NORD2000 for road traffic noise prediction

Weather classes and statistics

Requested by: Delta

VTT TECHNICAL RESEARCH CENTRE OF FINLAND

NORD2000 for road traffic noise prediction

WP4. Weather classes and statistics

VTT
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Contents

1 OUTLINE OF WP4

WP 4 dealt with the description of weather classes and statistics and defining how to use them to calculate yearly average noise levels. The work was carried out by VTT but input was given from all Nordic countries.

At the beginning of the project the following tasks were identified:

1) Weather classes

2) Available meteorological data

3) Method for calculating the yearly average noise level

4) Guidance on effects of seasonal changes

In addition to the meteorological considerations, measurements of Finnish vehicle noise data were the responsibility of VTT for the project.

2 AVAILABLE METEOROLOGICAL DATA

In co-operation with The Finnish Meteorological Institute it was investigated what kind of meteorological data is available in different parts of Finland, see also Appendix 1. VTT sent an informal note to the partners specifying what kind of weather data should be gathered from national meteorological institutes. Each partner contacted their local meteorological institutes and collected the weather data needed.

Questions for national Offices of Meteorology:

- What kind of weather stations you have in use (locations and types of the stations)?
- What kind of data (basic data needed is described below) is it possible to get from the stations (time period of observation; 1 hour, 3 hours, averaged values etc.)?
- For how long a time backwards you can provide the data, and in which format (electronic data, other)?
- How well the observations made at the weather station represent weather conditions of areas further away from the stations (distances between stations)?
- Would it be possible to estimate (by calculation programs) weather conditions of these areas further away (distances between calculation grid points)?
- Do you already have weather classes (stability classes) available or can they be found somewhere?
- What are the costs of the weather data/presentation format for research purposes?

Basic data needed (preferably measured at heights of 2 and 10 m from the earth surface):

- wind direction and wind speed
- temperature

For the determination of stability classes also the following information might be needed:

- the amount of the total solar radiation coming onto the earth surface
- cloudiness/cloud cover (as eighths)
- times of sunrise and sunset for each day of the year
- deviation of the direction of the wind

Other data

- relative humidity of the air and air pressure
- daily condition of the earth surface (dry, wet, ice cover, snow cover etc.)
- precipitation

VTT had a meeting with representatives from The Finnish Meteorological Institute and all pertinent information for the project was discussed. The Finnish Meteorological Institute promised to send to VTT a summary of available meteorological information in Finland, see Appendix 1.

3 WEATHER CLASSES

Different ways of defining possible weather classes were investigated. The suitability of weather classes used in the air pollution dispersion to the prediction of sound propagation was investigated. The number of weather classes needed in the case of sound propagation was elaborated based on the results of the Harmonoise project [1, 2, 3] (and also the French calculation method for road traffic noise). Statistics on the frequency of occurrence of weather classes in different parts of the Nordic countries allowing computations of yearly average noise levels were determined.

According to the Environmental Noise Directive (END) noise indicators L_{day}, L_{evening} and L_{night} form the compound indicator L_{den} as follows:

$$L_{den} = 10 \cdot \lg \frac{1}{24}\left[T_d \cdot 10^{L_{Aeqday}/10} + T_e \cdot 10^{\left(L_{Aeqevening}+5\right)/10} + T_n \cdot 10^{\left(L_{Aeqnight}+10\right)/10}\right] \quad (1)$$

where L_{day}, L_{evening} and L_{night} are long-term noise levels according to ISO 1996-2:1987 and they are determined over all day, evening and night periods of a year. T_{d}, T_{e} and T_{n} are the lengths of the day, evening and night periods and according to the END the lengths of these are T_{d} = 12 hours, T_{e} = 4 hours and T_{n} = 8 hours (in Finland it has been decided to use different periods for evening and night: T_{e} = 3 hours and T_{n} = 9 hours).

In determining the yearly average of L_{den} each of these periods (Day, Evening and Night) should be considered separately. Because the "real" day and night on the Northern hemisphere vary quite differently compared to these periods defined in the END depending on the time of the year and also because the meteorological conditions depend on the rising and setting times of the sun, the best way to determine the meteorological correction is to use the hourly raw data of meteorological observations as a starting point.

To be able to determine yearly average noise levels when calculating with Nord2000 Road traffic calculation method a system taking meteorological conditions into account is needed. For the determination of weather classes used in calculation it was decided that weather-classes used in Nord2000 Road shall be based on the Harmonoise method by using 25 weather classes. In practice all of these 25 classes are not needed and the number of classes may be less in actual calculation.

It was decided to use the meteorological coordinate system for wind direction when defining directions. Wind direction for meteorological purposes is defined as the direction, in tens of degrees, from which the wind is blowing, and it is measured in degrees clockwise from true north (north = 0°, east = 90°, south = 180° and west = 270°).

Difference of 0° between wind direction and sound propagation direction corresponds to direct downwind.

Difference of 180° between wind direction and sound propagation direction corresponds to direct upwind.

It shall be possible to represent the results of computation as:

- $L_{\mathrm{den,year}}$ (including L_{day}, L_{evening} and L_{night})
- $L_{\mathrm{Aeq,24h}}$ and (in Finland) $L_{\mathrm{Aeq,day}}$ (07-22 hrs) and $L_{\mathrm{Aeq,night}}$ (22-07 hrs) with "reference meteorological condition = slight downwind"

In the following a procedure for translating weather data into statistics to be used as input values for Nord2000 and calculating the yearly average noise levels is presented

4 DETERMINATION OF STATISTICAL WEIGHTS

Determination of statistical weights is based on the work done in connection with the Harmonoise reference [2] and engineering methods [1] taking into account the demands of the Environmental Noise Directive and the information presented in references [4 and 5]. The method uses altogether 25 classes (five aerodynamic classes determined by wind speed and direction and five thermal classes determined by cloudiness) as a starting point.

The effect of meteorology on sound propagation can be approximated by a combination of logarithmic and linear sound speed profiles. The effective speed of sound *c* is:

$$C = A\ln\left(1+\frac{z}{z_0}\right) + Bz + C(0) \qquad (2)$$

where

z height above ground surface

z_0	a constant interpreted as the roughness length
A	coefficient of the logarithmic term (m/s)
B	coefficient of the linear term (1/s)
C(0)	sound speed at height z = 0 m (m/s).

If vertical profiles of wind speed, wind direction, and temperature are measured, the vertical profiles of the effective sound speed can be calculated directly, and the profile coefficients A and B in Eq. (2) can be determined with a curve fitting algorithm.

Usually, vertical profiles are not directly measured but meteorological data are available only for a certain height above ground. In these cases the profiles must be approximated. In Harmonoise engineering method this is done by using the following parameters:

- friction velocity (u_*)
- Monin-Obukhov length (L)
- temperature scale (T_*)

If routine meteorological data from a weather station are available, the scaling parameters (and surface temperature) can be derived from Tables 3 - 5 with meteorological propagation classes defined by Tables 1 - 2. The classes depend on the following parameters:

- wind speed at 10 m above ground, V (z = 10 m)
- cloud cover in octas
- time of the day (day/night)

Table 1. Wind speed classification

wind speed at 10 m above ground	wind speed class
0 to 1 m/s	W1
1 to 3 m/s	W2
3 to 6 m/s	W3
6 to 10 m/s	W4
> 10 m/s	W5

Table 2. Classification of atmospheric stability.

time of day	cloud cover	stability class
day	0/8 to 2/8	S1
day	3/8 to 5/8	S2
day	6/8 to 8/8	S3
night	5/8 to 8/8	S4
night	0/8 to 4/8	S5

Table 3. Friction velocity, by wind speed class.

wind speed class	*u*∗ *in* m/s
W1	0,00
W2	0,13
W3	0,30
W4	0,53
W5	0,87

Table 4. Temperature scale T∗, by wind speed class and stability class.

	S1	S2	S3	S4	S5
W1	-0,4	-0,2	0,0	+0,2	+0,3
W2	-0,2	-0,1	0,0	+0,1	+0,2
W3	-0,1	-0,05	0,0	+0,05	+0,1
W4	-0,05	0,0	0,0	0,0	+0,05
W5	0,0	0,0	0,0	0,0	0,0

Table 5. Inverse of the Monin-Obukhov length 1/L, by wind speed class and stability class.

	S1	S2	S3	S4	S5
W1	-0,08	-0,05	0,0	+0,04	+0,06
W2	-0.05	-0,02	0,0	+0,02	+0,04
W3	-0,02	-0,01	0,0	+0,01	+0,02
W4	-0,01	0,0	0,0	0,0	+0,01
W5	0,0	0,0	0,0	0,0	0,0

The constants A and B can be determined as follows:

- during day (stability classes S_1, S_2 and S_3)

$$B = \frac{u_* \cos(\alpha)}{C_{vk} L} + \left(\frac{1}{2}\frac{c_0}{T_{ref}}\right)\left(0{,}74\frac{T_*}{C_{vk} L} - \frac{g}{c_p}\right) \quad (3)$$

- during night (stability classes S_4 and S_5)

$$B = 4{,}7\frac{u_* \cos(\alpha)}{C_{vk} L} + \left(\frac{1}{2}\frac{c_0}{T_{ref}}\right)\left(4{,}7\frac{T_*}{C_{vk} L} - \frac{g}{c_p}\right) \quad (4)$$

$$A = \frac{u_* \cos(\alpha)}{C_{vk}} + \left(\frac{1}{2}\frac{c_0}{T_{ref}}\right)\left(0{,}74\frac{T_*}{C_{vk} L}\right) \quad (5)$$

where

u_*	is the friction velocity in m/s, given by Table 3
T_*	is the temperature scale in K, given by Table 4
L	is the Monin-Obukhov length in m, given by Table 5
c_{vk}	is the Von Karman constant = 0,4
g	is the Newton's gravity acceleration = 9,81 m/s
c_p	is the specific heat capacity of air at constant pressure, 1005 J/kg K

T_{ref} is the reference temperature = 273 K
α is the angle between wind direction and the direction of sound propagation.

Once u_*, L, and T_* have been determined, the profile parameters can be calculated with the help of flux-profile relations.

Each pair of profile parameters A and B describes a specific situation of sound propagation. Some examples of class intervals are shown in Tables 6 (linear profile parameters) and 7 (logarithmic profile parameters). The parameters are aggregated to a reasonable number of classes. Each class is defined by intervals of A and B, and is represented by a specific pair of parameters out of the intervals. Propagation calculations are carried out for the representative pairs of A and B. Statistical weights w_m are equal to the frequencies of occurrence of the classes, determined on the basis of data collected for a period of at least a year and, preferably, 10 years.

Table 6. Examples of class intervals and representative values of linear profile parameters.

	B_1	B_2	B_3	B_4	B_5
interval	$-\infty < B_1 \leq -0{,}08$	$-0{,}08 < B_2 \leq -0{,}02$	$-0{,}02 < B_3 \leq 0{,}02$	$0{,}02 < B_4 \leq 0{,}08$	$0{,}08 < B_5 < \infty$
representative value	-0,12	-0,04	0	0,04	0,12

Table 7. Examples of class intervals and representative values of logarithmic profile parameters.

	A_1	A_2	A_3	A_4	A_5
interval	$-\infty < A_1 \leq -0{,}7$	$-0{,}7 < A_2 \leq -0{,}2$	$-0{,}2 < A_3 \leq 0{,}2$	$0{,}2 < A_4 \leq 0{,}7$	$0{,}7 < A_5 < \infty$
representative value	-1,0	-0,4	0	0,4	1,0

According to Ref. [6] 25 classes (five intervals of A times five intervals of B) ensures a determination of long-term average sound levels with an error at most 2 dB at 1000 m range.

The statistical weights for each of the 25 meteorological classes shall be presented in monthly tables separately for Day, Evening and Night for each 10° of propagation direction 0° - 350°. The number of occurrences shall be given as well as the percentage of occurrences, i.e. two sets of tables shall be produced. Average humidity and average temperature shall be given per direction and meteo-class.

To be able to determine the statistical weights the following information is needed (for every hour or at least for every 3 hours):

- site coordinate
- day
- time of day
- wind speed (at a height of 10 m)
- wind direction (at a height of 10 m)

- cloud cover (in octas)
- air relative humidity
- air temperature.

Supplementary, information on snow cover shall be collected, for use with ground impedance. It is recommended that L_{den} is based on the average for the most recent period of 10 years. If hourly data is not available or some part of it is missing, interpolation should be used to estimate the missing data.

4.1 Calculation of statistical weights

For the calculation of statistical weights a Matlab-program developed by Delta was used to calculate the weights for some sites in each Nordic country. For each meteo-class and each direction, the following tables (separately for Day, Evening and Night) are calculated:

- percentages of occurrence
- frequencies of occurrence
- average temperature
- average humidity

Fig. 1 shows an example of statistical weights presented as percentages for the period "Day" (Helsinki-Vantaa Airport, Finland) based on weather data for the Finnish test-year [7].

Finland_D	%																																					
			0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	210	220	230	240	250	260	270	280	290	300	310	320	330	340	350
class	A (log)	B (lin)																																				
1	-1,00	-0,12	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
2	-1,00	-0,04	0,2	0,2	0,2	0,2	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,1	0,1	0,1	0,1	0,1	0,1	0,1
3	-1,00	**0**	22,0	22,7	23,3	23,7	22,4	20,5	18,3	17,4	14,4	11,2	9,1	7,1	6,2	5,2	4,6	4,2	4,6	4,8	5,0	5,2	5,0	6,0	7,4	7,8	7,9	8,9	9,2	8,9	10,1	11,1	12,3	14,1	15,4	17,9	20,2	21,2
4	-1,00	0,04	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
5	-1,00	0,12	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
6	-0,40	-0,12	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
7	-0,40	-0,04	2,6	2,7	2,8	2,6	2,5	2,4	2,3	2,3	1,8	1,5	1,5	1,6	1,5	1,4	1,4	1,5	1,6	1,7	1,8	2,0	2,1	2,0	2,1	2,4	2,5	2,4	2,4	2,3	2,2	2,3	2,1	2,0	2,0	2,3	2,7	2,7
8	-0,40	**0**	29,8	28,7	27,2	25,5	25,1	25,4	27,3	27,0	28,4	30,0	28,8	25,5	21,9	20,3	18,5	17,9	17,2	17,8	17,0	16,5	16,3	16,2	16,8	17,9	18,7	19,0	20,7	23,1	23,7	23,6	25,8	27,9	28,6	28,9	29,2	29,9
9	-0,40	0,04	1,8	2,0	2,0	2,2	2,3	2,5	2,5	2,5	2,5	2,4	2,2	2,1	2,2	2,4	2,4	2,5	2,3	2,1	1,8	1,7	1,6	1,8	1,8	1,7	1,7	1,7	1,6	1,7	1,8	1,9	2,0	2,0	1,9	1,8	1,7	1,8
10	-0,40	0,12	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
11	0,00	-0,12	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
12	0,00	-0,04	0,3	0,3	0,1	0,1	0,5	0,3	0,1	0,1	0,4	0,2	0,1	0,1	0,2	0,2	0,2	0,1	0,1	0,2	0,2	0,2	0,1	0,4	0,4	0,2	0,2	0,4	0,3	0,2	0,3	0,1	0,1	0,2	0,3	0,1	0,1	0,1
13	0,00	**0**	20,8	21,0	22,1	22,8	22,0	22,6	22,3	21,3	20,8	21,2	23,0	27,4	28,8	27,4	28,4	26,9	25,4	22,6	22,3	23,2	24,7	24,5	23,2	23,3	23,4	23,4	23,6	23,3	24,8	28,9	30,6	28,9	29,0	26,3	23,2	20,9
14	0,00	0,04	0,3	0,2	0,3	0,3	0,3	0,2	0,2	0,4	0,5	0,6	0,5	0,5	0,5	0,4	0,3	0,2	0,2	0,2	0,2	0,2	0,2	0,4	0,5	0,5	0,4	0,3	0,2	0,1	0,1	0,1	0,1	0,1	0,2	0,3	0,4	0,3
15	0,00	0,12	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
16	0,40	-0,12	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
17	0,40	-0,04	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
18	0,40	**0**	13,1	12,5	12,5	12,5	13,4	14,2	14,6	15,8	18,3	20,7	21,7	22,4	24,9	27,2	27,6	27,0	26,6	27,5	27,5	26,3	25,1	24,0	24,3	25,0	25,8	25,5	26,7	27,6	25,7	22,3	17,9	16,7	14,8	14,5	14,2	14,7
19	0,40	0,04	3,9	3,8	3,5	3,1	3,1	3,4	4,0	4,2	4,1	4,1	4,1	3,7	3,1	3,0	3,1	3,6	3,9	3,7	3,8	3,9	3,8	3,6	3,6	3,4	3,7	4,1	3,9	3,6	3,4	3,5	3,5	3,2	3,2	3,3	3,4	3,7
20	0,40	0,12	1,4	1,3	1,3	1,2	1,0	0,8	0,8	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,8	0,9	1,0	1,2	1,2	1,2	1,2	1,3	1,4	1,4	1,5	1,5	1,7	1,8	1,8	1,7	1,6	1,6	1,6	1,5	1,5
21	1,00	-0,12	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
22	1,00	-0,04	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
23	1,00	**0**	3,1	3,6	3,6	4,4	5,7	6,0	6,3	7,2	7,0	6,4	7,3	7,9	8,9	10,5	11,2	13,7	15,7	16,7	17,4	18,1	18,1	18,2	17,0	15,0	13,1	11,8	8,9	6,5	5,2	3,7	3,2	2,4	2,4	2,2	2,8	2,7
24	1,00	0,04	0,8	0,9	1,2	1,5	1,5	1,4	1,3	1,0	1,0	0,8	0,7	0,9	1,2	1,3	1,6	1,5	1,5	1,6	1,7	1,6	1,7	1,6	1,5	1,5	1,2	1,0	1,1	0,9	0,8	0,7	0,6	0,7	0,6	0,5	0,5	0,5
25	1,00	0,12	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0

Fig. 1. An example of statistical weights for a period "Day" (presented as percentages).

5 CALCULATION OF YEARLY AVERAGE NOISE LEVELS

Based on the knowledge of available meteorological data a method for calculating the yearly average noise level was defined, taking the effect of weather into consideration. Results obtained in Harmonoise and work carried out by DELTA and SP was utilised.

When calculating the yearly average noise levels it is not possible to calculate the effect of every possible meteorological condition during a year. For the calculation of yearly average noise levels meteorological conditions are divided in a small number of categories (classes) and calculations are carried out separately for each of these classes.

Typical values for the parameters of logarithmic and linear sound profiles are:

A (log) =	-1,0	-0,4	0	0,4	1,0	m/s
B (lin) =	-0,12	-0,04	0	0,04	0,12	1/s

Together these make up 25 sound speed profiles. For each of these profiles statistical weights can be determined by using local meteorological data. The statistical weights describe the frequency of occurrence of the meteorological conditions that fall into respective classes during a year.

When statistical weights have been determined it is possible to calculate the effect of wind and temperature gradients on yearly average noise levels. To get a real annual noise level for a year, also the variation of the source and the surroundings during a year should be taken into account.

Attenuation is calculated for each point source separately for all sound speed profiles (25 altogether) and for all propagation paths.

The noise level per frequency band for each source position is calculated according to the following equation:

$$L = 10\log\left(\sum_{m=1}^{25}\sum_{i=1}^{3} p_{m,i} w_i 10^{\frac{L_m + \Delta L_a\left(t_{m,i}, RH_{m,i}\right)}{10}}\right) \tag{6}$$

where

m is the meteo-class number
i indicates the time of day (1: day, 2: evening, 3: night)
L_m is the sound level without air absorption in meteo-class *m*
$\Delta L_a(t_{m,i},RH_{m,i})$ is the effect of air absorption in the meteo-class m and time period *i*
t is the temperature
RH is the relative humidity.
$p_{m,i}$ is the probability of meteo-class *m* in time period *i*
w_i is the time of day weight (includes 5 and 10 dB adjustments for evening and night, the duration of the time periods and varying source emission).

The method given by Taraldsen [8] can be used to estimate the probability $p_{m,i}$ for cases with reflected sound paths. Probabilities $p_{m,i}$ which take hourly variations of traffic numbers into account can be calculated according to [9].

6 GUIDANCE ON EFFECTS OF SEASONAL CHANGES

Besides wind and temperature gradients also other factors have an effect on yearly average noise levels. The surfaces of the ground (and also water) may differ quite a lot during different seasons and this should be taken into account when calculating yearly noise levels. At summertime the ground may be covered, for example, with grass but at wintertime the ground is in many places covered with snow and the snow can be soft or frozen etc. The surface of the seas is considered acoustically hard at summertime, but at wintertime the water is frozen and this may be covered with soft snow that changes the surface to acoustically soft. Also the coincidence of morning and evening inversions with traffic rush hours can at some time of the year give rise to more noise than at other times.

To include the variations of the acoustic properties of the ground in determining yearly average noise levels one must know what properties are related to the acoustic impedance of the ground and how these factors vary in different areas at different times of the year. Parameters that are significant are for example wetness, snow cover, ice cover and the state of vegetation.

In the following some possible factors (excluding wind and temperature gradients) having an effect on the yearly average noise levels of road traffic noise are considered. The influence of seasonal changes of source noise emission and propagation (ground characteristics) are considered separately. In addition to this, some tentative results of long-time measurements carried out by VTT are presented [10, 11].

6.1 Emission

Noise emission (and also the directivity) of road traffic depends on both the vehicle including the tyres and the road surface. There are many factors influencing noise emission to be used as an input for calculating the yearly average noise levels.

<u>Vehicle</u>
- A change in temperature can change the noise emission of the engine.
- The speed of the traffic can be different during different times of the year (for example in Finland some roads have different speed limits during wintertime) and also in different weather conditions (rain, snow, low visibility, slippery road surface etc.).

<u>Road and tyres</u>
- Noise depends on the state of the road surface (wet, snowy, frozen etc.). For example, maintenance habits at wintertime can have an influence on snow and/or ice on the road surface. Also the absorption characteristics of the road surface can be different during different weather conditions. Different types of road surfaces can wear differently (and thus change noise emission) during the year, this concerns especially low-noise surfaces and when studded tyres are used.

- Winter tyres, studded tyres and summer tyres have different noise emissions and also temperature of the road surface has an effect on the rolling noise.

Traffic flow
- The amount of traffic can be different during different times of the year. For example, in summertime (and also during skiing holidays) there is more traffic outside big cities.

6.2 Sound propagation

Because the state of the atmosphere is influenced by the underlying topography, the influences of ground and atmosphere on the propagation of sound are not independent of each other. For example buildings, trees and other vegetation and ground surface can give rise to atmospheric irregularities which can influence the propagation of sound.

When calculating yearly averages of road traffic noise it should be known how the ground surface, vegetation and all other factors influencing sound propagation change during a representative year.

Road
- At wintertime possible snow banks along roads can act as noise barriers and reduce the noise.

Ground surface
- The state of the ground surface (and also ground impedance) changes during the year and this has an influence on the propagation of sound. To be able to calculate the yearly average noise level the average ground impedance during the year should be known for all different types of ground surfaces including the vegetation that is in different state during different times of the year. For example, in Finland at wintertime the ground is covered by snow and the snow can be either soft or hard (frozen snow). During spring, summer and autumn the ground surface can also be different and also wet ground can have different ground impedance than dry ground.

Vegetation
- Vegetation changes during spring, summer and autumn and together with the characteristics of the ground can make the ground impedance different. Vegetation and particularly big trees can locally have an effect on the wind and temperature gradients and this effect may be different at different times of the year.

6.3 Calculating the effects of seasonal changes on yearly average noise levels

It is not possible at this moment to take all these effects into account when calculating the yearly average noise levels. There is not enough knowledge about many of the factors having an effect on noise when yearly averages are considered. Furthermore, many factors are different at different areas and all yearly information about ground surface, road surface and vegetation should be known for the exact area that is considered in calculations.

One possible way could be to divide the year into different periods during which the circumstances could be taken as non-varying. The lengths of these periods could be, for example, one month and the statistical weights and also all other factors of seasonal changes could be determined for each month separately by taking into account the pertinent long-time weather statistics, road and ground characteristics of the area in consideration. The calculations should then be carried out separately for each of these monthly periods and finally added to a yearly average noise level.

6.4 Long-time measurements carried out by VTT

VTT has carried out long-time sound propagation measurements during 612 days in the years 2004 - 2005. The measurements were carried out in Sodankylä in the northern part of Finland. The distance between the loudspeaker and the microphone system (consisting of eight microphones) was 3240 meter and the automatic measuring system made a measurement every hour (measuring the noise produced by a horn-loudspeaker system). The terrain between emission and immission point is flat. The noise was measured in the frequency range 40 Hz – 1600 Hz. The measurement place situated near a meteorological station of The Finnish Meteorological Institute, where considerably amount of meteorological parameters were recorded simultaneously with the noise measurements. Meteorological measurements were also carried out near the sound source by using a SODAR that gives the instantaneous temperature profile and the components of wind up to the height of 750 m in steps of 25 m. Also near the measuring point wind speed and direction and temperature of the air were measured.

Fig. 2 shows the sound source and Fig. 3 the measuring system.

Fig. 2. Sound source configuration.

Fig. 3. Detector configuration.

The research project is part of the Finnish Defense Forces Akusti-project. The objectives of the Akusti-project are to evaluate acoustical surveillance systems in Finnish climate conditions. The main objective of the project is to gain more reliable results from sound propagation calculations by implementing calculation of weather conditions to state-of-the-art physical propagation models. VTT will develop a new sound propagation model for large distances utilizing the results from the measurements.

The measuring system is described in detail in reference [11] and information is available at the web-site [12]. Fig. 4 shows excess attenuation during the measurement period (612 days). Excess attenuation means all other attenuation than geometric divergence and it may be either positive or negative.

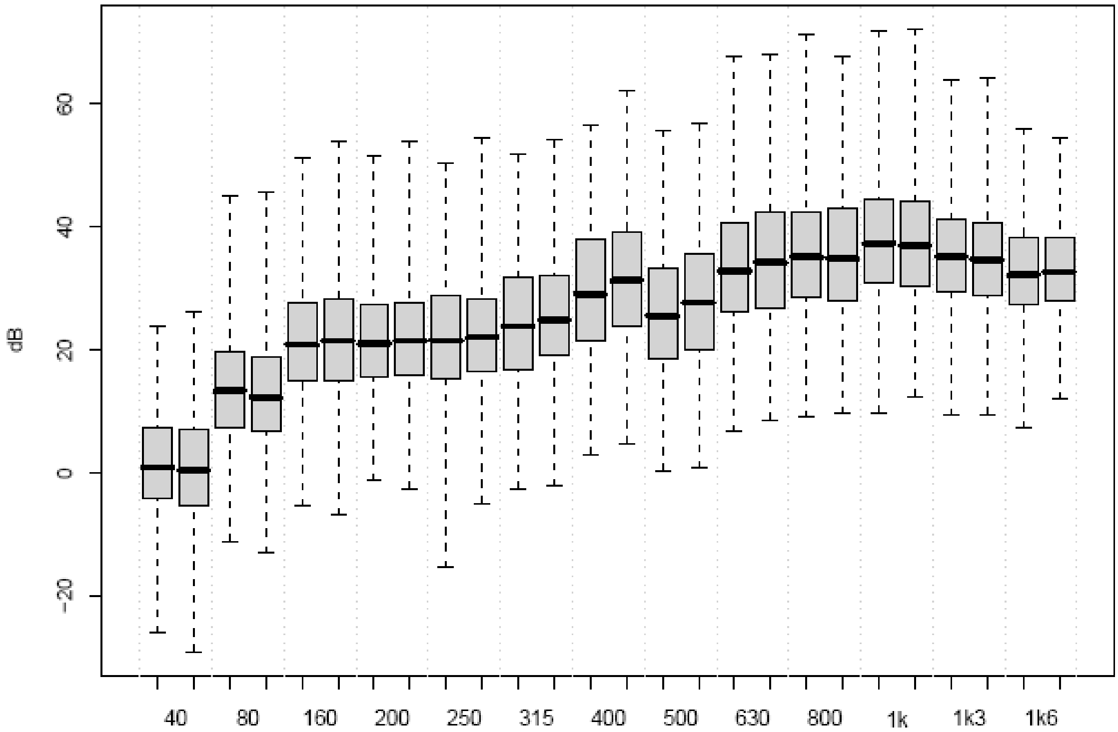

Fig. 4. Excess attenuation during the measurement period

The limit (highest and lowest) values are marked in dot lines, the area in the box marks the values inside 25 to 75 % of probability (50 % of values are inside the area of the box) and the solid bold line in the box means the average value. The difference between the highest and lowest values (maximum) is around 60 dB. At the 50 % confidence interval the difference is around 15 dB. The 50 % confidence interval changes in different seasons of the year (see Appendix 3).

The results show quite a big difference between the highest and lowest measured values but it is not possible at this phase of the analysis to apply the results to road traffic noise in much detail. The distance between the loudspeaker and the microphone system is quite large compared to usual distances in connection with road traffic noise and the noise source in this study is a steady monopole source rather than a moving point source as in road traffic noise. Further analysis of the results may give some more information to be applied to road traffic noise also. Fig. 5 shows, for example, average excess attenuation during the whole day in the measured frequency range.

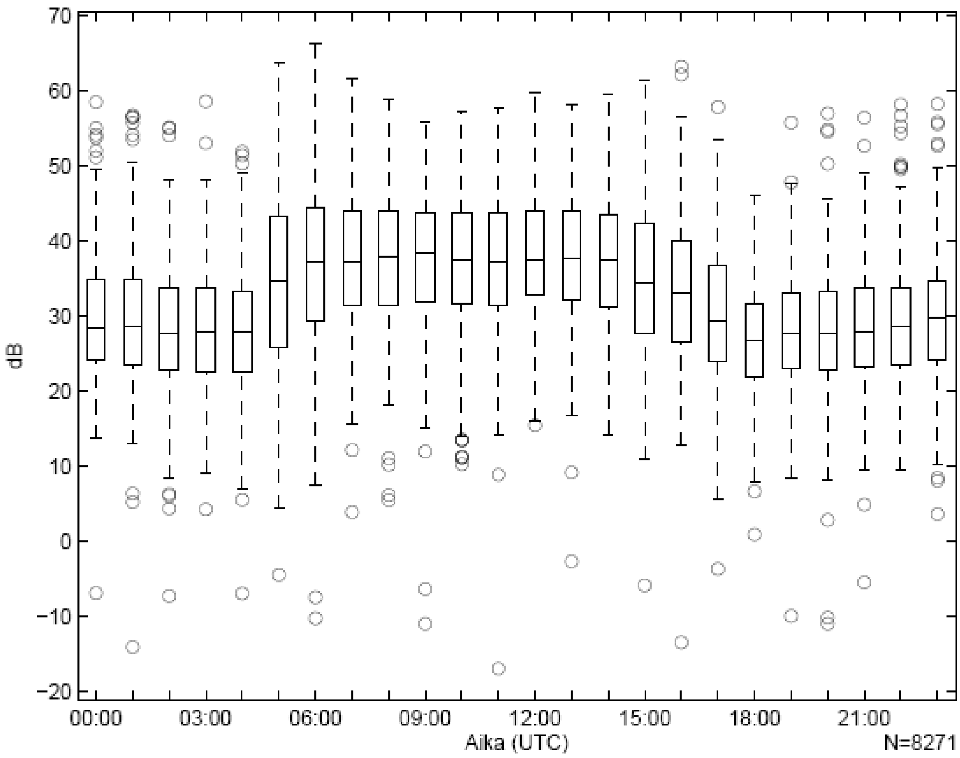

Fig. 5. Average excess attenuation during day (UTC-time) in the measured frequency range.

Appendix 3 shows some other examples of the results from the measurements. The analysis of the measurement results is not completely ready at this time, so it is only possible to show some tentative results.

7 MEASUREMENTS OF FINNISH VEHICLE NOISE DATA

VTT collected all available results from noise emission measurements carried out for Nord2000 road traffic noise prediction method in Finland and some new measurements were also carried out, see Appendix 2.

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APPENDIX 1: Meteorological data available in Finland

In co-operation with The Finnish Meteorological Institute it was investigated what kind of meteorological data is available in different parts of Finland. During a meeting with representatives from The Finnish Meteorological Institute it was decided that The Finnish Meteorological Institute would send information to VTT explaining the availability of meteorological data. In the following the results of this information is presented.

WEATHER STATIONS IN FINLAND

Basic information

Observation web changes slowly all the time.

Weather stations measuring merely precipitation are about 300- 400.
Stations measuring air temperature, relative humidity, air pressure and also wind are about 120 - 150.
The solar radiation is measured at about 30 stations

As a result of automatization most of the data is available at intervals of one hour. (momentary value and the average of one hour). As regards to wind typically an average of 10 minutes is also available (situation in this respect varies between stations).

Station-specific observations at 3 hour intervals are available 3 mostly from the year 1961 (the observation web is changed over this period of 40 years). As a result of automatization the observation made at one hour interval has become common during the last decade. The data is available for example in ASCII format.

The representativeness of the measured value (as regards to the surrounding area) depends on the time, quantity of weather and it is not possible to give accurate answer. However for each station representativeness has been tried to estimate.

It is also possible to estimate the weather data further from the station

For air quality measurements also the stability classes are needed and also these are most probably available.

The cost of the data depends on the using purpose. If they are only used in a project and they are not given further or are not used for commercial purposes- i.e. only for pure research purposes, the cost are formed only from the labour needed to separate the data needed from the data base.

<u>Basic quantities</u>:

- Wind direction and velocity and air temperature are available at interval of one hour at certain level from the earth surface (temperature at 2 m level; wind velocity and direction level 10 m as 10 minutes average). Unfortunately gradients are not available in most cases, but there is some masts or towers where you can get wind data from different levels (for example Sodankylä, Espoo/Kivenlahti, Inkoo, the availability of those data varies).

Accessory data:

- Solar radiation at earth level is available from 30 stations.
- Cloudiness (as eights) is available as manual observations at 30 stations and there are more stations from which the cloudiness is gathered automatically.
- Time of sun rise and sun set can be gathered from the almanac. It is perhaps some kind of programme.
- The deviation of the wind direction is problematic. Wind velocity and direction is measured normally as 10 minutes average at one hour intervals.

Other data:

- Relative humidity and air pressure is available at one hour intervals.
- Observations relating to the earth surface (dry, wet, snow or ice covered) is available.
- Precipitation is available as average of 12 or 24 hours (depend on the station).

TEST YEAR DATA OF 1979

There is in the ASCII-form a whole test year (1979) data from Helsinki (Vantaa), Jyväskylä (Luonetjärvi) and Sodankylä [7], which contains:

- Air temperature and relative humidity at 2m level as a average of one hour at every hour intervals

- Wind velocity and direction at 10 m level as ten minute average at every hour

- Solar radiation (direct and diffused) average of one hour at every hour

- Cloudiness (manual data as prevailing weather, cloudiness can be interpolated at 3 hour intervals as eights

- Observations of earth surface (manual 3 hour at intervals)

- Precipitation 2 times in day (12 hour intervals).

The wind velocity and other gradients are problematic. However stability classes can be approximated with certain accuracy and added to the basic data of a test year. Also the times of sun rise and sun set can be added. The labour needed to complement the database is about 2 days.

APPENDIX 2: Finnish emission measurements for Nord 2000

Finnish emission measurements for the Nord 2000 road traffic noise calculation method have thus far been carried out at three measuring sites. The first set of measurements was carried out in the year 2000 and the second in 2005. All measurement results have been sent in a suitable format to SP for further analysis.

Table A2.1 shows the pertinent information for each measuring site.

Table A2.1. Information for each measuring site.

Measuring site	d_1 (m)	d_2 (m)	speed limit (km/h)	T_{air} (°C)	T_{road} (°C)	road surf.	wind m/s	date
Kirkkonummi	8,0	11,7	100	12-13	20-24	1a	< 5	16.5.2000
Koivu-Mankkaantie	7,5	11,1	50	15-17	22-24	1a	< 5	6.6.2000
Lahdentie	10,8	14,6	80	18-20	23-25	1a	< 5	1.9.2005

The measuring microphones were situated at the heights of 0,2 m and 4 m from the ground surface. Measurements were carried out for traffic on both directions (in Table 1 d_1 = the distance to vehicles on the nearer lane and d_2 the distance on the farther lane). All pass-bys were recorded on DAT-tape. From the traffic all vehicles that passed by the measuring site in such a way that no other vehicle or other background noise was disturbing the measurement were selected (in practice there was only one car on the road). For these the exact time of passing the microphones was written down and the speed of the vehicle was measured with a hand-held radar. In addition to this, all information for the vehicle (for example type of the vehicle and the way of driving) was documented.

The recordings were later analyzed in the laboratory by choosing the separate pass-bys of the vehicles selected. For these the sound exposure level and the maximum noise level (L_{Fmax}) were determined for the third-octave bands 20 Hz - 10 kHz. Measuring time for each vehicle was different: the integration was started when it was possible to hear the noise of the vehicle from the background noise and it was stopped before the background noise was dominant again. Each measured value thus has only the noise of the vehicle in question and no noise from any other vehicles or some other noise sources. Fig. A.2.1 shows an example of the measuring set-up at one measuring site.

Fig A.2.1. Measuring set-up at Kirkkonummi measuring site.

The vehicles were divided in the following classes:

1 Cars
1a Passenger cars excluding other light vehicles 4 wheels, two axles
1b Other light vehicles: cars with trailers or caravans, light utility vehicles, minibuses, vans, motor homes, recreational and utility vehicles 4 wheels, two axles or 6wheels, 3 axles

2 Dual-axle heavy vehicles. 6 wheels, two axles
2a City buses 6 wheels, two axles
2b Light and medium trucks 4-6 wheels, two axles

3 Multi-axle heavy vehicles
3a Large city buses 8-10 wheels, 3 axles
3b Medium trucks 8-10 wheels, 3 axles
3c Heavy trucks 4-5 axles
3d Very heavy trucks > 6 axles

4 Motor cycles

5 Mopeds

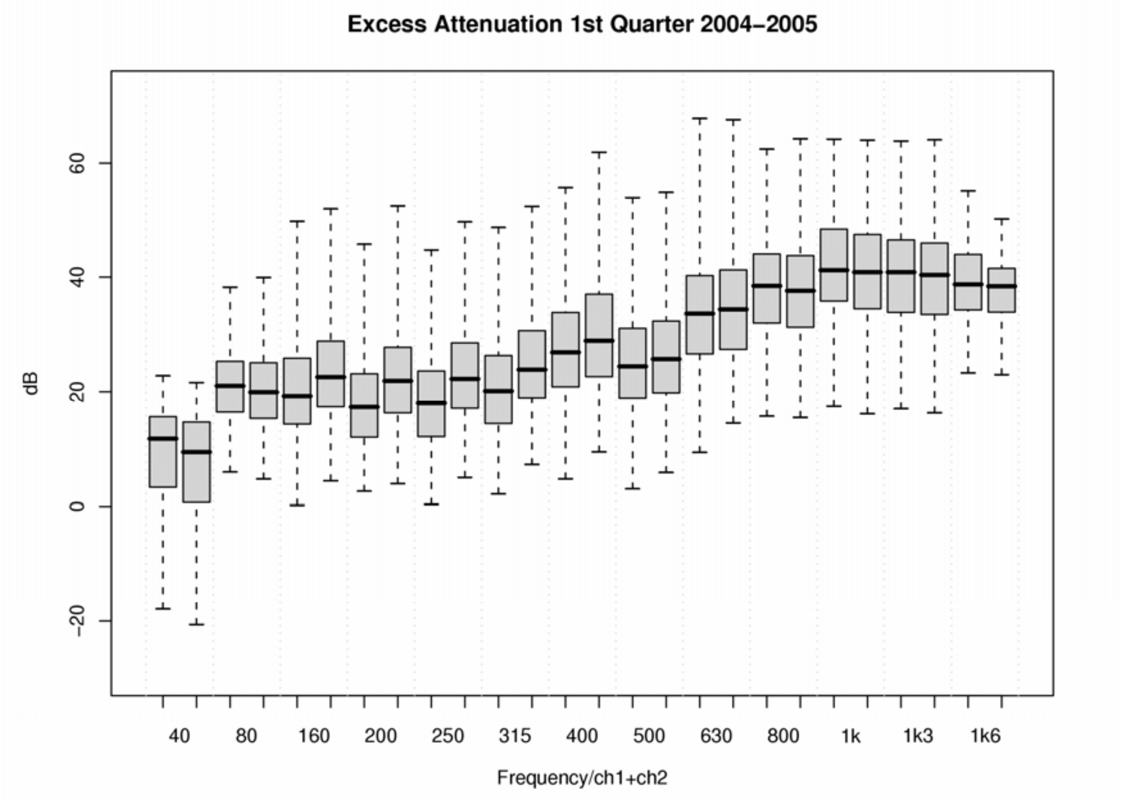
Equipment used in measurements:

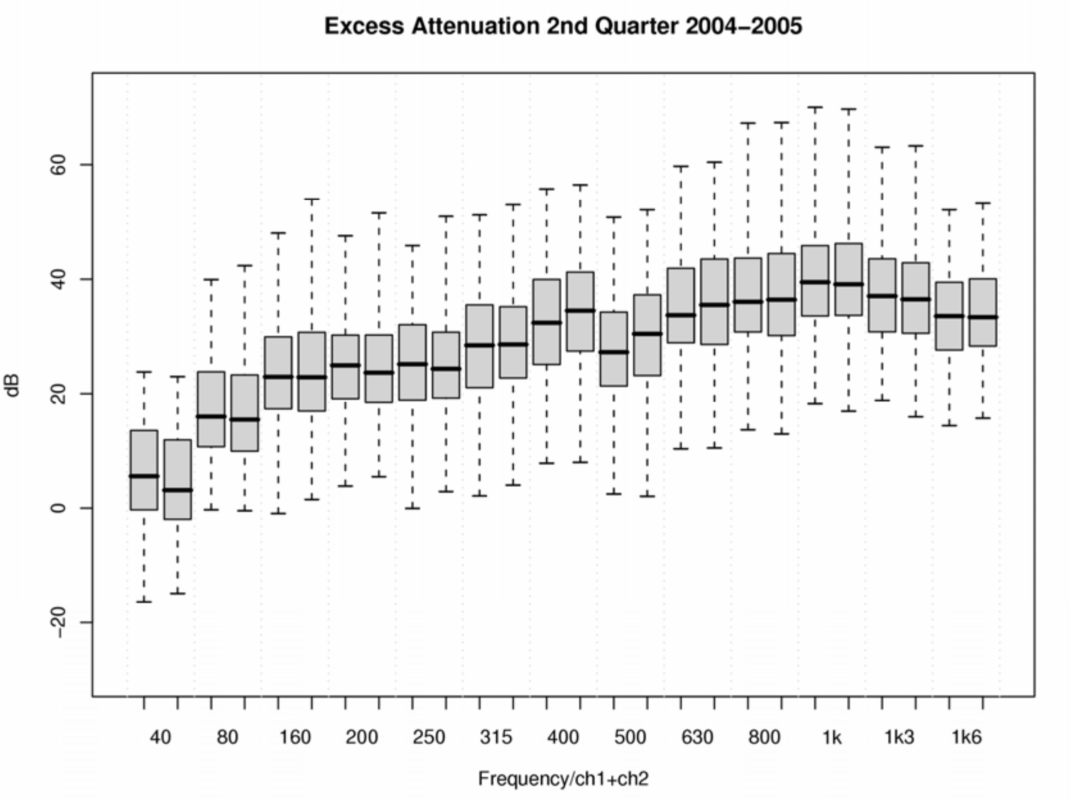
sound level meter B&K 2260 Investigator
condenser microphone B&K 4190
microphone pre-amplifier B&K 2669
microphone power supply B&K 5935
DAT-recorder Denon DTR 80P
sound level calibrator B&K 4231
windshield B&K UA 0237
anemometer Ferropilot Windy
radar Muni Quip K-GP

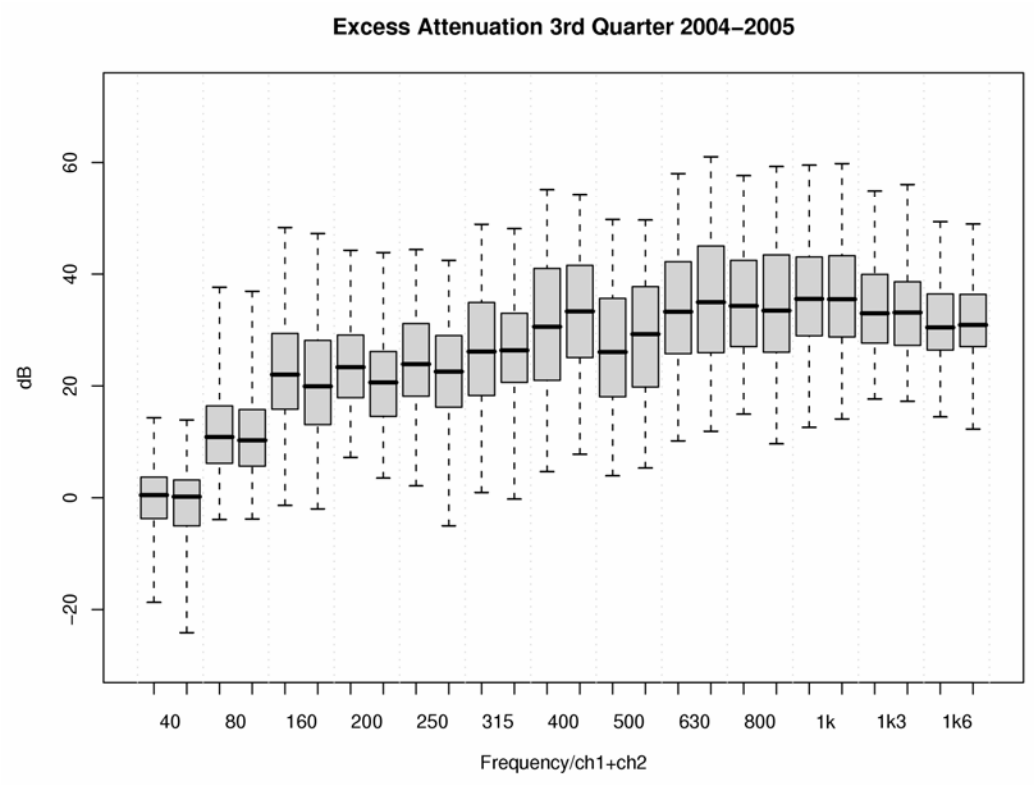
Equipment used in analysis:

DAT-recorder Denon DTR 80P
2-channel real-time analyzer Norsonic 830
B&K Pulse front-end 2827, LANInterface Module 7533, 4/2-Input/Output Module

APPENDIX 3: Some examples of the results of long-time measurements carried out by VTT






Excess Attenuation 3rd Quarter 2004−2005
dB
60
40
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40
80
160
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250
315
400
500
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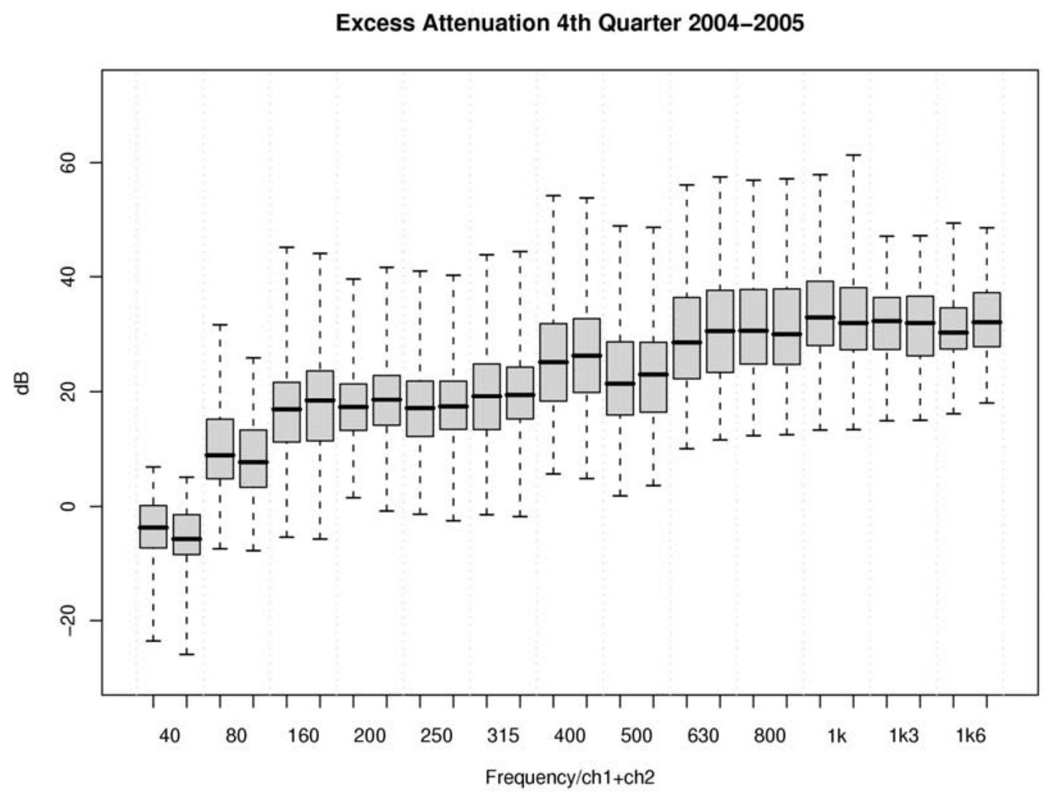
800
1k
1k3
1k6
Frequency/ch1+ch2


Excess Attenuation 4th Quarter 2004−2005
dB
60
40
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800
1k
1k3
1k6
Frequency/ch1+ch2