Noise optimization and planning of alternatives within industrial sites

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The prediction of noise levels within large industrial sites is an essential part of the elaboration of Action Plans oriented to reduce noise pollution. There is a number of calculation methods widely used to predict the noise from industrial sources such as ISO 9613-2 or the recent CNOSSOS-EU calculation method, which has been developed by the European Commission as a harmonized methodological framework for noise assessment within the EU Member States. In either case, the general problem is to decide about the input data of the relevant industry noise sources, such as emission values or directivities.
On the other hand the required noise protection measures to reduce the noise below the limits set by regulations may sum up to 6% of the total investment of new industrial installations, or even more in case of existing ones. Moreover, noise protection solutions may affect the performance of the industrial plants. Therefore the acoustical model must be clearly arranged with an efficient structure allowing the fast comparison of different scenarios and operating conditions.
This paper addresses solutions for common challenges such as the unavailability of source´s data, strategies applied to improve existing methods and the handling of planning scenarios.

1 INTRODUCTION

The assessment of noise impact in the vicinity of industrial installations is an important task which normally leads to noise reduction solutions at existing sites or to different layouts at new sites. The calculations applied in this assessment make use of calculation standards such as the widely used ISO 9613-2[1] or the recent CNOSSOS-EU[2], developed by the European

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Commission. Regardless the used standard, one of the basic problems is to decide about the right input parameters to define the sound emission of the sources.

The preferred approach in order to collect the appropriate sound power spectra for use in the calculation of industrial noise is to perform measurements of the source, although a further pre-defined database would be available in case measurements are not possible. In addition, there could be a number of special situations where the collection of data is extremely difficult, such as emission from windows or surfaces radiating noise which is produced inside the working rooms, or complex systems where it is not possible to measure.

Finally, after those emissions have been determined and set as input data in the model, the current scenario is calculated and the resulting sound pressure levels evaluated. The planning of new scenarios should include measures to reduce noise, which can be applied to either the receiver positions or directly to the sources (e.g. comparison of different operating conditions).

This paper discusses some of the available methods on determining the emission of industrial sources and suggests additional tools applied to the planning of industrial sites.

2 SOUND POWER EMISSION OF SOURCES

In most of the calculation methods, the acoustical emission of all sources is defined as directional sound power level emitted per frequency band. Industrial sources can be defined as point sources, line sources and area sources. On every case, the emission includes the reflecting surfaces that may be close to the real source as defined in ISO 9614[3] (for industrial noise, the most common reflecting surfaces are the ground under a source and any vertical surface placed nearby and opposite to the direction of the path between source and receiver.

In case no sound power levels are available, measurements should be carried out. For example, the CNOSSOS-EU[2] model advises to make use of the following standards to collect appropriate sound power spectra for use in the calculation of industrial noise:

- Sound pressure enveloping surface method (ISO 3744 and 3746)
- Reverberation room method (ISO 3741)
- Reference sound source method (ISO 3747)
- Intensity method (ISO 9614 1-3)
- Multi-source industrial plants (ISO 8297)
- Transmission outdoors (EN 12354-4)

2.1 Determination of the emission of point sources based on measurements

A point source is an elementary representation of an ideal source of noise located in the space, and it is characterized by the sound power level L_W. In case no real L_W is available, it can be calculated from the measured sound pressure level L_p. Several situations can be addressed. For example, if the measuring distance is larger compared with the source dimensions and the radiation of the source is non directional, the sound power level can be calculated with (1):

$$L_W = L_p + 10\lg\left(\frac{4\pi r^2}{m^2}\right) + 10\lg\left(\frac{n\%}{100\%}\right) \tag{1}$$

where:

L_W: sound power level at frequency f in dB
L_p = sound pressure level at distance r and at frequency f in dB
r: measuring distance in m
n%: proportion of the full sphere in %

When the radiation of the source is directional, however, several points at the same distance from the source shall be measured, averaging the level spectra from different directions energetically.

In case of sound pressure levels have been measured on an envelope or on any other sound transmitting surface the sound power level can be calculated with Equation (2):

$$L_W = L_p + 10\lg\left(\frac{S}{m^2}\right) + K \tag{2}$$

where:

L_W: sound power level at frequency f in dB
L_p: averaged sound pressure level on the surface S at frequency f in dB
S: surface S of the envelope in m²
K: near field correction

The near field correction is to be specified in case that the sound intensity vectors do not pass the envelope perpendicular or when the sound pressure level was measured near the surface (thus the distance r < wavelength), causing a near field error. The standards ISO 3744/3745/3746 provide information with regards to the magnitude of both errors and how to reduce them. In case that the sound intensity has been measured rather than the sound pressure level (e.g. with ISO 9614), both errors are avoided.

2.2 Determination of the emission of line sources

Line sources can be used when the largest dimension is more than ½ of the distance between the source and the receiver. They can be used to represent conveyor belts, pipe lines, etc. thus the sound power per unit length $L_W{}'$ is used. They are also suitable to model vehicles, each associated with the sound power L_W. The sound power per unit length is then derived from the speed and number of vehicles passing by.

$$L_W{}' = L_{W\,pt} + 10 \cdot \lg\left(\frac{Q}{h^{-1}}\right) - 10 \cdot \lg\left(\frac{v}{km/h}\right) - 30dB \tag{3}$$

2.3 Emission from multi-source industrial sites

The area sources are used to determine sound power level emissions in a variety of situations provided they can be horizontal and vertical. One of the applications is the determination of sound power levels for multi-source industrial plants. This special case is relevant when industrial facilities are to be taken into account within bigger planning projects (e.g. a city noise map). Within a city, roads are used to be the main sources. On the other hand, industrial areas usually are not modelled by taking into account every single source inside, and measurements are often not possible either. Therefore, the only possibility is to measure outside around the border of the industrial facility.

In this case, an estimation of the sound power level per unit area can be carried out by calculating the values at the receivers placed in the measurement points. A "test" sound power level is chosen for the calculation. After the calculation results at receiver points as well as the real measurements have been averaged, the sound power level is calculated with:

$$L_{W,unknown}'' = L_{W,test} + \bar{L}_{p,measured} - \bar{L}_{p,calculated} dB \tag{4}$$

where:

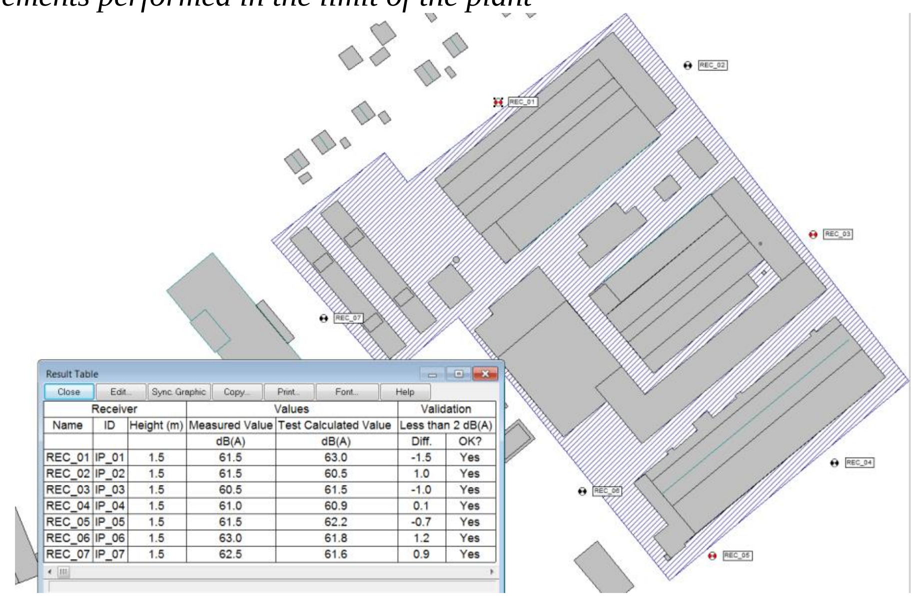
$L_{W,test}$: sound power level at frequency f in dB

$L_{p,\ measured}$: averaged sound pressure level at measured points

$L_{p,\ calculated}$: averaged sound pressure level at receiver points calculated

In the figure below, the sound power level of an industrial site has been calculated by using an acoustical model and the measurements performed in a closed line fencing the plant. After applying the equation (4) the sound pressure levels have been re-calculated on the basis of the resulting sound power level value.

Fig. 1 – Multi-source industrial site modelled with an area source. The emission is determined from measurements performed in the limit of the plant



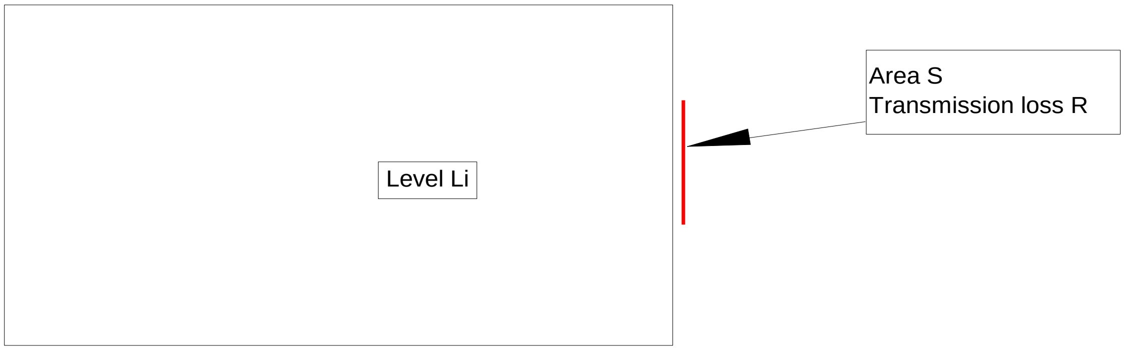
Receiver			Values		Validation	
Name	ID	Height (m)	Measured Value	Test Calculated Value	Less than 2 dB(A)	
			dB(A)	dB(A)	Diff.	OK?
REC_01	IP_01	1.5	61.5	63.0	-1.5	Yes
REC_02	IP_02	1.5	61.5	60.5	1.0	Yes
REC_03	IP_03	1.5	60.5	61.5	-1.0	Yes
REC_04	IP_04	1.5	61.0	60.9	0.1	Yes
REC_05	IP_05	1.5	61.5	62.2	-0.7	Yes
REC_06	IP_06	1.5	63.0	61.8	1.2	Yes
REC_07	IP_07	1.5	62.5	61.6	0.9	Yes

In the example shown in Fig. 1, the sound power level is calculated by using the Equation (4). The table shows the difference between measured values and calculated values.

2.4 Calculation of sound power levels based on the interior level of industrial halls

The vertical area sources are normally used to calculate radiation by industrial buildings related to interior sound pressure levels that have been measured or calculated.

Fig.2 – Input elements for the calculation of sound power level of a radiating surface based on the interior level of a industrial hall and the transmission loss



When no measured values are available, the interior level in the room in the diffuse sound field is usually calculated beforehand following the statistical theory of sound reverberation in rooms:

$$L_i = PWL - 10\lg\left(\frac{\alpha * S}{m^2}\right) + 6dB \tag{5}$$

where:

L_i: interior level in the room per frequency band in dB
PWL: sound power level of all sources present in the room per frequency band in dB
A: equivalent sound absorption area in the frequency band in m^2
α: mean absorption coefficient of the room surfaces
S: area of the room surfaces in m^2

The sound power level radiated from the surface element S (m^2), per frequency band is:

$$L_W = L_i - R - 6 + 10 \cdot \lg(S) \tag{6}$$

where:

L_w: sound power level per unit area
R: Transmission Loss of the wall per frequency band.

2.2 Correction for the working hours

Besides the sound power level, methods like CNOSSOS-EU[2] includes a number of additional input parameters considered as essential , meaning that the range of values the parameter can take yields variations of L_{den} or L_{night} of more than ±2 dB(A) for a level of confidence of 95%. In these additional parameters the working hours (day, evening, night, on a yearly basis), location (x, y, z), dimensions and orientation, directivity and operating conditions are included.

The correction for the working hours, to be added to the source sound power to define the corrected sound power that is to be used for calculations over each time period is calculated as follows:

$$C_W = 10 \lg \left(\frac{T}{T_0} \right) \tag{7}$$

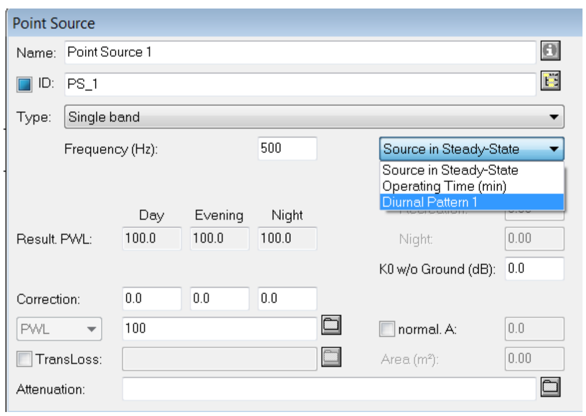
Where

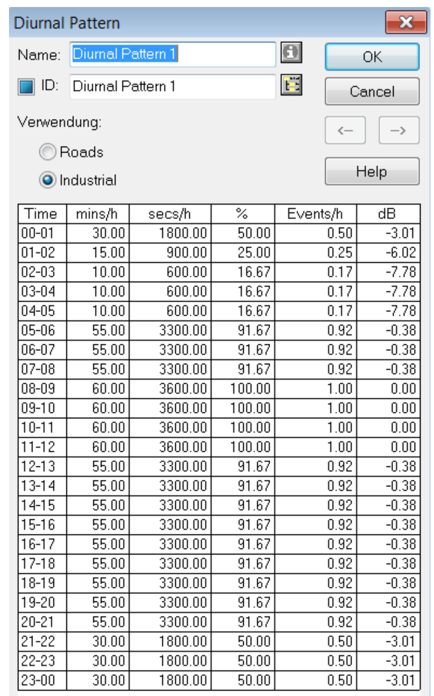
T: active source time per period based on a yearly averaged situation, in hours

T_0: reference period expressed in hours (day: 12 hours, evening: 4 hours, night: 8 hours)

The correction for working hours has been conveniently implemented in the CadnaA[6] prediction software by means of the use of diurnal patterns:

Fig.3 – Diurnal pattern defined for an industrial machine (left) selection in the edit dialog of the point source (right)

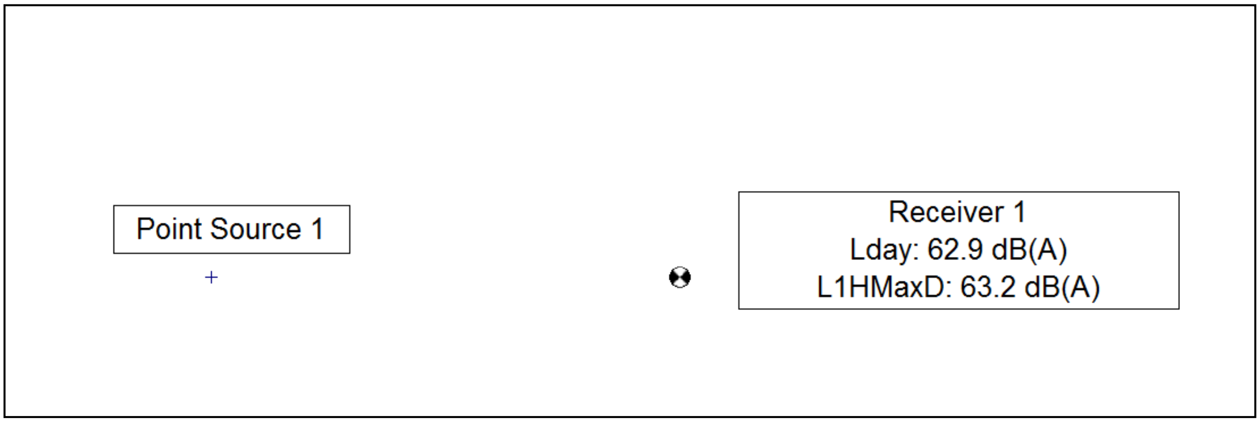




Time	mins/h	secs/h	%	Events/h	dB
00-01	30.00	1800.00	50.00	0.50	-3.01
01-02	15.00	900.00	25.00	0.25	-6.02
02-03	10.00	600.00	16.67	0.17	-7.78
03-04	10.00	600.00	16.67	0.17	-7.78
04-05	10.00	600.00	16.67	0.17	-7.78
05-06	55.00	3300.00	91.67	0.92	-0.38
06-07	55.00	3300.00	91.67	0.92	-0.38
07-08	55.00	3300.00	91.67	0.92	-0.38
08-09	60.00	3600.00	100.00	1.00	0.00
09-10	60.00	3600.00	100.00	1.00	0.00
10-11	60.00	3600.00	100.00	1.00	0.00
11-12	60.00	3600.00	100.00	1.00	0.00
12-13	55.00	3300.00	91.67	0.92	-0.38
13-14	55.00	3300.00	91.67	0.92	-0.38
14-15	55.00	3300.00	91.67	0.92	-0.38
15-16	55.00	3300.00	91.67	0.92	-0.38
16-17	55.00	3300.00	91.67	0.92	-0.38
17-18	55.00	3300.00	91.67	0.92	-0.38
18-19	55.00	3300.00	91.67	0.92	-0.38
19-20	55.00	3300.00	91.67	0.92	-0.38
20-21	55.00	3300.00	91.67	0.92	-0.38
21-22	30.00	1800.00	50.00	0.50	-3.01
22-23	30.00	1800.00	50.00	0.50	-3.01
23-00	30.00	1800.00	50.00	0.50	-3.01

The diurnal pattern dialog can be edited by the input of the working minutes (or seconds) per hour, the percentage of time the machine is active, the number of events per hour or the final correction in dB. After a diurnal pattern has been addressed to a source, the additional parameter L1hMax (loudest hourly level per time period D, E, N) can be selected and thus calculated.

Fig.4 – Calculation of the L_{day} and the loudest hourly level for the day period



3 ADDITIONAL SOFTWARE TECHNIQUES FOR THE DETERMINATION OF SOUND POWER EMISSIONS

As seen in the above paragraphs, there are a considerable number of standards on measurement methods for industrial noise sources. These standards are meant to be the best practices to use for the determination of sound power levels for different industrial source types. Unfortunately, the methods described in the standards are often not intended for providing input data for noise mapping purposes. On the other hand, in some cases the described methods can be improved by the use of software solutions in order to obtain the desired input data as well as a more realistic model.

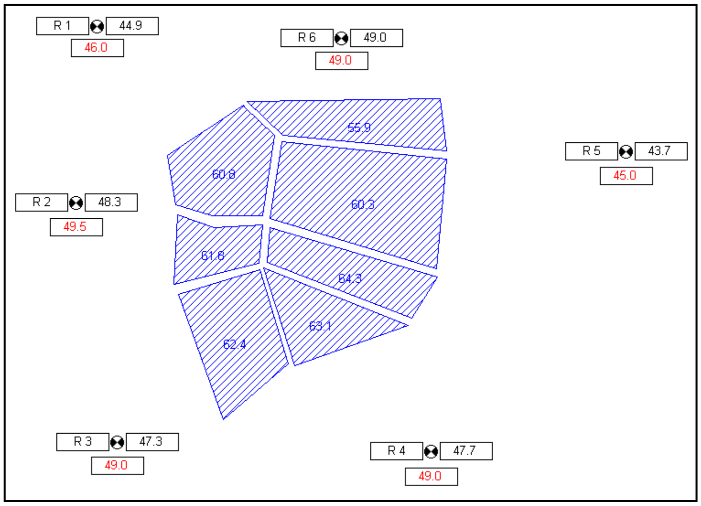
3.1 Calculation of sound power levels from technical parameters of sources

One of these examples is the calculation of sound emission of sources from their technical parameters. The software program CadnaA[6] features a module (SET) where sound power levels which are unknown can be calculated by the program depending on the values parameters such as the nominal capacity (in case of a motor). This feature can be used to automatically calculate sound power levels of sources as well as transmissions to further elements and therefore single sources can thus be combined to assemble complex noise emitting systems.

3.2 Optimization of sound power levels of multi-source industrial sites

Another example is the automatic optimization of sound power levels from multi-source industrial sites. When the sound power level of the industrial site is unknown, the emission values of the different areas are adjusted to allow for the maximal sound power level without exceeding a certain value, which can be a limiting value or a real measurement.

Fig.5 – Automatic optimization of area sources; results from measurements are shown in red color, while values in black are the calculated noise levels at the receivers based on optimized sound power levels of seven area sources with unknown emission

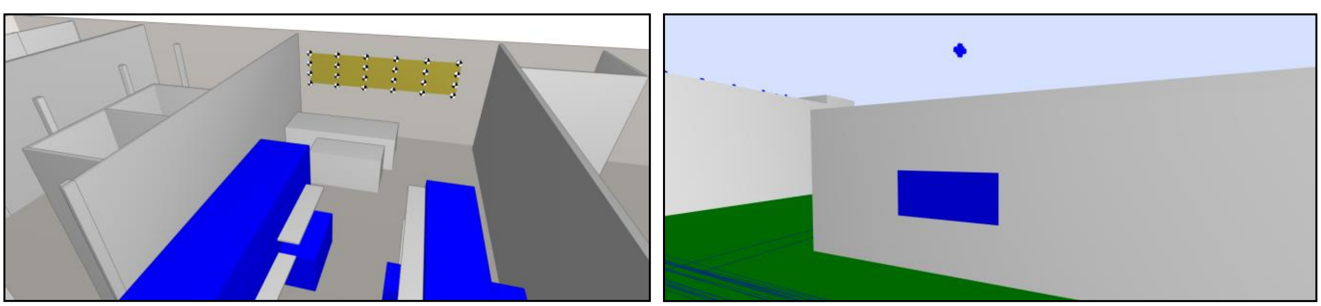


3.2 Indoor to outdoor calculations

A procedure to calculate sound power levels based on the interior level of industrial halls has been explained in point 2.4. The calculation of interior noise level based on the statistical theory disregards a number of effects and interactions such as the geometry of the room and other effects produced by obstacles (diffraction, local absorption, transmission and scattering), which are relevant in order to collect accurate results. A solution could be a detailed model generated in software for calculation of interior sound levels[7] that feeds the software for calculation outdoors.

The following figure illustrates a detailed acoustical model of an industrial hall, where all the elements including walls, noise sources and further obstacles are present. The radiating surface is covered by an array of receivers, evenly distributed over its area. Furthermore, the radiating surface is modelled in CadnaA[6].

Fig.6 – Indoor model of an industrial hall in CadnaR[7] (left) Vertical radiating surface in the CadnaA[6] prediction software



After the calculation at receiver levels, the mean value was calculated and then exported to CadnaA.

Table 1 – Calculation results at receiver array.

	Sound Pressure Levels (dB)					
Receiver	**125**	**250**	**500**	**1000**	**2000**	**4000**
RP_01	70,30	70,3	70,3	70,3	70,2	69,8
RP_02	69,40	69,4	69,3	69,3	69,2	68,9
RP_03	69,80	69,8	69,8	69,7	69,6	69,3
RP_04	69,90	69,9	69,9	69,8	69,7	69,4
RP_05	69,90	69,9	69,9	69,8	69,7	69,4
RP_06	69,00	69	69	68,9	68,8	68,5
RP_07	71,40	71,4	71,3	71,3	71,2	70,8
RP_08	70,70	70,7	70,6	70,6	70,5	70,2
RP_09	71,30	71,3	71,2	71,2	71,1	70,7
RP_10	71,40	71,4	71,4	71,3	71,2	70,9
RP_11	71,20	71,2	71,2	71,1	71	70,7
RP_12	70,50	70,5	70,5	70,4	70,3	69,9
RP_13	71,30	71,3	71,3	71,2	71,1	70,8
RP_14	70,60	70,6	70,6	70,5	70,4	70,1
RP_15	71,20	71,2	71,2	71,1	71	70,7
RP_16	71,20	71,1	71,1	71,1	71	70,6
RP_17	70,90	70,9	70,8	70,8	70,7	70,3
RP_18	70,50	70,5	70,4	70,4	70,3	69,9
RP_19	71,30	71,2	71,2	71,2	71,1	70,7
RP_20	70,60	70,5	70,5	70,5	70,4	70
RP_21	70,90	70,9	70,9	70,8	70,7	70,4
RP_22	71,00	71	70,9	70,9	70,8	70,4
RP_23	70,90	70,9	70,8	70,8	70,7	70,3
RP_24	70,30	70,3	70,2	70,2	70,1	69,7
Mean Level	**70,65**	**70,63**	**70,60**	**70,55**	**70,45**	**70,10**

Fig.7 – Sound Pressure Level spectrum calculated from the detailed indoor model

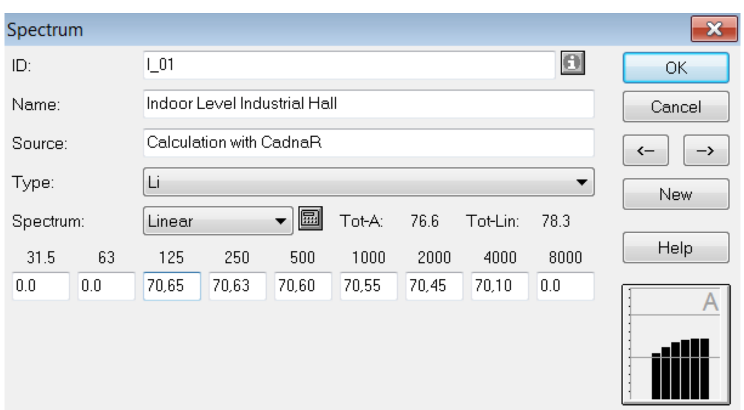
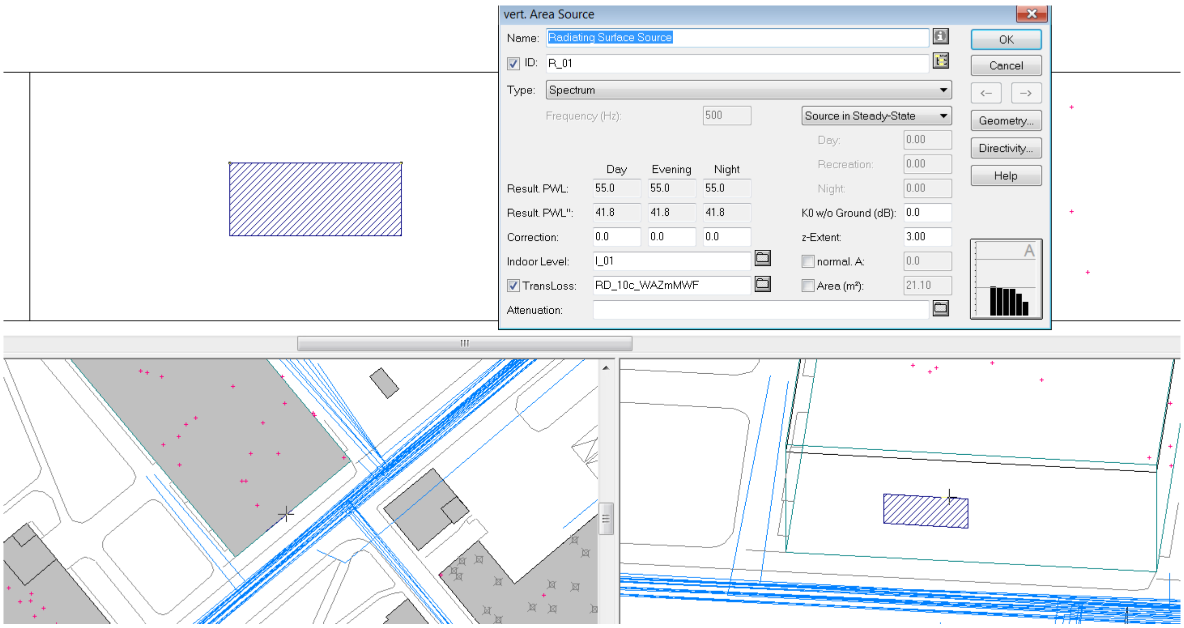


Fig.8 – Determination of the sound power level from the previously imported sound pressure level calculation and transmission loss



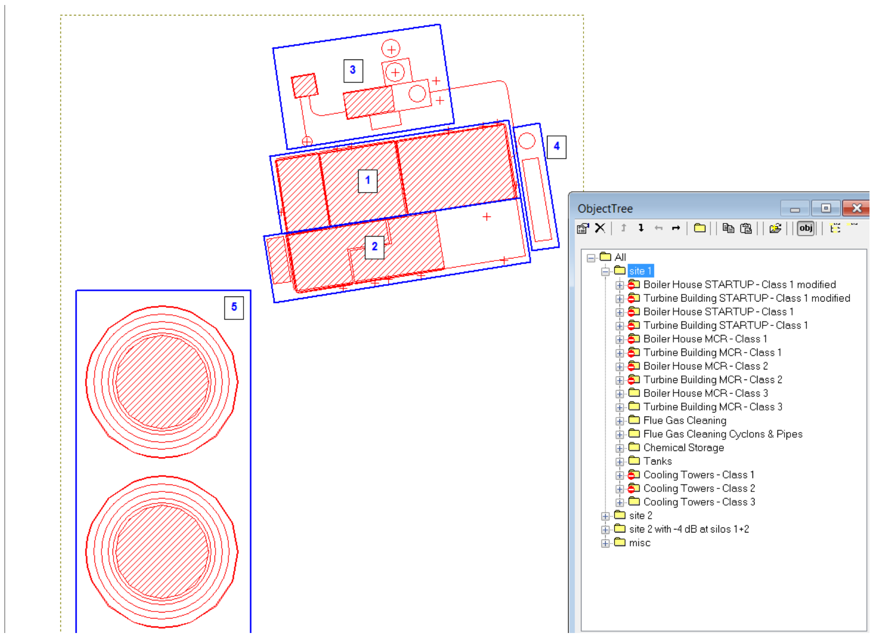
4 PLANNING OF ALTERNATIVES WITHIN INDUSTRIAL SITES

During the planning process of industrial plants, a number of noise measures are to be studied. These measures can include different operating conditions for the sources within the industrial site. In order to efficiently switch conditions and therefore, compare different scenarios, the acoustic model needs to have a clear and flexible structure.

As an example, a power plant model is shown to illustrate the organization carried out. Every plant section is organized by means of different groups organized in a hierarchical structure. The organization includes different operating conditions combined with three different reduction measures affecting the sound power level of the sources present in the plant: Class 3, with a basic reduction; class 2, with a damping of 3 dB for all kind of sources and class 1, with a damping of 6 dB for all kind of sources compared to class 3.

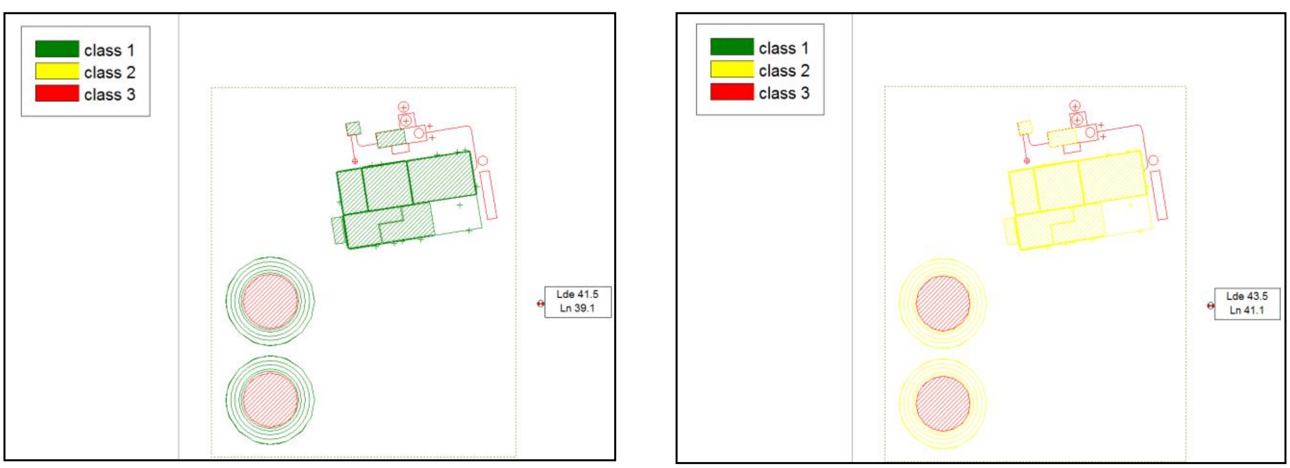
The "ObjectTree" is the software tool used to create such structure of folders while the different test scenarios are managed by different variants.

Fig.9 – Model of an industrial plant organized with the ObjectTree



This arrangement of folders allows to quickly compare variants and decide about the noise reduction measures. Below a comparison between two situations is shown. The red color means sources and even complete sections where reduction measures are not applied, while other sections include a further reduction class. This approach allows to optimize the final solution in order to reduce the noise at receiver positions to the target values.

Fig.10 – Comparison between two scenarios: Noise reduction class 1 (left) vs. Noise reduction class 2 (right)



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