September 2004

RECOMMENDATION
concerning
PRESENTATION of ACOUSTICAL DATA of INDUSTRIAL FANS

If we wish to know the sound power transmitted through a fan and ducting system, it is preferable to take measurements 'induct' in accordance with ISO 5136. Sometimes, however, it is necessary to know the noise around the fan, which may have broken out through its casing and local ducting or been emitted through an open inlet and/or outlet.

In practice, the room dimensions will be such that this noise will be absorbed or reflected by the floor, walls and ceiling. If the room were fully anechoic, then all the sound would be absorbed by these surfaces. If the walls were hard, then the room would be termed reverberant, and all the sound would be reflected. (Effectively, this would mean that the same noise would be measured more then once!).

Real rooms are usually neither fully reverberant nor fully anechoic, but somewhere in between. It is then extremely difficult to find a suitable position for measuring the noise from a particular fan.

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AIR HANDLING, AIR CONDITIONING AND REFRIGERATION
EQUIPEMNT MANUFACTURERS

The manufacturer is often asked to state the Sound Pressure Level of his fan for a particular duty. If the request for such information is specified at a particular distance, then it might be anticipated that an unambiguous answer could be given. This is far from the case and qualifications to the answer have to be made which may or may not be appropriate in a real life situation.

To take the analogy of an electric fire, the manufacturer can specify its power in kilowatts, but the purchaser will need to determine what particular temperature will be achieved at a given position in a room. This will be based on his experience or by calculation. Distance from the fire, its position in the room, how well the room is insulated, whether there are any reflective surfaces etc will all have an influence on the result.

It is exactly the same for a fan. The manufacturer can give the Fan Sound Power Level (analogous to the kilowatts of a fire) and the user can then determine the Sound Pressure Level (analogous to the temperature) at a particular position, based on the dimensions of the room, the position of the fan, the materials of the room and their absorptive or reflective properties.

Unfortunately, both Fan Sound Power Levels and Sound Pressure Levels are expressed in decibels, but **they are not the same decibels.**

The decibel is only used to compress a wide range of absolute values into a manageable range. It is not an absolute unit, but is a ratio. Without a reference level, it means nothing. Its use is not confined to acoustics and indeed it is widely quoted in electro-technology, vibration and in physics generally.

The definition of a decibel is:

$$dB = 10\ log_{10}\left(\frac{Quantity\ measured}{Reference\ level}\right)$$

- For Fan Sound Power Levels the reference level is 10^{-12} Watts
- For Sound Pressure levels the reference level is 2×10^{-5} Pascals

Thus, Fan Sound Power Level and Sound Pressure Level are completely different quantities and should not be confused. For preference, the former should be suffixed with a W i.e. dBW, but this is rarely observed. Even rarer is to give the reference level, which is also unambiguous.

It will therefore be realised that the Sound Pressure Level at a particular point in a room containing a fan can only really be determined by the user, based on his particular knowledge of how and where the fan is installed. However, specialist acoustical knowledge is not always available and the information which follows is given to assist the user to make the necessary calculations.

Fan sound power levels vary according to installation category, whether measured on the inlet or outlet, or breakout from the casing together with any ancillary motor noise. There are therefore at least noise levels associated with a fan as follows:

1) L_W(Atot) total sound power level of a fan type A installation (includes the contributions from the inlet, outlet, fan casing and drive).

2) L_W(Ain) free-inlet sound power level, type A installation.

3) L_{W}(Aout) free-outlet sound power level; type A installation.

4) L_{W}(Bin) free-inlet sound power level; type B installation.

5) L_{W}(Bin) free-inlet sound power level; type B installation.

6) L_{W}(Bin+cas) free-inlet sound power level plus casing radiated noise; type B installation.

7) L_{W}(Bout) ducted outlet sound power level; type B installation.

8) L_{W}(Cin) ducted inlet sound power level; type C installation.

9) L_{W}(Cout) free-outlet sound power level; type C installation

10) L_{W}(Cout+cas) free-outlet sound power level plus casing radiated noise; type C installation.

11) L_{W}(Din) ducted inlet sound power level; type D installation.

12) L_{W}(Dout) ducted outlet sound power level; type D installation.

13) L_{W}(Dcas) casing radiated sound power level; type D installation.

NOTE 1 All of these symbols may be used to indicate levels in one third -octave or octave frequency bands as well as overall sound power levels and A-weighted sound power levels provided that the sound power to which the symbols relate is clearly defined.

NOTE 2 Where noise from the drive may contribute to the noise radiated from a casing then this should be clearly stated by the addition of +dr e.g., L_{W} (Dcas + dr)

NOTE 3 Not all of the above levels need to be measured for a particular fan.

The system designer needs to ask the fan manufacturer for the Sound Power Level appropriate to the particular Installation Category for which the fan is to be used and for the particular position at which it will be measured. This will be determined by whether the fan is fully ducted or has an open inlet or outlet.

The formula connecting the sound pressure and sound power in a real room is:

$$SPL = SWL + 10\,log\left[\frac{Q_\theta}{4\pi r^2} + \frac{4}{R_c}\right]$$

Where:

SPL = Sound pressure level dB re 2 x 10^{-5} Pa
SWL = Sound power level dBW re 10^{-12} W
r = distance from the source m
Q_θ = directivity factor of the source in the direction of r
Rc = room constant = $\frac{S\alpha_{av}}{1-\alpha_{av}} m^2$
S = total surface are of the room m^2
α_{av} = average absorption coefficient in the room

Position of source	Directivity factor Q_θ
Near centre of room	1
At centre of floor	2
Centre of edge between floor and wall	4
Corner between two walls and floor	8

Values of the directivity factor, assuming an unidentified source in a large room

The first term in brackets in the formula is a measure of the direct sound under so call “free-field” conditions whilst the second term is a measure of the reflected sound.

If the fan were positioned in the absolute centre of a room i.e. equidistant from floor and ceiling, and equidistant from all parallel walls, then for a small source relative to the room size, the sound could be expected to radiate freely and almost equally in all directions. The measurement surface would then be the surface of a sphere i.e. $4\pi r^2$ and the directivity factor would be $Q_\theta = 1$.

If the fan were placed in the geometric centre of the floor for example, the sound would only be radiated over a half sphere with a surface area of $2\pi r^2$. The general formula could still be used by making $Q_\theta = 2$.

If the fan were placed at one side of the room but still at the middle of a wall, then the sound would be radiated over a quarter sphere with a surface area of πr^2. The general formula can then be used by making $Q_\theta = 4$.

If the fan were placed in the corner of the room at floor level then the sound would be radiated over an eighth of the sphere with a surface area of $\frac{\pi r^2}{2}$. The general formula can then be used by making $Q_\theta = 8$.

It will be realised that whilst the sound power output of the fan for a specific duty will remain unchanged, the sound pressure level at a particular position as measured by a noise meter, for this reason alone could vary by 10 log 8 = 9 dB, according to where the installer decided to site the fan. If the noise had a particularly enhanced directivity, or if the aspect ratio(s) of the room dimensions were far from even, then this value could be even more. Should the sound be reflected or absorbed, then it becomes more difficult to make the calculation, but further differences of up to 20 dB between Sound Pressure Level and Fan Sound Power Level are possible. The system designer must calculate the Sound Pressure Level within the room, based on the Fan Sound Power Level provided by the Fan manufacturer, the position of the fan within the room and the materials of the room walls, floor and ceiling, all of which he will know or will have decided.

The value of the average absorption coefficient α_{av} can be calculated. If we have an area S, of material in the room having an absorption coefficient α_1, and area S_2 with absorption coefficient α_2, and so on, $\alpha_{av} = \frac{1}{S}\left(S_1\alpha_1 + S_2\alpha_2 + S_3\alpha_3 + etc\right)$. α not only varies with the material, but also differs according to the frequency of the noise. It is therefore necessary to calculate the SPL from the SWL in each frequency.

Material	**63 Hz**	**125 Hz**	**250 Hz**	**500 Hz**	**1000 Hz**	**2000 Hz**	**4000 Hz**	**8000 Hz**
Brick work	.05	.05	.04	.02	.04	.05	.05	.05
Breezeblock	.1	.2	.45	.6	.4	.45	.4	.4
Concrete	.01	.01	.01	.02	.02	.02	.03	.03
Glazed tiles	.05	.05	.05	.05	.05	.05	.05	.05
Plaster	.04	.04	.05	.06	.08	.04	.06	.05
Rubber floor tiles	.05	.05	.05	.1	.1	.05	.05	.05

Typical values of absorption coefficient α

For special proprietary acoustic materials and all other surface finishes, refer to the manufacturers. If pressed, certain fan manufacturers will quote the sound pressure level of their units at a specified distance – usually 1.5m or 3 impeller diameters under ‘free field conditions’ and assuming spherical propagation. These would exist if the fan were suspended in space and there were no adjacent floor or walls to either absorb or reflect the noise. Using the formula above, $Q_\theta = 1$ and $R_c \to \infty$.

$$\text{Thus SPL} = \text{SWL} + 10 \log \frac{4}{4\pi r^2} = \text{SWL} - 10 \log 4\pi r^2$$

$$\text{and if } r = 1.5 \text{ then SPL} = \text{SWL} - 14.5 \text{ dB.}$$

Other manufacturers calculate for hemispherical’ propagation under the same free field conditions, i.e. it is assumed that the fan is mounted on a hard reflecting floor. Q_θ then equals 2.

$$\text{Thus SPL} = \text{SWL} + 10 \log \frac{2}{4\pi r^2} = \text{SWL} - 10 \log 2\pi r^2$$

$$\text{and if } r = 1.5 \text{ then SPL} = \text{SWL} - 11.5 \text{ dB.}$$

For three diameters, knowing the impeller diameter in metres, the difference in both cases may be calculated. Whilst these figures may be used as a basis for comparison between different units calculated in the same manner, it must be realised that the SPLs measured on site with a meter may be either above or below these values. **The actual result is as much a function of the room characteristics as of the fan.** The analogy of an electric fire in a room with or without heat losses should be remembered. The internal areas of modern commercial and industrial buildings have hard boundary surfaces which cause a high proportion of sound energy incident upon them to be reflected and a high reverberant sound pressure level to be built up. When this occurs, the sound pressure level readings indicated on a sound meter are independent of the distance from the noise source.

Understanding the difference between sound power level and sound pressure level, the engineer must also know how acceptable levels of sound pressure can be specified.

It is inconvenient to quote a series of sound values for each application. Efforts therefore have been made to express noise intensity and quality in one single number. The ear reacts differently according to frequency. All these single figure indices therefore mathematically weight the sound pressure level values at each octave band according to the ear’s response at that frequency.

dBA, dBB, dBC and dBD Sound Pressure Levels

A, B, C, and D noise levels are an attempt to produce single number and sound pressure indices. To obtain them different values are subtracted from the sound pressure levels in each of the frequency bands, subtracting most from those bands which affect the ear least. The results are then added logarithmically to produce an overall single number sound level. It must be emphasised, however, that this calculation should be the very last to be carried out, i.e. after the effects of the room materials (reflective or absorbent) have been calculated in each octave band. The ‘A’ weighting is by far the most popular and single figures are largely quoted in legislation. The ‘C’ weighting indicates the potential for hearing damage. The resulting noise levels are known respectively as dBA, dBB, dBC, and dBD.

Theoretically dBA values apply up to levels of 55 dB only, dBB for levels between 55-85 dB only and dBC for higher levels only. dBD is reserved for special noise, e.g., aircraft.

However, dBA is now used almost exclusively whatever the level and such levels are widely quoted in legislation. Engineers should check what weighting curves have been used by manufacturers and, if necessary convert them to a common base before comparisons are made.

A, B, C and D weightings are useful for making initial assessments (inexpensive sound level meters are available which measure directly on these scales), Unfortunately too much information is lost in combining all the data into one figure for it to be of use for calculation and design work. Most noise control depends on frequency analysis.

Sound Absorbing or Anechoic Chambers

If we wished to make measurements in a free field without any reflections, then the top of a very tall but small cross-section flagpole in the middle of the Sahara desert (after it had been raked flat) would probably be ideal. Obviously, there are difficulties and an anechoic room is a reasonable alternative. Here the walls, ceiling and floor are covered in a highly sound absorptive material to eliminate any reflections. Thus, the SPL in any direction may be measured.

Sound Reflecting or Reverberation Chamber

This is the opposite of the anechoic chamber. All surfaces are made as hard as possible to reflect the noise and all the walls are made at an angle to each other so that there are no parallel surfaces. Thus the sound energy is uniform throughout the room and a ‘diffuse field’ exists. It is therefore possible to measure the SWL, but the SPL measurements in any direction will be meaningless due to the many reflections. Such rooms are cheaper to build than anechoic chambers and are therefore very popular.

The real Room

In practice we usually wish to make measurements in a room that is neither anechoic nor reverberant, but somewhere in between. It is then difficult to find a suitable position for measuring the noise from a particular source. When determining noise from a single fan, several errors are possible. If you measure too closely, the SPL may vary considerably with a small change in position when the distance is less than the wavelength of the lowest frequency emitted or less than twice the greatest dimension of the fan, whichever is the greater. This is termed the *near field* and should be avoided.

Other errors arise if measurements are made too far from the fan. Reflections from walls and other objects may be as strong as the direct sound. Readings will be impossible in this *reverberant field*. A free field may exist between the reverberant and near field and can be found by seeing if the level drops 6 dB for a doubling in distance from the fan. It is here that measurements should be made. Sometimes, however, conditions are so reverberant or the room so small, that a free field will not be present.

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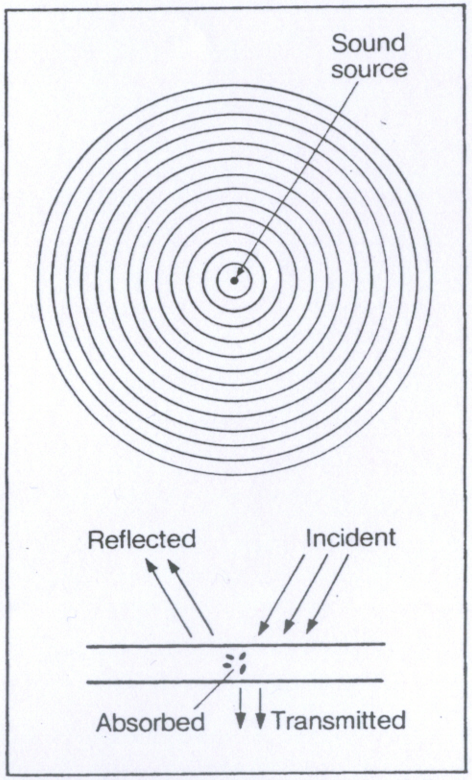


Fig 1 Sound in a free field (above) and sound incident on a surface (below)

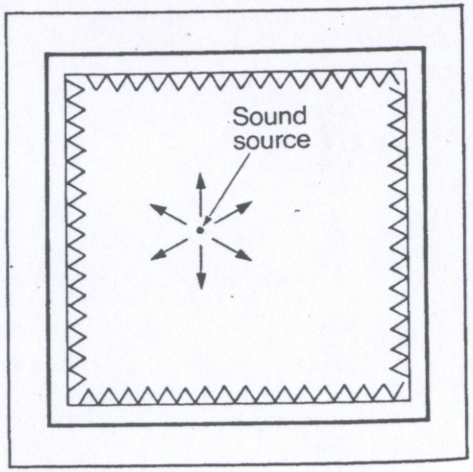


Fig 2 Sound in an anechoic chamber

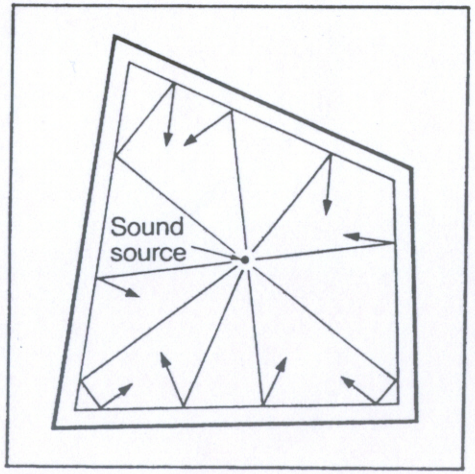


Fig 3 Sound in reverberation chamber

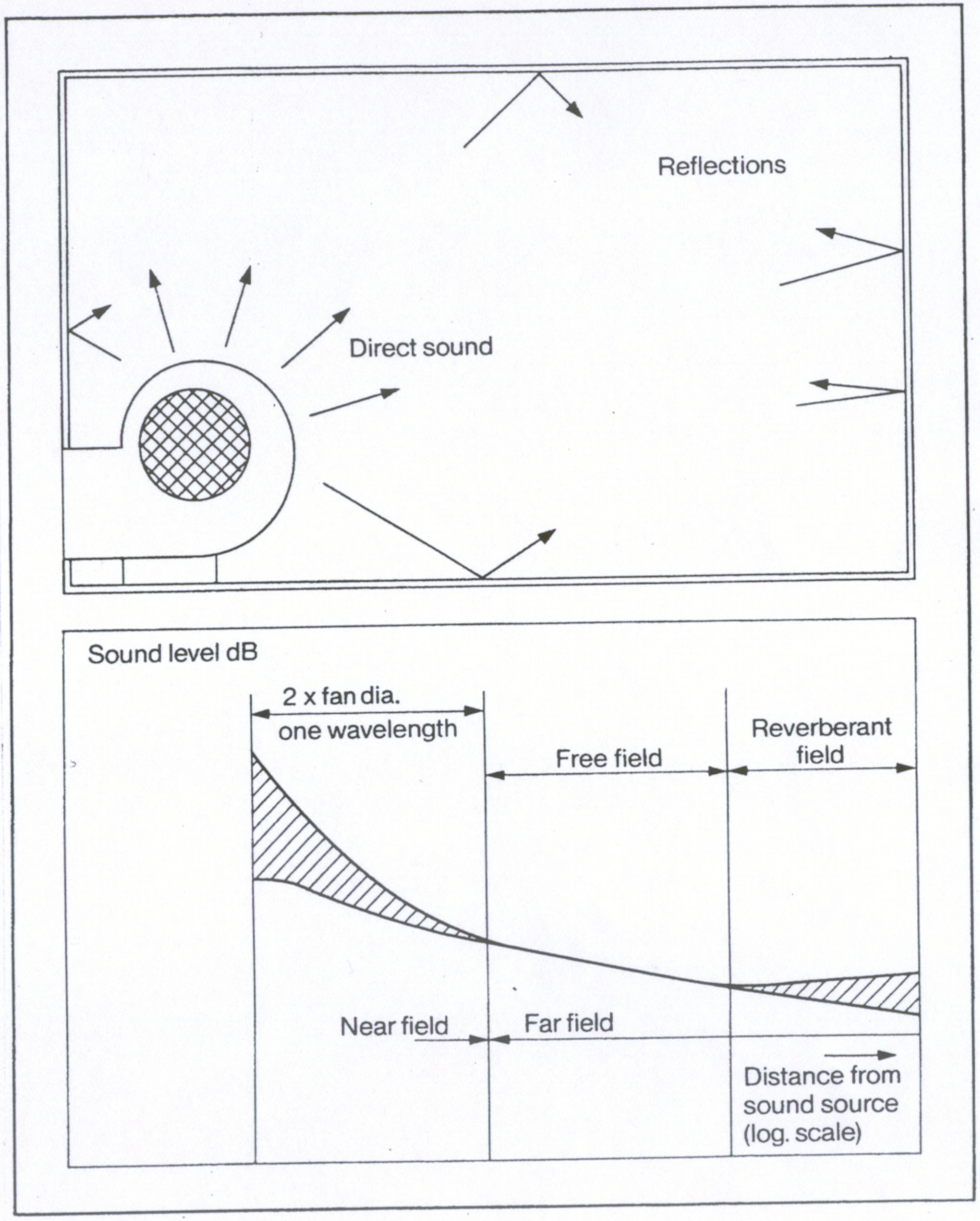
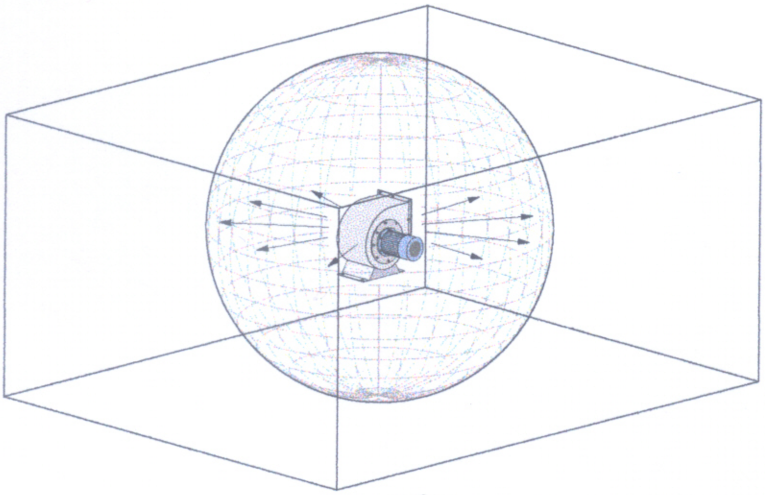
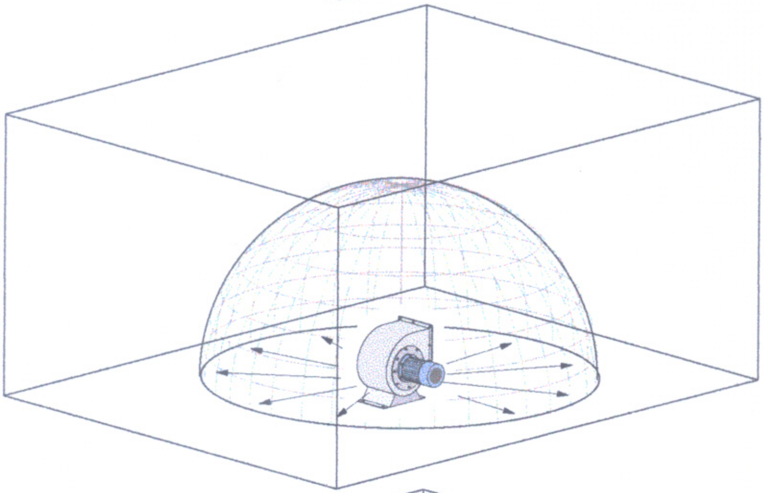


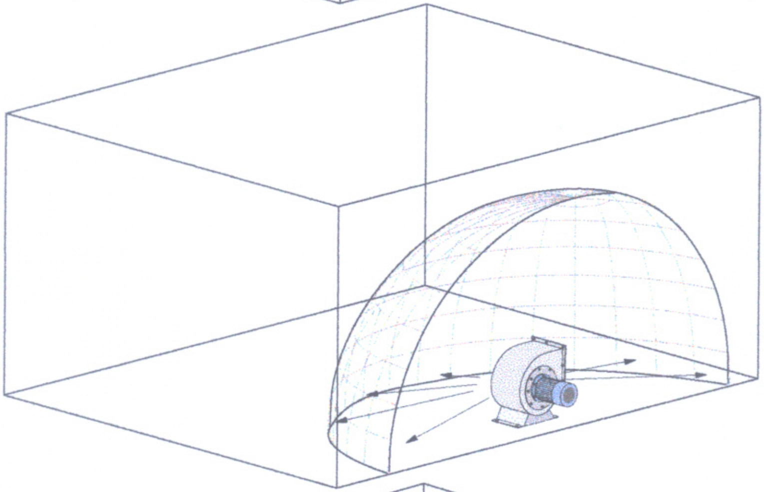
Fig 4 Fan in a 'real room'



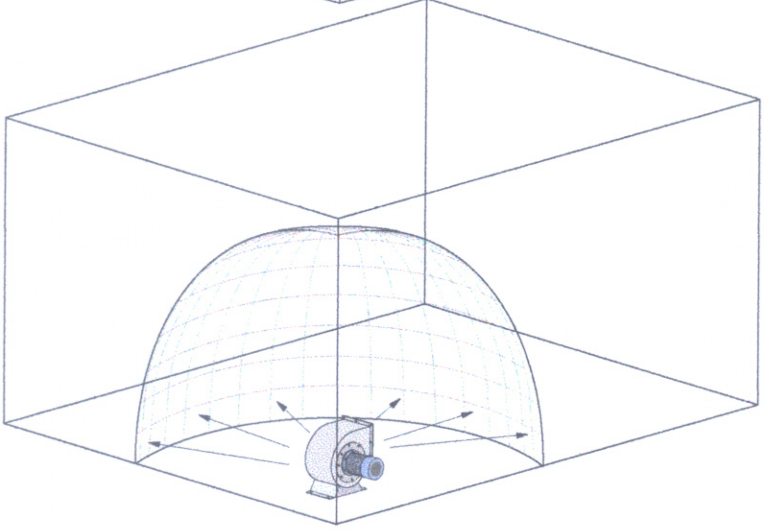
$Q_\theta = 1$



$Q_\theta = 2$



$Q_\theta = 4$



$Q_\theta = 8$