BADRY
HVAC

Villas & Townhomes Projects

Split Ducted Concealed & Ductless AC Units

HVAC WORKS

AC Testing & Commissioning

AC (T&C) Manual

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VILLAS & TOWNHOMES -- HVAC WORKS

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1- HVAC T&C / BALANCE FACTORS

Internal Tightly Closed Bed Room - A/C Balance / T&C Factors

Se	T&C Factor	Limit	Unit	In Duct Path - - Generation Point FCU A/C Fan Speed			On Grilla Outlet - Distribution Point FCU A/C Fan Speed			Applied Room Area - Terminal Point FCU A/C Fan Speed		
				High	Medium	Low	High	Medium	Low	High	Medium	Low
1	Noise Criterion	AVG	NC	45	45	45	40	40	40	35	35	35
2	Octave Band	AVG	OB	1	4	8	1	4	8	1	4	8
3	Frequency	AVG	Hz	50	250	500	50	250	500	50	250	500
4	Air Flow	AVG	CFM	650	550	450	600	500	400	450	350	250
5	Air Velocity	AVG	m/s	3.00	2.00	1.00	1.00	0.50	0.25	0.50	0.30	0.20
6	Sound Pressure Level	MAX	dB	68	56	50	66	51	45	64	46	40
7	Tempreature	MIN	°C	22	23	24	20	21	22	21	22	23

Internal Tightly Closed Others Room - A/C Balance / T&C Factors

Se	T&C Factor	Limit	Unit	In Duct Path - - Generation Point FCU A/C Fan Speed			On Grilla Outlet - Distribution Point FCU A/C Fan Speed			Applied Room Area - Terminal Point FCU A/C Fan Speed		
				High	Medium	Low	High	Medium	Low	High	Medium	Low
1	Noise Criterion	AVG	NC	50	50	50	45	45	45	40	40	40
2	Octave Band	AVG	OB	1	4	8	1	4	8	1	4	8
3	Frequency	AVG	Hz	50	250	500	50	250	500	50	250	500
4	Air Flow	AVG	CFM	650	550	450	600	500	400	450	350	250
5	Air Velocity	AVG	m/s	3.00	2.00	1.00	1.00	0.50	0.25	0.50	0.30	0.20
6	Sound Pressure Level	MAX	dB	70	61	55	68	56	50	66	51	45
7	Tempreature	MIN	°C	22	23	24	20	21	22	21	22	23

DOWN BELOW BADRY HVAC T&C MANUAL / REFERENCES.

2 DECIBEL

2-1 DECIBEL IS A LOGARITHMIC UNIT USED TO DESCRIBE THE RATIO OF THE SIGNAL LEVEL - POWER, SOUND PRESSURE, VOLTAGE, INTENSITY, ETC.

Most signal systems - as sound power or sound intensity, human speech, sonar, microwaves, radio signals and fiber optics - can be described by

- transmitting power
- transmission path loss
- receiver sensitivity

Transmitting power, path loss and receiver sensitivity are absolute power values - Watts in the SI system.

2-1-1 THE DEFINITION OF DECIBEL

Decibel is a logarithmic unit used to describe the ratio of the signal level - power, sound pressure, voltage or intensity or several other things.

The decibel can be expressed as:

$decibel = 10 \log(P / P_{ref})$ (1)

where

P = *signal power (W)*

P_{ref} = *reference power (W)*

A decibel is one-tenth of a *Bel* - named after Alexander Graham Bell, the inventor of the telephone.

Note! Doubling the signal level increases the decibel with *3 dB (10 log (2))*.

If we know the decibel value and the reference level, the absolute level can be calculated by transforming (1) to:

$P = P_{ref} 10^{(decibel / 10)}$ (2)

2-1-2 EXAMPLE - SOUND INTENSITY AND DECIBEL

The difference in sound intensity of 10^{-8} *watts/m²* and 10^{-4} *watts/m²* (*10,000 units*) can be calculated in decibels as

$\Delta L_I = 10 \log((10^{-4} watts/m^2) / (10^{-12} watts/m^2)) - 10 \log((10^{-8} watts/m^2) / (10^{-12} watts/m^2))$

$= 40$ dB

Increasing the sound intensity by a factor of

- *10 raises its level by 10 dB*
- *100 raises its level by 20 dB*
- *1,000 raises its level by 30 dB*
- *10,000 raises its level by 40 dB and so on*

3 ACCEPTABLE NOISE - DBA - LEVELS

3-1 ACCEPTABLE NOISE - DBA - LEVELS AT SOME LOCATIONS

The main advantages with dBA - the A weighting in noise measurements - are

- adapted to the the human ear response to sound
- possible to measure with low cost instruments

Maximum acceptable Equivalent Sound Level - L_{eq} - at some common locations are indicated in the table below:

Location	Effects	Maximum L_{eq} (dBA)	Time (hours)	Time of day
Bedroom	sleep disturbance, annoyance	30	8	night
Living area	annoyance, speech interference	50	16	day
Outdoor living area	moderate annoyance	50	16	day
Outdoor living area	serious annoyance	55	16	day
Outdoor living area	sleep disturbance, with open windows	45	8	night
School classroom	speech interference, communication disturbance	35	8	day
Hospitals patient rooms	sleep disturbance, communication interference	30 - 35	8	day and night

4 L_{EQ} - EQUIVALENT SOUND LEVEL

4-1 EQUIVALENT SOUND LEVEL - L_{EQ} - QUANTIFIES THE NOISE ENVIRONMENT AS A SINGLE VALUE OF SOUND LEVEL FOR ANY DESIRED DURATION

The Environmental Protection Agency - EPA - has adopted a system of four "sound descriptors"

- A-weighted sound level
- Sound Exposure Level - L_s
- Equivalent Sound Level - L_{eq}
- Day-Night Sound Level - L_{dn}

to summarize how sound is heard and measured, and to determine the impact of noise on health and welfare.

4-1-1 EQUIVALENT SOUND LEVEL - L_{EQ}

quantifies the noise environment as a single value of sound level for any desired duration. This descriptor correlates well with the effects of noise on people. L_{eq} is also sometimes known as **Average Sound Level** - L_{AT}.

Equivalent Sound Level - L_{eq} - can be expressed as

$L_{eq} = 10 \log [(1/T) \int p_A^2 \, dt/p_{ref}^2]$ (1)

where
L_{eq} = *equivalent sound level (db)*
T = time period (s)
p_A = *sound pressure (Pa, N/m²)*
p_{ref} = *reference sound pressure (20 10^{-6} Pa, N/m²)*

5 L_{DN} - DAY AND NIGHT SOUND LEVEL

5-1 THE EPA HAS DEFINED AN A-WEIGHTED SOUND LEVEL DAY AND NIGHT EQUIVALENT FOR A 24 HOUR PERIOD

The Environmental Protection Agency - EPA - has adopted a system of four "sound descriptors"

- A-weighted sound level
- Sound Exposure Level - L_s
- Equivalent Sound Level - L_{eq}
- Day-Night Sound Level - L_{dn}

to summarize how sound is heard and measured, and to determine the impact of noise on health and welfare.

5-1-1 DAY-NIGHT SOUND LEVEL - L_{DN}

is the A-weighted equivalent sound level for a *24 hour* period with an additional *10 dB* imposed on the equivalent sound levels for night time hours of *10 p.m*. to *7 am*.

Day-Night Sound Level can be expressed as

$L_{dn} = 10 \log (1/24 (15 (10^{Ld/10}) + 9 (10^{((Ln + 10)/10)}))$ *(1)*

where
L_{dn} = *day-night sound level (dB)*
L_d = *daytime equivalent sound level (dB)*
L_n = *nighttime equivalent sound level (dB)*

Examples of outdoor Day-Night Average Sound levels measured at various locations:

Location	L_{dn} (dBA)
Apartment next to freeway	87
3/4 mile from runway at major airport	86
Downtown with construction activity	79
Old urban residential area	59
Wooded residential	52
Agricultural crop land	44
Rural residential	39

Location	L_{dn} (dBA)
Wilderness ambient	35

6 OUTDOOR AMBIENT SOUND LEVELS

6-1 OUTDOOR AMBIENT SOUND LEVEL (DBA) IN RURAL AND URBAN BUSINESS AND INDUSTRIAL ENVIRONMENTS WITH OR WITHOUT LIMITED TRAFFIC

In residential areas most noise comes from transportation, construction, industrial, and human and animal sources. Road traffic noise is the major source of noise.

The noise can be highly variable. It is common that Day-Night sound levels - L_{dn} - in different areas may vary a range of 50 dB. The outdoor level - L_{dn} - in a wilderness areas may occur as low as *30-40 dBA* compared to *85-90 dBA* in a urban areas. Most urban dwellers lives in areas of L_{dn} more than *48 dBA*.

The table below indicates common outdoor sound pressure levels in rural and urban environments at different octave bands.

Outdoor Sound Pressure *(dBA)*									
Conditions		**Octave Band Center Frequency *(Hz)***							
		63	**125**	**250**	**500**	**1000**	**2000**	**4000**	**8000**
Night-time									
	Rural, no nearby traffic of concern	42	37	32	27	22	18	14	12
	Suburban, no nearby traffic of concern	47	42	37	32	27	23	19	17
	Urban, no nearby traffic of concern	52	47	42	37	32	28	24	22
	Business or commercial area	57	52	47	42	37	33	29	27
Daytime									
	Business or commercial area	62	57	52	47	42	38	34	32
	Industrial or manufacturing area	67	62	57	52	47	43	39	37
	Within 300 ft (91 m) of continuous heavy traffic	72	67	62	57	52	48	44	42

7 NOISE EXPOSURE - PERMISSIBLE LEVEL AND DURATION

7-1 NOISE EXPOSURE SHOULD BE CONTROLLED SO THAT EXPOSURE IS LESS THAN THE COMBINATION OF EXPOSURE LEVEL AND DURATION

According the National Institute for Occupational Safety - NIOSH - noise exposure should be controlled so that the exposure is less than the combination of exposure level - *L* - and duration - *t*.

The maximum time of exposure can be calculated as:

$t = 28{,}800 / 2^{(L - 85)/3}$ (1)

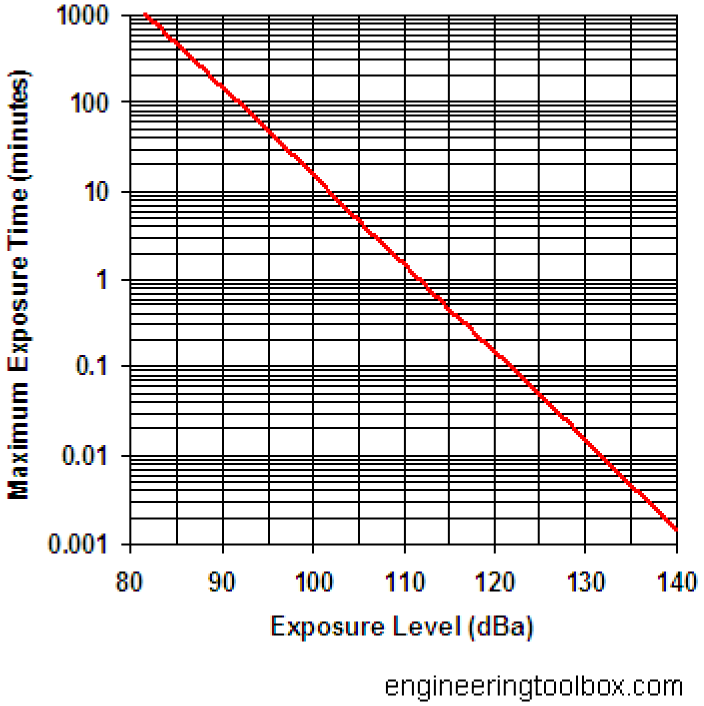
where

t = maximum exposure duration (seconds)

L = exposure level (dBA)

3 = exchange rate (dB)

85 = Recommended Exposure Limit - REL



Combinations of noise exposure levels and maximum duration time are expressed in the table below:

Exposure Level (dBA)	Duration Time - t - (s)		
	Hours	Minutes	Seconds
80	25	24	
81	20	10	
82	16		

Exposure Level (dBA)	Duration Time - t - (s)		
	Hours	Minutes	Seconds
83	12	42	
84	10	5	
85	8		
86	6	21	
87	5	2	
88	4		
89	3	10	
90	2	31	
91	2		
92	1	35	
93	1	16	
94	1		
95		47	37
96		37	48
97		30	
98		23	49
99		18	59
100		15	

Exposure Level (dBA)	Duration Time - t - (s)		
	Hours	Minutes	Seconds
101		11	54
102		9	27
103		7	30
104		5	57
105		4	43
106		3	45
107		2	59
108		2	22
109		1	53
110		1	29
111		1	11
112			56
113			45
114			35
115			28
116			22
117			18
118			14

Exposure Level (dBA)	Duration Time - t - (s)		
	Hours	Minutes	Seconds
119			11
120			9
121			7
122			6
123			4
124			3
125			3
126			2
127			1
128			1
129			1
130			1
-140			< 1

8 REL - NOISE RECOMMENDED EXPOSURE LIMIT

8-1 THE NIOSH NOISE RECOMMENDED EXPOSURE LIMIT - REL - FOR OCCUPATIONAL NOISE

The National Institute for Occupational Safety - NIOSH - Recommended Exposure Limit - REL - for occupational noise exposure is

- *85 decibels*, A-weighted, as an *8-hr* Time-Weighted Average -TWA - (*85 dBA* as an *8-hr* TWA)

Note! Exposures at and above this level are considered hazardous.
Exposure to continuous, varying, intermittent, or impulsive noise shall never exceed *140 dBA*.

9 SOUND INTENSITY

9-1 THE SOUND INTENSITY LEVEL IS THE ACOUSTIC POWER OF A SOUND PER UNIT OF AREA IN RELATION TO A FIXED REFERENCE

9-1-1 SOUND INTENSITY

Sound Intensity is the Acoustic or Sound Power *(W)* per unit area. The SI-units for Sound Intensity are W/m^2.

9-1-2 SOUND INTENSITY LEVEL

The dynamic range of human hearing and sound intensity spans from 10^{-12} W/m^2 to *10 - 100* W/m^2. The highest sound intensity possible to hear is *10,000,000,000,000* times as loud as the quietest!

This span makes the absolute value of the sound intensity impractical for normal use. A more convenient way to express the sound intensity is the relative logarithmic scale with reference to the lowest human hearable sound - 10^{-12} W/m^2 *(0 dB)*.

Note! In US a reference of 10^{-13} $watts/m^2$ are commonly used.

The Sound Intensity Level can be expressed as:

$L_I = 10 \log(I / I_{ref})$ *(1)*

where

L_I = *sound intensity level (dB)*

I = *sound intensity* (W/m^2)

$I_{ref} = 10^{-12}$ - *reference sound intensity* (W/m^2)

The logarithmic sound intensity level scale match the human sense of hearing. Doubling the intensity increases the sound level with *3 dB (10 log (2))*.

9-1-3 EXAMPLE - SOUND INTENSITY

The difference in intensity of 10^{-8} $watts/m^2$ and 10^{-4} $watts/m^2$ (*10,000 units*) can be calculated in decibels as

$\Delta L_I = 10 \log((10^{-4} \ watts/m^2) / (10^{-12} \ watts/m^2))$

$- 10 \log((10^{-8} \ watts/m^2) / (10^{-12} \ watts/m^2))$

= <u>40</u> dB

Increasing the sound intensity by a factor of

- *10 raises its level by 10 dB*
- *100 raises its level by 20 dB*
- *1,000 raises its level by 30 dB*
- *10,000 raises its level by 40 dB*
- *and so on*

Note! Since the sound intensity level may be difficult to measure, it is common to use sound pressure level measured in decibels instead. Doubling the Sound <u>Pressure</u> raises the Sound Pressure Level with *6 dB*.

9-1-4 LOUDNESS

Sound intensity and feeling of loudness:

- *110 to 225 dB - Deafening*
- *90 to 100 dB - Very Loud*
- *70 to 80 dB - Loud*
- *45 to 60 dB - Moderate*
- *30 to 40 dB - Faint*
- *0 - 20 dB - Very Faint*

9-1-5 SOUND POWER, INTENSITY AND DISTANCE TO SOURCE

The sound intensity decreases with distance to source. Intensity and distance can be expressed as:

$I = L_w / 4 \pi r^2$ *(2)*

where

L_w = *sound power (W)*

$\pi = 3.14$

r = *radius or distance from source (m)*

9-1-6 SOUND INTENSITY AND SOUND PRESSURE

The connection between Sound Intensity and Sound Pressure can be expressed as:

$I = p^2 / \rho c$ (3)

where

p = sound pressure *(Pa)*

ρ = density of air (1.2 kg/m^3 *at 20*^{o}*C)*

c = speed of sound *(331 m/s)*

10 SOUND POWER

10-1 SOUND POWER LEVEL AND THE SOUND POWER FROM SOME COMMON SOURCES AS FANS, JET ENGINES, CARS, HUMANS AND MORE ..

10-1-1 SOUND POWER

Sound power is the energy rate - the energy of sound per unit of time (*J/s, W* in SI-units) from a sound source.

10-1-2 SOUND POWER LEVEL

Sound power can more practically be expressed as a relation to the threshold of hearing - 10^{-12} *W* - in a logarithmic scale named Sound Power Level - L_w, expressed as

$L_w = 10 \log (N / N_o)$ (1)

where

L_w *= Sound Power Level in* Decibel *(dB)*

N = sound power (W)

$N_o = 10^{-12}$ *- reference sound power (W).*

Human hearable Sound Power spans from 10^{-12} *W* to *10 - 100 W*, a range of $10/10^{-12} = 10^{13}$.

The table below indicates the Sound Power and the Sound Power Level from some common sources.

Source	**Sound Power - *N* - (*W*)**	**Sound Power Level - L_w - (*dB*) (re 10^{-12} *W*)**
Saturn Rocket	100,000,000	200
Turbo Jet Plane Engine	100,000	170
	10,000	160
Inside jet engine test cell Jet Plane Take-off	1,000	150
Large centrifugal fan, 800.000 m^3/h Turbo Propeller Plane at take-off	100	140
Axial fan, 100.000 m^3/h Machine Gun Large Pipe Organ	10	130

Source	Sound Power - *N* - (*W*)	Sound Power Level - L_w - (*dB*) (re 10^{-12} *W*)
Large chipping hammer Symphonic orchestra Jet Plane from passenger ramp Heavy Thunder Sonic Boom Small aircraft engine	1	120
Centrifugal van, 25.000 m^3/h Accelerating Motorcycle Heavy Metal, Hard Rock Band Music Blaring radio Chain Saw Wood Working Shop Large air Compressor	0.1	110
Air chisel Subway Steel Wheels Magnetic drill press High pressure gas leak Banging of steel plate Drive gear Car at Highway Speed Normal Fan Vacuum Pump Banging Steel Plate Wood Planer Air Compressor Propeller Plane Outboard motor Loud street noise Power Lawn Mover Helicopter	0.01	100
Cut-off saw Hammer mill Small air compressor Grinder Heavy diesel vehicle Heavy city traffic Lawn mover Airplane Cabin at normal flight Kitchen Blender Spinning Machines Pneumatic Jackhammer	0.001	90
Alarm clock Dishwasher	0.0001	80

Source	**Sound Power** **- *N* -** **(*W*)**	**Sound Power Level** **- L_w -** **(*dB*)** **(re 10^{-12} *W*)**
Toilet Flushing Printing Press Inside Railroad Car Noisy Office Inside Automobile Clothes Dryer Vacuum Cleaner	0.00001	70
Large department store Busy restaurant or canteen Ventilation Fan Noisy Home Average Office Hair Dryer	0.000001	60
Room with window air conditioner Office Air Diffuser Quiet Office Average Home Quit Street	0.0000001	50
Voice, low Small Electric Clock Private Office Quiet Home Refrigerator Bird Singing Ambient Wilderness Agricultural Land	0.00000001	40
Room in a quiet dwelling at midnight Quiet Conversation Broadcast Studio	0.000000001	30
Rustling leaves Empty Auditorium Whisper Watch Ticking Rural Ambient	0.0000000001	20
Human Breath	0.00000000001	10
	0.000000000001	0

11 SOUND PRESSURE

11-1 SOUND PRESSURE IS THE FORCE OF SOUND ON A SURFACE AREA PERPENDICULAR TO THE DIRECTION OF THE SOUND

11-1-1 SOUND PRESSURE

The Sound Pressure is the force (*N*) of sound on a surface area (m^2) perpendicular to the direction of the sound. The SI-units for the Sound Pressure are N/m^2 or *Pa*.

Sound is usually measured with microphones responding proportionally to the sound pressure - *p*. The power in a sound wave goes as the square of the pressure.

(Similarly, electrical power goes as the square of the voltage.) The log of the square of x is just 2 log x, so this introduces a factor of 2 when we convert to decibels for pressures.

11-1-2 THE SOUND PRESSURE LEVEL

The lowest sound pressure possible to hear is approximately *$2\ 10^{-5}$ Pa (20 micro Pascal, 0.02 mPa)*, 2 ten billionths of a an atmosphere.

It therefore convenient to express the sound pressure as a logarithmic decibel scale related to this lowest human hearable sound - *$2\ 10^{-5}$ Pa, 0 dB*.

The Sound Pressure Level:

$L_p = 10 \log(p^2 / p_{ref}^2) = 10 \log(p / p_{ref})^2 = 20 \log (p / p_{ref})$ (1)

where

L_p = *sound pressure level (dB)*

p = sound pressure (Pa)

$p_{ref} = 2\ 10^{-5}$ *- reference sound pressure (Pa)*

If the pressure is doubled, the sound pressure level is increased with *6 dB (20 log (2))*.

- Recommended maximum sound pressure level in rooms with different activities.

The table below indicates the sound pressure level in decibel caused by some common sources.

Source	Sound Pressure Level *(dB)*
Threshold of Hearing	
Quietest audible sound for persons with excellent hearing under laboratory conditions[2)]	0
Quietest audible sound for persons under normal conditions	
Virtual silence	10
Rustling leaves, quiet room	20
Noticeably Quit - Voice, soft whisper	
Quiet whisper (1 m)	30

Source	Sound Pressure Level *(dB)*
Home	40
Moderate	
Quiet street	50
Loud - Unusual Background, Voice conversation 1 m	
Conversation	60
Loud - Voice conversation 0.3 m	
Inside a car Car (15 m) Vacuum cleaner (3 m) Freight Train (30 m)	70
Loud singing	75
Loud - Intolerable for Phone Use	
Automobile (10 m) Maximum sound up to 8 hour (OSHA criteria - hearing conservation program) Pneumatic tools (15 m) Buses, trucks, motorcycles (15 m)	80
Motorcycle (10 m)	88
Food blender (1 m) Maximum sound up to 8 hour (OSHA[1]) criteria - engineering or administrative noise controls) Jackhammer (15 m) Bulldozer (15 m)	90
Subway (inside)	94
Very Loud	

Source	Sound Pressure Level *(dB)*
Diesel truck (10 m)	100
Lawn mower (1 m)	107
Pneumatic riveter (1 m)	115
Threshold of Discomfort	
Large aircraft (150 m over head)	110
Chainsaw (1 m)	117
Deafening, Human pain limit	
Amplified Hard Rock (2 m) Siren (30 m)	120
Jet plane (30 m) Artillery Fire (3 m)	130
Short exposure can cause hearing loss	
Military Jet Take-off (30 meter)	150

[1)] OSHA - Occupational Safety and Health Act - The OSHA criteria document reevaluates and reaffirms the Recommended Exposure Limit (REL) for occupational noise exposure established by the National Institute for Occupational Safety and Health (NIOSH) in 1972.
The REL is *85 dB*, A-weighted, as an *8-hr* time-weighted average (*85 dBA* as an *8-hr* TWA). Exposures at or above this level are hazardous.
[2)] The reference level - 10^{-12} - for the decibel scale.

- Sound power level from some common sources

12 SOUND PRESSURE - RECOMMENDED MAXIMUM LEVELS IN ROOMS

12-1 MAXIMUM RECOMMENDED SOUND PRESSURE LEVELS IN ROOMS WITH ACTIVITIES AS KINDERGARTENS, AUDITORIUMS, LIBRARIES, CINEMAS AND MORE ...

Sound pressure level is the pressure of sound in relation to a fixed reference. The reference is the threshold of hearing - $2\ 10^{-5}$ *Pa* - and is given the value of *0 dB*.
The table below can be used as a guide to maximum acceptable sound pressure level in rooms with different types of activities.

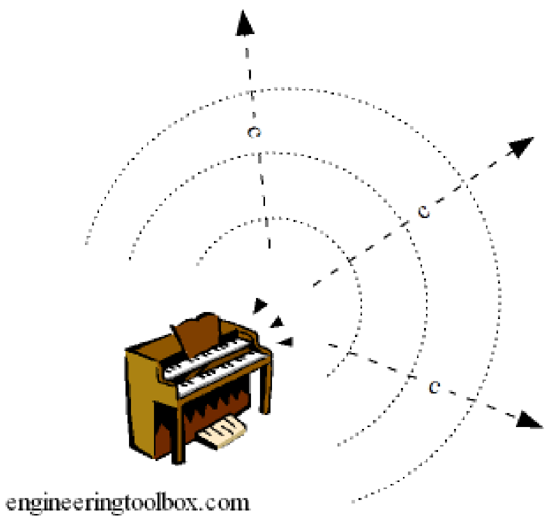
Activity and Type of Area	Noise Rating NR value	L_p (dBA)
Kindergartens	30	35
Auditorium	25	30
Library	30	35
Cinema	30	35
Concert hall	20	25
Court room	25	30
Theatre	25	30
Store, retail	35	40
Supermarkets	40	45
Hospital, corridor	30	35
Hospital, operating theatre	25	30
Hospital, private room	20	25
Hotel, lobby	35	40
Hotel, restaurant	40	45
Hotel, ballroom	30	35
Church	25	30
Office	30	35
School, lecture room	25	30
School, corridor	30	35

Activity and Type of Area	Noise Rating NR value	L_p (dBA)
School, gymnasium	30	35
Swimming pool	35	40
Studio, record	20	25
Studio, radio	15	20
Studio, television with audience	25	30
Studio, television without audience	20	25

13 SPEED OF SOUND FORMULAS

13-1 CALCULATION FORMULAS FOR VELOCITY OF SOUND IN GASES, FLUIDS OR SOLIDS

A disturbance introduced in some point of a substance will propagate through the substance with a finite velocity.



13-1-1 ACOUSTIC VELOCITY AND SPEED OF SOUND

The velocity at which a small disturbance will propagate through the medium is called **Acoustic Velocity** or **Speed of Sound.** The acoustic velocity is related to the change in pressure and density of the substance and can be expressed as

$c = (dp / d\rho)^{1/2}$ (1)

where

c = sound velocity (m/s, ft/s)

dp = change in pressure (Pa, psi)

dρ = change in density (kg/m^3, lb/ft^3)

13-1-2 SPEED OF SOUND IN GASES, FLUIDS AND SOLIDS

The acoustic velocity can alternatively be expressed with Hook's Law as

$c = (E / \rho)^{1/2}$ (2)

where
E = bulk modulus elasticity (Pa, psi)
ρ = density (kg/m^3, lb/ft^3)
This equation is valid for liquids, solids and gases. The sound travels faster through media with higher elasticity and/or lower density. If a medium is not compressible at all - incompressible - the speed of sound is infinite ($c \approx \infty$).

Substance	Bulk Modulus Elasticity - E - 10^9 (N/m^2)	Density - ρ - (kg/m^3)
Water	2.15	999.8
Oil	1.35	920
Ethyl Alcohol	1.06	810
Mercury	28.5	13595

- *properties at 1 bar and 0 ^oC*

13-1-3 SPEED OF SOUND IN IDEAL GASES
Since the acoustic disturbance introduced in a point is very small the heat transfer can be neglected and for gases assumed isentropic. For an isentropic process the ideal gas law can be used and the speed of sound can be expressed as
$c = (k\ p / \rho)^{1/2}$
$= (k\ R\ T)^{1/2}$ (3)
where
k = ratio of specific heats (adiabatic index)
p = pressure (Pa, psi)
R = gas constant
T = absolute temperature (^oK, ^oR)
For an ideal gas the speed of sound is proportional to the square root of the absolute temperature.

13-1-4 EXAMPLE - SPEED OF SOUND IN AIR
The speed of sound in air at *0 ^oC* and absolute pressure *1 bar* can be calculated as
$c = (1.4\ (287\ J/K\ kg)\ (273\ K))^{1/2}$
$= \underline{331.2}$ (m/s)
where
k = 1.4
and
R = 287 (J/K kg)
The speed of sound in air at *20 ^oC* and absolute pressure *1 bar* can be calculated as
$c = (1.4\ (287\ J/K\ kg)\ (293\ K))^{1/2}$
$= \underline{343.1}$ (m/s)

13-1-5 EXAMPLE - SPEED OF SOUND IN WATER
The speed of sound in water at *0 ^oC* can be calculated as
$c = ((2.06\ 10^9\ N/m^2) / (999.8\ kg/m^3))^{1/2}$
$= \underline{1435.4}$ (m/s)
where
$E_v = 2.06\ 10^9$ (N/m^2)
and
$\rho = 999.8$ (kg/m^3)

- Speed of Sound in Water - Speed of sound in water at different temperatures - imperial and SI units.

13-1-6 SPEED OF SOUND IN SOLIDS

- Speed of Sound in some common Solids
- Elastic Properties and Young Modulus for some Materials
- The Bulk Modulus for Elasticity
- Material Properties

13-1-7 SUBSONIC AND SUPERSONIC SPEED

- If the Mach Number is below *1*, the flow velocity is lower than the speed of sound - and the speed is **subsonic**.
- If the Mach Number is *1* - the speed is **transonic**.
- If the Mach Number is above *1*, the flow velocity is higher than the speed of sound - and the speed is **supersonic.**

14 GASES - RATIOS OF SPECIFIC HEAT

14-1 HEAT CAPACITY OF A GAS IN A CONSTANT PRESSURE PROCESS - TO HEAT CAPACITY IN A CONSTANT VOLUME PROCESS

14-1-1 INTERNAL ENERGY

For an ideal gas the internal energy - *u* - is a function of temperature and the change in internal energy can be expressed as

$du = c_v\, dT$ (1)

where

du = change in internal energy

c_v = *specific heat for the gas in a constant volume process*

dT = change in temperature

c_v varies with temperature, but within a moderate temperature change the heat capacity - c_v - can be regarded as constant.

- Specific Heat for Gases

14-1-2 ENTHALPY

For an ideal gas the enthalpy - *h* - is function of temperature and the change in enthalpy can be expressed as

$dh = c_p\, dT$ (2)

where

dh = change in enthalpy

c_p= *specific heat for the gas in a constant pressure process*

c_p can within a moderate temperature change be regarded as constant.

- More about Gases and Specific Heat

The enthalpy in a fluid is defined as:

$h = u + p / \rho$ (3)

where

h = enthalpy

u = internal energy

p = absolute pressure

ρ = density

Combining (3) and the Ideal Gas Law gives:

$h = u + R\,T$ (4)

where

R = the individual gas constant

The change in enthalpy can be expressed by differentiating (4):

$dh = du + R\, dT$ (5)

Dividing (5) with *dT* gives:

$(dh / dT) - (du / dT) = R$ (6)

Modifying (6) with (1) and (2):

$c_p - c_v = R$ *(7)*

The difference $c_p - c_v$ is constant for an ideal gas.

14-1-3 THE RATIO OF SPECIFIC HEATS

The Ratio of Specific Heats can be expressed as:

$k = c_p / c_v$ *(8)*

where

k = the ratio of specific heats

Ratio of Specific Heats for some common gases:

Gas	Ratio of Specific Heats
Acetylene	1.30
Air, Standard	1.40
Ammonia	1.32
Argon	1.66
Benzene	1.12
N-butane	1.18
Iso-butane	1.19
Carbon Dioxide	1.28
Carbon Disulphide	1.21
Carbon Monoxide	1.40
Chlorine	1.33
Ethane	1.18
Ethyl alcohol	1.13
Ethyl chloride	1.19
Ethylene	1.24
Helium	1.66

Gas	Ratio of Specific Heats
N-heptane	1.05
Hexane	1.06
Hydrochloric acid	1.41
Hydrogen	1.41
Hydrogen chloride	1.41
Hydrogen sulphide	1.32
Methane	1.32
Methyl alcohol	1.20
Methyl butane	1.08
Methyl chloride	1.20
Natural Gas (Methane)	1.32
Nitric oxide	1.40
Nitrogen	1.40
Nitrous oxide	1.31
N-octane	1.05
Oxygen	1.40
N-pentane	1.08
Iso-pentane	1.08
Propane	1.12

Gas	Ratio of Specific Heats
R-11	1.14
R-12	1.14
R-22	1.18
R-114	1.09
R-123	1.10
R-134a	1.20
Steam (water)	1.33
Sulphur dioxide	1.26
Toulene	1.09

Since the ratio is dimensionless the value is the same in the SI and the imperial system of units.

15 SPEED OF SOUND IN AIR

15-1 SPEED OF SOUND IN AIR AT TEMPERATURES FROM *-40 - 1000 ^{O}C (-40 - 1500 ^{O}F)* AT STANDARD ATMOSPHERIC PRESSURE - IMPERIAL AND SI UNITS

Speed of Sound in Air at Standard Atmospheric Pressure in **Imperial (BG) Units**

Temperature *- t -* *(^{o}F)*	Speed of Sound *- c -* *(ft/s)*

Temperature *- t -* *(^oF)*	Speed of Sound *- c -* *(ft/s)*
-40	1004
-20	1028
0	1051
10	1062
20	1074
30	1085
40	1096
50	1106
60	1117
70	1128
80	1138
90	1149
100	1159
120	1180
140	1200
160	1220
180	1239
200	1258

Temperature - *t* - (*^{o}F*)	Speed of Sound - *c* - *(ft/s)*
300	1348
400	1431
500	1509
750	1685
1000	1839
1500	2114

Speed of Sound in Air at Standard Atmospheric Pressure in **SI Units**

Temperature - *t* - (*^{o}C*)	Speed of Sound - *c* - *(m/s)*
-40	306.2
0	331.4
5	334.4
10	337.4
15	340.4
20	343.3
25	346.3
30	349.1
40	354.7
50	360.3

Temperature *- t -* *(^oC)*	Speed of Sound *- c -* *(m/s)*
60	365.7
70	371.2
80	376.6
90	381.7
100	386.9
200	434.5
300	476.3
400	514.1
500	548.8
1000	694.8

16 SPEED OF SOUND IN GASES

16-1 SPEED OF SOUND IN SOME COMMON GASES

Speed of sound in some common gases at *0^oC* and atmospheric pressure are indicated below:

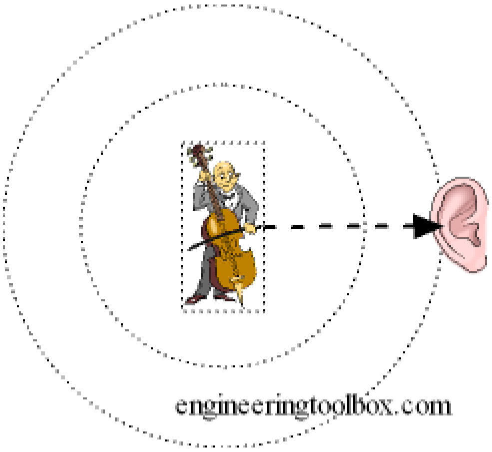
Gas	Speed of Sound

	(m/s)	(ft/s)
Air	331	1086
Carbon Dioxide	259	850
Carbon Monoxide	336	
Oxygen	316	1037
Helium	965	3166
Hydrogen	1290	4232
Water vapor	405	1328

17 ABATEMENT AND DISTANCE FROM SOURCE

17-1 THE DISRUPTION OF SOUND PRESSURES WAVES WHICH REDUCES THE NOISE IS CALLED ATTENUATION - SOUND PRESSURE LEVEL CALCULATOR

17-1-1 SPHERICAL DISTANCE



The sound pressure in a spherical distance from a source can be expressed as:

$p^2 = \rho\ c\ N / (4\ \pi\ r^2)$ (1)

where

p = sound pressure (Pa, N/m^2*)*

ρ = density of air (kg/m^3*)*

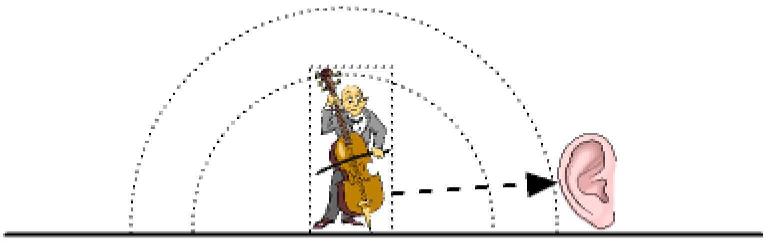
c = speed of sound (m/s)

N = sound power (W)

π = 3.14

r = distance from source (m)

17-1-2 HALF SPHERICAL DISTANCE



The sound pressure in a half spherical distance from a source can be expressed as:

$p^2 = \rho\ c\ N / (4\ \pi\ r^2 / 2) = 2\ \rho\ c\ N / (4\ \pi\ r^2)$ (2)

A more generic expression can be formulated to:

$p^2 = D\ \rho\ c\ N / (4\ \pi\ r^2)$ (3)

where

D = directivity coefficient (1 spherical, 2 half sperical)

The directivity coefficient depends on several parameters - the position and direction of the source, the room or the surrounding area, etc.

The Sound Pressure Level - L_p - can be expressed logarithmic as:

$L_p = 20 \log (p / p_{ref}) = 20 \log ((D\ \rho\ c\ N / (4\ \pi\ r^2))^{1/2} / p_{ref})$

$= 20 \log (1/r\ (D\ \rho\ c\ N / (4\ \pi))^{1/2} / p_{ref})$ (4)

where

L_p *= sound pressure level (dB)*

$p_{ref} = 2\ 10^{-5}$ *- reference sound pressure (Pa)*

Note! that for every doubling of the distance from the noise source, the sound pressure levels - $L_{p,}$ will be reduced by *6 decibels*.

17-1-3 SOUND PRESSURE LEVEL CALCULATOR

ρ - air density (kg/m^3*)*

c - sound velocity (m/s)

N - sound power (W)

r - distance from source (m)

D - directivity coefficient

Sound Pressure Level (*dB*) : **78**

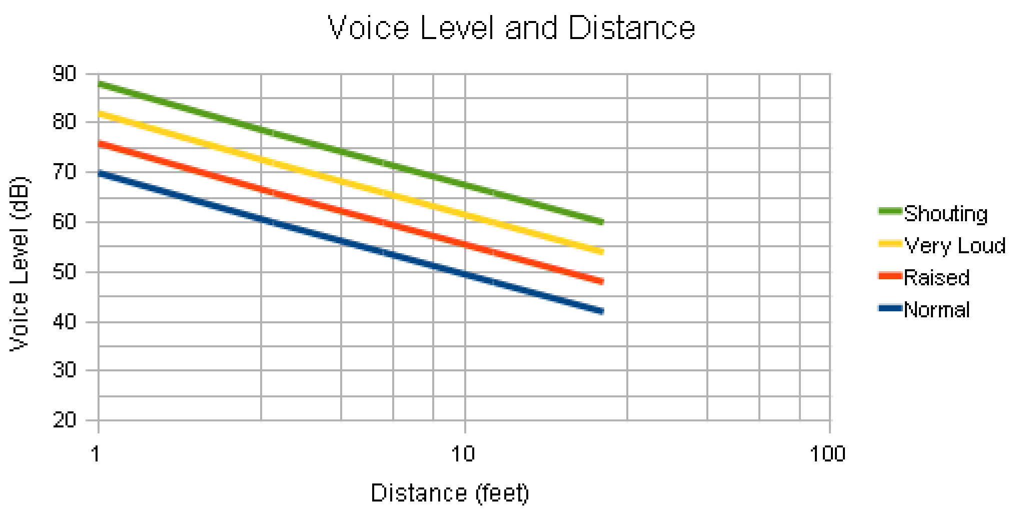
18 VOICE LEVEL AND DISTANCE

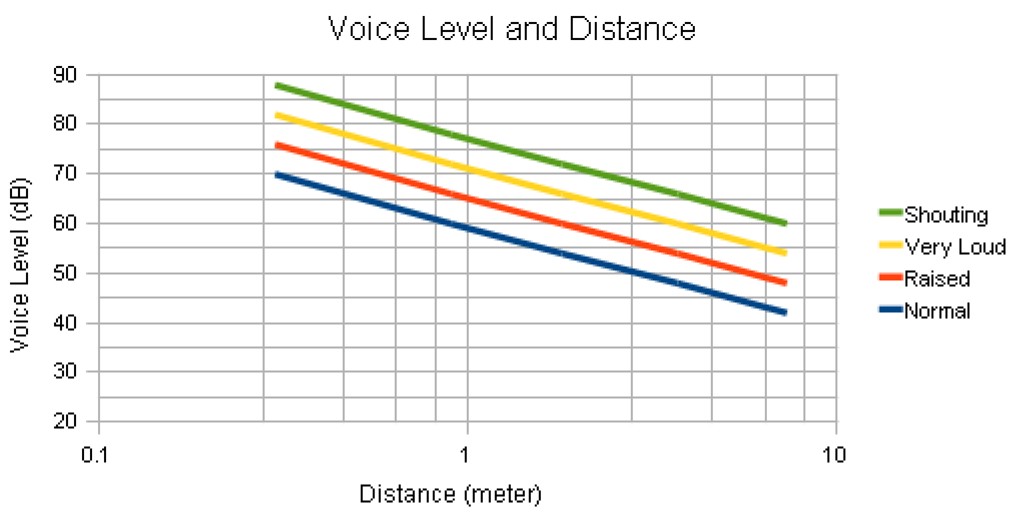
18-1 THE VOICE LEVEL AT VARIOUS DISTANCES

Talking with a normal voice approximate to a sound pressure level of *70 dB*, a raised voice to *76 dB*, a very loud voice to *82 dB* and a shouting voice to *88 dB* (*1 ft* distance).
For every doubling of the distance from the noise source the sound pressure levels will be reduced by *6 decibels*. This may be expressed like:

Distance		Voice Level (*dB*)			
(*feet*)	(*m*)	Normal	Raised	Very Loud	Shouting
1	0.3	70	76	82	88
3	0.9	60	66	72	78
6	1.8	54	60	66	72
12	3.7	48	54	60	66
24	7.3	42	48	54	60

In social situations people often talk with normal voice levels at distances of 1 to 4 meters. In such cases the noise level should not exceed *55* to *60* *dB(A)*.
In outdoor play and recreational areas, people often communicate with a raised or very loud voice at distances of *5* to *10 meters*. In such cases background noise should not exceed *45* to *55* *dB(A)*.





19 DUCTS - NOISE GENERATION

19-1 AIR FLOW AND NOISE GENERATED IN DUCTS

When air flows through ducts noise are generated. The noise can be calculated with the empirical equation below:

L_w = 10 + 50 log(v) + 10 log(A) (1)

where

L_w = sound power level (dB)

v = air velocity (m/s)

A = duct cross sectional area (m^2)

19-1-1 *EXAMPLE - NOISE GENERATED IN DUCTS*

The noise generated in a 200 mm circular duct with airflow 10 m/s can be calculated as

L_w = 10 + 50 log(10 m/s) + 10 log(π ((0.2 m) / 2)^2)

= 45 db

The noise generated in a 200 mm circular duct with airflow 20 m/s can be calculated as

L_w = 10 + 50 log(20 m/s) + 10 log(π ((0.2 m) / 2)^2)

= *60* db

Note! - the noise is generated inside the duct. Compared to the noise from the fans - the noise generated by the duct can in general be neglected.

20 FANS AND NOISE POWER GENERATION

20-1 SOUND POWER LEVEL FROM A FAN DEPENDS ON MOTOR POWER, CAPACITY, STATIC PRESSURE AND DISCHARGED VOLUME

The empiric expressions below can be used to indicate the Sound Power Levels from fans. **Note!** Exact Sound Power Level should be obtained from manufacturer specifications.

20-1-1 SOUND POWER LEVEL - SI-UNITS

$L_w = 67 + 10 \log(S) + 10 \log(p)$ (1a)

$L_w = 40 + 10 \log(Q)+ 20 \log(p)$ (1b)

$L_w = 94 + 20 \log(S) - 10 \log(Q)$ (1c)

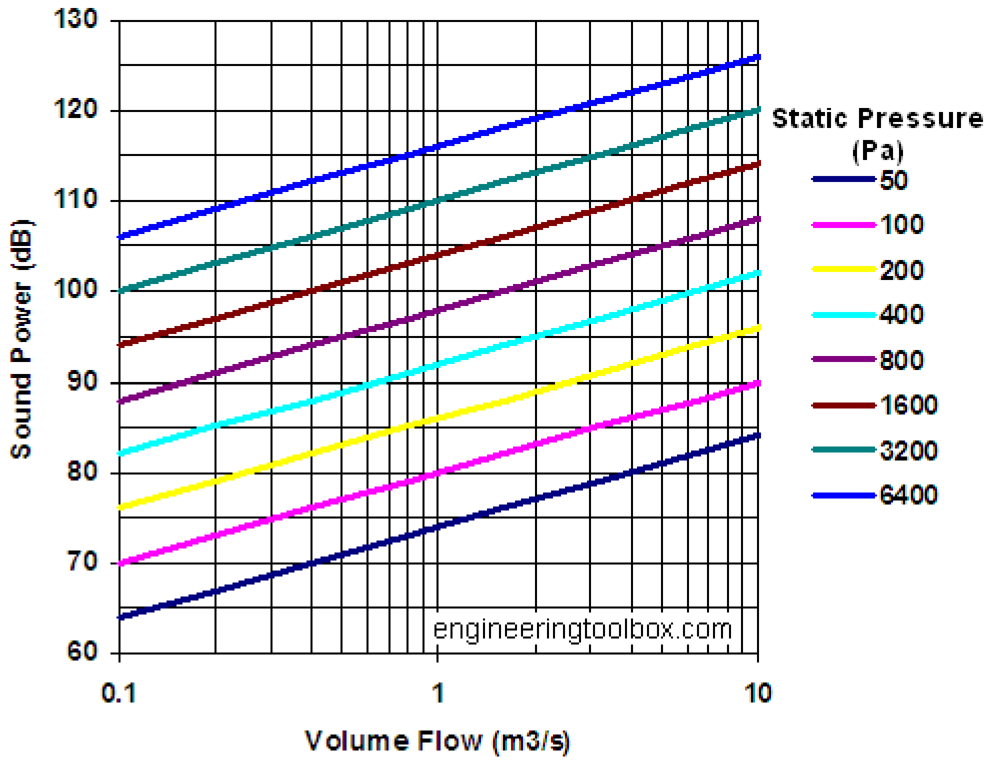
where

L_w = *sound power level (dB)*

S = rated motor power (kW)

p = fan static pressure (Pa, N/m²)

Q = volume discharged (m³/s)



20-1-2 SOUND POWER FREQUENCIES

The sound power calculated in the expressions and diagram above can be determined for each octave by adding:

dB added

Fan Type	Octave							
	63	125	250	500	1000	2000	4000	8000
Centrifugal fan, backward-curved blades	-4	-6	-9	-11	-13	-16	-19	-22
Centrifugal fan, forward-curved blades	-2	-6	-13	-18	-19	-22	-25	-30
Centrifugal fan, straight radial blades	-3	-5	-7	-7	-8	-11	-16	-18
Axial fan	-7	-9	-7	-7	-8	-11	-16	-18

20-1-3 SOUND POWER LEVEL - IMPERIAL UNITS

$L_w = 90 + 10 \log(s) + 10 \log(h)$ (2a)

$L_w = 55 + 10 \log(q) + 20 \log(h)$ (2b)

$L_w = 125 + 20 \log(s) - 10 \log(q)$ (2c)

where

s = rated motor power (hp)

h = fan static head (inch water gauge)

q = volume discharged (ft^3/min)

20-1-4 DISCHARGE VELOCITIES FROM FANS FOR QUIET OPERATIONS

The discharge velocity from fans should be kept within certain limits to avoid noisy operations. As an indication the values below can be used:

Application	Maximum Discharge Velocity *(m/s)*	
	Supply System	Exhaust System
Sound studios, churches, libraries	4 - 5	5 - 7
Cinemas, theatres, ballrooms	5 - 7	6 - 8
Restaurants, offices, hotels, shops	6 - 8	7 - 9

20-1-5 ACMA CERTIFIED SOUND LEVELS

Certified Sound-Power Level (decibels)				
Octave Band (Hz)	Fan 1	Fan 2	Fan 3	Fan 4

Certified Sound-Power Level (decibels)				
Octave Band (Hz)	**Fan 1**	**Fan 2**	**Fan 3**	**Fan 4**
63	117	113	120	101
125	118	116	113	98
250	109	111	111	107
500	106	106	107	120
1000	103	103	103	116
2000	97	98	98	114
4000	94	95	93	109
8000	92	92	88	105

21 SOUND FREQUENCY, WAVELENGTH AND OCTAVE

21-1 AN INTRODUCTION TO THE NATURE OF SOUND - FREQUENCY, WAVELENGTH AND OCTAVES

Sound energy is transmitted through air (or other particles) as a traveling pressure wave. In air the displacement wave amplitude may range from 10^{-7} *mm* to a few mm per second.

21-1-1 FREQUENCY

The frequency - cycles per second - of a sound is expressed in hertz - *Hz*. The frequency can be expressed as

$f = 1 / T \qquad (1)$

where

f = *frequency* (s^{-1}, *Hz*)

T = *time for completing one cycle (s)*

Example - Frequency

The time for completing one cycle for a *500 Hz* tone can be calculated using (1) as

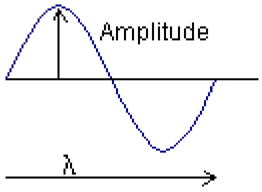
$T = 1 / (500 Hz)$

$= \underline{0.002}$ s

The range for human hearing is *20* to *20.000 Hz*. By age *12-13.000 Hz* are the upper limit for many people.

21-1-2 WAVELENGTH

The wavelength of sound is the distance between analogous points of two successive waves.



λ = c / f *(2)*
where
λ = wavelength (m)
c = speed of sound (m/s)
f = frequency (s^{-1}, Hz)

Example - the Wavelength of a Tone

In air at normal atmosphere at *$0\,^oC$* the speed of sound is *331.2 m/s*. The wavelength of a *500 Hz* tone can be calculated as:
λ = (331.2 m/s) / (500 Hz)
= 0.662 m

- Speed of Sound Calculator

22 OCTAVE

An octave is the interval between two points where the frequency at the second point is twice the frequency of the first.

Octave	1	2	3	4	5	6	7	8
Frequency *(Hz)*	63	125	250	500	1K	2K	4K	8K
Wavelength in air *(70^oF, 21^oC) (ft)*	17.92	9.03	4.52	2.26	1.129	0.56	0.28	0.14
Wavelength in air *(70^oF, 21^oC) (m)*	5.46	2.75	1.38	0.69	0.34	0.17	0.085	0.043

A musical tone is eight full tones above or below an another tone, with twice or half as many vibrations per second as the other tone.

23 NR - NOISE RATING CURVES

23-1 AN INTRODUCTION TO NOISE RATING - NR - CURVES, DEVELOPED BY THE INTERNATIONAL ORGANIZATION FOR STANDARDIZATION (ISO) - NR DIAGRAM

The Noise Rating - NR - curves are developed by the International Organization for Standardization (ISO) to determine the acceptable indoor environment for hearing preservation, speech communication and annoyance.
In U.S. it is common to use the Noise Criterion - NC.
The noise rating graphs for different sound pressure levels are plotted at acceptable sound pressure levels at different frequencies. Acceptable sound pressure level vary with the room and the use of it. Different curves are obtained for each type of use. Each curve is obtained by a NR number.

Note! Noise Rating - NR - is common used in Europe. The Noise Criterion - NC - is more common in USA.

23-1-1 RECOMMENDED NOISE RATING - NR - LEVELS

The Noise Rating level for different uses should not exceed the Noise Ratings indicated in the table below:

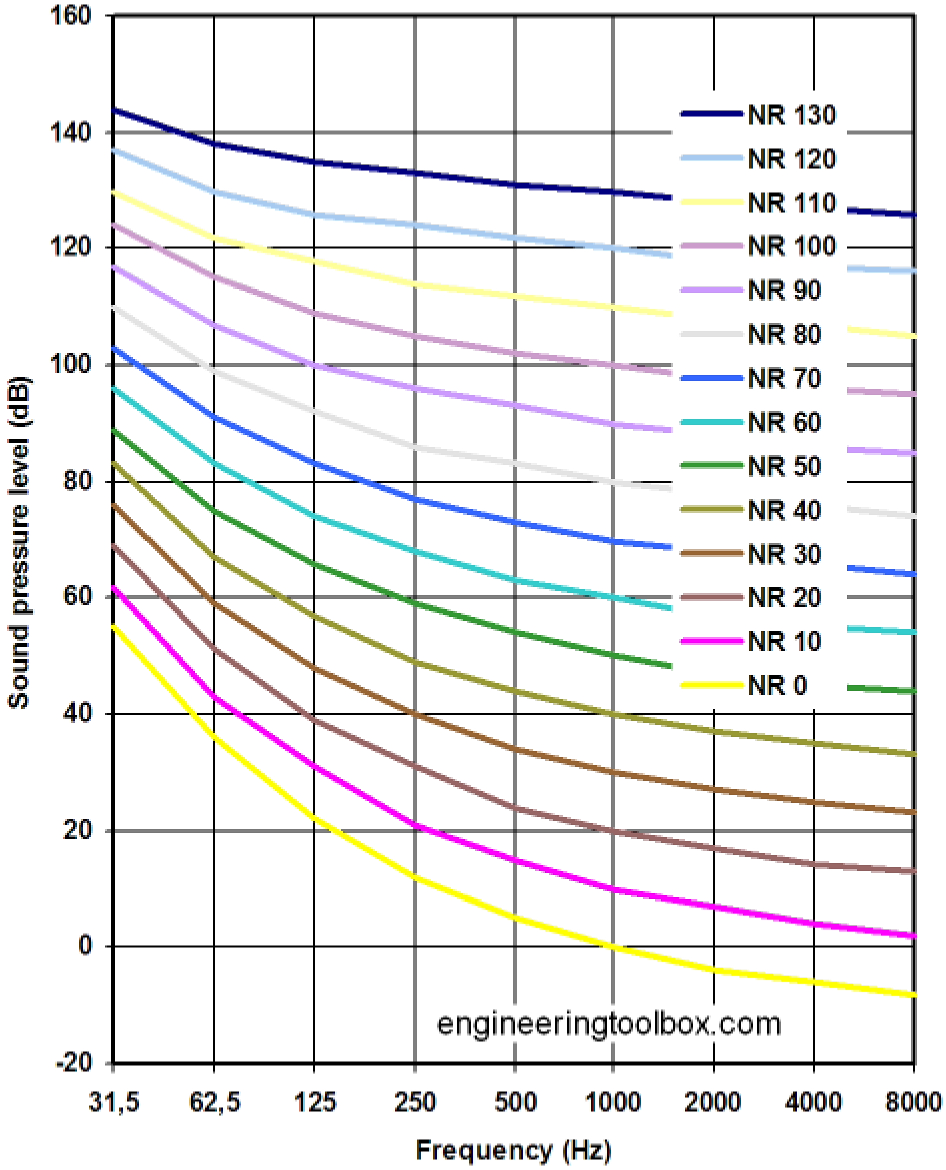
Noise rating curve	Application
NR 25	Concert halls, broadcasting and recording studios, churches
NR 30	Private dwellings, hospitals, theatres, cinemas, conference rooms
NR 35	Libraries, museums, court rooms, schools, hospitals operating theaters and wards, flats, hotels, executive offices
NR 40	Halls, corridors, cloakrooms, restaurants, night clubs, offices, shops
NR 45	Department stores, supermarkets, canteens, general offices
NR 50	Typing pools, offices with business machines
NR 60	Light engineering works
NR 70	Foundries, heavy engineering works

23-1-2 NOISE RATING CURVES

Maximum Sound Pressure Level (dB)									
Noise Rating - NR - Curve	Octave band mid-frequency (Hz)								
	31.5	62.5	125	250	500	1000	2000	4000	8000
NR 0	55	36	22	12	5	0	-4	-6	-8
NR 10	62	43	31	21	15	10	7	4	2
NR 20	69	51	39	31	24	20	17	14	13
NR 30	76	59	48	40	34	30	27	25	23
NR 40	83	67	57	49	44	40	37	35	33
NR 50	89	75	66	59	54	50	47	45	44

Maximum Sound Pressure Level (dB)									
Noise Rating - NR - Curve	**Octave band mid-frequency (Hz)**								
	31.5	**62.5**	**125**	**250**	**500**	**1000**	**2000**	**4000**	**8000**
NR 60	96	83	74	68	63	60	57	55	54
NR 70	103	91	83	77	73	70	68	66	64
NR 80	110	99	92	86	83	80	78	76	74
NR 90	117	107	100	96	93	90	88	86	85
NR 100	124	115	109	105	102	100	98	96	95
NR 110	130	122	118	114	112	110	108	107	105
NR 120	137	130	126	124	122	120	118	117	116
NR 130	144	138	135	133	131	130	128	127	126

23-1-3 NR - NOISE RATING DIAGRAM

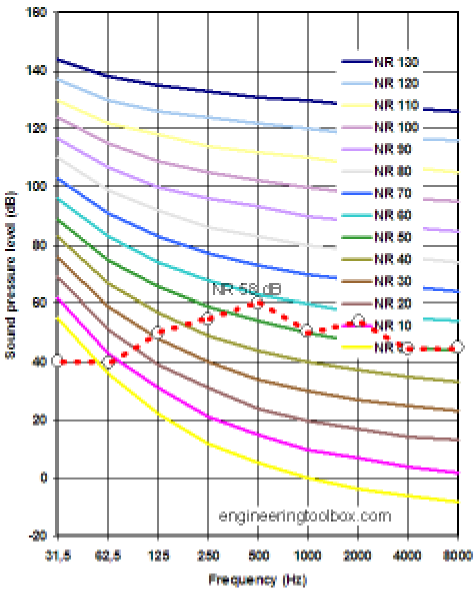


23-1-4 EXAMPLE - ESTIMATING NR - NOISE RATING

The Noise Rating - NR - of a noise spectrum like

- 31.5 Hz : 40 dB
- 62.5 Hz : 40 dB
- 125 Hz : 50 dB
- 250 Hz : 55 dB
- 500 Hz : 60 dB
- 1000 Hz : 50 dB
- 2000 Hz : 55 dB
- 4000 Hz : 45 dB
- 8000 Hz : 45 dB

can be estimated to NR = 58 dB as indicated in the diagram below.



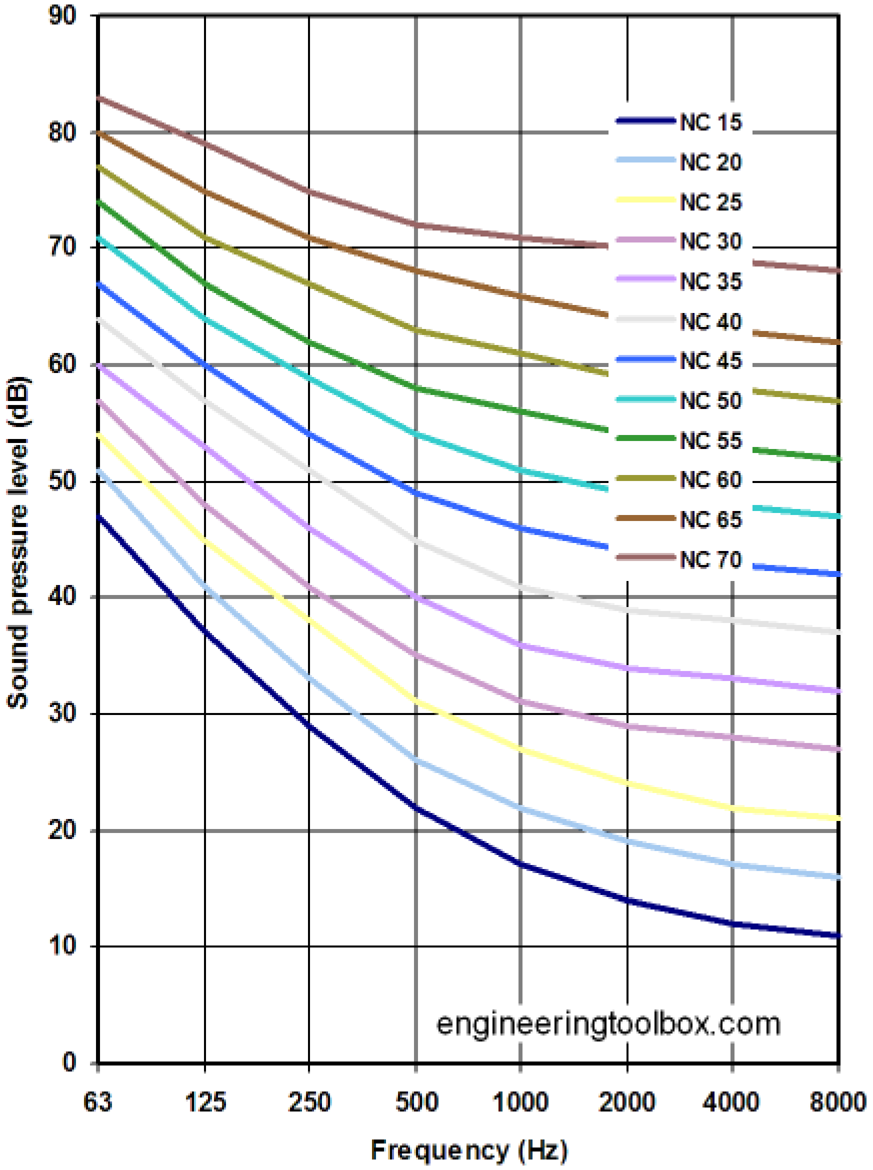
24 NC - NOISE CRITERION

24-1 FOR A GIVEN NOISE SPECTRUM, THE NC RATING CAN BE OBTAINED BY PLOTTING ITS OCTAVE BAND LEVELS ON THE SET OF NC CURVES

Noise Criterion - NC - were established in U.S. for rating indoor noise, noise from air-conditioning equipment etc. In Europe it is common to use Noise Rating Curves - NR.

The method consists of a set of criteria curves extending from 63 to 8000 Hz, and a tangency rating procedure. The criteria curves define the limits of octave band spectra that must not be exceeded to meet occupant acceptance in certain spaces.

The NC rating can be obtained by plotting the octave band levels for a given noise spectrum - the NC curves. The noise spectrum is specified as having a NC rating same as the lowest NC curve which is not exceeded by the spectrum.



Noise Criterion	Octave Band Center Frequency *(Hz)*							
	63	125	250	500	1000	2000	4000	8000
	Sound Pressure Levels *(dB)*							
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

Noise Criterion	Octave Band Center Frequency *(Hz)*							
	63	125	250	500	1000	2000	4000	8000
	Sound Pressure Levels *(dB)*							
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

24-1-1 RECOMMENDED NOISE CRITERION - NC

The noise in different types of rooms should not exceed the Noise Criterion limits listed below:

Type of Room - Space Type	Recommended NC Level NC Curve	Equivalent Sound Level dBA
Residences		
Apartment Houses	25-35	35-45
Assembly Halls	25-30	35-40
Churches	30-35	40-45
Courtrooms	30-40	40-50
Factories	40-65	50-75
Private Homes, rural and suburban	20-30	30-38

Type of Room - Space Type	Recommended NC Level NC Curve	Equivalent Sound Level dBA
Private Homes, urban	25-30	34-42
Hotels/Motels		
- Individual rooms or suites	25-35	35-45
- Meeting or banquet rooms	25-35	35-45
- Service and Support Areas	40-45	45-50
- Halls, corridors, lobbies	35-40	50-55
Offices		
- Conference rooms	25-30	35-40
- Private	30-35	40-45
- Open-plan areas	35-40	45-50
- Business machines/computers	40-45	50-55
Hospitals and Clinics		
- Private rooms	25-30	35-40
- Operating rooms	25-30	35-40
- Wards	30-35	40-45
- Laboratories	35-40	45-50
- Corridors	30-35	40-45
- Public areas	35-40	45-50
Schools		

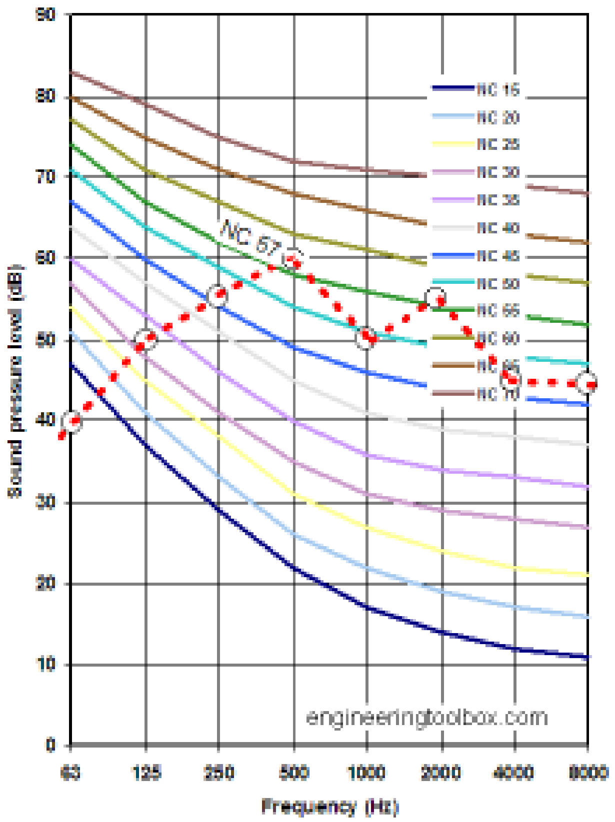
Type of Room - Space Type	Recommended NC Level NC Curve	Equivalent Sound Level dBA
- Lecture and classrooms	25-30	35-40
- Open-plan classrooms	35-40	45-50
Movie motion picture theaters	30-35	40-45
Libraries	35-40	40-50
Legitimate theaters	20-25	30-65
Private Residences	25-35	35-45
Restaurants	40-45	50-55
TV Broadcast studies	15-25	25-35
Recording Studios	15-20	25-30
Concert and recital halls	15-20	25-30
Sport Coliseums	45-55	55-65
Sound broadcasting	15-20	25-30

24-1-2 EXAMPLE - ESTIMATING NC - NOISE CRITERION

The Noise Criterion - NC - of a noise spectrum like

- 62.5 Hz : 40 dB
- 125 Hz : 50 dB
- 250 Hz : 55 dB
- 500 Hz : 60 dB
- 1000 Hz : 50 dB
- 2000 Hz : 55 dB
- 4000 Hz : 45 dB
- 8000 Hz : 45 dB

can be estimated to NC = 57 dB as indicated in the diagram below.



25 COMPARING NOISE CRITERIA

25-1 COMPARING NOISE CRITERIA - NOISE CRITERION (NC), NOISE RATING (NR) AND DB(A)

Noise Criterion - *NC* - were established in U.S. for rating indoor noise, noise from air-conditioning equipment etc. In Europe it is common to use Noise Rating Curves - *NR*.
db(A) - L_A - is a weighted method compensating for the human hearing of sound pressure at different frequencies.
Choosing an appropriate noise criteria is important when specifying acceptable levels of noise. Most organizations use a particular index based upon practical experience. Recommended maximum noise levels for different types of rooms and standards are indicated in the table below

Type of Room - Occupancy		Noise Criterion - NC -	Noise Rating - NR -	db(A)
Very quiet	Concert and opera halls, recording studios, theaters, etc.	10 - 20	20	25 - 30
	Private bedrooms, live theaters, television and radio studios, conference and lecture rooms, cathedrals and large churches, libraries, etc.	20 - 25	25	25 - 30
	Private living rooms, board rooms, conference and lecture rooms, hotel bedrooms	30 - 40	30	30 - 35

Type of Room - Occupancy		Noise Criterion - NC -	Noise Rating - NR -	db(A)
Quiet	Public rooms in hotels, small offices classrooms, courtrooms	30 - 40	35	40 - 45
Moderate noisy	Drawing offices, toilets, bathrooms, reception areas, lobbies, corridors, department stores, etc.	35 - 45	40	45 - 55
Noisy	Kitchens in hospitals and hotels, laundry rooms, computer rooms, canteens, supermarkets, office landscape, etc.	40 - 50	45	45 - 55

26 FREQUENCY LIMITS FOR OCTAVE BANDS

26-1 FREQUENCY LIMITS FOR OCTAVE BANDS AND 1/3-OCTAVE BANDS

Each octave band may be separated into three ranges - referred to as **one-third-octave** bands.

Frequency *(Hz)*					
Octave Bands			1/3 Octave Bands		
Lower Band Limit *(Hz)*	Center Frequency *(Hz)*	Upper Band Limit *(Hz)*	Lower Band Limit *(Hz)*	Center Frequency *(Hz)*	Upper Band Limit *(Hz)*
11	16	22	14.1	16	17.8
			17.8	20	22.4
			22.4	25	28.2
22	31.5	44	28.2	31.5	35.5
			35.5	40	44.7
			44.7	50	56.2
44	63	88	56.2	63	70.8
			70.8	80	89.1
			89.1	100	112
88	125	177	112	125	141
			141	160	178
			178	200	224
177	250	355	224	250	282
			282	315	355
			355	400	447
355	500	710	447	500	562
			562	630	708
			708	800	891

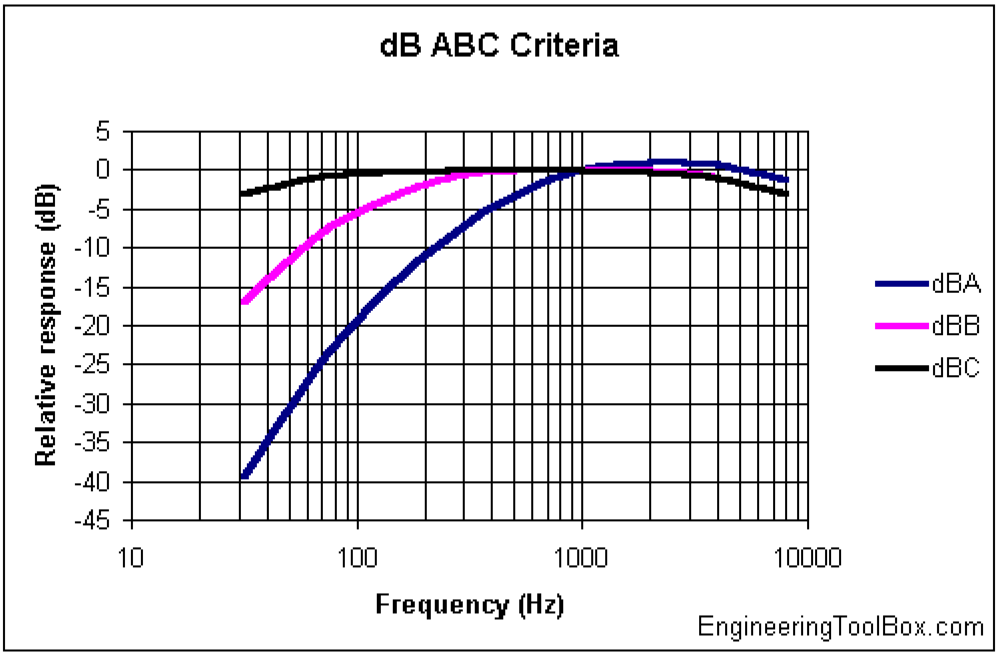
710	1000	1420	891	1000	1122
			1122	1250	1413
			1413	1600	1778
1420	2000	2840	1778	2000	2239
			2239	2500	2818
			2818	3150	3548
2840	4000	5680	3548	4000	4467
			4467	5000	5623
			5623	6300	7079
5680	8000	11360	7079	8000	8913
			8913	10000	11220
			11220	12500	14130
11360	16000	22720	14130	16000	17780
			17780	20000	22390

27 DECIBEL A, B AND C

27-1 SOUND PRESSURE IS NOT EQUALLY SENSED BY HUMAN EAR AT DIFFERENT FREQUENCIES - COMPENSATED WITH DB(A), DB(B) OR DB(C) FILTERS

The human ear is more sensitive to sound in the frequency range 1 kHz to 4 kHz than to sound at very low or high frequencies. Higher sound pressures are therefore acceptable at lower and higher frequencies than in the mid range.
The knowledge about human ear is important in acoustic design and sound measurement. To compensate, sound meters are normally fitted with filters adapting the measured sound response to the human sense of sound. Common filters are

- *dB(A)*
- *dB(B)*
- *dB(C)*



27-1-1 DB(A)

The decibel A filter is widely used. dB(A) roughly corresponds to the inverse of the *40 dB* (at *1 kHz*) equal-loudness curve for the human ear.

Using the dBA-filter, the sound level meter is less sensitive to very high and very low frequencies. Measurements made with this scale are expressed as dB(A).

27-1-2 DB(B) AND DB(C)

The decibel C filter is practically linear over several octaves and is suitable for subjective measurements at very high sound pressure levels. The decibel B filter is between C and A. The B and C filters are seldom used.

27-1-3 COMPARING DB(A), DB(B) AND DB(C)

The decibel filters A, B and C are compared below:

Relative Response (dB)	Frequency (Hz)								
	31.5	63	125	250	500	1000	2000	4000	8000
dB(A)	-39.4	-26.2	-16.1	-8.6	-3.2	0	1.2	1	-1.1
dB(B)	-17	-9	-4	-1	0	0	0	-1	-3
dB(C)	-3	-0.8	-0.2	0	0	0	-0.2	-0.8	-3

27-1-4 EXAMPLE - MEASURING DB(A)

If sound pressure is measured at different octaves the resulting dB(A) sound pressure can be calculated by logarithmic addition.

Octave	1	2	3	4	5	6	7	8
Measured Sound Pressure Level (*dB*)	54	60	64	53	48	43	39	32
db(A) filter (*dB*)	26	16	9	4	0	-1	-1	1
Resulting Sound Pressure Level (*dB*)	28	44	55	49	48	44	40	31

- Logarithmic adding decibels in octave 4 and 5 gives approximately 51.5 dB.
- Logarithmic adding decibels in octave 3 together with the sum from 4 and 5 (1) gives approximately 56.5 dB.
- The resulting sound pressure level in octave 1, 2, 6, 7 and 8 is low compared with (2) and can be neglected.
- The resulting sound pressure level can therefore be estimated to approximately 57 dB(A)

28 ADDING DECIBELS

28-1 THE LOGARITHMIC DECIBEL SCALE IS CONVENIENT CALCULATING SOUND POWER LEVELS AND SOUND PRESSURE LEVELS FOR TWO OR MORE SOUND SOURCES

28-1-1 ADDING EQUAL SOUND OR NOISE POWER SOURCES

The resulting sound power when adding equal sound power sources can be expressed as:

$L_{wt} = 10 \log(n\, N / N_0)$

$= 10 \log(N / N_0) + 10 \log(n)$

$= L_{ws} + 10 \log(n)$ (1)

where

L_{wt} *= the total sound power level (dB)*

L_{ws}*= sound power level from each single source (dB)*

N = sound power (W)

$N_0 = 10^{-12}$ *- reference sound power (W)*

n = number of sources

Adding Equal Sound Power Calculator

1 *N - sound power (W)*

0.000000000 N_0 *- reference sound power (W)*

2 *n - number of sources*

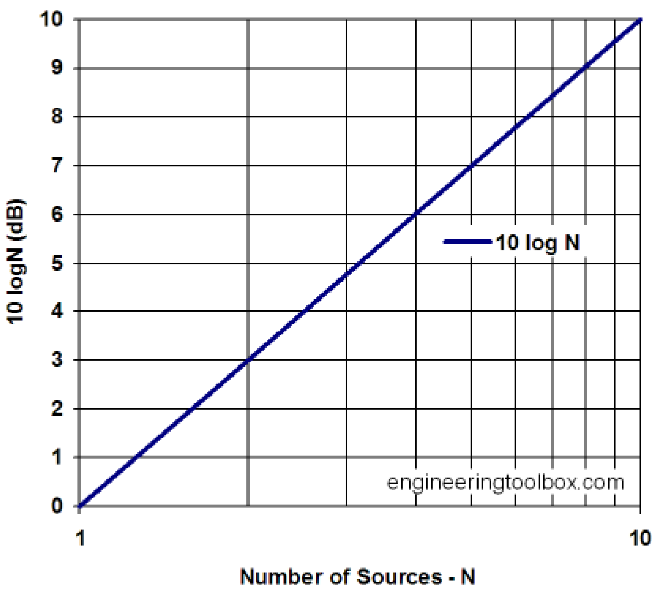
Sound Power Level (dB) : 123

50 L_{ws} *- sound power level (dB)*

2 *n - number of sources*

Sound Power Level (dB) : 53

Adding of equal sound power sources can be expressed graphically



Note! Adding of two identical sources will increase the total sound power level with 3 dB (10 log(2)).

Sound power and sound power level are often used to specify the noise or sound emitted from technical equipment like fans, pumps or other machines.

Sound measured with microphones or sensors are sound pressure.

28-1-2 ADDING EQUAL SOUND PRESSURE LEVELS

The resulting sound pressure level when adding equal sound pressure can be expressed as:

$L_{pt} = L_{ps} + 20 \log(n)$ (2)

where

L_{pt} = *total sound pressure level (dB)*

L_{ps} = *sound pressure level from each single source (dB)*

n = number of sources

Adding Equal Sound Pressure Levels Calculator

50 L_{ws} - *sound power level (dB)*

2 *n - number of sources*

Sound Pressure Level (dB) : 56

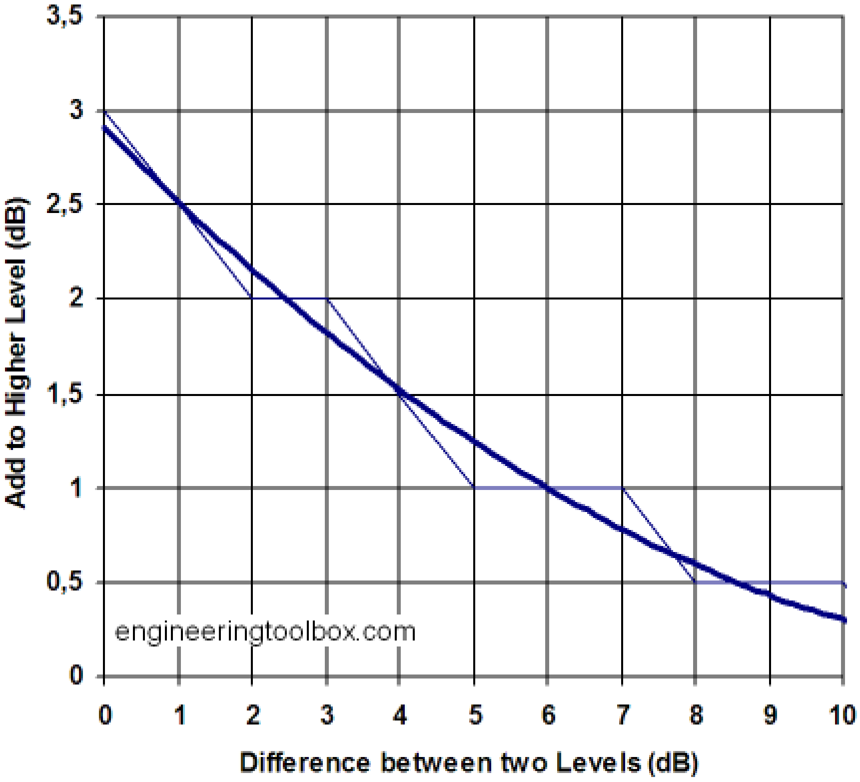
Number of Sources	Increase in Sound Power Level (dB)	Increase in Sound Pressure Level (dB)
2	3	6
3	4.8	9.6
4	6	12
5	7	14
10	10	20
15	11.8	23.6
20	13	26

28-1-3 ADDING SOUND POWER FROM SOURCES WITH DIFFERENT SOUND POWERS

The sound power level from more than one source can be calculated as

$L_{wt} = 10 \log((N_1 + N_2 ... + N_n) / N_o)$ (3)

Adding two sources at different levels can be expressed graphically as



Sound Power Level Difference between two Sound Sources (dB)	**Added Decibel to the Highest Sound Power Level (dB)**
0	3
1	2.5
2	2
3	2
4	1.5
5	1
6	1
7	1
8	0.5

Sound Power Level Difference between two Sound Sources (dB)	Added Decibel to the Highest Sound Power Level (dB)
9	0.5
10	0.5
> 10	0

29 PNC - PREFERRED NOISE CRITERION

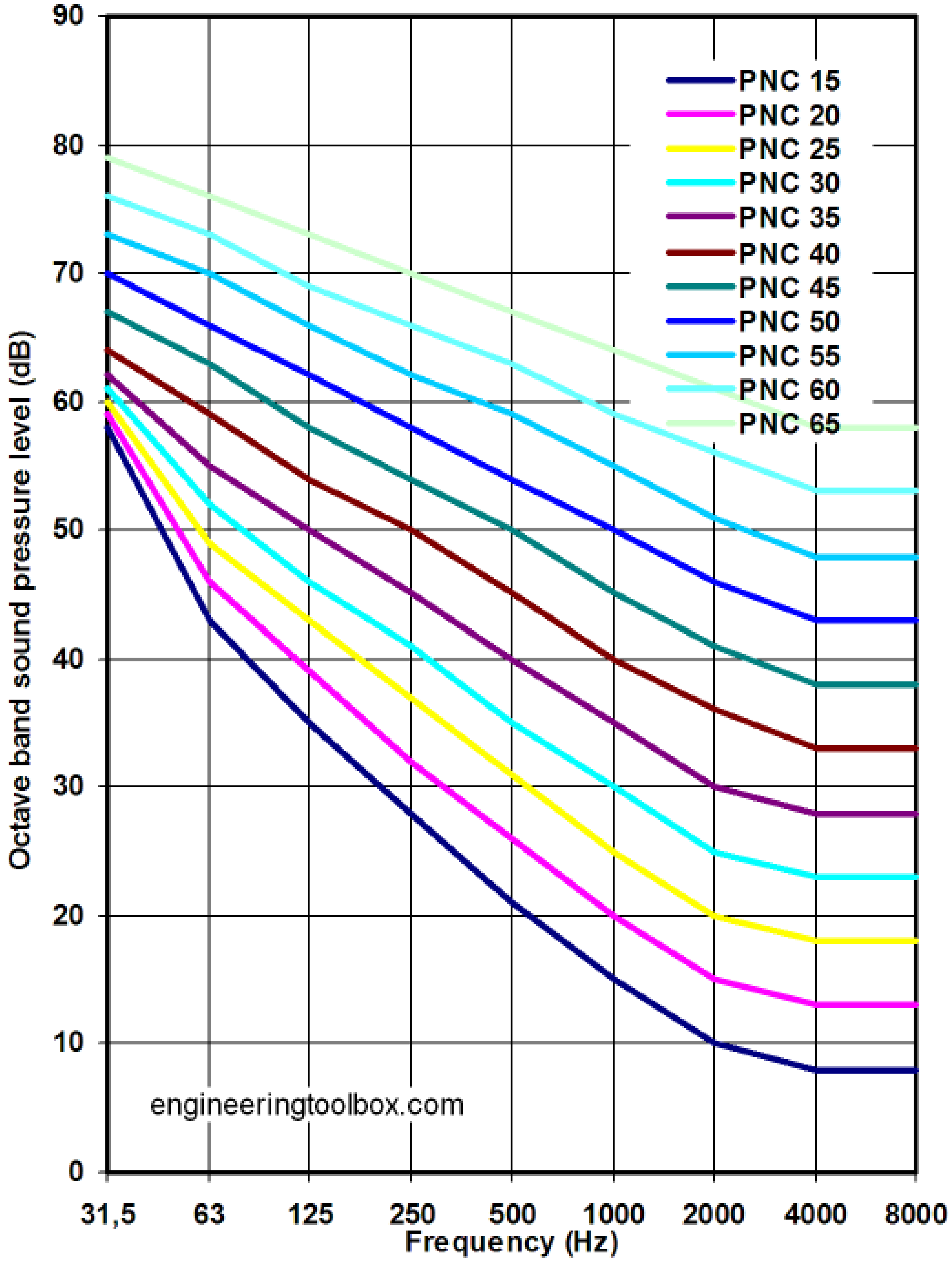
29-1 A NOISE MEASUREMENT SYSTEM FOR CONTINUOUS OR AMBIENT NOISE IN INDOOR ENVIRONMENTS PROPOSED BY LEO BERANEK IN 1971

Preferred Noise Criterion curves (PNC) are often used to judge the acceptability of ventilation and other background broad band noise.
Noise Criterion - NC - curves are generally preferred over PNC curves, because the PNC criteria at lower frequencies are more stringent than that of the NC curves.

Maximum Sound Pressure Level (dB)									
PNC Preferred Noise Criterion	Center frequency (Hz)								
	31.5	63.0	125	250	500	1000	2000	4000	8000
PNC - 15	58	43	35	28	21	15	10	8	8
PNC - 20	59	46	39	32	26	20	15	13	13
PNC - 25	60	49	43	37	31	25	20	18	18
PNC - 30	61	52	46	41	35	30	25	23	23
PNC - 35	62	55	50	45	40	35	30	28	28
PNC - 40	64	59	54	50	45	40	35	33	33
PNC - 45	67	63	58	54	50	45	41	38	38

Maximum Sound Pressure Level (dB)									
PNC Preferred Noise Criterion	Center frequency (Hz)								
	31.5	63.0	125	250	500	1000	2000	4000	8000
PNC - 50	70	66	62	58	54	50	46	43	43
PNC - 55	73	70	66	62	59	55	51	48	48
PNC - 60	76	73	69	66	63	59	56	53	53
PNC - 65	79	76	73	70	67	64	61	58	58

PNC-type criteria provide no protection for low frequency sound exposure, and further, tend to rely on the public's increasing toleration of background noise and what seems to be decreasing auditory skills.

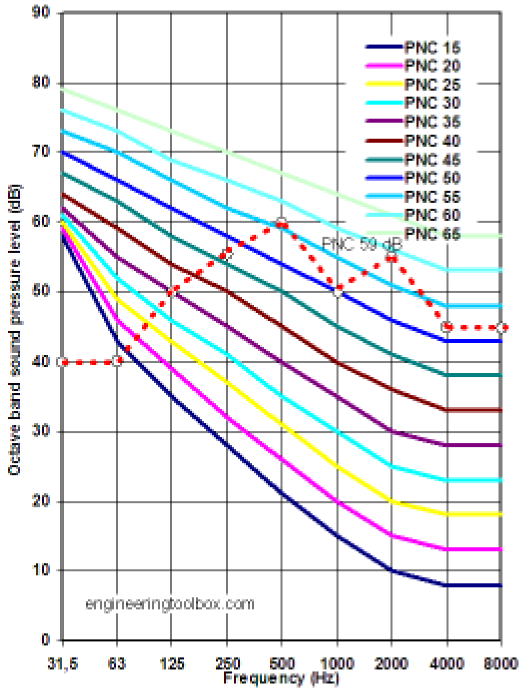


29-1-1 EXAMPLE - ESTIMATING PNC - PREFERRED NOISE CRITERION

The Preferred Noise Criterion - PNC - of a noise spectrum like

- 31.5 : 40 dB
- 62.5 Hz : 40 dB
- 125 Hz : 50 dB
- 250 Hz : 55 dB
- 500 Hz : 60 dB
- 1000 Hz : 50 dB
- 2000 Hz : 55 dB
- 4000 Hz : 45 dB
- 8000 Hz : 45 dB

can be estimated to PNC = 57 dB as indicated in the diagram below.



30 DUCT VELOCITY

30-1 CALCULATE VELOCITIES IN CIRCULAR AND RECTANGULAR DUCTS - IMPERIAL AND SI-UNITS - ONLINE CALCULATOR

30-1-1 IMPERIAL UNITS

The velocity of air in a ventilation duct can be expressed in imperial units like

$v_i = q_i / A_i = 576\, q_i / (\pi d_i^2) = 144\, q_i / (a_i b_i)$ *(1)*

where

v_i = *air velocity (ft/min)*

q_i = *air flow (cfm)*

A_i = *area of duct (square feet)*

d_i = *diameter of duct (inches)*

a_i = *width of duct (inches)*

b_i = *width of duct (inches)*

Imperial Units Air Flow Velocity Calculator

Air velocity can be calculated with the calculator below. Add air volume - *q* - and diameter - *d* - (or length *a* and *b*).

1000 *Air volume - q_i - (cfm)*

12 *Diameter - d_i - (inches)*

or alternatively

Length side - a_i - (inches)

Length side - b_i - (inches)

30-1-2 SI - UNITS

Air velocity in a duct can alternatively be expressed in SI units like

$v_m = q_m / A_m = 4\, q_m / (\pi d_m^2) = q_m / (a_m b_m)$ *(2)*

where

v_m = *air velocity (m/s)*

q_m = *air flow (m^3/s)*

A_m = *area of duct (m^2)*

d_m = diameter of duct (m)
a_m = width of duct (m)
b_m = width of duct (m)

SI Units Air Flow Velocity Calculator

Air velocity can be calculated with the calculator below. Add air volume - *q* - and diameter - *d* - (or length *a* and *b*).

1 *Air volume - q_m - (m^3/s)*

Diameter - d_m - (m)

or alternatively

0.5 *Length side - a_m - (m)*

0.5 *Length side - b_m - (m)*

31 AIR VELOCITIES IN DUCTS

31-1 RECOMMENDED MAXIMUM AIR VELOCITIES IN VENTILATION DUCTS

Air velocities in ducts should not exceed certain limits to avoid high pressure losses and unacceptable noise generation. The values below are common guidelines for some typical applications.

Air Ducts	Air Velocity	
	(m/s)	*(ft/s)*
Combustion air ducts	12 - 20	40 - 66
Air inlet to boiler room	1 - 3	3.3 - 9.8
Warm air for house heating	0.8 - 1.0	2.6 - 3.3
Vacuum cleaning pipe	8 - 15	26 - 49
Compressed air pipe	20 - 30	66 - 98
Ventilation ducts (hospitals)	1.8 - 4	5.9 - 13
Ventilation ducts (office buildings)	2.0 - 4.5	6.5 - 15

32 RECOMMENDED AIR VELOCITIES IN DUCTS

32-1 DUCTS AND RECOMMENDED AIR VELOCITIES

Air flow velocity in ducts should be kept within certain limits to avoid noise and unacceptable friction loss and energy consumption.

32-1-1 LOW AND MEDIUM PRESSURE DUCTS

- Maximum friction rate *0.1 - 0.2 inches W.G./100 ft*
- Velocity *1,500 - 2,000 ft/min (8 - 10 m/s)*

Air Flow Rate		Maximum Velocity	
(m^3/h)	*(CFM)*	*(m/s)*	*(ft/min)*
< 300	< 175	2.5	490
< 1,000	< 590	3	590
< 2,000	< 1,200	4	785
< 4,000	< 2,350	5	980
< 10,000	< 5,900	6	1,180
> 10,000	> 5,900	7	1,380

32-1-2 HIGH PRESSURE DUCTS

- Maximum friction rate less than *0.4 inches W.G./100 ft*
- Velocity *2,000 - 3,500 ft/min (10 - 18 m/s)*

Shafts

Air Flow Rate		Maximum Velocity	
(m^3/h)	*(CFM)*	*(m/s)*	*(ft/min)*
< 5,000	< 2,950	12	2,350
< 10,000	< 5,900	15	2,950
< 17,000	< 10,000	17	3,350
< 25,000	< 14,700	20	3,940
< 40,000	< 23,500	22	4,300
< 70,000	< 41,000	25	4,900

Air Flow Rate		Maximum Velocity	
(m^3/h)	*(CFM)*	*(m/s)*	*(ft/min)*
< 100,000	< 59,000	30	5,800

It is common to keep main duct velocity above *20 m/s (3940 ft/min).*

Corridors

Air Flow Rate		Maximum Velocity	
(m^3/h)	*(CFM)*	*(m/s)*	*(ft/min)*
< 5,000	< 2,950	10	2,000
< 10,000	< 5,900	12	2,350
< 17,000	< 10,000	15	2,950
< 25,000	< 14,700	17	3,350
< 40,000	< 23,500	20	3,940

User Areas

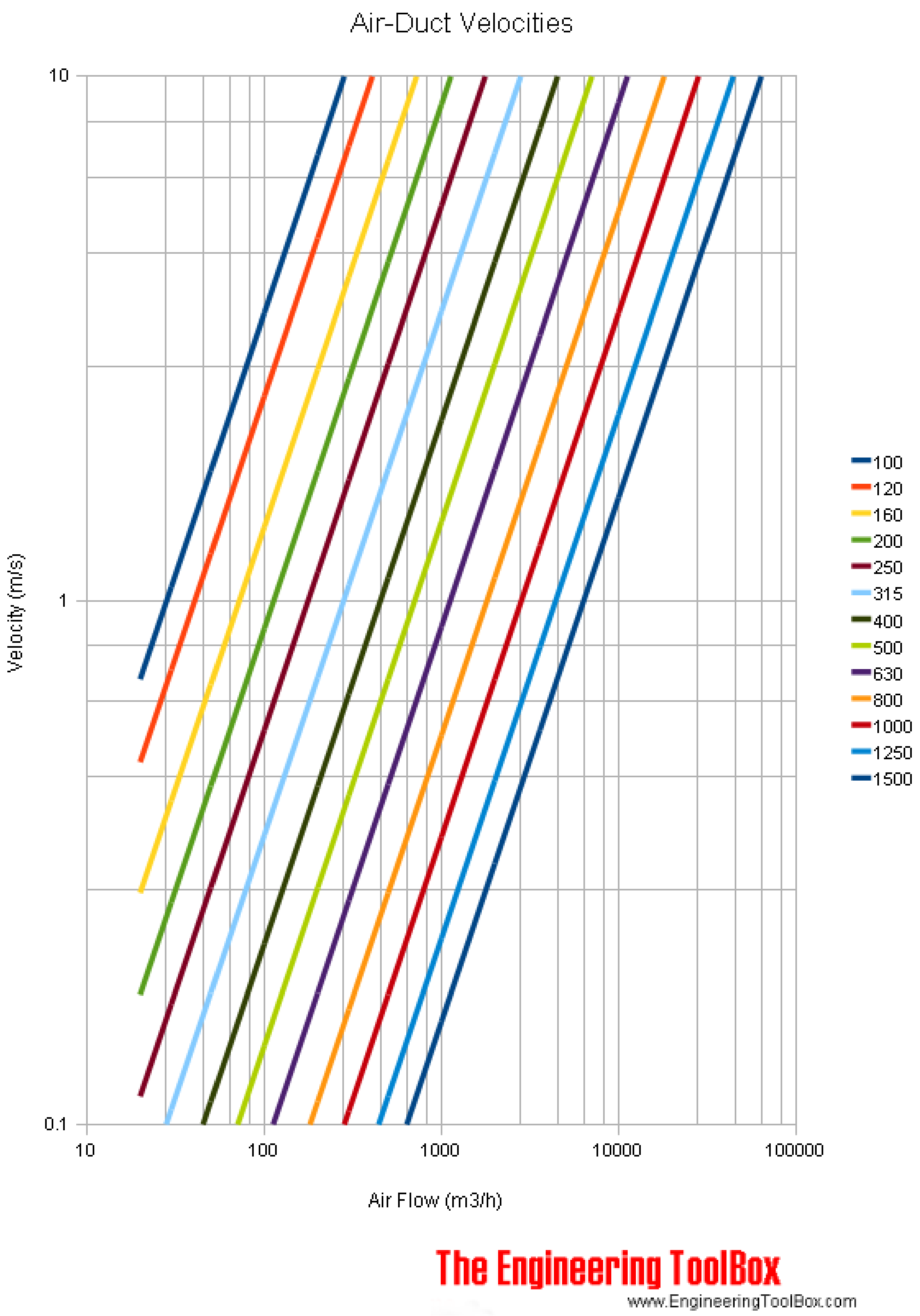
- Offices, receptions, lounges and similar

Air Flow Rate		Maximum Velocity	
(m^3/h)	*(CFM)*	*(m/s)*	*(ft/min)*
< 5,000	< 2,950	10	2,000
< 10,000	< 5,900	12	2,350
< 17,000	< 10,000	14	2,750
< 25,000	< 14,700	16	3,150

33 AIR DUCT VELOCITY DIAGRAM

33-1 AIR FLOW VOLUME, DUCT SIZE, VELOCITY AND DYNAMIC PRESSURE

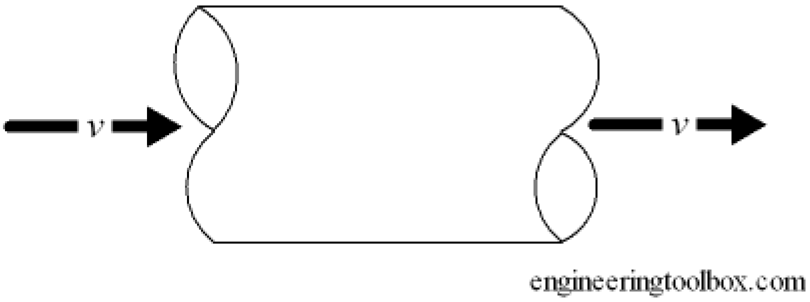
The diagram below indicates velocity and dynamic pressure in air ducts.



34 VELOCITIES IN VENTILATION DUCTS

34-1 RECOMMENDED VELOCITIES IN VENTILATION DUCTS

The duct velocity in air condition and ventilation systems should not exceed certain limits to avoid unnecessary noise generation and pressure drop in the duct work.



The limits of velocities depends on the actual application. The background noise in an industrial building is significant higher than the noise in a public building and more duct generated noise can be accepted.
Commonly accepted duct velocities can be found in the table below.

Service	Velocity - *v*			
	Public buildings		Industrial plant	
	(m/s)	*(ft/min)*	*(m/s)*	*(ft/min)*
Air intake from outside	2.5 - 4.5	500 - 900	5 - 6	1000 - 1200
Heater connection to fan	3.5 - 4.5	700 - 900	5 - 7	1000 - 1400
Main supply ducts	5.0 - 8.0	1000 - 1500	6 - 12	1200 - 2400
Branch supply ducts	2.5 - 3.0	500 - 600	4.5 - 9	900 - 1800
Supply registers and grilles	1.2 - 2.3	250 - 450	1.5 - 2.5	350 - 500
Low level supply registers	0.8 - 1.2	150 - 250		
Main extract ducts	4.5 - 8.0	900 - 1500	6 - 12	1200 - 2400

Service	Velocity - *v*			
	Public buildings		Industrial plant	
	(m/s)	*(ft/min)*	*(m/s)*	*(ft/min)*
Branch extract ducts	2.5 - 3.0	500 - 600	4.5 - 9	900 - 1800

35 FRICTION LOSS IN DUCTS

35-1 FRICTION LOSS OR MAJOR LOSS IN DUCTS - EQUATIONS AND ONLINE CALCULATOR FOR RECTANGULAR AND CIRCULAR DUCTS - IMPERIAL UNITS

The major loss, or friction loss, in a circular duct in galvanized steel with turbulent flow can for imperial units be expressed

$\Delta p = (0.109136\ q^{1.9}) / d_e^{5.02}$ *(1)*

where

Δp = friction (head or pressure loss) (inches water gauge/100 ft of duct)

d_e = equivalent duct diameter (inches)

q = air volume flow - (cfm - cubic feet per minute)

For rectangular ducts the equivalent diameter must be calculated.

35-1-1 AIR DUCTS FRICTION LOSS CALCULATOR

The friction loss calculator below is based on formula *(1)*:

800 *Air Volume Flow - q - (cfm)*

10 *Equivalent duct diameter - d_e - (inches)*

- velocities in rectangular ducts

Pressure loss and air flow velocity for some common duct sizes and air flow volumes can be taken from the table below:

Pressure Loss *(inches water gauge per 100 feet duct)*							
Air velocity *(ft/min)*							
Air Volume *(cfm)*	Duct Size *(inches)*						
	4	5	6	8	10	12	16
100	0.65	0.21	0.09	0.02	0.01		
	1146	733	509	286	183		

Pressure Loss *(inches water gauge per 100 feet duct)*							
Air velocity *(ft/min)*							
Air Volume *(cfm)*	Duct Size *(inches)*						
	4	5	6	8	10	12	16
200		0.8	0.32	0.08	0.02	0.01	
		1467	1019	573	367	255	
400			1.19	0.28	0.09	0.04	0.01
			2037	1146	733	509	286
800					0.34	0.14	0.03
					1467	1019	573
1600							0.12
							1146

The air velocity should not exceed certain limits to avoid unacceptable noise generation.

36 MAJOR LOSS IN DUCTS, TUBES AND PIPES

36-1 MAJOR LOSS - HEAD LOSS OR PRESSURE LOSS - DUE TO FRICTION IN DUCTS, PIPES AND TUBES

36-1-1 PRESSURE AND PRESSURE LOSS

According the Energy Equation for a fluid the total energy can be summarized as elevation energy, velocity energy and pressure energy. The Energy Equation can then be expressed as:

$p_1 + \rho v_1^2 / 2 + \rho g h_1 = p_2 + \rho v_2^2 / 2 + \rho g h_2 + p_{loss}$ (1)

where

p = *pressure in fluid (Pa (N/m²), psi (lb/ft²))*

p_{loss} = *pressure loss (Pa (N/m²), psi (lb/ft²))*

ρ = *density of the fluid (kg/m³, slugs/ft³)*

v = *flow velocity (m/s, ft/s)*

g = *acceleration of gravity (m/s², ft/s²)*

h = *elevation (m, ft)*

For horizontal steady state flow $v_1 = v_2$ and $h_1 = h_2$, - (1) can be transformed to:

$p_{loss} = p_1 - p_2$ (2)

The pressure loss is divided in

- **major loss** due to friction and
- **minor loss** due to change of velocity in bends, valves and similar.

The pressure loss in pipes and tubes depends on the flow velocity, pipe or duct length, pipe or duct diameter, and a friction factor based on the roughness of the pipe or duct, and whether the flow us turbulent or laminar - the Reynolds Number of the flow. The pressure loss in a tube or duct due to friction, major loss, can be expressed as:

$p_{loss} = \lambda (l / d_h) (\rho v^2 / 2)$ (3)

where

p_{loss} = *pressure loss (Pa, N/m²)*

λ = friction coefficient

l = length of duct or pipe (m)

d_h = *hydraulic diameter (m)*

(3) is also called the **D'Arcy-Weisbach Equation**. (3) is valid for fully developed, steady, incompressible flow.

36-1-2 HEAD AND HEAD LOSS

The Energy equation can be expressed in terms of head and head loss by dividing each term by the specific weight of the fluid. The total head in a fluid flow in a tube or a duct can be expressed as the sum of elevation head, velocity head and pressure head.

$p_1 / \gamma + v_1^2 / 2 g + h_1 = p_2 / \gamma + v_2^2 / 2 g + h_2 + h_{loss}$ (4)

where

h_{loss} = *head loss (m, ft)*

$\gamma = \rho g$ = *specific weight (N/m³, lb/ft³)*

For horizontal steady state flow $v_1 = v_2$ and $h_1 = h_2$, - (4) can be transformed to:

$h_{loss} = h_1 - h_2$ (5)

where

$h = p / \gamma$ = *head (m, ft)*

The head loss in a tube or duct due to friction, major loss, can be expressed as:

$h_{loss} = \lambda (l / d_h) (v^2 / 2 g)$ (6)

where

h_{loss} = *head loss (m, ft)*

36-1-3 FRICTION COEFFICIENT - Λ

The friction coefficient depends on the flow - if it is

- laminar,
- transient or
- turbulent

and the roughness of the tube or duct.

To determine the friction coefficient we first have to determine if the flow is laminar, transient or turbulent - then use the proper formula or diagram.

Friction Coefficient for Laminar Flow

For fully developed laminar flow the roughness of the duct or pipe can be neglected. The friction coefficient depends only the Reynolds Number - *Re* - and can be expressed as:

$\lambda = 64 / Re$ (7)

where

Re = *the dimensionless Reynolds number*

The flow is

- laminar when $Re < 2300$
- transient when $2300 < Re < 4000$
- turbulent when $Re > 4000$

Friction Coefficient for Transient Flow

If the flow is transient - 2300 < Re < 4000 - the flow varies between laminar and turbulent flow and the friction coefficient is not possible to determine.

Friction Coefficient for Turbulent Flow

For turbulent flow the friction coefficient depends on the Reynolds Number and the roughness of the duct or pipe wall. On functional form this can be expressed as:

$\lambda = f(Re, k / d_h)$ (8)

where

*k = **absolute roughness** of tube or duct wall (mm, ft)*

*k / d_h = **the relative roughness - or roughness ratio***

Roughness for materials are determined by experiments. Absolute roughness for some common materials are indicated in the table below

Surface	Absolute Roughness - *k*	
	10^{-3} (m)	*(feet)*
Copper, Lead, Brass, Aluminum (new)	0.001 - 0.002	3.3 - 6.7 10^{-6}
PVC and Plastic Pipes	0.0015 - 0.007	0.5 - 2.33 10^{-5}
Epoxy, Vinyl Ester and Isophthalic pipe	0.005	1.7 10^{-5}
Stainless steel	0.015	5 10^{-5}
Steel commercial pipe	0.045 - 0.09	1.5 - 3 10^{-4}
Stretched steel	0.015	5 10^{-5}
Weld steel	0.045	1.5 10^{-4}
Galvanized steel	0.15	5 10^{-4}
Rusted steel (corrosion)	0.15 - 4	5 - 133 10^{-4}
New cast iron	0.25 - 0.8	8 - 27 10^{-4}
Worn cast iron	0.8 - 1.5	2.7 - 5 10^{-3}
Rusty cast iron	1.5 - 2.5	5 - 8.3 10^{-3}
Sheet or asphalted cast iron	0.01 - 0.015	3.33 - 5 10^{-5}
Smoothed cement	0.3	1 10^{-3}

Surface	Absolute Roughness - *k*	
	10^{-3} *(m)*	*(feet)*
Ordinary concrete	0.3 - 1	1 - 3.33 10^{-3}
Coarse concrete	0.3 - 5	1 - 16.7 10^{-3}
Well planed wood	0.18 - 0.9	6 - 30 10^{-4}
Ordinary wood	5	16.7 10^{-3}

The friction coefficient - λ - can be calculated by the Colebrooke Equation:

$1 / \lambda^{1/2} = -2{,}0 \log_{10} [(2{,}51 / (Re\ \lambda^{1/2})) + (k / d_h) / 3{,}72]$ (9)

Since the friction coefficient - λ - is on both sides of the equation, it must be solved by iteration. If we know the Reynolds number and the roughness - the friction coefficient - λ - in the particular flow can be calculated.

A graphical representation of the Colebrooke Equation is the **Moody Diagram**:

- The Moody Diagram - The Moody diagram in a printable format.

With the Moody diagram we can find the friction coefficient if we know the **Reynolds Number** - *Re* - and the ***Relative Roughness Ratio*** - k / d_h

In the diagram we can see how the friction coefficient depends on the Reynolds number for laminar flow - how the friction coefficient is undefined for transient flow - and how the friction coefficient depends on the roughness ratio for turbulent flow.

For hydraulic smooth pipes - the roughness ratio limits zero - and the friction coefficient depends more or less on the Reynolds number only.

For a fully developed turbulent flow the friction coefficient depends on the roughness ratio only.

36-1-4 EXAMPLE - PRESSURE LOSS IN AIR DUCTS

Air at *0 °C* is flows in a *10 m* galvanized duct - *315 mm* diameter - with velocity *15 m/s*.

Reynolds number are expressed as:

$Re = d_h\ v\ \rho / \mu$ (10)

where

Re = *Reynolds number*

v = velocity

ρ = density

μ = dynamic or absolute viscosity

Reynolds number calculated:

$Re = (15\ m/s)\ (315\ mm)\ (10^{-3}\ m/mm)\ (1.23\ kg/m^3) / (1.79\ 10^{-5}\ Ns/m^2)$

$= 324679\ (kgm/s^2)/N$

$= \underline{324679}$ ~ *Turbulent flow*

Turbulent flow indicates that Colebrooks equation (9) must be used to determine the friction coefficient - λ -.

With roughness - ε - for galvanized steel *0.15 mm*, the roughness ratio can be calculated:

$Roughness\ Ratio = \varepsilon / d_h$

$= (0.15\ mm) / (315\ mm)$

$= \underline{4.76\ 10^{-4}}$

Using the graphical representation of the Colebrooks equation - the Moody Diagram - the friction coefficient - λ - can be determined to:

$\lambda = \underline{0.017}$

The major loss for the *10 m* duct can be calculated with the Darcy-Weisbach Equation (3) or (6):

$p_{loss} = \lambda\ (l / d_h)\ (\rho\ v^2 / 2)$

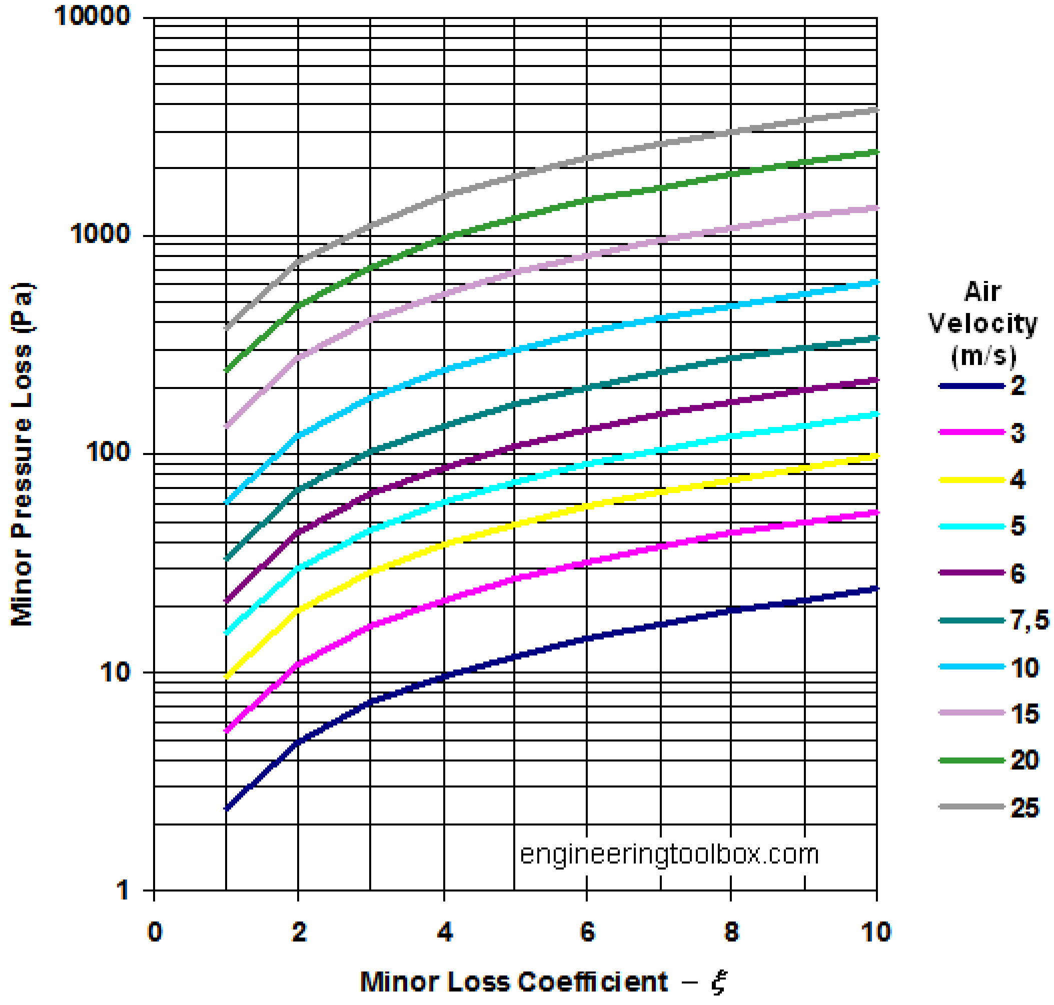
$= 0.017\ ((10\ m) / (0.315\ m))\ ((1.23\ kg/m^3)\ (15\ m/s)^2 / 2)$

$= \underline{74}\ Pa\ (N/m^2)$

37 AIR DUCTS MINOR LOSS COEFFICIENT DIAGRAMS

37-1 MINOR LOSS COEFFICIENT DIAGRAMS FOR AIR DUCTWORK, BENDS, EXPANSIONS, INLETS AND OUTLETS - SI UNITS

Minor loss in air ducts based on a summarized minor loss coefficient and air flow velocity can be estimated with the diagram below:

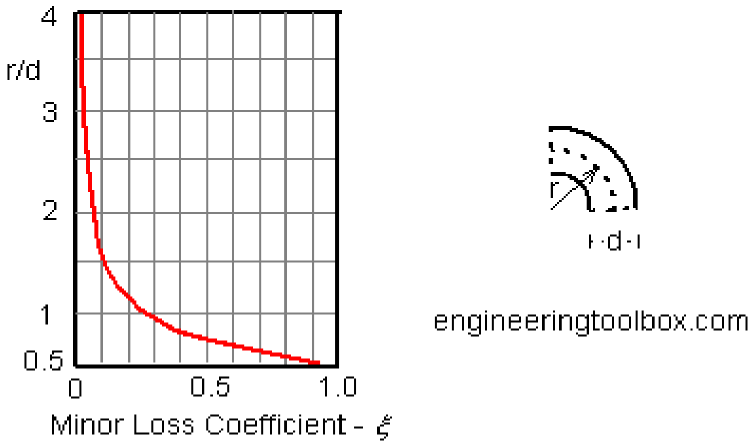


- *1 Pa = 1 N/m^2 = 1.4504x10^{-4} lb/in^2 = 1x10^{-5} bar = 4.03x10^{-3} in water = 0.336x10^{-3} ft water = 0.1024 mm water = 0.295x10^{-3} in mercury = 7.55x10^{-3} mm mercury = 0.1024 kg/m^2 = 0.993x10^{-5} atm*

Minor loss for some common ductwork components like bends, expansions, inlets and outlets can be estimated with the diagrams below.

37-1-1 MINOR LOSS COEFFICIENTS - BENDS

The minor loss coefficients in 90^o bends can be estimated with the diagram below.



The minor loss in bends 0 - 180° can be estimated with the equation

$\xi_{0-180} = \xi_{90}\ \alpha / 90$ *(1)*

where

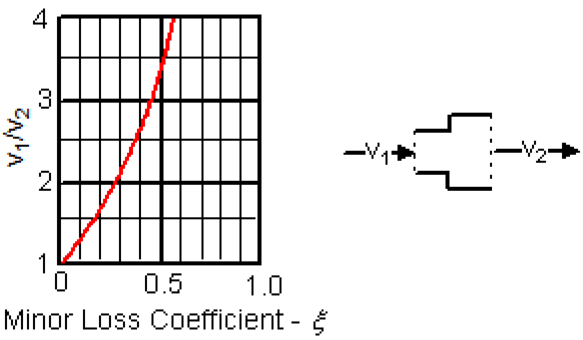
ξ_{0-180} *= minor loss coefficient for the bend with the actual angle*

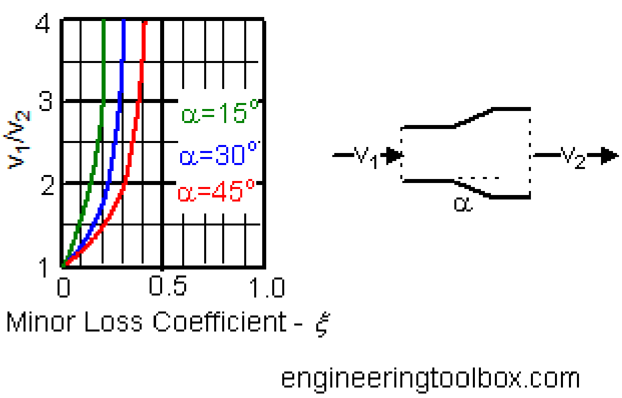
ξ_{90} *= minor loss coefficient for the 90° bend according the diagram above*

α = angle of the actual bend

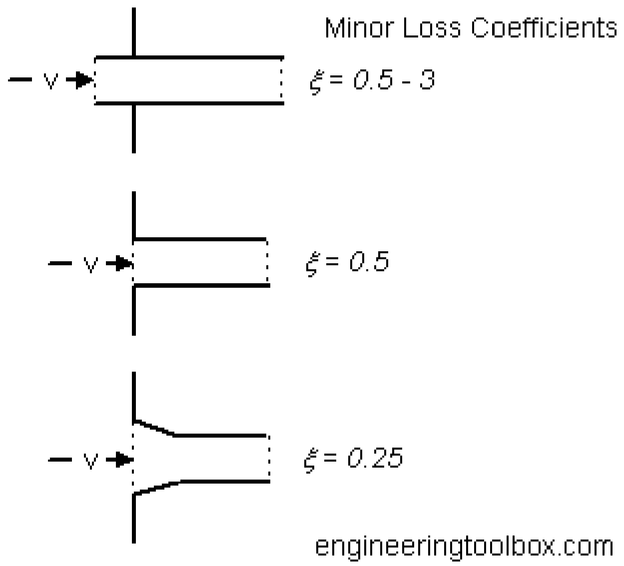
The minor loss coefficient in a 90° bend like the one below is 1.0.

37-1-2 MINOR LOSS COEFFICIENTS - EXPANSIONS

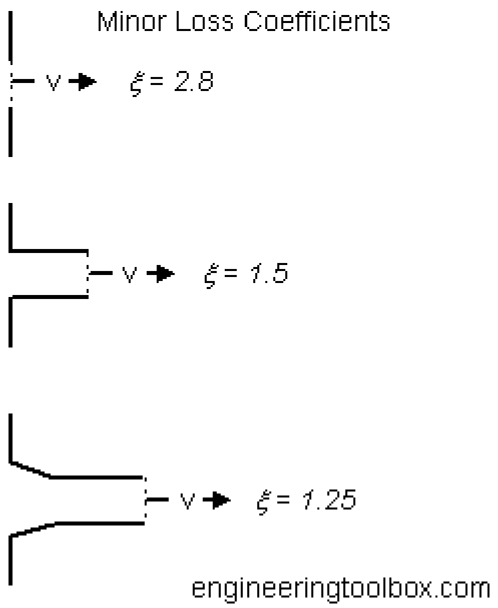




37-1-3 MINOR LOSS COEFFICIENTS - INLETS



37-1-4 MINOR LOSS COEFFICIENTS - OUTLETS



38 MINOR LOSS COEFFICIENTS FOR AIR DUCT COMPONENTS

38-1 MINOR LOSS - PRESSURE OR HEAD LOSS - COEFFICIENTS FOR AIR DUCT DISTRIBUTION SYSTEMS COMPONENTS

Minor Loss - Head or Pressure Loss in Air Duct Components - can be expressed as

$h_{minor\_loss} = \xi v^2 / 2 g$ (1)

where

h_{minor_loss} = *minor head loss (m, ft)*

ξ = *minor loss coefficient*

v = flow velocity (m/s, ft/s)

g = acceleration of gravity $(m/s^2, ft/s^2)$

Minor loss can also be expressed as pressure loss instead of head loss.

Minor loss coefficients for different components common in air duct distribution systems

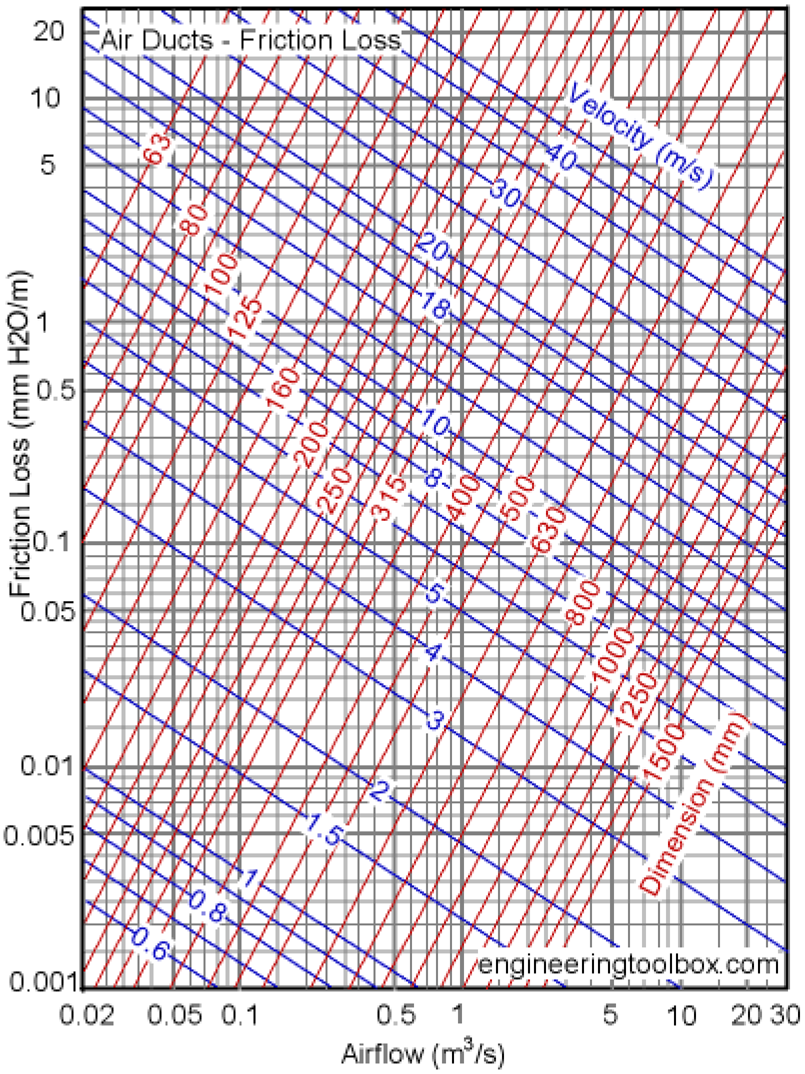
Component or Fitting	Minor Loss Coefficient - ξ -
90^o bend, sharp	*1.3*
90^o bend, with vanes	*0.7*
90^o bend, rounded radius/diameter duct <1	*0.5*
90^o bend, rounded radius/diameter duct >1	*0.25*
45^o bend, sharp	*0.5*
45^o bend, rounded radius/diameter duct <1	*0.2*
45^o bend, rounded radius/diameter duct >1	*0.05*
T, flow to branch (applied to velocity in branch)	*0.3*
Flow from duct to room	*1.0*
Flow from room to duct	*0.35*
Reduction, tapered	*0*
Enlargement, abrupt (due to speed before reduction) (v_1= velocity before enlargement and v_2 = velocity after enlargement)	$(1 - v_2 / v_1)^2$
Enlargement, tapered angle < 8^o (due to speed before reduction) (v_1= velocity before enlargement and v_2 = velocity after enlargement)	$0.15 (1 - v_2 / v_1)^2$
Enlargement, tapered angle > 8^o (due to speed before reduction)	$(1 - v_2 / v_1)^2$

Component or Fitting	Minor Loss Coefficient - ξ -
(v_1= velocity before enlargement and v_2 = velocity after enlargement)	
Grilles, 0.7 ratio free area to total surface	*3*
Grilles, 0.6 ratio free area to total surface	*4*
Grilles, 0.5 ratio free area to total surface	*6*
Grilles, 0.4 ratio free area to total surface	*10*
Grilles, 0.3 ratio free area to total surface	*20*
Grilles, 0.2 ratio free area to total surface	*50*

39 AIR DUCTS FRICTION LOSS DIAGRAM

39-1 MAJOR LOSS DIAGRAM AIR DUCTS - SI UNITS

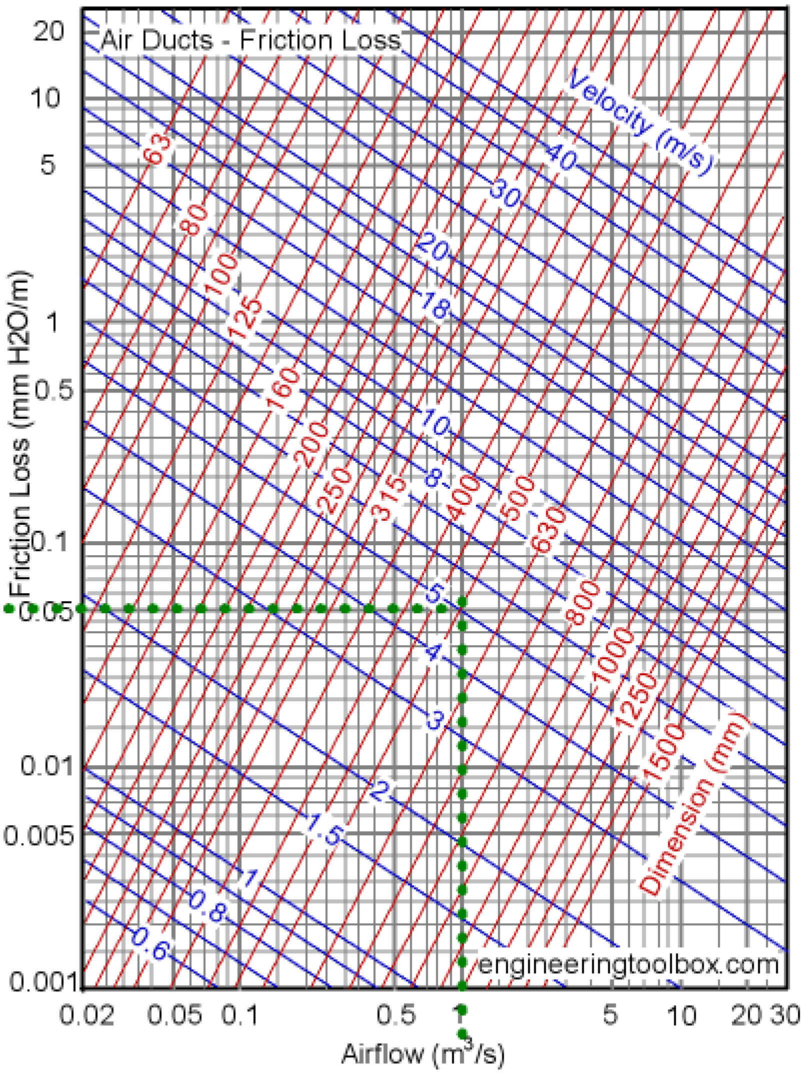
Friction loss in standard air ducts are indicated in the diagram below.



- *1 m/s = 196.85 ft/min*
- *1 m^3/s = 3600 m3/h = 1000 dm^3(liter)/s = 35.32 ft^3/s = 2118.9 ft^3/min = 13200 Imp.gal (UK)/min = 15852 gal (US)/min*
- *1 mm H_2O = 9.81 Pa = 9.807x10^{-6} N/mm^2 = 0.0987 10^{-3} bar = 1 kp/m^2 = 0.09678 10^{-3} atm = 1.422 10^{-3} psi (lb_f/in^2)*

39-1-1 EXAMPLE - AIR DUCT AND FRICTION LOSS

The friction loss in a *500 mm* main duct in comfort system with air flow *1 m^3/s* can be estimated as indicated below to *0.05 mm H_2O/m (~ 0.5 Pa/m)*.

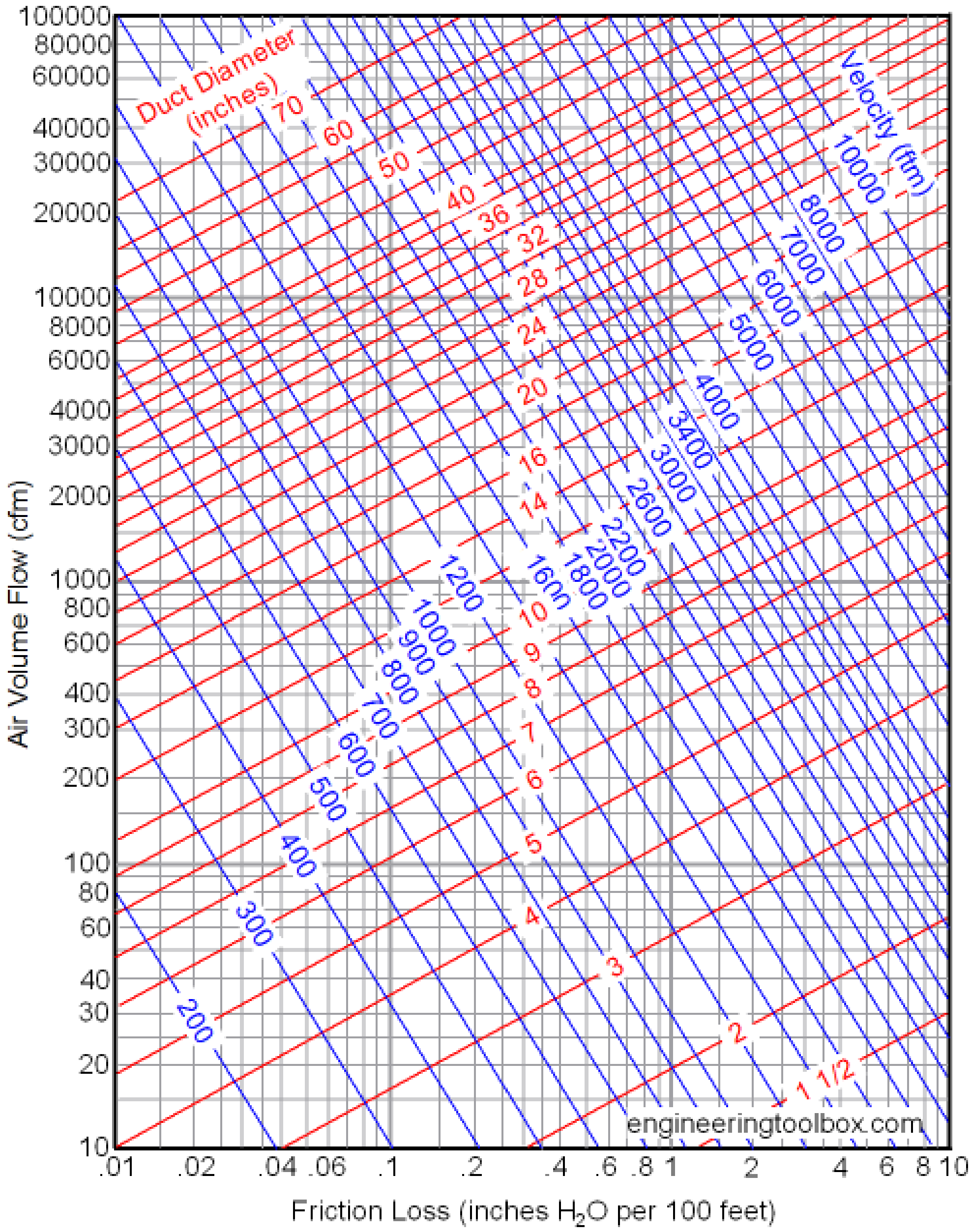


The air velocity in the duct is *5 m/s.*

40 AIR DUCTS FRICTION LOSS DIAGRAM

40-1 MAJOR LOSS DIAGRAM AIR DUCTS - IMPERIAL UNITS RANGING *10 - 100 000 CFM*

Friction loss (head loss) in standard air ducts are indicated in the diagram below:

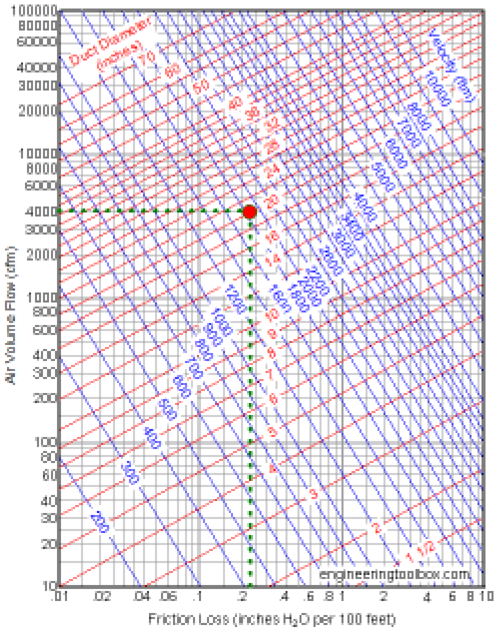


The diagram is based on standard air *0.075 lb/ft³* in clean round galvanized metal ducts.

- *1 inch water = 248.8 N/m² (Pa)= 0.0361 lb/in² (psi) = 25.4 kg/m² = 0.0739 in mercury*
- *1 ft³/min (cfm) = 1.7 m³/h = 0.47 l/s*
- *1 ft/min = 5.08x10⁻³ m/s*
- *1 inch = 25.4 mm = 2.54 cm = 0.0254 m = 0.08333 ft*

40-1-1 EXAMPLE - FRICTION LOSS IN AIR DUCT

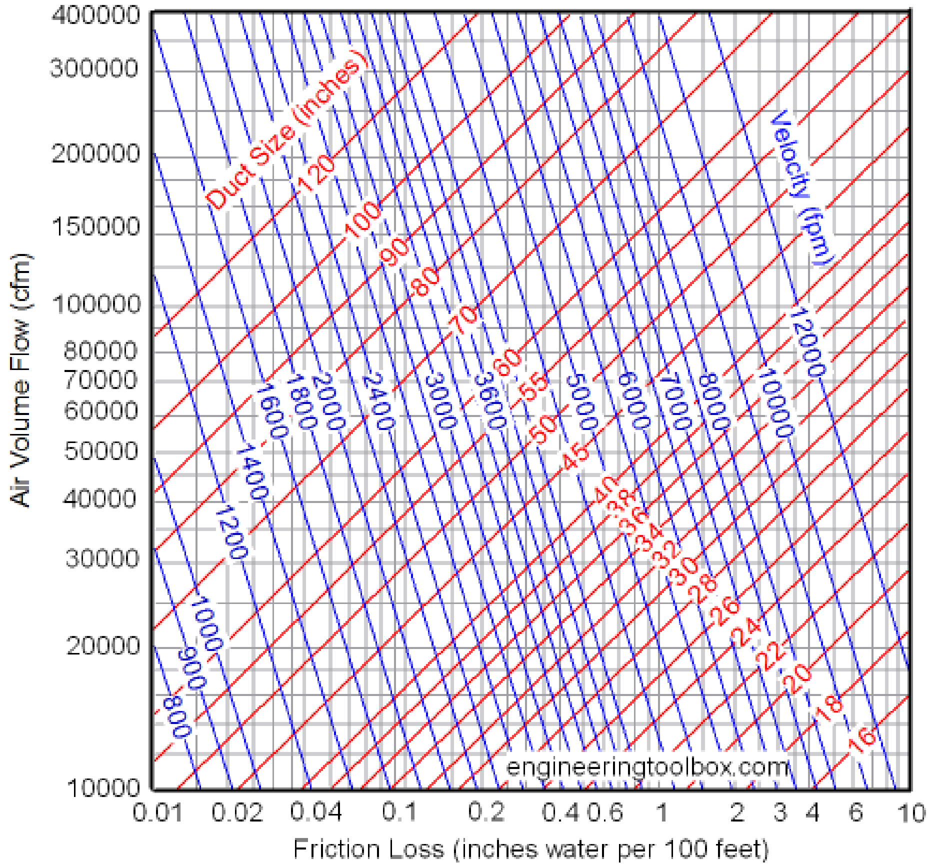
The friction loss in a *20 inches* duct with air flow *4000 cfm* can be estimated to approximately *0.23 inches water per 100 feet* duct as shown in the diagram below. The air velocity can be estimated to approximately *1850 feet per minute*.



41 AIR DUCTS FRICTION LOSS DIAGRAM

41-1 MAJOR LOSS DIAGRAM AIR DUCTS - IMPERIAL UNITS RANGING *10 000 - 400 000 CFM*

Friction loss (head loss) in standard air ducts are indicated in the diagram below:

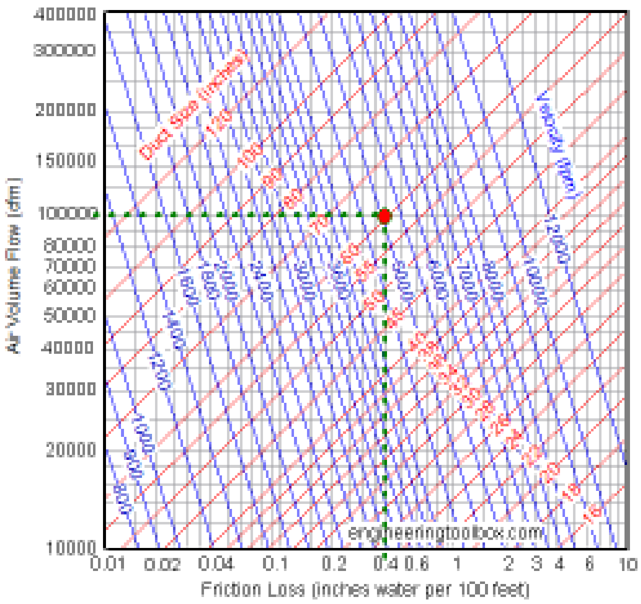


The diagram is based on standard air *0.075 lb/ft^3* in clean round galvanized metal ducts.

- *1 inch water = 248.8 N/m^2 (Pa)= 0.0361 lb/in^2 (psi) = 25.4 kg/m^2 = 0.0739 in mercury*
- *1 ft^3/min (cfm) = 1.7 m^3/h = 0.47 l/s*
- *1 ft/min = 5.08x10^{-3} m/s*
- *1 inch = 25.4 mm = 2.54 cm = 0.0254 m = 0.08333 ft*

41-1-1 EXAMPLE - FRICTION LOSS IN AIR DUCT

The friction loss in a *60 inches* duct with air flow *100,000 cfm* can be estimated to approximately *0.4 inches water per 100 feet* duct as shown in the diagram below. The air velocity can be estimated to approximately *5,000 feet per minute*.

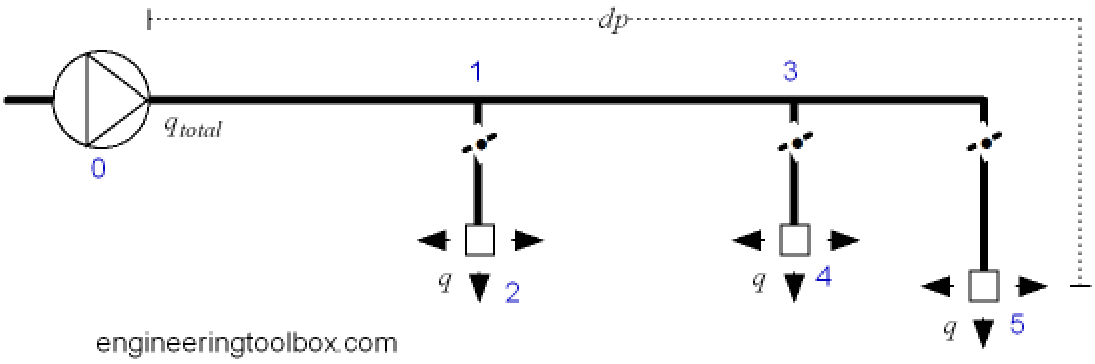


42 EQUAL FRICTION METHOD

42-1 THE EQUAL FRICTION METHOD OF SIZING DUCTS IS EASY AND STRAIGHTFORWARD TO USE

The equal friction method of sizing ducts is often preferred because it is quite easy to use. The method can be summarized to

1. Compute the necessary air flow volume *(m^3/h, cfm)* in every room and branch of the system
2. Use [1)] to compute the total air volume *(m^3/h, cfm)* in the main system
3. Determine the maximum acceptable airflow velocity in the main duct
4. Determine the major pressure drop in the main duct
5. Use the major pressure drop for the main duct as a constant to determine the duct sizes throughout the distribution system
6. Determine the total resistance in the duct system by multiplying the static resistance with the equivalent length of the longest run
7. Compute balancing dampers



42-1-1 1. COMPUTE THE AIR VOLUME IN EVERY ROOM AND BRANCH

Use the actual heat, cooling or air quality requirements for the rooms and calculate the required air volume - *q*.

42-1-2 2. COMPUTE THE TOTAL VOLUME IN THE SYSTEM

Make a simplified diagram of the system like the one above.
Use [1)] to summarize and accumulate the total volume - q_{total} - in the system.
Note! Be aware that maximum load conditions almost never occurs in all of the rooms at the same time. Avoid over-sizing the main system by multiplying the accumulated volume with a factor less than one (This is probably the hard part - and for larger systems sophisticated computer-assisted indoor climate calculations are often required).

42-1-3 3. DETERMINE THE MAXIMUM ACCEPTABLE AIRFLOW VELOCITY IN THE MAIN DUCTS

Select the maximum velocity in the main duct on basis of the application environment. To avoid disturbing noise levels - keep maximum velocities within experienced limits:

- comfort systems - air velocity *4 to 7 m/s (13 to 23 ft/s)*
- industrial systems - air velocity *8 to 12 m/s (26 to 40 ft/s)*
- high speed systems - air velocity *10 to 18 m/s (33 to 60 ft/s)*

Use the maximum velocity limits when selecting the size of the main duct.

42-1-4 4. DETERMINE THE STATIC PRESSURE DROP IN MAIN DUCT

Use a pressure drop table or similar to determine the static pressure drop in the main duct.

42-1-5 5. DETERMINE THE DUCT SIZES THROUGHOUT THE SYSTEM

Use the static pressure drop determined in [4)] as a constant to determine the ducts sizes throughout the system. Use the air volumes calculated in [1)] for the calculation. Select the duct sizes with the pressure drop for the actual ducts as close to the main duct pressure drop as possible.

42-1-6 6. DETERMINE THE TOTAL RESISTANCE IN THE SYSTEM

Use the static pressure from [4)] to calculate the pressure drop through the longest part of the duct system. Use the equivalent length which is

- the actual length + additional lengths for bends, T's, inlets and outlets

42-1-7 7. CALCULATE BALANCING DAMPERS

Use the total resistance in [6)] and the volume flow throughout the system to calculate necessary dampers and the theoretical pressure loss through the dampers.

42-1-8 NOTE ABOUT THE EQUAL FRICTION METHOD

The **equal friction method** is straightforward and easy to use and gives an automatic reduction of the air flow velocities throughout the system. The reduced velocities are in general within the noise limits of the application environment.
The method can increase the numbers of reductions compared to other methods, and often a poorer pressure balance in the system require more adjusting dampers. This may increase the system cost compared to other methods.

42-1-9 EXAMPLE - EQUAL FRICTION METHOD

The equal friction method can be done manual or more or less semi automatic with a spreadsheet as shown in the table below.

Section	Length (m)	Airflow (m3/s)	Diameter (m)	Velocity (m/s)	Friction Loss (Pa/m)	Frictionloss (Pa)	Minor Loss Coefficients (ξ)	Minor Loss (Pa)	Pressure Loss Damper (Pa)	Total Pressure Loss (Pa)		Pressure Loss Path 0-1-2 (Pa)	Pressure Loss Path 0-1-3-4 (Pa)	Pressure Loss Path 0-1-3-5 (Pa)
0-1	20	3	0.8	6.0	0.4	8	1	17.8		25.8		25.8	25.8	25.8
1-2	20	1	0.5	5.1	0.5	10	2	26.0	15.3	51.3		51.3		
1-3	10	2	0.8	4.0	0.2	2	2	15.8		17.8			17.8	17.8
3-4	10	1	0.5	5.1	0.5	5	2	26.0	2.5	33.5			33.5	
3-5	15	1	0.5	5.1	0.5	7.5	2	26.0		33.5				33.5
												77.1	77.1	77.1

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The table is based on the diagram above. Air flow and friction loss from a diagram is added. Minor pressure loss coefficients must be summarized for for the actual applications.
The pressure loss in each path is summarized on the right and pressure loss is added manually in the dampers to balance the system.