TRANE

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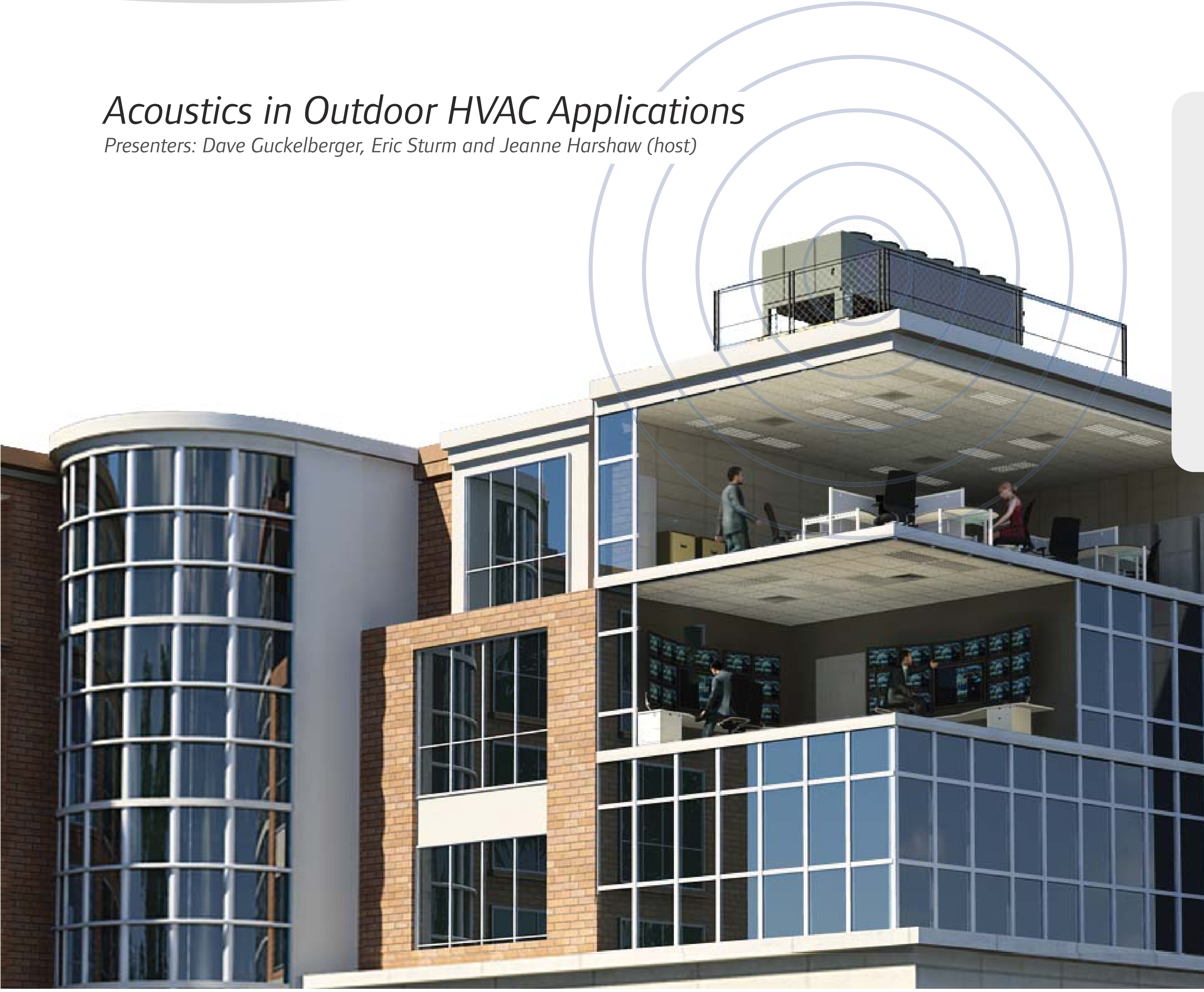

Acoustics in Outdoor HVAC Applications

Presenters: Dave Guckelberger, Eric Sturm and Jeanne Harshaw (host)

CONTINUING EDUCATION AIA

GBCI CMP

Ingersoll Rand

Trane program number: APP-CMC060-EN

Agenda

Trane *Engineers Newsletter Live* Series

Acoustics in Outdoor HVAC Applications

Abstract

Acoustics in Outdoor Applications reviews the analysis steps required to avoid noise complaints caused by outdoor HVAC equipment. Topics include equipment and sound attenuation selection, equipment location, sound ordinances, barrier walls, reflective surfaces and sound power to sound pressure conversion calculations.

Presenters: Trane engineers Dave Guckelberger and Eric Sturm

After viewing attendees will be able to:

1. Identify common sound ordinance language.
2. Apply the source-path-receiver model to correct sound power data for distance.
3. Understand complicating factors to simple outdoor sound correction.
4. Identify and incorporate methods for outdoor sound attenuation.

Agenda

- Sound targets
- Source-path-receiver model
- Complicating factors and assumptions
- Dealing with complications
- Attenuation options
- Acoustic barrier complications
- Summary

Presenter biographies

Acoustics in Outdoor HVAC Applications

Dave Guckelberger | applications engineer | Trane

Dave's expertise includes acoustic analysis and modeling of HVAC systems, electrical distribution system design, and the refrigeration system requirements established by ASHRAE Standard 15. He also provides research and interpretation on how building, mechanical, and fire codes impact HVAC equipment and systems. In addition to traditional applications engineering support, Dave has authored a variety of technical articles on subjects ranging from acoustics to ECM motors to codes.

Dave is a past president of the Wisconsin Mechanical Refrigeration Code Council and has served on several ASHRAE committees at the national level. After graduating from Michigan Tech with a BSME in thermo-fluids, he joined Trane as a development engineer in 1982 and moved into his current position in Applications Engineering in 1987.

Eric Sturm | applications engineer | Trane

Eric joined Trane in 2006 after graduating from the University of Wisconsin – Platteville with a Bachelor of Science degree in mechanical engineering. Prior to joining the applications engineering team, he worked in the Customer Direct Services (C.D.S.) department as a marketing engineer and product manager for the TRACE™ 700 load design and energy simulation software application. As a C.D.S. marketing engineer he supported and trained customers globally. In his current role as an applications engineer, Eric's areas of expertise include acoustics, airside systems, and standards and codes.

Eric is currently involved with ASHRAE at the local chapter as president and nationally as member of the "Global Climate Change" and "Sound and Vibration" technical committees. In 2015, Eric was named recipient of the Young Engineers in ASHRAE Award of Individual Excellence for service to the La Crosse Area Chapter of ASHRAE.

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Learning Objectives

- Identify common sound ordinance language.
- Apply the source-path-receiver model to correct sound power data for distance.
- Understand complicating factors to simple outdoor sound correction.
- Identify and incorporate methods for outdoor sound attenuation.

AGENDA

- Sound targets
- The source-path-receiver model
- Complicating factors and assumptions
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Today's Presenters

Dave Guckelberger
Applications Engineer

Eric Sturm
Applications Engineer

Example Lot Line Sound Ordinance

18.10.010 Land Use Zones.

PERMISSIBLE SOUND LEVELS

(7 am-10 pm, otherwise minus 5 dBA)

		Zone Categories of Receiver (measured at property line)			
Zone Categories of Source		Residential	Open Space	Commercial	Industrial
	Residential	55	55	60	65
	Open Space	55	55	60	65
	Commercial	60	60	70	70
	Industrial	65	65	70	75

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this
night

Example Lot Line Sound Ordinance

TABLE 8.060E

TABLE OF ZONING DISTRICT NOISE STANDARDS

Maximum Allowable Octave Band Sound Pressure Levels

Octave Band Center Frequency Measurement (Hz)	Residential Area		Residential in Industrial		Commercial Area	Industry Area
	Daytime	Other Time	Daytime	Other Time	Anytime	Anytime
31.5	76	68	79	72	79	83
63	75	67	78	71	78	82
125	69	61	73	65	73	77
250	62	52	68	57	68	73
500	56	46	62	51	62	67
1,000	50	40	56	45	56	61
2,000	45	33	51	39	51	57
4,000	40	28	47	34	47	53
8,000	38	26	44	32	44	50
Single Number Equivalent (dB(A)	60	50	65	55	65	70

Daytime hours: 7:00 a.m. – 6:00 p.m.

Nighttime hours: 6:00 p.m. – 7:00 a.m.

Classroom Site Requirement

space requirement + transmission loss (TL) = site requirement


AGENDA
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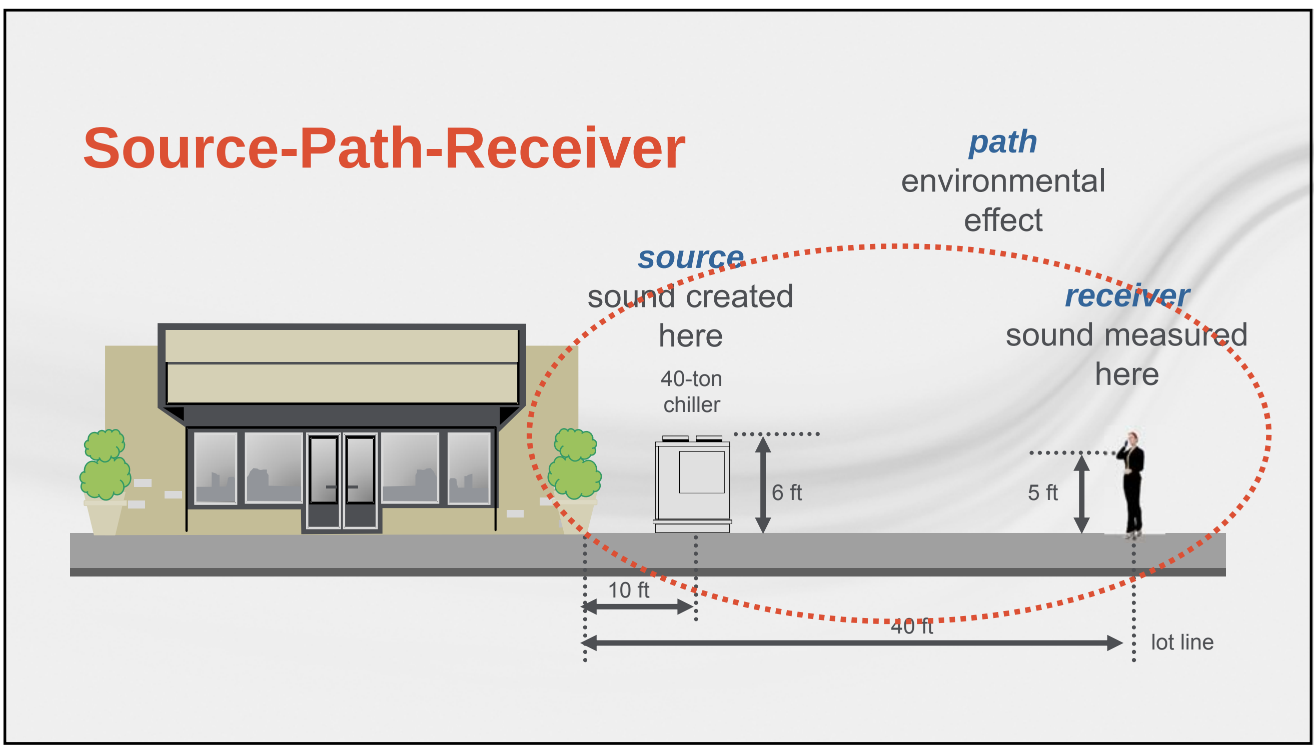
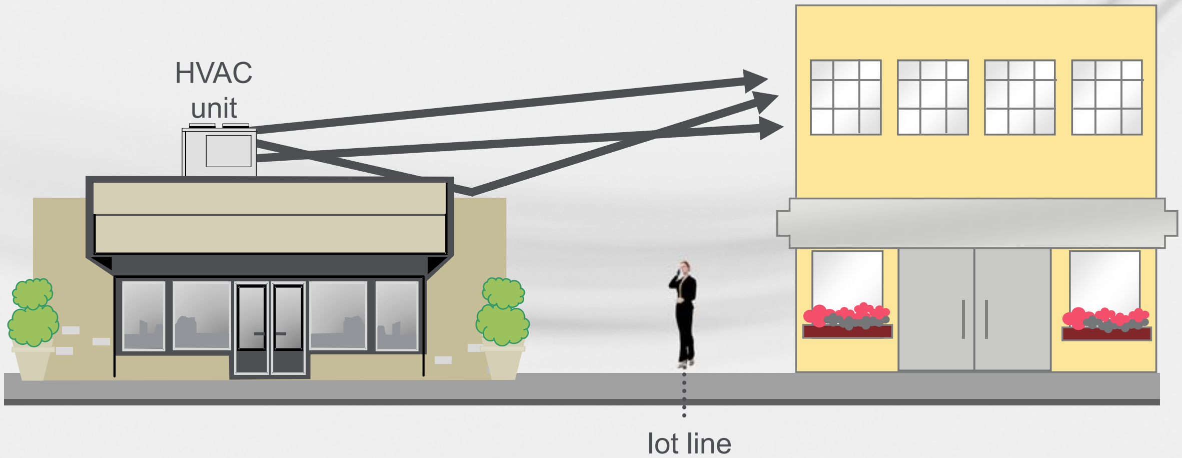
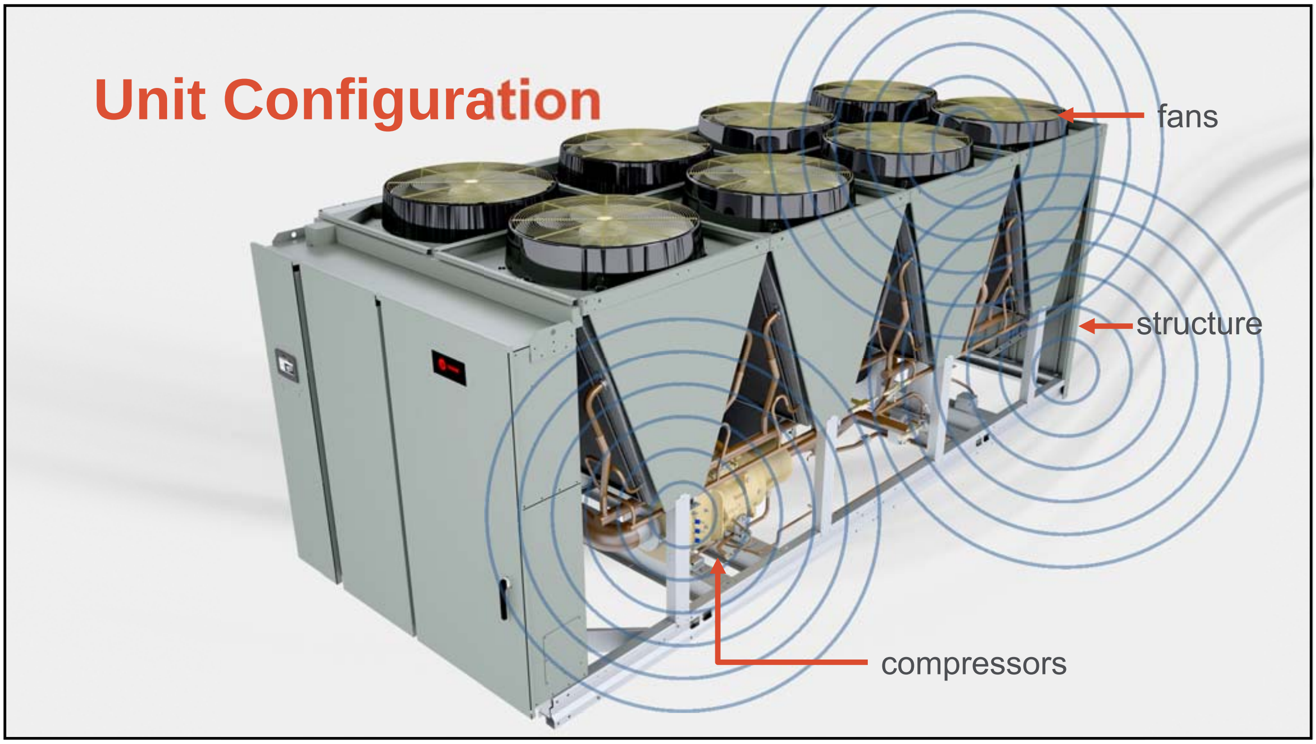

Source-Path-Receiver
path
environmental
effect
source
sound created
here
40-ton
chiller
6 ft
receiver
sound measured
here
5 ft
10 ft
40 ft
lot line

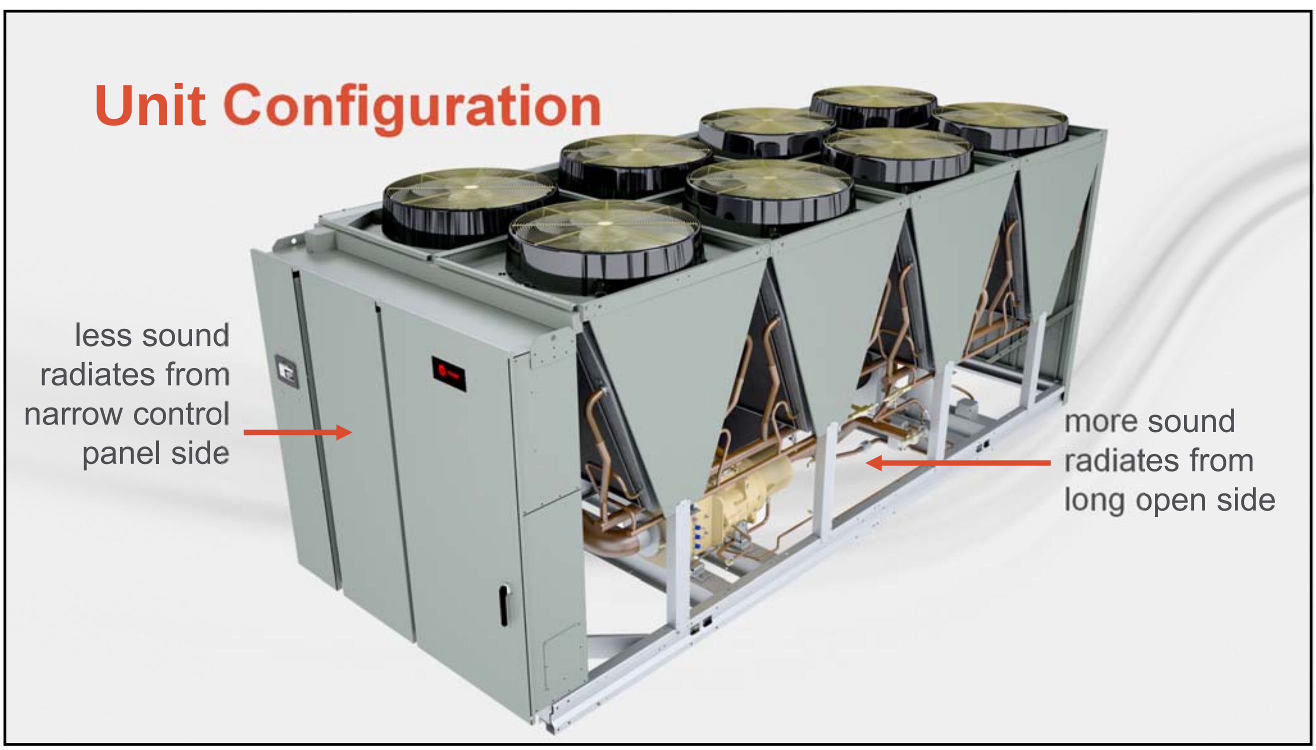
Outdoor Sound



Prediction Complications

- Receiver well above source
  - Sound tests miss some upward radiated sound
  - Predicted sound will be lower than actual
- Understand target requirements
  - Lot line vs. neighboring property
  - Allowance for existing sound


Unit Configuration
fans
structure
compressors


Unit Configuration
less sound radiates from narrow control panel side
more sound radiates from long open side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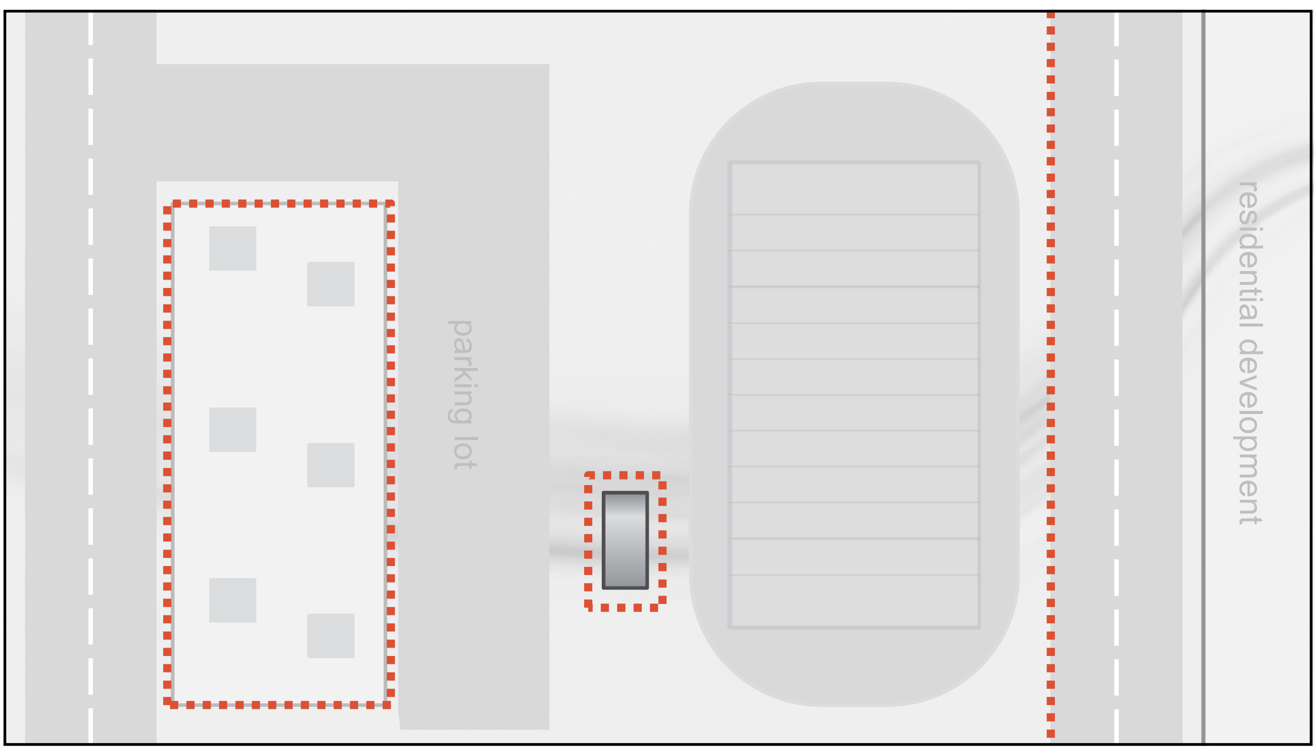
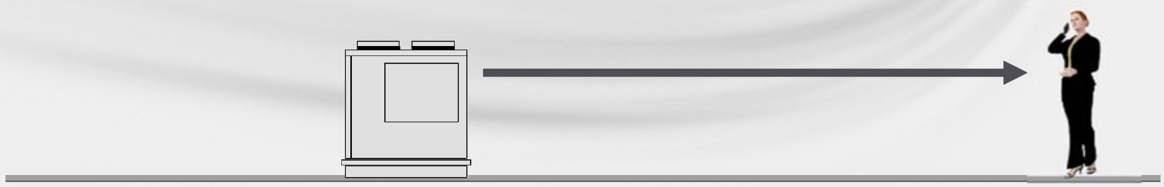

parking lot
residential development

Sound Power to Pressure Conversion

$$L_P = L_W + 10 \log (Q) - 20 \log (d) + 0.7$$

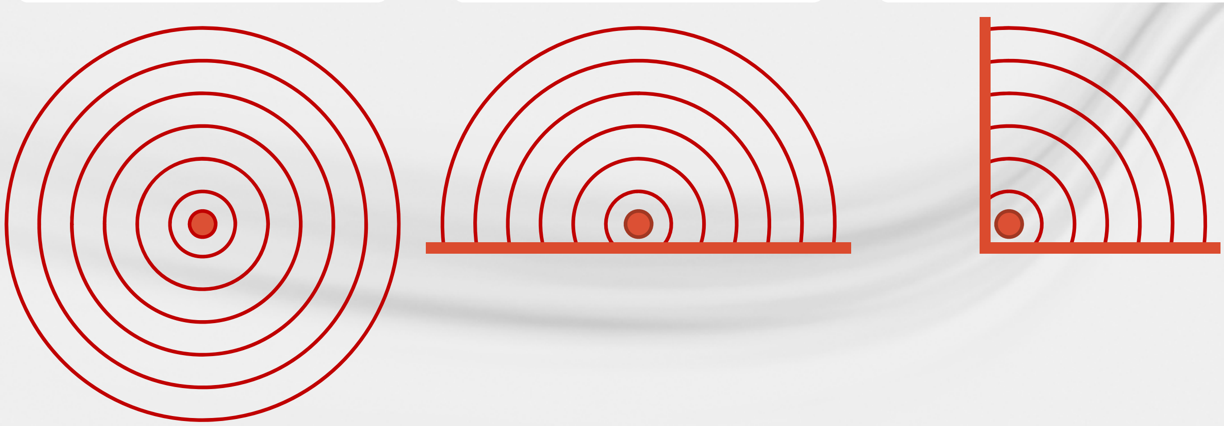


Sound Radiation and Directivity (Q)

Point source in space

Point source on a plane

Point source
in quarter space

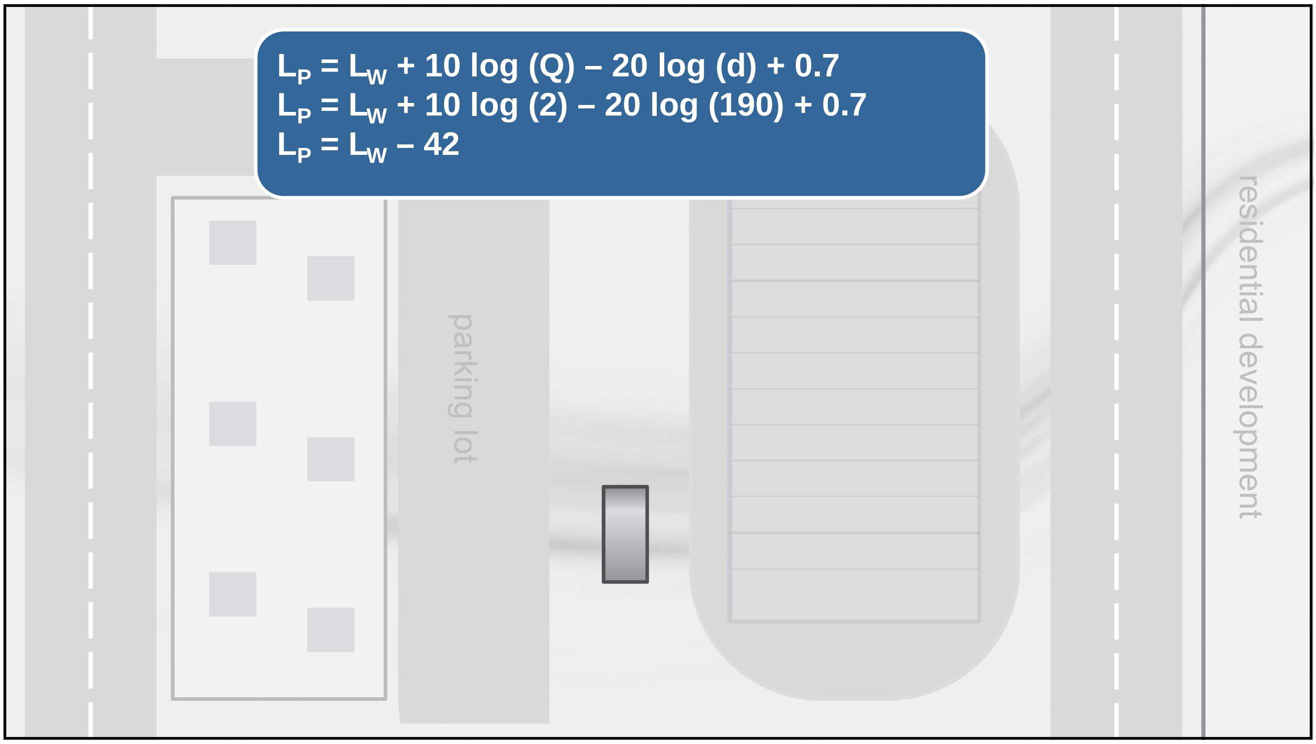


Q=1; 10×Log (1) = 0

Q=2; 10×Log (2) = 3

Q=4; 10×Log (4) = 6

$$L_P = L_W + 10 \log (Q) - 20 \log (d) + 0.7$$
$$L_P = L_W + 10 \log (2) - 20 \log (190) + 0.7$$
$$L_P = L_W - 42$$



Corrected Sound Pressure

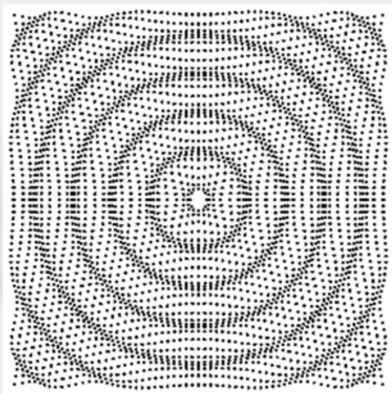
	63	125	250	500	1000	2000	4000	8000
Chiller L_W	95	101	98	97	97	90	83	77
Dist. Corr	-42	-42	-42	-42	-42	-42	-42	-42
L_P	53	59	56	55	55	48	41	35
A-Weighted								58 dBA

Prediction Complications

- Sound data
  - Quality: poor data = poor prediction
  - Start with sound POWER, not sound pressure
  - Data per AHRI 270 or AHRI 370
  - Units are rated at full load conditions
- Full load not always loudest operating point
  - Part load factors
  - Ambient conditions

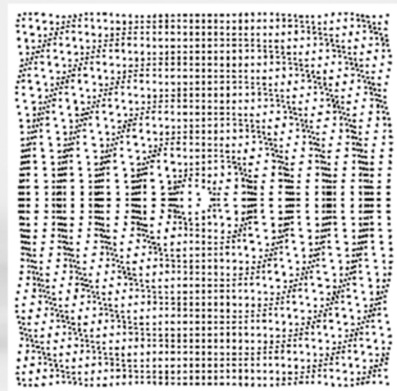
Sound Radiation From Point Source(s)

Point source



Uniform sound field

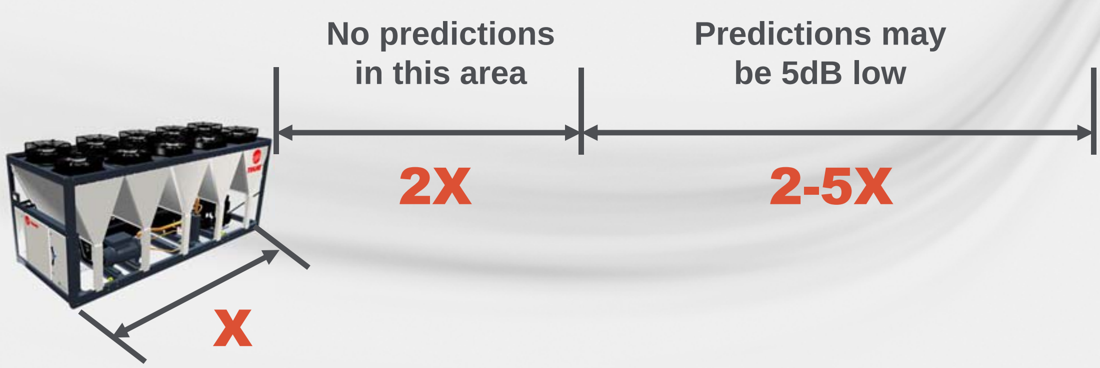
Two adjacent sources



Uneven sound field

Animation courtesy of Dr. Dan Russell, Grad. Prog. Acoustics, Penn State

Avoid Near Field Predictions



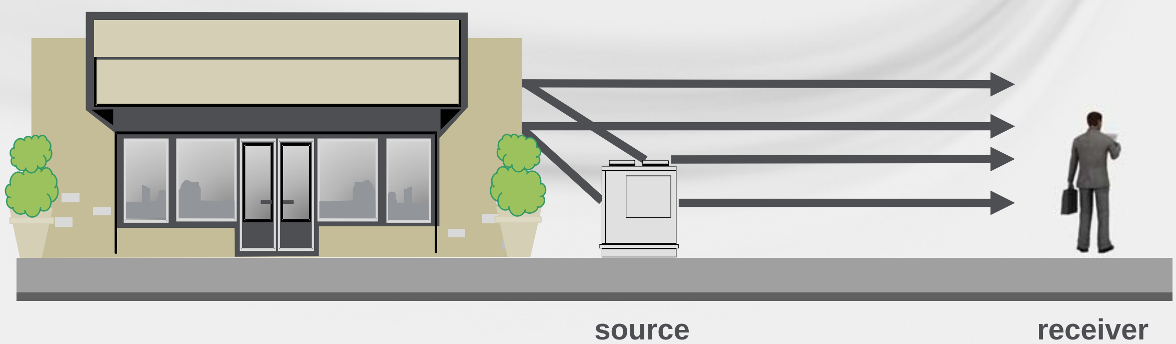
Prediction Complications

- Unit sound sources
  - Sound radiates from many areas
  - None resemble point sources
- Overlapping sound fields
  - Create unstable area called the near field
  - Predictions in near field difficult
- Acoustical effects of sound field
  - Reflective surfaces
  - Barriers

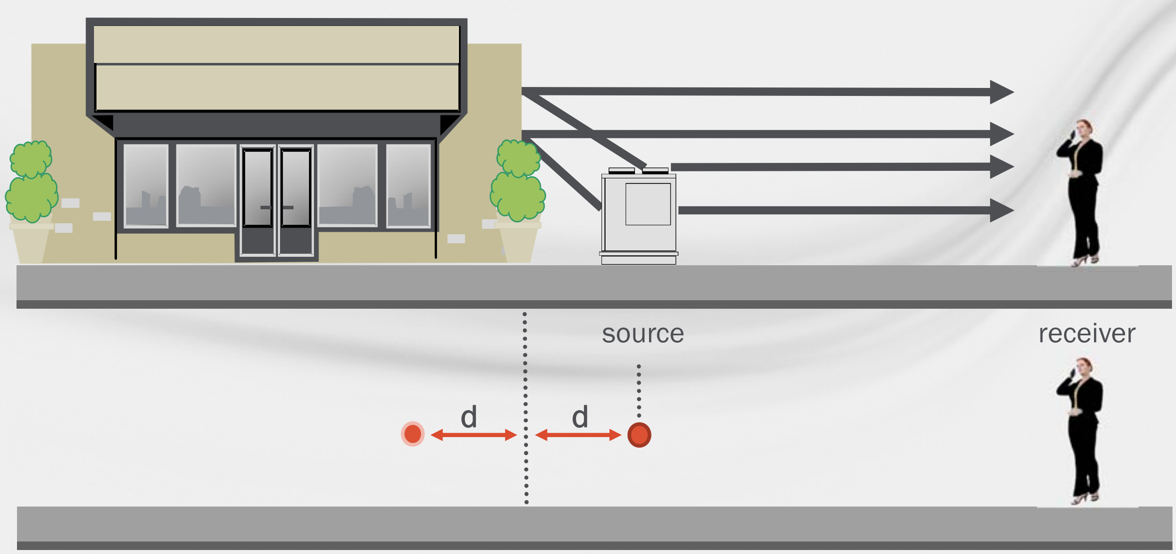
AGENDA

- Sound targets
- The source-path-receiver model
- Complicating factors and assumptions
- **Dealing with complications**
- Attenuation options
- Acoustic barrier complications
- Summary

Sound Reflected Toward Receiver



Sound Reflected Toward Receiver




Sound Reflected Away From Receiver
source
receiver


Complicated acoustical environment


AGENDA
• Sound targets
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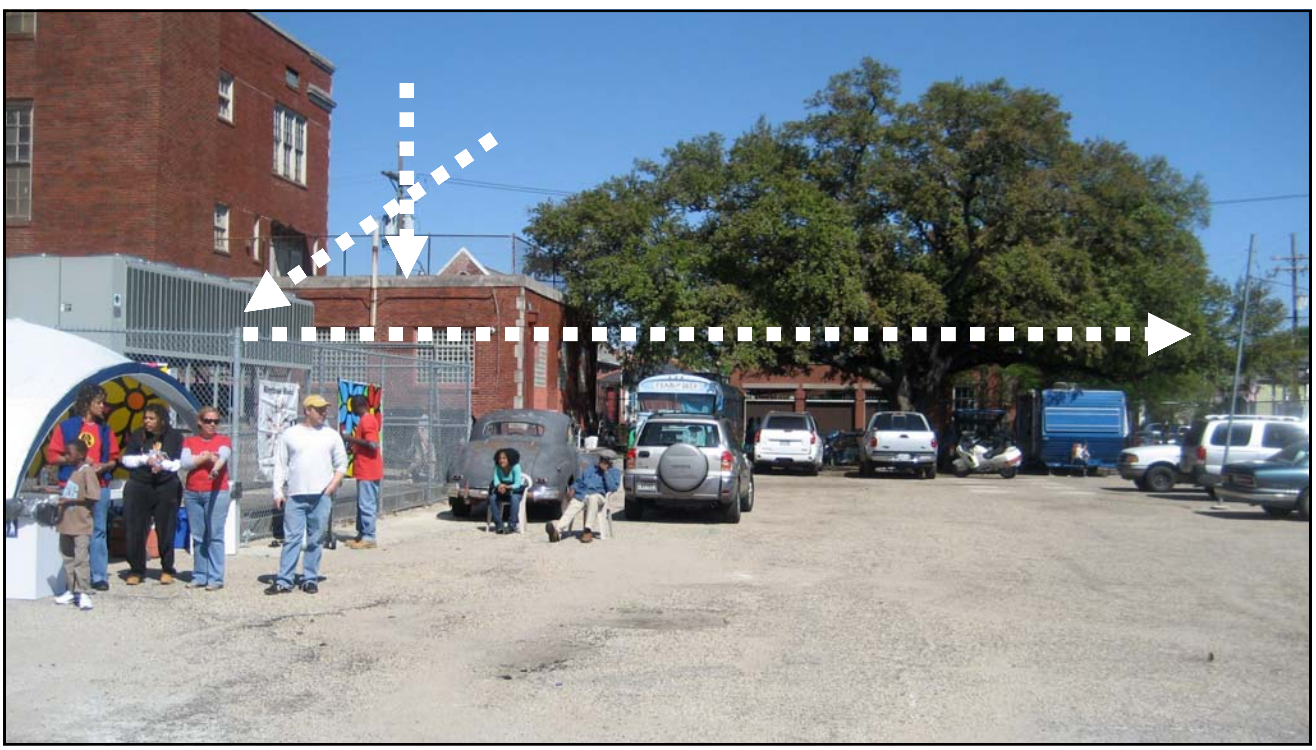
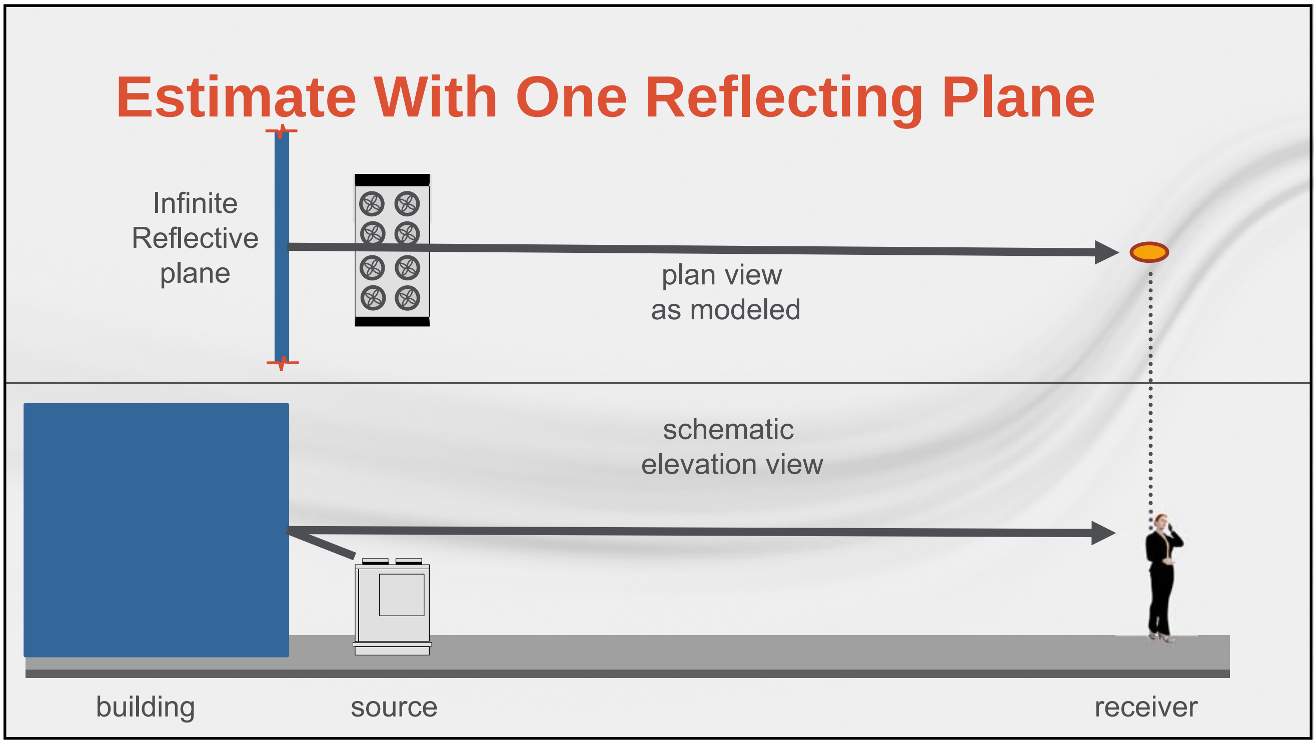
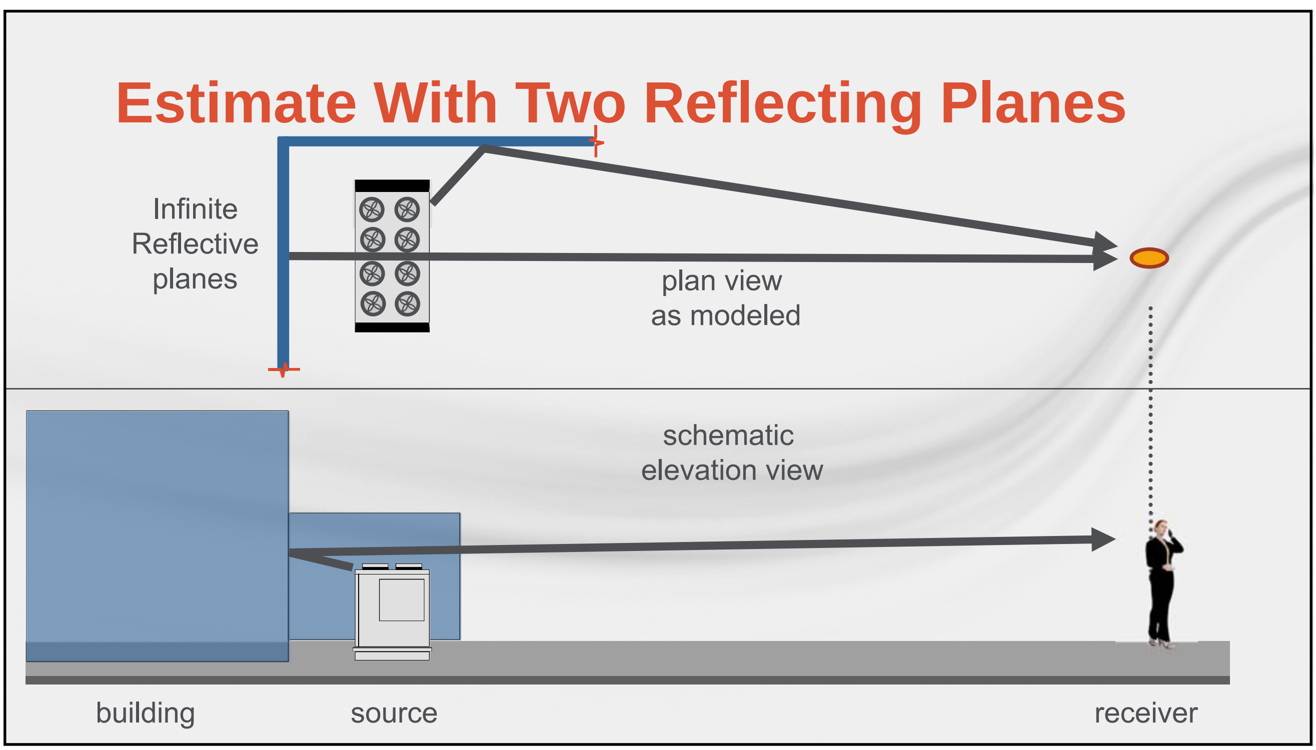


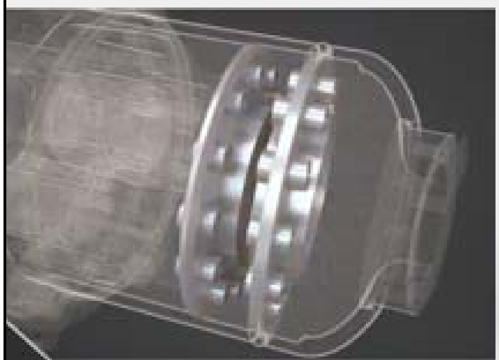

Estimate With One Reflecting Plane
Infinite
Reflective
plane
plan view
as modeled
schematic
elevation view
building
source
receiver

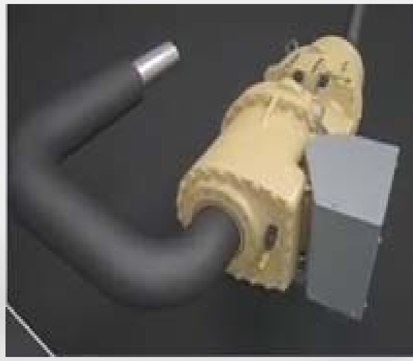

Estimate With Two Reflecting Planes
Infinite
Reflective
planes
plan view
as modeled
schematic
elevation view
building
source
receiver

Estimates vs. Target

- High estimate lower than target
  - No further attenuation required
- Low estimate higher than target
  - Need to reduce source sound
- Target between the two estimates
  - Further analysis required

Factory-Tested Sound Options





1 Mufflers

2 Suction and discharge wraps

3 Compressor wraps

Example Manufacturer Data

Table 1. Sound pressure levels (Lp, in dBA)[(a)] - 10m from center of broad sides of chiller

Unit Size[(b)]	InvisiSound[(c)] Option					
	Std	Superior	Ultimate			
	920 rpm	825 rpm	700 rpm	650 rpm	600 rpm	920 rpm
AHRI Rating Point - 100% Load						
150S	72	68	63	62	60	70
165S	74	69	65	64	63	71
150	72	68	63	61	60	70
165	74	70	63	62	60	71
180	73	69	63	62	60	71
200	72	70	64	62	60	70
225	72	69	64	62	60	72
250	73	70	64	63	61	72
275	74	70	66	65	64	73
300	75	71	66	65	63	73

(a) A-weighted sound pressure level, dBA, ref 20 micro Pa. Measurement at 30 ft (10m) distance from unit.
(b) Data for 150S and 165S units are estimates.
(c) Sound option is indicated in Model Number digit 12.
Standard Unit Digit 12 = 1. InvisiSound Superior Digit 12 = 2.
InvisiSound Ultimate Digit 12 = 3.

School Example – Factory Attenuation

	63	125	250	500	1000	2000	4000	8000
Chiller L_W	94	98	95	93	93	87	80	75
Dist. Corr	-42	-42	-42	-42	-42	-42	-42	-42
L_P	52	56	53	51	51	45	38	33
A-Weighted								55 dBA

Field Modifications

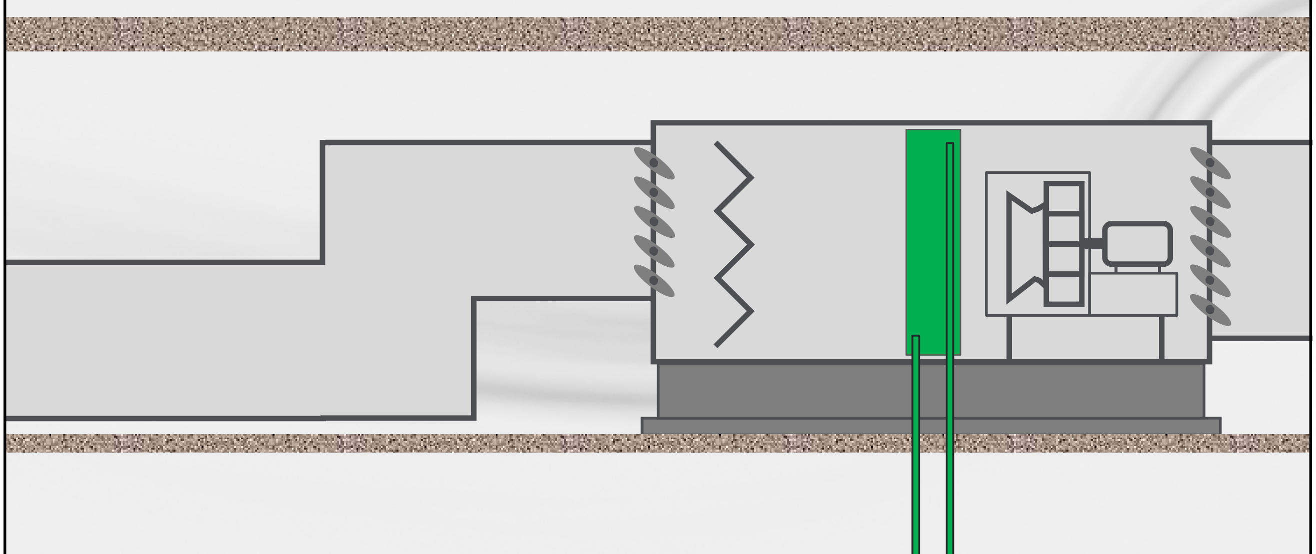
Field Modifications – Compressor Wrap

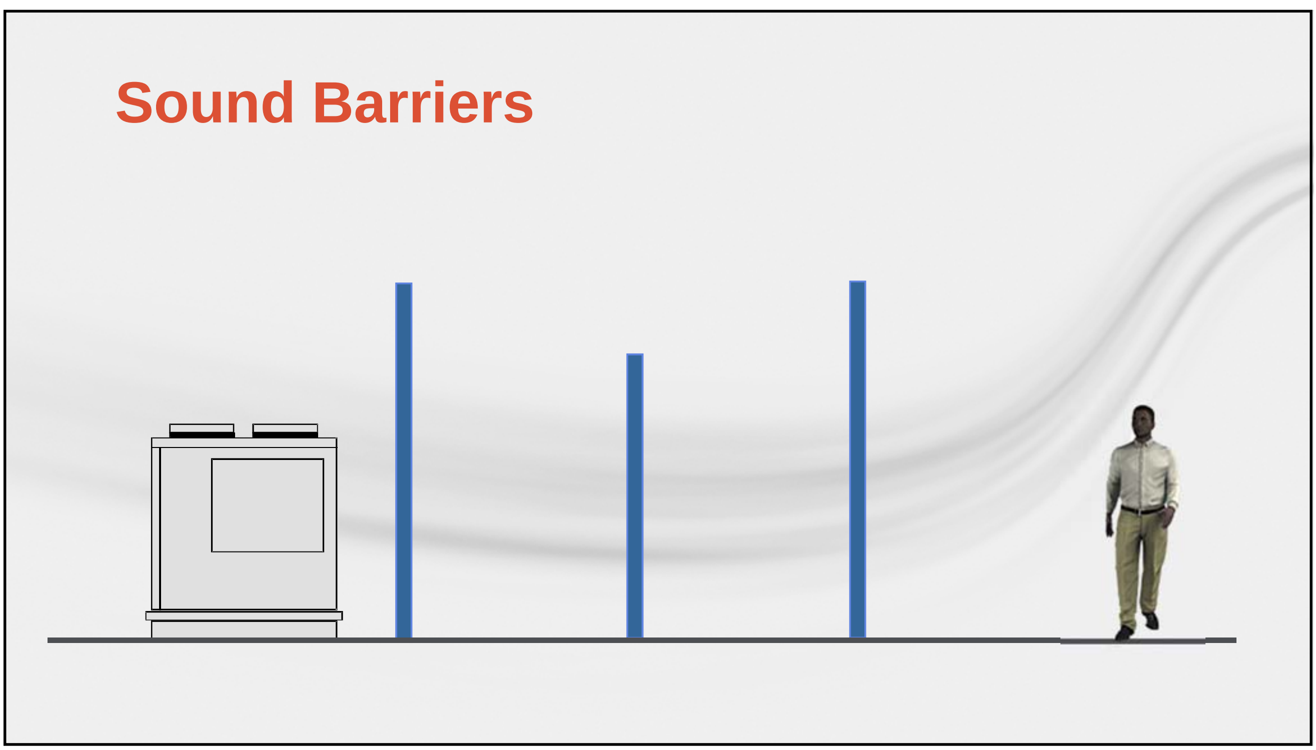
Photos courtesy of BRD Noise and Vibration Control

Field Modifications – Silencers

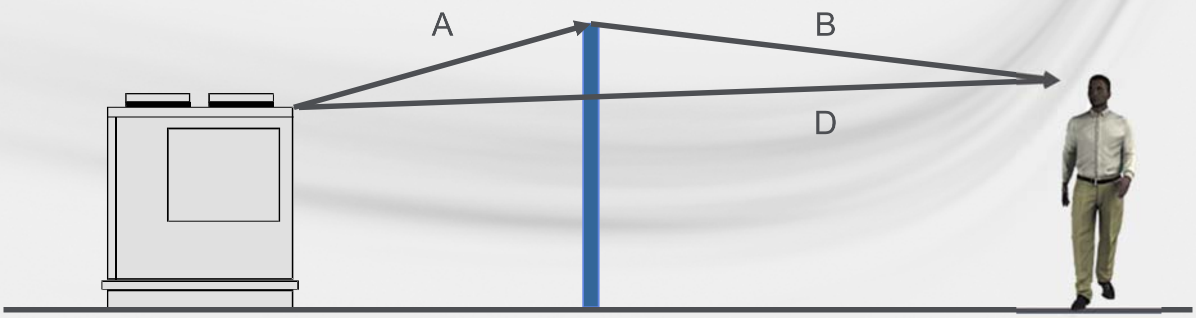
Field Modifications – Louvers

Split Systems for Acoustical Reasons



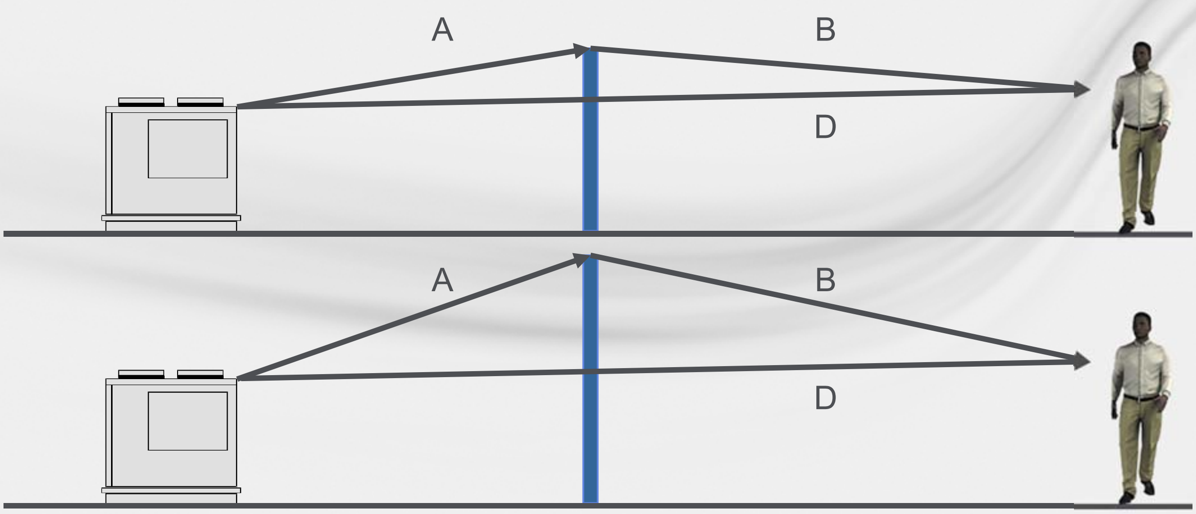

Sound Barriers

Sound Barrier Attenuation

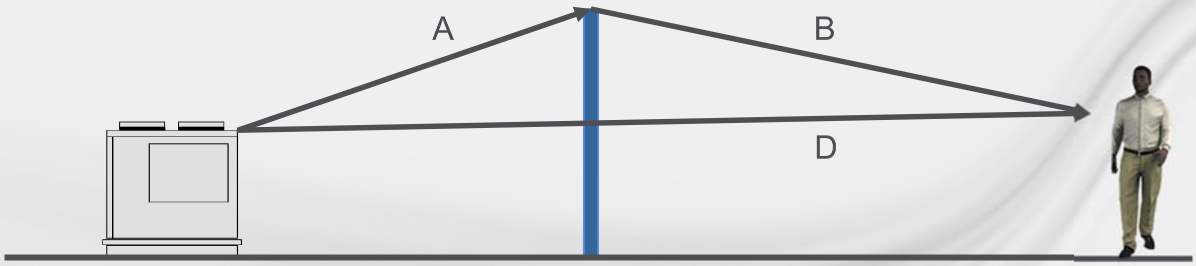


Barrier attenuation increases as A + B – D increases

Sound Barrier Height

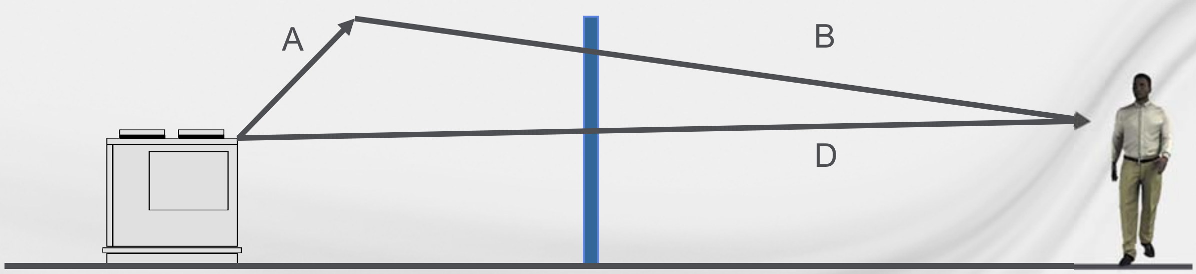


Sound Source and Barrier Proximity



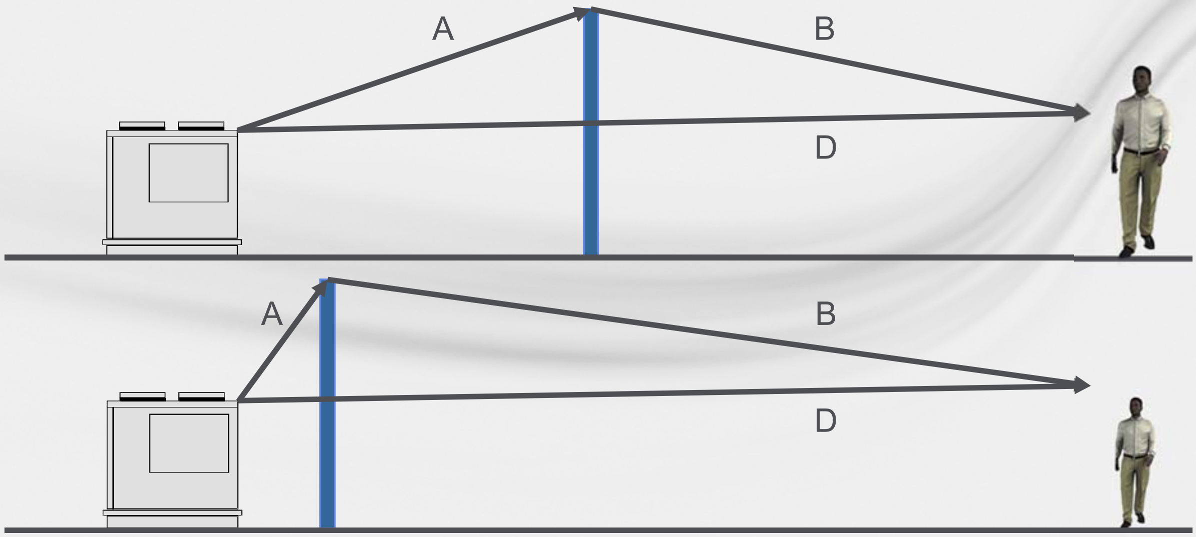
D = 33.6 feet
A = 14.5 feet
B = 20.1 feet
Path-length difference = A + B – D = 14.5 + 20.1 – 33.6 = **1.0 feet**

Sound Source and Barrier Proximity



D = 33.6 feet
A = 14.5 feet
B = 20.1 feet
Path-length difference = A + B – D = 5.9 + 30.3 – 33.6 = **2.6 feet**

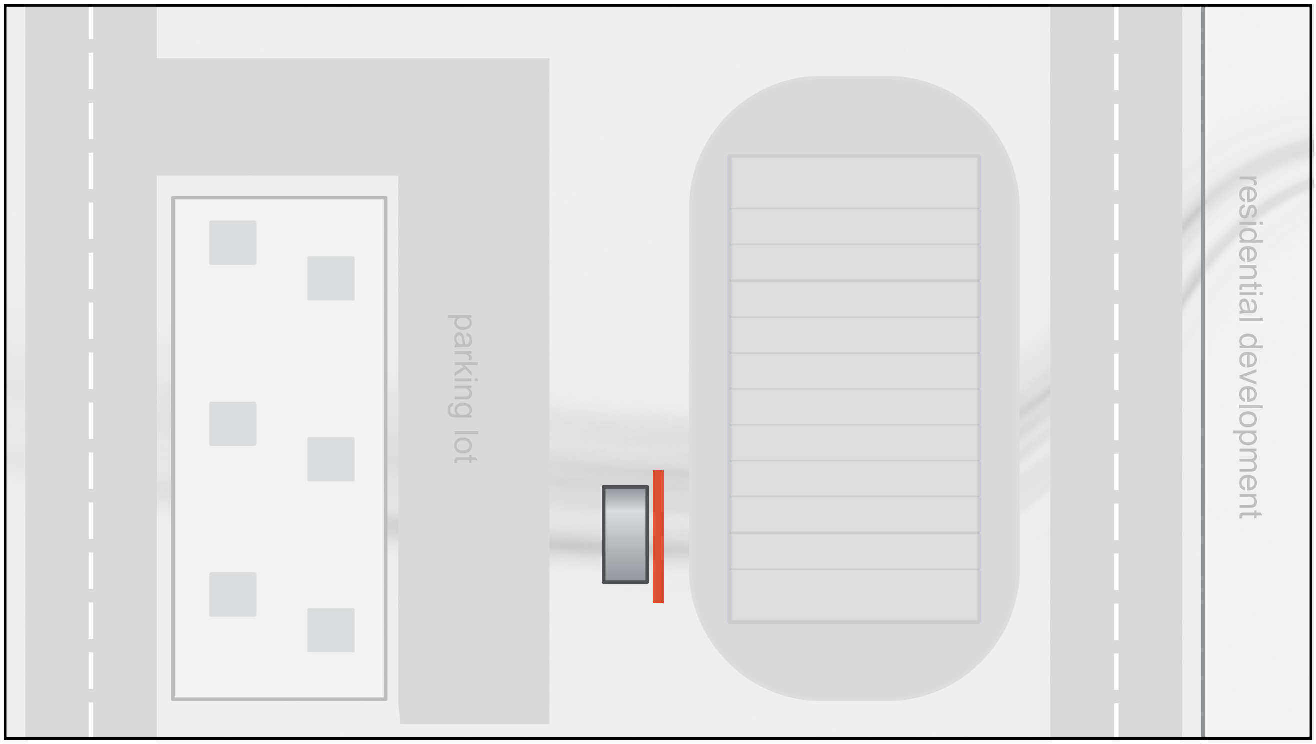
Sound Source and Barrier Proximity



Barrier Insertion Loss Values

Path-Length Difference, ft.	Insertion Loss, dB							
	31.5	63	125	250	500	1000	2000	4000
0.1	5	5	5	6	7	9	11	13
0.2	5	5	6	8	9	11	13	16
0.5	6	7	9	10	12	15	18	20
1	7	8	10	12	14	17	20	22
2	8	10	12	14	17	20	22	23
5	10	12	14	17	20	22	23	24
10	12	15	17	20	22	23	24	24
20	15	18	20	22	23	24	24	24

Source: Chapter 48, 2015 ASHRAE Handbook – HVAC Applications

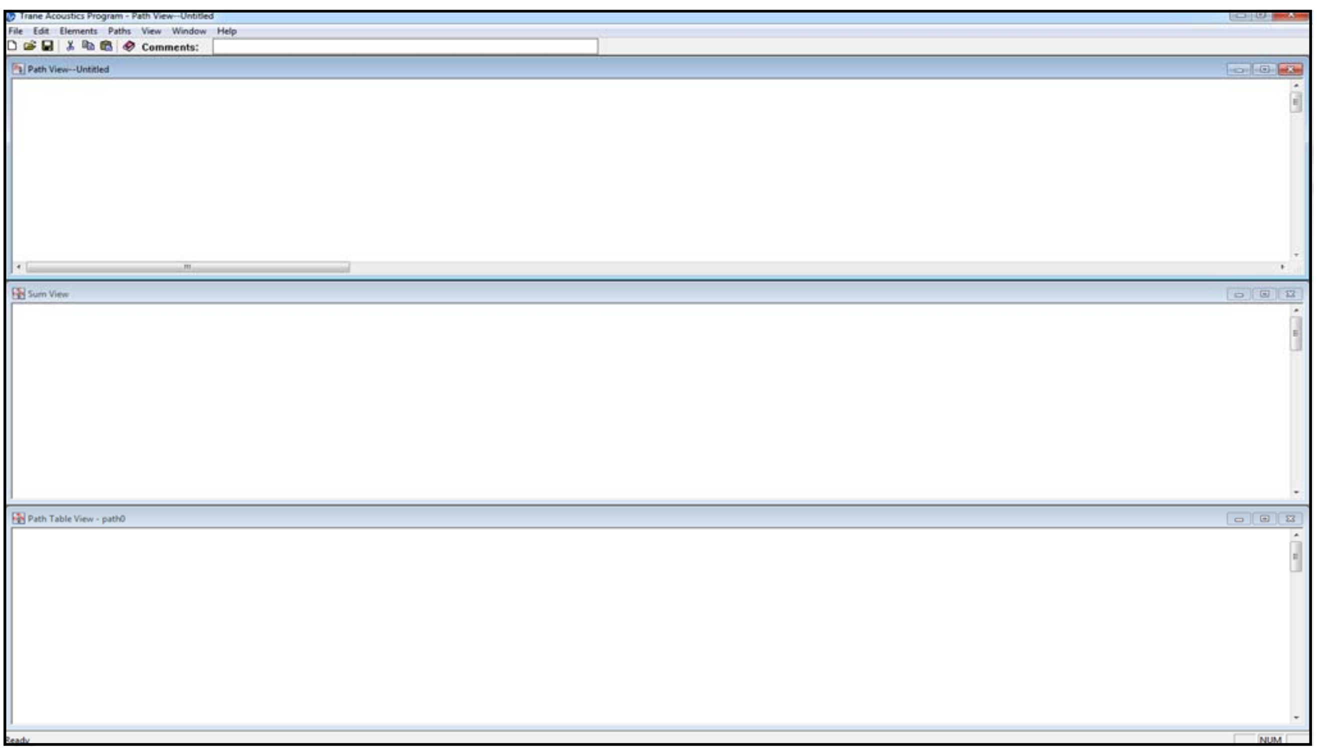


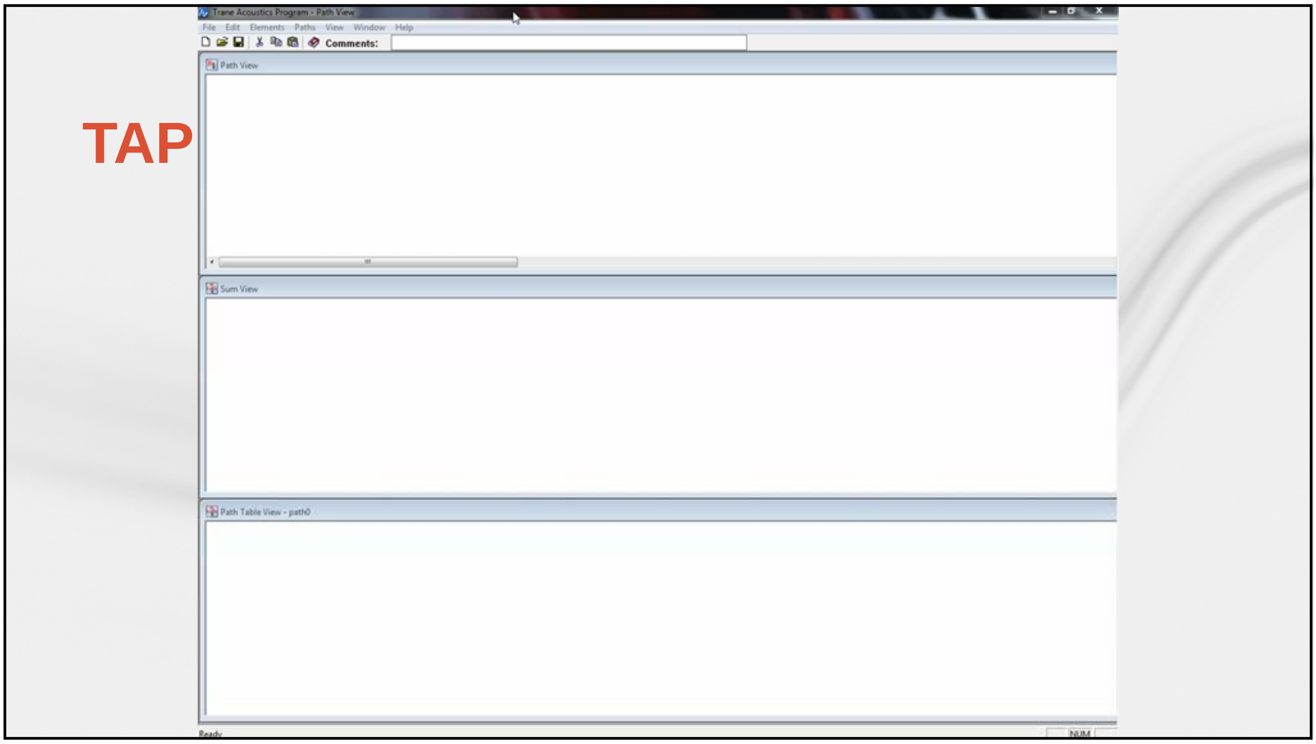
School Example – Vertical Barrier

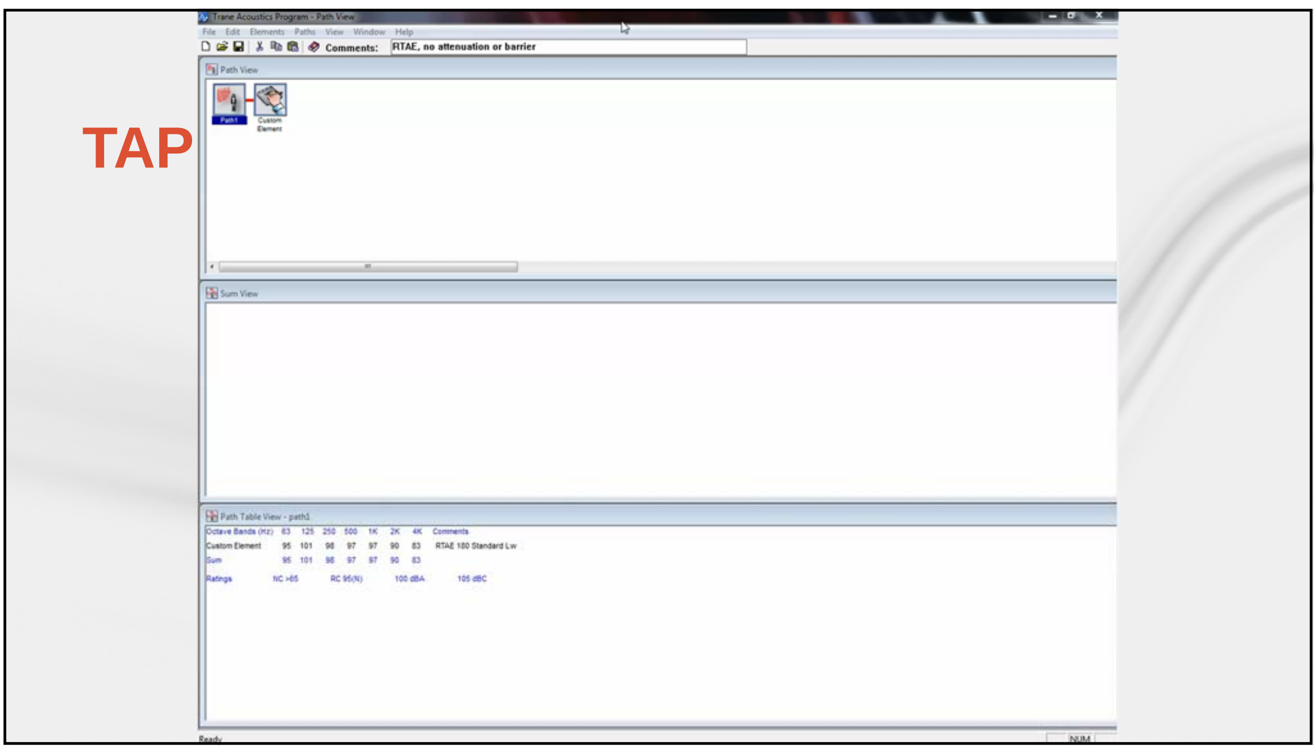
	63	125	250	500	1000	2000	4000	8000
Chiller L_W	94	98	95	93	93	87	80	75
Barrier IL	-8	-10	-12	-14	-17	-20	-22	-22
Dist. Corr	-42	-42	-42	-42	-42	-42	-42	-42
L_P	44	46	41	37	34	25	16	11
A-weighted	39 dBA							

Acoustical Modeling Software

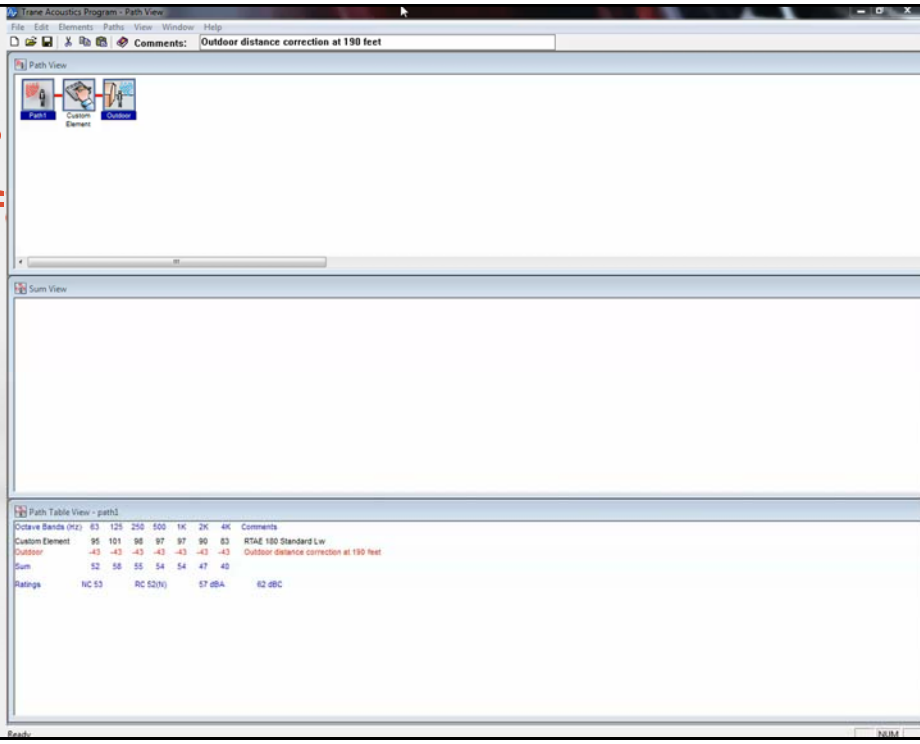
- Trane Acoustics Program (TAP™)
- SoundPLAN®
- Olive Tree Lab
- SPM9613
- Predictor-LimA™



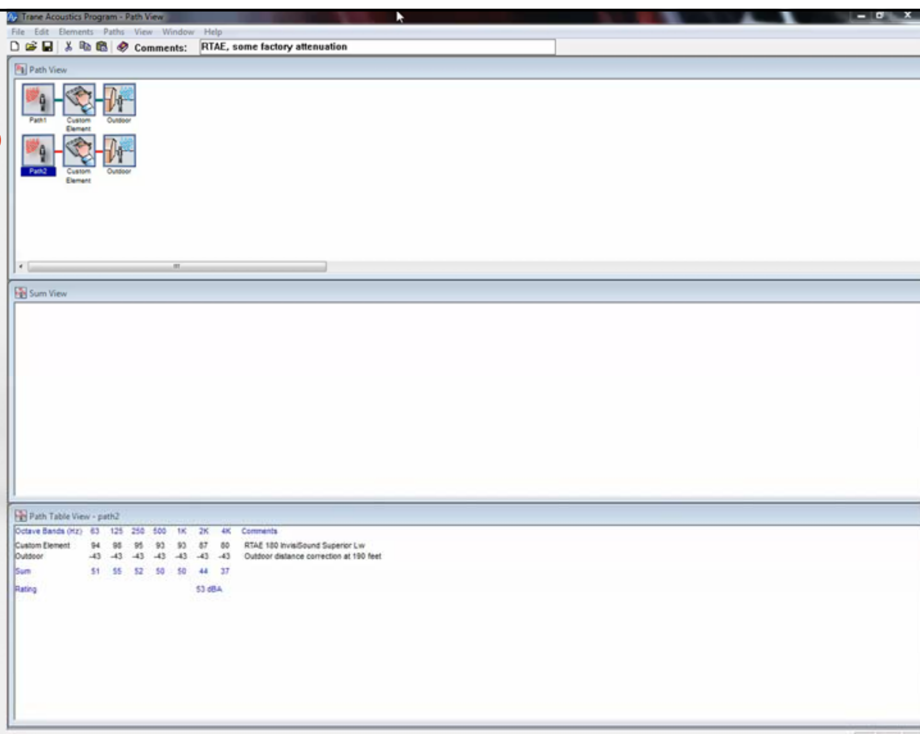

TAP
Trane Acoustics Program - Path View
File Edit Elements Paths View Window Help
Comments:
Path View
Sum View
Path Table View - path0
Ready
NUM


TAP
Trane Acoustics Program - Path View
File Edit Elements Paths View Window Help
Comments: RTAE, no attenuation or barrier
Path View
Path1
Custom Element
Sum View
Path Table View - path1
Octave Bands (Hz) 63 125 250 500 1K 2K 4K Comments
Custom Element 95 101 98 97 97 90 83 RTAE 180 Standard Lw
Sum 95 101 98 97 97 90 83
Ratings NC >65 RC 95(N) 100 dBA 105 dBC
Ready
NUM

TAP
Perf


Trane Acoustics Program - Path View
File Edit Elements Paths View Window Help
Comments: Outdoor distance correction at 190 feet
Path View
Path1
Custom Element
Outdoor
Sum View
Path Table View - path1
Octave Bands (Hz) 63 125 250 500 1K 2K 4K Comments
Custom Element 95 101 98 97 97 90 83 RTAE 180 Standard Lw
Outdoor -43 -43 -43 -43 -43 -43 -43 Outdoor distance correction at 190 feet
Sum 52 58 55 54 54 47 40
Ratings NC 53 RC 52(N) 57 dBA 62 dBC
Ready
NUM

TAP


Trane Acoustics Program - Path View
File Edit Elements Paths View Window Help
Comments: RTAE, some factory attenuation
Path View
Path1
Custom Element
Outdoor
Path2
Custom Element
Outdoor
Sum View
Path Table View - path2
Octave Bands (Hz) 63 125 250 500 1K 2K 4K Comments
Custom Element 94 98 95 93 93 87 80 RTAE 180 InvisiSound Superior Lw
Outdoor -43 -43 -43 -43 -43 -43 -43 Outdoor distance correction at 190 feet
Sum 51 55 52 50 50 44 37
Rating 53 dBA
Ready
NUM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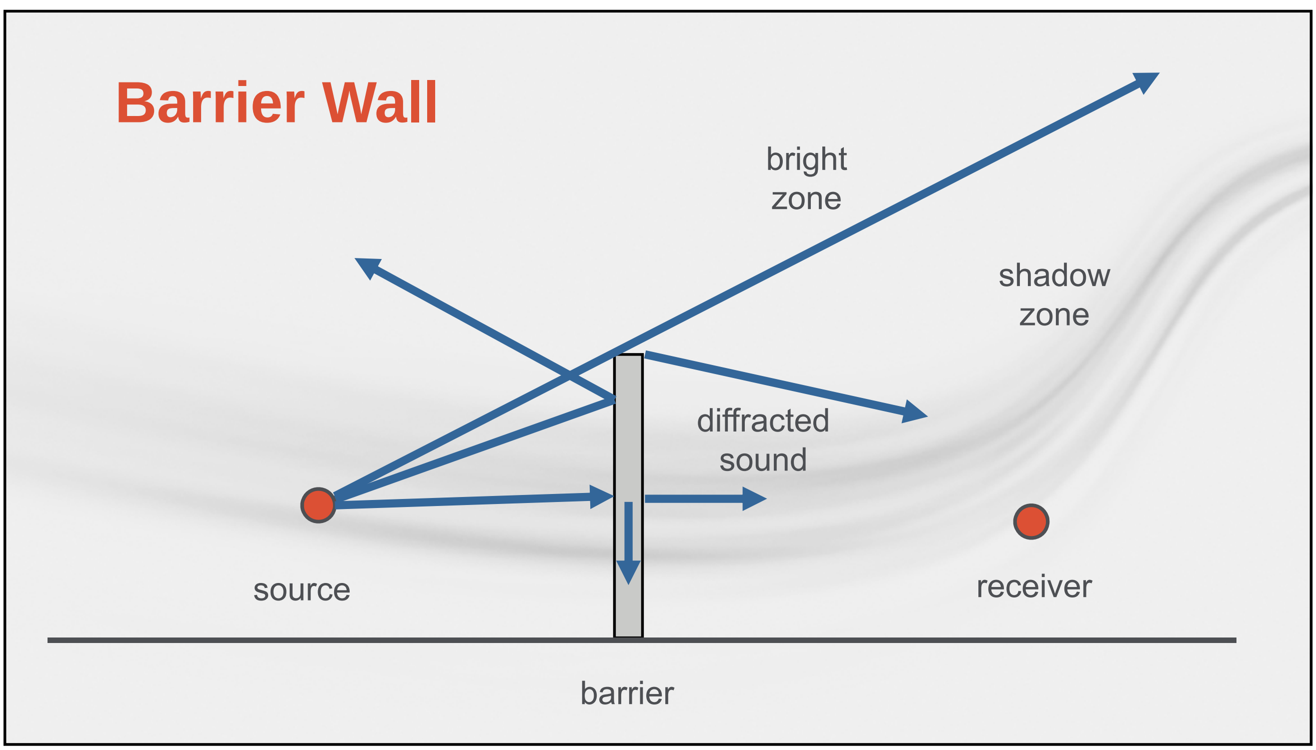
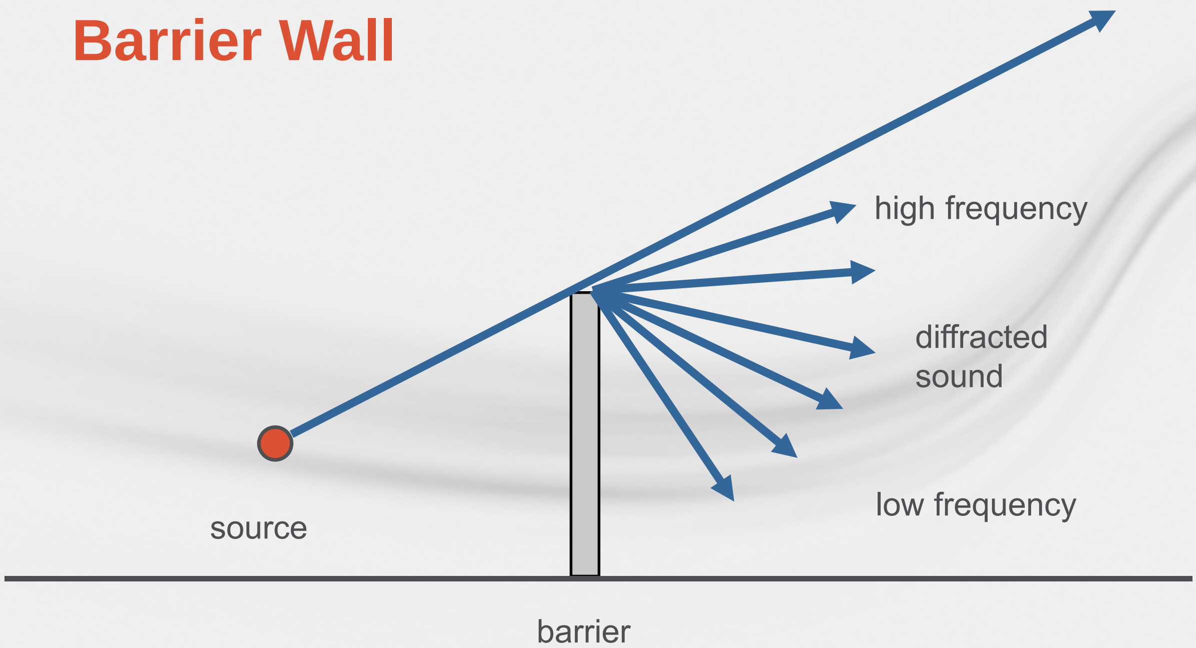
• The source-path-receiver model
• Complicating factors and assumptions
• Dealing with complications
• Attenuation options
• Acoustic barrier complications
• Summary


Barrier Wall
bright zone
shadow zone
diffracted sound
source
receiver
barrier

Barrier Wall



Barrier Wall Considerations

- Assumption by barrier equation
  - Insignificant sound through barrier wall
- Transmission loss (TL)
  - Determines sound reduction of wall
  - Dependent on wall material
  - Increases with mass
  - Varies with frequency

Barrier Wall Materials

Composite Transmission Loss

- Transmission loss (TL)
- Transmission coefficient (T)
- Surface area (S)

$$TL = 10\log_{10}(1/T)$$

For composite walls

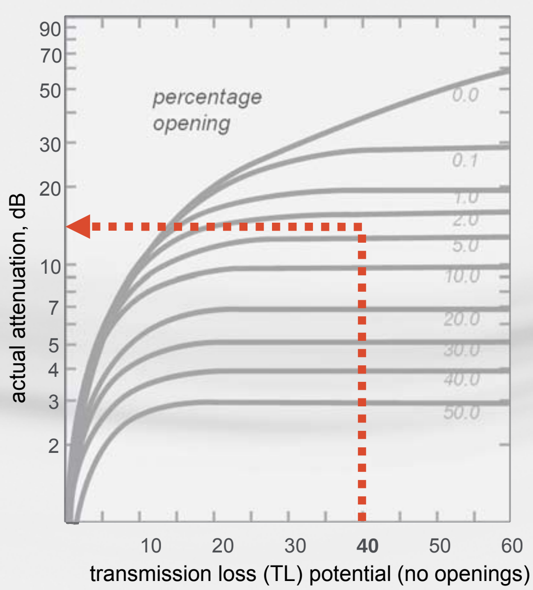
$$T_{eq} * S = Sum(T_i * S_i)$$

Composite Transmission Loss

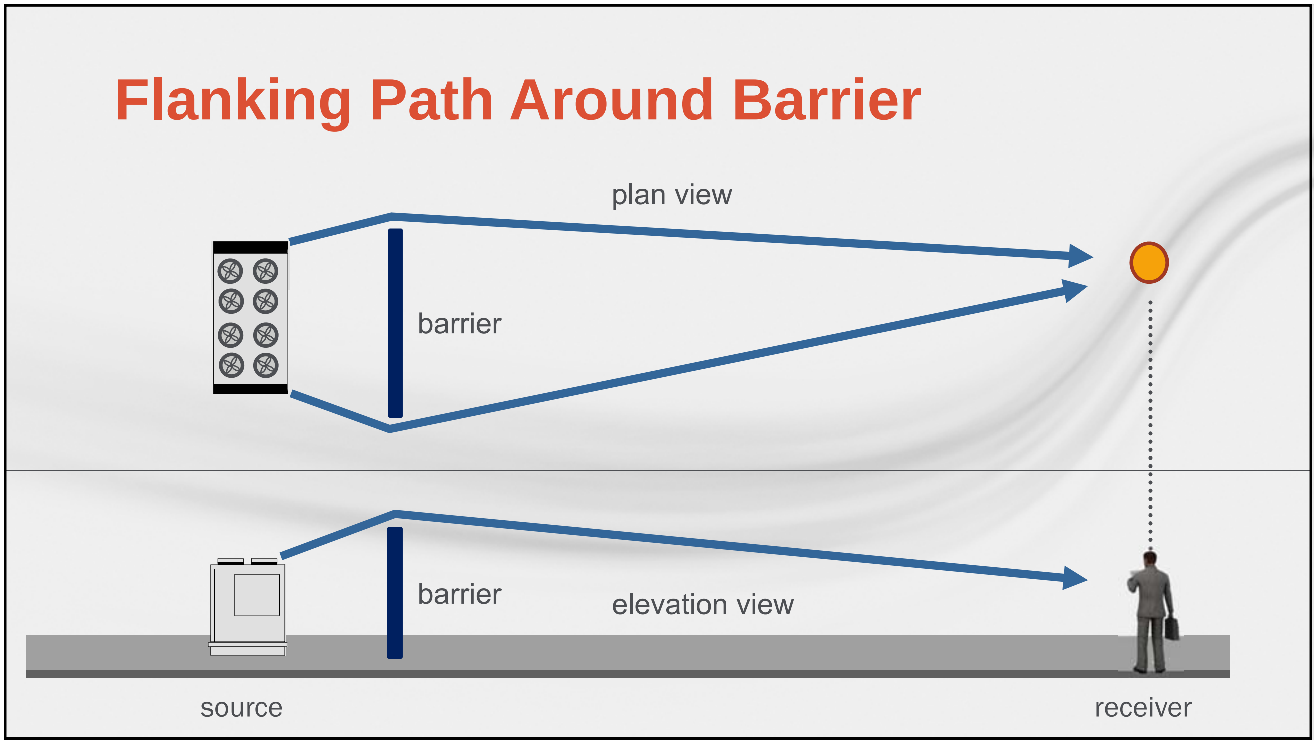
- 8ft x 20ft barrier with a **40dB** TL
- 3in gap at bottom, 0dB TL
- Total area including the gap is 165ft^2
- T_{eq} * 165 = 10^{-4} * 160 + 1.0 * 5 = 0.03
- TL_{eq} = 10 $\log_{10}$ (1/ 0.03) = **15dB**

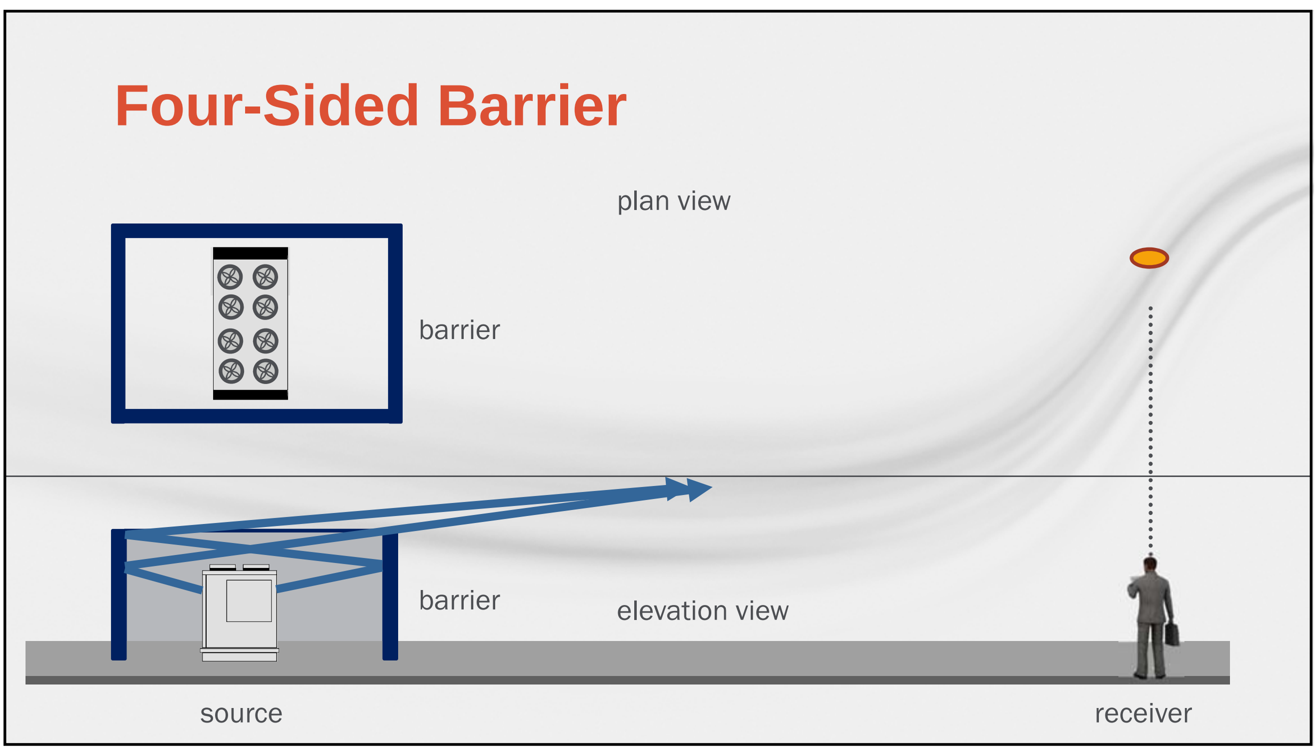
Composite Transmission Loss

decrease in TL



increase in open area


Flanking Path Around Barrier
plan view
barrier
barrier
elevation view
source
receiver


Four-Sided Barrier
plan view
barrier
barrier
elevation view
source
receiver

Absorptive Barrier Wall Lining

AGENDA

- Sound targets
- The source-path-receiver model
- Complicating factors and assumptions
- Dealing with complications
- Attenuation options
- **Acoustic barrier complications**
- Summary

When barriers aren’t enough…

Photo provided courtesy of Kinetics Noise Control

Acoustical Enclosure Considerations

- **Service Access** – method for service personnel to enter the structure and room to work
- **Airflow** – room for outdoor air to circulate through coils evenly without degrading capacity
- **Space** – area around unit needed to construct enclosure
- **Controls** – integrate new fans, VFDs, and controls
- **Cost** – expect this to be an expensive solution—possibly more than original unit

Summary

- Attenuation
- Factory-designed, factory tested
- Field modifications
- Source-path-receiver model
- Vertical barriers
- Enclosures

Where to Learn More

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Special Thank You

Steve Lind

Kris Knickrehm

Kinetics Noise Control
BRD Noise and Vibration Control

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Analysis Software

Trane Acoustics Program (TAP™). Program details and trial software available at **www.trane.com/TAP**

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APP-CMC060-EN QUIZ

1. The A-weighting procedure can be applied to both sound power and sound pressure.
   a. True
   b. False
2. The source-path-receiver model analyzes the source of sound, the various paths sound takes to reach the receiver, and the environment of the receiver to determine sound pressure at the receiver.
   a. True
   b. False

3. Overlapping sound waves create an unstable acoustical environment called a *near field.*
   a. True
   b. False

4. High frequency sound and low frequency sound diffract equally because both are able to bend around the top of a barrier.
   a. True
   b. False

5. True/False: AHRI sound power rating standards require the unit to be run at the loudest operating point.
   a. True
   b. False

6. Transmission loss for a barrier:
   a. Decreases as the mass of the barrier material increases.
   b. Increases as the mass of the barrier material decreases
   c. Increases as the percent open area in the barrier increases.
   d. B and C above
   e. None of the above

7. Lot line sound ordinances must be met anywhere along the lot line regardless of height.
   a. True
   b. False

8. For a given barrier height, moving the barrier closer to the sound source will:
   a. Increase sound pressure at the receiver location.
   b. Decrease sound pressure at the receiver location.
   c. Have no effect on the sound pressure at the receiver location.