							
Noise Criterion	63	125	250	500	1000	2000	4000	8000
NC-15	47	36	29	22	17	14	12	11
NC-20	51	40	33	26	22	19	17	16
NC-25	54	44	37	31	27	24	22	21
NC-30	57	48	41	35	31	29	28	27
NC-35	60	52	45	40	36	34	33	32
NC-40	64	56	50	45	41	39	38	37
NC-45	67	60	54	49	46	44	43	42
NC-50	71	64	58	54	51	49	48	47
NC-55	74	67	62	58	56	54	53	52
NC-60	77	71	67	63	61	59	58	57
NC-65	80	75	71	68	66	64	63	62

Steps 3 through 6: Determine Environmental Sound Effects

Neighbors who are either indoors in their own building or outdoors on their property may hear sound from outdoor equipment. When outdoor sound passes into a building, it reduces, even if the building has open windows. The approximate sound reduction values provided by several typical building constructions are given in **Table 5;** the listed wall constructions are labeled with letters A through G and are described in the notes under **Table 5.** Adding these amounts of sound reduction to the indoor NC curves, band-by-band, provides a "tentative outdoor noise criterion" based on hearing the sound indoors in the neighbor's building.

Table 5. Approximate Sound Reduction (dB) Provided by Typical Exterior Wall Construction

Octave Frequency Band in Hz	Wall Type (See Notes Below)						
	A	B	C	D	E	F	G
63	0	10	13	19	14	24	32
125	0	10	14	20	20	25	34
250	0	10	15	22	26	27	36
500	0	10	16	24	28	30	38
1000	0	10	17	26	29	33	42
2000	0	10	18	28	30	38	48
4000	0	10	19	30	31	43	53
8000	0	10	20	30	33	48	58

Determining Sound Attenuation Requirements Example Continued

Step 3: Analyze Sound Reduction Due to the Building. Determine the wall construction of **Table 5** that best describes the exterior wall of the classroom. Wall B can be selected for normally open windows during the summer time. Insert the Wall B values in the Item 3 spaces of **Appendix F** on **page J72**.

Step 4: Determine Tentative Outdoor Noise Criterion. Still in **Appendix F1** Add the values of Steps 2 and 3 together and insert these sums in the Item 4 spaces. This is the "tentative outdoor noise criterion." See **Appendix F** for Item 4.

NOTE:

A: No wall; outside conditions.

B: Any typical wall construction, with open windows covering about 5% of exterior wall area.

C: Any typical wall construction, with small open-air vents of about 1% of exterior wall area, all windows closed.

D: Any typical wall construction, with closed but operable windows covering about 10%-20% of exterior wall area.

E: Sealed glass wall construction, 1/4 inch thickness over approximately 50% of exterior wall area.

F: Approximately 20 lb/sq ft solid wall construction with no windows and no cracks or openings.

G: Approximately 50 lb/sq ft solid wall construction with no windows and no cracks or openings.

In a relatively noisy outdoor area, it is possible that the outdoor background sound is even higher than the "tentative outdoor noise criterion." In this case, the steady background sound in the area may mask the sound from the evaporative cooling equipment and take over as the controlling outdoor sound criterion.

The best way to judge this is to take a few sound pressure level measurements to get the average minimum background level during the quietest intervals in which the equipment is expected to operate, or during the intervals when noise complaints are most likely to be caused. For example, test at night in residential areas where cooling equipment is operating at night, or during the day in office areas exposed to daytime cooling equipment sound.

In the event that background sound measurements cannot be made, **Figure 3** and **Tables 6** and **7,** may be used to estimate the approximate outdoor background noise. **Table 6** on the following page also lists the approximations as numbers.

These estimates should be used only as approximations of background sounds, because local conditions can give rise to a wide range of actual sound levels.

Determining Sound Attenuation Requirements Example

Step 5: Determine Outdoor Background Sound. In the Item 5 spaces, enter either the measured average minimum background sound pressure levels or the estimated background levels obtained from the use of **Figure 3** and **Tables 6** and **7**. See **Appendix F** on **page J72** for Item 5. In this example, we estimate that the traffic activity is best represented by "1000-2000 ft (304.8-609.6 m) from continuous heavy-density traffic." This leads to line 22 in **Table 6** which points to curve 5 in **Figure 3**. The same curve 5 information is used to discern the octave band center frequency in **Table 7 on the following page**. These numbers are shown for you in **Appendix F1**.

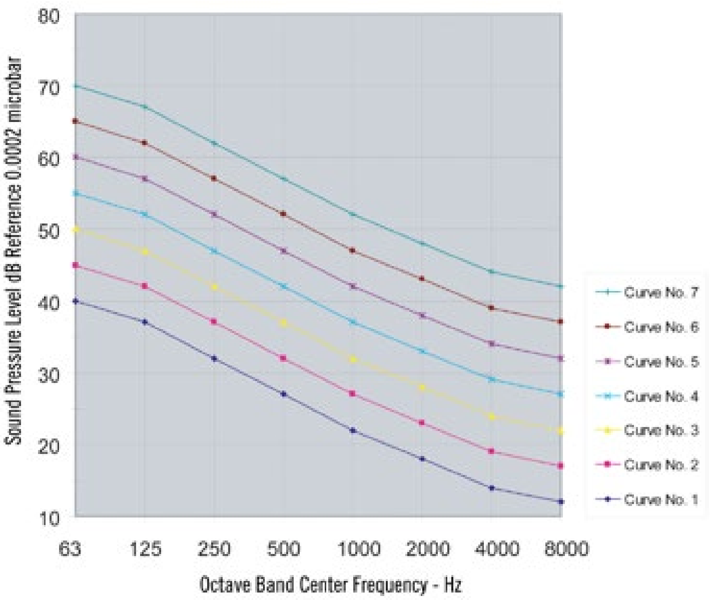


Figure 3. Approximate Average Minimum Outdoor Background Sound Pressure Levels Associated with the Conditions in **Table 6**

Table 6. Estimate of Outdoor Background Sounds Based on General Type of Community Area and Nearby Automotive Traffic Activity

Condition	Curve Number In Figure 3	Condition	Curve Number In Figure 3
1. Nighttime, rural; no nearby traffic of concern	1	13. Within 300 ft of continuous medium-density traffic	6
2. Daytime, rural; no nearby traffic of concern	2	14. Within 300 ft of continuous heavy-density traffic	7
3. Nighttime, suburban, no nearby traffic of concern	2	15. 300 to 1000 ft from intermittent light traffic	3
4. Daytime, suburban; no nearby traffic of concern	3	16. 300 to 1000 ft from continuous light traffic	4
5. Nighttime, urban; no nearby traffic of concern	3	17. 300 to 1000 ft from continuous medium-density traffic	5
6. Daytime, urban; no nearby traffic of concern	4	18. 300 to 1000 ft from continuous heavy-density traffic	6
7. Nighttime, business or commercial area	4	19. 1000 to 2000 ft from intermittent light traffic	2
8. Daytime, business or commercial area	5	20. 1000 to 2000 ft from continuous light traffic	3
9. Nighttime, industrial or manufacturing area	5	21. 1000 to 2000 ft from continuous medium-density traffic	4
10. Daytime, industrial or manufacturing area	6	22. 1000 to 2000 ft from continuous heavy-density traffic	5
11. Within 300 ft of intermittent light traffic	4	23. 2000 to 4000 ft from intermittent light traffic	1
12. Within 300 ft of continuous light traffic	5	24. 2000 to 4000 ft from continuous light traffic	2

The measured or estimated average minimum background sound levels should now be compared, band-by-band, with the "tentative outdoor noise criterion" determined previously. The larger of these values, in each frequency band, now becomes the octave band sound pressure levels that comprise the "final outdoor noise criterion" for the equipment installation.

Any new intruding sound is generally judged in comparison with the existing background sound. If the new sound stands out above the existing sound, the neighbors may notice it, be disturbed by it, and object to it. On the other hand, if the new sound can hardly be heard in the presence of the old sound, it will pass relatively unnoticed. Therefore, if the sound coming from the equipment is below or just equal to the final noise criterion, it will not be noticed and our objectives will have been satisfied.

If there are two or more different criterion for a particular installation, the analysis should be carried out for each situation and the lowest final criterion should be used.

Determining Sound Attenuation Requirements Example Continued

Step 6: Determine Final Noise Criterion. In the Item 6 spaces insert the higher value, in each frequency band, of either the Item 4 or Item 5 values. This is the "final noise criterion." At this point the values across Item 6 should read "67-58-52-47-42-39-38-37," as noted in the completed sample in **Appendix F1**.

Table 7. Octave Band Sound Pressure Levels (dB) of Outdoor Background Noise Curves in **Figure 3**

Octave Band Center Frequency in Hz	Curve Number In Figure 3						
	1	2	3	4	5	6	7
63	40	45	50	55	60	65	70
125	37	42	47	52	57	62	67
250	32	37	42	47	52	57	57
500	27	32	37	42	47	52	52
1000	22	27	32	37	42	47	48
2000	18	23	28	33	38	43	39
4000	14	19	24	29	34	39	44
8000	12	17	22	27	32	37	42

Step 7: Determine Sound Pressure Levels at the Proper Distance

The BAC Selection Program can measure the sound levels radiated by its units at various distances for the five principle directions, (four horizontal and one vertical). The sample sound rating data sheet shown in **Appendix D** indicates the five principle directions and the type of sound data available for a Series 3000 Cooling Tower at 300 ft. Sound data can be generated for different distances, as required for the application, for all BAC units in the BAC Selection Program.

Current sound data for all BAC equipment is available from your local BAC Representative and from the BAC Selection Program, available at www.BaltimoreAircoil.com.

Steps 8-11: Adjust for the Effects of Reflecting Walls

Frequently, the geometry of an installation involves some nearby reflecting walls or buildings, which adds to the acoustic complexity of the site. Let us consider this for three typical situations:

- Cases in which reflecting walls modify the radiation pattern of the sound from the unit to the neighbor
- Cases in which close-in walls confine the unit and cause a build-up of close-in sound levels
- Cases in which the unit is located in a well and all the sound radiates from the top

Determining Sound Attenuation Requirements Example Continued

Step 7: Use BAC Selection Program to Determine the Sound Pressure Levels at 300 ft. Decide on the preferred orientation of the cooling tower at the site. Using the sample data from **Appendix D**, the BAC Sound Rating Data Sheet, determine the sound pressure levels at 300 ft (91.4 m) from the side of the cooling tower facing the college classroom. Insert these sound pressure level values in the Item 7 spaces of the Sound Evaluation Work Sheet found in **Appendix F1**.

Step 8: Apply Reflection Adjustment. Had there been a sound increase due to the presence of a reflecting wall that met one of the conditions illustrated in **Appendix E**, corrections would be inserted now in the Item 8 spaces. Had this been a close-in problem involving a build-up of sound levels due to some nearby enclosing walls around the tower, "+5 dB" would have been inserted in the Item 8 spaces. Since neither of these conditions applied in this example, we insert "0" in each of the Item 8 spaces.

Effect of Reflecting Walls

There are several factors that influence the power of the reflected sound:

1. The sound radiation pattern (directivity) of the equipment
2. The radiating area of the equipment
3. The orientation of the equipment
4. The distance between the unit to the neighbors
5. The distance of the equipment to the reflecting wall
6. The area of the reflecting wall
7. Various angles of incidence and reflection between the equipment, the wall, and the neighbors

Because so many variables are involved, a simplified procedure for estimating the influence of a reflecting wall is provided. We caution that if a large surface is located near the equipment, it should be considered as a potential reflector of sound. If the equipment is oriented such that its loudest side is already facing toward the neighbor, the influence of the reflecting wall can be ignored. However, if this is not the case, these conditions must be met for the reflected sound to be of concern:

1. The area of the reflecting wall is at least three times the area of the side of the equipment that faces that wall.
2. The distance from the unit to the reflecting wall is less than half the distance from the equipment to the neighbor.
3. If a simple optical ray diagram is drawn from the center of each unit to all parts of the reflecting wall, and the reflecting rays are then drawn away from the wall, the neighbor is located within the reflected angular range as shown in **Figure E1** in **Appendix E.**
4. If each of these three conditions is met, then the sound pressure levels at the neighbor may be higher than if the wall were not there.

Determining Sound Attenuation Requirements Example Continued

Step 9: Tabulate Resultant Unit L_p at Critical Neighbor Location. Item 9 is the sum of Items 7 and 8 (see **Appendix F**, **page J72**). This is the sound pressure level of the cooling tower at the 300 ft (91.4 m) distance.

Step 10: Determine Outdoor Noise Criterion for the Critical Neighbor. To simplify the next step, copy into Item 10 the values taken from Item 6, the “Final Noise Criterion” (**Appendix F**).

Step 11: Ascertain Tentative Sound Reduction Required for Unit. Subtract the Final Noise Criterion (Item 10) from the Resultant Cooling Tower Sound Pressure Levels (Item 9). Enter this calculation into Item 11. Any positive-valued remainder represents sound excess above the criterion. Any negative-valued remainder means that the cooling tower level is below the criterion and no sound reduction is required in the frequency bank; hence, “0” is inserted in that space.

If the cooling tower levels in all eight octave bands are below the criterion values, there should be no sound problem. If two or three of the cooling tower levels exceed the criterion values by only 1, 2, or 3 dB, there will probably be no sound problem. If several octave band sound levels exceed the criterion by 5 to 10 dB, or more, a sound problem should be anticipated – the higher the sound excess, the greater likelihood there will be a problem if suitable measures are not taken.

Step 12: Adjust for the Judgment Factor of the Engineer

At this point, some remarks should be made on the overall reliability of this approach, and an opportunity should be provided for inserting a judgment factor. Since the original criterion selection was based mostly on lower range NC values for the various environments considered, the derivation presented here may be somewhat conservative. Because of this, decisions based on this approach will usually lead to acceptance of the sound from the equipment. As explained throughout the procedure, several approximations are made, such as for the sound reduction of various general types of walls, and the sound estimates of community or traffic background sounds, and others. These approximations may lead to some variability from one installation to the next, although it is believed that a small amount of variability can be accommodated by the procedure without changing the results unreasonably.

Experience shows that where the criterion is based on sleeping at night, the criterion should not be exceeded, and therefore, the conclusions reached by this procedure should be followed. However, where the criterion is based on somewhat less critical daytime activities, and the background sound frequently ranges considerably above the average minimum conditions used here, then the risk is not too great if the criterion is exceeded by about 5 dB. In such cases the criterion should not be exceeded by more than 5 dB for fear of serious objections. If it is decided to permit the sound to exceed the criterion by as much as 10 dB or more, sound reduction steps should be considered for future addition to the installation, even though they may not be included in the initial installation.

In view of the above, if the equipment's owner, architect, or engineer chooses to follow a conservative approach or even to allow for some excess sound on a particular project (that is, permit the equipment's sound to exceed the background sounds slightly and thus be identifiable and possibly disturbing to the neighbors), this opportunity is afforded in Items 12 of the Sound Evaluation Work Sheet (**Appendix F** on **page J72**).

Steps 13: Determining the Final Sound Reduction Requirement

The sound reduction required for evaporative cooling equipment is the excess of the equipment's sound pressure levels over the applicable noise criterion levels. This is shown numerically by the dB values found in Item 13 of the Sound Evaluation Work Sheet (**Appendix F**) when the particular calculation is carried out. Whether it will be a simple or complex sound reduction problem lies largely in the amount and frequency distribution of the required sound reduction. A brief discussion of sound control for evaporative cooling equipment is given in the next section.

Determining Sound Attenuation Requirements Example Continued

Step 12: Apply Judgment Factor. Insert the cooling tower owner's Judgment Factor. For a "conservative approach" insert 0 dB in the Item 12 spaces of the Work Sheet. To purposely allow the cooling tower sound to exceed the acceptable levels slightly, insert 5 dB in the Item 12 spaces.

Step 13: Tabulate Final Sound Reduction Requirement for Job. The Final Sound Reduction Requirement for the cooling tower is the difference, in each band, obtained by subtracting Item 12 from Item 10 as shown in **Appendix F1** on **page J72**. These are the attenuation values in each octave band necessary to reduce the cooling tower sound to an acceptable level.

Acknowledgment:
BAC extends its sincere appreciation to Mark E. Schaffer, P.E. (President of Schaffer Acoustics Inc of Pacific Palisades, CA) for his contributions to this article.

Evaporative Cooling Equipment Sound Control

Job conditions may allow some quieting to be obtained by strategically positioning the equipment, controlling the fan motor, installing a low sound fan option, or constructing barrier walls located between the equipment and neighbor. Additional sound reduction needs may be met with packaged attenuators or other acoustic treatments, which, in general, can achieve high frequency noise reduction rather easily but usually involve larger weight and space requirements to accomplish low frequency quieting.

EC Fans

For more information on fan and sound options available, see **page H30**.

XE Models

XE models are tailored for projects that require an extremely efficient unit. In addition to lower sound, this solution reduces energy consumption, system wiring, switch gear cost, and starter costs. With the reduction in sound levels and energy consumption. XE models are an environmentally conscious approach to reducing sound.

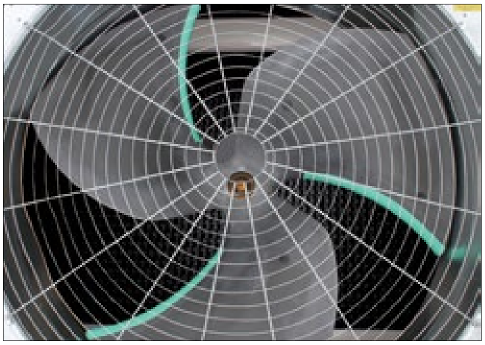
High Solidity Axial Fans

Adding a high solidity fan decreases sound levels by decreasing fan speed, which proportionally decreases sound levels. BAC offers three fan options for reduced sound pressure levels.

Standard Fan - All BAC standard fans are selected to optimize low sound levels and maximize thermal performance.

Low Sound Fan - The Low Sound Fan option reduces sound levels up to 9 dBA and has been certified in accordance with CTI Standard STD-201.

Whisper Quiet Fan - For the most extreme sound limitations, BAC's Whisper Quiet Fan can reduce sound 10-20 dBA.



Whisper Quiet Fan

An Evaporative Condenser with Full Sound Attenuation

Intake and Discharge Sound Attenuation

Factory designed, tested, and rated sound attenuation is available for both the air intake and discharge. Adding sound attenuation dampens the sound propagating from the unit.

Water Silencers

The water splashing noise produced in induced draft counterflow cooling towers can be the dominant source of sound at short distances. Water silencers reduce this noise to nearly negligible levels.

Single Sided Air Intake Units

Particularly sound-sensitive areas can be accommodated by facing the back panel to the sound-sensitive direction, reducing the propagation of sound.

Centrifugal Fan Units

Centrifugal fans have inherent low sound characteristics. The ability of centrifugal fan units to overcome higher static pressures allows for the units to be ducted. Ducting shields blade noise to further reduce sound.

BALTIGUARD™ Fan Drive System

The BALTIGUARD™ Fan System consists of two standard motors and drive assemblies. A full size motor (sized for the design conditions) and a lower horsepower motor (sized at approximately one third the horsepower of the standard motor) are connected to the same fan shaft. When operating the BALTIGUARD™ Fan System with the low horsepower motor, fan speed is reduced, leading to sound level reductions of approximately 6-8 dBA. Since periods of reduced load often coincide with requirements for lower sound levels, such as at night, the BALTIGUARD™ Fan System can often provide the desired sound reduction and is a convenient solution for meeting the needs of sound sensitive installations.

Variable Frequency Drive (VFD) Controls

The human ear picks up sharp variances in sound levels more effectively than a gradual change, so the sound generated from a unit cycled on and off is much more noticeable compared to the sound of a unit continuously operated. The “soft-start” feature provided by a VFD minimizes the start-up sound. Additionally, VFDs provide smooth acceleration to maximum speed. These features blend the evaporative cooling equipment sound levels into the background and make the units less noticeable to neighbors and building occupants.

Barrier Walls (Provided by Outside Sources)

Barrier walls dampen the noise from evaporative cooling equipment to minimize sound transmission. Barrier walls can also provide value by concealing the unit from view. Layout requirements should be taken into consideration during design to ensure that the unit has an adequate supply of fresh ambient air. BAC recommends working with an acoustical consultant in conjunction with your local BAC Representative to achieve specified sound requirements, while maintaining unit efficiency.

Series V Centrifugal Fan Single Side Air Intake Unit with Full Sound Attenuation

BALTIGUARD™ Fan Drive System

VFD Controls

Barrier Walls Being Erected Around FXV Dual Air Intake Units

Effects of Sound Reduction Options on Equipment Performance

The cost of sound attenuation, including the effect on performance, must be evaluated versus simpler methods such as over sizing the unit(s) to meet the sound criteria for a project.

To determine the most fitting sound solution, consult your local BAC Representative who can provide the most cost effective option to meet your specific needs. Note that with either low sound fans or “add-on” attenuation, lower sound levels often come at the expense of lower airflow. The system designer must ensure that the manufacturer’s ratings are adjusted to account for any decrease in thermal performance from this reduction in airflow. Thus, engineering requirements can often dictate the solution. When attempting to reduce sound, some other considerations which may affect the type of sound mitigation chosen are the site configuration (i.e. reflecting walls, receiver elevation relative to the source) and signature of the noise source (pure tone, pulsation, etc.). Evaluating a sound problem involves accounting for many variables yet there are a variety of solutions that can silence HVAC equipment to provide your sound attenuation needs.

Summary

This section provides a simple and direct evaluation method for determining whether or not a given evaporative cooling equipment installation is producing, or will produce, excess sound. It also offers some general information on methods that can be used to reduce the sound.

Current sound data for all BAC equipment is available from your local BAC Representative and from the BAC Selection Program, available at www.BaltimoreAircoil.com. Consult your local BAC Representative for specific project applications.

Appendix A

The Calculation of Sound Power Level (L_w) from Measured Sound Pressure Levels (L_p)

NOTE:

BAC recommends following the latest methodology described in the current edition of the CTI ATC-128 Test Code for Measurement of Sound from Water Cooling Towers. This methodology in Appendix A is based on CTI ATC-128 Test Code for Measurement of Sound from Water Cooling Towers, Edition 2014 or the hemispheric surface method found in ISO 3744.

Sound power is a measure of the total acoustic power radiated by a sound source. “Sound power level” is the sound power, expressed in decibels, relative to a reference power typically 10^{-12} watt.

Sound power is not directly measured as such. Instead, it is a calculated quantity and is obtained from the measurement of sound pressure levels at a suitable number of measurement positions. Even in indoor testing with reverberant or semi-reverberant rooms and a standard reference sound source, sound power level is calculated from sound pressure level measurements. In this discussion, no technical detail is given for the derivation of sound power level; instead, a very simple procedure is provided for establishing the approximate sound power level of evaporative cooling equipment for the case in which the sound pressure level is measured at four horizontal positions (each position at a specific distance from each of the four sides) plus one vertical position above the unit. The measurement positions may be at any distance between 2 and 4 times the unit’s largest dimension, which is usually its length.

The measured sound pressure levels must be obtained with accurate, calibrated equipment, and the sound data must be in the conventional eight octave bands of frequency. The measurements should be made under essentially free-field conditions: i.e., outside in an area free of any nearby reflecting surfaces. The unit is assumed to be located on the ground or on a platform reasonably close to ground level.

The approximate sound power level in each of the eight octave bands is the sum, by decibel addition, of the individual five sound pressure level readings in each octave band plus a correction term (K) which is a function of the number of measurements positions, the measurement distance and the reference power. In equation form, this can be expressed as:

$$\mathbf{Lw} = \mathbf{\Sigma Lp} + \mathbf{K}$$

The decibel summation of a number of sound pressure levels is determined from the material given in **Appendix C** and the correction terms are given in **Table A** for the appropriate conditions. The use of the five measurement positions and the decibel addition of the five readings automatically introduce the directivity characteristics of the unit into the calculated sound power level. No further provision for directivity is required in this simplified method.

To illustrate this procedure, suppose we wish to estimate the sound power level (L_w) in one octave band for the case of the five-position measurements 50 ft (15.2 m) from a cooling tower. Assume the five sound pressure levels measured in the particular frequency band are 56, 53, 59, 53, and 47 dB (reference 0.0002 microbar).

By the decibel addition method shown in **Appendix C** we find that the decibel sum of these five sound pressure levels is 62 dB. From **Table A** we then find that at 50 ft (15.2 m) measurement distance, the correction term is 25 dB reference 10^{-12} watt. For this example:

$$\begin{aligned} L_w &= \Sigma L_p + K \\ &= 62 + 25 \\ &= 87 \text{ dB} \end{aligned}$$

The same procedure could be followed for all octave bands to get the complete L_w of the cooling tower. The procedure given here is for the specific five measurement positions noted and may not be applicable generally to other situations. The procedure is not accurate to less than 1 dB, so fractional values of decibels should not be used or relied upon.

Table A. Correction Term K for L_w Reference 10^{-12} Watt (dB)

Measurement Distance to Acoustic Center (ft)	Correction Term K
25	19
30	20
35	21
40	23
45	24
50	25
60	26
70	27
80	29
90	30
100	31

Appendix B

The Calculation of Average Sound Pressure Level (L_p) for a Given Sound Power Level (L_w)

For comparative purposes it may occasionally be necessary to estimate the approximate average sound pressure level radiated by a unit for which only the sound power level is given. There are also some applications that are best appraised by converting sound power back to average sound pressure levels. The procedure outlined in this appendix will provide this estimate.

It is important to realize that the resulting value is an average sound pressure level that theoretically would be radiated the same in all directions from the unit. In practice, the unit probably would not radiate the same levels in all directions; but, when only the sound power level is given it is not possible to know the directivity characteristics of the unit.

The average sound pressure level at a desired distance is obtained by subtracting from the sound power level in any given octave frequency band the appropriate correction term (C) from **Table B1**. In equation form, this relationship is expressed as:

$$L_p \text{ Avg.} = L_w - C$$

As an illustration, suppose we wish to know the average sound pressure at a distance of 50 ft (15.2 m) for a cooling tower that is stated to have a sound power level 87 dB reference 10-12 watt. (Note that this is the counterpart of the example given in **Appendix A**). From **Table B1**, for a distance of 50 ft, we see that the correction term is 32 dB.

$$\begin{aligned} L_p \text{ Avg.} &= L_w - C \\ &= 87 - 32 \\ &= 55 \text{ dB} \end{aligned}$$

By comparing this value with the five levels used in the calculation in **Appendix A**, we see that although this is an average value, it actually does not equal any of the levels from the five measured directions. Note again that the average value is not intended to show the directivity characteristics of the sound source.

If two competitive cooling towers are being compared for a particular site condition, a comparison of the sound power level or the average sound pressure level may be a general clue to the relative sound from the two units, but a more careful comparison should take into account the actual sound levels to be radiated in the particular critical direction(s).

Table B1. Correction Term C for L_p Reference 10^{-12} Watt (dB)

Measurement Distance to Acoustic Center (ft)	Correction Term C
25	26
30	27
35	28
40	30
45	31
50	32
60	33
70	34
80	36
90	37
100	38

NOTE:

The correction term C is based on the sound radiating uniformly over a hemisphere. This would apply for a typical ground level installation or for a unit located on a large roof. If there are conditions such that the sound will radiate over a large angle, say a 3/4 sphere, add 3 dB to the above C. Subtract 3 dB from the above C for a 1/4 sphere radiation.

For distance beyond 100 ft (30.4 m) calculate the average L_p for 50 ft (15.2 m) using the method here; then extrapolate by subtracting the desired distance using the L_p reduction values of **Table B2** below.

Table B2. Reduction of Sound Pressure Level (dB) for Distances Beyond 50 ft

Distance (ft)	Octave Band Center Frequency in Hz							
	63	125	250	500	1000	2000	4000	8000
100	6	6	6	6	6	6	7	7
125	8	8	8	8	8	8	9	10
160	10	10	10	10	10	10	11	12
200	12	12	12	12	12	13	14	15
250	14	14	14	14	14	15	16	18
320	16	16	16	16	16	17	18	21
400	18	18	18	18	19	19	21	24
500	20	20	20	20	21	22	24	27
630	22	22	22	22	23	24	27	31
800	24	24	24	25	25	26	30	35
1000	26	26	26	27	27	29	34	40
1250	28	28	28	29	30	32	38	46
1600	30	30	30	31	32	35	43	53
2000	32	32	32	33	35	38	47	61
2500	34	34	34	35	38	42	53	70

Appendix C

Addition of Decibels

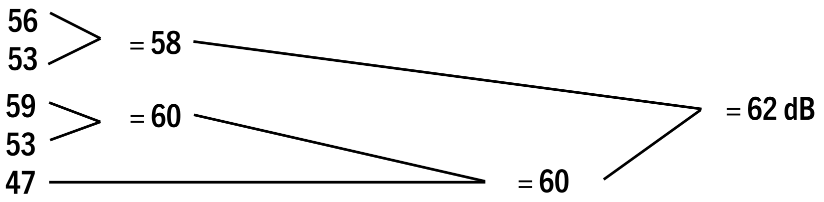
Since decibels are logarithmic values it is not proper to add them by normal algebraic addition. For example, 63 dB plus 63 dB does not equal 126 dB but only 66 dB.

A very simple, but adequate schedule for adding decibels is as follows:

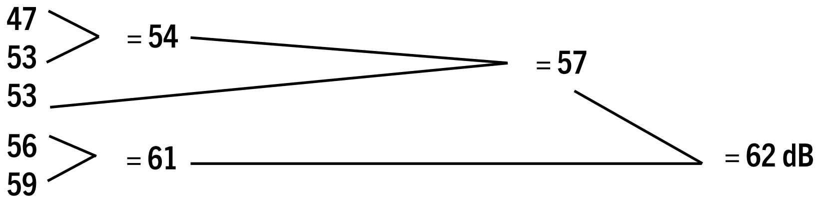
When Two Decibel Values Differ By	Add the Following Amount to the Higher Value
0 or 1 dB	3 dB
2 or 3 dB	2 dB
4 to 8 dB	1 dB
9 dB or more	0 dB

When several decibel values are to be added, perform the above operation on any two numbers at a time, the order does not matter. Continue the process until only a single value remains.

As an illustration let us add the five sound levels used in the example of **Appendix A.**



Or, suppose we arrange the same numbers in a different order, as in:



Sometimes, using different orders of adding may yield sums that might differ by 1 dB, but this is not a significant difference in acoustics. In general, the above simplified summation procedure will yield accurate sums to the nearest 1 dB. This degree of accuracy is considered acceptable in the material given in this article.

Appendix D

Baltimore Aircoil Company

Cooling Tower Selection Report

Version:	8.11.18 NA
Product data correct as of:	November 14, 2022
Project Name:	
Selection Name:	
Project State/Province:	Maryland
Project Country/Region:	United States
Date:	January 20, 2023

Model Information

Product Line: Series 3000
Model: S3E-1222-07N
Number of Units: 1
Fan Type: Standard Fan
Fan Motor: (1) 25.00 = 25.00 HP/Unit

IBC 2018 Code Compliance: No
California OSHPD Project: No
Special Seismic Certification: No
Intake Option: None
Internal Option: None
Discharge Option: None

Total Standard Fan Power: Full Speed, 25.00 BHP/Unit

Octave band and A-weighted sound pressure levels (Lp) are expressed in decibels (dB) reference 0.0002 microbar. Sound power levels (Lw) are expressed in decibels (dB) reference one picowatt. Octave band 1 has a center frequency of 63 Hertz.

Top
Sound Pressure (dB)

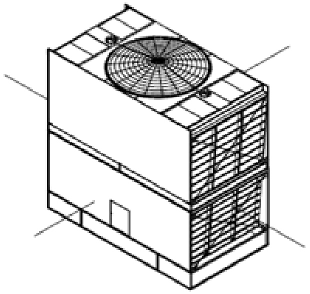
Octave	Distance	
Band	5 ft.	50 ft.
1	85	74
2	86	74
3	84	74
4	81	68
5	78	63
6	72	59
7	68	54
8	67	51
A-wgtd	**83**	**70**

Air Inlet
Sound Pressure (dB)

Octave	Distance	
Band	5 ft.	50 ft.
1	82	68
2	83	67
3	82	69
4	75	65
5	69	60
6	63	52
7	58	46
8	55	43
A-wgtd	**77**	**66**

End
Sound Pressure (dB)

Octave	Distance	
Band	5 ft.	50 ft.
1	78	72
2	79	66
3	76	68
4	69	62
5	65	57
6	57	49
7	50	43
8	48	39
A-wgtd	**72**	**64**



End
Sound Pressure (dB)

Octave	Distance	
Band	5 ft.	50 ft.
1	78	72
2	79	66
3	76	68
4	69	62
5	65	57
6	57	49
7	50	43
8	48	39
A-wgtd	**72**	**64**

Air Inlet
Sound Pressure (dB)

Octave	Distance	
Band	5 ft.	50 ft.
1	82	68
2	83	67
3	82	69
4	75	65
5	69	60
6	63	52
7	58	46
8	55	43
A-wgtd	**77**	**66**

Total Sound Power (dB)

Octave Band	Center Frequency (Hertz)	Lw
1	63	106
2	125	106
3	250	106
4	500	100
5	1000	95
6	2000	91
7	4000	86
8	8000	83
A-wgtd		**102**

Note: The use of frequency inverters (variable frequency drives) can increase sound levels.
Extra Notes: Sound data provided by CTI ATC-128 sound test code revision 2019

Appendix E

Figures For Single Air Intake Units

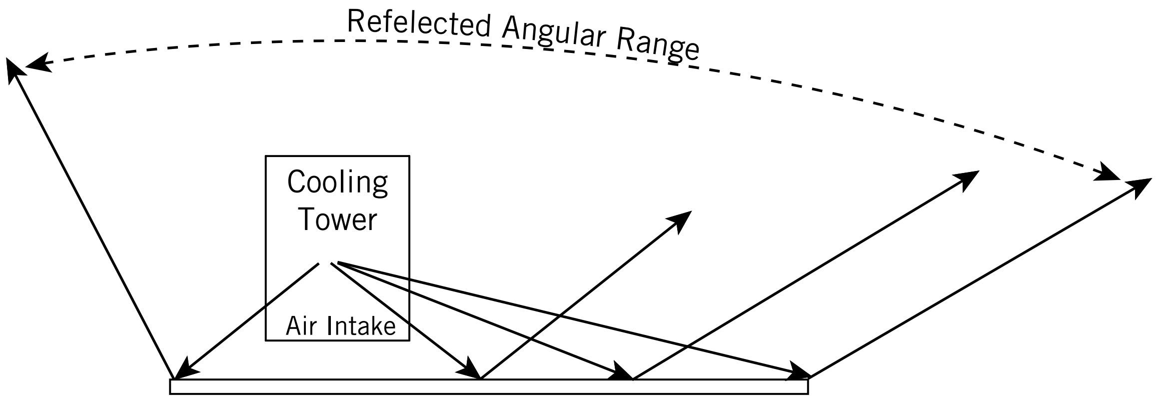
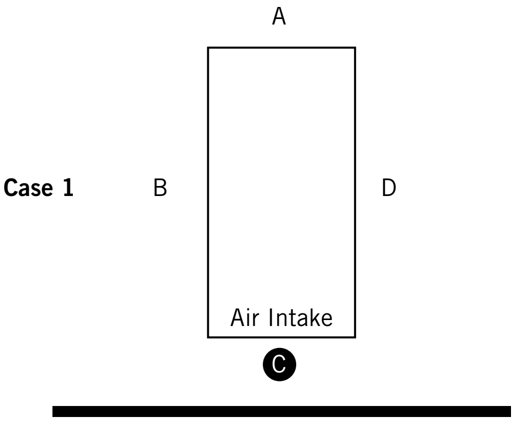


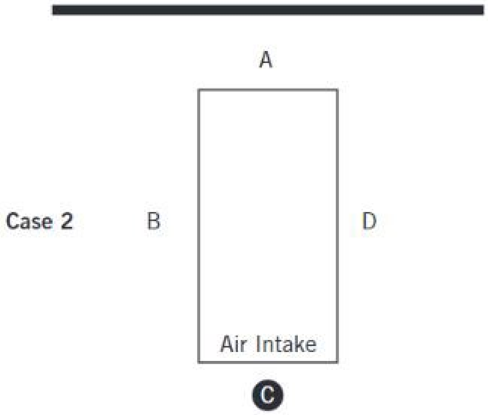
Figure B1. Neighbor area influenced by the reflecting wall

In **Cases 1-10**, a few representative reflecting walls are shown for various orientations, and approximate sound pressure level adjustments are suggested for **A, B, C,** and **D** directions away from the equipment. These adjustments should be made using the 50 ft (15.2 m). **Cases 1-6 apply to units having one air intake, while Cases 7-10 apply to units having two air intakes. Cases 11-13 apply to PT2, PFi and PCC units which have air intakes on all four sides.**

As an example, for Case 1, if the neighbor is located off the A side of the unit, apply the "A" adjustment to the A side 50 ft (15.2 m) sound pressure level rating of the unit and then correct as necessary to the neighbor's distance. If the situation is that of Case 9 and the neighbor is located in the direction D, then the "D" adjustment would be utilized to arrive at a 50 ft sound pressure level for the unit.

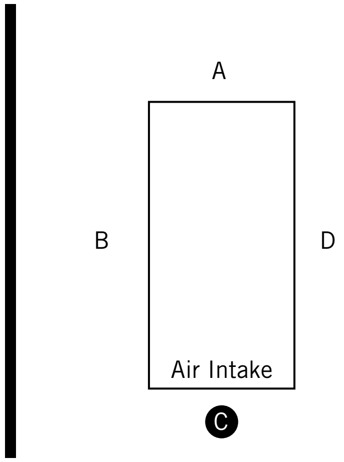


A. Use average of A and C levels
B. Use average of B and C levels
C. Not applicable
D. Use average of D and C levels



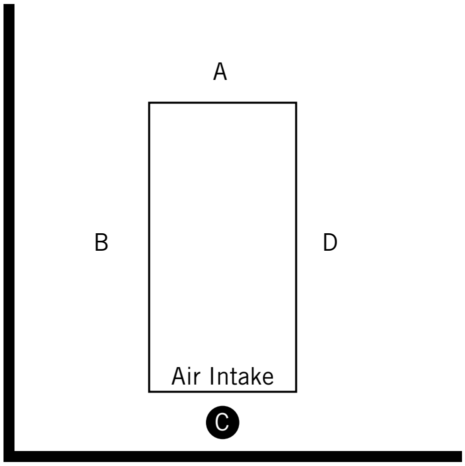
A. Not applicable
B. Use greater of B level or average of B and A levels
C. No change to C levels
D. Use greater of D level or average of D and A levels

Case 3



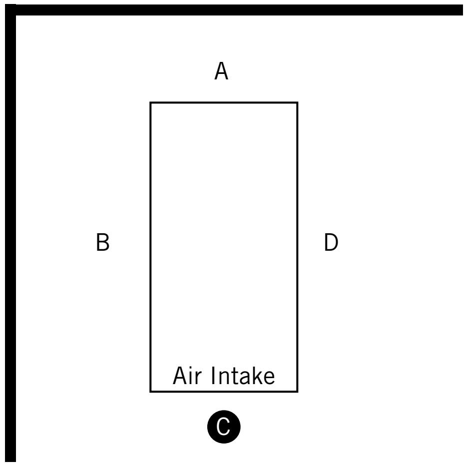
A. Use greater of A level or average of A and B levels
B. Not applicable
C. No change to C levels
D. Add 2 dB to D levels

Case 4



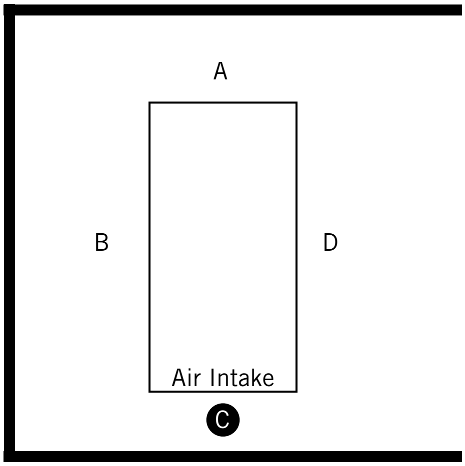
A. Use average of A and C levels
B. Not applicable
C. Not applicable
D. Use average of D and C levels

Case 5



A. Not applicable
B. Not applicable
C. No change to C levels
D. Use average of A, C, D levels

Case 6

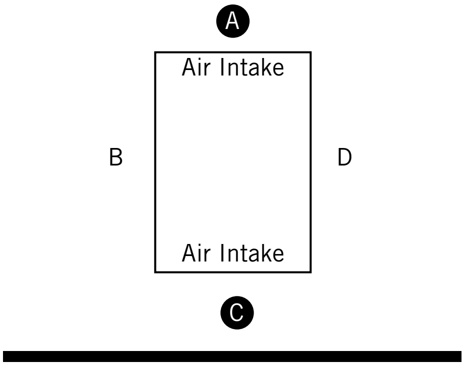


For sound levels out the open end of a 3-sided enclosure, add 3 dB to the sound pressure levels of the air intake side of the unit.

Appendix E

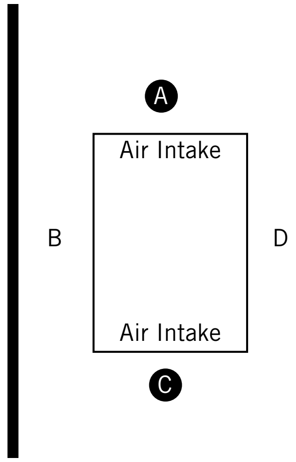
Figures For Dual Air Intake Units

Case 7



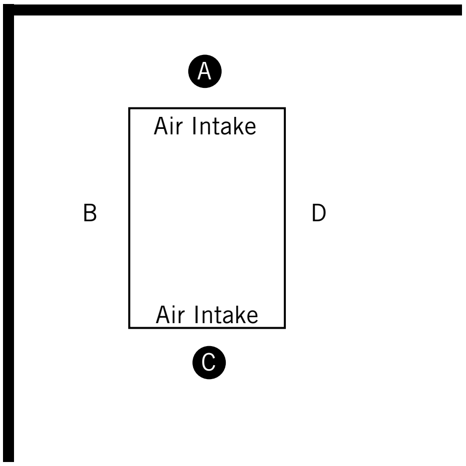
A. Add 2 dB to A levels
B. Use average of B and C levels
C. Not applicable
D. Use average of C and D levels

Case 8



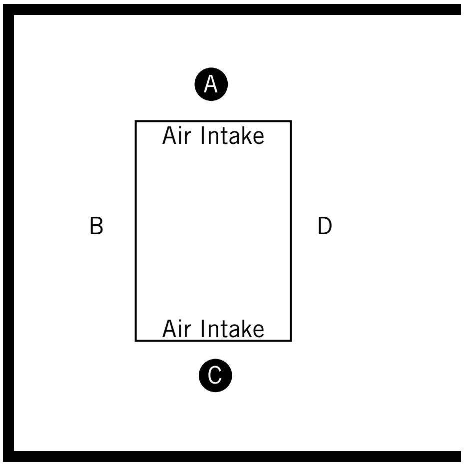
A. No change to A levels
B. Not applicable
C. No change to C levels
D. Add 3 dB to D levels

Case 9



A. Not applicable
B. Not applicable
C. Add 2 dB to C levels
D. Add 3 dB to D levels

Case 10



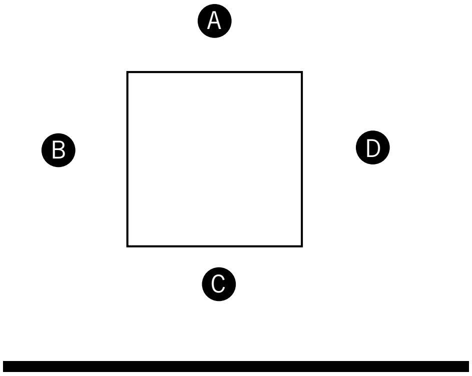
For sound levels out the open end of a 3-sided enclosure, add 3 dB to the sound pressure levels of the air intake side(s) of the unit.

These figures and their associated adjustment values are to be used to correct base 50 ft sound pressure level ratings in the neighbor direction for the effect of the reflecting surface conditions shown. Instructions on when and how to do so are presented on **page J54**.

Appendix E

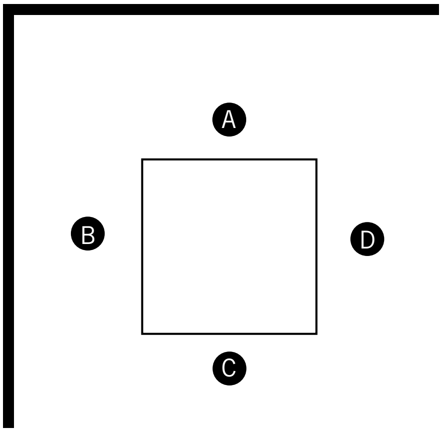
Figures For PT2, PFi, and PCC Quad Intake Units

Case 11



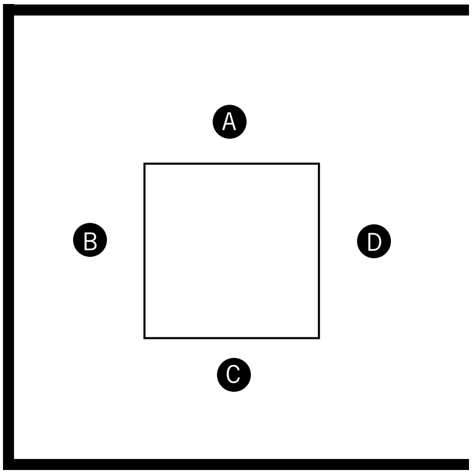
A. Add 3 dB to A levels
B. Add 2 dB to B levels
C. Not applicable
D. Add 2 dB to D levels

Case 12



A. Not applicable
B. Not applicable
C. Add 3 dB to C levels
D. Add 3 dB to D levels

Case 13



For sound levels out the open end of a 3-sided enclosure, add 5 dB to the sound pressure levels of D, the exposed air intake side of the unit.

NOTE:

PT2, PFi, and PCC units have air intakes on all four sides.

Appendix F1

BAC Sound Evaluation Worksheet:

Sample Using the Running Example from **Page J51 to J58**

Job Name Example

Date

Address

Engineer

Architect

BAC Unit

Steps	Items	Octave Band Center Frequency in Hz							
		63	125	250	500	1000	2000	4000	8000
Noise Criterion	1. Determine appropriate "NC" Criterion for neighbor activity from ASHRAE Handbook or **Table 3** of this section.	NC =30							
	2. Insert sound pressure levels (Lp) for selected "NC" Criterion (Obtain values from **Table 4**).	57	48	41	35	31	29	28	27
	3. Tabulate sound reduction provided by wall construction (Obtain values from **Table 5**).	10	10	10	10	10	10	10	10
	4. Establish tentative outdoor Noise Criterion for the unit (Item 2 plus Item 3).	67	58	51	45	41	39	38	37
	5. List average minimum outdoor background sound levels (Measured, or estimated from **Figure 3** and **Tables 6** and 7).	60	57	52	47	42	38	34	32
	6. Set final outdoor background Noise Criterion (high value, by octave band, of Items 4 and 5).	67	58	52	47	42	39	38	37
Sound Levels	7. Enter unit sound pressure level rating at 300 ft from the BAC selection program. This sample uses the End L_p ratings from the data sheet provided in **Appendix D.**	55	49	51	45	41	32	27	23
	8. Apply reflection adjustment to meet condition existing at unit site. Refer to **Appendix E** for the effects of reflecting of walls; or add 5dB for close-in build up of noise; 0 dB if no reflection effects.	0	0	0	0	0	0	0	0
	9. Tabulate resultant unit Lp at critical neighbor location (Item 7 plus Item 8).	55	49	51	45	41	32	27	23
Comparison, Criteria vs Levels	10. Copy item 6 levels from above. This is the outdoor noise criterion for the critical neighbor.	67	58	52	47	42	39	38	37
	11. Ascertain tentative sound reduction required for unit (Item 9 minus Item 10). Insert "0" for negative values.	12	9	1	2	1	7	11	14
	12. Apply judgment factor (For conservative approach, use "0" in all bands. To permit unit noise to exceed background levels slightly, insert "5").	0	0	0	0	0	0	0	0
	13. Tabulate final sound reduction requirement for the job (Item 11 minus Item 12).	12	9	1	2	1	7	11	14

Appendix F2

BAC Sound Evaluation Worksheet

Job Name ______________________________

Address ______________________________

Architect ______________________________

Date ______________________________

Engineer ______________________________

BAC Unit ______________________________

Steps	Items	Octave Band Center Frequency in Hz							
		63	125	250	500	1000	2000	4000	8000
Noise Criterion	1. Determine appropriate "NC" Criterion for neighbor activity from ASHRAE Handbook or **Table 3** of this section.	**NC** =							
	2. Insert sound pressure levels (Lp) for selected "NC" Criterion (Obtain values from **Table 4**).								
	3. Tabulate sound reduction provided by wall construction (Obtain values from **Table 5**).								
	4. Establish tentative outdoor Noise Criterion for the unit (Item 2 plus Item 3).								
	5. List average minimum outdoor background sound levels (Measured, or estimated from **Figure 3** and **Tables 6** and **7**).								
	6. Set final outdoor background Noise Criterion (high value, by octave band, of Items 4 and 5).								
Sound Levels	7. Enter unit sound pressure level rating at 300 ft from the BAC selection program. Enter the unit sound pressure level at the desired distance from the BAC Selection Software.								
	8. Apply reflection adjustment to meet condition existing at unit site. Refer to **Appendix E** for the effects of reflecting of walls; or add 5dB for close-in build up of noise; 0 dB if no reflection effects.								
	9. Tabulate resultant unit Lp at critical neighbor location (Item 7 plus Item 8).								
Comparison, Criteria vs Levels	10. Copy item 6 levels from above. This is the outdoor noise criterion for the critical neighbor.								
	11. Ascertain tentative sound reduction required for unit (Item 9 minus Item 10). Insert "0" for negative values.								
	12. Apply judgment factor (For conservative approach, use "0" in all bands. To permit unit noise to exceed background levels slightly, insert "5").								
	13. Tabulate final sound reduction requirement for the job (Item 11 minus Item 12).								