CHALMERS

An empirical investigation of the directivity of external industrial noise sources

Master's Thesis in the Master programme in Sound and Vibration

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Göteborg, Sweden 2005

Examensarbete 2005:18

MASTER'S THESIS 2005:18

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Reproservice / Department of Civil and Environmental Engineering
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Abstract

This thesis work deals with the directivity of external industrial noise sources. The purpose is to investigate the possibility of making measurements with consideration to the directivity of these types of sources, and using this knowledge as a basis for the possibility of taking measures for reduction of sound pressure levels at specified points of perception. The objectives are to illustrate the concept of directivity and to show, by performing measurements on real sources, that there are actual differences when the directivity is regarded during measurements and when it is not. This will be shown empirically through measurements on a number of typical external industrial noise sources and by an analysis based on the results from these measurements. A method for implementation of the measurements methods described in standards ISO 3744-2 [1] and DIN 45635-47 [2], relevant for this work, has also been developed within the extent of this project. It has, by the use of empirical methods, been investigated that there are significant differences in the results received without consideration of directivity and the result received when the directivity has been considered. Also, the method, developed by us for the purpose of making measurement (with regards to directivity) possible to implement in reality, worked as intended. Also, it has been shown that one, with the use of simplified methods, can perform measurements in only one direction and achieve correct results, but without the knowledge of the directivity one looses the advantages of redirecting the source.

Key words: outdoor sound propagation, directivity, industry noise, chimney, outlets.

Acknowledgement

The thesis work has been performed at Ingemansson Technology AB in Göteborg, Sweden during the period from September 2004 to January 2005.

First and foremost we would like to thank our supervisors and all of the personnel at Ingemansson for their extended help and interest in the subject and for facilitating us at their company, making it possible for us carry out the project.

Thank you; Martin Almgren, Joseph Barsi, Peter Bengtsson, Sonny Berndtsson, Sven Tyrland, Pär Wigholm and the rest of you.

Extended thanks to Sven Tyrland, of Ingemansson in Örnsköldsvik, for the idea of the thesis work and abundant guidance throughout the course of the project.

Also, we would like to thank our supervisor Maarten Hornikx at Chalmers, department of Applied Acoustics, for all his help and co-ordination of the project.

Thanks also to;

Kenth Andersson, Celero, Volvo LV, Tuve
Mihkel Laks and Christer Drougge, Volvo PV, Torslanda
Per Palmer, Klippan AB, Mölndal
Leif Svensson, Elmo Leather AB, Svenljunga

For giving us access to their roofs.

Contents

1 Introduction

In today's society there is an increasing demand for more silent industries. The thresholds for the maximum levels regarding noise from industries are lowered more frequently than before and as societies and cities spread, the industries, previously unaffected by these demands, will need to adjust to these new urbanized locations. For industries that, for example, are forced to increase the activity with a night shift (due to internal reasons such as production rate etc) there are several requirements to be fulfilled and extensive noise reduction measures to be taken before the demands for such an increase are satisfied. Environmental noise impact assessments and surveys for industries[1] have to be undertaken in order to locate the critical noise sources within the industry to recommend measures of noise reduction to levels satisfying the requirements. These measures are in most cases very expensive and therefore knowledge of the most cost-efficient measures is important.

In ENASI done today, the sound pressure level of a noise source is usually only measured at one point which is thought to give the right sound power level for calculations of the total sound pressure level at a point of perception. This sound power level can however differ from the sound power level gained by measurements performed on the recommendations in standards ISO 3744-2 [1] or DIN 45635-47 [2]. Sound power levels gained from standardized measurements are certainly the most correct (source descriptive), despite the fact that consideration to the levels at specified points of perception are not included in these standards. Therefore, the practical methods used by consultants today are probably the most useful methods available for this purpose, since they are simplified methods giving accurate results and are more time efficient then the other methods investigated within this thesis work. Another benefit with the use of this method is that it considers the directivity of the source already at the stage where a measurement point is selected.

How can the sound power levels measured according to recent standards be less correct than the sound power levels gained from the more simplified measurements performed by consultants?
Because of the fact that most sources have directive behavior to a certain extent, the sound power level (gained by the use of the consultants method) depends on the location of the measurement point in which the measurement has been performed.

According to ISO 3744-2 [1], one measures over a surface and retrieves the average sound pressure level, however information about the directive properties of the source is unknown. If one instead measures in a point giving the suitable sound power level for later calculations of sound pressure levels at specified receiver points, then that sound power level will be correct for these specific calculations while maybe not representing the true radiated sound power level from the source itself. If one instead uses the recommendation in Appendix E, ISO 3744-2 [1], information about the sound power level radiated from the source and a correction term in form of a directivity index can easily be evaluated. With knowledge about the source directivity one has (an advantage and) a possibility for later considerations of noise reduction measures. For example, by simple alterations of the source direction one can in some cases end up with much

[1] In this report called ENASI from now on.

lower sound pressure levels at the specified points of perception. This is a cheap and simple measure that can be used with the condition that one allows for higher noise levels in the direction which the source is heading after the interference. With the practical methods used today (the consultants method), the possibility of using this simple measure is lost because the sound power level is only calculated from measurements performed in one measurement point, representing the sound power level and directivity by which the source affects the receiver point in question. Also, a measurement based on standardized methods would lack this opportunity, if the formulae in Appendix E in ISO 3744-2 [1] were not used.

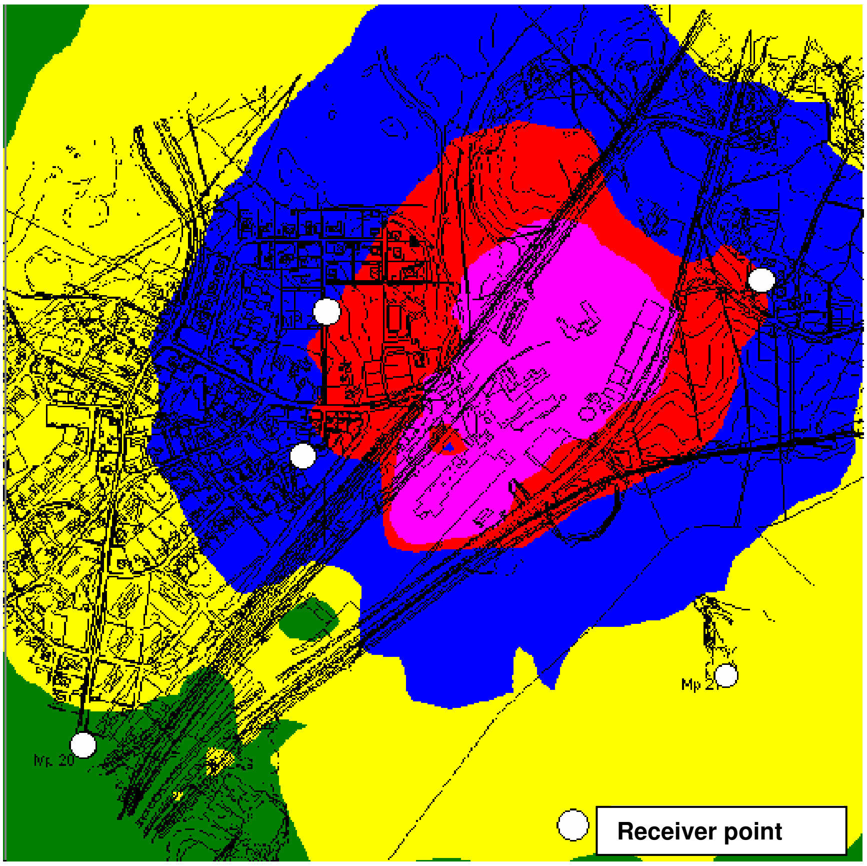


Figure 1 Example of a sound map made in an ENASI for an industrial plant.

2 Problem description

2.1 Directivity

Knowledge of the directive properties of a source gives a possibility to use these characteristics as an alternative to expensive external noise reduction measures[2] in order to reduce the sound pressure levels at the points of perception.

The determination of sound power levels of external industrial noise sources today are made either according to simplified methods based on experience, standard DIN 45635-47 [2] or standard ISO 3744-2 [1] (in which the determination of the directivity is mentioned in appendix E). The problem with this determination is that it is optional and not compulsory. In practice, the sound pressure level at the receiving point is calculated based on the sound pressure levels measured at a given distance in the directions that are thought to be the most representative (with respect to the receiving point) for the source, this without calculations of the total sound power level and the directivity index for the given direction. This procedure is of course valid and has been practiced by consultants within the field of acoustics, with success, for many years.

The problem with the measurement methods used today is therefore not the question of accuracy concerning the measurement values but the fact that one, while measuring only in one direction, excludes the possibility of using the directivity as a possible measure in the further investigation. In other words, one cannot adjust the sources according to their directive properties.

2.2 Determination of the emitted sound power and background levels

In order to obtain a valid estimation of the directivity of a source, the sources sound power level has to be determined correctly. In real life however, as will be shown later in this report, it is hard to achieve an accurate determination of the sound power levels according to the standard due to several different factors. The dominant problems are to locate the measurement points on the measurement surface with enough accuracy and to determine the background noise level at every measurement point according to ISO 3744-2 [1].

[2] Measures such as silencers or encapsulations of the source.

Figure 2 Typical environment on roofs of industries

2.3 Objectives

To empirically, with the aid of current standards for the determination of sound power levels of external industrial noise sources, corroborate the influence of directivity on the results calculated for sound pressure levels at specified receiver points, and thereby investigating the validity of the practical estimations of the sound power levels used today (While performing measurements and determinations of emission values from external industrial noise sources).

2.4 Method

To reach the objectives, following will be done:

- A study on how the calculation from measurements of the radiated sound power from the sources affects the sound pressure levels at different points of perception, and how one can affect these results by knowing and using the directive behavior of the source;

- A comparison between the modified method (see chapter 3.3), the consultants method, and the measurement methods according to standard, DIN 45635-47 [2];

- Development of a measurement method intended for making the current standards possible to implement in real life surroundings;

2.5 Limitations

This work has been limited to:

- External industrial noise sources (air outlets with fans mounted below the roof-level[3]).
- Empirical investigations based on measurements.
- Measurements according to ISO 3744-2 [1] and DIN 45635-47 [2] and methods based on these standards.

2.6 Typical noise sources

The sources studied within this work are all quite typical external industrial noise sources and have been selected in congruence with the limitations in chapter 2.5. They are exclusively air outlets. Pictures of three randomly selected sources are shown below; figure 3, figure 4 and figure 5.

Figure 3

Figure 4

Figure 5

[3] With two exceptions; source no. 1 and source no.18 (see Table 1)

Presented below (Table 1) is a descriptive list of all investigated sources within the thesis, in numerical order. High source means that the measurement sphere envelops the peripheral outlet of the source. Low source means that the measurement sphere cannot entirely envelop the peripheral outlet of the source. Large radius equals 2 meters. Small radius equals 1 meter.

Source	no	Location	Height/radius	Type
Source	1	Volvo LV	High source, large radius	Outlet, fan above roof
Source	2	Volvo LV	High source, small radius	Outlet
Source	3	Volvo LV	High source, small radius	Outlet
Source	4	Volvo LV	High source, small radius	Outlet
Source	5	Volvo PV	High source, large radius	Outlet
Source	6	Volvo PV	High source, large radius	Outlet
Source	7	Volvo PV	High source, large radius	Outlet
Source	8	Volvo PV	High source, large radius	Outlet
Source	9	Volvo PV	High source, small radius	Outlet
Source	10	Volvo PV	High source, small radius	Outlet
Source	11	Volvo PV	High source, small radius	Outlet
Source	12	Volvo LV	Low source	Outlet
Source	13	Volvo PV	Low source	Outlet
Source	14	Volvo PV	Low source	Outlet
Source	15	Elmo Calf	Low source	Outlet
Source	16	Elmo Calf	Low source	Outlet
Source	17	Klippan AB	High source, small radius	Outlet
Source	18	Klippan AB	High source, small radius	Outlet, fan above roof

Table 1 Source name, location, and type.

3 Description of measurement methods, SPL and software

The literature review consists of studies of the standards used in this thesis and the methods used for practical measurements on the type of sources under study. The standards are ISO 3744-2 [1] and DIN 45635-47 [2]; ISO 9613-2 [3] is used for calculations of sound propagation to the receiving points. A method called the modified method, which is based on an interpretation of ISO 3744-2 [1], and the consultants method is also described in this chapter.

3.1 Standard ISO 3744-2 [1]

This International Standard specifies a method for measuring the sound pressure levels on a measurement surface enveloping the source, and for calculating the sound power level produced by the source. The following text and figures are mainly excerpts from the standard.

3.1.1 Excerpts from Chapter 7.1

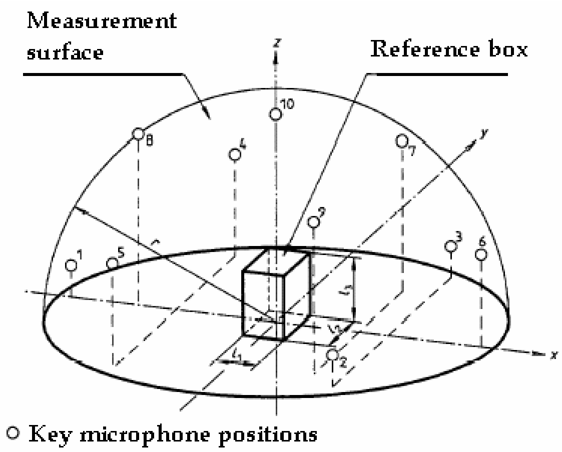
To facilitate the location of the microphone positions on the measurement surface, a hypothetical reference box shall be defined (see fig 3). When defining the dimensions of this reference box, elements protruding from the source which are not significant radiators of sound energy may be disregarded. The microphone positions lie on the measurement surface, a hypothetical surface of area *S* that envelops the source as well as the reference box and terminates on the reflecting plane(s). The location of the source under test, the measurement surface and the microphone positions are defined by a co-ordinate system with the horizontal axes x and y in the ground parallel to the length and width of the reference box.

3.1.2 Excerpts from Chapter 7.2

The hemispherical measurement surface shall be centered in the middle of the reference box consisting of the reference box and its images in the adjoining reflecting planes. The radius, *r*, of the hemisphere shall be equal to or greater than twice the characteristic source dimension, d_0, and not less than 1 m.

3.1.3 Excerpts from Annex B:1

Ten key microphone positions associated with equal areas of the measurement surface are numbered 1 to 10 in figure B.1, and their co-ordinates according to the co-ordinate system defined in 7.1 are listed in table B.1. Ten additional microphone positions are numbered 11 to 20 in figure B.2 and their co-ordinates are also listed in table B.1.



Microphone position	$\frac{x}{r}$	$\frac{y}{r}$	$\frac{z}{r}$
1	− 0,99	0	0,15
2	0,50	− 0,86	0,15
3	0,50	0,86	0,15
4	− 0,45	0,77	0,45
5	− 0,45	− 0,77	0,45
6	0,89	0	0,45
7	− 0,33	0,57	0,75
8	− 0,66	0	0,75
9	0,33	− 0,57	0,75
10	0	0	1,0
11	0,99	0	0,15
12	− 0,50	0,86	0,15
13	− 0,50	− 0,86	0,15
14	0,45	− 0,77	0,45
15	0,45	0,77	0,45
16	− 0,89	0	0,45
17	− 0,33	− 0,57	0,75
18	0,66	0	0,75
19	− 0,33	0,57	0,75
20 (≙10)	0	0	1,0

Figure 6 Picture from appendix B:1 [1] **Table 2** Picture from appendix B:1

3.1.4 Main formulae, ISO 3744-2 [1], chapter 8; Calculation of surface sound pressure level and sound power level.

The sound pressure level averaged over the surface is calculated using equation (1) and (2), (4) and (5) in ISO 3744-2 [1]

$$\overline{L'_p} = 10\lg\left[\frac{1}{N}\sum_{i=1}^{N}10^{0,1L'_{pi}}\right]\text{dB} \quad (1)$$

$$\overline{L''_p} = 10\lg\left[\frac{1}{N}\sum_{i=1}^{N}10^{0,1L''_{pi}}\right]\text{dB} \quad (2)$$

$\overline{L'_p}$ is the sound pressure level averaged over the measurement surface in decibels, with the source under test operation;

$\overline{L''_p}$ is the sound pressure of the background noise level averaged over the measurement surface in decibels;

L'_{pi} is the sound pressure level measured at the i^{th} microphone position, in decibels;

L''_{pi} is the sound pressure level on the background noise measured at the i^{th} microphone position, in decibels;

N is the number of microphone positions.

Note; the averaging procedure in equation (1) and (2) is based on uniform distribution of the microphone positions on the measurement surface

The sound power level is calculated using equation (3), (9) in ISO 3744-2 [1]

$$L_w = \overline{L_{pf}} + 10\lg\left(\frac{S}{S_0}\right)\text{dB} \quad (3)$$

Where

S is the area of the measurement surface, in square meters;

S_0 = 1 m^2

$\overline{L_{pf}}$ is the sound pressure level averaged over the measurement surface corrected for surroundings and background noise

3.1.5 Annex E

The directivity in the direction of microphone position *i*, DI_i, in decibels, is defined for a hemispherical measurement surface by the following equation:

$$DI_i = L^{\bullet}_{pi} - \overline{L^{\bullet}_{pi}} \tag{4}$$

Where; $L^{\bullet}_{pi}$ is the sound pressure level at the microphone position i, corrected for background noise;

$\overline{L^{\bullet}_{pi}}$ is the sound pressure level averaged over the measurement surface, corrected for background noise.

3.2 Standard DIN 45635-47 [2]

3.2.1 Excerpts from DIN 45635-1 [4]

This standard is applicable to industrial noise sources such as equipment, machines, machine components, sub –assemblies and plant, which are referred to in this standard as machines.

The principal noise emission parameter is the sound power level. The sound power is the sound energy passing in unit time trough a surface enveloping the machine. This standard describes the basic method for determining the sound power level of a machine with the aid of the enveloping surface method.

Background noise is any noise which is not generated by the machine under test or which is directly radiated by attached components that do not belong to the object under test.

3.2.2 Descriptive pictures and formulae from DIN 45635-47 [2]

The DIN 45635-47 [2] is the part of the DIN 45635-1 [4] standard that describes measurements of airborne noise emitted by machines and chimneys, the enveloping surface method.

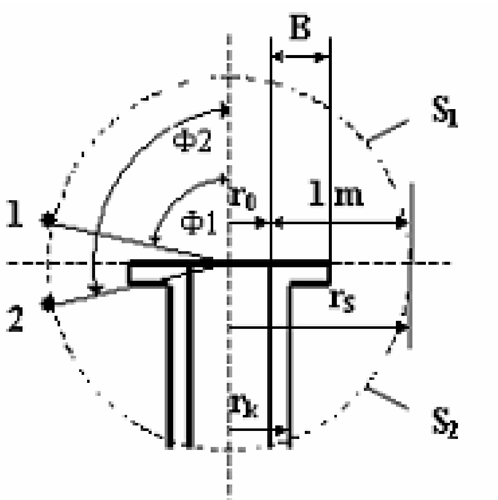


Figure 7 DIN 45635-47 [2] measurement positions, side view

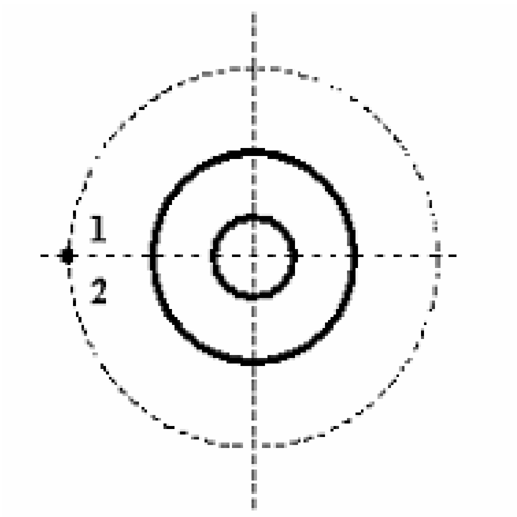


Figure 8 DIN 45635-47 [2] measurement positions, top view

The sound power level is calculated as follows

$$L_{wA} = 10\log(10^{L_{wA1}/10} + 10^{L_{wA2}/10}) \quad (5)$$

$$L_{wA1} = L_{pA1} + 10\log(\frac{S_1}{S_0}) \quad (6)$$

$$L_{wA2} = L_{pA2} + 10\log(\frac{S_2}{S_0})) \quad (7)$$

$$S_0 = 1m^2$$

$$S_1 = 2 \cdot \pi \cdot r_s^2$$

$$S_2 = 2 \cdot \pi \cdot r_s \cdot \sqrt{(r_s^2 - r_k^2)} \quad (8)$$

With $r_s = r_0 + 1m$

$70° \leq \Phi_1 \leq 80°$
$100° \leq \Phi_2 \leq 110°$

3.3 Modified method

The method we call “the modified method” in this report is a method based on the method described in the ISO 3744-2 [1]. In order to perform measurements on the type of sources investigated in this thesis work, certain adjustments to the standardized method had to be made.

The modified method is based on the following items:

- Spherical measurement surface
- Sphere centered in the middle of the source at the peripheral outlet
- 10 evenly distributed points on the spherical surface representing equal areas
- Background noise levels estimated from measurements and levels of surrounding sources
- Instrument set-up according to ISO 3744-2 [1]

Whereas the method in ISO 3744-2 [1] only considers half-spherical surfaces. Also, the ISO 3744-2 [1] would describe the whole chimney as a source and not only the peripheral outlet. The definition of measurement points, in the modified method, has been adapted from ISO 3744-2 [1] (while adjusted to the spherical surface) as well as the instrument set-up.

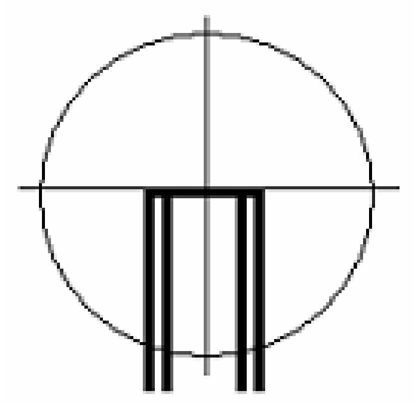


Figure 9 Measurement surface enveloping the outlet

To retrieve the positions and coordinates for the measurement points, on the spherical surface, calculations were made using a Matlab® program. These points were in accordance with ISO 3744-2 [1], uniformly placed on the sphere, representing equal areas. Four positions in the vertical plane and three positions in the horizontal plane. For every combination of source radius, height and measurement radius, the coordinates and angles for each measurement position were saved in text files and printed for use during measurements.
The Matlab® program can be retrieved in Appendix 2.

3.4 The consultants method

After a number of conversations with the supervisors and consultants at Ingemansson Technology AB, it is clear that the method used by consultants today is based on experience. The method is based on ISO 3744-2 [1] but is also a simplified version where the directive behavior of a source is considered as early as when the choice of measurement position is made. The object of their interest is to determine the source contribution to specified points of perception and not necessarily to determine the true sound power level from the source.

The consultants method is based on the following items:

- The sound pressure level is usually measured at a distance of one meter
- Measurements in an appropriate direction to retrieve the source contribution to specified points of perception
- If the accurate sound power level from the source is wanted, the measurement point is placed 45 degrees from the edge of the source (see figure 7)
- $Lw = Lp + 5, 8, 11$ dB; Depending on the amount of reflecting planes
- Only one value for the sound power level, no directivity indices

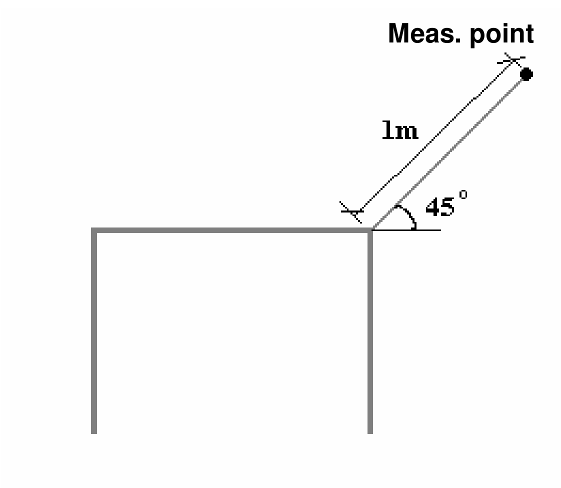


Figure 10 Consultants method

3.5 Standard ISO 9613-2 [3]

This part of ISO 9613-2 [3] is intended to enable noise levels in the community to be predicted from sources with known sound emission.

3.5.1 Excerpts from chapter 6

The equivalent continous downwind octaveband sound pressure level at a receiver location, $L_{fT}(DW)$, shall be calculated for each point source, and its image sources, and for the eight octavebands with nominal midband frequencies from 63 Hz to 8 kHz, from the following equation:

$$L_{fT}(DW) = L_w + D_C - A \qquad (9)$$

Where;

L_W is the octaveband sound power level, in decibels, produced by the point sound source relative to a reference sound power of one picowatt (1pW);

D_C is the directivity correction, in decibels, that describes the extent by which the equivalent continuous sound pressure level from the point sound source deviates in a specified direction from the level of an omnidirectional point sound source producing sound power level L_W; D_C equals the directivity index D_1 of the point sound source plus an index D_Ω that accounts for sound propagation into solid angles less than 4π radians; for an omnidirectional point sound source radiating into free space, D_C = 0 dB.

A is the octaveband attenuation, in decibels, that occurs during propagation from the point sound source to the receiver.

3.6 Software

3.6.1 Software characteristics and function [5]

SoundPLAN® uses a sector method. Starting from the receiver, search "rays" scan the geometry for sources, reflections, screens and geometry modifying the ground attenuation. The scanning rays use a constant increment angle of 1 degree. This is a default setting but one can choose any increment. A search triangle is in fact a more accurate description than a search ray. As one search triangle adjoins another, the search triangles cover the entire ground around the receiver, whereas a set of rays would miss the components between rays. When SoundPLAN® finds a source in the search direction; it automatically calculates the part of the source contained in the search triangle and processes that partial source contribution.

3.6.2 SoundPLAN® and Industry noise [5]

The SoundPLAN® parameter menu offers six different choices for calculations of frequency dependent industry noise. In this work, only the ISO 9613-2 [3] is considered. The ISO 9613-2 [3] does not supply different formulas for different frequencies and can therefore be used for any frequency.

4 Instrument listing

The following instruments have been used during the thesis work.

4.1 Instruments used during the measurement phase

- Norsonic real time octaveband analyzer, type 114.
- Norsonic real time octaveband analyzer, type 118.
- B&K microphone calibrator, type 4231
- B&K microphone holder
- Extension chords
- Mast
- Measuring tape
- Nicon Coolpix digital camera, type 3200.
- Device for measuring with constant measurement radius
- Adhesive tape

Instruments are calibrated with traceability to national and international references following the quality system at Ingemansson Technology AB, which fulfils the requirements in SS-EN ISO/IEC 17025.

4.2 Software

- SoundPLAN®; SoundPLAN® LLC, Braunstein + Berndt GmbH
- Matlab®; Mathworks corporation

5 Measurements

In this chapter, two different implementations of the modified method are described, performed and evaluated. For the DIN 45635-47 [2] method and the consultants method, the points are measured using our device (see Figure 12). A description of how the considerations of background noise have been taken is also included in the chapter. In order to implement the modified method, in other words measure with the help of fixed points on a known surface, practical methods for doing so have been developed. Two different methods were evaluated. The first method was based on the projection of the measurement points onto the ground (roof) and with the aid of an adjustable mast locating the points along the z-axis. For the second method, a fixed measurement radius together with calculated angles for the positioning in the vertical plane was used.

All measurements were performed according to the prerequisites in chapter 2 and according to the methods and standards described in chapter 3. The sources measured during this thesis work were located at the roofs of four different industries situated in the Gothenburg area (see Table 1).

5.1 Execution of the practical measurement methods

The method of projecting the measurement points onto the ground (roof) consisted of a number of steps. First, the positions were projected onto the ground (roof), after a correction was made for the source height and for eventual slope of the ground (roof), and marked around the source. After the marking was done, the microphone was attached to the mast with the help of a microphone holder and an extension cable. The measurements started from below with the first three positions in the *xy*-plane for the first *z*-coordinate and then continued upwards along the *z*-axis. L_{eq} was measured in each point over a period of 30 seconds, the minimum period time according to ISO 3744-2 [1]. The average total measurement time per source was approximately 30 minutes.

The method that involves the use of our device for measurements with fixed radius and varying angle proved to be easier and less time consuming to use in practice. The tables of position coordinates (see chapter 5.4.3) were used here. With the help of these tables and a compass, for location of the four cardinal points, the measurements proceeded as for the former method. The vertical angle[4] was set according to the table and then altered accordingly along the *z*-axis. L_{eq} was measured in each point over a period of 30 seconds, the minimum period time according to ISO 3744-2 [1]. The average total measurement time per source was approximately 15 minutes.

[4] Angle starting from 0 degrees (above the source), ending at 180 degrees (under the source)

5.2 Evaluation of the practical measurement methods

5.2.1 Projection of measurement points onto the ground (roof)

Preparations

As previously mentioned (see chapter 3.3), the positions of the measurement points were calculated so that they represented equal areas. A spherical surface (see chapter 3.3) was used as measurement surface (figure 11). The larger measurement radius was needed here since the measurement points were projected onto the ground (roof) and therefore a smaller surface would demand a higher degree of precision while marking the positions. This would be difficult to achieve for this type of measurement. On the other hand, despite the size of the measurement sphere chosen, one realized that almost perfect conditions would have to exist when measurements were to be performed even for the indication of the larger sphere to be precise. Ideally, the source would have to be solitarily placed on a smooth and leveled surface with no obstacles present in its surrounding.

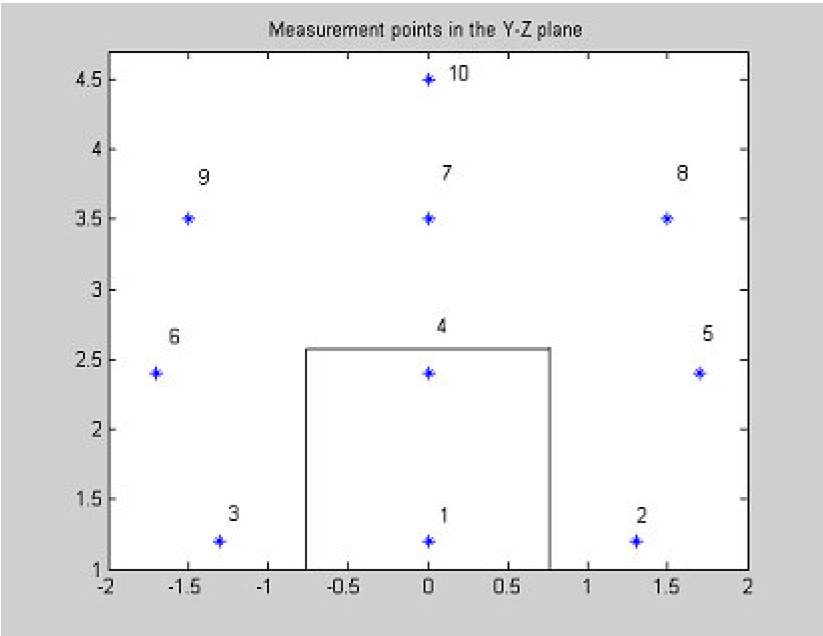


Figure 11 Measurement positions calculated and plotted for a high source in YZ plane

Performance

The implementation of the method turned out to be very unpractical and the measurements were time consuming with a total measurement time per source almost exceeding 30 minutes. Unpractical was also the fact that it was very hard to achieve a satisfactory degree of precision while trying to measure in the right points on the sphere, especially at the points situated on the two highest horizontal levels (points 4-9). Measuring point no 10 (above the source (0; 0; z)) was practically impossible if any kind of precision was to be taken into account. The determination of the sound power level radiated from the source was dependent on all measurement points and would thereby become afflicted with error if the measurements themselves were afflicted with errors. Clearly, when it came to the problems with nearby sources and the surface properties in the vicinity of the source, a smaller measurement surface would be preferred. With that, the earlier foreseen problems with the precision during the preparations were substantiated at this stage.

Conclusions

One can, with certainty, draw the conclusion that this implementation of the modified method in this case is not practically viable, except maybe under ideal circumstances. Also, the measurement time for this implementation is very long, which (probably) is not preferred in the case for most consultants companies whose interests are other than purely educational. The method at hand did not function desirably for our purposes and therefore another method had to be developed.

5.2.2 Measuring with fixed measurement radius and calculated angles

Preparations

If measurements with fixed measurement radius and calculated angles were to be possible to perform, a special device had to be used (figure 12, figure 13). Since such a device (or similar to it) to our knowledge does not exist on the market, it had to be designed and constructed. The device consists of jointed aluminum profiles and a scale, displaying angles from 0 to 180 degrees and allows for angle adjustments for desired angles from the source. The device also allows for masts of different sizes to be attached to the profiles of which it consists. Adjustments for source radius, measurement radius and angle from source had to be set before measurements were made.

Performance

The source radius was first to be determined on site; the radius decided the length of the mast attached to the profile, which represented the microphone holder attachment. The measurement surface (sphere) was previously determined; the length of the radius of the sphere was set onto the adjustable profile representing the measurement radius. The height of the source later determined the height of the handheld mast, which was to be perpendicular to the ground (roof) at all time. The measurements were performed at four different levels along the z-axis. The angles for the different levels (zero degrees straight up from the source (point no. 10)) were calculated in advance using a Matlab® program written for this purpose (see Appendix 2). This method turned out to be more practical and the measurements were less time consuming than for the previous method.

Conclusions

There were a number of advantages using of this method in comparison to the method previously described (see chapter 5.2.1). Obstacles on the ground (roof) surrounding the source constituted no problem since one could easily adjust the height of the handheld mast at will, as long as it stayed perpendicular to the ground (roof). The sway problem was also reduced due to the flap constructed for the purpose of bracing the rig against the edge of the source. As a consequence of that brace, the precision increased considerably. The total measuring time was also reduced because the positions of the measurement points did not have to be considered during preparations, knowledge of the cardinal points and the directions in which the measurement points should be located was enough.

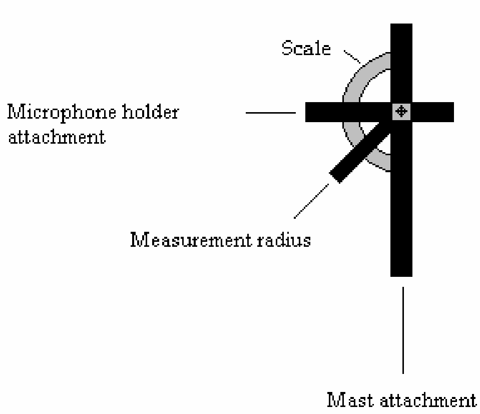


Figure 12 Our device, schematic picture.

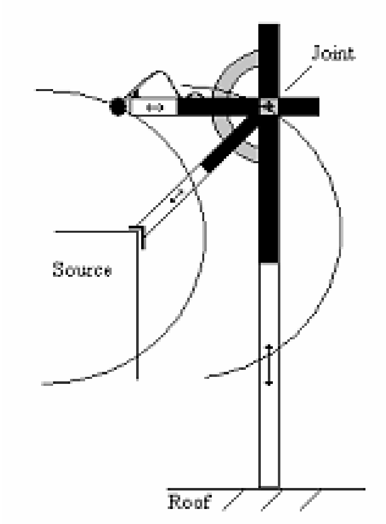


Figure 13 Our device, operation

Figure 14 Our device, practical operation.

5.3 Background noise

According to ISO 3744-2 [1], the background noise level should be measured in every measurement point. It would be problematic to satisfy this demand in real surroundings (see chapter 8.3.1) and therefore, a practical method was implemented instead. It was based on measurements at arbitrary positions around the source and the estimation of the background levels at these positions, to ensure that the background noise level was sufficiently below the levels measured in the different measurement points in order to validate the measurements. In order to minimize the background noise levels influence on the measurements, the smallest possible measurement radius was chosen for all sources.

6 Calculations & Analysis

The analysis of the results from measurements was performed using Matlab® programs of own design, excel sheets and SoundPLAN®. SoundPLAN® is a program designed for the purpose of calculating community noise, noise propagation, noise level prediction etc. In SoundPLAN®, the directivity indices can be assigned to each source in three dimensions, which is suitable for the purposes in this work.

6.1 Calculations made in Matlab®

The Matlab® programs (see Appendix 2) described in this chapter were designed for the purpose of making calculations of sound power levels, directivity indices, tables of measurement points positions, measurement surfaces etc. There was no focus on making the programs as efficient and short as possible, they were merely used as a tool for the purpose of saving time during the measurement part of the project (and therefore no effort has been made in optimizing the code since only basic formulas and interpolations were required).

6.2 Calculations according to ISO 3744-2 [1]

For the calculations of sound power levels and directivity indices, the program was built on the formulae in ISO 3744-2 [1] (see chapter 3.1.4). There was also a correction made for the background noise, for cases in which the background noise level constituted a significant problem. In the cases where the background noise levels were estimated to have little if any influence on the measurements, the correction factor was set to zero (no correction).

6.3 Interpolation for directivity indices used in SoundPLAN®

In SoundPLAN®, a directivity index has to be introduced for each point representing a 10-degree increment, resulting in a matrix with 36X18 (see figure 16) elements. Since measurement data is lacking for all points except for the ten actual measurement points, 638 points have to be interpolated. The program starts with the introduction of the results from the ten measurement points into the matrix, then a horizontal interpolation is made followed by a vertical interpolation. Beginning with the directivity indices given by the measurement data, the interpolations were made linearly using the pressures squared. For each octaveband the resulting matrix is saved as a text file for later implementation in SoundPLAN®. For some sources, measurements according to DIN 45635-47 [2] and the consultants method, where not performed. In these cases, the interpolated values constituted the basis for sound power level calculations represented by these methods. For the sources for which this method were used, the resulting calculations of sound power levels were made in the excel file used to plot the comparison between measurement methods regarding differences in sound power levels.

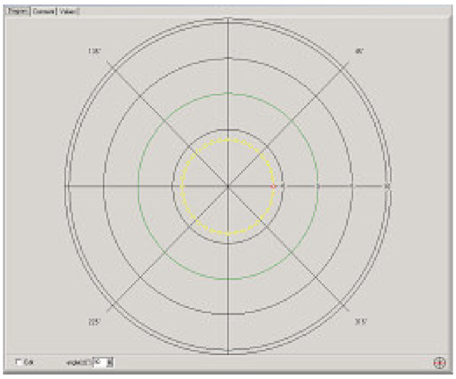


Figure 15 SoundPLAN® Directivity plot for single vertical angle

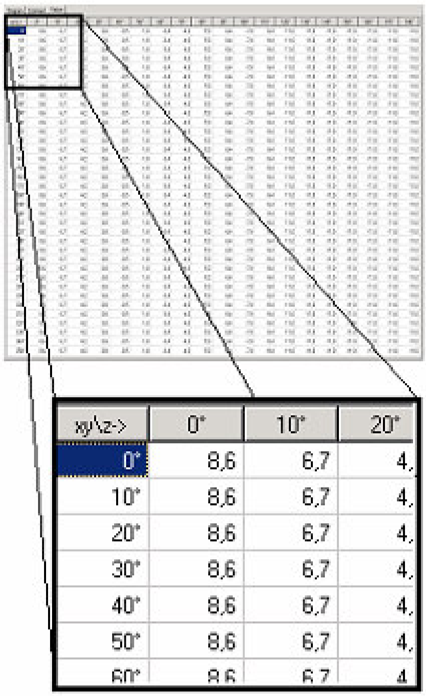


Figure 16 36*18 Matrix with directivity indices

6.4 Analysis in SoundPLAN®

In order to look into the possible benefits of using a measurement method that entails a description of the directivity of a source for different directions, a comparison between sound pressure levels at receiving points has to be made. These comparisons are performed by calculation of the sound propagation outdoors using SoundPLAN®. In this case, a simplified model of an environment was created for the purpose of looking into the differences in the sound pressure level for different receiver points and source definitions.

6.4.1 Different sound power level definitions within the calculation data

The sound power level for each source has four different definitions:

- Sound power levels calculated from measurements based on the modified method defined in this thesis (see section 5.3.1) which is derived from ISO 3744-2 [1].

- Sound power levels calculated from measurements based on the modified method without considering the directive properties of the sources.

- Sound power levels calculated from measurements based on the modified method but after the sources have been subdued to a tilt by 90 degrees towards a direction for which an increase in noise level are accepted.

- Sound power levels calculated from measurement based on the modified method but after the sources has been subdued to a tilt by 90 degrees in the opposite direction.

In order to calculate the sound pressure levels at a given distance from the source, receivers have to be placed into the modeled domain (see Figure 17). In this model, 240 receivers are placed at different distances and heights from the source for the purpose of giving a good appreciation of the changes in sound pressure levels achieved with different source definitions. The sound pressure levels at each different receiver as well as the magnitude of the contribution from the source to each receiver are presented in tables (see Appendix 3). For a more graphical result, calculations were made over a surface placed on a given height above the terrain and the results were displayed as color maps, in this case a model of a real environment was used.

For the vertical angles between 130 and 180 degrees there were no measurements performed and therefore there were no measurement data that could be used in the calculations of the directivity indices. To deal with this problem, the directivity indices in this interval were set to values based on the directivity indices measured at 130 degrees. Actual levels could (most probably) be lower in this interval. As a consequence of this action, the results were ensured to represent the worst case scenario.

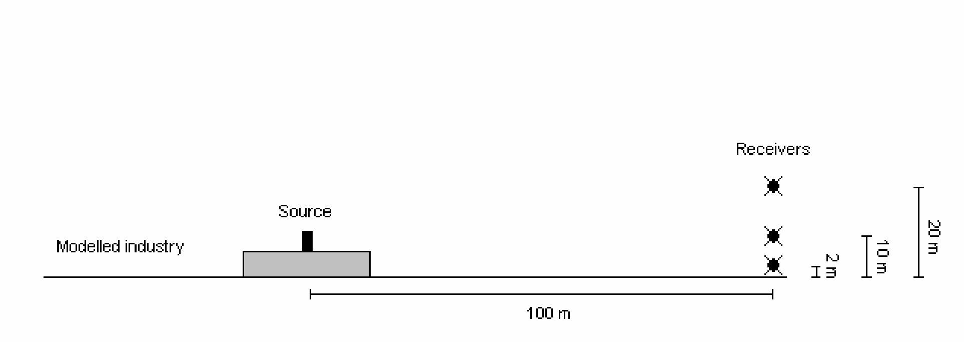


Figure 17 Modeled environment, receiver locations

7 Results

7.1 Results from measurements

In total, eighteen typical external industrial noise sources were measured during the course of this thesis work. Results, in full, from these measurements are presented in Appendix 1. For each source, plots showing the directivity indices, the radiated sound power level, a datasheet with measurement data and the different source characteristics are presented. A selection of measurement results from three different typical sources is presented in this chapter.

The sound pressure levels are presented in octavebands from 63 Hz to 8 kHz together with the average equivalent sound pressure levels. The levels displayed in octavebands are linear but the average sound pressure levels are A-weighted. A-weighted sound pressure levels are interesting for clients to companies dealing with ENASI because the demands on noise emission levels from industries, stated by the Swedish government, are presented in terms of A-weighted values.

7.1.1 Example of a high source with small radius, Source 11

Source physical properties

Air outlet, Fan placed under roof.

Source height = 5 m

Source radius = 0,4 m

Meas. radius = 1,0 m

Figure 18

Source 11, High source with large radius

Measurement data

Table showing measured sound pressure levels in A-weighted total level and linear octaveband levels from 63 to 8000 Hz.

Point no.	63 Hz	125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz	8 kHz	LAeq
1	74,6	76	75,3	71,2	66,3	58,6	50,2	41	72,2
2	74,6	75,7	75,2	70	65,6	58,4	50,6	40,1	71,6
3	74,9	76,1	75,3	70,4	65,8	58,1	50,5	38,1	71,8
4	76,4	77,7	77,5	73,9	69,5	61	55,2	43,6	74,9
5	77,6	77,7	77,7	73	69,3	62	56,2	43,7	74,7
6	78	77,7	77,6	73,2	69,7	61,9	56	44	74,8
7	81,3	80,1	81,3	79,2	78,1	71,8	69	61,8	82
8	78	80,1	81,6	78,8	77	71,5	68	61	81,3
9	83,7	80,7	81,7	78,6	76,9	71,2	68,2	61,1	81,2
10	78,1	80,5	83,5	80,8	80,1	72	68,5	62,3	83,5

Table 3 Source 11: Measurement data, linear octaveband levels, A-weighted total sound pressure level, dB re 20 µPa.

The measured sound pressure levels presented at the locations of the measurement positions on the measurement sphere.

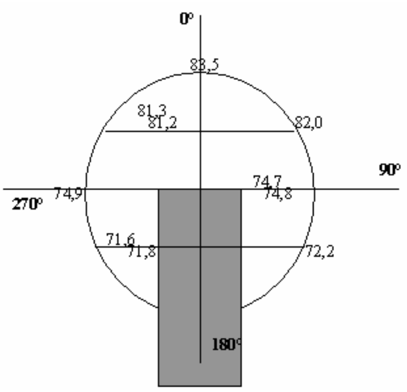


Figure 19 Side view of source 11

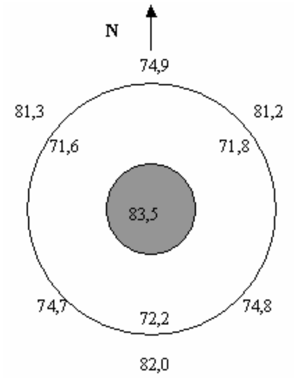


Figure 20 Top view of source 11

A comparison between total sound power levels received from different measurement methods is displayed below. Linear values except for the LA_{eq} level that is A-weighted.

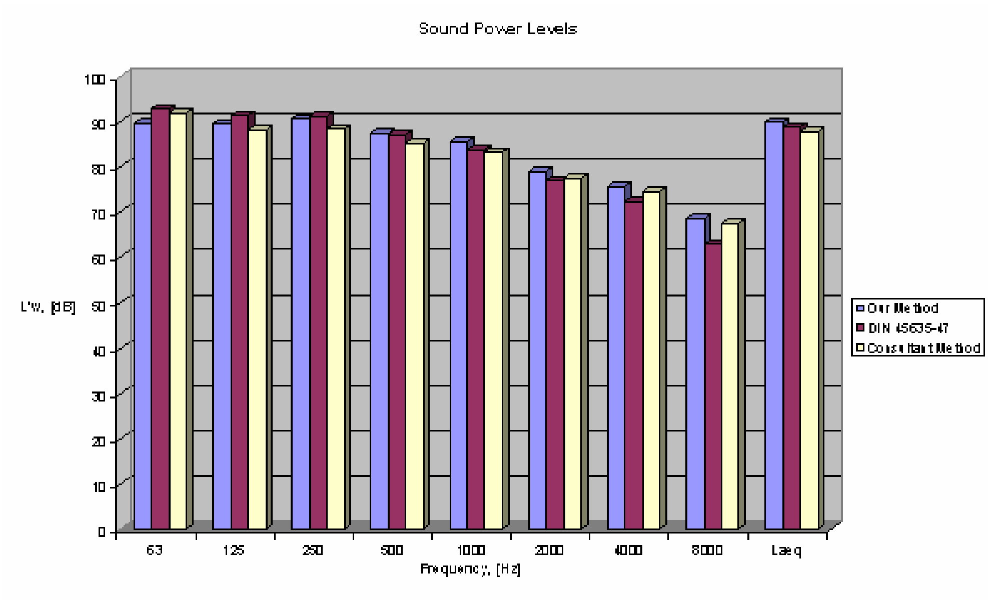


Figure 21 Source no. 11: Sound Power Levels, dB re 1 pW, linear octavebands and A-weighted total Sound Power Level. The modified method, DIN 45635-47 [2], consultants method.

7.1.2 Example of a high source with large radius, Source 7

Source physical properties

Air outlet, Fan placed under roof.

Source height = 5 m

Source radius = 0,8 m

Meas. radius = 2,0 m

Figure 22

Source 7: High source with large radius

Measurement data

Table showing measured sound pressure levels in A-weighted total level and linear octaveband levels from 63 to 8000 Hz.

Point no.	63 Hz	125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz	8 kHz	LAeq
1	69,5	67,5	63,6	59,1	55,4	48,1	40,5	28,9	61
2	69,8	67,2	66,1	59,5	55,4	48,7	40,2	27,4	61,8
3	70,1	67,9	65	58,7	53,5	46,2	38,2	24,9	60,7
4	69,4	67	65,3	60,8	56	49	41,8	31,5	62,1
5	69,4	68,7	66,9	60,5	56	48,7	41	26,9	62,7
6	69,2	69,5	66,7	60,4	55,2	47,8	38,1	24,4	62,3
7	76,3	70	68,7	64,3	59,6	51,4	44,5	37	65,6
8	70,4	70,8	70,5	65,6	59,5	51,1	44	36,8	66,5
9	86,9	79,1	72,7	65,3	60	52,3	47,9	42,8	68,8
10	83	76	69,2	63,7	58,6	52,9	48,5	42,7	66,5

Table 4 Source 7: Measurement data, linear octaveband levels, A-weighted total sound pressure level, dB re 20 µPa.

The measured sound pressure levels presented at the locations of the measurement positions on the measurement sphere.

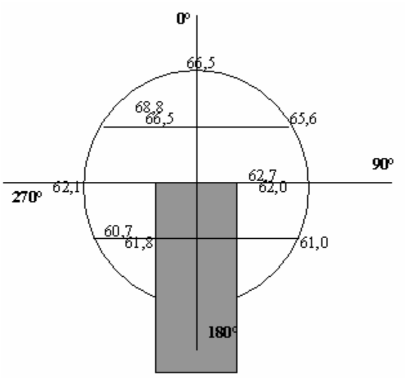


Figure 23 Side view of source 7

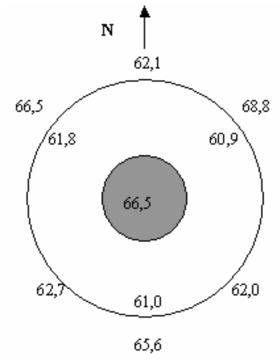


Figure 24 Top view of source 7

A comparison between sound power levels received from different measurement methods is displayed below. Linear values except for the LA_{eq} level that is A-weighted.

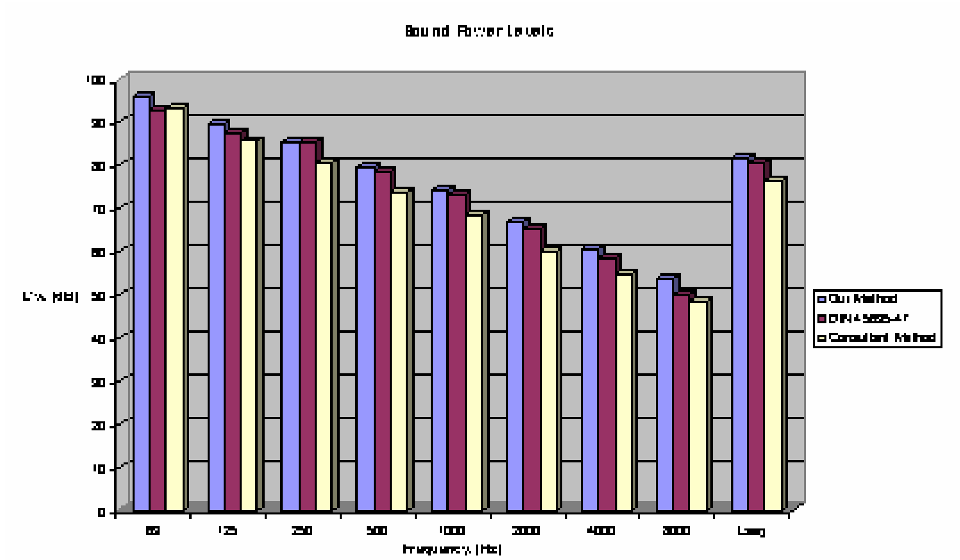


Figure 25 Source no. 7: Sound Power Levels, dB re 1 pW, linear octavebands and A-weighted total Sound Power Level. The modified method, DIN 45635-47 [2], consultants method.

7.1.3 Example of a low source

Source physical properties

Air outlet, fan placed under roof.

Source height = 1 m

Source radius = 0,5 m

Meas. radius = 2,0 m

Figure 26

Source 15: low source

Measurement data

Table showing measured sound pressure levels in A-weighted total level and linear octaveband levels from 63 to 8000 Hz.

Point no.	63 Hz	125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz	8 kHz	LAeq
1	50.7	57.5	68.3	64.3	69.7	60.0	51.4	42.5	73.0
2	50.0	57.1	62.5	62.2	64.3	54.7	45.2	40.0	68.4
3	49.9	58.0	63.8	62.9	65.3	56.3	45.8	40.0	69.4
4	47.7	54.9	69.0	69.1	70.6	62.1	53.9	47.4	74.6
5	47.8	54.5	64.9	66.3	66.3	59.6	51.3	44.3	71.0
6	48.4	55.0	66.9	65.8	67.1	60.2	51.1	43.5	71.7
7	46.9	56.4	68.7	70.8	75.0	68.3	61.0	55.4	77.7
8	47.9	56.6	65.8	70.5	71.5	64.9	58.6	53.7	75.2
9	47.0	56.9	67.3	71.0	72.3	65.2	58.8	53.3	75.9
10	51.7	58.4	69.4	71.7	74.5	68.2	61.1	56.0	77.8

Table 5 Source 15: Measurement data, linear octaveband levels, A-weighted total sound pressure level, dB re 20 µPa.

The measured sound pressure levels presented at the locations of the measurement positions on the measurement sphere.

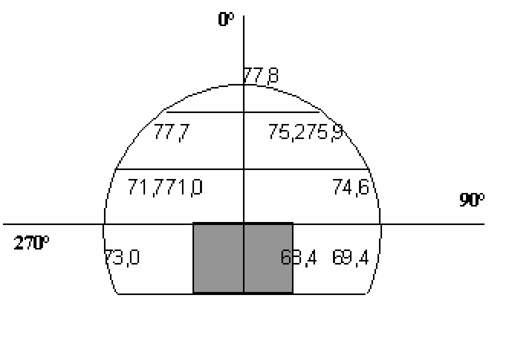


Figure 27 Side view of source 15

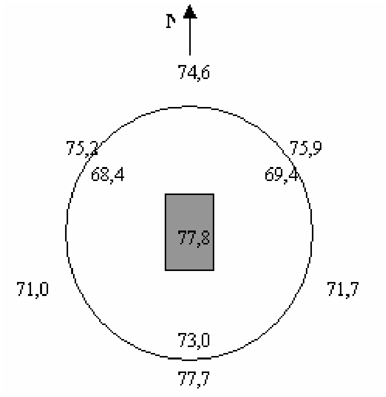


Figure 28 Top view of source 15

A comparison between sound power levels received from different measurement methods is displayed below. Linear values except for the LA_{eq} level that is A-weighted. No DIN 45635-47 [2] have been made on low sources.

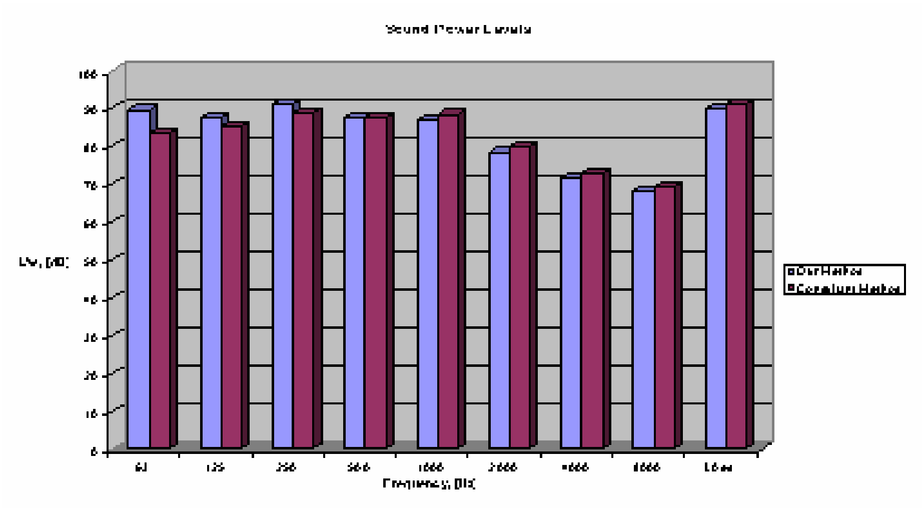


Figure 29 Source no. 15: Sound Power Levels, dB re 1 pW, linear octavebands and A-weighted total Sound Power Level. The modified method and the consultants method.

7.1.4 Example of directivity plots

The directivity indices were calculated using the formulae in Appendix E, ISO 3744-2 [1].

The directivity indices, presented in figure 30 and figure 31, represent the directivity as a function of vertical angle, θ, averaged over all Φ (see figure 30). Variations in the *xy*-plane have been used in the analysis in SoundPLAN®. The purpose of this is to display results from measurements from real sources, which is the main purpose of this thesis work. In the figures showing the directivity variations the directivity indices are plotted for different vertical angles. The measurement points along the z-axis are placed at four different angles; the values between these angles are therefore interpolated from these four points.

Directivity indices for each octaveband and the total equivalent level are plotted for each 10-degree angle between the top point and the lowest point.

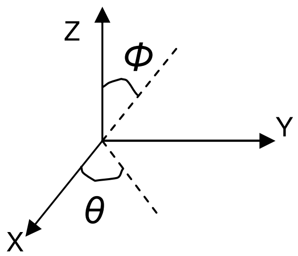


Figure 30

Coordinate system

Φ=0, Direction 0˚ from outlet

Θ=0, Direction 90˚ from outlet

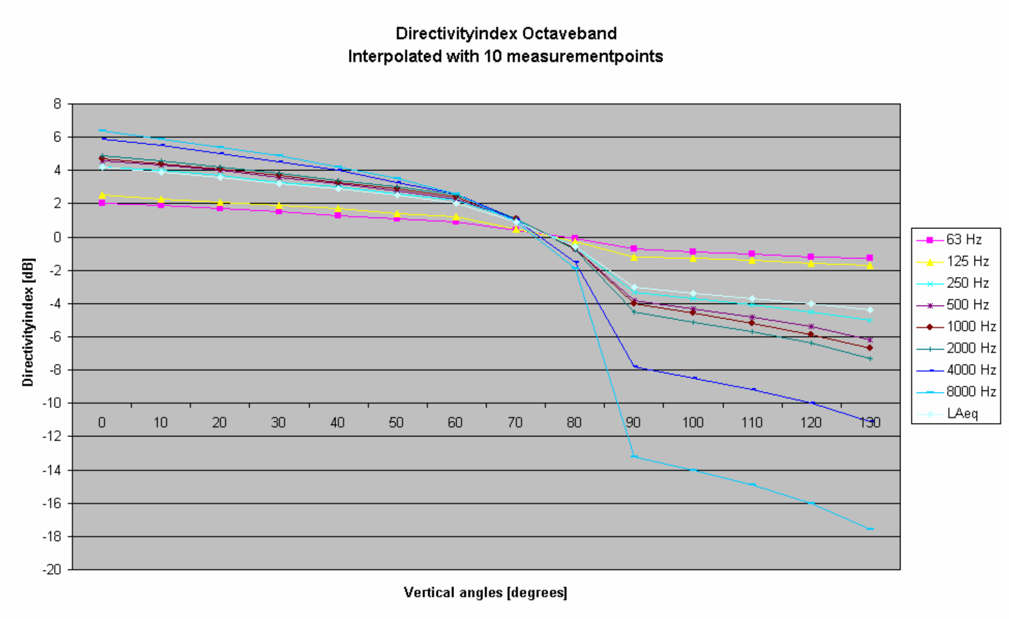


Figure 31 Source 2: High source, small radius. Directivity index plotted over vertical angles.

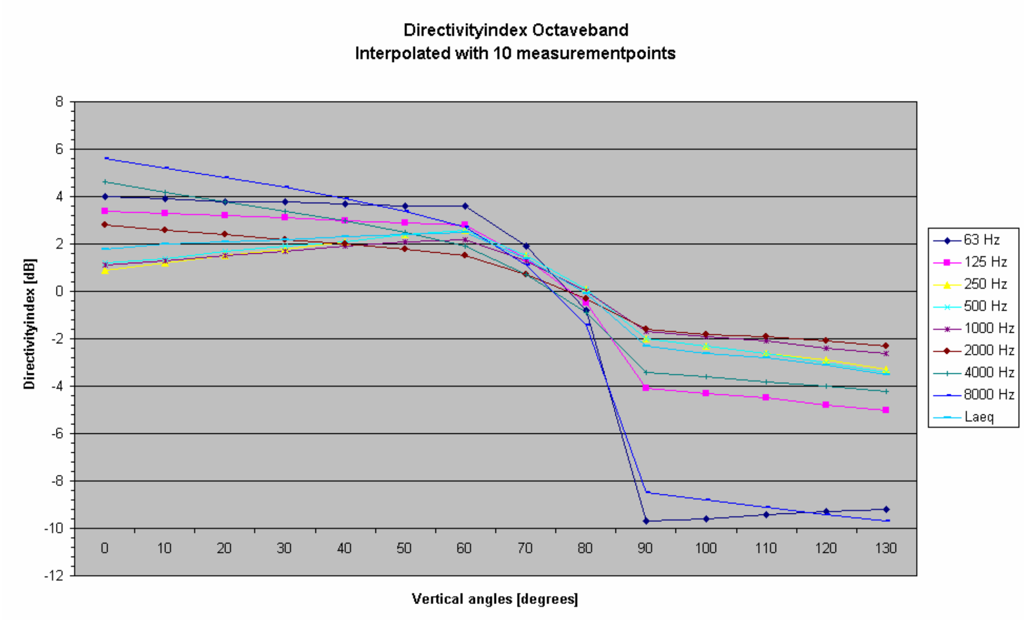


Figure 32 Source 7: High source, large radius. Directivity index plotted over vertical angles.

7.2 Results from analysis

The results from the analysis are based on levels calculated for receiver placement in the modeled environment created in SoundPLAN® (see chapter 6.4). Grid maps have also been calculated for one source to visualize the differences (see chapter 8.2.2, figure 40 to figure 43). The results displayed below (see figure 33) are calculated for the modeled environment. Since the differences in sound power level between the modified method, DIN 45635-47 [2] and the consultants method is insignificant they will generate equivalent differences in sound pressure level at the specified points of perception, there is no need for comparison between these methods in the analysis. The interesting comparison is the one between the different definitions (see chapter 6.4.1).

The result from the SoundPLAN® calculations are plotted for the receivers placed at a distance of 100 and 400 meters for 3 different heights, 2, 10 and 20 meters. The left set of bars shows the profit (in dB) in defining a source with or without directivity. The set of bars in the center shows the profits (in dB) with a redirection of the source. The set of bars on the right shows the profits (in dB) in a 180˚ redirection of a source that is already directed in the horizontal plane. Further, if the left and center sets of bars are added to each other, the differences between the definition of the source without directivity and the definition with the source with directivity, tilted 90˚, are retrieved.

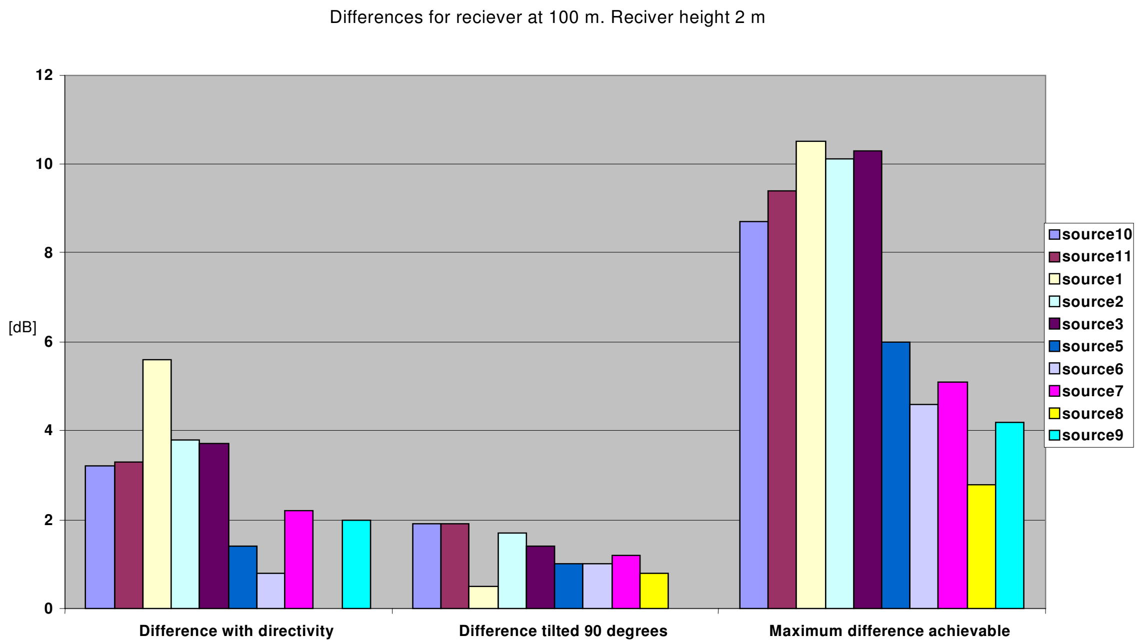


Figure 33 dB lower levels at receiver with different source definitions. Source height = 10m. Receiver height = 2m. Distance to receiver =100m.

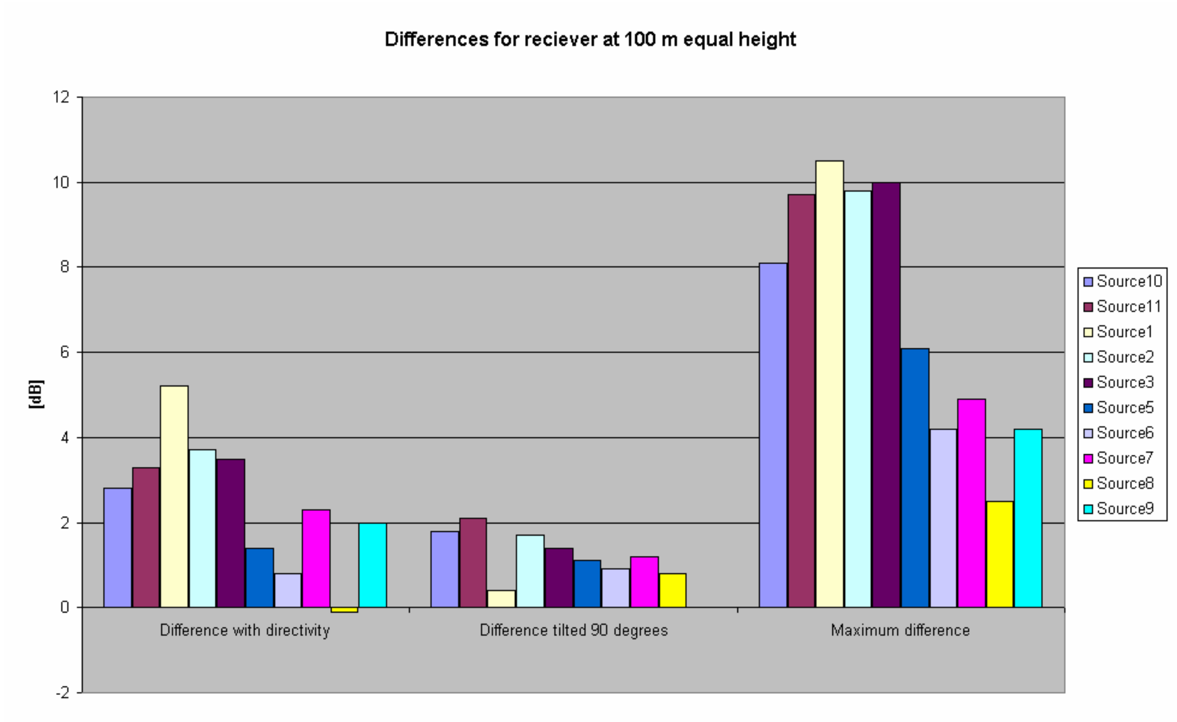


Figure 34 dB lower levels at receiver with different source definitions. Source height = 10m. Receiver height = 10m. Distance to receiver = 100m.

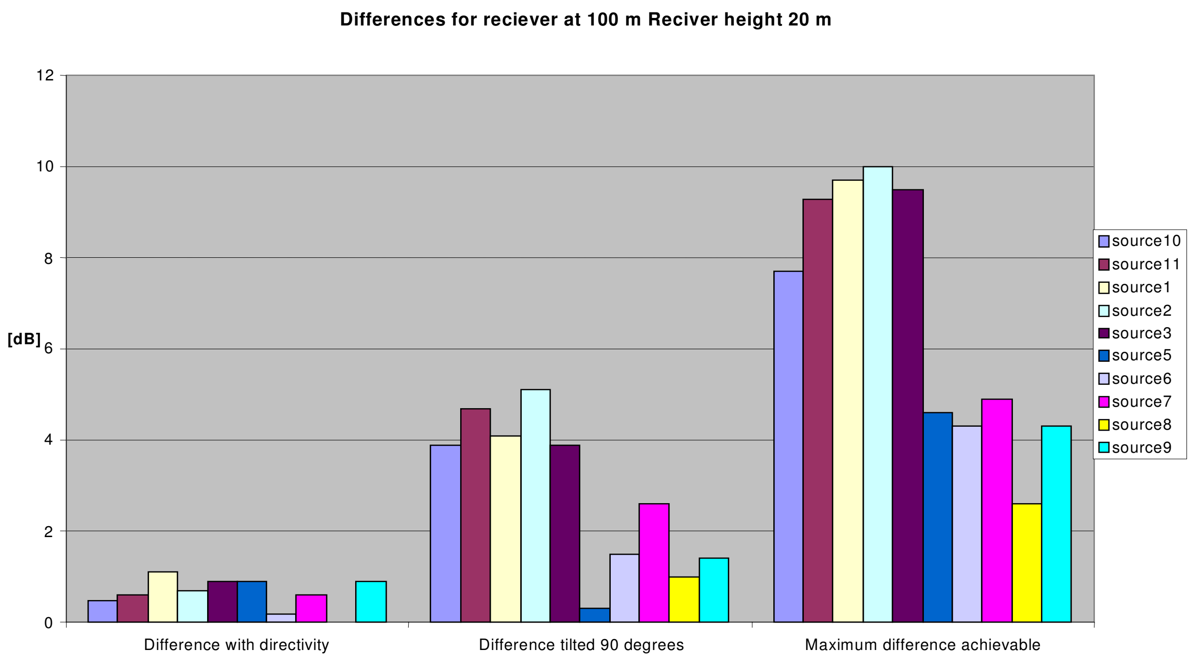


Figure 35 dB lower levels at receiver with different source definitions. Source height = 10m. Receiver height = 20m. Distance to receiver = 100m.

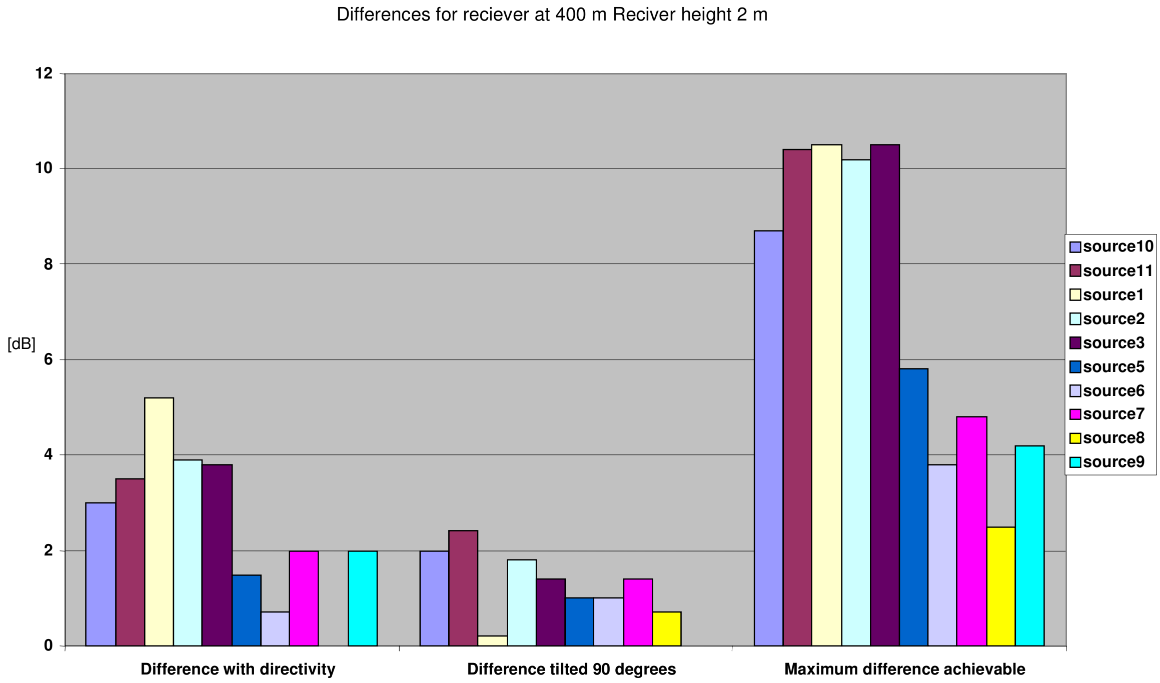


Figure 36 dB lower levels at receiver with different source definitions. Source height = 10m. Receiver height = 2m. Distance to receiver = 400m.

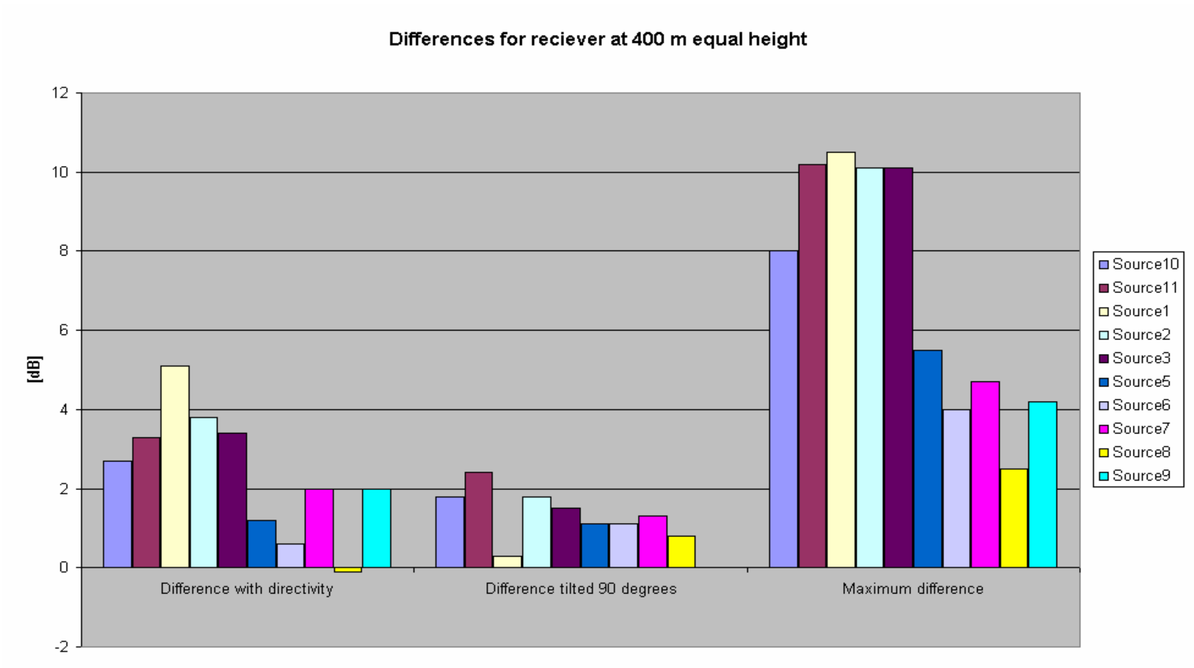


Figure 37 dB lower levels at receiver with different source definitions. Source height = 10m. Receiver height = 10m. Distance to receiver = 400m

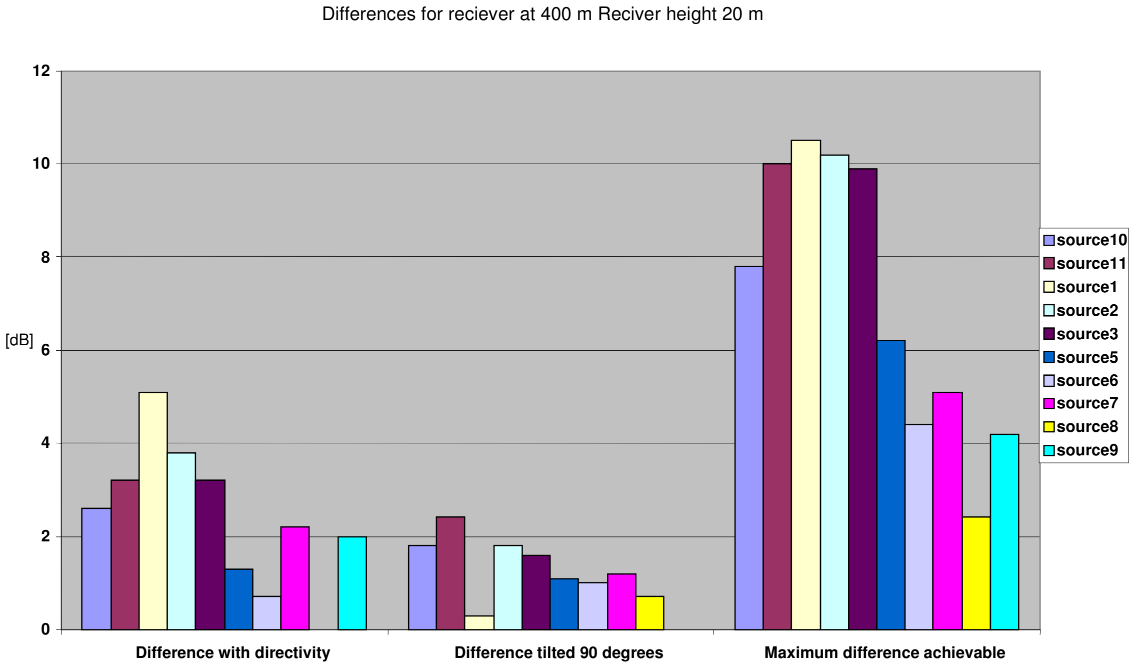


Figure 38 dB lower levels at receiver with different source definitions. Source height = 10m. Receiver height = 20m. Distance to receiver = 400m.

Example of contribution spectra for receiving point; Distance = 100m, height = 2m.

Source no.	63Hz	125Hz	250Hz	500Hz	1000Hz	2000Hz	4000Hz	8000Hz
1	15,5	15,5	23,7	30,7	34,7	31,2	24,6	1,1
2	16,1	19,3	18,8	18,5	20	17,7	16,3	-6,4
3	0,8	10	18,1	16	15,5	12,2	2,3	-13,8
4	5,7	10,5	17,2	17,7	18,8	14,8	8,2	-8,4
5	-1	10,4	14,1	13,8	14,3	10,9	2,6	-21,4
6	-0,7	8,6	13,1	12,8	14,1	7,9	0,9	-22,5
7	-0,6	9,3	14,7	14	12,9	8	5,7	-23,2
8	-3,9	4,7	8,3	11,1	11,8	8,3	1,8	-21,4
9	1,7	12,8	18,2	19,5	22,1	17,2	14,1	-4,7
10	0,9	11,3	21,7	19,5	19,4	11,3	6,4	-11,7
11	2	11,9	19,5	20,7	20,7	21,8	11,8	-11,1

Table 6 Distribution of source contribution to sound spectrum.

8 Discussion

The discussion concerns both the measurement part and the analysis made in SoundPLAN® for the selected sources. It illustrates and explains the difficulties associated with the different issues dealt with throughout the course of this project.

8.1 Measurement results

8.1.1 Determination of sound power levels

The determinations of sound power levels made in this thesis, for our sources, shows a great resemblance between the modified method and the method described in DIN 45635-47 [2] when high sources are considered, both when comparisons between the actual measured values are made and for the interpolated values. The differences are within reasonable limits (2-3 dB), thereby giving our measurement method justification since the DIN 45635-47 [2] standard offers a reliable method and the results from the use of this standard gives a good approximation of what the actual sound power level of the source should be. One cannot with certainty control the different technical aspects of the source and that is why differences in the range of 2-3 dB cannot conclusively be explained by differences between measurement methods, one has to take possible variations or changes in the operation of the source into account as well. DIN 45635-47 [2] only ensures a certainty of 4 dB in the results while the ISO 3744-2 [1] standard ensures a precision of 1 dB. One realizes however that this precision is hardly attainable under real outdoor circumstances; with regards to wind, operation variations of the sources and variations in background noise levels. All prerequisites of the method are seldom fulfilled.

For the cases where additional measurements have been made on a source, using the consultants method, the resulting differences in sound power levels between that method and ours are greater than for sound power levels calculated from the interpolated values. The reason is that, for some sources, our device is not capable of measurements in the point at which the measurement should be performed according to the consultants method. For these sources, measurements in that particular point were made using only a handheld mast and at 5 meters height, precision is hard to achieve with such equipment. There were also additional insecurities during the calculations of the sound power levels. For instance; a spherical or a half-spherical surface contributes differently to the results. Also, because of the fact that the distance to the edge of the source was assumed to be 1 meter, the error will become smaller for a small measurement radius than for a large in comparison with ISO 3744-2 [1] which assumes the distance to the center of the source instead (in our case, at the peripheral center of the outlet).

These arguments are not to be interpreted as if the consultants today are mistaken in using their practical methods. The fact is that they are very thorough when performing measurements; testing, making corrections, appreciating different variables and measuring in surrounding points in order to confirm their results. This process is of course based on individual experience, which takes time to develop; therefore it also shows that one with this practical method can make mistakes if one is inexperienced.

For low sources, DIN 45635-47 [2] is not applicable because the supposed lower half sphere, described in the standard, cannot enclose the source and therefore it has not been used for measurements on such sources in this thesis. The differences between the modified method and the consultants method are however quite similar to the differences seen for high sources.

There were two low sources measured with a large measurement radius during the course of this project. They showed larger differences, same behavior as for higher sources with larger measurement radius. Another problem with this type of source was that a substantial part of the emitted noise came from the source structure itself (e.g. vibrating walls) and not only from the outlet. The sides of the construction were often vibrating strongly and therefore had an influence on the sound pressure levels measured at the lower set of measurement points, thereby raising the total sound power level. The point at which the sound pressure level is measured according to the consultants method is located above the source and is thereby not affected to the same degree as the lower measurement points; it is mainly affected by the noise generated by the air coming through the outlet. For sources with small radius the conformity is very good. The selection of correction factor is obvious for these lower sources (one meter distance = 8 dB for a half sphere) since they are placed closely to the roof and a half sphere is chosen due to the presence of only one reflecting plane.

8.1.2 Determination of directivity

Interpretable from the plots in chapter 7.1.4 is the great differences between the points placed straight upward and the points placed straight sideways. The differences for the points located below 90 degrees are not that sizeable, in some cases even non-existent. At these points, the previously described effect, originating from the statement that the chimney itself is a contributing source, makes itself known (the levels at the lower set of points are in fact lower since they get a contribution from the chimney).

A correct measurement of the background noise level has not been performed, as previously mentioned (see chapter 3.3), just an appreciation of the background levels contribution ending up at approximately 15 dB lower then the measured sound pressured levels around the source. Since one does not now exactly what the background level contribution is, it is possible that the points located on the lower half sphere need to be adjusted according to ISO 3744-2 [1]. But because there is no foundation for such calculations, there has not been any performed. These corrections can however be excluded since they would not lead to smaller differences and the results will remain on the safe side.

The differences in directivity between the lowest and highest measurement points are not as important as to what the lowest values for the directivity indices are. These directivity indices are in fact representing the possible benefits of a measure involving redirection of the source. The directive behavior for most sources lay in the higher octavebands; this is a typical behavior of all noise sources. For the high and wide sources in this thesis however, the directivity indices for lower octavebands also show directive behavior. This can to some extent be explained as effects from the near distance to the source for lower angles. On the other hand, however, the shortest permissible distances between the sources and the measurement surfaces are 0,25 m for a rectangular surface, according to ISO 3744-2 [1]. A larger measurement radius could maybe have been used to avoid this problem but the size of the measurement radius is dependent on other factors (see chapter 5). When one however calculates the total A-weighted sound pressure level, the 250 Hz, 500 Hz and the 1000 Hz octavebands will be dominating and therefore these errors will not influence the final sound pressure levels at the receiving points.

8.1.3 Sources which were not selected for further analysis

Among the eighteen sources measured during the course of this project, only eleven were selected for further analysis in SoundPLAN®. The rejected sources are believed to not represent the true source-bound directivity. All low sources have been discarded because we believe that the measurements performed on these, with the modified method, are not representative for the source type. In these cases, the measurements have been complicated by the influence of ground reflections, background noise levels and the influence from the vicinity to surrounding objects. The measurement results from these measurements are however displayed in Appendix 1 because they are nevertheless a part of the measurement results. The calculation of the radiated sound power levels from these sources can be regarded as correct by the consideration that the calculation method was adapted to the ISO 3744-2 [1] standard. Unfortunately, they do not fulfill our objectives, which are to view the sources peripheral outlet as a separate source. For example, the sources situated at Klippan AB have all been rejected based on the type of sources and the amount of other sources in the vicinity of these.

8.2 Calculations in SoundPLAN®

8.2.1 Differences between source definitions, with and without consideration of directivity

For all sources one can clearly see the differences between defining a source with or without its directive properties. When the directivity is not considered, the sound pressure levels at the points of perception will be the same for a given distance independent of position in the vertical and horizontal planes when the terrain is uniform in all directions. This fact is obvious but also equally wrong since the source has been measured differently for different directions; there have to be differences depending on the direction in which the points of perception are located. The dominating octavebands for the total A-weighted sound pressure level at the distances used in this analysis is 250 Hz, 500 Hz and 1000 Hz. At these frequencies, clear directive behavior is shown which also is presented in the results. At these frequencies; the dubiousness of which was discussed in the previous segment about the behavior at the lower octavebands, is not present. If the source is elevated, SoundPLAN® will use the directivity value for a lower angle than before and the difference between the source definitions with or without directivity would be greater because a lower value for the directivity is used to describe the sound power level contributing to the points of perception. If the case would be contrary, a lowering of the source (a valley for instance), the differences would diminish. The directivity in this direction would be smaller and thereby agree with the radiated sound power level from the source without consideration of directivity. But in the latter case, the benefits from merely re-directing the source, as a measure for noise reduction would increase and it is therefore important to acknowledge the directivity.

8.2.2 Benefits of a redirection of the source?

The differences in directivity between the direction with the highest sound radiation and the direction with the lowest sound radiation are around 10 dB for the measured sources at most. The difference between the 90° and 180° is only 1 to 2 dB for our sources but in reality this would be greater. This due to the fact that the levels at the points, which could not be measured, located below 130°, are set equal to the levels representing the points at 130°. These levels are probably a little higher than necessary for the lower set of points but this is acceptable due to the risk of receiving too large differences otherwise and thereby achieving too optimistic results. It is reasonable however to calculate with a reduction of the sound pressure of a couple dB's for these points. The results will be better for every reduction in decibels obtainable under the level measured at 130 degrees, which is the lowest measurable point on the sphere. If the source on the other hand already is directed in a direction leading to high sound pressure levels at a reception point, an alteration by 180 degrees will lead to very large differences. These differences are not considered to current standards, they are however obvious for acousticians working continuously in the field. The sources measured within this thesis are selected for their suitability of making measurements on (with the modified method), in order to investigate the need for making measurements with consideration of directivity. Then there are other types of sources, such as: openings, differently shaped air intakes and outlets etc, where a description of the directivity probably is even more important.

Two examples of directed sources are shown below, figure 38 and figure 39.

Figure 39 Directed source

Figure 40 Directed sources

For the purpose of making calculations of the sound pressure levels at the receiver points from the sound power level radiated from existing sources, it is of course enough to measure so that the results will show a correct sound power level, representative for the direction of interest. But if calculations regarding possible measures are to be made, knowledge of the directive properties of the sources is essential. Maybe, the only thing worth knowing in this matter is the direction in which the directivity is as low as possible? Measuring in accordance with standards is not as important as measuring in the positions giving the correct input values for later calculations.

From another point of view, the average orderer of ENASI is probably not interested as to how these are performed or if a certain strict scientific method has been used during the making of them. The orderer is probably more interested in the validity and reliability of the results, and if necessary, advice about the cheapest possible measures which would insure him/her that the industry which he/she represents would fulfill the requirements set upon it by the government. A standardized measurement method, such as ISO 3744-2 [1] in this case, would take a lot of time and money to implement and still not be more accurate than measurements based on the practical method used by consultants today. The consideration of source characteristics and location of receiving points taken today, while measurements of industrial noise are being performed, is an abbreviation of the standardized methods but nevertheless correct according to ISO 3744-2 [1]. It does not however give an entirely correct description of the sound power from the source; it is only valid for calculations for receiving points located in the direction the measurement was made. A step in the right direction in order to get a more detailed description of the source would be to standardize the consideration of the directive behavior (as well as the true sound power level) of the source, since this information is needed as input data for later calculations and also for the possibility of taking measures for noise reduction such as the ones mentioned in the introduction.

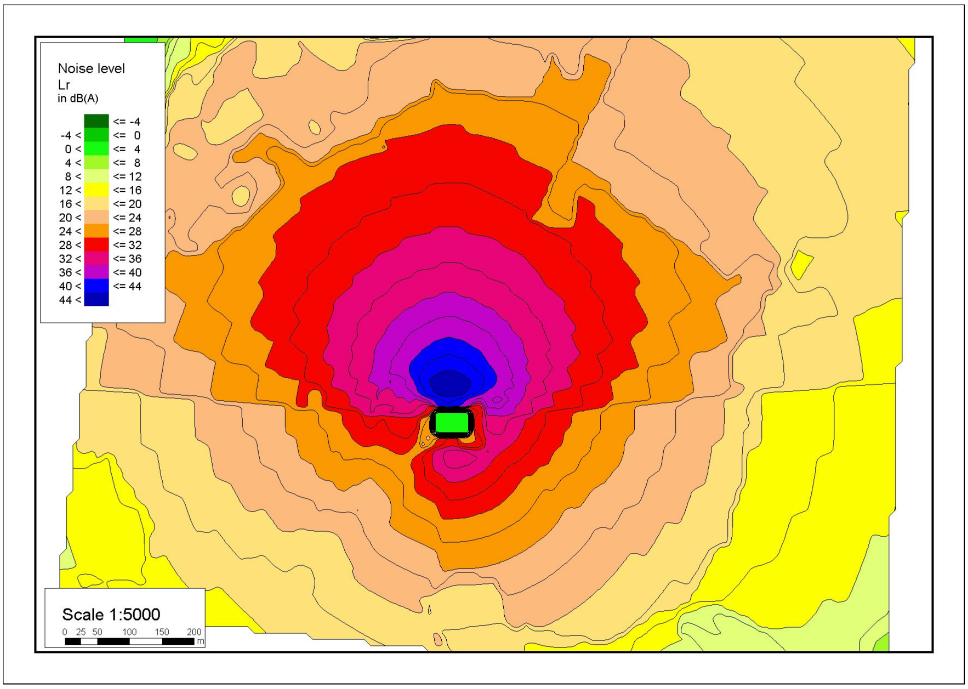


Figure 41 Source 2: tilted 90 degrees.

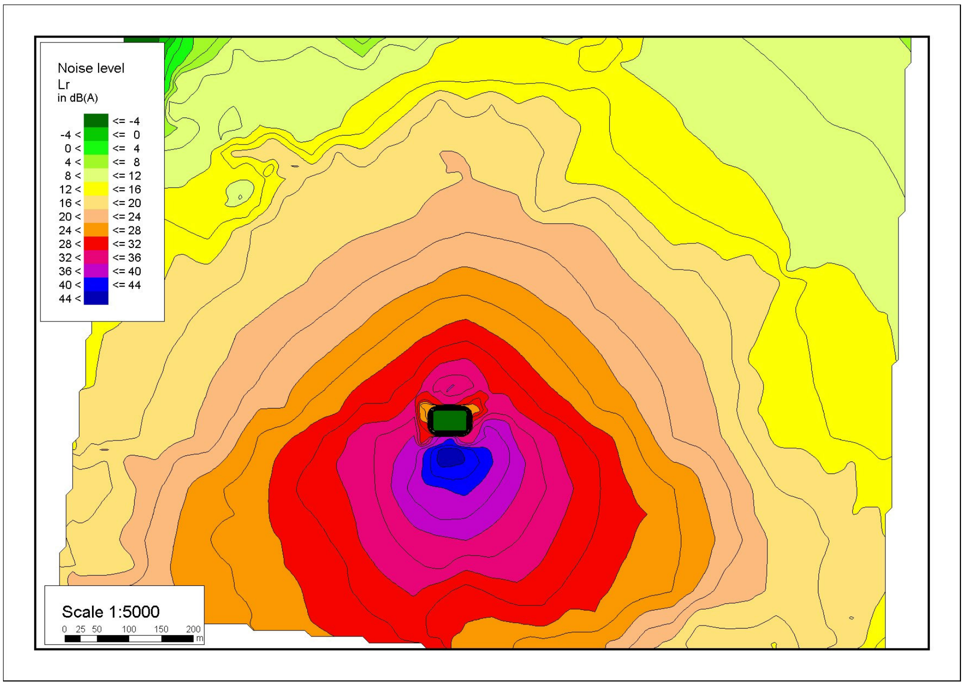


Figure 42 Source 2: tilted -90 degrees.

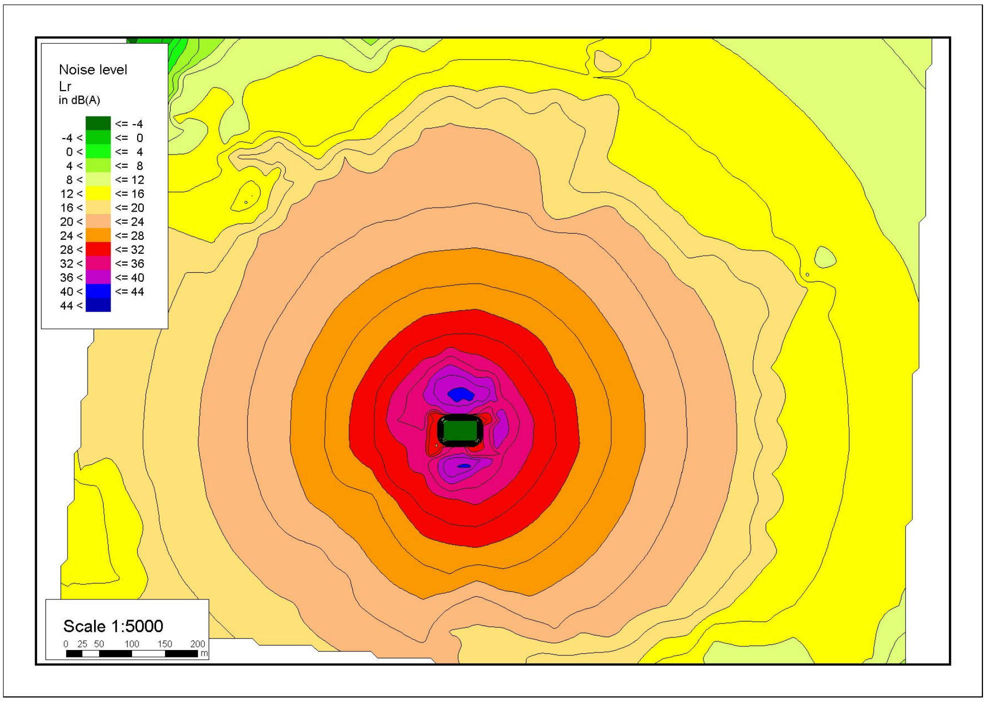


Figure 43 Source 2: Directed straight up. with directivity

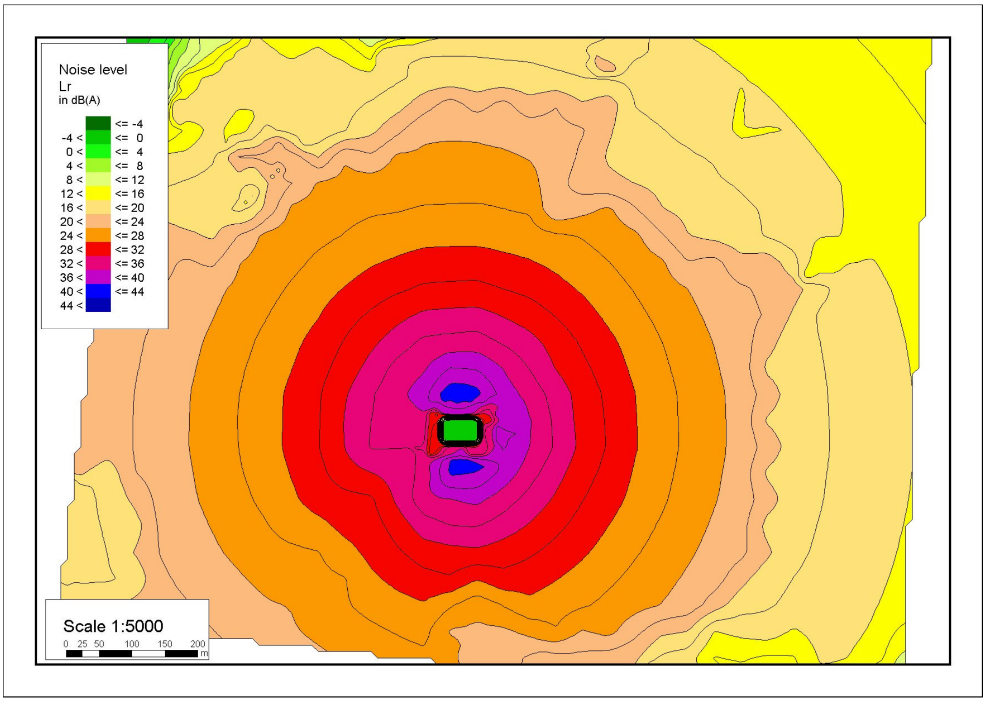


Figure 44 Source 2: Directed straight up. without directivity

8.3 Problems with standardized measurements in real life

During the process of investigating the benefits of using the directivity whilst determining the sound power levels for external industrial noise sources, other problems occurred, which had to be dealt with first, in order for us to continue with the principal investigation. These problems arise from the previously stated fact that ISO 3744-2 [1] is not sufficiently adapted to reality, in terms of the conditions of the surroundings and implementation times etc. The fact is that the measurements are performed on roofs in an environment where the accessibility often is limited with poor surface conditions (slippery etc), narrow ledges and stairs in combination with dangerous heights, makes simplifications and circumvention's necessary. In some cases it is even impossible to reach the source and for certain extreme cases, the person performing the measurement has to wear protective clothing in order to be near a source.

8.3.1 Background noise measurements

According to ISO 3744-2 [1], the background noise level should be measured at each measurement point with the source shut off, which of course is not practically possible under most circumstances. In order to avoid problems with the background noise levels while measurements were performed during the course of this project, mainly sources with high sound power levels have been chosen, thereby making the contribution from the background noise level to the measurement points minimal. At the same time, a small measurement radius had to be used where a larger radius would contribute to an increase in distance between the source and the measurement points and therefore an increase of the influence from nearby sources (which are almost always present on the roof of an industry). On the other hand, for points located at the lowest vertical angle, this reasoning is difficult to substantiate since the contribution from nearby sources to these points will be greater than for the rest of the points on the sphere. However, for our case, we are only interested in the differences in sound pressure levels. And as long as these differences are on the safe side, they can be used. During real investigations it is of course of the utmost importance to make correct estimations of the background noise level and therefore alternative methods have to be used. The consultants today are using these methods and they are correct (congruence between the calculated values and control measurements in the receiving points), but not always in accordance with current standards. Why is the standards not designed to consider real life surroundings and plausibility?

8.3.2 Measurement positions

In theory, measuring at the correct measurement positions with high accuracy may seem easy. In practice however, it is almost impossible. Measuring in a point located five meters above ground with a margin of ± 0,1 meters using only a handheld mast is very difficult, it would demand the use of a special measurement device or rig. A reasonable margin would be approximately 0,5 meters if the wind conditions were good at the time. In our case, a device was constructed in order to increase the accuracy while measuring at these heights. According to ISO 3744-2 [1], the largest valid measurement radius is 16 meters. How should a point located 16 meters above the ground be measured with the previously described degree of accuracy?

9 Conclusions & Recommendations

(Firstly, we would like to state that we believe that the objectives for this project have been reached). The results from measurements and analysis clearly show that the use of Appendix E in ISO 3744-2 [1] with the modified method has noticeable effects on the results; sizeable enough to not be discarded. It has been shown that for the measured sources, a 10 dB difference could be achieved only by using this consideration.

Even if one, using simplified measurement methods, can perform measurements in suitable directions and thereby circumventing the current standardized methods and still end up with a sound pressure level which is valid for the receiving points, one still does not have a sufficient description of the source, necessary for source alteration measures.

Concerning DIN 45635-47 [2], it has proved to be a very practical and useful standard for the types of measurement performed during this project. However, the problem with the uniform representation of the source, as for the consultants method, still remains.

Although the modified method, based on ISO 3744-2 [1], worked properly and our device proved to increase the accuracy during measurements as well as decreasing measurement time, the method is not practicable when a ENASI is to be performed and a large number of sources have to be measured under a limited period of time.

Further, one should consider the fact that the results received from our measurements are the actual results and may therefore differ from results acquired from the use of a hypothetical analytical model based on the same or similar sources. It is important to notice this fact since there would most probably be noticeable difference between the two.

The purpose of this thesis was to show the benefits of considering the directivity while determining the sound power levels from external industrial noise sources. Hopefully it will contribute to further studies within the field and plant a seed of thought among the people dealing with this subject on a daily basis.

10 Improvements and proposed further work

During the process of the thesis work, several questions and ideas have come to us. There are, as we experienced, a lot of thoughts and ideas around the subject of the thesis as well as in other related areas. Below is a list of recommendations for possible further investigations, sorted by topic and area of interest. Some of them may even be suited for other thesis works themselves.

We recommend the following topics for further investigation:

- An investigation into the possibility of making a practical method for determination of the background noise level, without turning off the source.

- A method for making precise measurements at calculated measurement positions (either a development of the modified method or design of another method), high accuracy positioning of the microphone.

- Development of a simplified measurement method for the determination and use of sound power levels with consideration to directivity. How many measurement points are necessary? etc.

- Design of a standard for simpler determination of directivity. This could be a combination of:

    1) Theoretical directivity of different types of sources e.g. chimney outlet, ventilation grid in a wall, etc.
    2) A measurement of sound pressure level in one carefully selected position.

- An investigation of how one would be able to foresee or determine the directivity from a source based on its physical properties alone. Properties such as; size, airflow velocity etc.

The work may in the future inspire to a continuation of the research into the current field of investigation. This could lead to a revised edition of the standards regarding directivity determination and possibly even an account of how one should and must treat measurement values in order to achieve a correct assessment of the directivity.

11 References

[1] ISO 3744-2, Acoustics – Determination of sound power levels of noise sources using sound pressure –Engineering method in an essentially free field over a reflecting plane (ISO 3744:1994)

[2] DIN 45635-47, Measurement of noise emitted by machines; airborne noise emission; enveloping surface method; chimneys, June 1985.

[3] ISO 9613-2, Acoustics – Attenuation of sound during propagation outdoors – Part 2: General method of calculation – (ISO 9613-2:1996)

[4] DIN 45635-1, Measurement of noise emitted by machines; Airborne noise measurement, enveloping surface method; Test report (test record) form for enveloping surface method, 1984-04.

[5] Braunstein + Berndt GmbH, SoundPLAN®, Users manual, January, 17th 2002.

Appendix 1

Measurement data and results

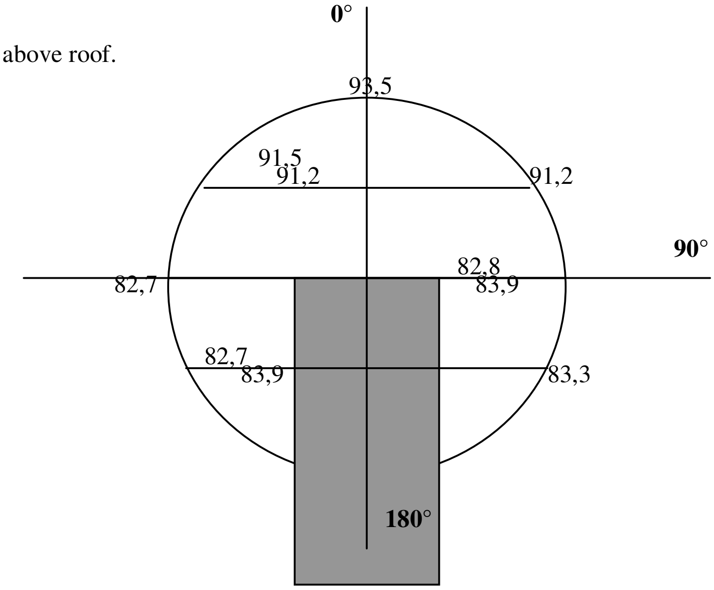
In this appendix, measurement data and results are displayed for each measured source. The measurement data is displayed in form of sheets containing a picture of the actual source, a table of the coordinates used during the measurement, a table containing measurement information and a table displaying the measured sound pressure levels in each measurement position.

The results for each source are presented in a graph and a plot. The graph contains a comparison between the different measurement methods used and sows the equivalent A-weighted sound pressure level as well as the sound power levels for each octave band. The plot shows the directivity indices for the source in octave bands interpolated from ten measurement points.

Volvo LV, Tuve 041011

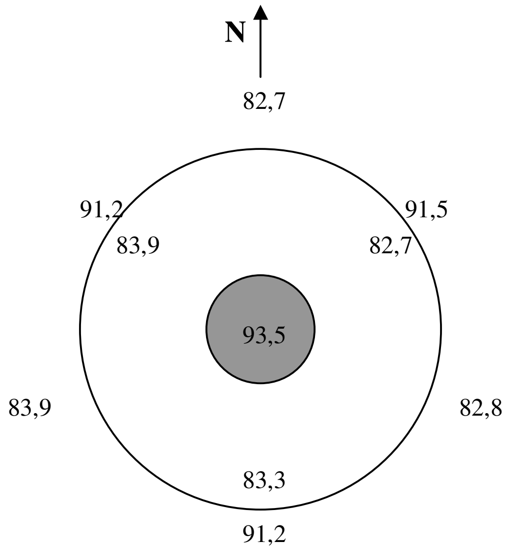
Source no; 1, Exhaust on roof of the restaurant.

Comment: Downward airflow present, fan placed above roof.



Measurement positions:

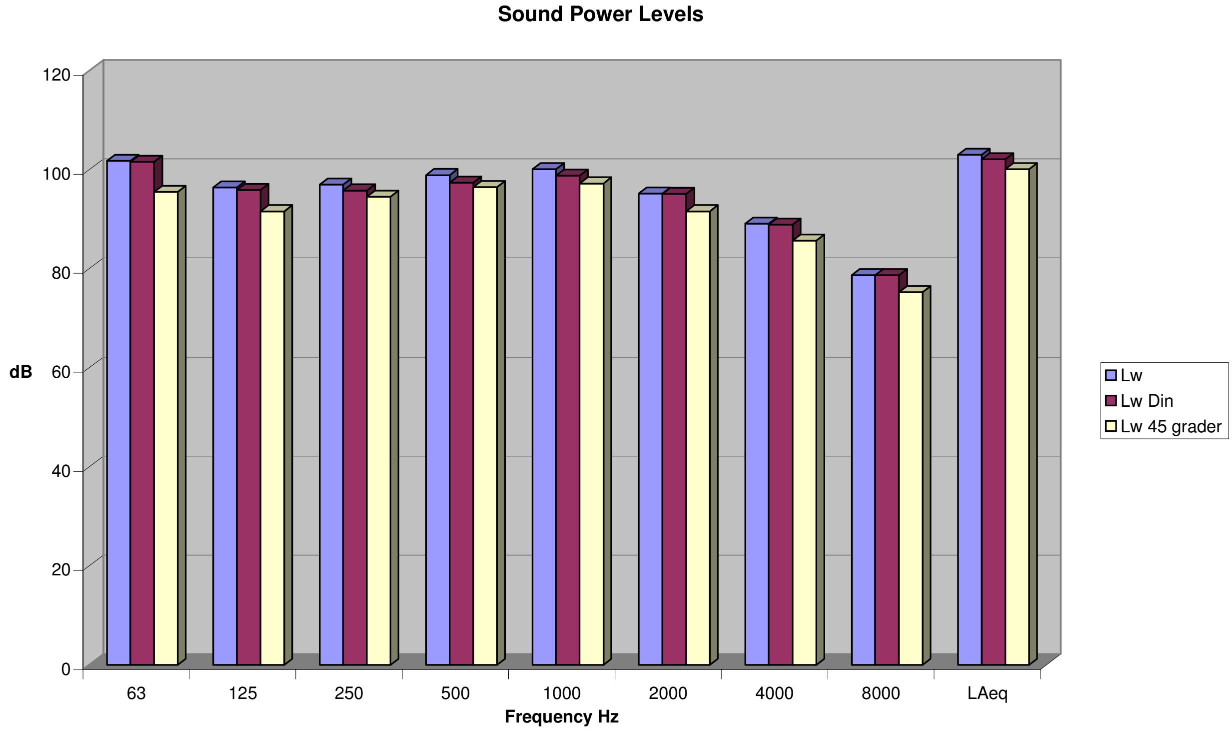
X	Y	Z	angle XY	angle Z
-1.2	0.0	-0.9	180.0	-37.0
0.6	1.0	-0.9	60.0	-37.0
0.6	-1.0	-0.9	300.0	-37.0
1.5	0.0	-0.1	0.0	-2.1
-0.7	1.3	-0.1	120.0	-2.1
-0.7	-1.3	-0.1	240.0	-2.1
-1.3	0.0	0.8	180.0	31.9
0.6	1.1	0.8	60.0	31.9
0.6	-1.1	0.8	300.0	31.9
0.0	0.0	1.5	NaN	90.0

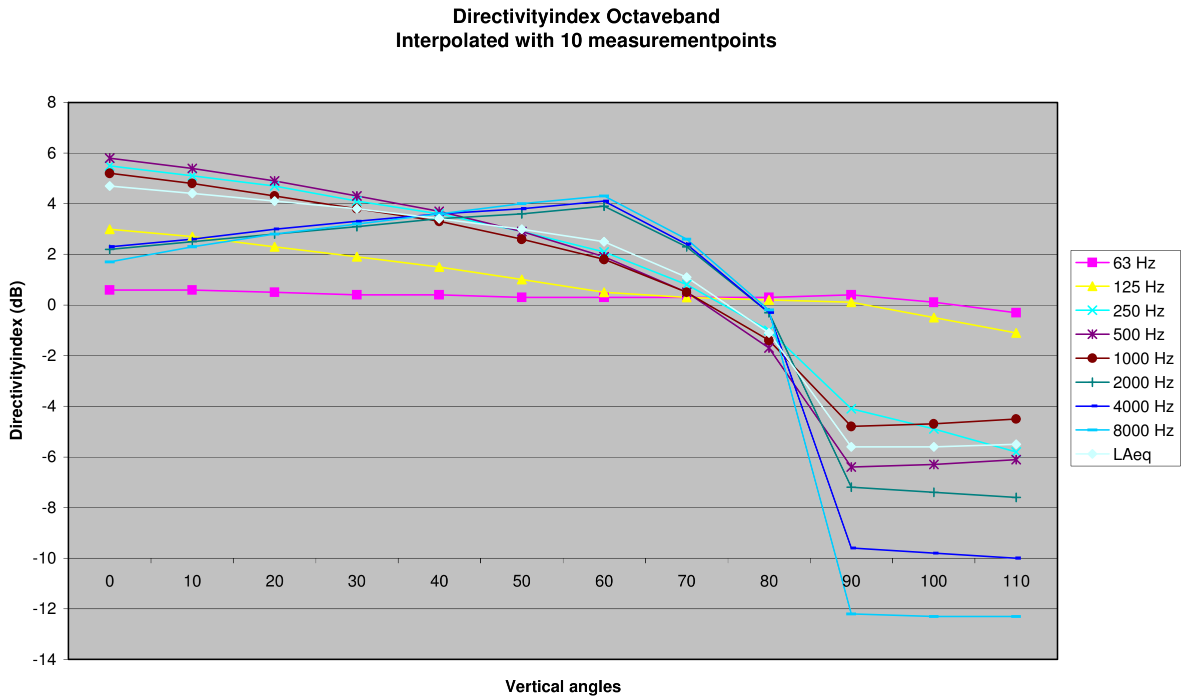


Area	26.6
Meas. radius	1.5
Source radius	0.7
Source height	5.0
No. of meas. Points, Z axis	4.0
No. of meas. Points, XY axis	3.0

Results:

Point no.	63 Hz	125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz	8 kHz	LAeq
1	86,4	80	73,1	79	81,5	72,8	64,4	51,7	83.3
2	86,3	79,5	75,2	79,1	82,3	73,3	64,7	53	83.9
3	86,8	78,6	74,5	78,2	80,9	72,4	64,2	51,3	82.7
4	87,8	81,9	78,9	77,7	80,5	73,2	64,6	51,1	82.7
5	87,8	82,4	78,1	78,9	81,8	74,6	66	53,3	83.9
6	88	82,3	78,9	78,1	80,5	73,4	64,8	52	82.8
7	87,7	82,3	82,7	86,7	87,7	84,7	78,7	68,7	91.2
8	87,7	82,8	85,2	86,2	87,6	84,7	78,9	68,7	91.2
9	87,9	82,6	86	86,9	87,6	85	79,1	69	91.5
10	88,1	85,1	88,3	90,5	91	83,1	77,1	66,2	93.5

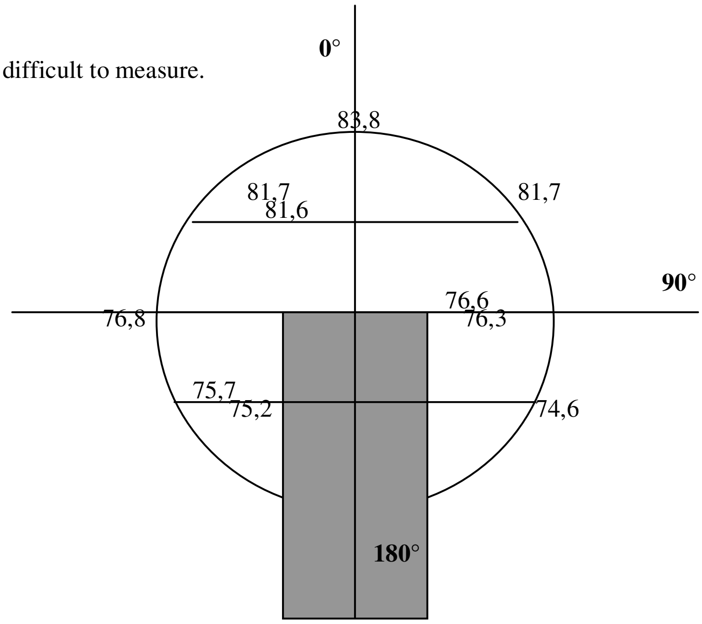

Sound Power Levels
120
100
80
60
40
20
0
dB
63
125
250
500
1000
2000
4000
8000
LAeq
Frequency Hz
Lw
Lw Din
Lw 45 grader


Directivityindex Octaveband
Interpolated with 10 measurementpoints
8
6
4
2
0
-2
-4
-6
-8
-10
-12
-14
Directivityindex (dB)
0
10
20
30
40
50
60
70
80
90
100
110
Vertical angles
63 Hz
125 Hz
250 Hz
500 Hz
1000 Hz
2000 Hz
4000 Hz
8000 Hz
LAeq

Volvo LV, Tuve 041011

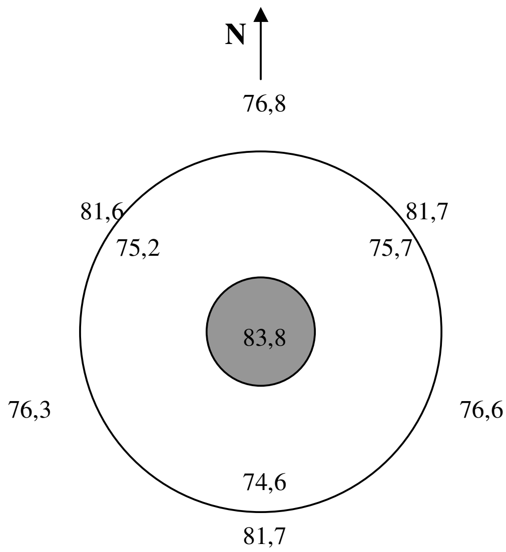
Source no; 2, Exhaust on roof of the restaurant.

Comment: Source is placed in a corner of the roof, difficult to measure.



Measurement positions:

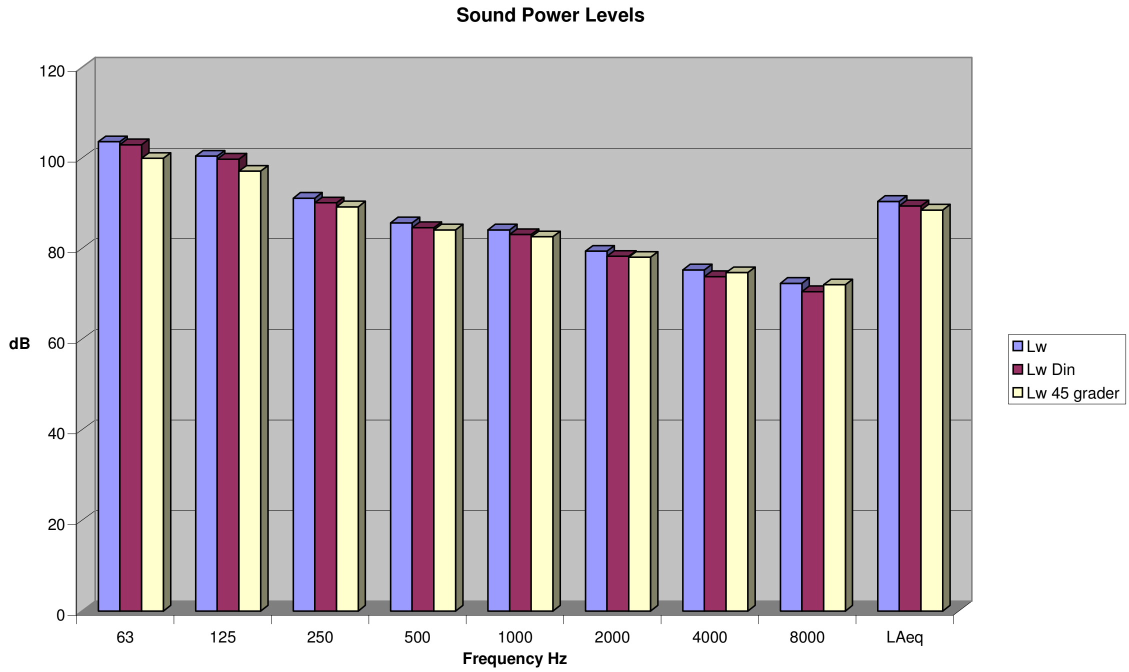
X	Y	Z	angle XY	angle Z
-0.8	0.0	-0.6	180.0	-39.0
0.4	0.7	-0.6	60.0	-39.0
0.4	-0.7	-0.6	300.0	-39.0
1.0	0.0	-0.1	0.0	-3.1
-0.5	0.9	-0.1	120.0	-3.1
-0.5	-0.9	-0.1	240.0	-3.1
-0.9	0.0	0.5	180.0	31.4
0.4	0.7	0.5	60.0	31.4
0.4	-0.7	0.5	300.0	31.4
0.0	0.0	1.0	NaN	90.0

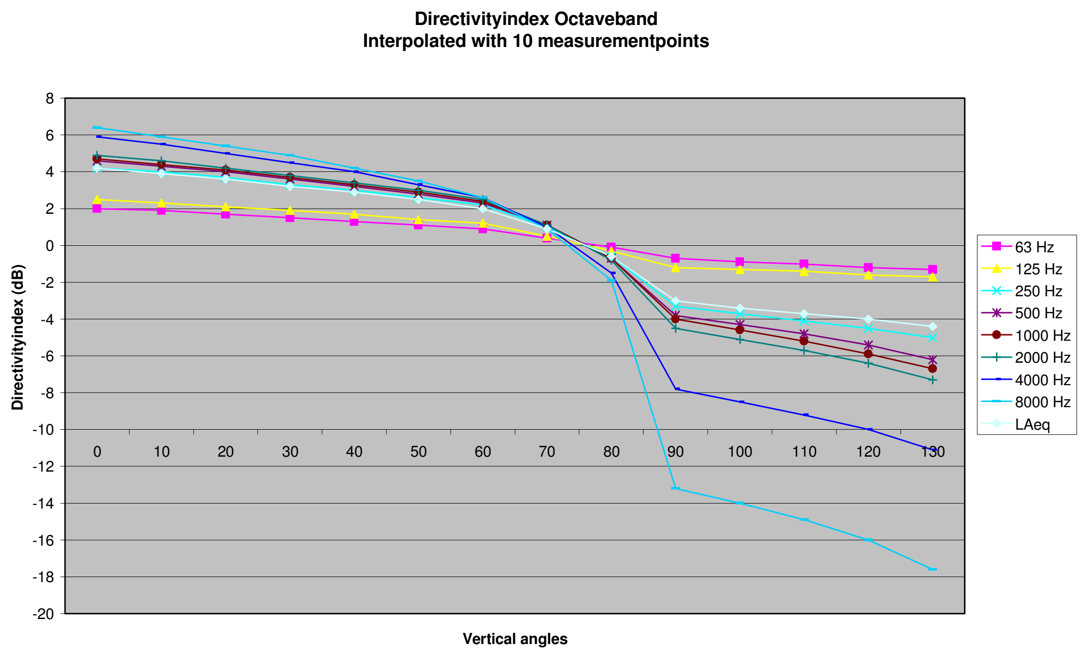


Area	12.0
Meas. radius	1.0
Source radius	0.4
Source height	5.0
No. of meas. Points, Z axis	4.0
No. of meas. Points, XY axis	3.0

Results:

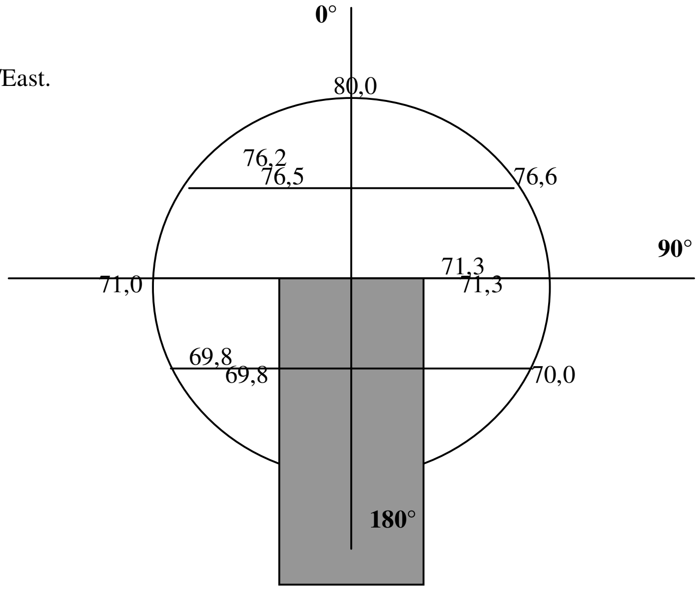
Point no.	63 Hz	125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz	8 kHz	LAeq
1	90,9	87,7	74,9	68,4	65	59,5	51,5	43,8	74.6
2	91,2	87,7	75,7	68,5	67,1	61,6	53,4	43,5	75.2
3	92,1	88,4	75,1	69,1	67,4	62,5	54,7	44,5	75.7
4	92,2	88,4	76,9	71,3	70,1	64,3	56,7	47,7	76.8
5	91,5	88,1	76,9	70,5	69,1	63,9	56,9	49,7	76.3
6	92,3	88,6	77,1	71,4	68,5	64,1	56,4	47,1	76.6
7	94,1	91,1	82,4	77,2	75,7	70,9	66,9	64,1	81.7
8	93,5	90,7	82,5	76,8	75,7	71,1	67	64	81.6
9	93,2	90,5	82,5	77,5	75,8	71,3	67,3	64,3	81.7
10	94,8	92,1	84,5	79,5	78	73,5	70,4	67,9	83.8


Sound Power Levels
120
100
80
dB 60
40
20
0
63
125
250
500
1000
2000
4000
8000
LAeq
Frequency Hz
Lw
Lw Din
Lw 45 grader


Directivityindex Octaveband
Interpolated with 10 measurementpoints
Directivityindex (dB)
8
6
4
2
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
10
20
30
40
50
60
70
80
90
100
110
120
130
Vertical angles
63 Hz
125 Hz
250 Hz
500 Hz
1000 Hz
2000 Hz
4000 Hz
8000 Hz
LAeq

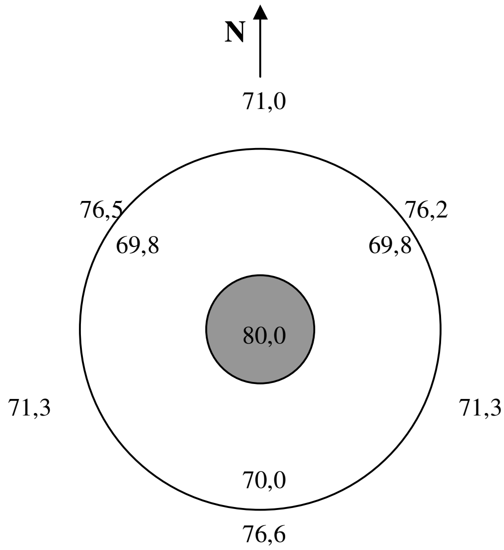
Volvo LV, Tuve 041011
Source no; 3, Exhaust on roof LA.

Comment: Nearby sources are located in the South/East.



Measurement positions:

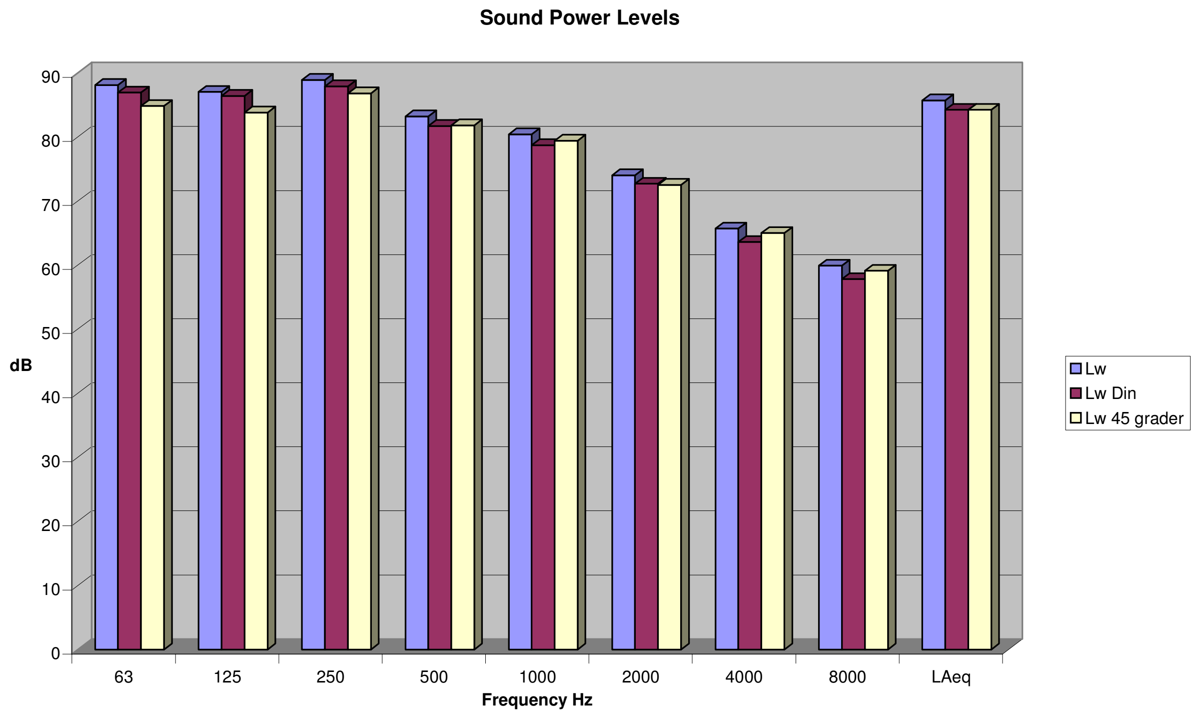
X	Y	Z	angle XY	angle Z
-0.8	0.0	-0.7	180.0	-41.4
0.4	0.6	-0.7	60.0	-41.4
0.4	-0.6	-0.7	300.0	-41.4
1.0	0.0	-0.1	0.0	-4.3
-0.5	0.9	-0.1	120.0	-4.3
-0.5	-0.9	-0.1	240.0	-4.3
-0.9	0.0	0.5	180.0	30.8
0.4	0.7	0.5	60.0	30.8
0.4	-0.7	0.5	300.0	30.8
0.0	0.0	1.0	NaN	90.0

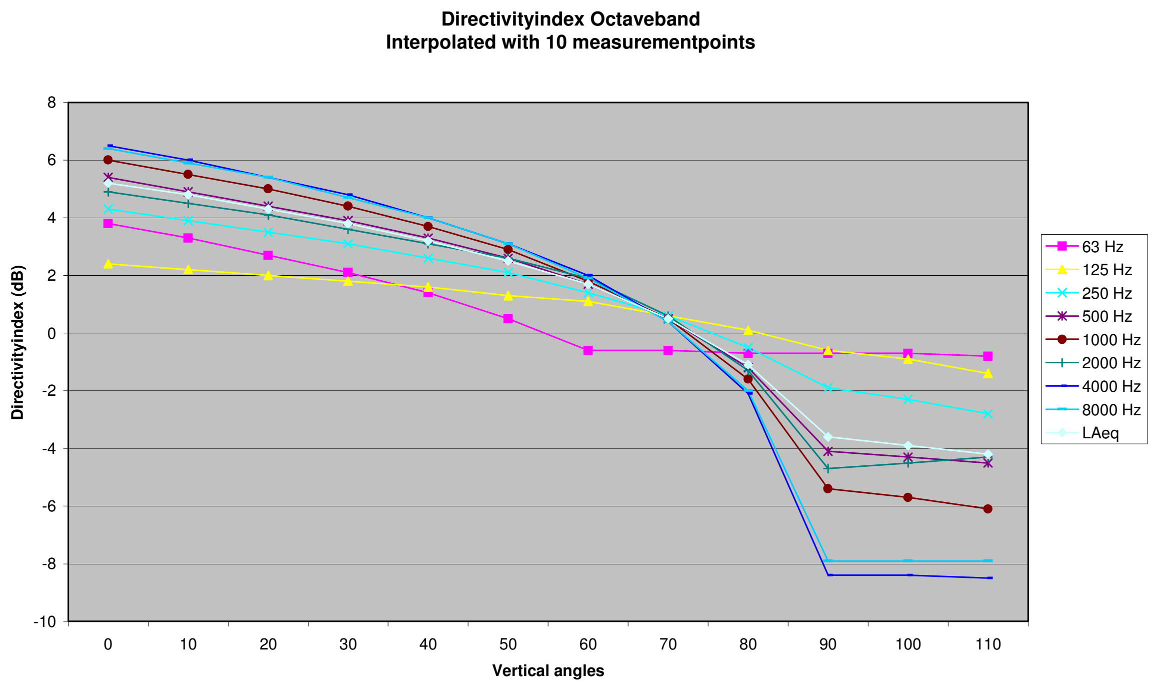


Area	12.3
Meas. radius	1.0
Source radius	0.3
Source height	5.0
No. of meas. Points, Z axis	4.0
No. of meas. Points, XY axis	3.0

Results:

Point no.	63 Hz	125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz	8 kHz	LAeq
1	76,7	73,8	74,1	67,6	62,9	59,4	46,2	41,1	70.0
2	76,2	73,2	73,9	67,4	62,7	59,7	46,2	41,2	69.8
3	76,1	74,2	74,3	67,2	62,5	58,6	46,5	41,1	69.8
4	76,4	75,2	75,9	68	63,8	58,4	46,3	41,1	71.0
5	76,7	75,5	76,3	68,3	64,1	58,8	46,6	41,1	71.3
6	76,6	75,8	76,1	68,5	64,4	58	46,4	41,1	71.3
7	77,1	77,3	79,5	73,9	71,7	65,6	57,4	51,3	76.6
8	76,3	77	79,5	74,5	71,1	65,1	56,6	50,8	76.5
9	76,3	77,2	79,4	73,7	71,3	64,4	56,4	50,6	76.2
10	81	78,5	82,3	77,7	75,5	68	61,3	55,4	80.0


Sound Power Levels
90
80
70
60
50
40
30
20
10
0
dB
63
125
250
500
1000
2000
4000
8000
LAeq
Frequency Hz
Lw
Lw Din
Lw 45 grader


Directivityindex Octaveband
Interpolated with 10 measurementpoints
8
6
4
2
0
-2
-4
-6
-8
-10
Directivityindex (dB)
0
10
20
30
40
50
60
70
80
90
100
110
Vertical angles
63 Hz
125 Hz
250 Hz
500 Hz
1000 Hz
2000 Hz
4000 Hz
8000 Hz
LAeq

Volvo LV, Tuve 040929
Source no; 4, Exhaust on roof LB.

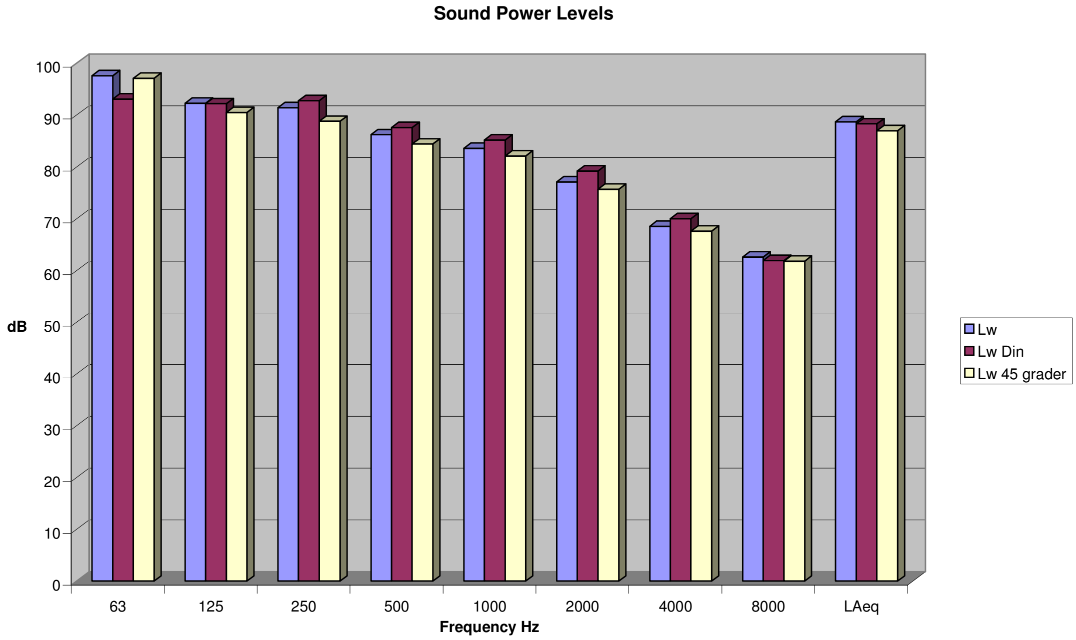
Measurement method: Projection of the measurement points onto the ground (roof), test with 16 points.

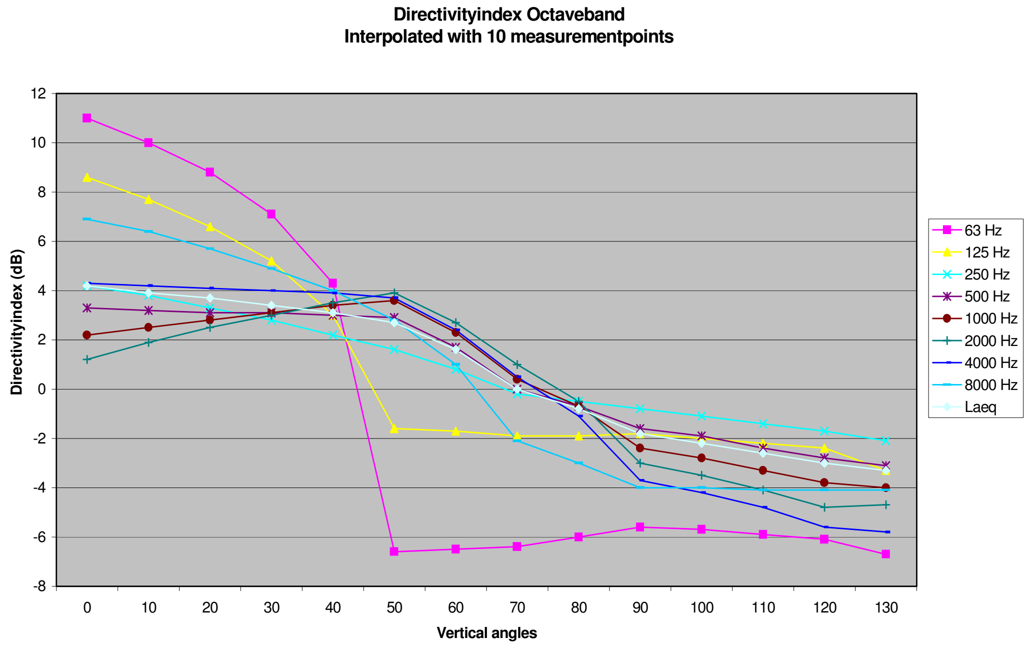
Measurement positions:

X	Y	Z
-1.2	0.0	1.9
0.6	1.0	1.9
0.6	-1.0	1.9
1.8	0.0	2.6
-0.9	1.6	2.6
-0.9	-1.6	2.6
-2.0	0.0	3.4
1.0	1.7	3.4
1.0	-1.7	3.4
1.9	0.0	4.1
-0.9	1.6	4.1
-0.9	-1.6	4.1
-1.4	0.0	4.9
0.7	1.3	4.9
0.7	-1.3	4.9
0.0	0.0	5.5

Results:

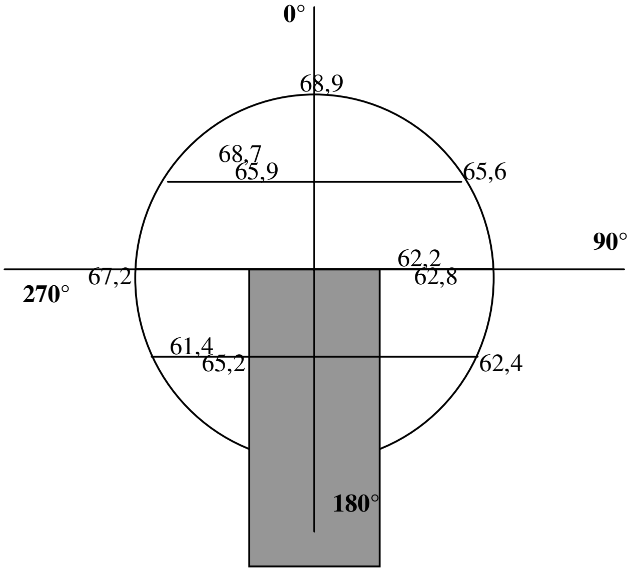
Point no.	63 Hz	125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz	8 kHz	LAeq
1	46.5	55.1	63.2	62.5	62.1	55.9	45.5	40.4	67.9
2	46.6	53.9	62.9	61.7	62.0	56.4	46.8	40.2	67.5
3	47.5	55.5	63.9	63.1	62.8	57.3	46.6	40.2	68.6
4	48.2	56.8	64.2	63.4	62.9	56.5	47.9	40.6	68.9
5	48.1	55.0	63.4	62.6	62.3	56.2	46.0	40.3	68.0
6	48.7	58.1	64.6	63.5	63.1	56.7	46.7	40.3	69.2
7	49.2	57.8	64.9	64.6	64.0	58.0	48.6	40.6	69.9
8	48.1	56.7	64.6	63.7	63.8	57.8	48.4	40.4	69.4
9	49.1	57.7	65.4	64.9	64.8	59.0	49.4	40.4	70.4
10	48.0	57.2	66.0	66.2	67.3	62.4	53.3	42.7	72.0
11	47.4	56.6	64.8	65.1	65.7	61.3	52.1	41.6	70.7
12	48.6	58.1	66.0	66.6	67.8	63.0	53.4	42.7	72.3
13	47.8	57.6	67.2	68.8	69.9	64.9	56.2	47.3	74.2
14	46.9	56.8	66.8	68.0	69.8	64.8	55.5	46.1	73.9
15	48.6	58.5	68.0	69.7	70.8	65.7	56.9	48.2	75.1
16	65.4	67.8	70.0	69.3	68.8	62.5	56.8	51.4	75.9


Sound Power Levels
dB
100
90
80
70
60
50
40
30
20
10
0
63
125
250
500
1000
2000
4000
8000
LAeq
Frequency Hz
Lw
Lw Din
Lw 45 grader


Directivityindex Octaveband
Interpolated with 10 measurementpoints
Directivityindex (dB)
12
10
8
6
4
2
0
-2
-4
-6
-8
0
10
20
30
40
50
60
70
80
90
100
110
120
130
Vertical angles
63 Hz
125 Hz
250 Hz
500 Hz
1000 Hz
2000 Hz
4000 Hz
8000 Hz
Laeq

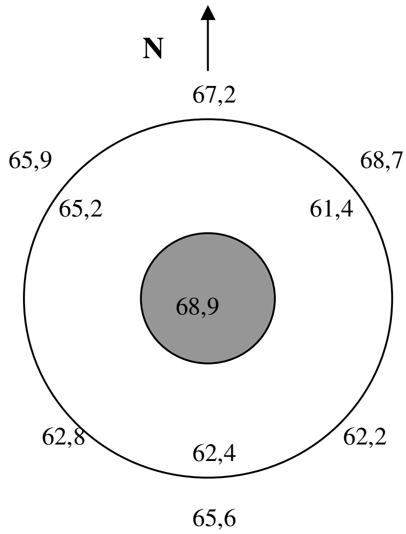
Volvo PV, Torslanda 041116
Source no; 5, Exhaust on roof, paintshop.

Comment: -



Measurement positions:

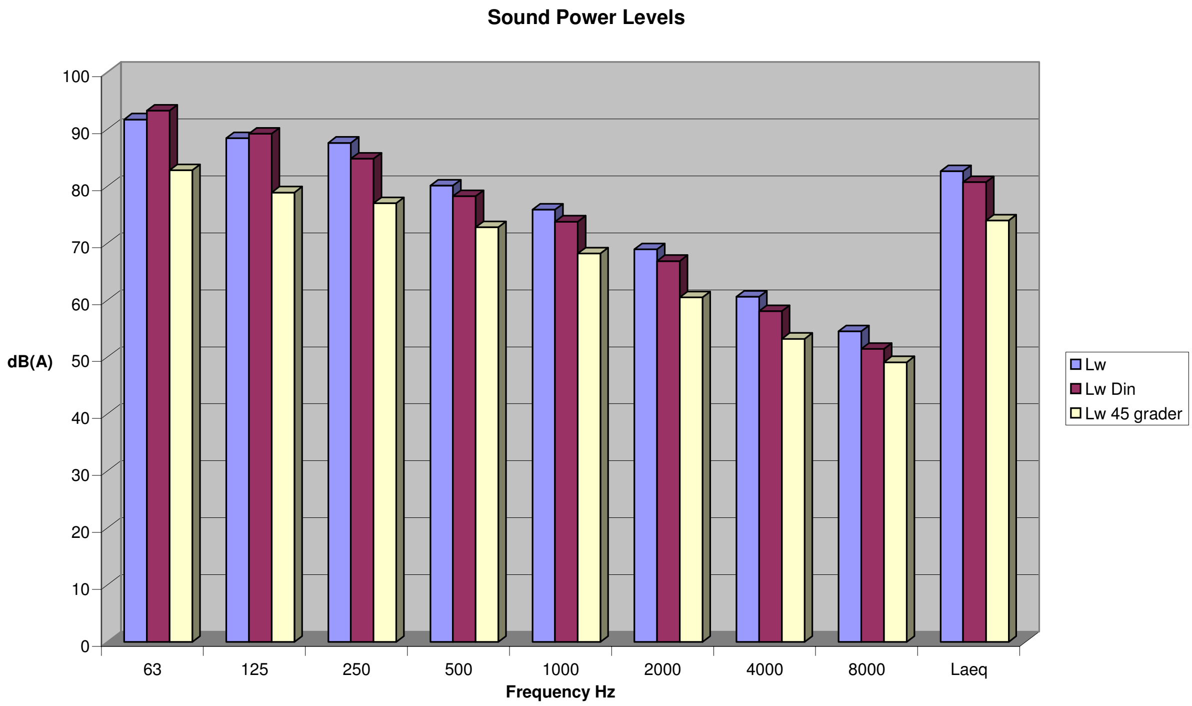
X	Y	Z	angle XY	angle Z
-1.6	0.0	-1.3	180.0	-39.0
0.8	1.3	-1.3	60.0	-39.0
0.8	-1.3	-1.3	300.0	-39.0
2.0	0.0	-0.1	0.0	-3.1
-1.0	1.7	-0.1	120.0	-3.1
-1.0	-1.7	-0.1	240.0	-3.1
-1.7	0.0	1.0	180.0	31.4
0.9	1.5	1.0	60.0	31.4
0.9	-1.5	1.0	300.0	31.4
0.0	0.0	2.0	NaN	90.0

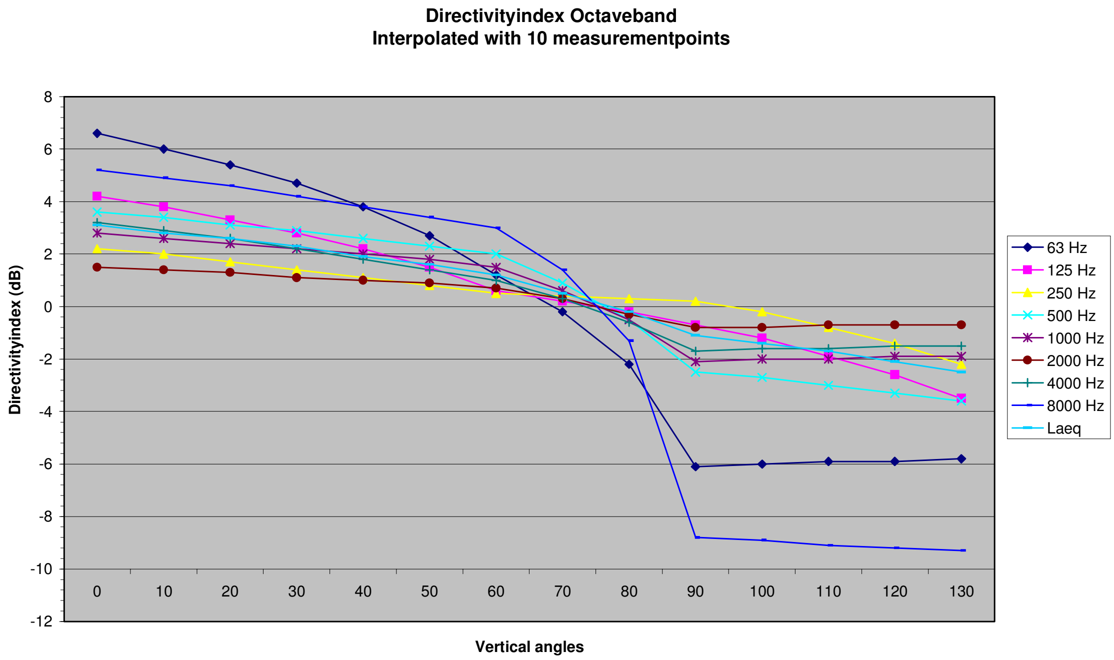


Area	48.2
Meas. radius	2.0
Source radius	0.8
Source height	5.0
No. of meas. Points, Z axis	4.0
No. of meas. Points, XY axis	3.0

Results:

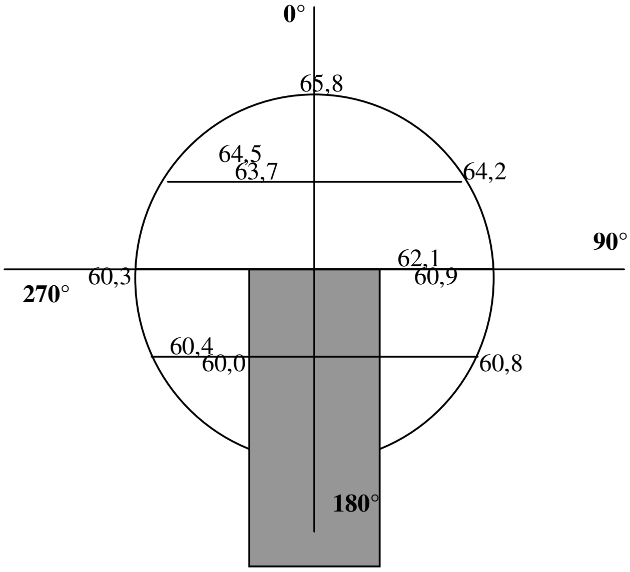
Point no.	63 Hz	125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz	8 kHz	LAeq
1	69,1	66,6	65,6	59,1	57,2	52,8	44,3	31,1	62,4
2	70	70,3	71,8	60,5	58,2	50,9	40,9	25,7	65,2
3	68,1	66,3	64,7	59,3	55,7	50	40,5	26,3	61,4
4	68,5	74,5	74,7	61,7	56,9	51,4	43,7	30,7	67,2
5	69,1	67,3	67,4	60,8	56,8	49,2	40,1	26,5	62,8
6	68,8	65,5	64,6	59,8	57,3	52,5	41,5	28,5	62,2
7	78,2	71,8	67,5	64,6	59,6	52	44,7	40,9	65,6
8	68,7	68,3	67,7	64,5	61,4	53,4	44,6	39,9	65,9
9	76,8	74,5	74,5	66,4	60,6	52,8	44,8	41,2	68,7
10	81,5	75,8	73	66,9	61,9	53,6	46,9	42,9	68,9


Sound Power Levels
100
90
80
70
60
50
40
30
20
10
0
dB(A)
63
125
250
500
1000
2000
4000
8000
Laeq
Frequency Hz
Lw
Lw Din
Lw 45 grader


Directivityindex Octaveband
Interpolated with 10 measurementpoints
8
6
4
2
0
-2
-4
-6
-8
-10
-12
Directivityindex (dB)
0
10
20
30
40
50
60
70
80
90
100
110
120
130
Vertical angles
63 Hz
125 Hz
250 Hz
500 Hz
1000 Hz
2000 Hz
4000 Hz
8000 Hz
Laeq

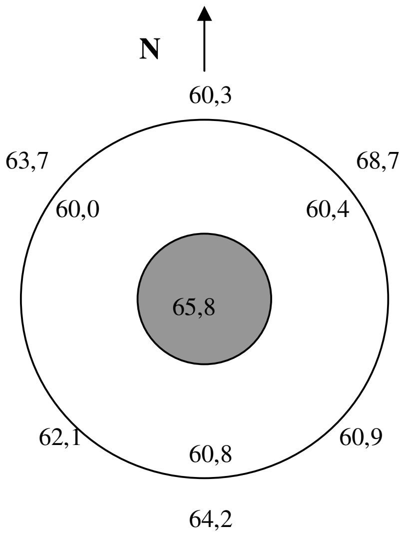
Volvo PV, Torslanda 041116
Source no; 6, Exhaust on roof, paintshop.

Comment: -



Measurement positions:

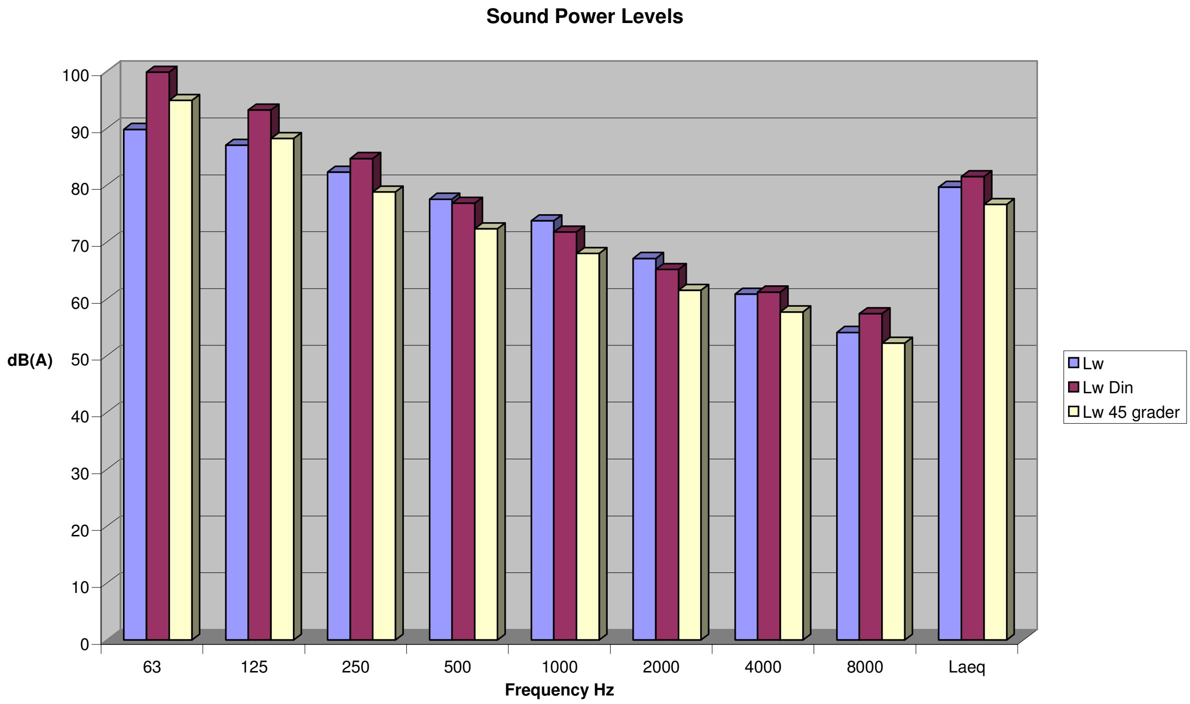
X	Y	Z	angle XY	angle Z
-1.6	0.0	-1.3	180.0	-39.0
0.8	1.3	-1.3	60.0	-39.0
0.8	-1.3	-1.3	300.0	-39.0
2.0	0.0	-0.1	0.0	-3.1
-1.0	1.7	-0.1	120.0	-3.1
-1.0	-1.7	-0.1	240.0	-3.1
-1.7	0.0	1.0	180.0	31.4
0.9	1.5	1.0	60.0	31.4
0.9	-1.5	1.0	300.0	31.4
0.0	0.0	2.0	NaN	90.0

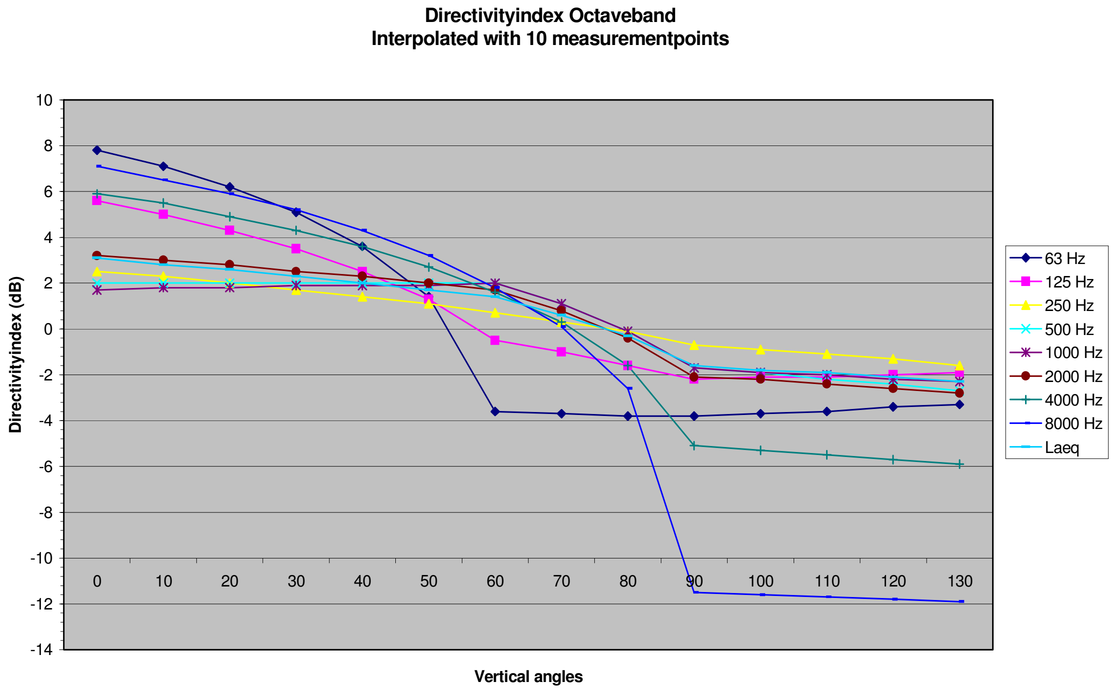


Area	48.2
Meas. radius	2.0
Source radius	0.8
Source height	5.0
No. of meas. Points, Z axis	4.0
No. of meas. Points, XY axis	3.0

Results:

Point no.	63 Hz	125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz	8 kHz	LAeq
1	69,6	68,2	64,4	58,7	54,7	47,7	38,2	26,3	60,8
2	69,2	68,4	63,5	57,1	54,3	47	37,7	25,5	60
3	70,1	68,3	63,7	57,9	54,6	47,7	38,3	24	60,4
4	69,2	66,9	63,6	58,5	54	48,2	38,2	23,8	60,3
5	69	69	66	59,7	56,2	48,8	40	25,7	62,1
6	69,3	67,8	64,5	58,8	54,9	47,5	38,2	27	60,9
7	68,8	70,5	65,9	63	58,6	52,3	45,2	38,3	64,2
8	68,4	68,5	65,9	62,4	58,3	51,4	45,8	38,9	63,7
9	70,5	69,8	66,7	62,7	59,5	52,2	45,8	39,7	64,5
10	80,8	75,8	68	62,7	58,6	53,5	49,9	44,3	65,8

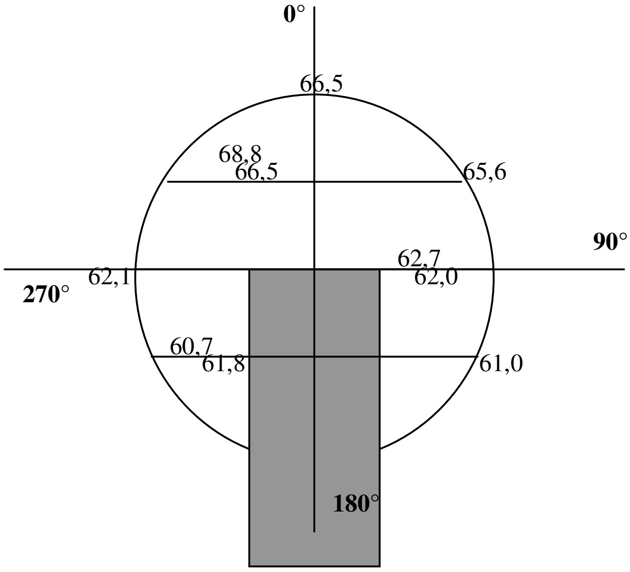

Sound Power Levels
100
90
80
70
60
50
40
30
20
10
0
dB(A)
63
125
250
500
1000
2000
4000
8000
Laeq
Frequency Hz
Lw
Lw Din
Lw 45 grader


Directivityindex Octaveband
Interpolated with 10 measurementpoints
10
8
6
4
2
0
-2
-4
-6
-8
-10
-12
-14
Directivityindex (dB)
0
10
20
30
40
50
60
70
80
90
100
110
120
130
Vertical angles
63 Hz
125 Hz
250 Hz
500 Hz
1000 Hz
2000 Hz
4000 Hz
8000 Hz
Laeq

Volvo PV, Torslanda 041116

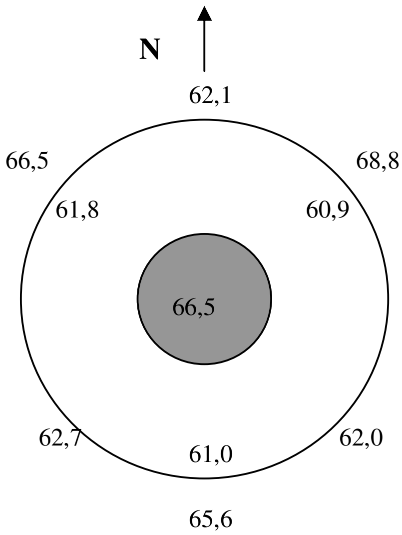
Source nr; 7, Exhaust on roof, paintshop.

Comment: -



Measurement positions:

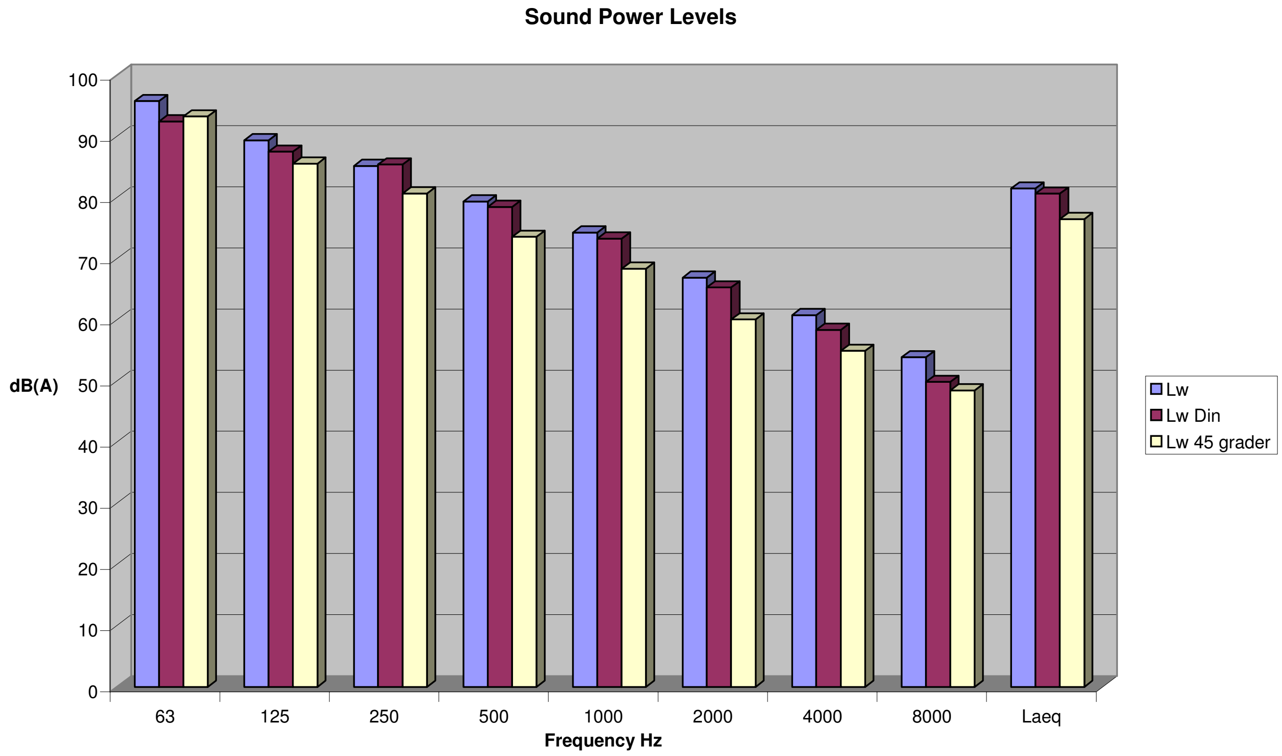
X	Y	Z	angle XY	angle Z
-1.6	0.0	-1.3	180.0	-39.0
0.8	1.3	-1.3	60.0	-39.0
0.8	-1.3	-1.3	300.0	-39.0
2.0	0.0	-0.1	0.0	-3.1
-1.0	1.7	-0.1	120.0	-3.1
-1.0	-1.7	-0.1	240.0	-3.1
-1.7	0.0	1.0	180.0	31.4
0.9	1.5	1.0	60.0	31.4
0.9	-1.5	1.0	300.0	31.4
0.0	0.0	2.0	NaN	90.0

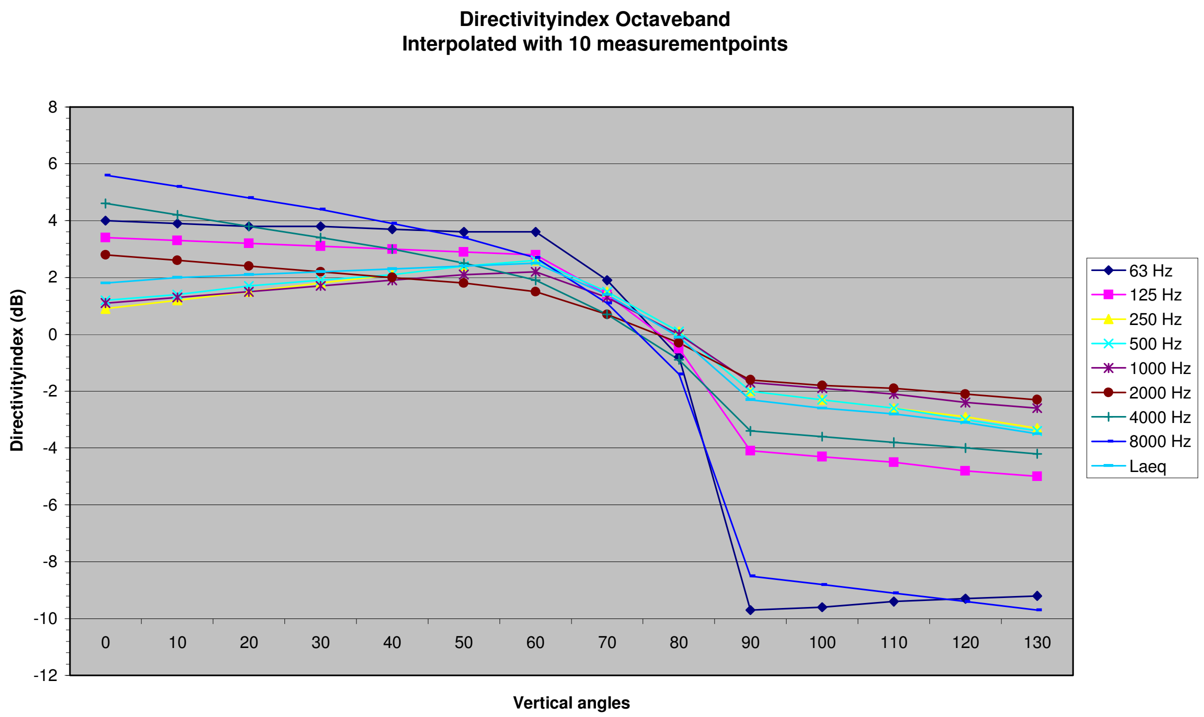


Area	48.2
Meas. radius	2.0
Source radius	0.8
Source height	5.0
No. of meas. Points, Z axis	4.0
No. of meas. Points, XY axis	3.0

Results:

Point no.	63 Hz	125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz	8 kHz	LAeq
1	69,5	67,5	63,6	59,1	55,4	48,1	40,5	28,9	61
2	69,8	67,2	66,1	59,5	55,4	48,7	40,2	27,4	61,8
3	70,1	67,9	65	58,7	53,5	46,2	38,2	24,9	60,7
4	69,4	67	65,3	60,8	56	49	41,8	31,5	62,1
5	69,4	68,7	66,9	60,5	56	48,7	41	26,9	62,7
6	69,2	69,5	66,7	60,4	55,2	47,8	38,1	24,4	62,3
7	76,3	70	68,7	64,3	59,6	51,4	44,5	37	65,6
8	70,4	70,8	70,5	65,6	59,5	51,1	44	36,8	66,5
9	86,9	79,1	72,7	65,3	60	52,3	47,9	42,8	68,8
10	83	76	69,2	63,7	58,6	52,9	48,5	42,7	66,5

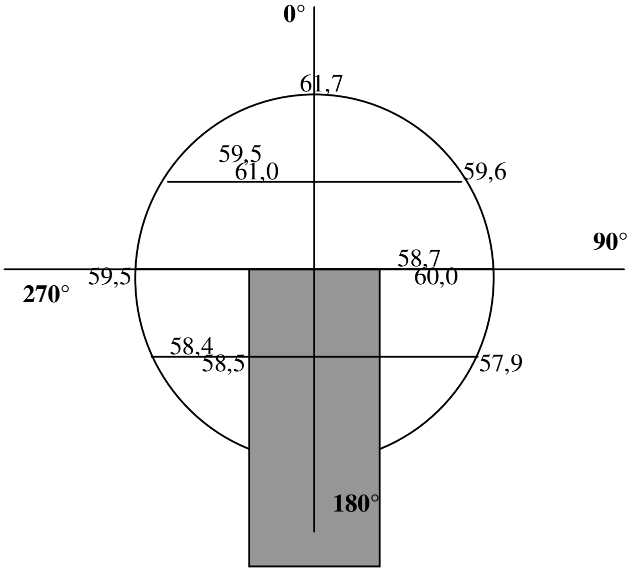

Sound Power Levels
100
90
80
70
60
50
40
30
20
10
0
dB(A)
63
125
250
500
1000
2000
4000
8000
Laeq
Frequency Hz
Lw
Lw Din
Lw 45 grader


Directivityindex Octaveband
Interpolated with 10 measurementpoints
8
6
4
2
0
-2
-4
-6
-8
-10
-12
Directivityindex (dB)
0
10
20
30
40
50
60
70
80
90
100
110
120
130
Vertical angles
63 Hz
125 Hz
250 Hz
500 Hz
1000 Hz
2000 Hz
4000 Hz
8000 Hz
Laeq

Volvo PV, Torslanda 041116

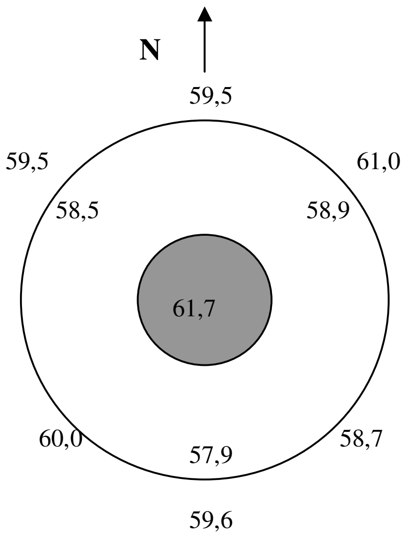
Source no; 8, Exhaust on roof, paintshop.

Comment: -



Measurement positions:

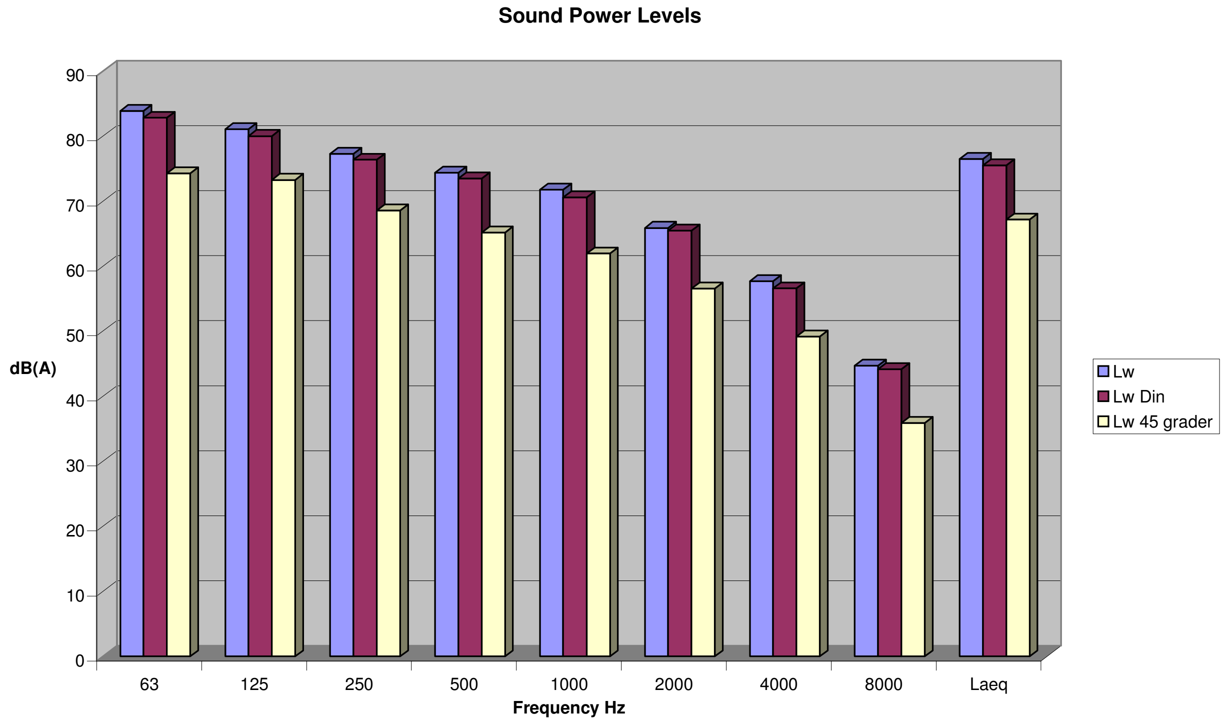
X	Y	Z	angle XY	angle Z
-1.6	0.0	-1.3	180.0	-39.0
0.8	1.3	-1.3	60.0	-39.0
0.8	-1.3	-1.3	300.0	-39.0
2.0	0.0	-0.1	0.0	-3.1
-1.0	1.7	-0.1	120.0	-3.1
-1.0	-1.7	-0.1	240.0	-3.1
-1.7	0.0	1.0	180.0	31.4
0.9	1.5	1.0	60.0	31.4
0.9	-1.5	1.0	300.0	31.4
0.0	0.0	2.0	NaN	90.0

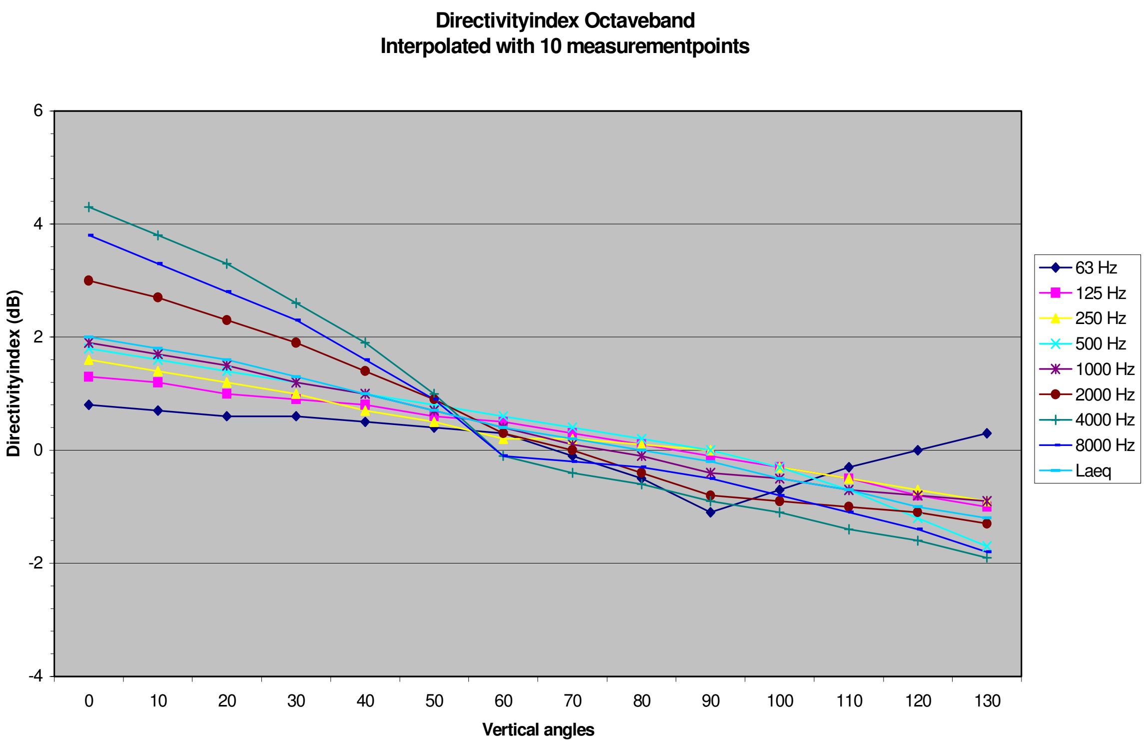


Area	48.2
Meas. radius	2.0
Source radius	0.8
Source height	5.0
No. of meas. Points, Z axis	4.0
No. of meas. Points, XY axis	3.0

Results:

Point no.	63 Hz	125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz	8 kHz	LAeq
1	66,5	61,6	58,9	55,3	53,6	47,6	39,1	26,1	57,9
2	67,8	64	60,1	56,1	53,7	47,3	38,7	25,3	58,5
3	67,8	63,6	59,6	56,3	54,8	48,4	39,1	26,8	58,9
4	66	63,4	60,4	58,2	54,4	47,8	39,8	27,2	59,5
5	66,4	64,9	60,6	57,9	55,3	49,3	40,9	28,5	60
6	65,7	64	60,4	56,7	53,7	47,7	39,2	26,4	58,7
7	65,2	64,4	60,3	58,1	54,6	48,6	40,1	27,3	59,6
8	68,6	64,9	60,5	57,5	54,5	48,6	40	28	59,5
9	67,9	64,8	61,4	58,8	56,6	50,7	41,9	28,2	61
10	67,9	65,5	62,1	59,4	56,9	52,1	45,2	31,7	61,7

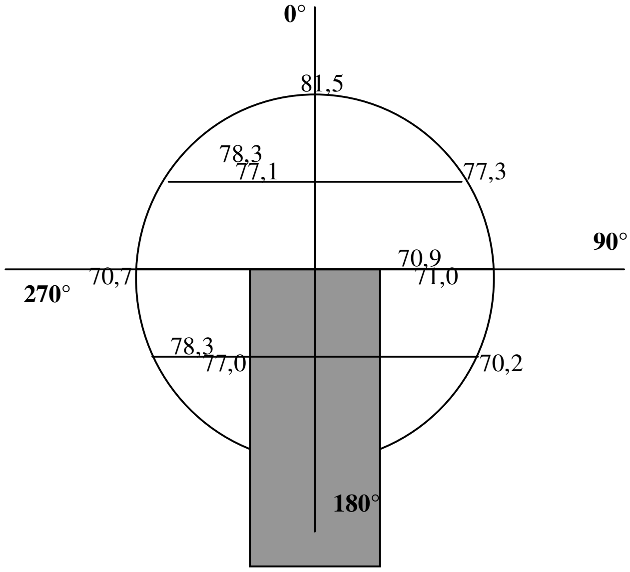

Sound Power Levels
dB(A)
90
80
70
60
50
40
30
20
10
0
63
125
250
500
1000
2000
4000
8000
Laeq
Frequency Hz
Lw
Lw Din
Lw 45 grader


Directivityindex Octaveband
Interpolated with 10 measurementpoints
Directivityindex (dB)
6
4
2
0
-2
-4
0
10
20
30
40
50
60
70
80
90
100
110
120
130
Vertical angles
63 Hz
125 Hz
250 Hz
500 Hz
1000 Hz
2000 Hz
4000 Hz
8000 Hz
Laeq

Volvo PV, Torslanda 041116

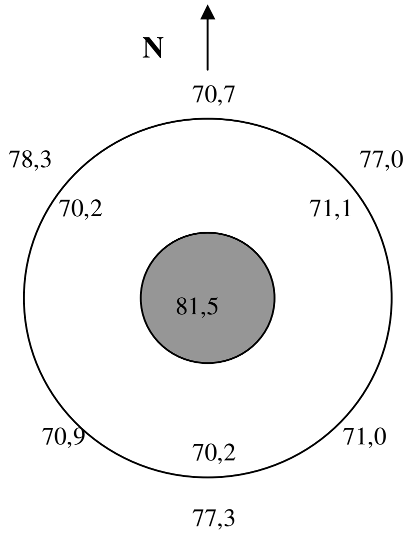
Source no; 9, Exhaust on roof, paintshop.

Comment: -



Measurement positions:

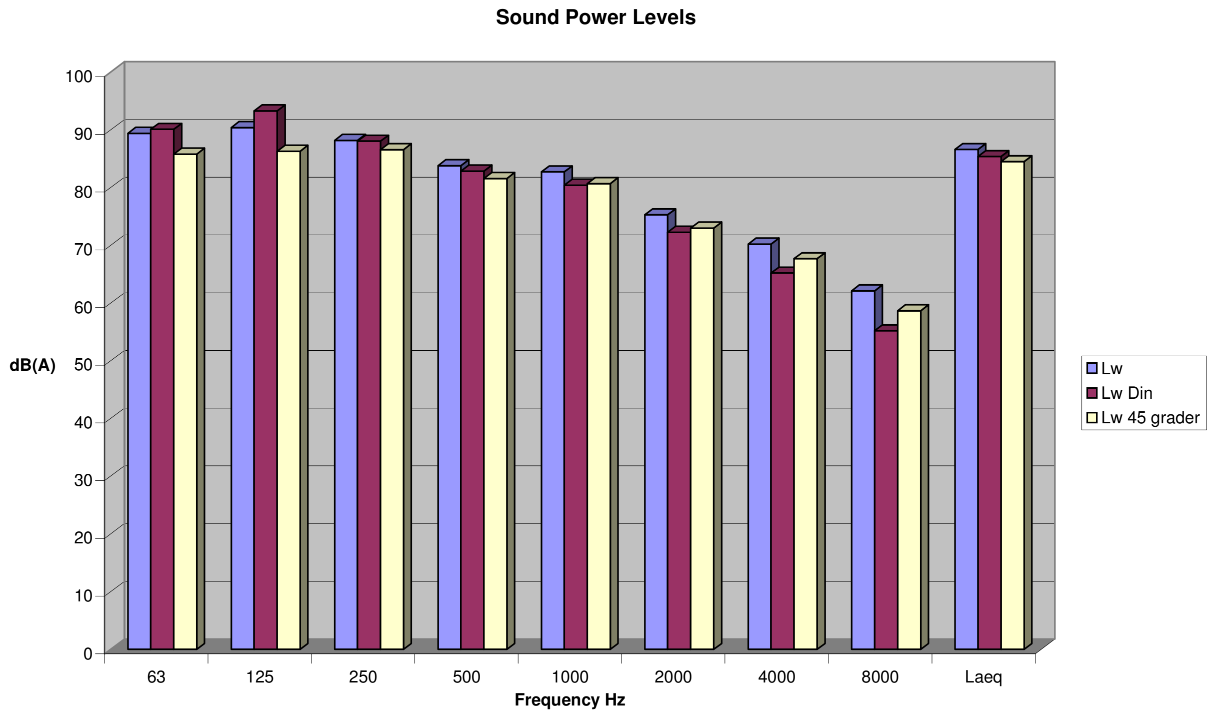
X	Y	Z	angle XY	angle Z
-0.8	0.0	-0.6	180.0	-39.0
0.4	0.7	-0.6	60.0	-39.0
0.4	-0.7	-0.6	300.0	-39.0
1.0	0.0	-0.1	0.0	-3.1
-0.5	0.9	-0.1	120.0	-3.1
-0.5	-0.9	-0.1	240.0	-3.1
-0.9	0.0	0.5	180.0	31.4
0.4	0.7	0.5	60.0	31.4
0.4	-0.7	0.5	300.0	31.4
0.0	0.0	1.0	NaN	90.0

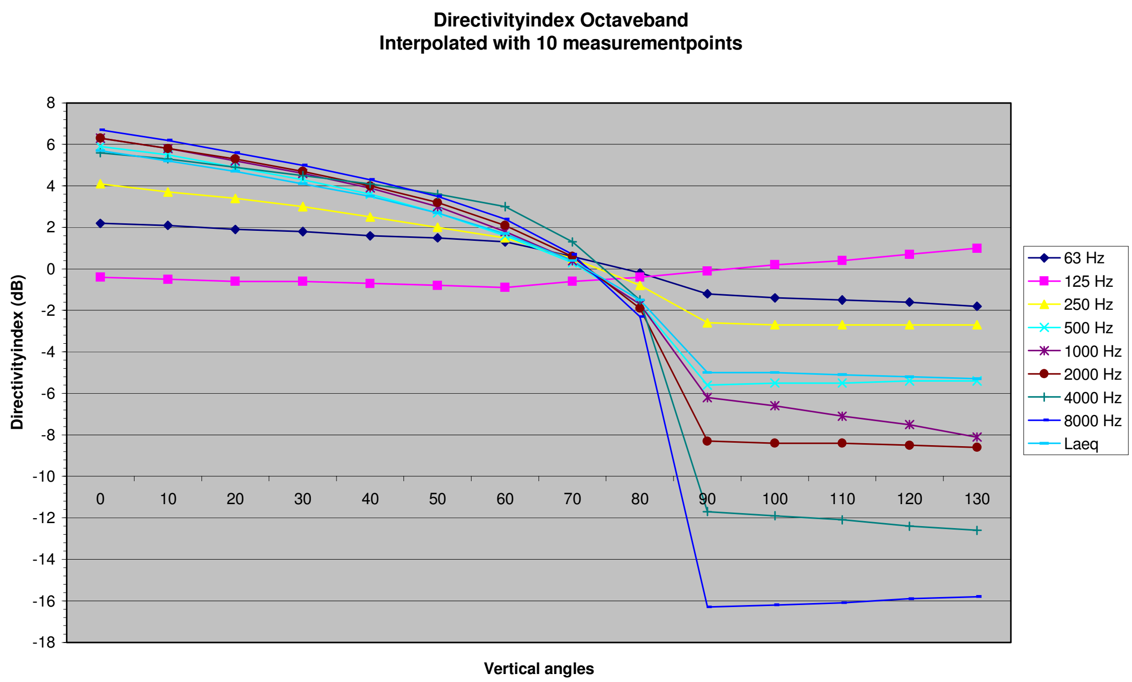


Area	12.0
Meas. radius	1.0
Source radius	0.4
Source height	5.0
No. of meas. Points, Z axis	4.0
No. of meas. Points, XY axis	3.0

Results:

Point no.	63 Hz	125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz	8 kHz	LAeq
1	77,4	81,4	74,1	67,3	63	55	45,9	35,2	70,2
2	75,9	78,3	75	67,1	63,9	55,6	45,6	34,3	70,2
3	77,1	81,3	75	68,3	64,6	56,7	48,2	36,7	71,1
4	76,7	77,5	74,7	67,8	65,8	55,7	47,4	33,9	70,7
5	76,6	79,7	74,8	67,2	65,8	56,4	47,9	34,3	70,9
6	78,5	80,6	74,8	67	65,5	56,4	47,7	36,4	71
7	81,5	78	78,4	74,2	73,6	66,7	62,7	54,3	77,3
8	78,2	78,7	79,6	75,2	74,4	67,3	63,2	54,5	78,3
9	79,5	79,3	78,5	74,3	73,3	65,6	60,9	52	77
10	80,8	79,2	81,5	78,9	78,2	70,7	65	58	81,5

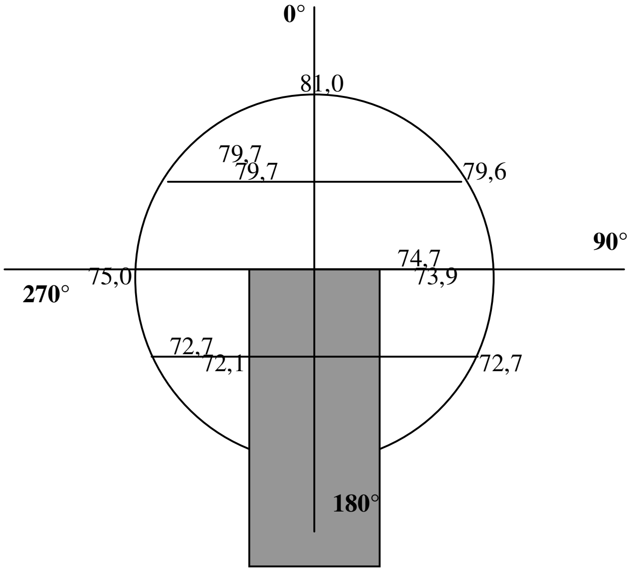

Sound Power Levels
100
90
80
70
60
50
40
30
20
10
0
dB(A)
63
125
250
500
1000
2000
4000
8000
Laeq
Frequency Hz
Lw
Lw Din
Lw 45 grader


Directivityindex Octaveband
Interpolated with 10 measurementpoints
Directivityindex (dB)
8
6
4
2
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
0
10
20
30
40
50
60
70
80
90
100
110
120
130
Vertical angles
63 Hz
125 Hz
250 Hz
500 Hz
1000 Hz
2000 Hz
4000 Hz
8000 Hz
Laeq

Volvo PV, Torslanda 041116

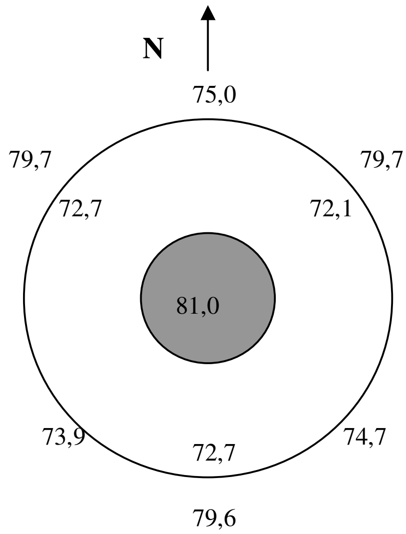
Source no; 10, Exhaust on roof, paintshop.

Comment: -



Measurement positions:

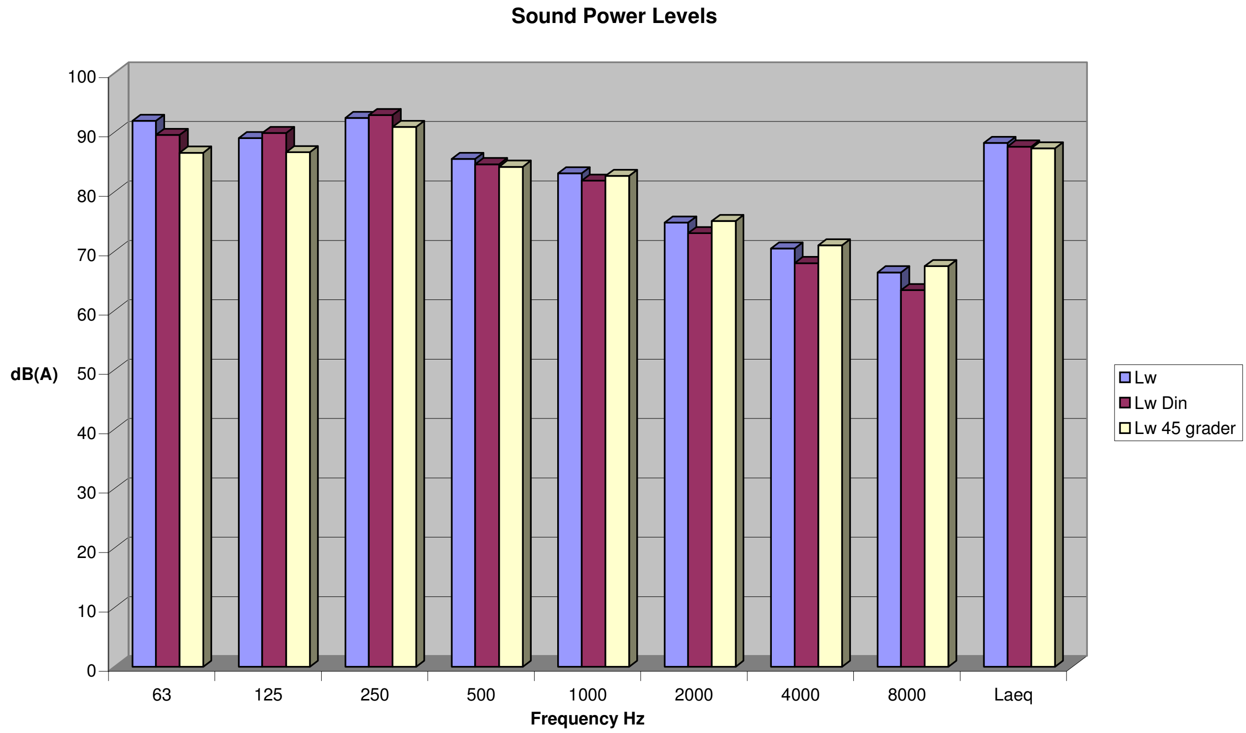
X	Y	Z	angle XY	angle Z
-0.8	0.0	-0.6	180.0	-39.0
0.4	0.7	-0.6	60.0	-39.0
0.4	-0.7	-0.6	300.0	-39.0
1.0	0.0	-0.1	0.0	-3.1
-0.5	0.9	-0.1	120.0	-3.1
-0.5	-0.9	-0.1	240.0	-3.1
-0.9	0.0	0.5	180.0	31.4
0.4	0.7	0.5	60.0	31.4
0.4	-0.7	0.5	300.0	31.4
0.0	0.0	1.0	NaN	90.0



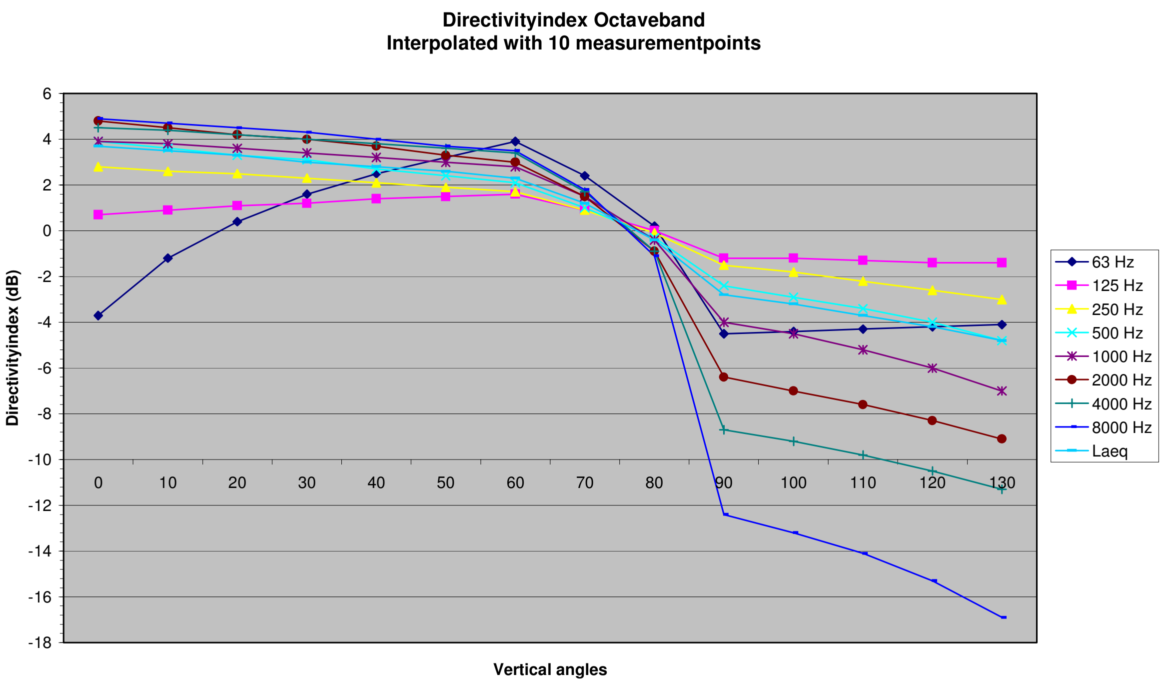
Area	12.0
Meas. radius	1.0
Source radius	0.4
Source height	5.0
No. of meas. Points, Z axis	4.0
No. of meas. Points, XY axis	3.0

Results:

Point no.	63 Hz	125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz	8 kHz	LAeq
1	78,4	76,5	78,7	70,1	65,7	54,9	48,6	38,6	72,7
2	75,8	76,8	78,7	70,2	65,6	54,8	48,3	38,1	72,7
3	76,5	76,9	78,4	69,3	64,5	55	47,9	39,3	72,1
4	76,2	76,9	80,6	72,8	68,6	57,6	51,2	42,8	75
5	77,4	77	79,7	71,4	67,5	57,3	49,7	42,6	73,9
6	76,2	77,1	80	72,5	68,7	57,9	51,4	43,9	74,7
7	85,7	79,7	83,1	76,7	75	66,7	62,7	58,7	79,6
8	76,6	77,7	83,4	77,1	75,1	67	63	59,3	79,7
9	87,3	81,3	83,4	76,3	75,1	67,3	63,1	59,1	79,7
10	77,4	78,9	84,4	78,5	76,2	68,8	64,1	60,5	81



Sound Power Levels
dB(A)
100
90
80
70
60
50
40
30
20
10
0
63
125
250
500
1000
2000
4000
8000
Laeq
Frequency Hz
Lw
Lw Din
Lw 45 grader

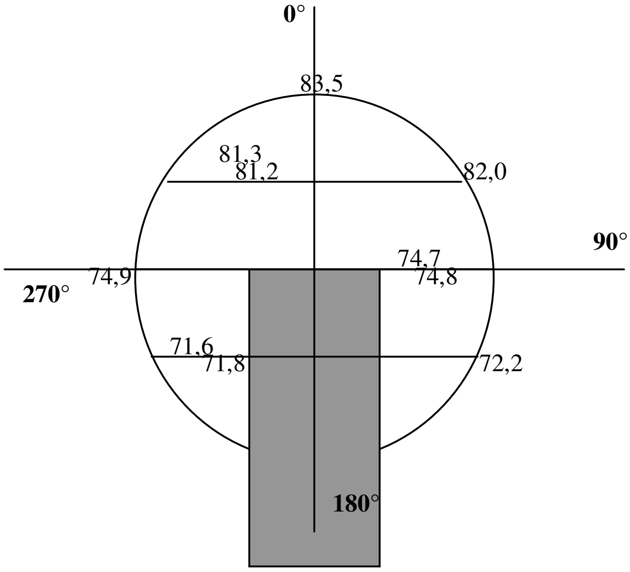


Directivityindex Octaveband
Interpolated with 10 measurementpoints
Directivityindex (dB)
6
4
2
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
0
10
20
30
40
50
60
70
80
90
100
110
120
130
Vertical angles
63 Hz
125 Hz
250 Hz
500 Hz
1000 Hz
2000 Hz
4000 Hz
8000 Hz
Laeq

Volvo PV, Torslanda 041116

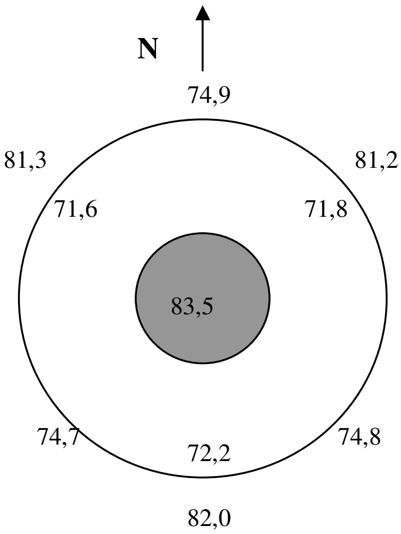
Source no; 11, Exhaust on roof, paintshop.

Comment: -



Measurement positions:

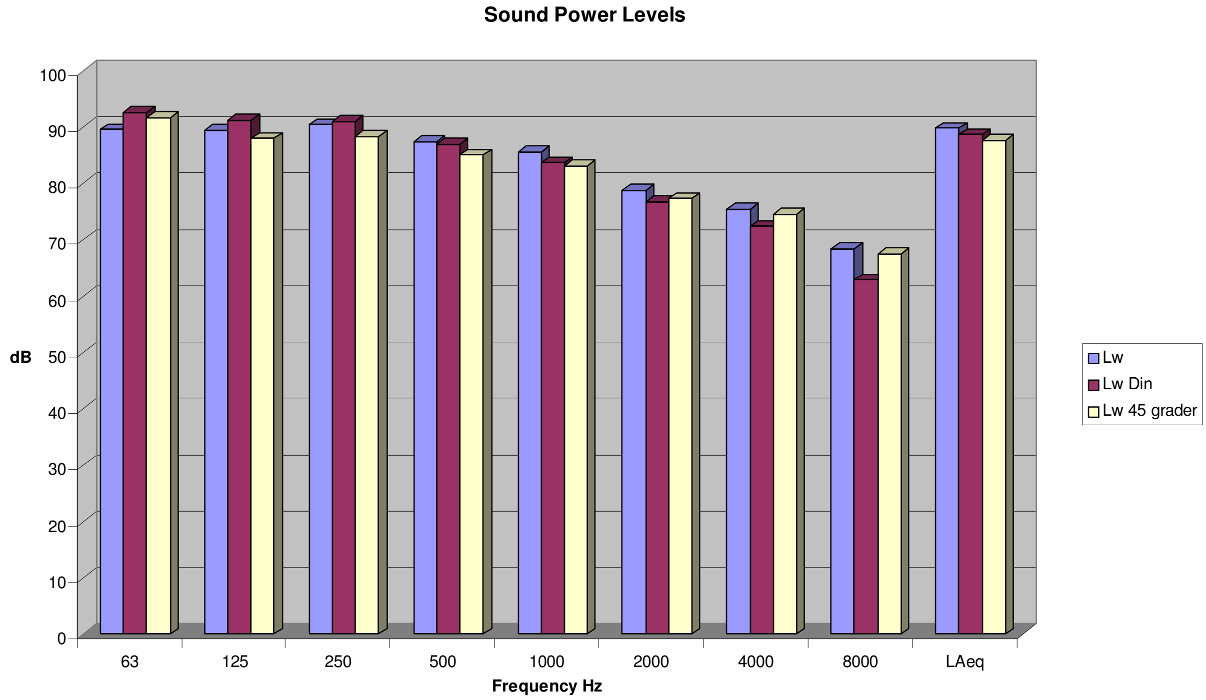
X	Y	Z	angle XY	angle Z
-0.8	0.0	-0.6	180.0	-39.0
0.4	0.7	-0.6	60.0	-39.0
0.4	-0.7	-0.6	300.0	-39.0
1.0	0.0	-0.1	0.0	-3.1
-0.5	0.9	-0.1	120.0	-3.1
-0.5	-0.9	-0.1	240.0	-3.1
-0.9	0.0	0.5	180.0	31.4
0.4	0.7	0.5	60.0	31.4
0.4	-0.7	0.5	300.0	31.4
0.0	0.0	1.0	NaN	90.0

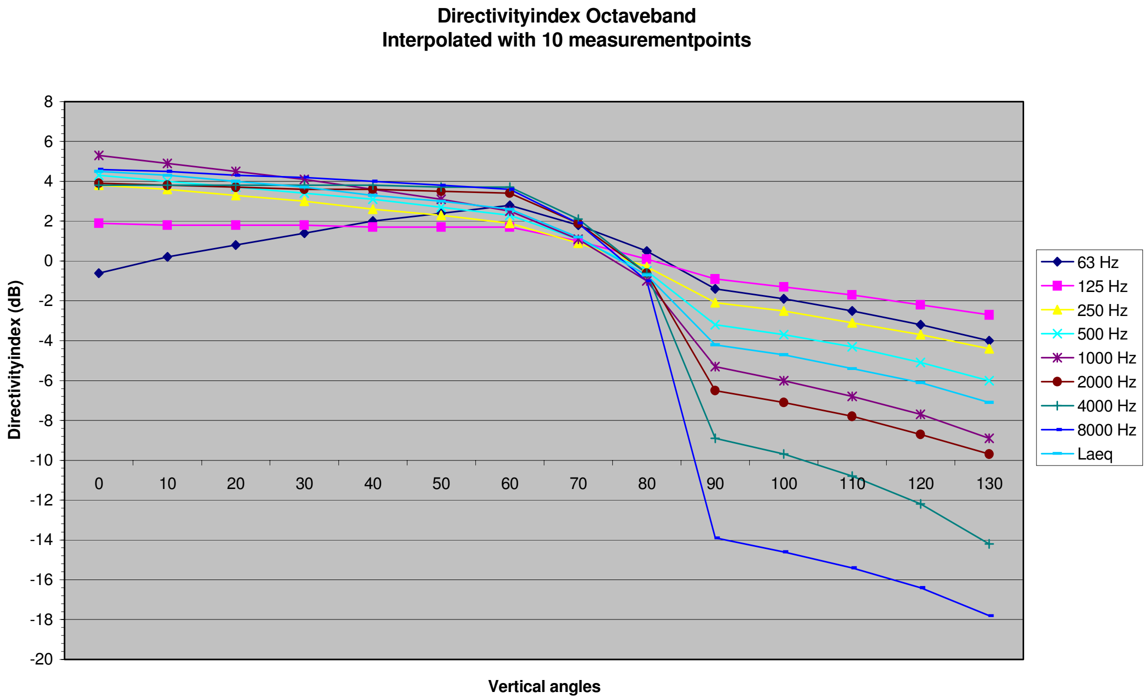


Area	12.0
Meas. radius	1.0
Source radius	0.4
Source height	5.0
No. of meas. Points, Z axis	4.0
No. of meas. Points, XY axis	3.0

Results:

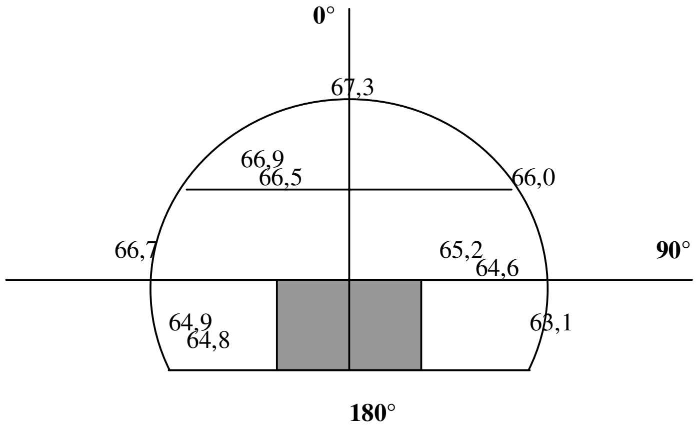
Point no.	63 Hz	125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz	8 kHz	LAeq
1	74,6	76	75,3	71,2	66,3	58,6	50,2	41	72,2
2	74,6	75,7	75,2	70	65,6	58,4	50,6	40,1	71,6
3	74,9	76,1	75,3	70,4	65,8	58,1	50,5	38,1	71,8
4	76,4	77,7	77,5	73,9	69,5	61	55,2	43,6	74,9
5	77,6	77,7	77,7	73	69,3	62	56,2	43,7	74,7
6	78	77,7	77,6	73,2	69,7	61,9	56	44	74,8
7	81,3	80,1	81,3	79,2	78,1	71,8	69	61,8	82
8	78	80,1	81,6	78,8	77	71,5	68	61	81,3
9	83,7	80,7	81,7	78,6	76,9	71,2	68,2	61,1	81,2
10	78,1	80,5	83,5	80,8	80,1	72	68,5	62,3	83,5


Sound Power Levels
100
90
80
70
60
50
40
30
20
10
0
dB
63
125
250
500
1000
2000
4000
8000
LAeq
Frequency Hz
Lw
Lw Din
Lw 45 grader


Directivityindex Octaveband
Interpolated with 10 measurementpoints
8
6
4
2
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
Directivityindex (dB)
0
10
20
30
40
50
60
70
80
90
100
110
120
130
Vertical angles
63 Hz
125 Hz
250 Hz
500 Hz
1000 Hz
2000 Hz
4000 Hz
8000 Hz
Laeq

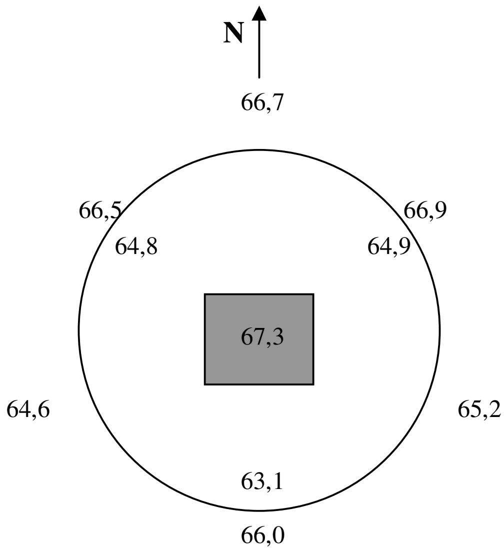
Volvo LV, Tuve 041011
Source no; 12, Exhaust on roof LB.

Comment: High background noise level.



Measurement positions:

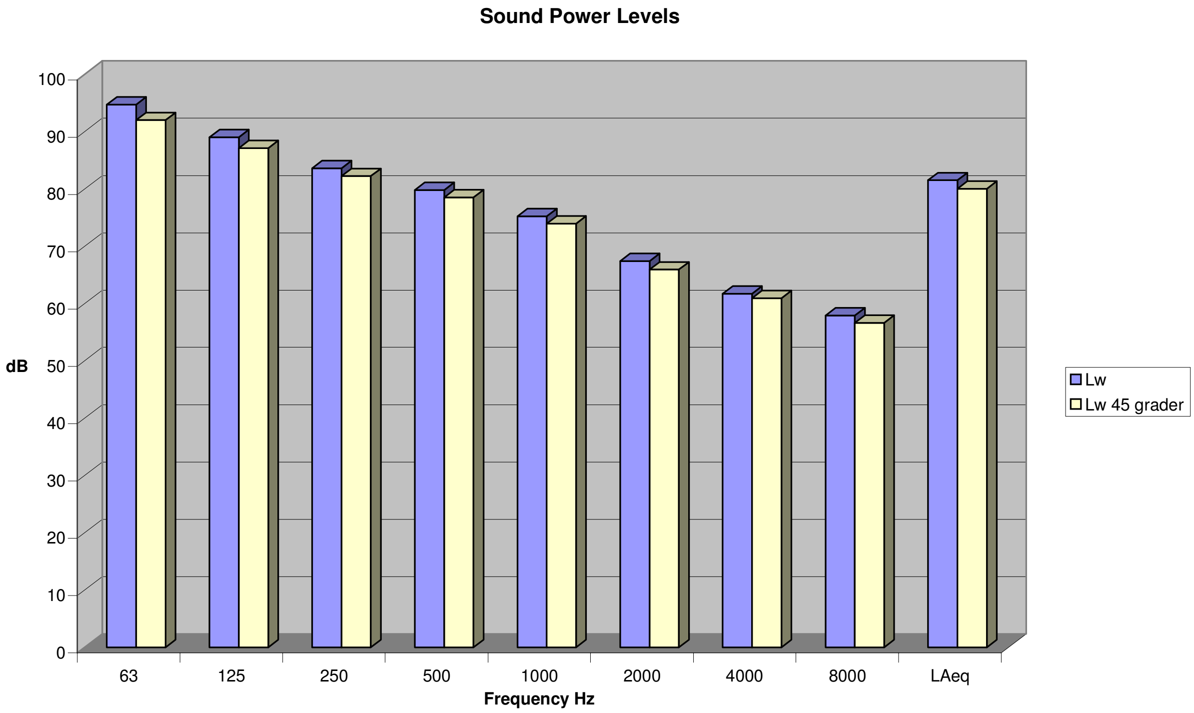
X	Y	Z	angle XY	angle Z
-1.9	0.0	-0.6	180.0	-16.0
1.0	1.7	-0.6	60.0	-16.0
1.0	-1.7	-0.6	300.0	-16.0
2.0	0.0	0.4	0.0	10.1
-1.0	1.7	0.4	120.0	10.1
-1.0	-1.7	0.4	240.0	10.1
-1.6	0.0	1.3	180.0	38.7
0.8	1.4	1.3	60.0	38.7
0.8	-1.4	1.3	300.0	38.7
0.0	0.0	2.0	NaN	90.0



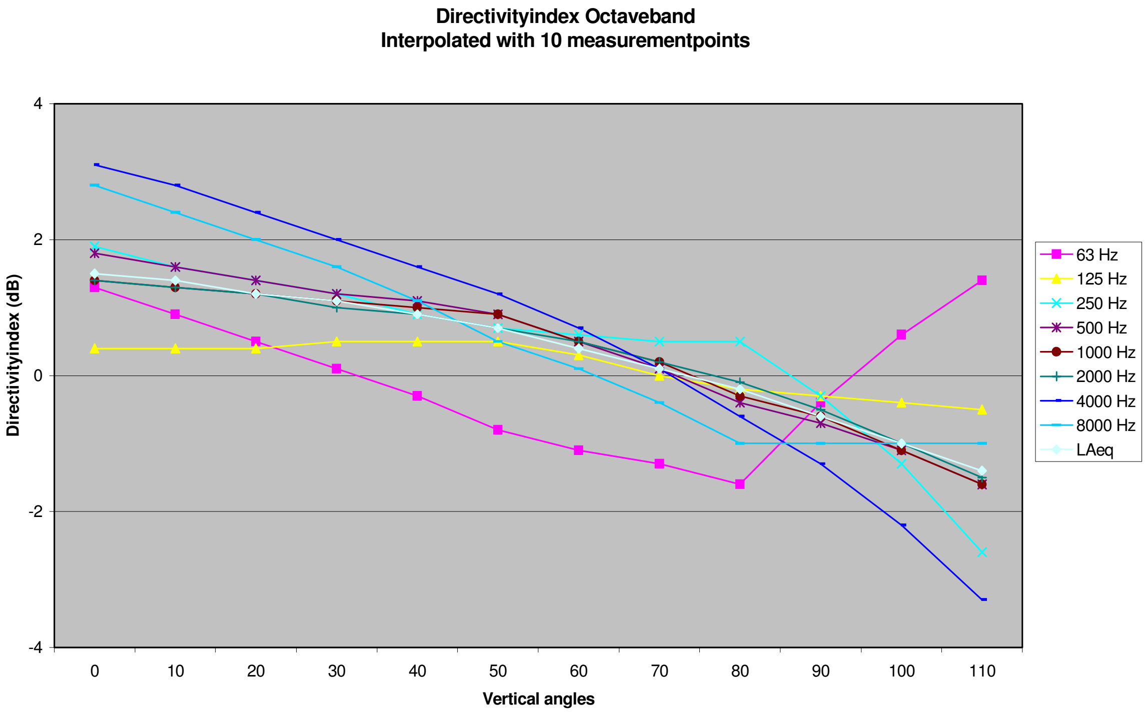
Area	37.7
Meas. radius	2.0
Source radius	0.1
Source height	1.0
No. of meas. Points, Z axis	4.0
No. of meas. Points, XY axis	3.0

Results:

Point no.	63 Hz	125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz	8 kHz	LAeq
1	78,8	71,4	64,1	61,3	57	47,6	39,7	41,1	63.1
2	80,8	73,7	65,6	62,6	58,2	50,6	43,4	41,1	64.8
3	81	72,9	65,8	63,2	58,4	51,5	43,8	41,1	64.9
4	78,1	74	69,7	65	59,8	52,5	45,9	41,2	66.7
5	76,9	72,4	65,9	63	58,6	51,1	45,8	41,1	64.6
6	76,8	72,4	68,5	62,7	59,2	50,8	44,2	41,1	65.2
7	78,5	74	68,1	64,1	59,6	52,2	47	42,8	66.0
8	78,6	73,9	68,7	64,8	60,3	52,5	47,3	42,7	66.5
9	77,1	73,3	68,7	65,7	61,1	52,5	47	42,5	66.9
10	80,2	73,6	69,7	65,8	60,9	53,1	49	44,9	67.3



Sound Power Levels
dB
100
90
80
70
60
50
40
30
20
10
0
63
125
250
500
1000
2000
4000
8000
LAeq
Frequency Hz
Lw
Lw 45 grader

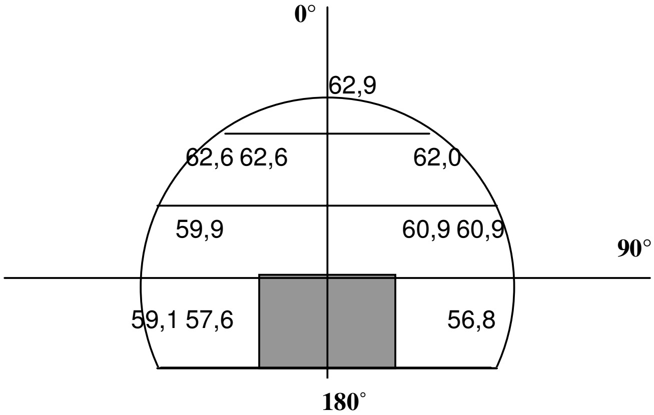


Directivityindex Octaveband
Interpolated with 10 measurementpoints
Directivityindex (dB)
4
2
0
-2
-4
0
10
20
30
40
50
60
70
80
90
100
110
Vertical angles
63 Hz
125 Hz
250 Hz
500 Hz
1000 Hz
2000 Hz
4000 Hz
8000 Hz
LAeq

Volvo PV, Torslanda 041117

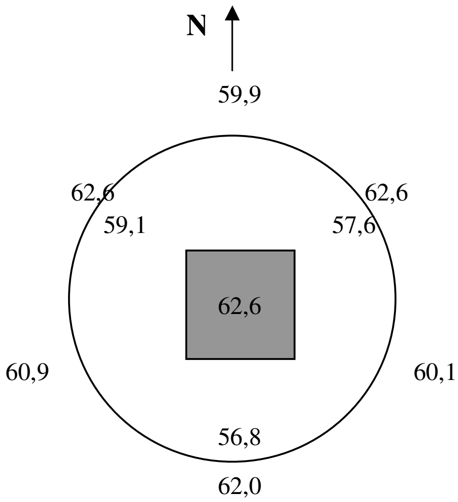
Source no; 13, Exhaust on roof, paintshop.

Comment: -



Measurement positions:

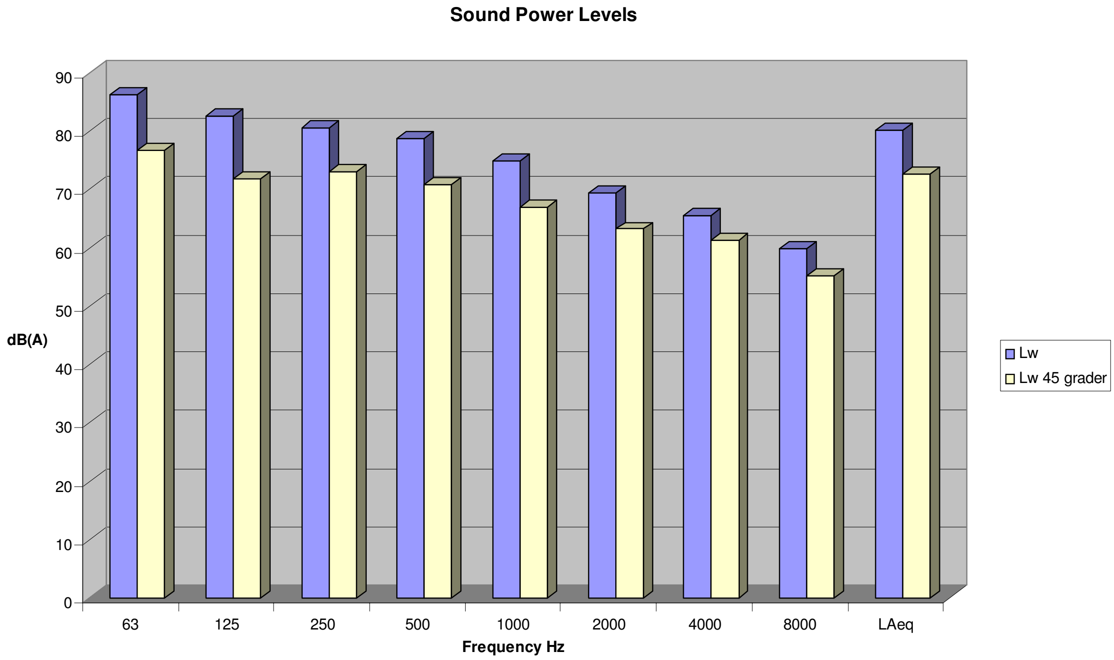
X	Y	Z	angle XY	angle Z
-2,9	0	-0,8	180	-16
1,4	2,5	-0,8	60	-16
1,4	-2,5	-0,8	300	-16
3	0	0,5	0	10,1
-1,5	2,6	0,5	120	10,1
-1,5	-2,6	0,5	240	10,1
-2,3	0	1,9	180	38,7
1,2	2	1,9	60	38,7
1,2	-2	1,9	300	38,7
0	0	3	NaN	90

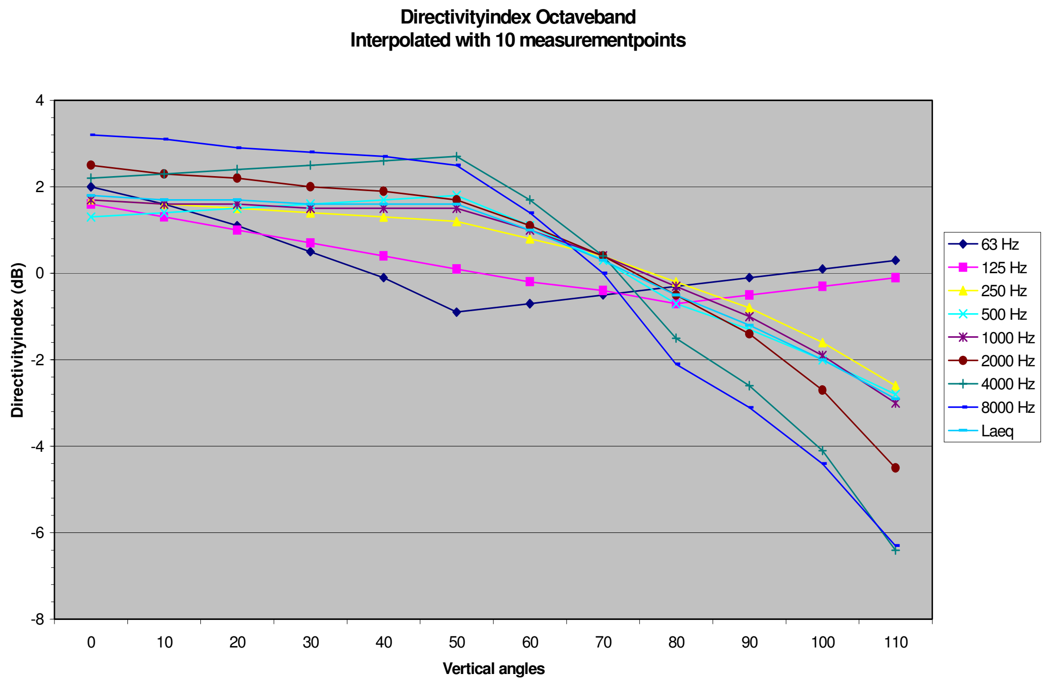


Area	84,8
Meas. radius	3.0
Source radius	1,1
Source height	1.5
No. of meas. Points, Z axis	4.0
No. of meas. Points, XY axis	3.0

Results:

Point no.	63 Hz	125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz	8 kHz	LAeq
1	66,7	62	57,7	55,9	51,3	44,4	37,1	29,6	56,8
2	67,9	64,7	59,5	57,9	53,8	46,5	41,1	36,4	59,1
3	67,1	62,5	58,5	56,2	52,1	45,8	40,6	34,4	57,6
4	67,1	63,2	61,5	58,3	54,9	48,1	42,3	35,5	59,9
5	66,7	62,9	61	59,4	55,7	50,9	46,7	40	60,9
6	66,2	61,7	60,6	58,8	55,1	49,5	44,5	38,9	60,1
7	65,9	62,9	62,5	60,7	56,8	51,7	47,6	41	62
8	66,5	64,2	62,7	61,7	57,1	51,3	49,1	43,3	62,6
9	66	62,9	62,1	61,5	57	52,4	50	44,3	62,6
10	69	64,9	62,9	60,9	57,2	52,6	48,5	43,8	62,6

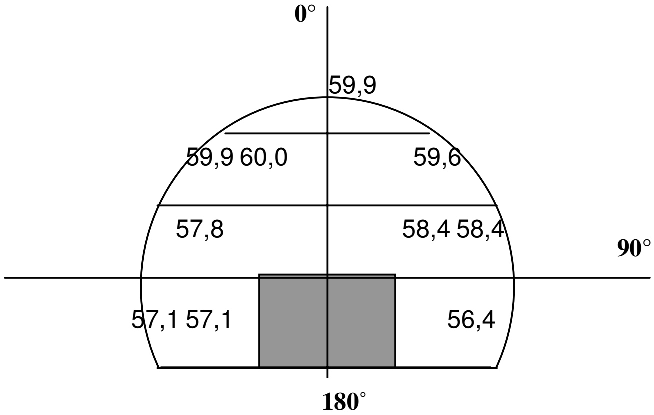

Sound Power Levels
90
80
70
60
50
40
30
20
10
0
dB(A)
63
125
250
500
1000
2000
4000
8000
LAeq
Frequency Hz
Lw
Lw 45 grader


Directivityindex Octaveband
Interpolated with 10 measurementpoints
4
2
0
-2
-4
-6
-8
Directivityindex (dB)
0
10
20
30
40
50
60
70
80
90
100
110
Vertical angles
63 Hz
125 Hz
250 Hz
500 Hz
1000 Hz
2000 Hz
4000 Hz
8000 Hz
Laeq

Volvo PV, Torslanda 041117

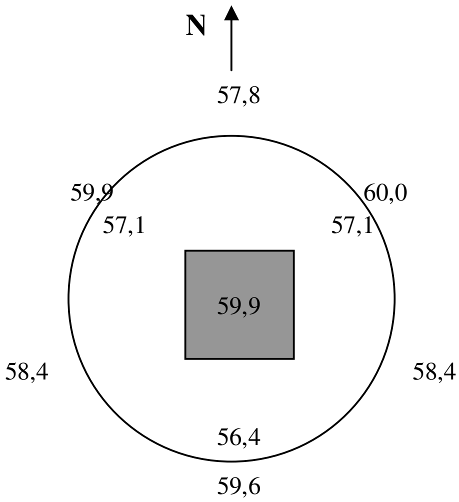
Source no; 14, Exhaust on roof, paintshop.

Comment: -



Measurement positions:

X	Y	Z	angle XY	angle Z
-2,9	0	-0,8	180	-16
1,4	2,5	-0,8	60	-16
1,4	-2,5	-0,8	300	-16
3	0	0,5	0	10,1
-1,5	2,6	0,5	120	10,1
-1,5	-2,6	0,5	240	10,1
-2,3	0	1,9	180	38,7
1,2	2	1,9	60	38,7
1,2	-2	1,9	300	38,7
0	0	3	NaN	90

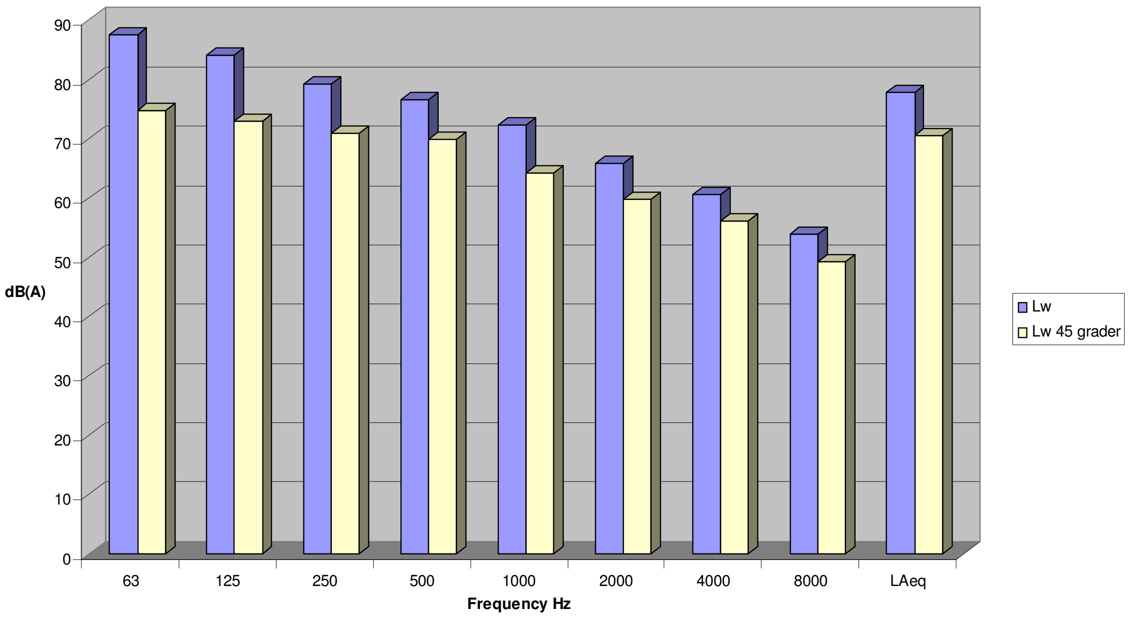


Area	84,8
Meas. radius	3.0
Source radius	1,1
Source height	1.5
No. of meas. Points, Z axis	4.0
No. of meas. Points, XY axis	3.0

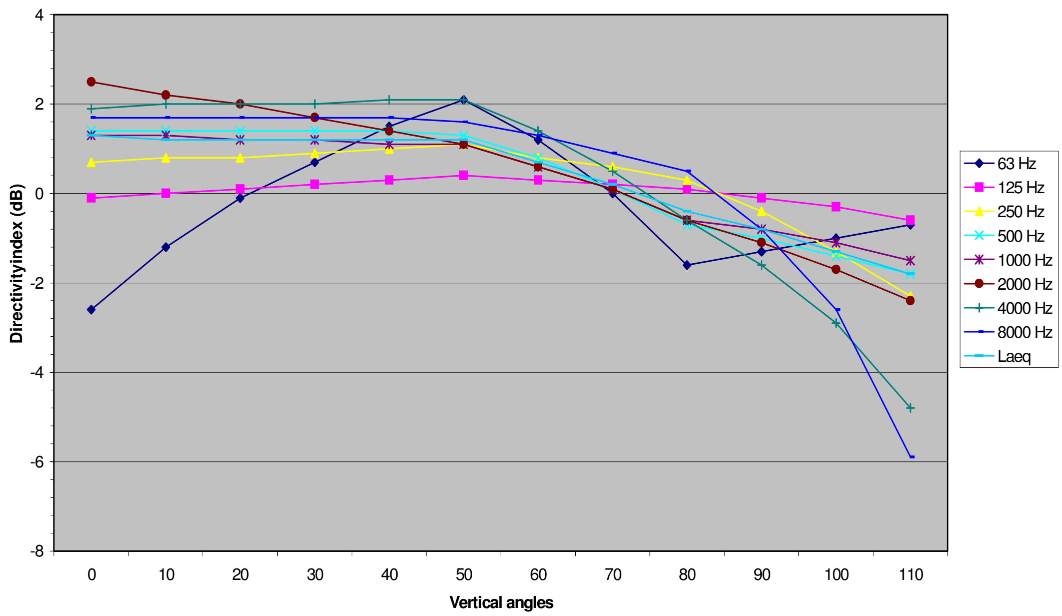
Results:

Point no.	63 Hz	125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz	8 kHz	LAeq
1	67,6	63,6	56,9	55,4	51,4	43,1	34,1	24,5	56,4
2	67,4	64,7	58	55,8	51,8	44,4	36,7	26,8	57,1
3	67,3	64,3	57,9	55,6	51,7	45,1	38,1	31,7	57,1
4	66,7	65,1	59,7	55,9	52,2	45,7	39,4	33,6	57,8
5	66,5	64,8	60,7	57	52,7	46,2	41,7	35,7	58,4
6	66,6	64,8	60,2	57	52,7	46,3	40,8	35,6	58,4
7	66,5	64,2	62	58,3	53,8	48,1	43,1	35,5	59,6
8	73,6	66,5	61	58,5	54	47	43,1	36,4	59,9
9	66,5	64,7	59,8	59,3	54,7	48,1	44,1	36,7	60
10	65,6	64,7	60,6	58,8	54,4	49,1	43,3	36,3	59,9

Sound Power Levels

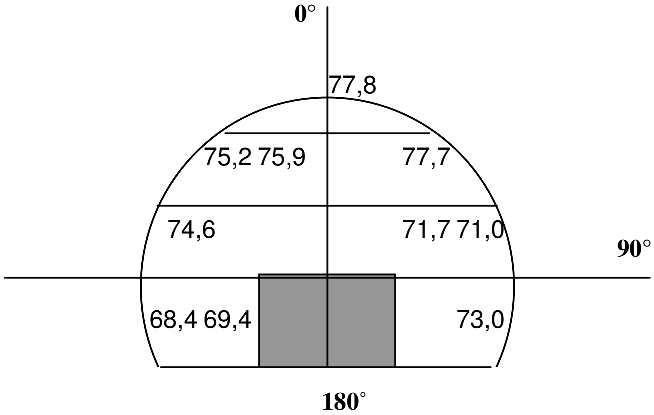


Directivityindex Octaveband
Interpolated with 10 measurementpoints



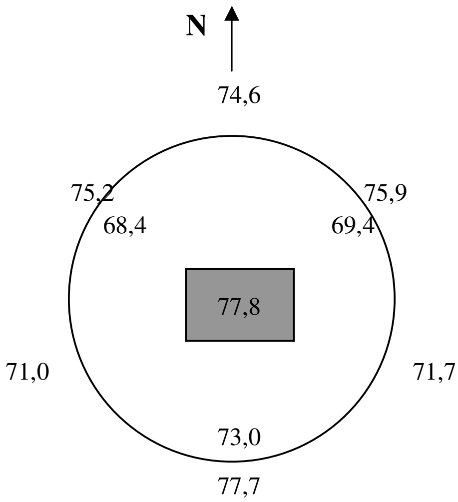
Elmo Calf, Svenljunga 041028
Source no; 15, Exhaust on roof.

Comment: Background level measured while the source was shut off.



Measurement positions:

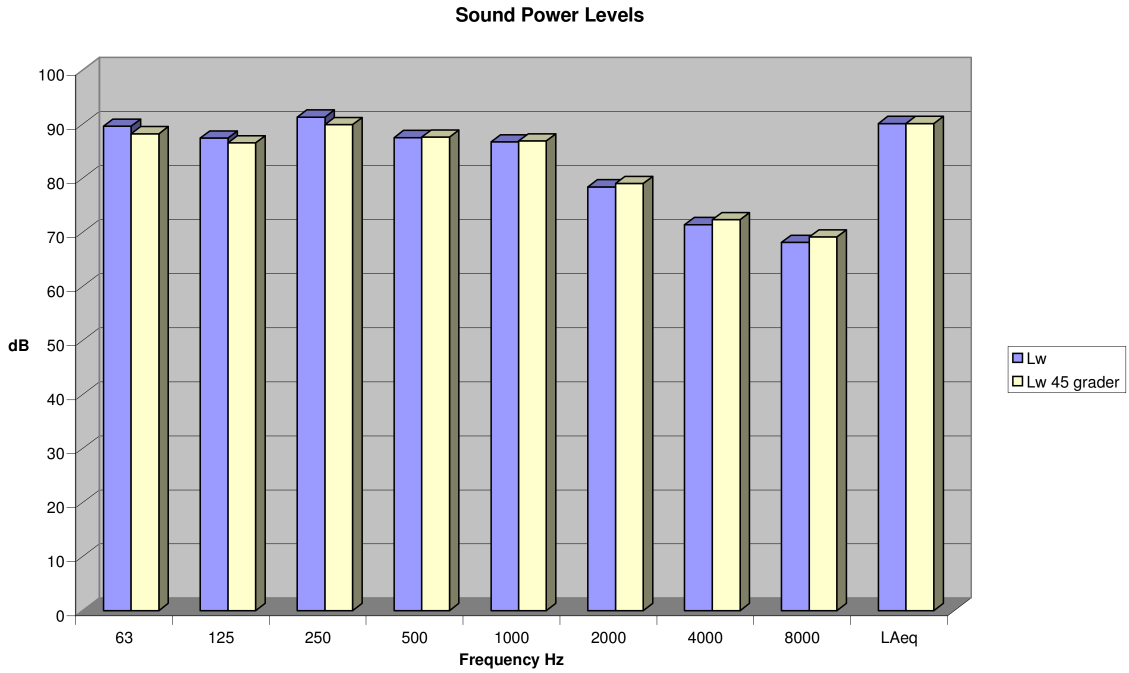
X	Y	Z	angle XY	angle Z
-1.9	0.0	-0.6	180.0	-16.0
1.0	1.7	-0.6	60.0	-16.0
1.0	-1.7	-0.6	300.0	-16.0
2.0	0.0	0.4	0.0	10.1
-1.0	1.7	0.4	120.0	10.1
-1.0	-1.7	0.4	240.0	10.1
-1.6	0.0	1.3	180.0	38.7
0.8	1.4	1.3	60.0	38.7
0.8	-1.4	1.3	300.0	38.7
0.0	0.0	2.0	NaN	90.0

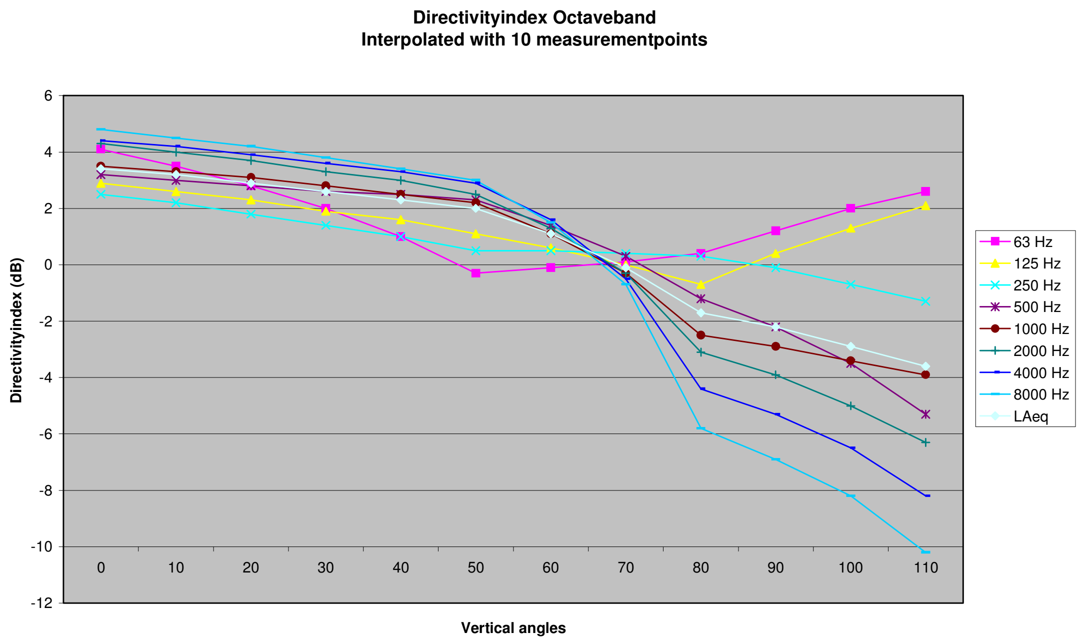


Area	37.7
Meas. radius	2.0
Source radius	0.5
Source height	1.0
No. of meas. Points, Z axis	4.0
No. of meas. Points, XY axis	3.0

Results:

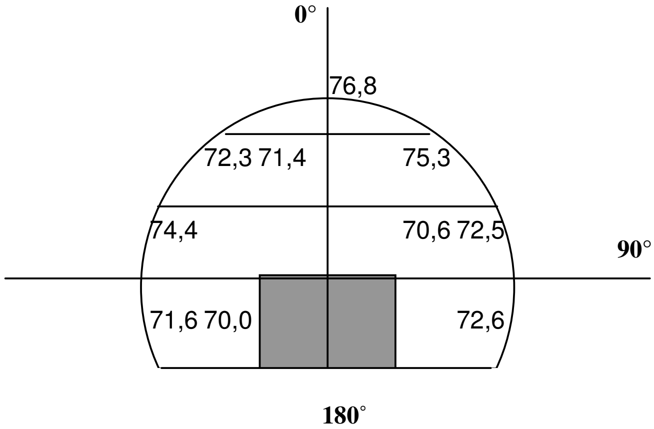
Point no.	63 Hz	125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz	8 kHz	LAeq
1	76,9	73,6	76,9	67,5	69,7	58,8	50,4	43,6	73.0
2	76,2	73,2	71,1	65,4	64,3	53,5	44,2	41,1	68.4
3	76,1	74,1	72,4	66,1	65,3	55,1	44,8	41,1	69.4
4	73,9	71	77,6	72,3	70,6	60,9	52,9	48,5	74.6
5	74	70,6	73,5	69,5	66,3	58,4	50,3	45,4	71.0
6	74,6	71,1	75,5	69	67,1	59	50,1	44,6	71.7
7	73,1	72,5	77,3	74	75	67,1	60	56,5	77.7
8	74,1	72,7	74,4	73,7	71,5	63,7	57,6	54,8	75.2
9	73,2	73	75,9	74,2	72,3	64	57,8	54,4	75.9
10	77,9	74,5	78	74,9	74,5	67	60,1	57,1	77.8


Sound Power Levels
dB
100
90
80
70
60
50
40
30
20
10
0
63
125
250
500
1000
2000
4000
8000
LAeq
Frequency Hz
Lw
Lw 45 grader


Directivityindex Octaveband
Interpolated with 10 measurementpoints
Directivityindex (dB)
6
4
2
0
-2
-4
-6
-8
-10
-12
0
10
20
30
40
50
60
70
80
90
100
110
Vertical angles
63 Hz
125 Hz
250 Hz
500 Hz
1000 Hz
2000 Hz
4000 Hz
8000 Hz
LAeq

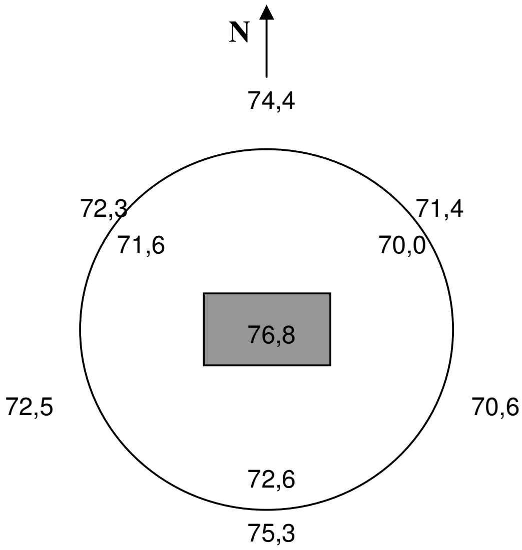
Elmo Calf, Svenljunga 041028
Source no; 16, Exhaust on roof.

Comment: -



Measurement positions:

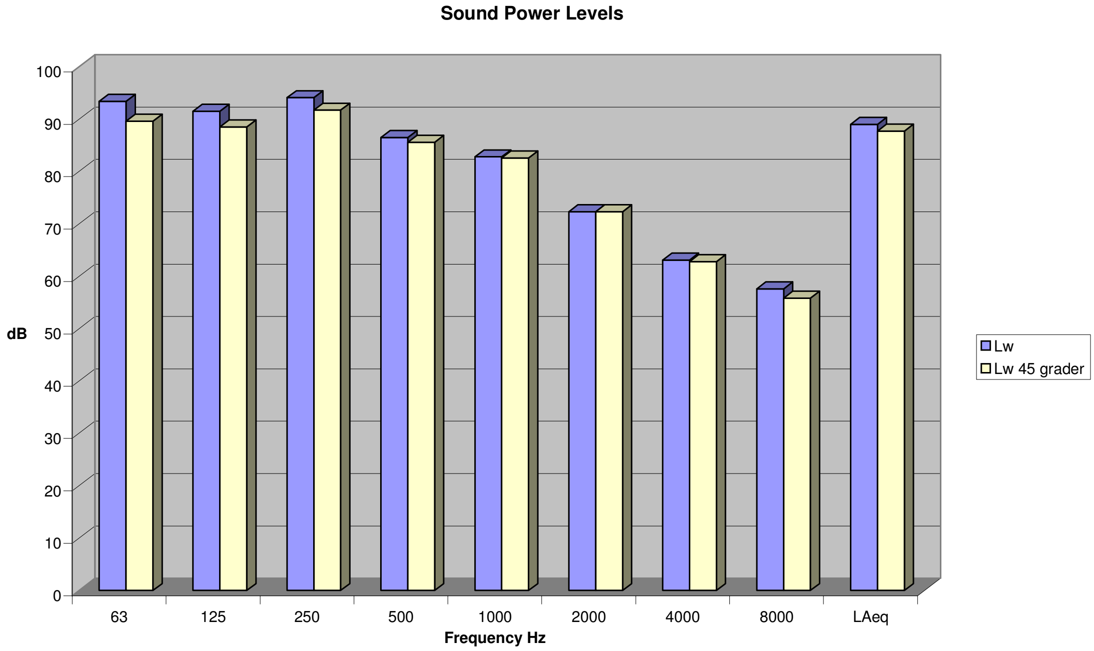
X	Y	Z	angle XY	angle Z
-1.9	0.0	-0.6	180.0	-16.0
1.0	1.7	-0.6	60.0	-16.0
1.0	-1.7	-0.6	300.0	-16.0
2.0	0.0	0.4	0.0	10.1
-1.0	1.7	0.4	120.0	10.1
-1.0	-1.7	0.4	240.0	10.1
-1.6	0.0	1.3	180.0	38.7
0.8	1.4	1.3	60.0	38.7
0.8	-1.4	1.3	300.0	38.7
0.0	0.0	2.0	NaN	90.0



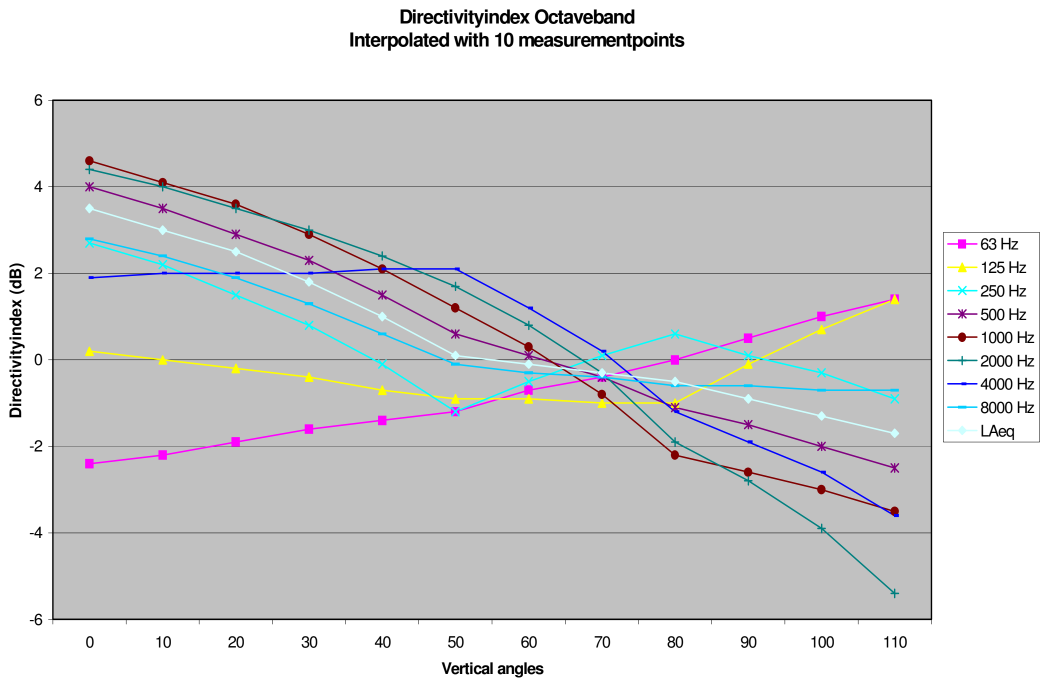
Area	37.7
Meas. radius	2.0
Source radius	0.5
Source height	1.0
No. of meas. Points, Z axis	4.0
No. of meas. Points, XY axis	3.0

Results:

Point no.	63 Hz	125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz	8 kHz	LAeq
1	78,6	77,4	78,2	69,6	65,8	52,1	44,3	41,1	72.6
2	79,7	77,9	78,3	66,8	61,9	50,7	44,5	41,1	71.6
3	78,7	76	75,3	67,8	61,6	50,1	42,3	41,1	70.0
4	77,8	73,8	80,2	72	67,1	56,4	47,1	41,4	74.4
5	78,4	75,6	79,3	68,2	63,3	53,2	45,4	41,1	72.5
6	76,5	74,5	76,7	67	62,6	53,4	45,7	41,1	70.6
7	76,3	75,5	79	72,7	70,8	60,2	51,1	42,2	75.3
8	76,9	74,9	76,6	70,5	66,3	57,2	48,8	41,4	72.3
9	76,2	74	74,8	70,2	65,8	56,2	47,9	41,3	71.4
10	75,2	75,9	81,1	74,7	71,7	60,9	49,3	44,6	76.8



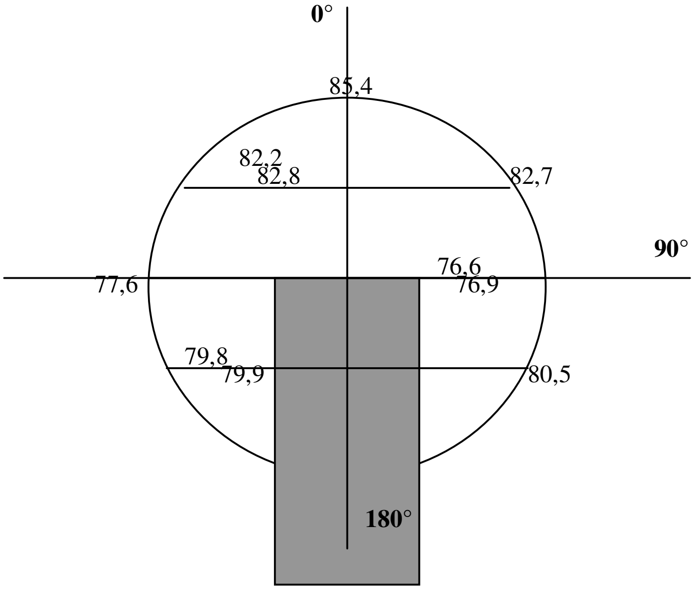
Sound Power Levels
dB
100
90
80
70
60
50
40
30
20
10
0
63
125
250
500
1000
2000
4000
8000
LAeq
Frequency Hz
Lw
Lw 45 grader



Directivityindex Octaveband
Interpolated with 10 measurementpoints
Directivityindex (dB)
6
4
2
0
-2
-4
-6
0
10
20
30
40
50
60
70
80
90
100
110
Vertical angles
63 Hz
125 Hz
250 Hz
500 Hz
1000 Hz
2000 Hz
4000 Hz
8000 Hz
LAeq

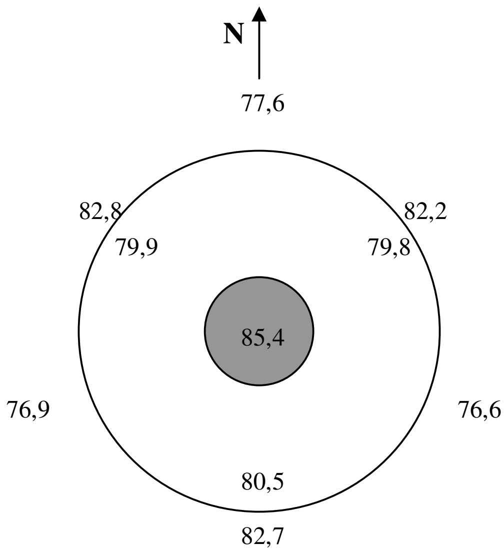
Klippan AB, Mölndal 041014
Source no; 17, Exhaust on roof.

Comment: Downward airflow present.



Measurement positions:

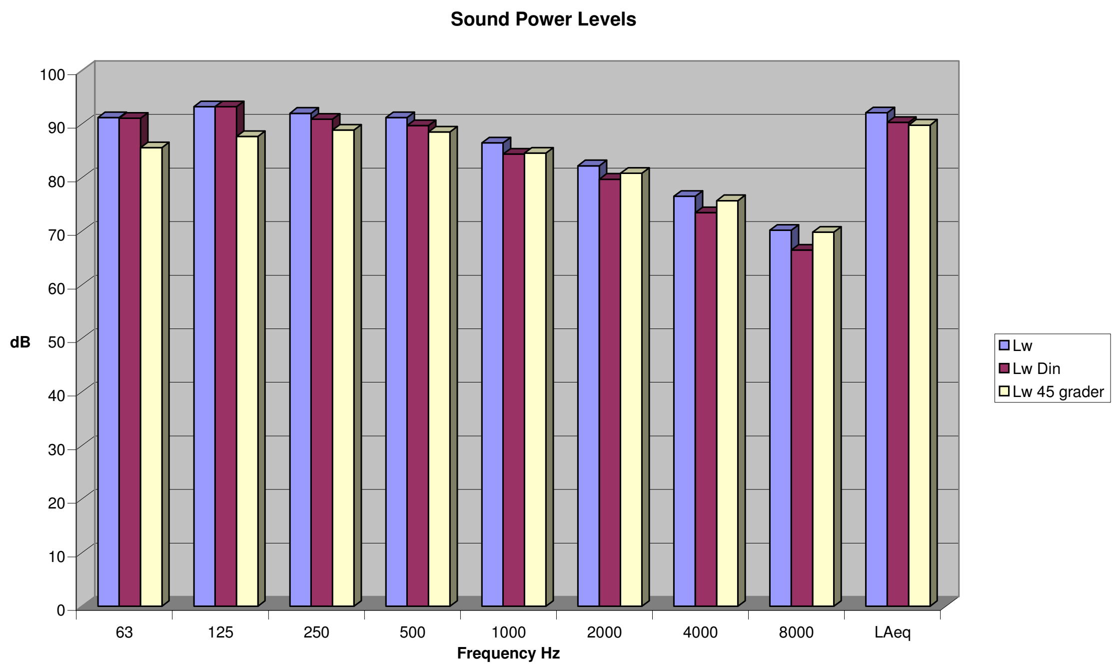
X	Y	Z	angle XY	angle Z
-0.8	0.0	-0.6	180.0	-39.0
0.4	0.7	-0.6	60.0	-39.0
0.4	-0.7	-0.6	300.0	-39.0
1.0	0.0	-0.1	0.0	-3.1
-0.5	0.9	-0.1	120.0	-3.1
-0.5	-0.9	-0.1	240.0	-3.1
-0.9	0.0	0.5	180.0	31.4
0.4	0.7	0.5	60.0	31.4
0.4	-0.7	0.5	300.0	31.4
0.0	0.0	1.0	NaN	90.0



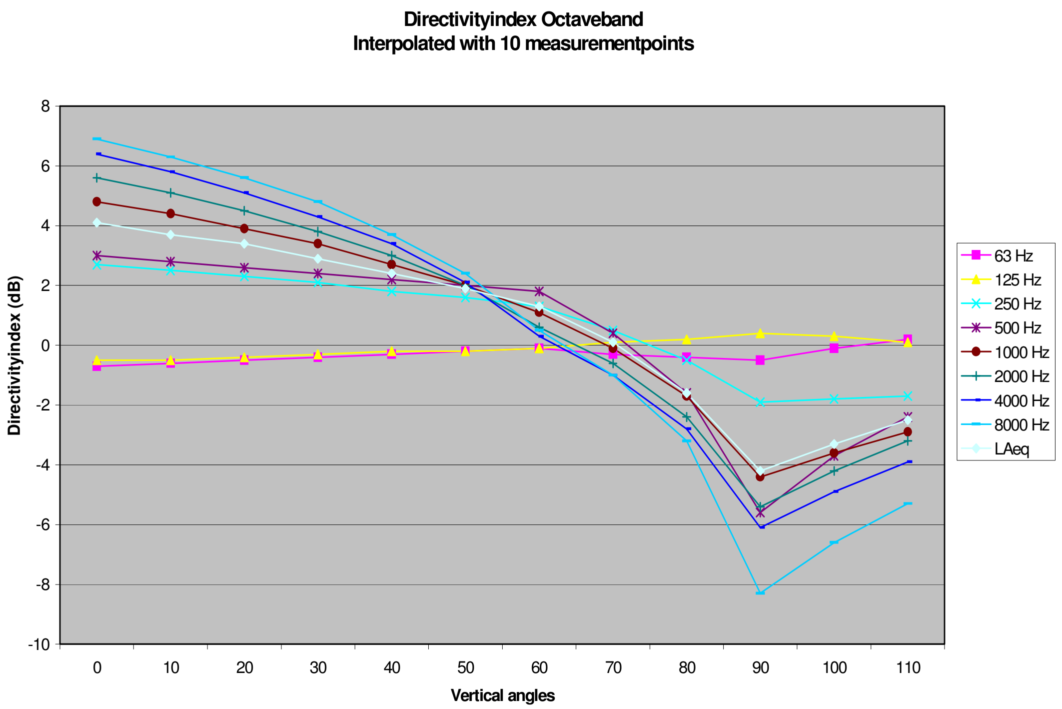
Area	12.0
Meas. radius	1.0
Source radius	0.4
Source height	5.0
No. of meas. Points, Z axis	4.0
No. of meas. Points, XY axis	3.0

Results:

Point no.	63 Hz	125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz	8 kHz	LAeq
1	81,3	81,9	80	80,7	74,1	69,2	63,3	55,8	80.5
2	80,4	82,3	79,1	79,8	73,6	69,3	62,7	55,3	79.9
3	81,5	82,6	79,9	78,8	73,8	70,3	63,7	56,5	79.8
4	79,6	83,2	79,8	75,5	71,8	66,4	60,4	51,7	77.6
5	79,9	82,2	79,1	73,8	71,9	66,2	59,5	50,9	76.9
6	80,1	83	78,9	75	70	65,2	58,8	50,7	76.6
7	80,7	82,6	82,4	82,8	76,4	71,9	66,1	60,4	82.7
8	80,1	82	82,7	82,1	77,4	72,4	66,6	60,4	82.8
9	79,8	82,3	82,4	81,7	76,5	71,6	65,3	58,9	82.2
10	79,7	81,9	83,9	83,4	80,5	77	72,1	66,3	85.4



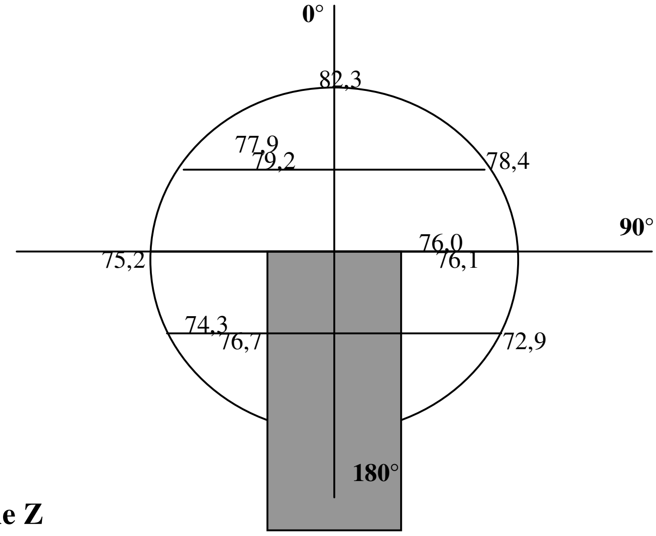
Sound Power Levels
dB
100
90
80
70
60
50
40
30
20
10
0
63
125
250
500
1000
2000
4000
8000
LAeq
Frequency Hz
Lw
Lw Din
Lw 45 grader



Directivityindex Octaveband
Interpolated with 10 measurementpoints
Directivityindex (dB)
8
6
4
2
0
-2
-4
-6
-8
-10
0
10
20
30
40
50
60
70
80
90
100
110
Vertical angles
63 Hz
125 Hz
250 Hz
500 Hz
1000 Hz
2000 Hz
4000 Hz
8000 Hz
LAeq

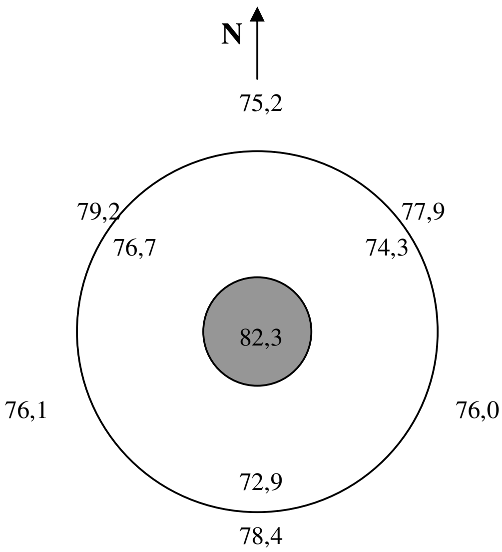
Klippan AB, Mölndal 041014
Source no; 18, Exhaust on roof.

Comment: The source lets out a large amount of steam. Two obstacles present (likely to generate reflections), in the angles 60 and 180 degrees.



Measurement positions:

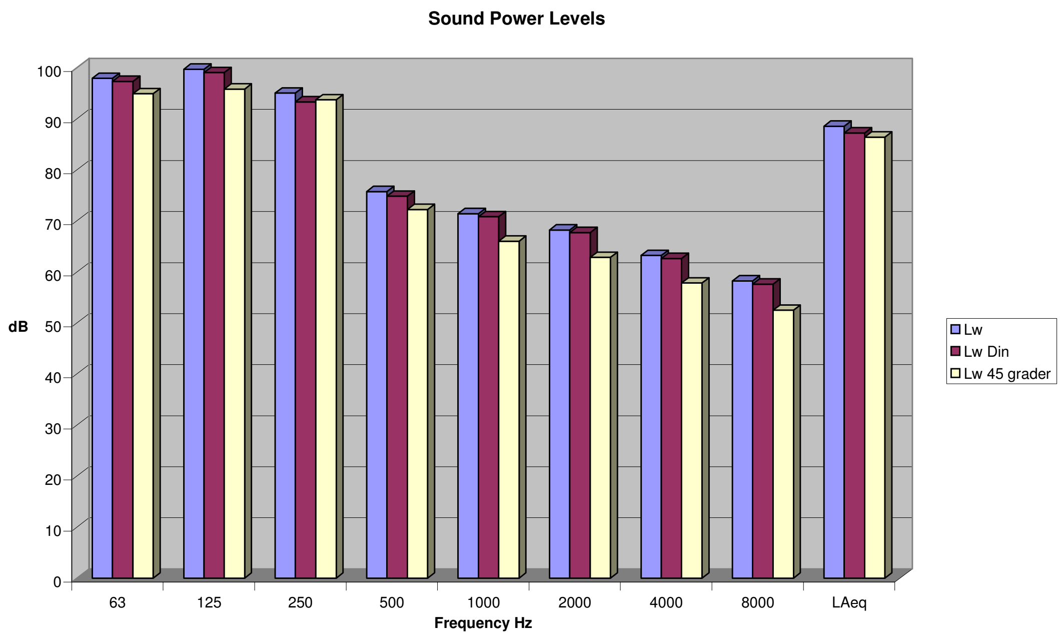
X	Y	Z	angle XY	angle Z
-0.8	0.0	-0.6	180.0	-39.0
0.4	0.7	-0.6	60.0	-39.0
0.4	-0.7	-0.6	300.0	-39.0
1.0	0.0	-0.1	0.0	-3.1
-0.5	0.9	-0.1	120.0	-3.1
-0.5	-0.9	-0.1	240.0	-3.1
-0.9	0.0	0.5	180.0	31.4
0.4	0.7	0.5	60.0	31.4
0.4	-0.7	0.5	300.0	31.4
0.0	0.0	1.0	NaN	90.0

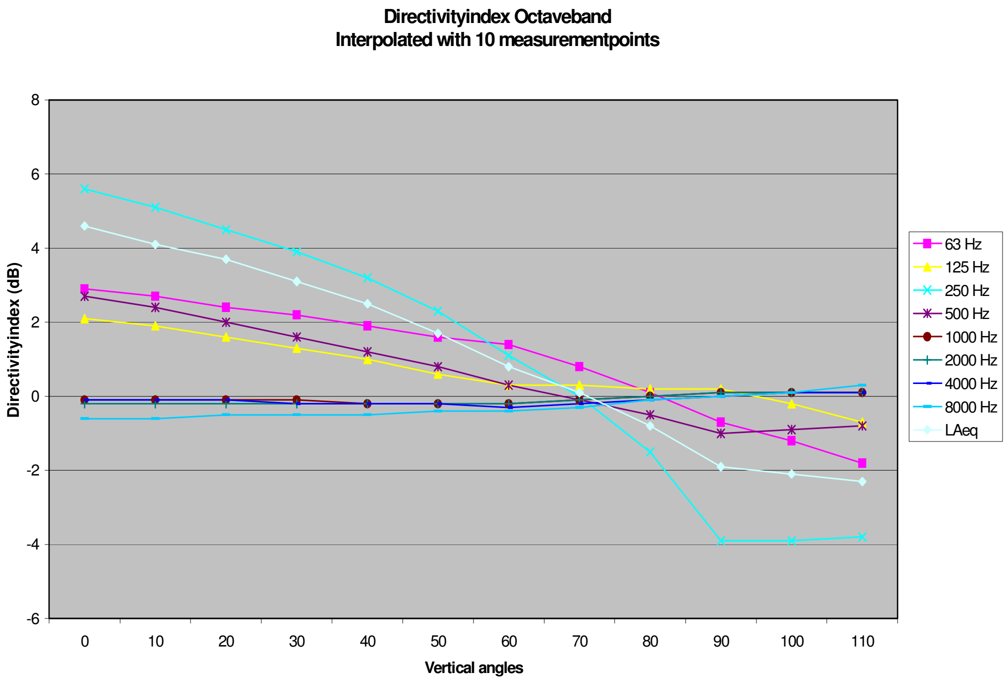


Area	12.0
Meas. radius	1.0
Source radius	0.4
Source height	5.0
No. of meas. Points, Z axis	4.0
No. of meas. Points, XY axis	3.0

Results:

Point no.	63 Hz	125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz	8 kHz	LAeq
1	83,8	85	77,4	64,8	61,6	58,4	53,9	49,2	72.9
2	84	87,9	83,3	64,1	59,4	54,9	50,1	44,4	76.7
3	83,6	87,9	77,9	63,7	60,7	58,5	53,1	48,8	74.3
4	86,6	89,7	77,1	63,1	60,1	57,4	52,2	47,4	75.2
5	86,2	89	81,3	64,3	61,1	56,9	52,4	47,3	76.1
6	86,5	88,4	81,4	64,3	60,8	58,3	52,6	47,4	76.0
7	88,4	89	85,2	65,3	60,4	57,1	52,3	47,3	78.4
8	88,5	89,1	86,4	65,3	60,1	56,6	51,9	46,8	79.2
9	88,5	89,3	84,2	65	60,6	57,9	52,2	46,8	77.9
10	90	91	89,8	67,6	60,5	57,2	52,3	46,8	82.3


Sound Power Levels
100
90
80
70
60
50
40
30
20
10
0
dB
63
125
250
500
1000
2000
4000
8000
LAeq
Frequency Hz
Lw
Lw Din
Lw 45 grader


Directivityindex Octaveband
Interpolated with 10 measurementpoints
8
6
4
2
0
-2
-4
-6
Directivityindex (dB)
0
10
20
30
40
50
60
70
80
90
100
110
Vertical angles
63 Hz
125 Hz
250 Hz
500 Hz
1000 Hz
2000 Hz
4000 Hz
8000 Hz
LAeq

Appendix 2

Matlab programs
In this appendix the m-files constructed and used during the work are presented.

File for calculating measurement coordinates

```
%Läser in data om källan från filen matdata.txt Om filen ej
%finns frågar programet om värdena.

val=0;
cd ([katalog])
finns=exist('matdata.txt');
cd ..
   if finns==2;
      cd ([katalog])
      load matdata.txt
      cd ..
      radius=matdata(1,1)
      skorstensradie=matdata(1,2)
      skorstenshojd=matdata(1,3)
      antalpunkterizled=matdata(1,4)
      antalpunkterixyled=matdata(1,5)
   else
      while val==0
         radius=input('ange radie på mätytan: ');
         skorstensradie=input('ange radie på källan: ');
         skorstenshojd=input('ange höjden på källan: ');
         antalpunkterizled=input('Antal punkter i z-led: ');
         antalpunkterixyled=input('Antal punkter xy-led: ');
         val=input('är du nöjd ja=1 nej=0: ');
      end
   end
save koordinatdata radius skorstensradie skorstenshojd antalpunkterizled
antalpunkterixyled
% Räknar ut jämt fördelade punkter i en sfär med mittpunkt i mitten av
% öppningen på källan. Sen vänder man punkterna i xyplanet i varannan höjd
% genom att vända y axeln.

vinkel=0;
k=0;
antalpunkter=antalpunkterixyled*(antalpunkterizled-1)+1;

if skorstenshojd<radius
   area=(2*pi*radius^2+pi*2*radius*skorstenshojd);
   hojd=skorstenshojd+radius;
   nivohojd=0;
else
   area=(2*pi*radius^2+pi*2*radius*(sqrt(radius^2-skorstensradie^2)));
   hojd=radius+(sqrt(radius^2-skorstensradie^2));
   nivohojd=skorstenshojd-(sqrt(radius^2-skorstensradie^2));
end
```

continues...

```
punktarea=area/antalpunkter;
hojdtoppunkt=punktarea/(2*pi*radius);
hojdkvar=hojd-hojdtoppunkt;
delhojd=hojdkvar/(antalpunkterizled-1);

koordinater=zeros(antalpunkter-1,3);
it=1;
for iter=1:antalpunkterizled-1
    zkoordinater(1:antalpunkterixyled,iter)=nivohojd+delhojd/2;
    nivohojd=nivohojd+delhojd;
    koordinater(it:it+antalpunkterixyled-1,3)=zkoordinater(:,iter);
    it=it+antalpunkterixyled;
end

koordinater(:,3)=koordinater(:,3)-skorstenshojd;
vinkelandring=2*pi/antalpunkterixyled;

for xyiter=0:antalpunkterixyled:antalpunkter-antalpunkterixyled
   vinkel=0;
   rr=sqrt(radius^2-koordinater(xyiter+1,3)^2);
   for vinkeliter=1:antalpunkterixyled
       koordinater(xyiter+vinkeliter,1)=rr*cos(vinkel);
       koordinater(xyiter+vinkeliter,2)=rr*sin(vinkel);
       vinkel=vinkel+vinkelandring;
   end
   vinkeliter=1;
end

koordinater(antalpunkter,:)=[0,0,radius];
an=size(koordinater);
an=an(1);

for tt=1:antalpunkterixyled*2:an-1
     koordinater(tt:tt+antalpunkterixyled-1,1)=koordinater(tt:tt+antalpunkterixyled-1,1).*-1;
end

matkoordinater=koordinater;
matkoordinater(:,3)=[koordinater(:,3)+skorstenshojd];
matkoordinater=matkoordinater*10;
matkoordinater=round(matkoordinater);
matkoordinater=matkoordinater/10;
x,y,z]=cylinder(skorstensradie,20);
z=z*skorstenshojd;

for vink=1:(antalpunkterizled-1)*antalpunkterixyled+1

vinkelmatris(vink,1)=acos(koordinater(vink,1)/sqrt(koordinater(vink,1)^2+koordinater(vink,2)^2));

vinkelmatris(vink,2)=atan(koordinater(vink,3)/sqrt(koordinater(vink,1)^2+koordinater(vink,2)^2));
    if koordinater(vink,2)<0;
        vinkelmatris(vink,1)=2*pi-vinkelmatris(vink,1);
    end
end

vinkelmatris=vinkelmatris.*(180/pi);
vinklarkoordinater=[koordinater,vinkelmatris];
vinklarkoordinater(:,6)=[area];
```

continues...

```
vinklarkoordinater(:,7)=zeros(antalpunkter,1);
vinklarkoordinater(1:5,7)=[radius;skorstensradie;skorstenshojd;antalpunkterizled;antalpunk
terixyled];

%Sparar ner data om källan.

cd ([katalog])
matdata=vinklarkoordinater(1:5,7);
fp=fopen('matdata.txt','w+');
fprintf(fp,'%4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f',matdata);
fclose(fp);

save area.txt area -ascii
cd ..
```

File for reading measurement results and coordinates

```
cd ([katalog])

%Läser in data från filer med mätresultat och bakgrund.

punktkoordinater=koordinater;
load matresultat.txt
load matresultatbakgrund.txt
radius=vinklarkoordinater(1,7);
skorstenradie=vinklarkoordinater(2,7);
punkterresultat=[punktkoordinater,matresultat];
cd ..
```

File for calculating the directivity indices according to ISO 3744-2

```
%calculation of sound pressure level average over surface
r=0;
storlek=size(punkterresultat);
antalpunkter=storlek(1,1);
direktivitetindex=punkterresultat;   %3 första kolumner är koordinater. dom andra skrivs
över skrivs det över
for r=5:13
    summa=sum(10.^(0.1.*punkterresultat(1:antalpunkter,r)));
    medelLpokorrigerad=10*log10((summa/antalpunkter));
    summabakgrund=sum(10.^(0.1.*matresultatbakgrund(1:antalpunkter,r-3)));
    medelLpbakgrund=10*log10((summabakgrund/antalpunkter));
    medelLp=medelLpokorrigerad-(-10*log10(1-10^(-0.1*(medelLpokorrigerad-
medelLpbakgrund))));
    punkterresultat(antalpunkter+1,r)=medelLp;
    punkterresultat(antalpunkter+2,r)=medelLp+10*log10(area/1);
    v=0;

    %loop som korrigerar varje punkt för bakgrund men högst med -1.3 dB och
    %räknar ut DI enl appendix E
```

continues...

```
for v=1:antalpunkter
        deltapressure=(punkterresultat(v,r)-matresultatbakgrund(v,r-3));
        if deltapressure~=0
            matnivokorrigeradbakgrund=punkterresultat(v,r)-(-10*log10(1-10^(-
0.1*deltapressure)));
        end
        if deltapressure <= 15 & deltapressure >= 6;
            direktivitetindex(v,r)=matnivokorrigeradbakgrund-medelLp;
        end
        if  deltapressure > 15
            direktivitetindex(v,r)=punkterresultat(v,r)-medelLp;
        end
        if  deltapressure < 6
            direktivitetindex(v,r)=(punkterresultat(v,r)-1.3)-medelLp;
        end
    end
end
Lpaverage=punkterresultat(antalpunkter+1,:);
Lw=punkterresultat(antalpunkter+2,:);
```

File for calculating the sound power level using DIN 45635-47 as well as the consultants method and interpolating the directivity indices for the 36*18 matrix used in Soundplan

```
peteryta=input('input vilken yta skulle peter använt ? 2 = 2*pi*r^2 4 = 4*pi*r^2 ');
%*pi*raqdius^2
cd ([katalog])
for loopar=5:13
    punkter=[direktivitetindex(:,1:3),direktivitetindex(:,loopar)];


    punkter(:,4)=(2e-5)^2.*10.^(punkter(:,4)./10);
    punktmatris=zeros(20,37);
    punktmatris=(2e-5)^2.*10.^(punktmatris./10);
    punktmatris(1,:)=[0,0:10:350];

punktmatris(:,1)=[0;0;10;20;30;40;50;60;70;80;90;100;110;120;130;140;150;160;170;180];
    antal=size(punkter);
    antalpunkter=antal(1);

%loop som sätter in matpunkternas direktivitet i sounplan tabell

for n=1:antalpunkter
    if punkter(n,1)>0
        a=1;
        vinkelxy=(180/pi)*atan(punkter(n,2)/punkter(n,1));
        if punkter(n,2)<0
        vinkelxy=360+vinkelxy;
        end
    end

    if punkter(n,1)<0
        %b=1
        vinkelxy=atan(punkter(n,2)/punkter(n,1));
        vinkelxy=180+(180/pi)*vinkelxy;
    end

    if punkter(n,1)==0 & punkter(n,2)==0
        %c=3
        vinkelxy=0;
    end
```

continues...

```
vinkelz=(180/pi)*atan(punkter(n,3)/sqrt(punkter(n,1)^2+punkter(n,2)^2));
    vinkelxy=round(vinkelxy/10);
    vinkelz=round(vinkelz/10);

    punktmatris(9-vinkelz+2,vinkelxy+2)=punkter(n,4);

end

%Loopar som intepolerar direktivitet för alla vinklar Först i xy axeln sen
%z axeln.

antalkolumner=37;
antalrader=18;


for m=2:antalrader+2

    vektor=punktmatris(m,2:antalkolumner);
    vektor=[vektor,vektor];
    a=0;
    mellanrum=0;
    varde1=0;
    koll=0;
    nollstart=0;
    for k=1:(antalkolumner-1)*2
        if 10*log10(vektor(1,k)/(2e-5)^2)~=0
            a=a+1;
            varde2=vektor(1,k);
            koll=1;
            if 10*log10(varde1/(2e-5)^2)~=0
                skillnadvarjesteg=abs(varde1-varde2)/(mellanrum+1);
                for t=1:mellanrum
                   if varde2>varde1
                        vektor(1,k-t)=vektor(1,k-t+1)-skillnadvarjesteg;
                    else
                        vektor(1,k-t)=vektor(1,k-t+1)+skillnadvarjesteg;
                    end
                end

                mellanrum=0;
            end
            a=1;
            varde1=varde2;
        end

        if 10*log10(vektor(1,k)/(2e-5)^2)==0
            mellanrum=mellanrum+1;

        end
        if koll==0

            nollstart=nollstart+1;
            mellanrum=0;
            if k>(antalkolumner)*2/2
               nollstart=antalkolumner-2;
           end
        end


    end
```

continues...

```
vektor2=[vektor((k/2+1):k/2+nollstart),vektor(nollstart+1:k/2)];
punktmatris(m,2:antalkolumner)=vektor2;
end
punktmatris=punktmatris';


antalkolumner=20;
antalrader=35;
m=0;
k=0;
t=0;
for m=2:(antalrader+2)


    vektor=punktmatris(m,2:antalkolumner);

    a=0;
    mellanrum=0;
    varde1=0;
    koll=0;
    nollstart=0;
    for k=1:(antalkolumner-1)
        if 10*log10(vektor(1,k)/(2e-5)^2)~=0
            a=a+1;
            varde2=vektor(1,k);
            koll=1;
            if 10*log10(varde1/(2e-5)^2)~=0
                skillnadvarjesteg=abs(varde1-varde2)/(mellanrum+1);
                for t=1:mellanrum
                   if varde2>varde1
                        vektor(1,k-t)=vektor(1,k-t+1)-skillnadvarjesteg;
                    else
                        vektor(1,k-t)=vektor(1,k-t+1)+skillnadvarjesteg;
                    end
                end

                mellanrum=0;
            end
            a=1;
            varde1=varde2 ;
        end

        if 10*log10(vektor(1,k)/(2e-5)^2)==0
            mellanrum=mellanrum+1;

        end
        if koll==0

            nollstart=nollstart+1;
            mellanrum=0;
            if k>(antalkolumner)*2/2
               nollstart=antalkolumner-2;
           end
        end

    end

punktmatris(m,2:antalkolumner)=vektor;

end
```

continues...

```
punktmatris=punktmatris';
punktmatris(2:20,2:37)=10.*log10(punktmatris(2:20,2:37)./(2e-5)^2);
punktmatris=punktmatris';

%% Massa if satser som sparar ner filer. borde vara en med filnamn som
%% ändrar sig. Skall göra om tid finns.



   if loopar==4
      cd direktivitet
      din=0;
      for din=2:37
         dinLp1=punktmatris(din,9)+Lpaverage(loopar);
         dinLp2=punktmatris(din,13)+Lpaverage(loopar);
         dinLp1=dinLp1+10*log10(radius^2/(skorstenradie+1)^2);
         dinLp2=dinLp2+10*log10(radius^2/(skorstenradie+1)^2);
         dinS1=2*pi*(skorstenradie+1)^2;
         dinS2=2*pi*radius*sqrt((skorstenradie+1)^2-skorstenradie^2);
         dinLw1=dinLp1+10*log10(dinS1);
         dinLw2=dinLp2+10*log10(dinS2);
         dinLw(din-1,loopar-4)=10*log10(10^(dinLw1/10)+10^(dinLw2/10));
         riktigvinkel=atan((sqrt(2)/2)/(skorstenradie+(sqrt(2)/2)));
         riktigavstand=(sqrt(2)/2)/sin(riktigvinkel);
         riktigvinkel=round((180/pi)*riktigvinkel/10);
         Lppeterpunkt=punktmatris(din,riktigvinkel+2)+Lpaverage(loopar);
         Lppeterpunkt=Lppeterpunkt+10*log10(radius^2/riktigavstand^2);
         Lwpeterpunkt(din-1,loopar-4)=Lppeterpunkt+10*log10(peteryta*pi*1^2);
      end
      %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%5


      fp=fopen('direktivitet31.txt','w+');
      fprintf(fp,'%4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t
%4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f
\n',punktmatris');
      fclose(fp);
      cd ..
   end
   if loopar==5
      cd direktivitet
      din=0;
      for din=2:37
         dinLp1=punktmatris(din,9)+Lpaverage(loopar);
         dinLp2=punktmatris(din,13)+Lpaverage(loopar);
         dinLp1=dinLp1+10*log10(radius^2/(skorstenradie+1)^2);
         dinLp2=dinLp2+10*log10(radius^2/(skorstenradie+1)^2);
         dinS1=2*pi*(skorstenradie+1)^2;
         dinS2=2*pi*radius*sqrt((skorstenradie+1)^2-skorstenradie^2);
         dinLw1=dinLp1+10*log10(dinS1);
         dinLw2=dinLp2+10*log10(dinS2);
         dinLw(din-1,loopar-4)=10*log10(10^(dinLw1/10)+10^(dinLw2/10));
         riktigvinkel=atan((sqrt(2)/2)/(skorstenradie+(sqrt(2)/2)));
         riktigavstand=(sqrt(2)/2)/sin(riktigvinkel);
         riktigvinkel=round((180/pi)*riktigvinkel/10);
         Lppeterpunkt=punktmatris(din,riktigvinkel+2)+Lpaverage(loopar);
         Lppeterpunkt=Lppeterpunkt+10*log10(radius^2/riktigavstand^2);
         Lwpeterpunkt(din-1,loopar-4)=Lppeterpunkt+10*log10(peteryta*pi*1^2);
      end
      %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%5
```

continues...

```
fp=fopen('direktivitet63.txt','w+');
        fprintf(fp,'%4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t
%4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f
\n',punktmatris');
        fclose(fp);
        cd ..
    end
    if loopar==6
        cd direktivitet
        din=0;
        for din=2:37
            dinLp1=punktmatris(din,9)+Lpaverage(loopar);
            dinLp2=punktmatris(din,13)+Lpaverage(loopar);
            dinLp1=dinLp1+10*log10(radius^2/(skorstenradie+1)^2);
            dinLp2=dinLp2+10*log10(radius^2/(skorstenradie+1)^2);
            dinS1=2*pi*(skorstenradie+1)^2;
            dinS2=2*pi*radius*sqrt((skorstenradie+1)^2-skorstenradie^2);
            dinLw1=dinLp1+10*log10(dinS1);
            dinLw2=dinLp2+10*log10(dinS2);
            dinLw(din-1,loopar-4)=10*log10(10^(dinLw1/10)+10^(dinLw2/10));
            riktigvinkel=atan((sqrt(2)/2)/(skorstenradie+(sqrt(2)/2)));
            riktigavstand=(sqrt(2)/2)/sin(riktigvinkel);
            riktigvinkel=round((180/pi)*riktigvinkel/10);
            Lppeterpunkt=punktmatris(din,riktigvinkel+2)+Lpaverage(loopar);
            Lppeterpunkt=Lppeterpunkt+10*log10(radius^2/riktigavstand^2);
            Lwpeterpunkt(din-1,loopar-4)=Lppeterpunkt+10*log10(peteryta*pi*1^2);
        end
        %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%5
        fp=fopen('direktivitet125.txt','w+');
        fprintf(fp,'%4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t
%4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f
\n',punktmatris');
        fclose(fp);
        cd ..
    end
    if loopar==7
        cd direktivitet
        din=0;
        for din=2:37
            dinLp1=punktmatris(din,9)+Lpaverage(loopar);
            dinLp2=punktmatris(din,13)+Lpaverage(loopar);
            dinLp1=dinLp1+10*log10(radius^2/(skorstenradie+1)^2);
            dinLp2=dinLp2+10*log10(radius^2/(skorstenradie+1)^2);
            dinS1=2*pi*(skorstenradie+1)^2;
            dinS2=2*pi*radius*sqrt((skorstenradie+1)^2-skorstenradie^2);
            dinLw1=dinLp1+10*log10(dinS1);
            dinLw2=dinLp2+10*log10(dinS2);
            dinLw(din-1,loopar-4)=10*log10(10^(dinLw1/10)+10^(dinLw2/10));
            riktigvinkel=atan((sqrt(2)/2)/(skorstenradie+(sqrt(2)/2)));
            riktigavstand=(sqrt(2)/2)/sin(riktigvinkel);
            riktigvinkel=round((180/pi)*riktigvinkel/10);
            Lppeterpunkt=punktmatris(din,riktigvinkel+2)+Lpaverage(loopar);
            Lppeterpunkt=Lppeterpunkt+10*log10(radius^2/riktigavstand^2);
             Lwpeterpunkt(din-1,loopar-4)=Lppeterpunkt+10*log10(peteryta*pi*1^2);
        end
        %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%5
        fp=fopen('direktivitet250.txt','w+');
```

continues...

```
fprintf(fp,'%4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f
\t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f
\n',punktmatris');
        fclose(fp);
        cd ..
    end
    if loopar==8
        cd direktivitet
                %dinutrakningaveffekt
        din=0;
        for din=2:37
            dinLp1=punktmatris(din,9)+Lpaverage(loopar);
            dinLp2=punktmatris(din,13)+Lpaverage(loopar);
            dinLp1=dinLp1+10*log10(radius^2/(skorstenradie+1)^2);
            dinLp2=dinLp2+10*log10(radius^2/(skorstenradie+1)^2);
            dinS1=2*pi*(skorstenradie+1)^2;
            dinS2=2*pi*radius*sqrt((skorstenradie+1)^2-skorstenradie^2);
            dinLw1=dinLp1+10*log10(dinS1);
            dinLw2=dinLp2+10*log10(dinS2);
            dinLw(din-1,loopar-4)=10*log10(10^(dinLw1/10)+10^(dinLw2/10));
            riktigvinkel=atan((sqrt(2)/2)/(skorstenradie+(sqrt(2)/2)));
            riktigavstand=(sqrt(2)/2)/sin(riktigvinkel);
            riktigvinkel=round((180/pi)*riktigvinkel/10);
            Lppeterpunkt=punktmatris(din,riktigvinkel+2)+Lpaverage(loopar);
            Lppeterpunkt=Lppeterpunkt+10*log10(radius^2/riktigavstand^2);
            Lwpeterpunkt(din-1,loopar-4)=Lppeterpunkt+10*log10(peteryta*pi*1^2);
        end
        %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%5
        fp=fopen('direktivitet500.txt','w+');
        fprintf(fp,'%4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t
%4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f
\n',punktmatris');
        fclose(fp);
        cd ..
    end
    if loopar==9
        cd direktivitet
        din=0;
        for din=2:37
            dinLp1=punktmatris(din,9)+Lpaverage(loopar);
            dinLp2=punktmatris(din,13)+Lpaverage(loopar);
            dinLp1=dinLp1+10*log10(radius^2/(skorstenradie+1)^2);
            dinLp2=dinLp2+10*log10(radius^2/(skorstenradie+1)^2);
            dinS1=2*pi*(skorstenradie+1)^2;
            dinS2=2*pi*radius*sqrt((skorstenradie+1)^2-skorstenradie^2);
            dinLw1=dinLp1+10*log10(dinS1);
            dinLw2=dinLp2+10*log10(dinS2);
            dinLw(din-1,loopar-4)=10*log10(10^(dinLw1/10)+10^(dinLw2/10));
            riktigvinkel=atan((sqrt(2)/2)/(skorstenradie+(sqrt(2)/2)));
            riktigavstand=(sqrt(2)/2)/sin(riktigvinkel);
            riktigvinkel=round((180/pi)*riktigvinkel/10);
            Lppeterpunkt=punktmatris(din,riktigvinkel+2)+Lpaverage(loopar);
            Lppeterpunkt=Lppeterpunkt+10*log10(radius^2/riktigavstand^2);
            Lwpeterpunkt(din-1,loopar-4)=Lppeterpunkt+10*log10(peteryta*pi*1^2);
        end
        %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

continues...

```
fp=fopen('direktivitet1000.txt','w+');
        fprintf(fp,'%4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t
%4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f
\n',punktmatris');
        fclose(fp);
        cd ..
    end
    if loopar==10
        cd direktivitet
                %dinutrakningaveffekt
        din=0;
        for din=2:37
            dinLp1=punktmatris(din,9)+Lpaverage(loopar);
            dinLp2=punktmatris(din,13)+Lpaverage(loopar);
            dinLp1=dinLp1+10*log10(radius^2/(skorstenradie+1)^2);
            dinLp2=dinLp2+10*log10(radius^2/(skorstenradie+1)^2);
            dinS1=2*pi*(skorstenradie+1)^2;
            dinS2=2*pi*radius*sqrt((skorstenradie+1)^2-skorstenradie^2);
            dinLw1=dinLp1+10*log10(dinS1);
            dinLw2=dinLp2+10*log10(dinS2);
            dinLw(din-1,loopar-4)=10*log10(10^(dinLw1/10)+10^(dinLw2/10));
            riktigvinkel=atan((sqrt(2)/2)/(skorstenradie+(sqrt(2)/2)));
            riktigavstand=(sqrt(2)/2)/sin(riktigvinkel);
            riktigvinkel=round((180/pi)*riktigvinkel/10);
            Lppeterpunkt=punktmatris(din,riktigvinkel+2)+Lpaverage(loopar);
            Lppeterpunkt=Lppeterpunkt+10*log10(radius^2/riktigavstand^2);
            Lwpeterpunkt(din-1,loopar-4)=Lppeterpunkt+10*log10(peteryta*pi*1^2);
        end
        %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%5
        fp=fopen('direktivitet2000.txt','w+');
        fprintf(fp,'%4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t
%4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f
\n',punktmatris');
        fclose(fp);
        cd ..
    end
    if loopar==11
        cd direktivitet
        din=0;
        for din=2:37
            dinLp1=punktmatris(din,9)+Lpaverage(loopar);
            dinLp2=punktmatris(din,13)+Lpaverage(loopar);
            dinLp1=dinLp1+10*log10(radius^2/(skorstenradie+1)^2);
            dinLp2=dinLp2+10*log10(radius^2/(skorstenradie+1)^2);
            dinS1=2*pi*(skorstenradie+1)^2;
            dinS2=2*pi*radius*sqrt((skorstenradie+1)^2-skorstenradie^2);
            dinLw1=dinLp1+10*log10(dinS1);
            dinLw2=dinLp2+10*log10(dinS2);
            dinLw(din-1,loopar-4)=10*log10(10^(dinLw1/10)+10^(dinLw2/10));
            riktigvinkel=atan((sqrt(2)/2)/(skorstenradie+(sqrt(2)/2)));
            riktigavstand=(sqrt(2)/2)/sin(riktigvinkel);
            riktigvinkel=round((180/pi)*riktigvinkel/10);
            Lppeterpunkt=punktmatris(din,riktigvinkel+2)+Lpaverage(loopar);
            Lppeterpunkt=Lppeterpunkt+10*log10(radius^2/riktigavstand^2);
            Lwpeterpunkt(din-1,loopar-4)=Lppeterpunkt+10*log10(peteryta*pi*1^2);
        end
        %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

continues...

```
fp=fopen('direktivitet4000.txt','w+');
        fprintf(fp,'%4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t
%4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f
\n',punktmatris');
        fclose(fp);
        cd ..
    end
    if loopar==12
        cd direktivitet
        din=0;
        for din=2:37
            dinLp1=punktmatris(din,9)+Lpaverage(loopar);
            dinLp2=punktmatris(din,13)+Lpaverage(loopar);
            dinLp1=dinLp1+10*log10(radius^2/(skorstenradie+1)^2);
            dinLp2=dinLp2+10*log10(radius^2/(skorstenradie+1)^2);
            dinS1=2*pi*(skorstenradie+1)^2;
            dinS2=2*pi*radius*sqrt((skorstenradie+1)^2-skorstenradie^2);
            dinLw1=dinLp1+10*log10(dinS1);
            dinLw2=dinLp2+10*log10(dinS2);
            dinLw(din-1,loopar-4)=10*log10(10^(dinLw1/10)+10^(dinLw2/10));
            riktigvinkel=atan((sqrt(2)/2)/(skorstenradie+(sqrt(2)/2)));
            riktigavstand=(sqrt(2)/2)/sin(riktigvinkel);
            riktigvinkel=round((180/pi)*riktigvinkel/10);
            Lppeterpunkt=punktmatris(din,riktigvinkel+2)+Lpaverage(loopar);
            Lppeterpunkt=Lppeterpunkt+10*log10(radius^2/riktigavstand^2);
            Lwpeterpunkt(din-1,loopar-4)=Lppeterpunkt+10*log10(peteryta*pi*1^2);
        end
        %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%5
        fp=fopen('direktivitet8000.txt','w+');
        fprintf(fp,'%4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t
%4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f
\n',punktmatris');
        fclose(fp);
        cd ..
    end
        if loopar==13
        cd direktivitet
        din=0;
        for din=2:37
            dinLp1=punktmatris(din,9)+Lpaverage(loopar);
            dinLp2=punktmatris(din,13)+Lpaverage(loopar);
            dinLp1=dinLp1+10*log10(radius^2/(skorstenradie+1)^2);
            dinLp2=dinLp2+10*log10(radius^2/(skorstenradie+1)^2);
            dinS1=2*pi*(skorstenradie+1)^2;
            dinS2=2*pi*radius*sqrt((skorstenradie+1)^2-skorstenradie^2);
            dinLw1=dinLp1+10*log10(dinS1);
            dinLw2=dinLp2+10*log10(dinS2);
            dinLw(din-1,loopar-4)=10*log10(10^(dinLw1/10)+10^(dinLw2/10));
            riktigvinkel=atan((sqrt(2)/2)/(skorstenradie+(sqrt(2)/2)));
            riktigavstand=(sqrt(2)/2)/sin(riktigvinkel);
            riktigvinkel=round((180/pi)*riktigvinkel/10);
            Lppeterpunkt=punktmatris(din,riktigvinkel+2)+Lpaverage(loopar);
            Lppeterpunkt=Lppeterpunkt+10*log10(radius^2/riktigavstand^2);
            Lwpeterpunkt(din-1,loopar-4)=Lppeterpunkt+10*log10(peteryta*pi*1^2);
        end
        %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

continues...

```
fp=fopen('direktivitettotal.txt','w+');
        fprintf(fp,'%4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t
%4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f
\n',punktmatris');
        fclose(fp);
        cd ..
    end
    zangle=2;
    for zangle=2:20
        summadir=sum(10.^(0.1.*punktmatris(2:37,zangle)));
        medeldbdir(zangle)=10*log10((summadir/36));
    end
    medeldirektivitet(loopar-4,:)=medeldbdir;

summaxyaxeln=sum(10.^(0.1.*punktmatris(2:20,:)));
medelLp=10*log10((summa/antalpunkter));

end

cd direktivitet
oktavbanden=[63,125,250,500,1000,2000,4000,8000,0];
dinvinklar=[0:10:350];
for medelgrej=1:9

    dinLwmedel(1,medelgrej)=10*log10(1/36.*sum(10.^(0.1*dinLw(:,medelgrej))));


Lwpeterpunktmedel(1,medelgrej)=10*log10(1/36.*sum(10.^(0.1*Lwpeterpunkt(:,medelgrej))
));
end

dinLw=[dinvinklar',dinLw];
dinLw=[0,oktavbanden;dinLw];
dinLwmedel=[oktavbanden;dinLwmedel];
Lwpeterpunkt=[dinvinklar',Lwpeterpunkt];
Lwpeterpunkt=[0,oktavbanden;Lwpeterpunkt];
Lwpeterpunktmedel=[oktavbanden;Lwpeterpunktmedel];

Lw=Lw(5:13);
Lpaverage=Lpaverage(5:13);

Lw=[oktavbanden;Lw];
Lpaverage=[oktavbanden;Lpaverage];

Lwdinpeter=[Lw;dinLwmedel(2,:);Lwpeterpunktmedel(2,:)];

medeldirektivitet(:,1)=[oktavbanden'];
vinklarrad1=[0,0:10:180];
medeldirektivitet=[vinklarrad1;medeldirektivitet];
excelfilen=[medeldirektivitet;punktmatris];
fclose(fp);
p=fopen('Lw.txt','w+');
fprintf(fp,'%4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \n',Lw');
fclose(fp);
fp=fopen('Lpaverage.txt','w+');
fprintf(fp,'%4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f
\n',Lpaverage');
fclose(fp);
fp=fopen('Lwpeterpunkt.txt','w+');
```

continues...

```
fprintf(fp,'%4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f
\n',Lwpeterpunkt');
fclose(fp);
fp=fopen('dinLw.txt','w+');
fprintf(fp,'%4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f
\n',dinLw');
fclose(fp);
fp=fopen('Lwpeterpunktmedel.txt','w+');
fprintf(fp,'%4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f
\n',Lwpeterpunktmedel');
fclose(fp);
fp=fopen('dinLwmedel.txt','w+');
fprintf(fp,'%4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f
\n',dinLwmedel');
fclose(fp);
fp=fopen('Lwdinpetermedel.txt','w+');
fprintf(fp,'%4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f
\n',Lwdinpeter');
fclose(fp);
fp=fopen('direktivitetmedel.txt','w+');
fprintf(fp,'%4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f
\t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f
\n',medeldirektivitet');
fclose(fp);
fp=fopen('excelfilen.txt','w+');
fprintf(fp,'%4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f
\t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f \t %4.1f
\n',excelfilen');
fclose(fp);


cd ..
save peteryta peteryta
save data dinLw vinklarkoordinater matresultat Lpaverage Lw area matresultatbakgrund
Lwpeterpunkt Lwpeterpunktmedel dinLwmedel
clear all
load data
cd direktivitet
load direktivitettotal.txt

cd ..
cd ..
```

Appendix 3

Results from the analysis in Soundplan

0,-100,10m	**dB(A)**
Source10directivity	37,7
Source10withoutdirectivity	40,1
Source10tilted	43,6
Source11directivity	38,2
Source11withoutdirectivity	41,4
Source11tilted	45,7
Source1directivity	48,1
Source1withoutdirectivity	54,2
Source1tilted	59,1
Source2directivity	37,9
Source2withoutdirectivity	41,8
Source2tilted	46,4
Source3directivity	33,9
Source3withoutdirectivity	37,3
Source3tilted	42,5
Source4directivity	35,1
Source4withoutdirectivity	40,4
Source4tilted	51,4
Source5directivity	33,1
Source5withoutdirectivity	34,7
Source5tilted	38,4
Source6directivity	30,1
Source6withoutdirectivity	31,5
Source6tilted	34,1
Source7directivity	31,2
Source7withoutdirectivity	33,4
Source7tilted	35
Source8directivity	27,6
Source8withoutdirectivity	28,2
Source8tilted	30
Source9directivity	37,9
Source9withoutdirectivity	38,4
Source9tilted	40,6
0,-100,20m	
Source10directivity	39,8
Source10withoutdirectivity	40,1
Source10tilted	43,4
Source11directivity	40,7
Source11withoutdirectivity	41,3
Source11tilted	45,3
Source1directivity	53
Source1withoutdirectivity	54,2
Source1tilted	58,7
Source2directivity	41,4
Source2withoutdirectivity	42
Source2tilted	46,2
Source3directivity	36,2
Source3withoutdirectivity	37,3
Source3tilted	42
Source4directivity	34,8
Source4withoutdirectivity	40,4
Source4tilted	50,4
Source5directivity	34,8
Source5withoutdirectivity	34,7
Source5tilted	38,1
Source6directivity	31,1
Source6withoutdirectivity	31,5
Source6tilted	34,1
Source7directivity	34,3
Source7withoutdirectivity	33,6
Source7tilted	35,3
Source8directivity	28,2
Source8withoutdirectivity	28,2
Source8tilted	29,8
Source9directivity	38,7
Source9withoutdirectivity	38,4
Source9tilted	40,4
0,-100,2m	
Source10directivity	30,7
Source10withoutdirectivity	33,4
Source10tilted	37
Source11directivity	31,9
Source11withoutdirectivity	35,1
Source11tilted	39,3
Source1directivity	41,9
Source1withoutdirectivity	48,4
Source1tilted	52,8
Source2directivity	31,7
Source2withoutdirectivity	35,5
Source2tilted	40,1
Source3directivity	26,9
Source3withoutdirectivity	30,7
Source3tilted	35,9
Source4directivity	28,4
Source4withoutdirectivity	33,7
Source4tilted	44,7
Source5directivity	26,2
Source5withoutdirectivity	27,8
Source5tilted	31,4
Source6directivity	23,3
Source6withoutdirectivity	24,8
Source6tilted	27,6
Source7directivity	24,3
Source7withoutdirectivity	26,6
Source7tilted	28,3
Source8directivity	21
Source8withoutdirectivity	21,7
Source8tilted	23,7
Source9directivity	31,5
Source9withoutdirectivity	32
Source9tilted	34,2
0,-400,10m	
Source10directivity	25
Source10withoutdirectivity	27,2
Source10tilted	30,7
Source11directivity	25
Source11withoutdirectivity	28,2
Source11tilted	32,7
Source1directivity	34,9
Source1withoutdirectivity	40,8
Source1tilted	45,9

Source2directivity	24,3
Source2withoutdirectivity	28,1
Source2tilted	32,6
Source3directivity	21
Source3withoutdirectivity	24,4
Source3tilted	29,6
Source4directivity	22,1
Source4withoutdirectivity	27,4
Source4tilted	38,4
Source5directivity	20,2
Source5withoutdirectivity	21,8
Source5tilted	25
Source6directivity	17,1
Source6withoutdirectivity	18,3
Source6tilted	20,6
Source7directivity	18,2
Source7withoutdirectivity	20,3
Source7tilted	21,7
Source8directivity	14,5
Source8withoutdirectivity	15
Source8tilted	16,8
Source9directivity	24,8
Source9withoutdirectivity	25,3
Source9tilted	27,5
0,-400,20m	
Source10directivity	25,1
Source10withoutdirectivity	27,3
Source10tilted	30,7
Source11directivity	25,1
Source11withoutdirectivity	28,3
Source11tilted	32,7
Source1directivity	34,9
Source1withoutdirectivity	40,8
Source1tilted	45,9
Source2directivity	25,2
Source2withoutdirectivity	29,1
Source2tilted	33,7
Source3directivity	21,2
Source3withoutdirectivity	24,5
Source3tilted	29,6
Source4directivity	22,3
Source4withoutdirectivity	27,6
Source4tilted	38,6
Source5directivity	20,5
Source5withoutdirectivity	22,1
Source5tilted	25,9
Source6directivity	17,4
Source6withoutdirectivity	18,8
Source6tilted	21,5
Source7directivity	18,5
Source7withoutdirectivity	20,8
Source7tilted	22,5
Source8directivity	14,8
Source8withoutdirectivity	15,3
Source8tilted	17
Source9directivity	25
Source9withoutdirectivity	25,5
Source9tilted	27,7
0,-400,2m	
Source10directivity	24,1
Source10withoutdirectivity	26,5
Source10tilted	30,2
Source11directivity	24,7
Source11withoutdirectivity	28,1
Source11tilted	32,6
Source1directivity	35
Source1withoutdirectivity	41
Source1tilted	46,1
Source2directivity	23,7
Source2withoutdirectivity	27,6
Source2tilted	32,1
Source3directivity	20,1
Source3withoutdirectivity	23,9
Source3tilted	29,2
Source4directivity	21,6
Source4withoutdirectivity	26,9
Source4tilted	37,9
Source5directivity	19,1
Source5withoutdirectivity	20,9
Source5tilted	24,2
Source6directivity	16,6
Source6withoutdirectivity	17,8
Source6tilted	19,9
Source7directivity	17,4
Source7withoutdirectivity	19,6
Source7tilted	21
Source8directivity	14,2
Source8withoutdirectivity	14,8
Source8tilted	16,6
Source9directivity	24,5
Source9withoutdirectivity	25
Source9tilted	27,2
0,100,10m	
Source10directivity	37,3
Source10withoutdirectivity	40,1
Source10tilted	35,4
Source11directivity	38,1
Source11withoutdirectivity	41,4
Source11tilted	36
Source1directivity	48,9
Source1withoutdirectivity	54,2
Source1tilted	48,6
Source2directivity	38
Source2withoutdirectivity	41,8
Source2tilted	36,1
Source3directivity	33,9
Source3withoutdirectivity	37,3
Source3tilted	32,4
Source4directivity	34,4
Source4withoutdirectivity	40,4
Source4tilted	33,1
Source5directivity	33,4
Source5withoutdirectivity	34,7
Source5tilted	32,3

Source6directivity	30,8
Source6withoutdirectivity	31,5
Source6tilted	29,8
Source7directivity	31,3
Source7withoutdirectivity	33,4
Source7tilted	30
Source8directivity	28,2
Source8withoutdirectivity	28,2
Source8tilted	27,5
Source9directivity	36,4
Source9withoutdirectivity	38,4
Source9tilted	36,4
0,100,20m	
Source10directivity	39,6
Source10withoutdirectivity	40,1
Source10tilted	35,7
Source11directivity	40,7
Source11withoutdirectivity	41,3
Source11tilted	36
Source1directivity	53,1
Source1withoutdirectivity	54,2
Source1tilted	49
Source2directivity	41,3
Source2withoutdirectivity	42
Source2tilted	36,2
Source3directivity	36,4
Source3withoutdirectivity	37,3
Source3tilted	32,5
Source4directivity	34
Source4withoutdirectivity	40,4
Source4tilted	32,6
Source5directivity	33,8
Source5withoutdirectivity	34,7
Source5tilted	33,5
Source6directivity	31,3
Source6withoutdirectivity	31,5
Source6tilted	29,8
Source7directivity	33
Source7withoutdirectivity	33,6
Source7tilted	30,4
Source8directivity	28,2
Source8withoutdirectivity	28,2
Source8tilted	27,2
Source9directivity	37,5
Source9withoutdirectivity	38,4
Source9tilted	36,1
0,100,2m	
Source10directivity	30,2
Source10withoutdirectivity	33,4
Source10tilted	28,3
Source11directivity	31,8
Source11withoutdirectivity	35,1
Source11tilted	29,9
Source1directivity	42,8
Source1withoutdirectivity	48,4
Source1tilted	42,3
Source2directivity	31,7
Source2withoutdirectivity	35,5
Source2tilted	30
Source3directivity	27
Source3withoutdirectivity	30,7
Source3tilted	25,6
Source4directivity	27,7
Source4withoutdirectivity	33,7
Source4tilted	26,4
Source5directivity	26,4
Source5withoutdirectivity	27,8
Source5tilted	25,4
Source6directivity	24
Source6withoutdirectivity	24,8
Source6tilted	23
Source7directivity	24,4
Source7withoutdirectivity	26,6
Source7tilted	23,2
Source8directivity	21,7
Source8withoutdirectivity	21,7
Source8tilted	20,9
Source9directivity	30
Source9withoutdirectivity	32
Source9tilted	30
0,100,10m	
Source10directivity	37,3
Source10withoutdirectivity	40,1
Source10tilted	35,4
Source11directivity	38,1
Source11withoutdirectivity	41,4
Source11tilted	36
Source1directivity	48,9
Source1withoutdirectivity	54,2
Source1tilted	48,6
Source2directivity	38
Source2withoutdirectivity	41,8
Source2tilted	36,1
Source3directivity	33,9
Source3withoutdirectivity	37,3
Source3tilted	32,4
Source4directivity	34,4
Source4withoutdirectivity	40,4
Source4tilted	33,1
Source5directivity	33,4
Source5withoutdirectivity	34,7
Source5tilted	32,3
Source6directivity	30,8
Source6withoutdirectivity	31,5
Source6tilted	29,8
Source7directivity	31,3
Source7withoutdirectivity	33,4
Source7tilted	30
Source8directivity	28,2
Source8withoutdirectivity	28,2
Source8tilted	27,5
Source9directivity	36,4
Source9withoutdirectivity	38,4
Source9tilted	36,4

0,100,20m	
Source10directivity	39,6
Source10withoutdirectivity	40,1
Source10tilted	35,7
Source11directivity	40,7
Source11withoutdirectivity	41,3
Source11tilted	36
Source1directivity	53,1
Source1withoutdirectivity	54,2
Source1tilted	49
Source2directivity	41,3
Source2withoutdirectivity	42
Source2tilted	36,2
Source3directivity	36,4
Source3withoutdirectivity	37,3
Source3tilted	32,5
Source4directivity	34
Source4withoutdirectivity	40,4
Source4tilted	32,6
Source5directivity	33,8
Source5withoutdirectivity	34,7
Source5tilted	33,5
Source6directivity	31,3
Source6withoutdirectivity	31,5
Source6tilted	29,8
Source7directivity	33
Source7withoutdirectivity	33,6
Source7tilted	30,4
Source8directivity	28,2
Source8withoutdirectivity	28,2
Source8tilted	27,2
Source9directivity	37,5
Source9withoutdirectivity	38,4
Source9tilted	36,1
0,100,2m	
Source10directivity	30,2
Source10withoutdirectivity	33,4
Source10tilted	28,3
Source11directivity	31,8
Source11withoutdirectivity	35,1
Source11tilted	29,9
Source1directivity	42,8
Source1withoutdirectivity	48,4
Source1tilted	42,3
Source2directivity	31,7
Source2withoutdirectivity	35,5
Source2tilted	30
Source3directivity	27
Source3withoutdirectivity	30,7
Source3tilted	25,6
Source4directivity	27,7
Source4withoutdirectivity	33,7
Source4tilted	26,4
Source5directivity	26,4
Source5withoutdirectivity	27,8
Source5tilted	25,4
Source6directivity	24
Source6withoutdirectivity	24,8
Source6tilted	23
Source7directivity	24,4
Source7withoutdirectivity	26,6
Source7tilted	23,2
Source8directivity	21,7
Source8withoutdirectivity	21,7
Source8tilted	20,9
Source9directivity	30
Source9withoutdirectivity	32
Source9tilted	30
0,400,10m	
Source10directivity	24,5
Source10withoutdirectivity	27,2
Source10tilted	22,7
Source11directivity	24,9
Source11withoutdirectivity	28,2
Source11tilted	22,5
Source1directivity	35,7
Source1withoutdirectivity	40,8
Source1tilted	35,4
Source2directivity	24,3
Source2withoutdirectivity	28,1
Source2tilted	22,5
Source3directivity	21
Source3withoutdirectivity	24,4
Source3tilted	19,5
Source4directivity	21,4
Source4withoutdirectivity	27,4
Source4tilted	20,1
Source5directivity	20,6
Source5withoutdirectivity	21,8
Source5tilted	19,5
Source6directivity	17,7
Source6withoutdirectivity	18,3
Source6tilted	16,6
Source7directivity	18,3
Source7withoutdirectivity	20,3
Source7tilted	17
Source8directivity	15,1
Source8withoutdirectivity	15
Source8tilted	14,3
Source9directivity	23,3
Source9withoutdirectivity	25,3
Source9tilted	23,3
0,400,20m	
Source10directivity	24,7
Source10withoutdirectivity	27,3
Source10tilted	22,9
Source11directivity	25,1
Source11withoutdirectivity	28,3
Source11tilted	22,7
Source1directivity	35,7
Source1withoutdirectivity	40,8
Source1tilted	35,4
Source2directivity	25,3
Source2withoutdirectivity	29,1

Source2tilted	23,5
Source3directivity	21,3
Source3withoutdirectivity	24,5
Source3tilted	19,7
Source4directivity	21,6
Source4withoutdirectivity	27,6
Source4tilted	20,3
Source5directivity	20,8
Source5withoutdirectivity	22,1
Source5tilted	19,7
Source6directivity	18,1
Source6withoutdirectivity	18,8
Source6tilted	17,1
Source7directivity	18,6
Source7withoutdirectivity	20,8
Source7tilted	17,4
Source8directivity	15,3
Source8withoutdirectivity	15,3
Source8tilted	14,6
Source9directivity	23,5
Source9withoutdirectivity	25,5
Source9tilted	23,5
0,400,2m	
Source10directivity	23,5
Source10withoutdirectivity	26,5
Source10tilted	21,5
Source11directivity	24,6
Source11withoutdirectivity	28,1
Source11tilted	22,2
Source1directivity	35,8
Source1withoutdirectivity	41
Source1tilted	35,6
Source2directivity	23,7
Source2withoutdirectivity	27,6
Source2tilted	21,9
Source3directivity	20,1
Source3withoutdirectivity	23,9
Source3tilted	18,7
Source4directivity	20,9
Source4withoutdirectivity	26,9
Source4tilted	19,6
Source5directivity	19,4
Source5withoutdirectivity	20,9
Source5tilted	18,4
Source6directivity	17,1
Source6withoutdirectivity	17,8
Source6tilted	16,1
Source7directivity	17,6
Source7withoutdirectivity	19,6
Source7tilted	16,2
Source8directivity	14,8
Source8withoutdirectivity	14,8
Source8tilted	14,1
Source9directivity	23
Source9withoutdirectivity	25
Source9tilted	23