03 Environmental noise

ELEC-E5640 - Noise Control D

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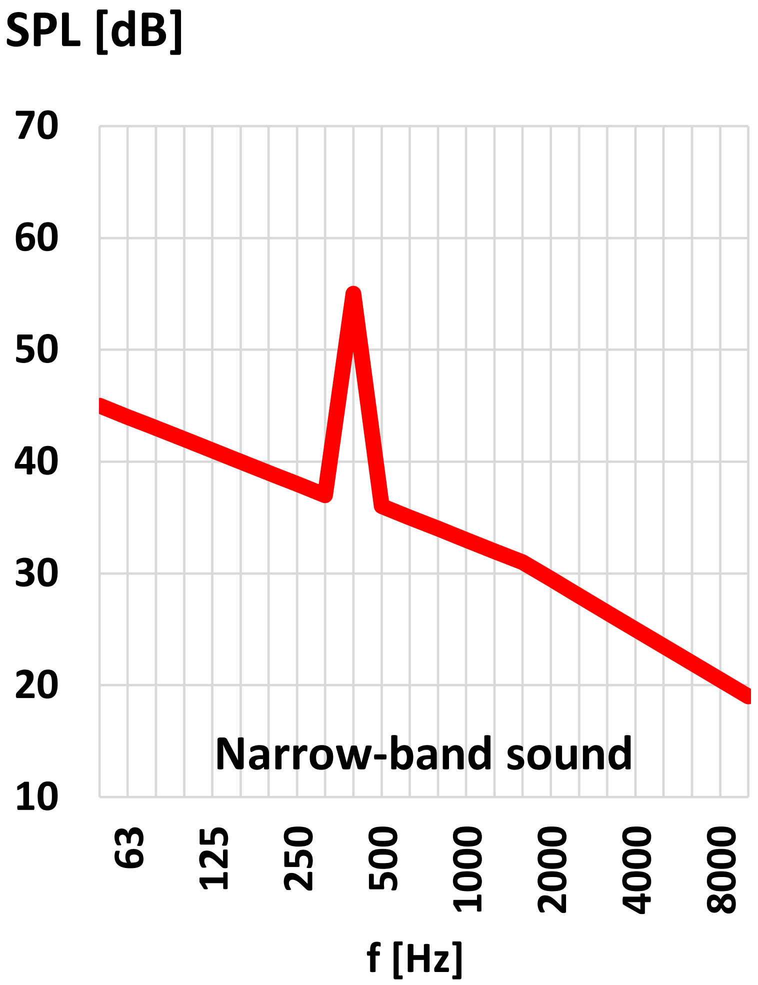
Target values

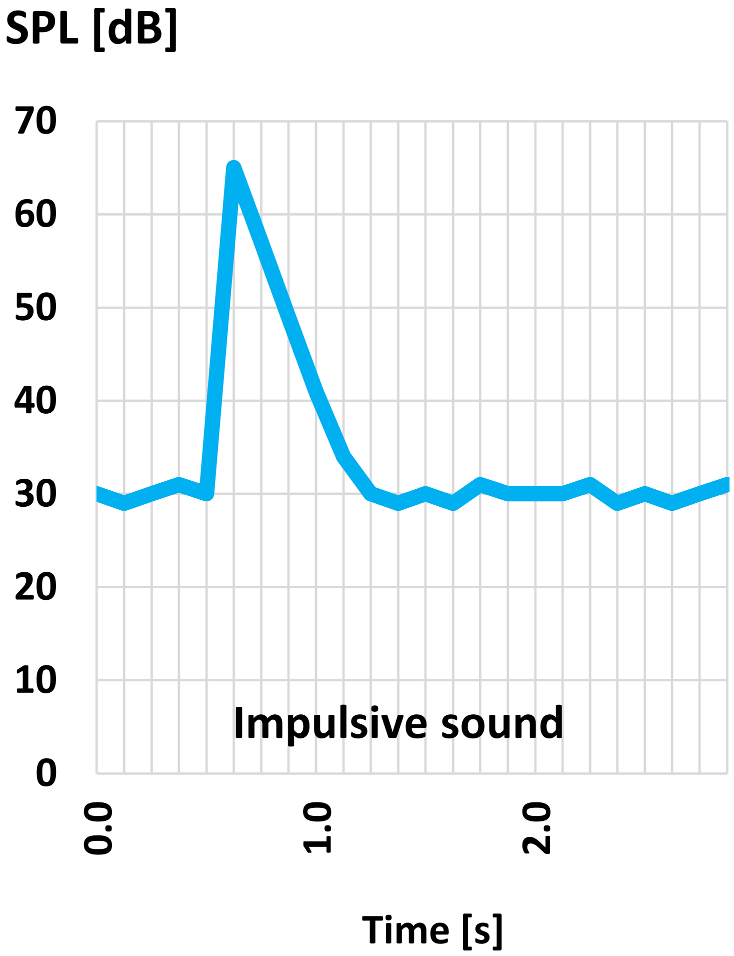
- Finnish target values concern **$L_{Aeq,T}$**:
  - Night time 22-07, T=9 h
  - Day time 07-22, T=15 h
- If the sound contains specific properties, a penalty is added, **k** [dB]
- Measurement uncertainty **E** is usually at least E=±2 dB
- The final value **$L_{Aeq,T}$ +k - E** is compared to target value.
- NOTE: If there are N noise sources, the target value for each of them is $10 \cdot \log_{10} N$ tighter

VnP 993/1992	**Day** **07 - 22** **T=15 h**	**Night** **22 - 07** **T=9 h**
Target values indoors	$L_{A,eq,T}$ [dB]	$L_{A,eq,T}$ [dB]
Living areas	55	50
New living areas	55	45
Educational areas	55	-
Recreational areas	45	40
Target values indoors	$L_{A,eq,T}$ [dB]	$L_{A,eq,T}$ [dB]
Living rooms	35	30
Education rooms	35	-
Office rooms	45	-

NOTE: If noise is impulsive or tonal, 5 dB is added before comparing to these values

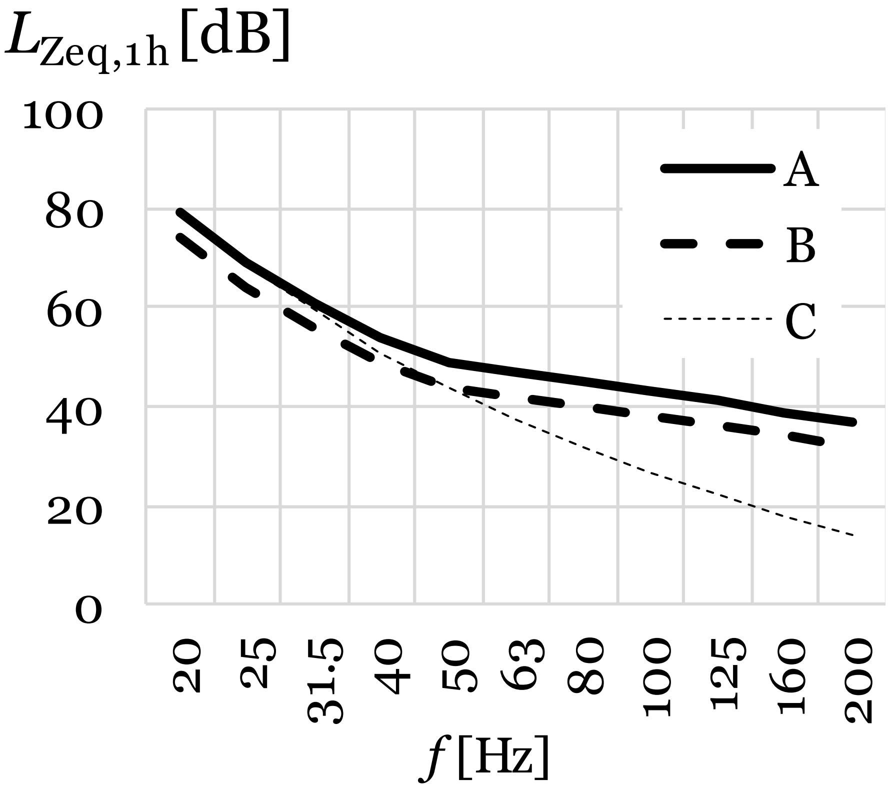
Specific properties leading to penalty





STM 545-2015 – Limit values for hourly low-frequency noise in rooms used for sleeping

Band f [Hz]	Day 07-22 $L_{Zeq,1h}$ A	Night 22-07 $L_{Zeq,1h}$ B	Night 22-07 $L_{Aeq,1h}$	Hearing threshold C
20	79	74	23.6	78.5
25	69	64	19.3	68.7
31.5	61	56	16.6	59.5
40	54	49	14.4	51
50	49	44	13.8	44
63	47	42	15.8	37.3
80	45	40	17.5	31.5
100	43	38	18.9	26.6
125	41	36	19.9	22
160	39	34	20.6	18
200	37	32	21.1	14.3



Decree 545 - 2015 of Ministry of Social Affairs and Health, Finland.

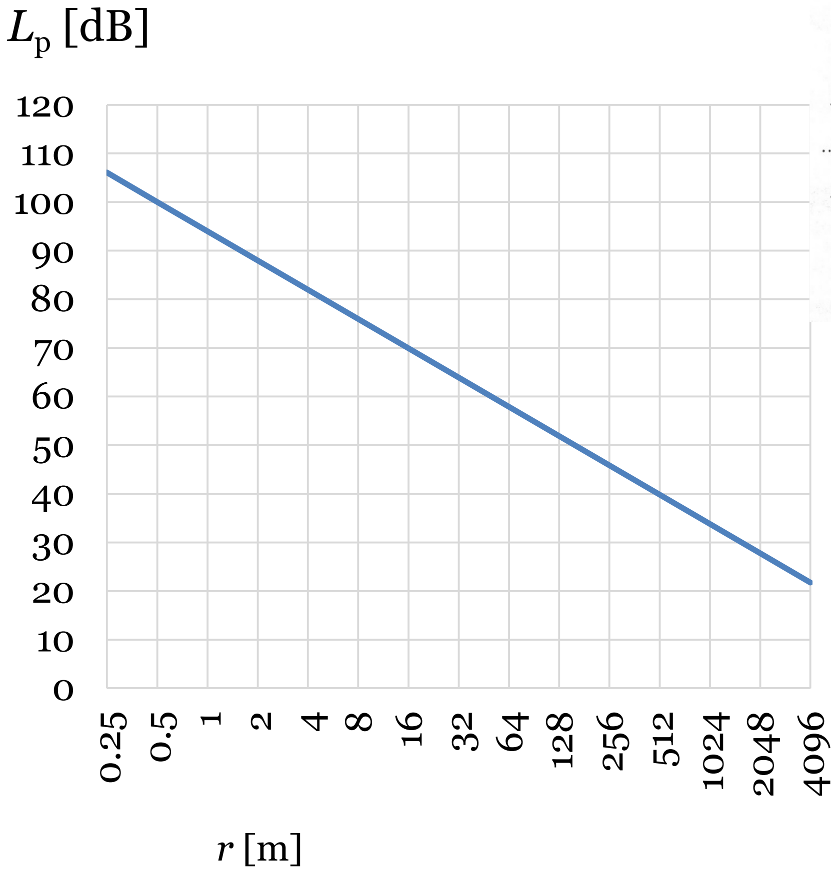
Geometric spatial attenuation
Point source in free field

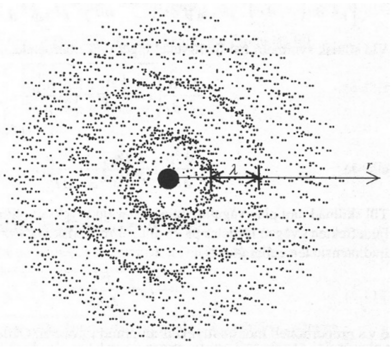
- Figure indicates the SPL produced by a point source with k=1 and Ω=4π. The outcome is a spherical symmetric wave.

Independent variables:

- Geometric attenuation term, D_{ge} [dB]
- Sound power level L_W [dB]
- Directivity constant k in the direction of interest
- Space angle Ω
- Distance to the source r [m]

$$L_p = L_W + D_{ge} = L_W + 10\log_{10}\left[\frac{k}{\Omega r^2}\right]$$

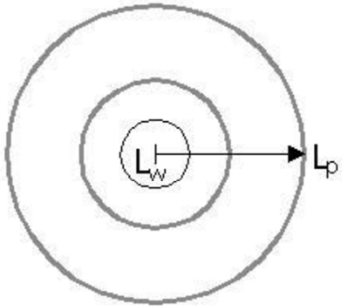




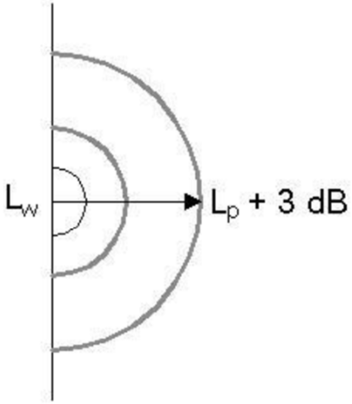
Space angle Ω

Suppressed space angle increases the SPL even by 11 dB.

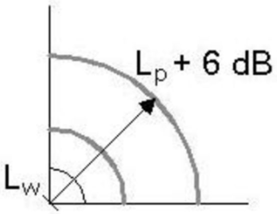
4π	Source is far from surfaces, e.g. wind turbine
2π	Source is near to one surface, e.g. source on the ground
π	Source is near to two surfaces, e.g. washing machine
π/2	Source is near to three surfaces, e.g. freezer



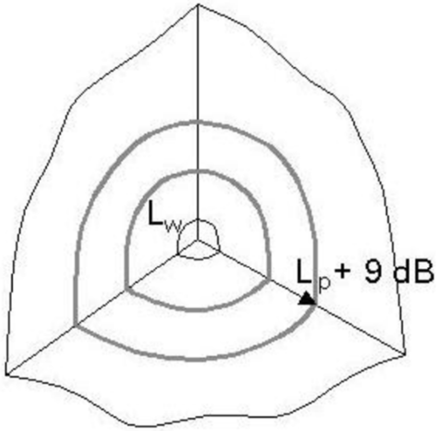
Ω=4π



Ω=2π



Ω=π



Ω=π/2

Directivity constant k_θ

- Directivity constant

$$k_\theta = \frac{I_\theta}{I_m}$$

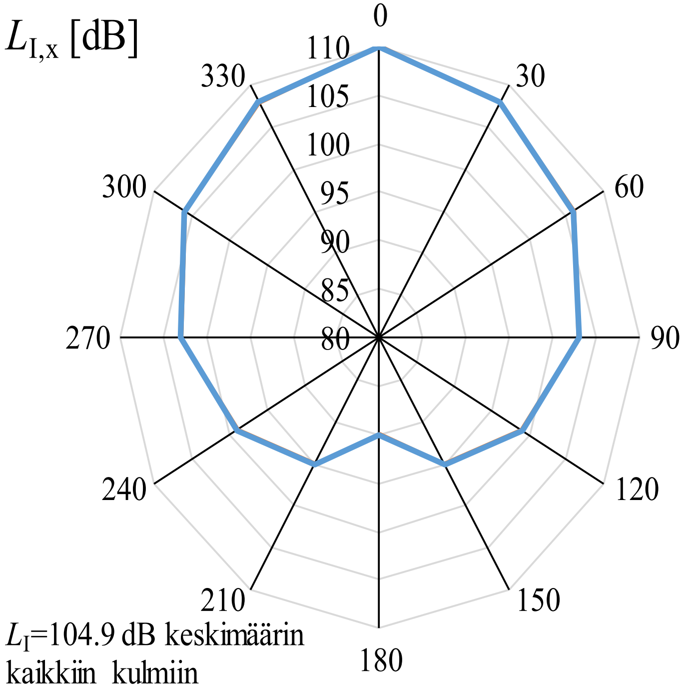
  - sound intensity in angle θ, I_θ
  - mean sound intensity in all angles, I_m

- With directivity index $L_{k,\theta}$ [dB]

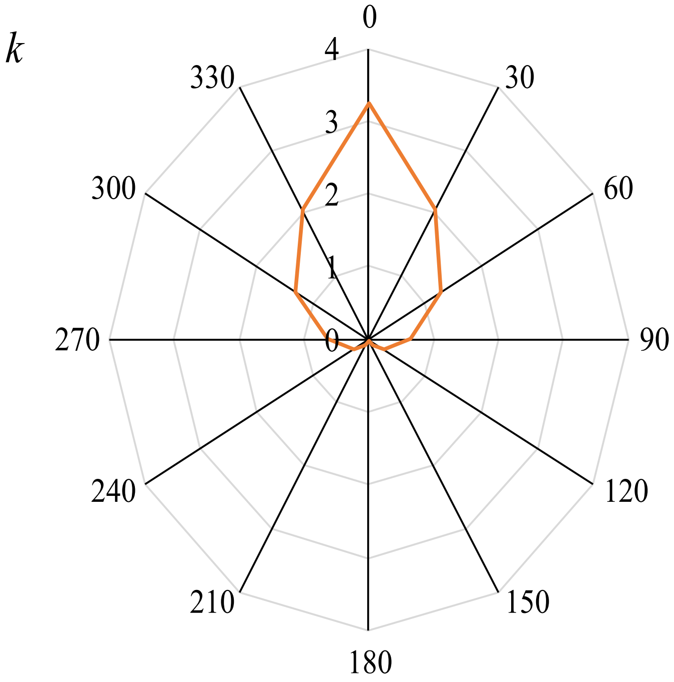
$$L_{k,\theta} = 10\log_{10} k_\theta$$

- the propagation equation gets an alternative form:

$$L_p = L_W + L_{k,\theta} + 10\log_{10}\left[\frac{1}{\Omega r^2}\right]$$



L_I=104.9 dB keskimäärin kaikkiin kulmiin

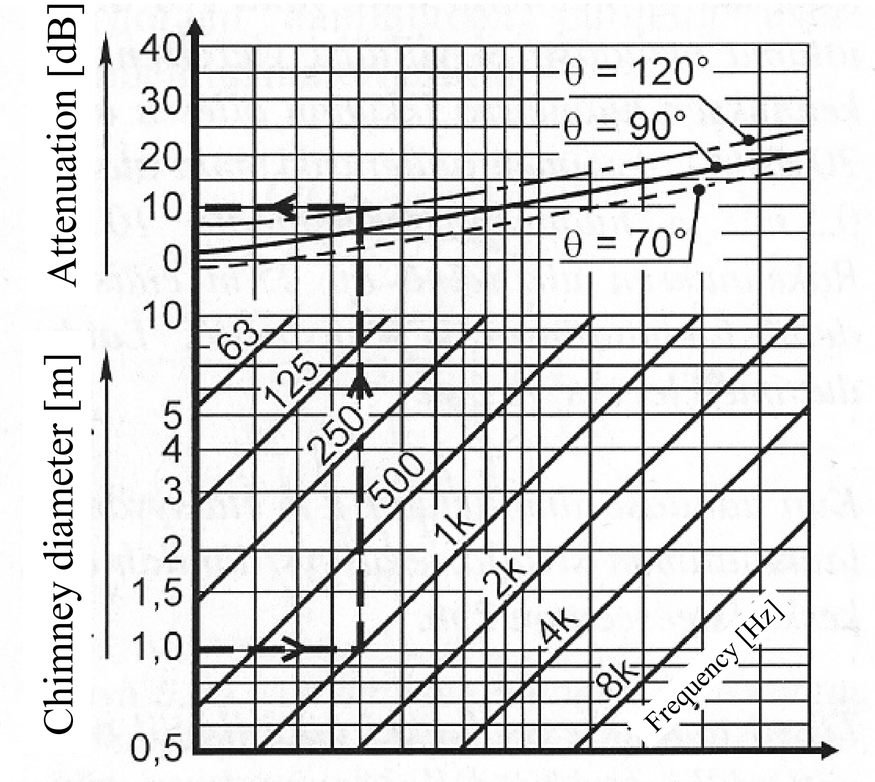


At 0°: k_θ=3.25 and L_k=5.1 dB.

3.1 When are the SWL and the SPL of a point source equal in free field?
Check separately the four space angles.

$$\boxed{L_p = L_W + D_{ge} = L_W + 10\log_{10}\left[\frac{k}{\Omega r^2}\right]}$$

Directivity index of a chimney L_k [dB]

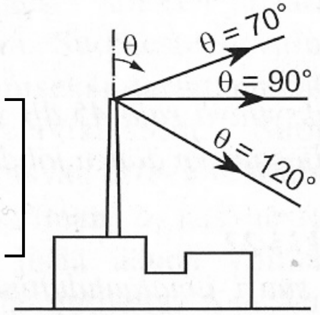


Directivity of sound from a tall chimney. The example with arrows concerns a chimney with a 1.0 m diameter, 1000 Hz and angle θ=120 °, where the attenuation is 10 dB

L_k [dB] for angles 90° and 120° with various chimney diameters *d*.

	Frequency [Hz]						
d*, *mm	*63*	*125*	*250*	*500*	*1k*	*2k*	*4k*
For Θ=90 degrees							
100	0	0	0	0	0	0	-1
200	0	0	0	0	0	-1	-4
400	0	0	0	0	-1	-4	-7
800	0	0	0	-1	-4	-7	-10
1600	0	0	-1	-4	-7	-10	-13
For Θ=120 degrees							
100	-3	-3	-3	-3	-3	-4	-5
200	-3	-3	-3	-3	-4	-5	-8
400	-3	-3	-3	-4	-5	-8	-11
800	-3	-3	-4	-5	-8	-11	-14
1600	-3	-4	-5	-8	-11	-14	-17

$$L_p = L_W + L_{k,\theta} + 10\log_{10}\left[\frac{1}{\Omega r^2}\right]$$

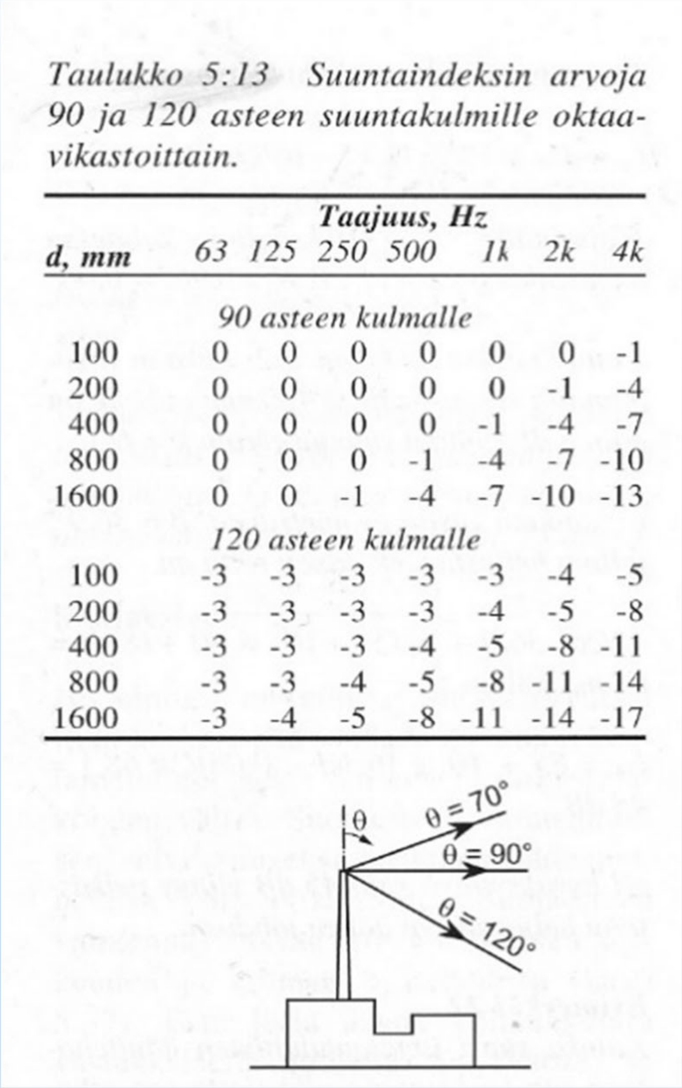


Halme&Seppänen, 2002

3.2

Chimney is 20 meters high. The diameter is d=1600 mm.
SWL is 115 dB at 63 Hz octave band.
What is the SPL at a yard locating 35 m away?

$$L_p = L_W + D + L_k = L_W + 10\log_{10}\left[\frac{1}{\Omega r^2}\right] + L_k$$



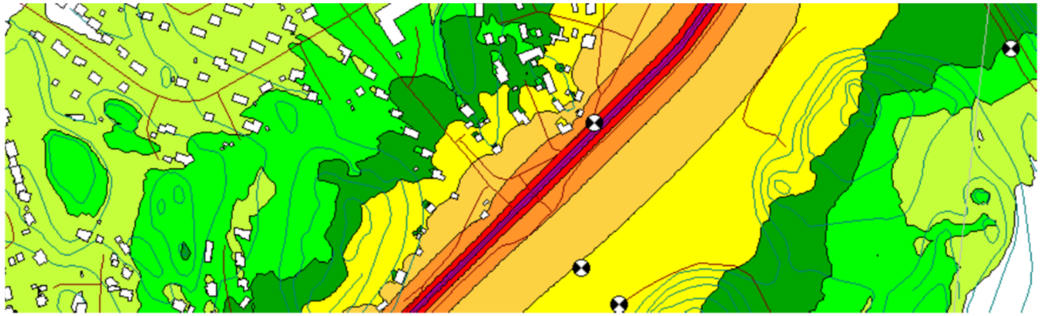
Taulukko 5:13 Suuntaindeksin arvoja 90 ja 120 asteen suuntakulmille oktaavikastoittain.

	Taajuus, Hz						
d, mm	*63*	*125*	*250*	*500*	*1k*	*2k*	*4k*
90 asteen kulmalle							
100	0	0	0	0	0	0	-1
200	0	0	0	0	0	-1	-4
400	0	0	0	0	-1	-4	-7
800	0	0	0	-1	-4	-7	-10
1600	0	0	-1	-4	-7	-10	-13
120 asteen kulmalle							
100	-3	-3	-3	-3	-3	-4	-5
200	-3	-3	-3	-3	-4	-5	-8
400	-3	-3	-3	-4	-5	-8	-11
800	-3	-3	-4	-5	-8	-11	-14
1600	-3	-4	-5	-8	-11	-14	-17

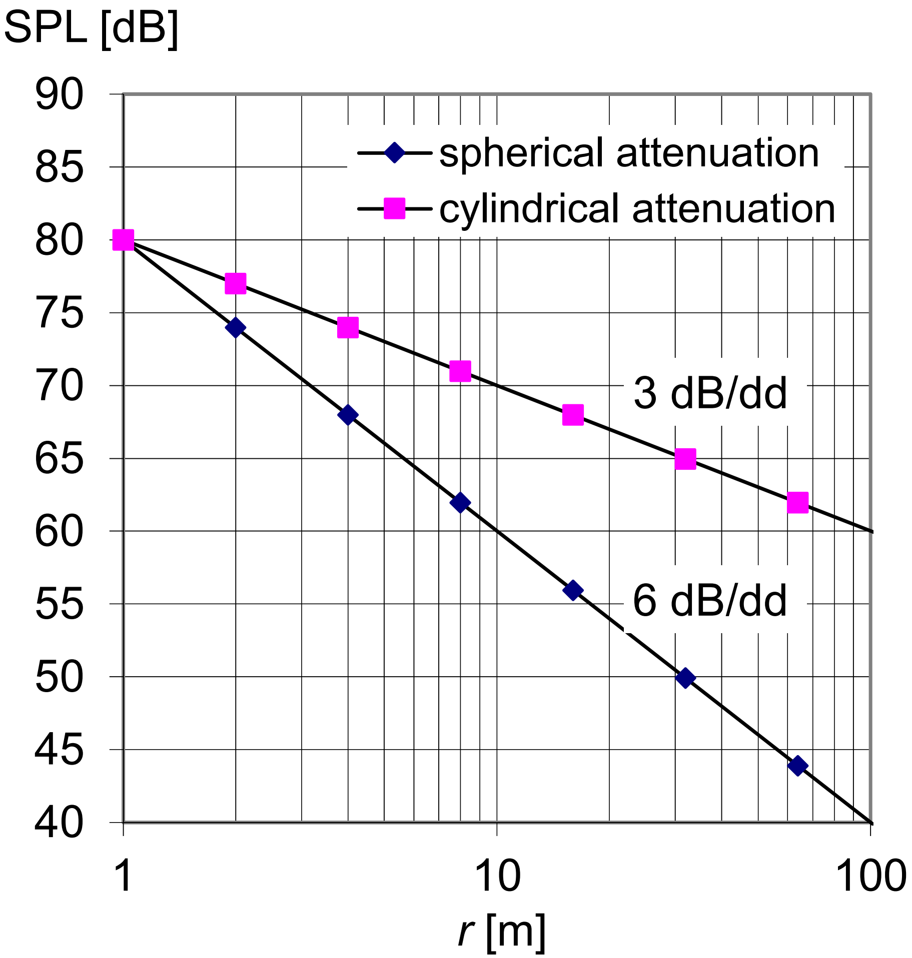
Geometric spatial attenuation D
line source, free field

- Cylinder source
- E.g., a road with constant traffic.
- Usually, line sources are expected to have a symmetric radiation, *k*=1
- SWL of a line source is not specifically defined because the line length depends on application. Emission sound pressure level $L_{p,1}$ is expressed at a distance r_1 and $L_{p,2}$ at another distance r_2 is determined by

$$L_{p,2} = L_{p,1} - 10 \cdot \log_{10}\left(\frac{r_2}{r_1}\right)$$



- Comparison of point and line sources when they have equal SPL at 1 m distance.



Spatial attenuation from point source

Ground and athmospheric attenuation included

- Sound power level L_W [dB]
- Directivity constant, k
- Space angle Ω
- Distance r *[m]*
- Ground correction D_{gr} [dB]
- Athmospheric attenuation D_{atm} [dB/km]

$$L_p = L_W + 10\log_{10}\left(\frac{k}{\Omega r^2}\right) + D_{gr} - D_{atm}$$

Athmospheric attenuation D_{atm}

- Water molecules absorb sound differently in different temperatures *T* and relative humidities *RH*
- Attenuation at distance *r* [m] is notated by D_{atm}
- D_{atm} is large at large distances and high frequencies

$$D_{atm} = \frac{\alpha r}{1000}$$

T [ºC]	*RH* [%]	α [dB/km] 63 Hz	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz
10	70	0.1	0.4	1	1.9	3.7	9.7	32.8	117
20	70	0.1	0.3	1.1	2.8	5	9	22.9	76.6
30	70	0.1	0.3	1	3.1	7.4	12.7	23.1	59.3
15	20	0.3	0.6	1.2	2.7	8.2	28.2	88.8	202
15	50	0.1	0.5	1.2	2.2	4.2	10.8	36.2	129
15	80	0.1	0.3	1.1	2.4	4.1	8.3	23.7	82.8

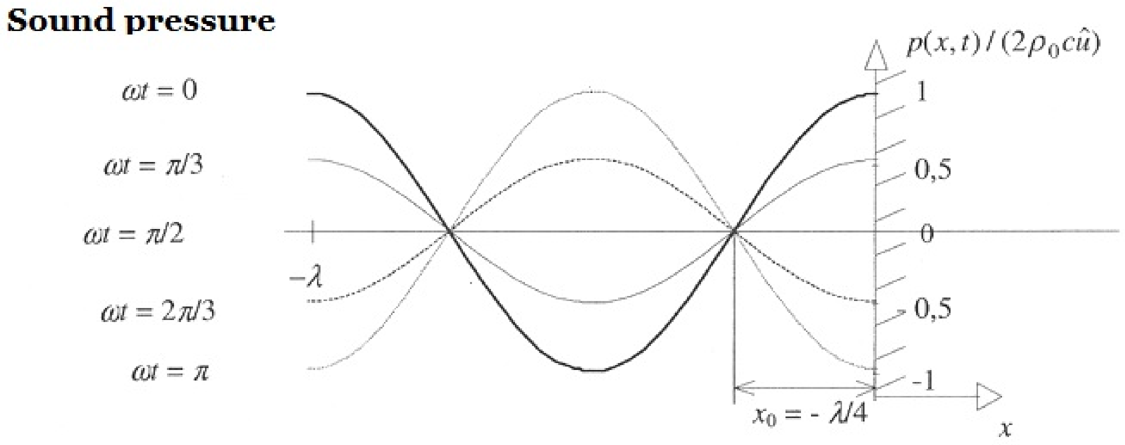
Table 2 of ISO 9613-2:1996

Ground correction D_{gr}

- Ground absorption coefficient α_G:
  - 0.0: hard (asphalt, water)
  - 0.3: mainly hard (sand fields, dense urban areas)
  - 0.7: mainly soft pehmeä (non-dense urban areas)
  - 1.0: soft (natural ground)
- If the ground is hard in the receiver's location, the level increases by 3 dB
  - The correction is valid if the height of the receiver is larger than the wavelength.
- Low-frequency noise deserves a specific attention since the distance from ground is usually less than $\lambda/4$. Closer than that, the standing wave produces an increment of 6 dB in SPL (same phase of incident and reflected wave).

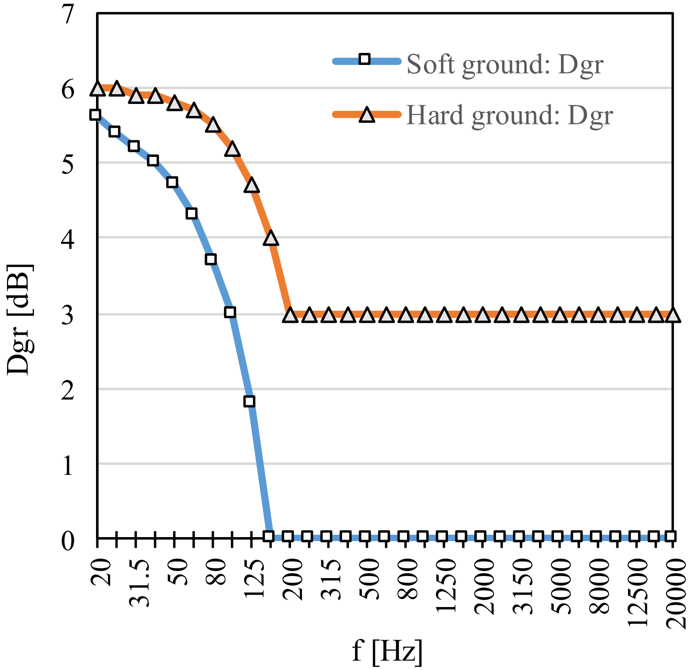
GENERAL RULES

- Hard ground: +3 dB
  - Water
  - Ice
  - Asphalt
- Soft ground: 0 dB
  - Snow
  - Forest



D_{gr} for wind turbine noise modeling

- Finnish guideline requires that the low-frequency standing wave is considered below 200 Hz (λ=1.7 m)



	f **[Hz]**	**20**	**25**	**31.5**	**40**	**50**	**63**	**80**	**100**	**125**	**160**	**200**	**250**	**315**	**400**
Soft ground	D_{gr} [dB]	5.6	5.4	5.2	5	4.7	4.3	3.7	3	1.8	0	0	0	0	0
Hard ground	D_{gr} [dB]	6	6	5.9	5.9	5.8	5.7	5.5	5.2	4.7	4	3	3	3	3

	f **[Hz]**	**500**	**630**	**800**	**1000**	**1250**	**1600**	**2000**	**2500**	**3150**	**4000**	**5000**	**6300**	**8000**	**10000**
Soft ground	D_{gr} [dB]	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard ground	D_{gr} [dB]	3	3	3	3	3	3	3	3	3	3	3	3	3	3

Ympäristöhallinnon ohje, 2/2014
https://julkaisut.valtioneuvosto.fi/handle/10138/42937

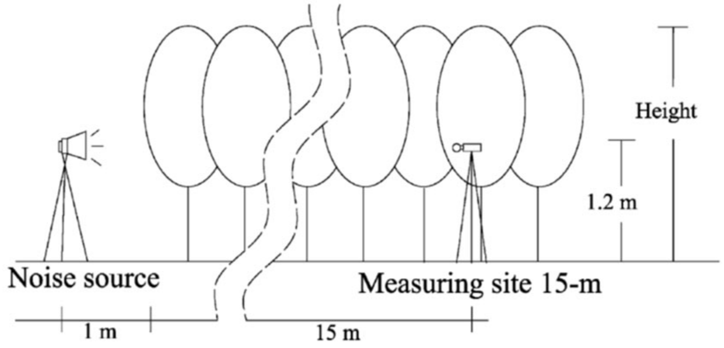
Vegetation attenuation D_{veg}

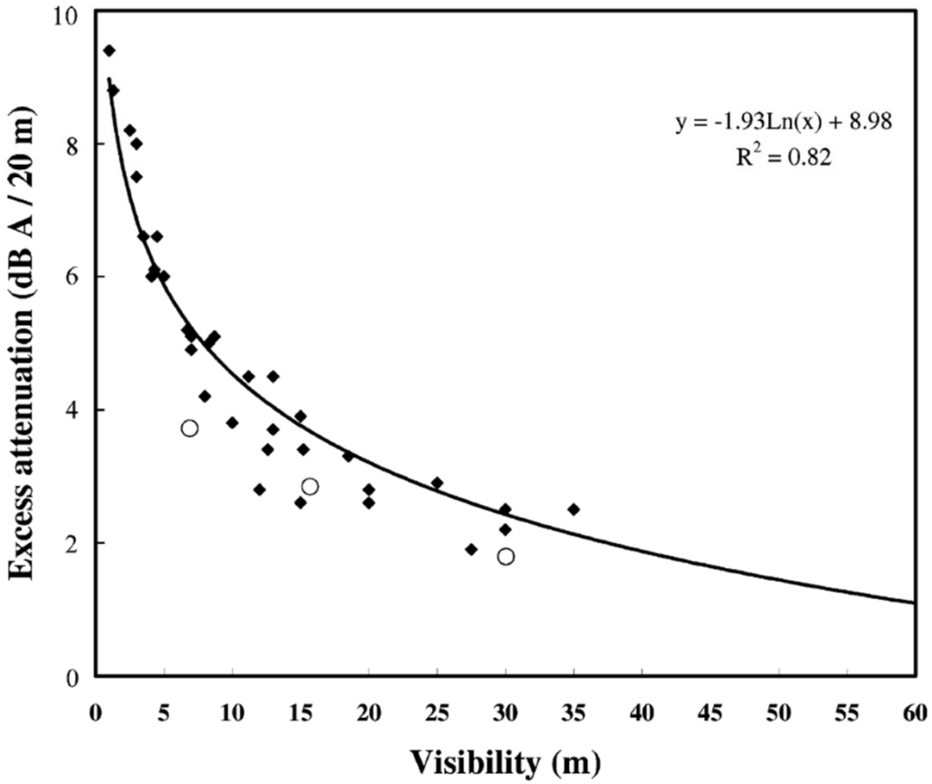
- Fang and Ling (2003) found that the attenuation D_{veg} [dB/20 m] through a vegetative zone is strongly associated with the visibility V_{veg} [m] through the vegetation.

$$D_{veg} = -1.9 \ln\left(V_{veg}\right) + 9$$

- A part of sound bends over the vegetation zones so that there is an upper limit that a vegetative zone can reduce noise in practice.
- Vegetation attenuation is difficult to assess and it also changes with time due to
  - Forestry operations or growth
  - Season of the year (leaves of the trees)
- Therefore, vegetation attenuation should never be overestimated in prediction models.

C.-F. Fang, D.-L. Ling / Landscape and Urban Planning 63 (2003) 187–195

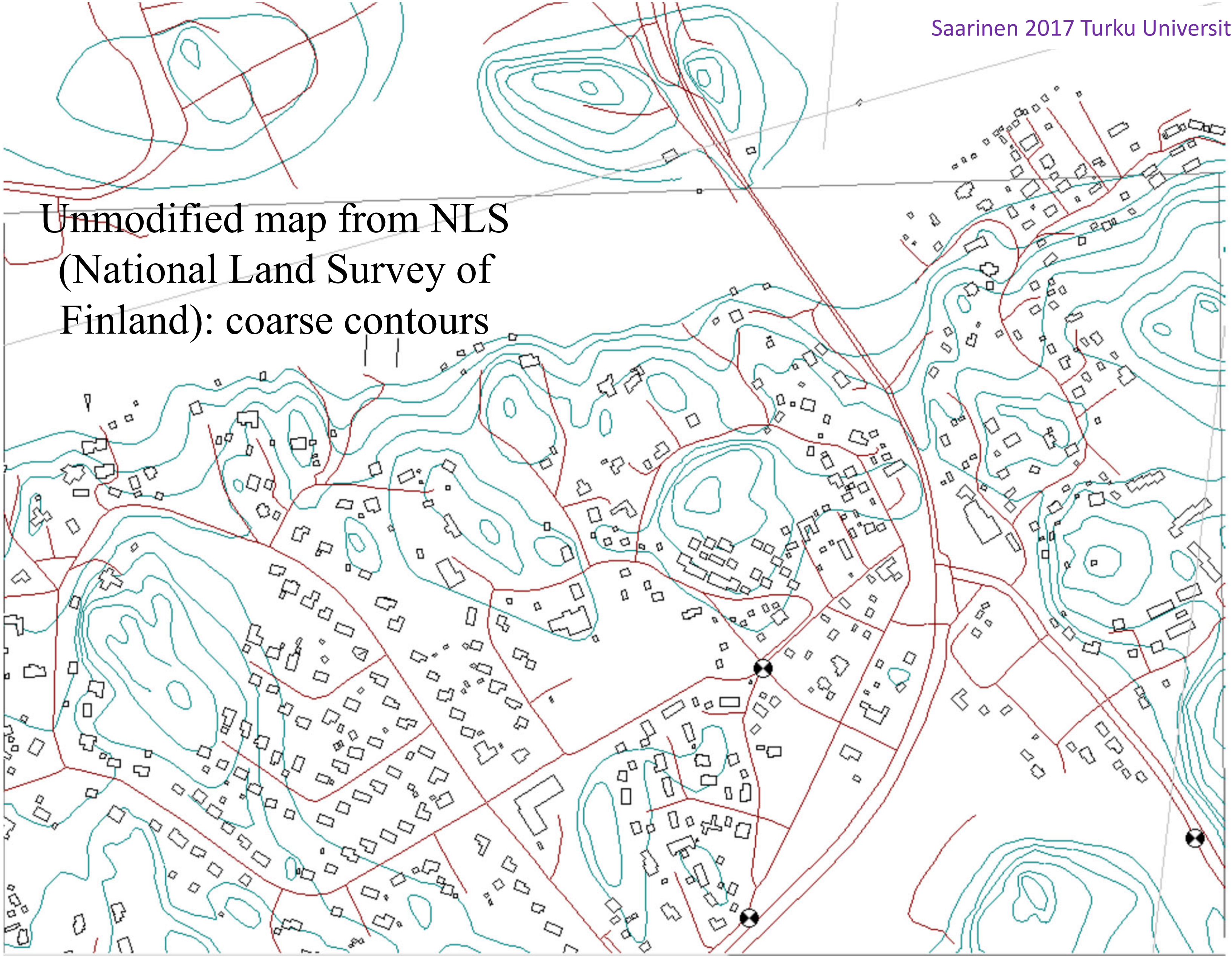




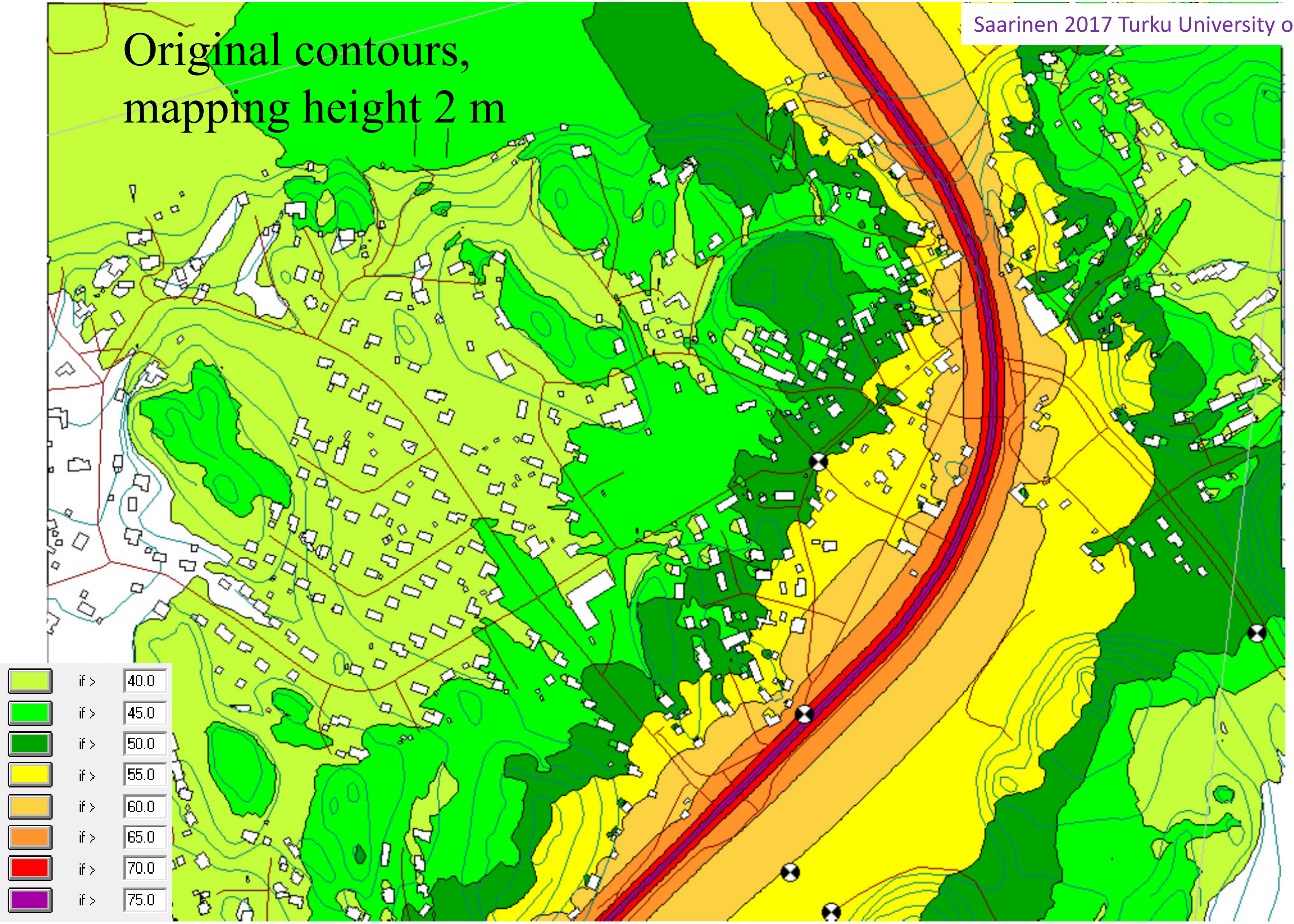
Topography

- Important for sound sources located close to ground
- Topography is downloaded from map service
- Maps give height contours with 5 m density
- Near the sound source, the accuracy of contours are sometimes improved by hand to 2 m density

Saarinen 2017 Turku University of Applied Sciences



Unmodified map from NLS (National Land Survey of Finland): coarse contours



Original contours, mapping height 2 m

Saarinen 2017 Turku University of Applied Sciences

Noise barriers

hansarakenne.fi

kuhmonbetoni.fi

a1highways.com.au/noise-barriers

sepa.fi

boscoitalia.it

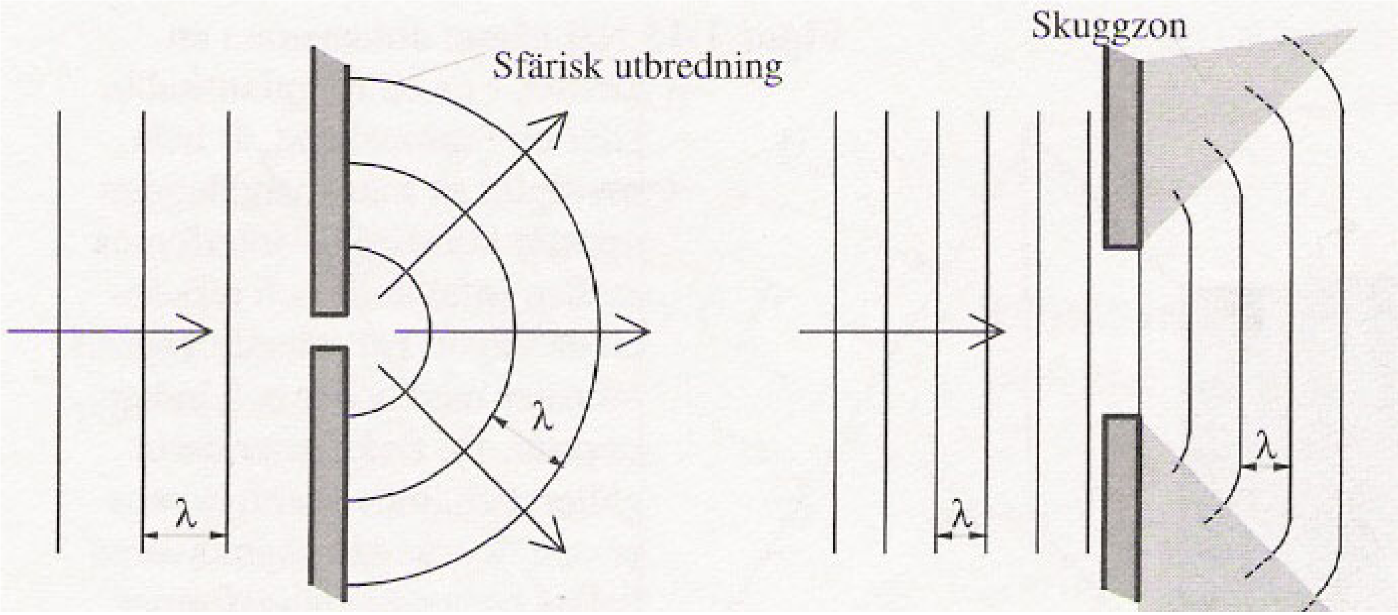
Diffraction in a hole

Strong and perfect diffraction: hole << λ:

- Phase is constant within the hole
- The hole acts as a perfect new point source
- Energy is equally transmitted in all directions behind the hole

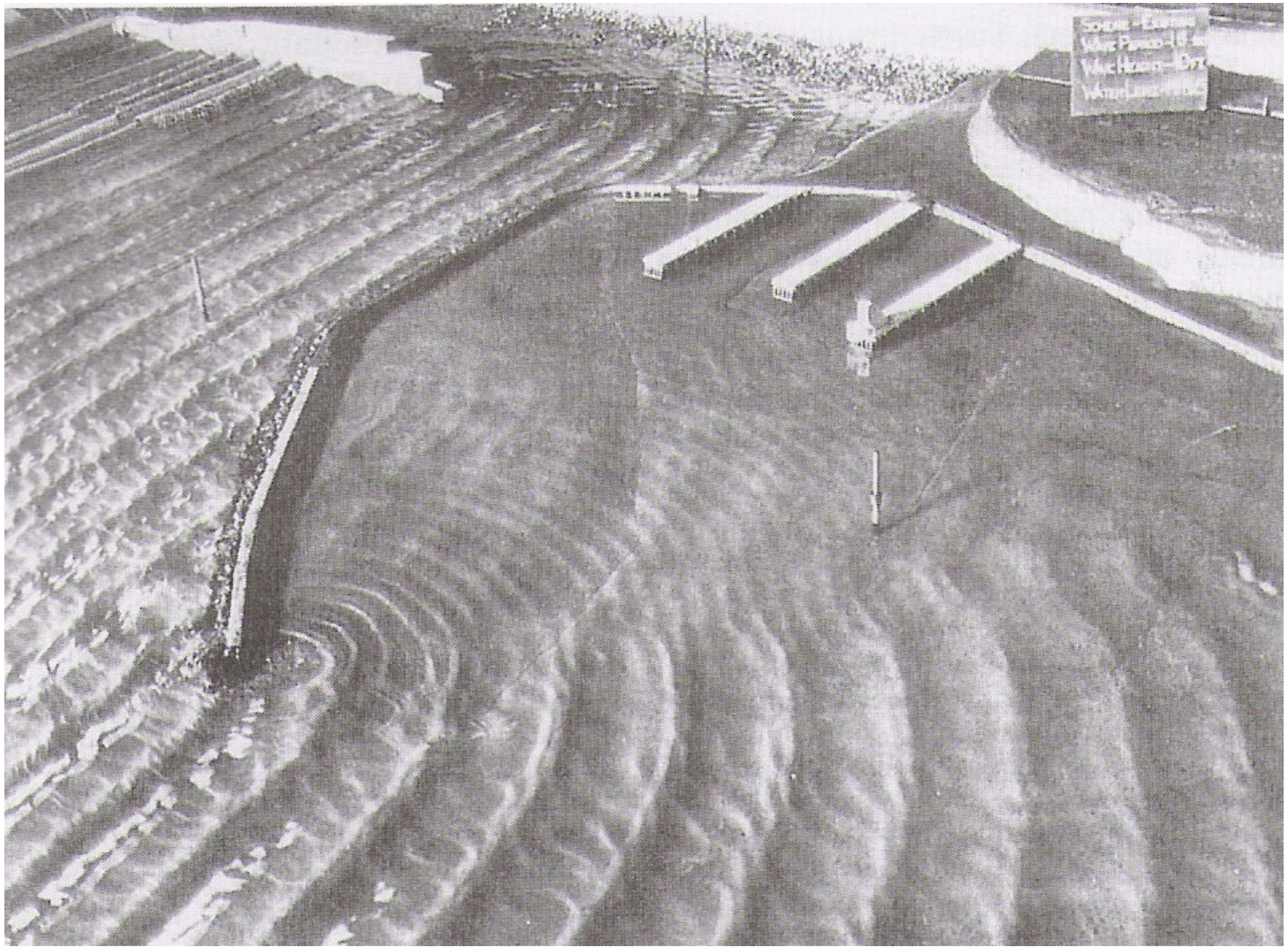
Weak diffraction: hole >> λ

- Phase is not constant within the hole
- Middle part of sound wave transmits the hole without any disturbance
- Only the sound waves closer than λ/2 to the edge ”perceive” full diffraction



Weak diffraction: hole >> λ

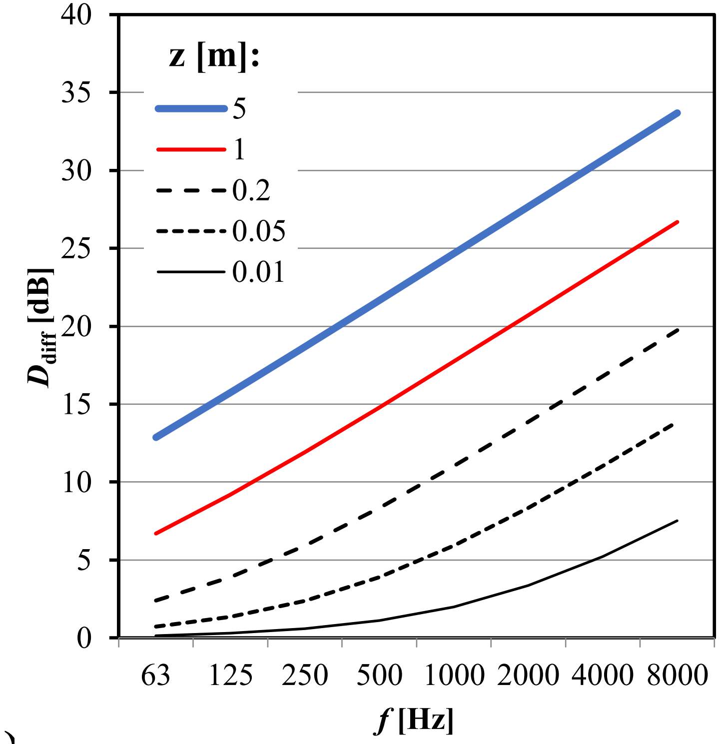
- Barrier can be considered as a one-sided infinite hole

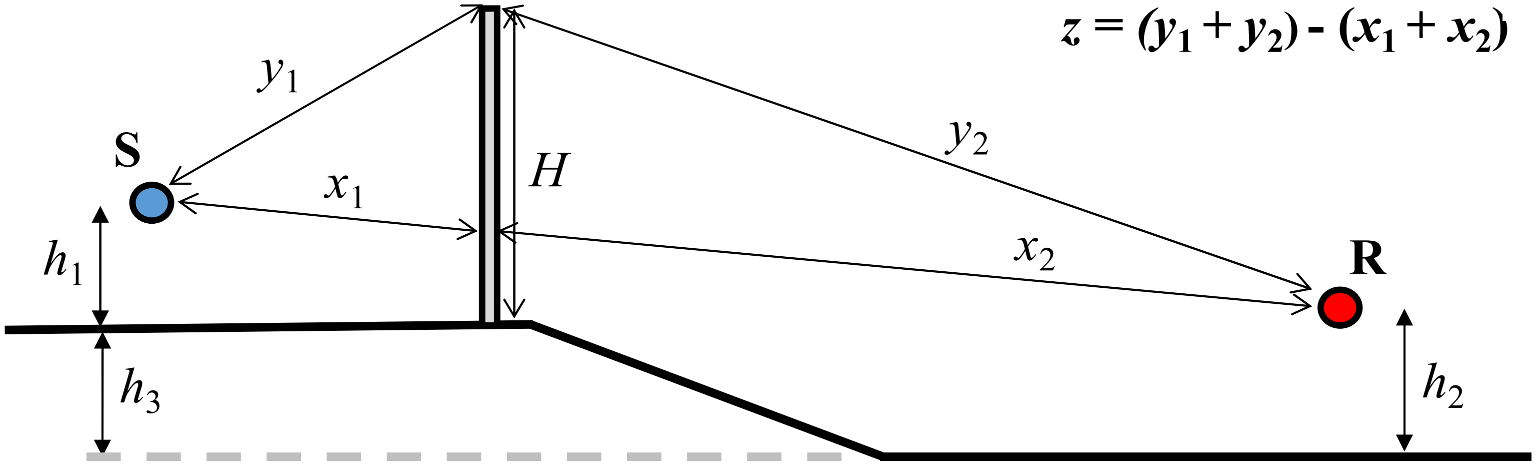


Distance difference *z*

- z increases by setting source S and receiver R close to the barrier
- Maximum value of z is 2H.

$$D_{diff} = 10\log_{10}\left(1 + 20\frac{z}{\lambda}\right)$$





$$z = (y_1 + y_2) - (x_1 + x_2)$$

Insertion loss of a barrier with finite sound reduction index in free field for a point source

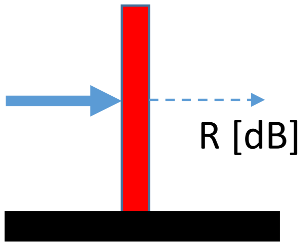
- *Insertion loss*: reduction of SPL in a specific point as consequence of a noise barrier, $D_{nb,tot}$ [dB]
- Factors affecting insertion loss are
  - diffraction over the barrier, D_{nb}
  - Transmission through the barrier, the sound reduction index, R [dB])
- If R is large, barrier's insertion loss equals with Maekawa's law:
  - L_{p1} without barrier
  - L_{p2} with barrier
  - z is the distance difference [m]

$$D_{nb,tot} = L_{p,1} - L_{p,2}$$

$$D_{nb,tot} = -10 \cdot \log_{10}\left(10^{-R/10} + 10^{-D_{diff}/10}\right)$$

Maekawa's Law

$$D_{diff} = 10 \log_{10}\left(1 + 20\frac{z}{\lambda}\right)$$



Overview of the prediction of sound propagation outdoors

Source type

- Point source
- Cylindrical source (line)
- Surface source

Source operation vs. time

- Hour-based operation or traffic amount

Source emission

- Point sources: SWL
- Point sources: SPL at 10 m
- Line sources: SPL at 10 m

In addition:

- Athmospheric absorption
  - Depends on T, RH and f
- Ground absorption
- Topography
- Obstacles between source and receiver (buildings, noise barriers)
- Vegetation zones
- Reflection coefficients of barriers and buildings

Neglegted factors (weather dependent)**:**

- Wind gradient
- Turbulence
- Temperature gradient

Selection of xyz positions:

- Sound source(s)
- Receiver(s) or receiver grid (sound maps)

Selection of prediction method:

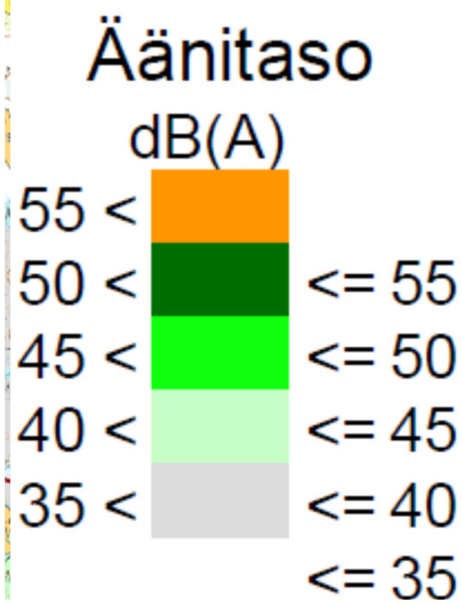
- ISO 9613
- Nordic model
- Cnossos
- National practices
- Independent methods

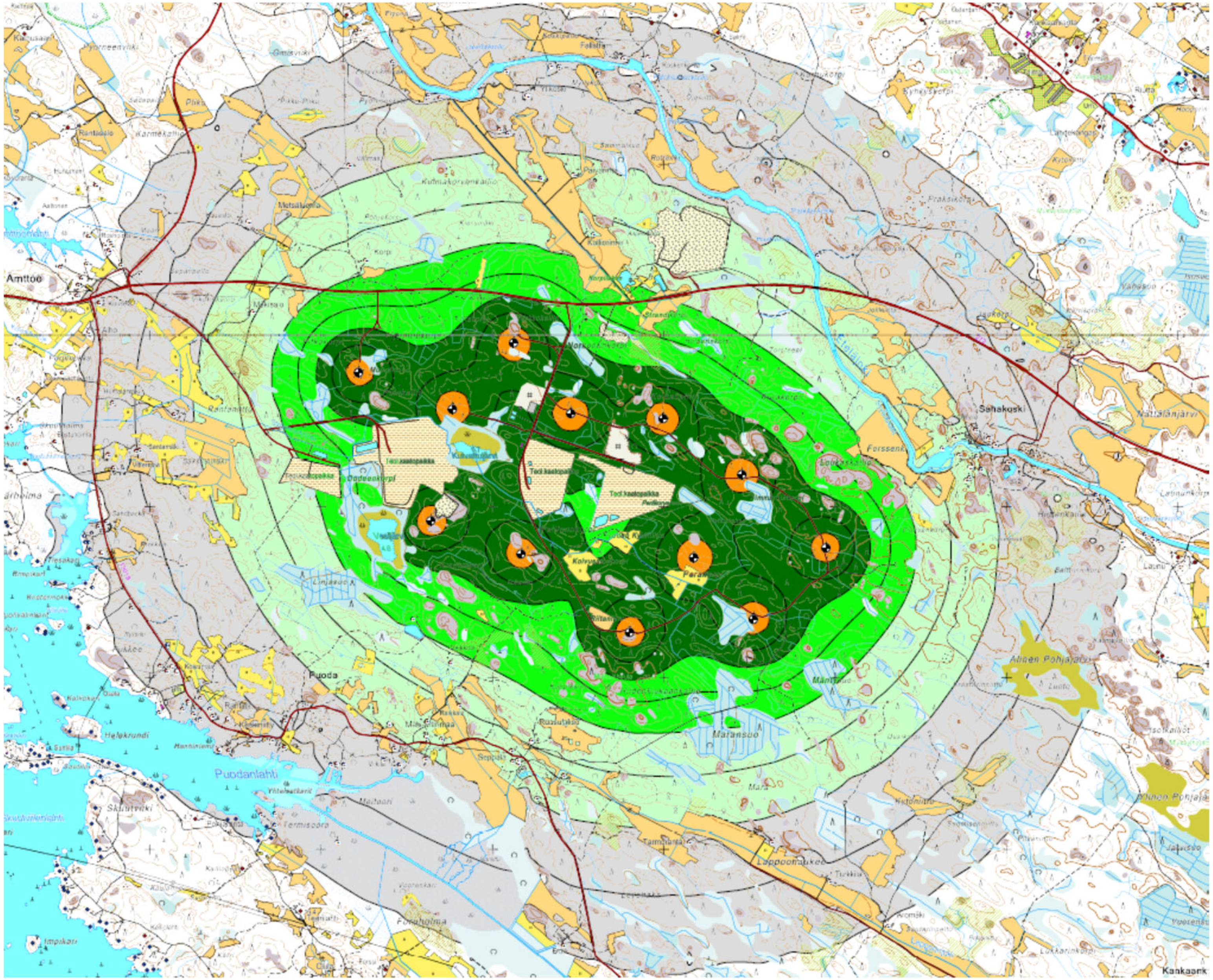
Resulting parameter:

- Usual design: L_{Aeq}
- EU maps: L_{den}

Noise map of a wind farm

- A-weighted SPL, i.e. L_{pA}, is reported using a map grid of 10 m resolution





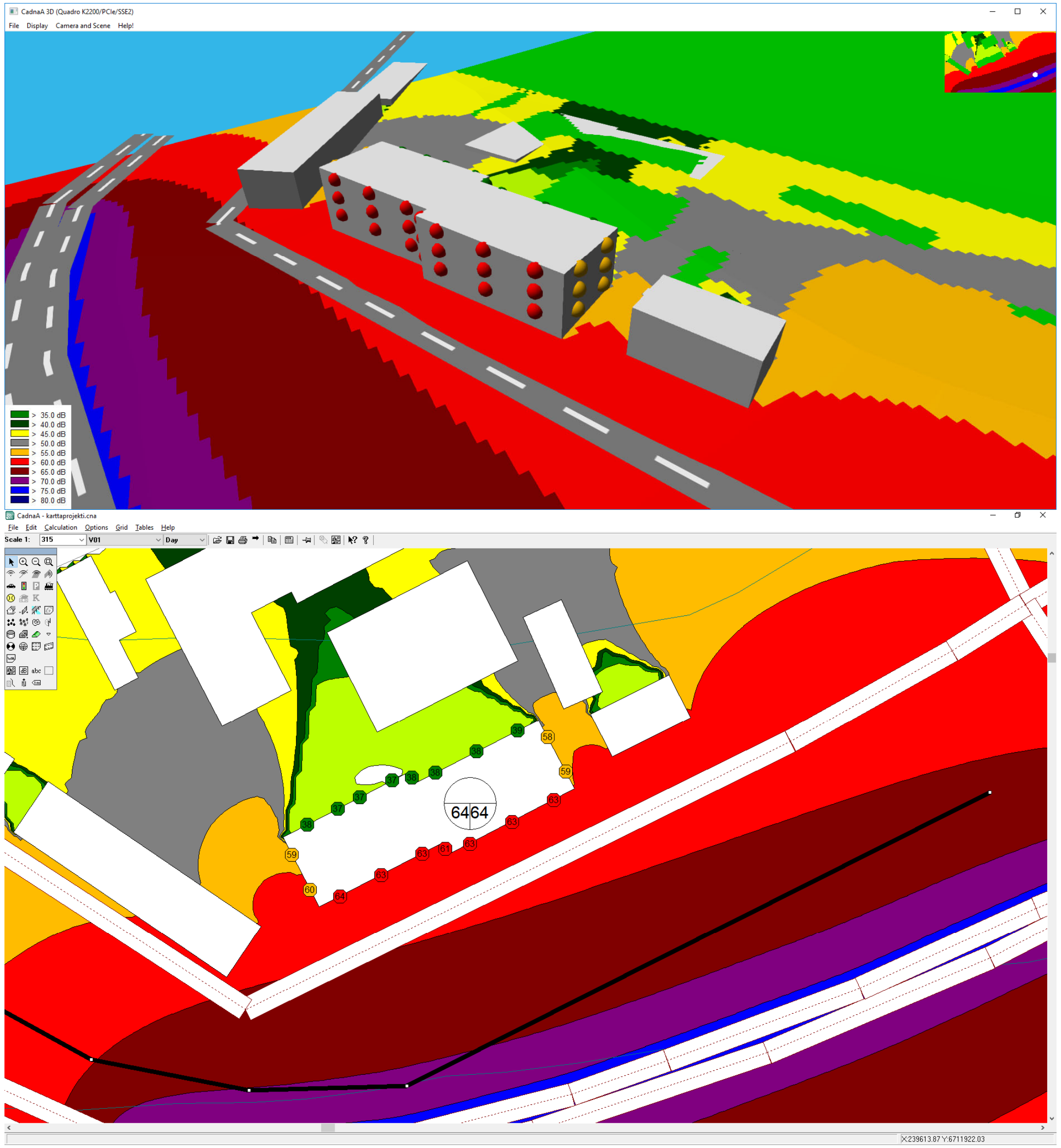
CadnaA software - modeling steps

- **Download the map file from Maanmittauslaitos by email request**
  - https://tiedostopalvelu.maanmittauslaitos.fi/tp/kartta
- **Importing the map to CadnaA**
  - Cadna uses different variables names for the map items that must be transformed
- **Finalization of the imported map**
  - Contours, roads, road ground heights, buildings, building ground heights, building heights, water lines, sea, lakes, rivers
- **Choosing the calculation method**
  - Various methods are available and the correct one (ISO 9613) is chosen
- **Sound source definitions**
  - coordinate point, source height, octave band sound power levels, diurnal variation
- **Ground absorption definitions**
  - Default: 1.0; Water: 0.0; Other grounds: 0.4.
- **Setting the noise map**
  - grid size, overall size, grid height over ground, noise category, color ID.
- **Double-checking and adjustments needed for the reporting**

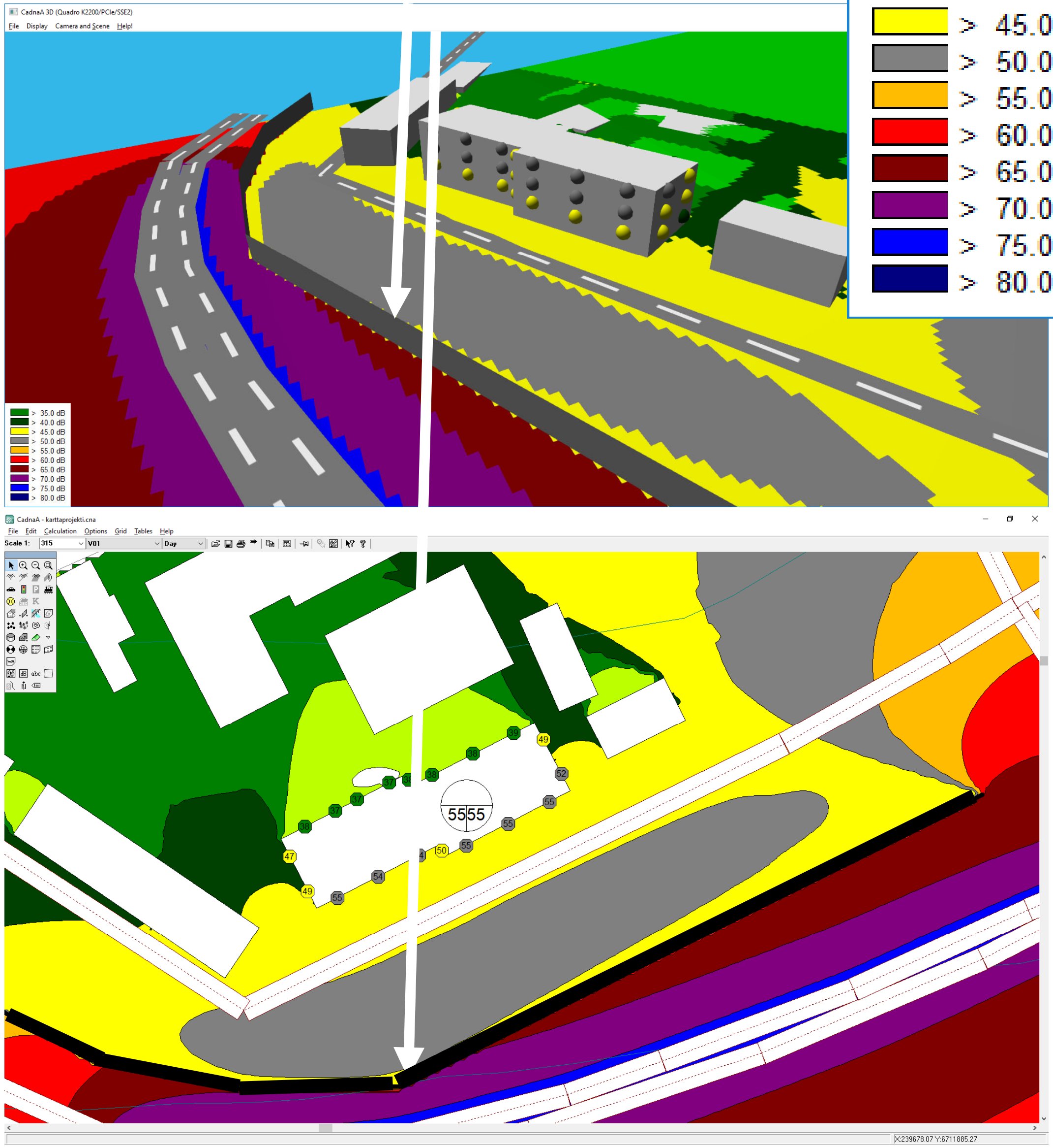
Cadna A. Screen height 4.0 m. 1000 vehicles per hour. 20% heavy vehicles. 50 km/h. Nordic prediction method. Ground absorption 0.4. House height 9 m. Maanmittauslaitoksen karttapohja. Purpose was to study the impact of screen on the facade of the three storey building. The maximum value on the facade reduced from 64 to 55 dB LAeq. The reduction was larger on the lowest floor.


Martinsillan Grilli Oy
V
Subwa
Paratiisintie
Yrjänän
Köydenpunojankaari
Köydenpunojankaari
Virusmäenramppi
Barrier
Google
Kartta
2D
Kuvat ©2018 Google Karttatiedot ©2018 Google
Suomi
Ehdot
Lähetä palautetta
10 m

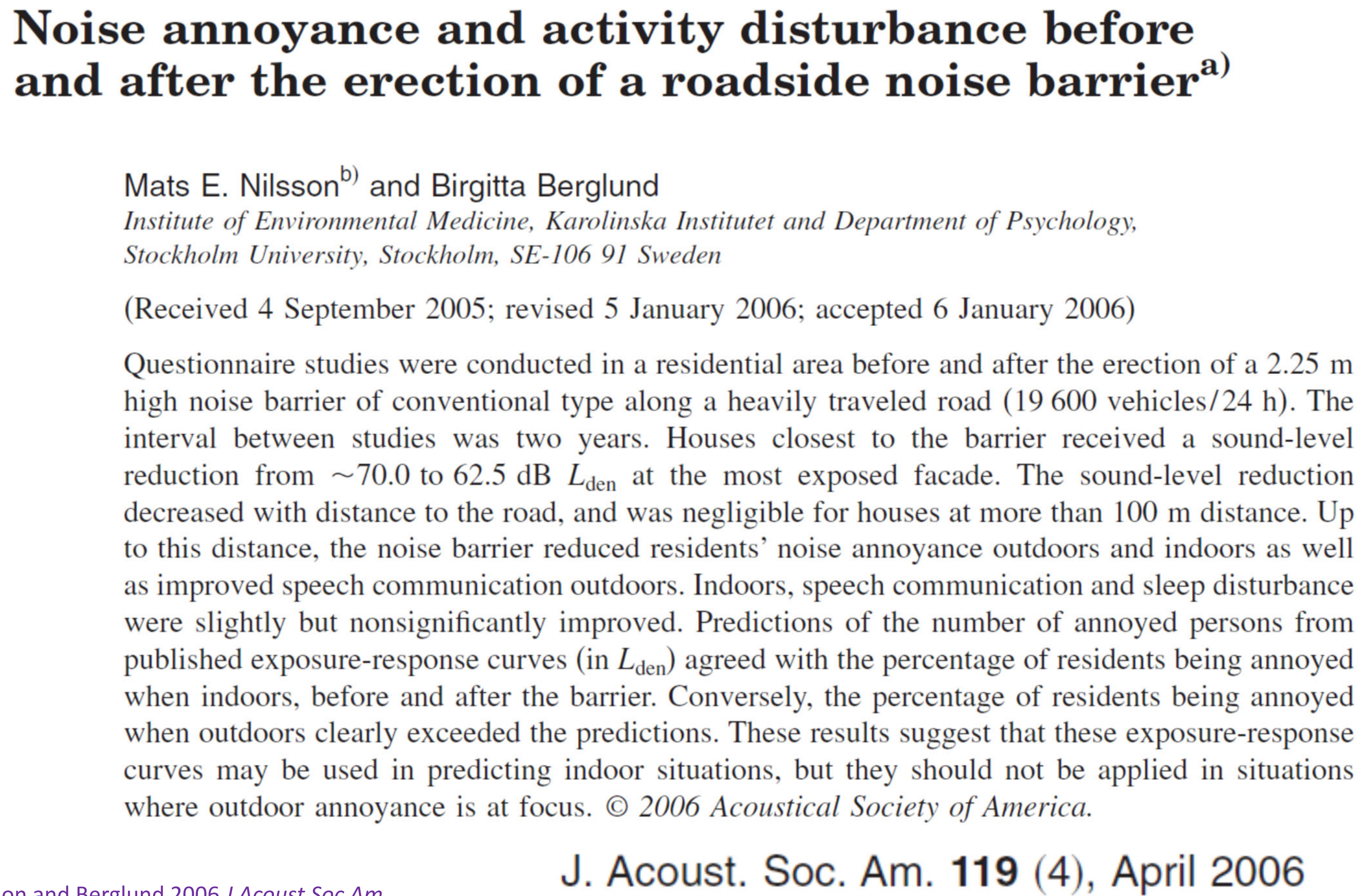
Without barrier



With barrier



🟩	> 35.0 dB
🟩	> 40.0 dB
🟨	> 45.0 dB
▨	> 50.0 dB
🟧	> 55.0 dB
🟥	> 60.0 dB
🟫	> 65.0 dB
🟪	> 70.0 dB
🟦	> 75.0 dB
🟦	> 80.0 dB



Noise annoyance and activity disturbance before and after the erection of a roadside noise barrier[a)]

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Questionnaire studies were conducted in a residential area before and after the erection of a 2.25 m high noise barrier of conventional type along a heavily traveled road (19 600 vehicles/24 h). The interval between studies was two years. Houses closest to the barrier received a sound-level reduction from ~70.0 to 62.5 dB L_{den} at the most exposed facade. The sound-level reduction decreased with distance to the road, and was negligible for houses at more than 100 m distance. Up to this distance, the noise barrier reduced residents' noise annoyance outdoors and indoors as well as improved speech communication outdoors. Indoors, speech communication and sleep disturbance were slightly but nonsignificantly improved. Predictions of the number of annoyed persons from published exposure-response curves (in L_{den}) agreed with the percentage of residents being annoyed when indoors, before and after the barrier. Conversely, the percentage of residents being annoyed when outdoors clearly exceeded the predictions. These results suggest that these exposure-response curves may be used in predicting indoor situations, but they should not be applied in situations where outdoor annoyance is at focus. *© 2006 Acoustical Society of America.*

J. Acoust. Soc. Am. **119** (4), April 2006

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FIG. 1. Aerial photograph of studied residential areas taken before the noise barrier was erected. The white lines show location of the future barrier. The apartment buildings of the reference area are marked by arrows.

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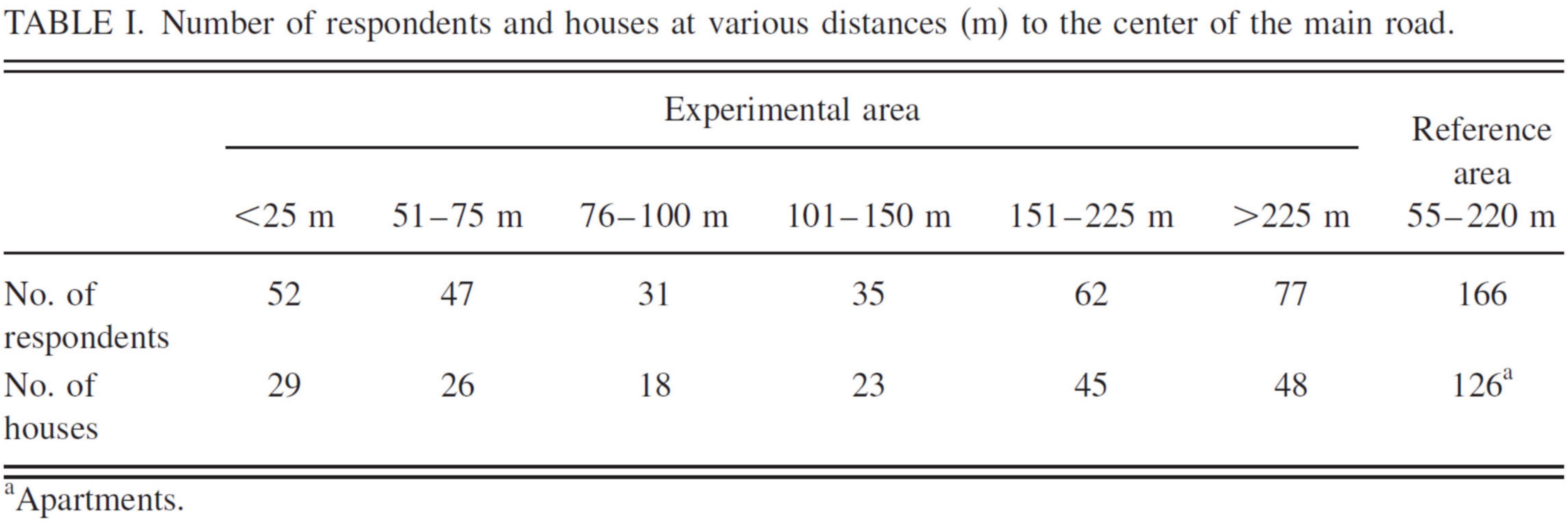

TABLE I. Number of respondents and houses at various distances (m) to the center of the main road.

	Experimental area						Reference area
	<25 m	51–75 m	76–100 m	101–150 m	151–225 m	>225 m	55–220 m
No. of respondents	52	47	31	35	62	77	166
No. of houses	29	26	18	23	45	48	126[a]

[a] Apartments.

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- D_{diff}

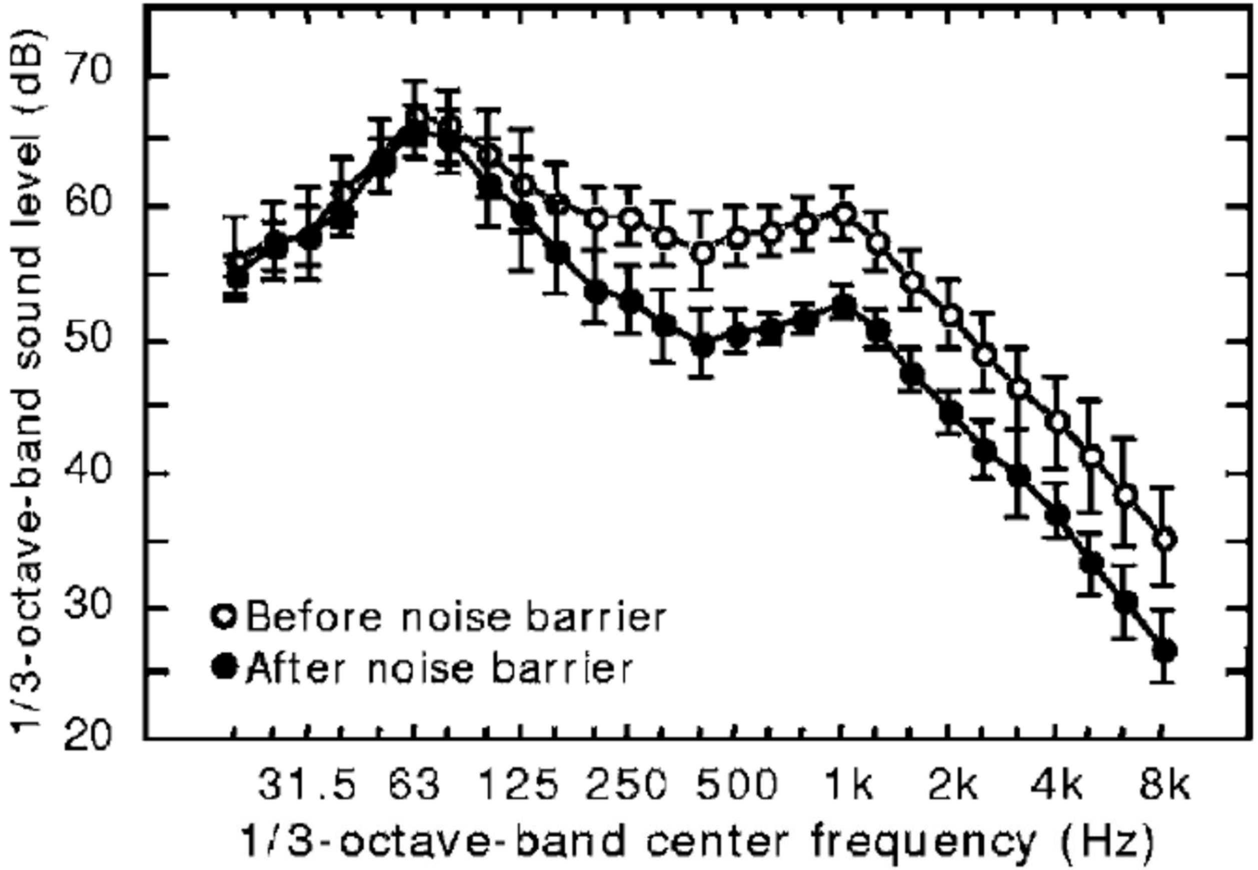

FIG. 2. Spectra for 45 min measurements conducted in eight gardens closest to the main road (23 m). Points show arithmetic averages of 1/3-octave-band sound levels ($L_{eq,45min}$) from eight measurements conducted before (open circles) and after the barrier (filled circles) was erected (error bars: ±1 standard deviation).

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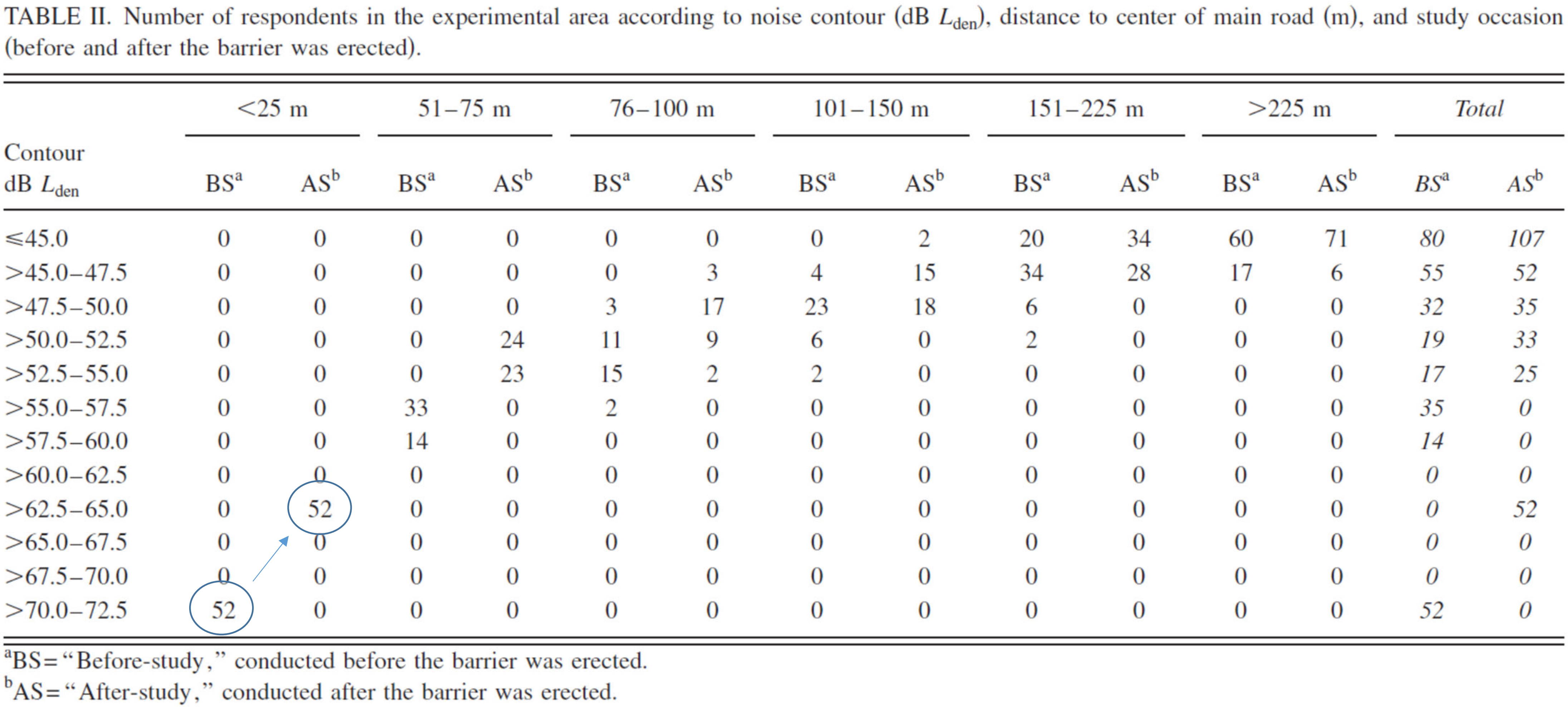

TABLE II. Number of respondents in the experimental area according to noise contour (dB L_{den}), distance to center of main road (m), and study occasion (before and after the barrier was erected).

Contour dB L_{den}	<25 m		51–75 m		76–100 m		101–150 m		151–225 m		>225 m		*Total*	
	BS[a]	AS[b]	BS[a]	AS[b]	BS[a]	AS[b]	BS[a]	AS[b]	BS[a]	AS[b]	BS[a]	AS[b]	*BS*[a]	*AS*[b]
⩽45.0	0	0	0	0	0	0	0	2	20	34	60	71	*80*	*107*
>45.0–47.5	0	0	0	0	0	3	4	15	34	28	17	6	*55*	*52*
>47.5–50.0	0	0	0	0	3	17	23	18	6	0	0	0	*32*	*35*
>50.0–52.5	0	0	0	24	11	9	6	0	2	0	0	0	*19*	*33*
>52.5–55.0	0	0	0	23	15	2	2	0	0	0	0	0	*17*	*25*
>55.0–57.5	0	0	33	0	2	0	0	0	0	0	0	0	*35*	*0*
>57.5–60.0	0	0	14	0	0	0	0	0	0	0	0	0	*14*	*0*
>60.0–62.5	0	0	0	0	0	0	0	0	0	0	0	0	*0*	*0*
>62.5–65.0	0	52	0	0	0	0	0	0	0	0	0	0	*0*	*52*
>65.0–67.5	0	0	0	0	0	0	0	0	0	0	0	0	*0*	*0*
>67.5–70.0	0	0	0	0	0	0	0	0	0	0	0	0	*0*	*0*
>70.0–72.5	52	0	0	0	0	0	0	0	0	0	0	0	*52*	*0*

[a] BS = "Before-study," conducted before the barrier was erected.

[b] AS = "After-study," conducted after the barrier was erected.

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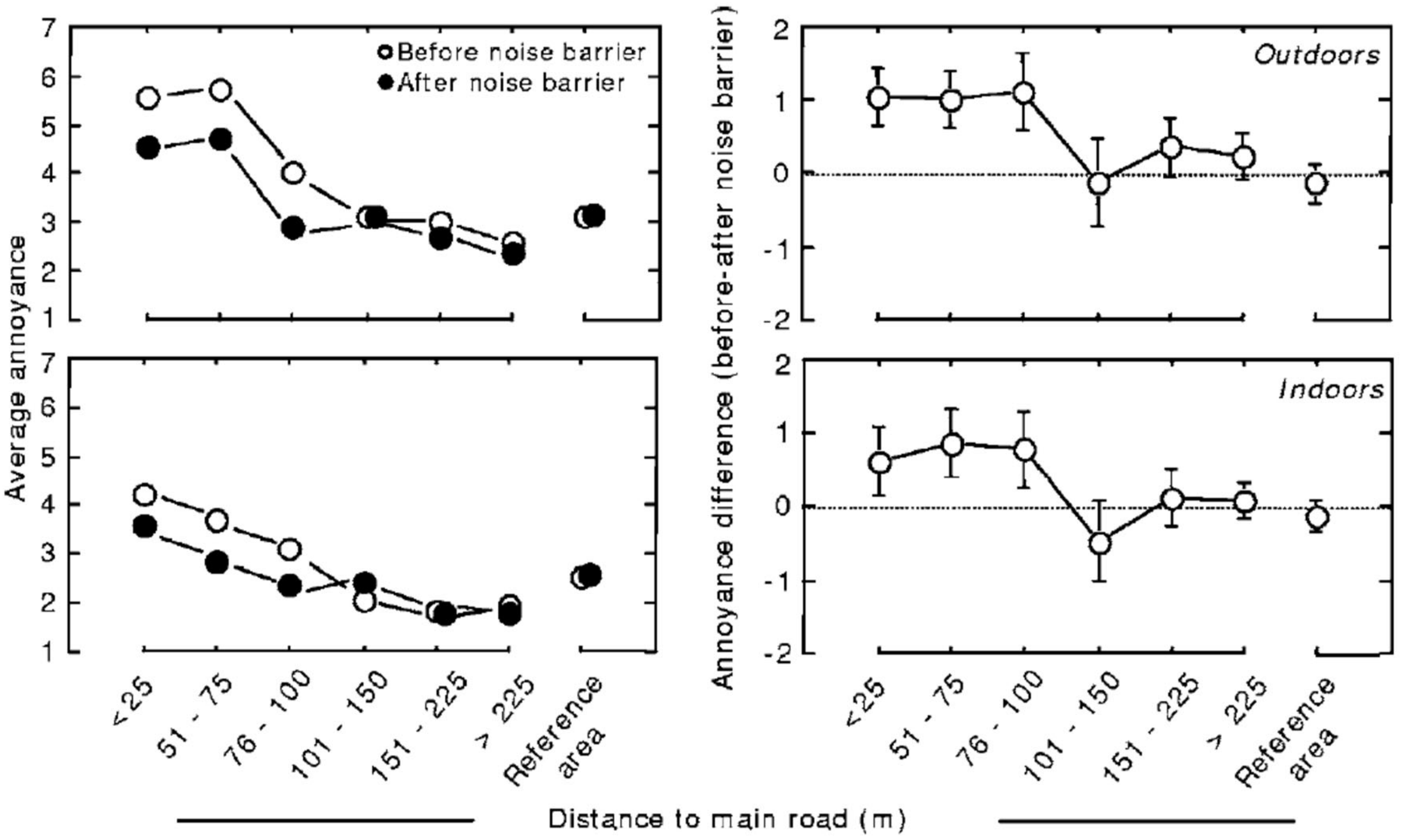

FIG. 3. Road-traffic noise annoyance (left panels) and annoyance difference between study waves (right panels), each plotted as a function of distance to the main road. Upper panels: outdoor annoyance. Lower panels: indoor annoyance. Left panels: Open symbols=before the barrier; filled symbols=after the barrier. Bars: 95% confidence intervals.

Annoyance response scale: 1 Not at all, 7 Very much

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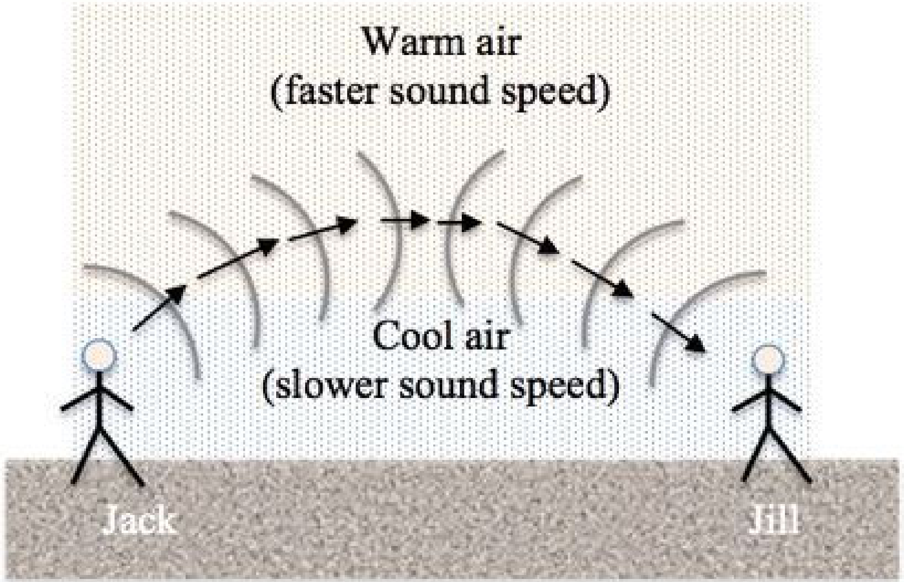
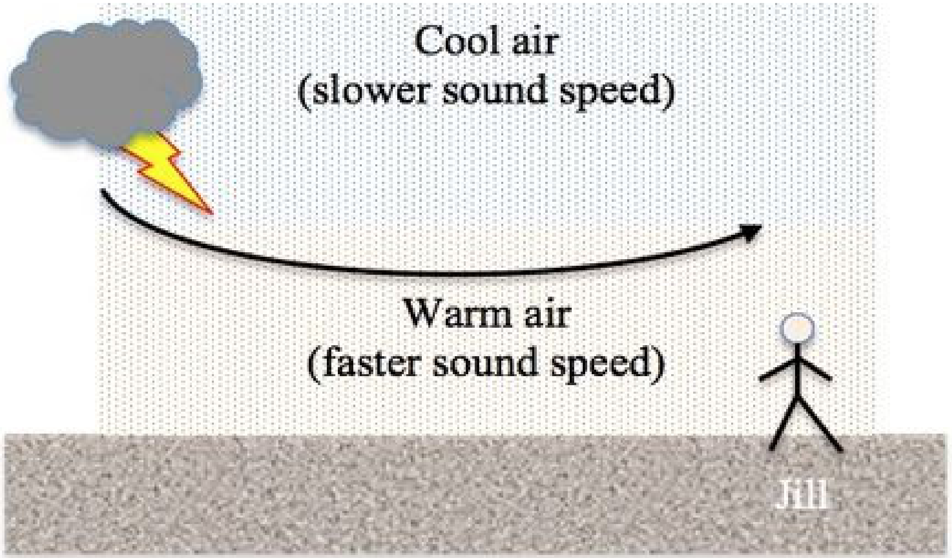
Effect of temperature layers on sound propagation

- In typical weather, high temperature goes down and attenuation is 6 dB per dd (distance doubling).
- In **inversion** condition, high temperature goes up, and attenuation is 3-6 dB per dd above
- Reduced attenuation is caused by reflection from the upper layers of the athmosphere.
- Reflection impacts sound levels above 500–1000 m from the turbines **in all directions.**

INVERSION CONDITION



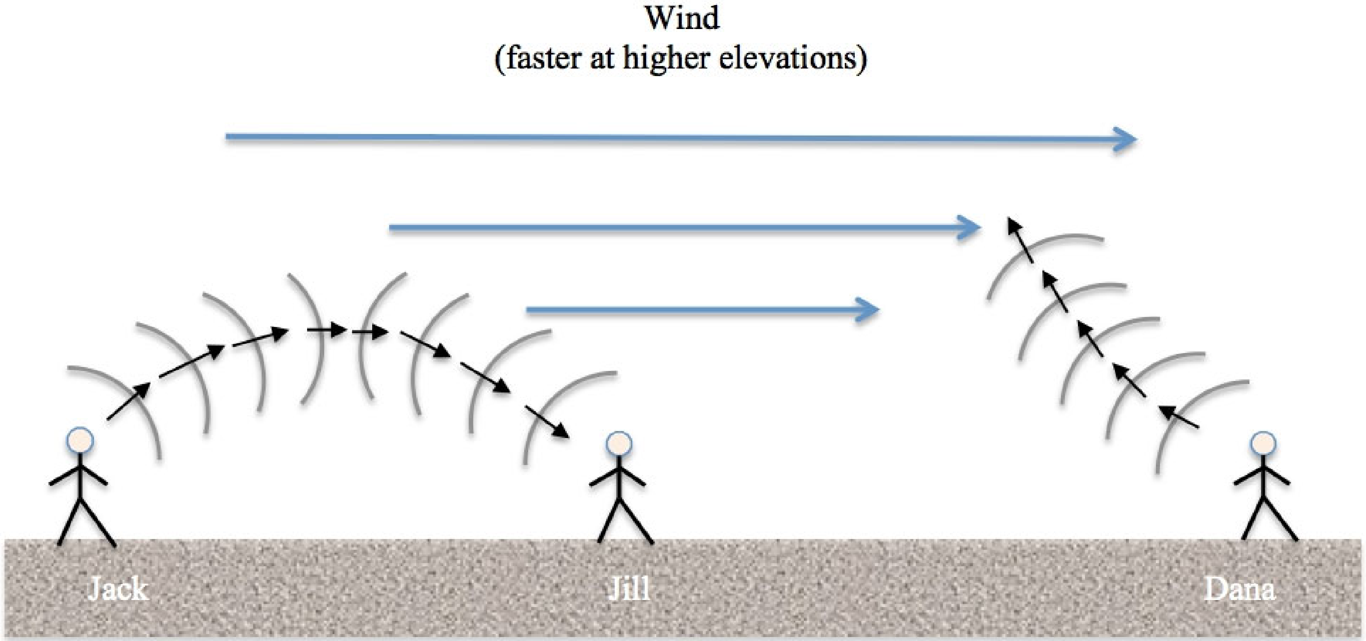
TYPICAL WEATHER



https://soundphysics.ius.edu/?page_id=788

Effect of wind speed layers on sound propagation

- Sound propagates more easily downwind than upwind
- The excessive noise occurs only downwind and opposite effect is found upwind: total noise does not increase !
- Reduced attenuation due to athmospheric phenomena never leads to the violation of regulated noise limits but it may result in intermittent annoyance reports in sensitive areas if the background noise is low.
  - Summer evenings
  - Cottage areas



https://soundphysics.ius.edu/?page_id=788

L_{den} and L_{dn}

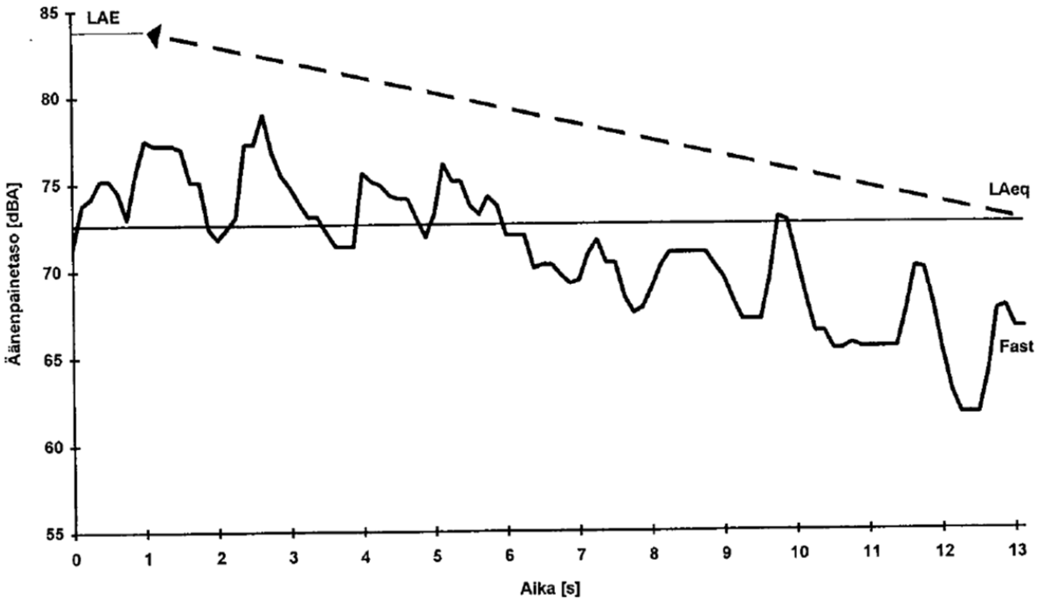
- L_{den} (DENL, day-evening-night level) describes the noise exposure using a single number.
- It has been found to explain well the health effects of environmental noise instead of using separate values for night, evening and day.
- L_{den} involves **penalty for different times of day:**
  - day 07-19: penalty **0 dB**
  - evening 19-23: penalty **5 dB**
  - night 23-07: penalty **10 dB**
- Some documents also use L_{dn}:
  - day 07-23: penalty **0 dB**
  - night 23-07: penalty **10 dB**

$$L_{den} = 10log_{10}\left[\frac{1}{24}\left(\begin{matrix} 12 \cdot 10^{\left(L_{Aeq,07-19}+0\right)/10} + \\ 4 \cdot 10^{\left(L_{Aeq,19-23}+\mathbf{5}\right)/10} + 8 \cdot 10^{\left(L_{Aeq,23-07}+\mathbf{10}\right)/10} \end{matrix}\right)\right]$$

Sound Exposure level L_{AE}

- L_{AE} (*SEL, sound exposure level*) expresses the energy of sound occurrence
- Used for sounds which consist of single occurrences:
  - Train
  - airplane
- L_{AE} means that the whole energy of the occurrences is normalized to 1-second-long occurrence so that different occurrences become comparable. (t_0=1 s).

$$L_{AE} = L_{Aeq,T} + 10\lg\left(\frac{T}{t_0}\right)$$



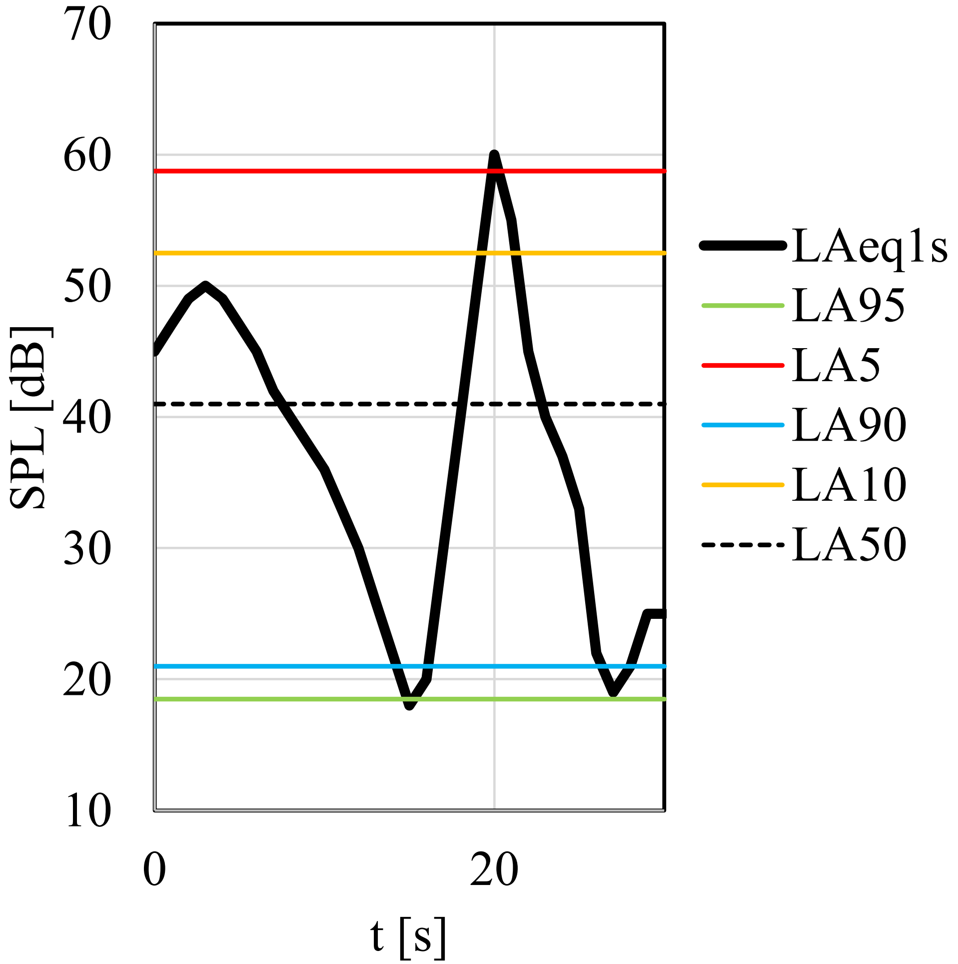
Kuva 6. Äänialtistustaso (L_{AE}) on tapahtuman keskiäänitaso (L_{Aeq}) normalisoituna yhteen sekuntiin.

Tiihinen & Hänninen, 1997

Percentile levels L_N

LA95	LA5	LA90	LA10	LA50
19	59	21	53	41

- Variability of noise can be described by percentile levels
- L_N expresses, that N percent of sound samples exceeds this level
- Variability can be described by, e.g., L_{10}-L_{90} (*noise climate*).
- Large value means large variability
- Excel: percentile -functions



Wind turbine noise:
Sound level prediction accuracy

Hongisto, V., Keränen, J., Oliva, D. (2017). Indoor noise annoyance due to 3-5 MW wind turbines - an exposure-response relationship, **The Journal of the Acoustical Society of America** 142(4) 2185-2196. Open access at: http://dx.doi.org/10.1121/1.5006903.

Hongisto V, Oliva D, Keränen J, Tuulivoimamelun häiritsevyyden riippuvuus äänitasosta, **Akustiikkapäivät 2017**, s. 164-169, 24-25.8.2017 Espoo, Akustinen Seura ry., Espoo, 2017 (ISBN 978-952-60-3734-9). Open access at: http://www.akustinenseura.fi/wp-content/uploads/2017/08/akustiikkapaivat_2017_s164.pdf

Purpose

- There is very little scientific data published on the accuracy of the sound level predictions.
- Our purpose was to determine how well the predicted L_{Aeq} conforms with the measured L_{Aeq}.
- The work was conducted in wind power areas, where a major socioacoustic survey of 429 participants was conducted.

Predictions

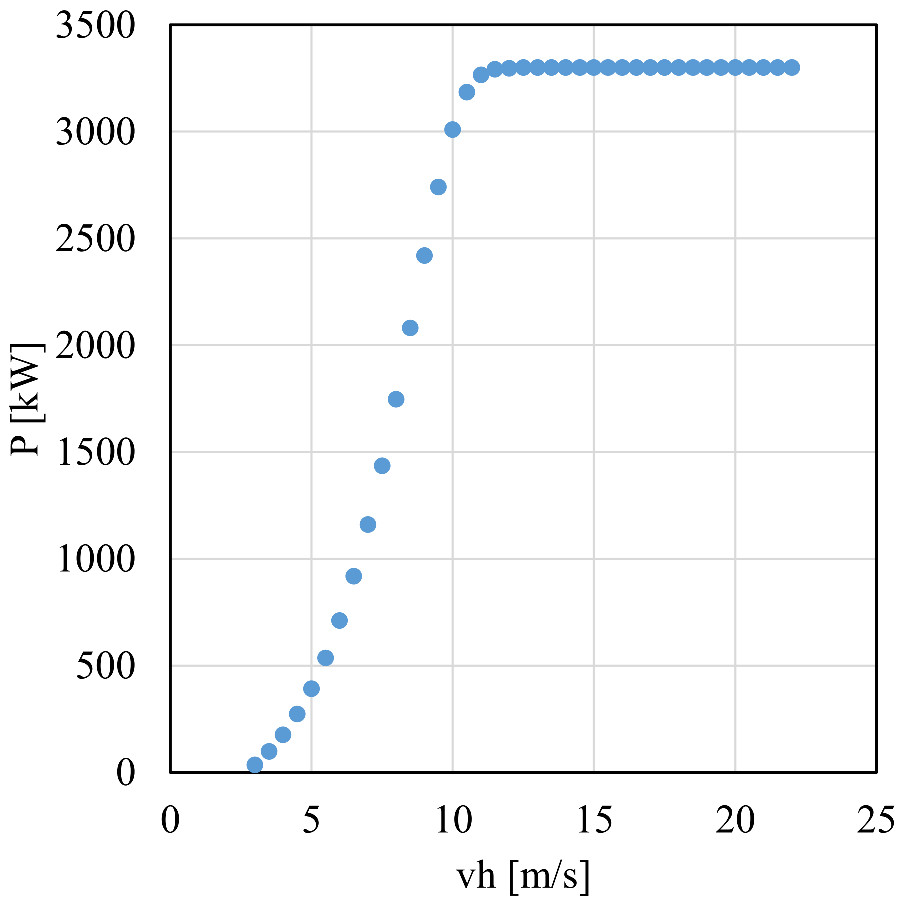
- ISO 9613-2 method of CadnaA software was used
- 70% RH, 15 C, 1/1 bands 31.5−8000 Hz, Ground absorption 0.40
- Map from National Land Survey of Finland (2016). Elevation contours, roads and buildings were used from the maps.
- SWL was obtained in 1/3-octave bands from the operators of the farms. The maximum SWL (8 m/s at 10 m height) was applied.
- Omnidirectional source
- Calculation height 4 m.
- Predictions were made to the 429 respondents yards and to the **eight measurement points**.

Measurements

- Eight measurement positions around the three wind farms were chosen.
- The distances to the nearest tower were within 244 – 899 m.
- The measurements took only four full days
  - One day the wind speed was too low and the data was useless.
- One year was waited to conduct the measurements since adequate weather conditions (maximum power, 8 m/s at 10 m height) occur only 8 % of the year and the locations needed to be far from the roads, rain must be avoided and the strong wind should last at least 12 hours to be sure that the measurements are successful.

About measurements

- Power curve explains the electric power as a function of wind speed at hub height.
- Sound emission is strongest when maximum power is produced, usually at vh=12 m/s



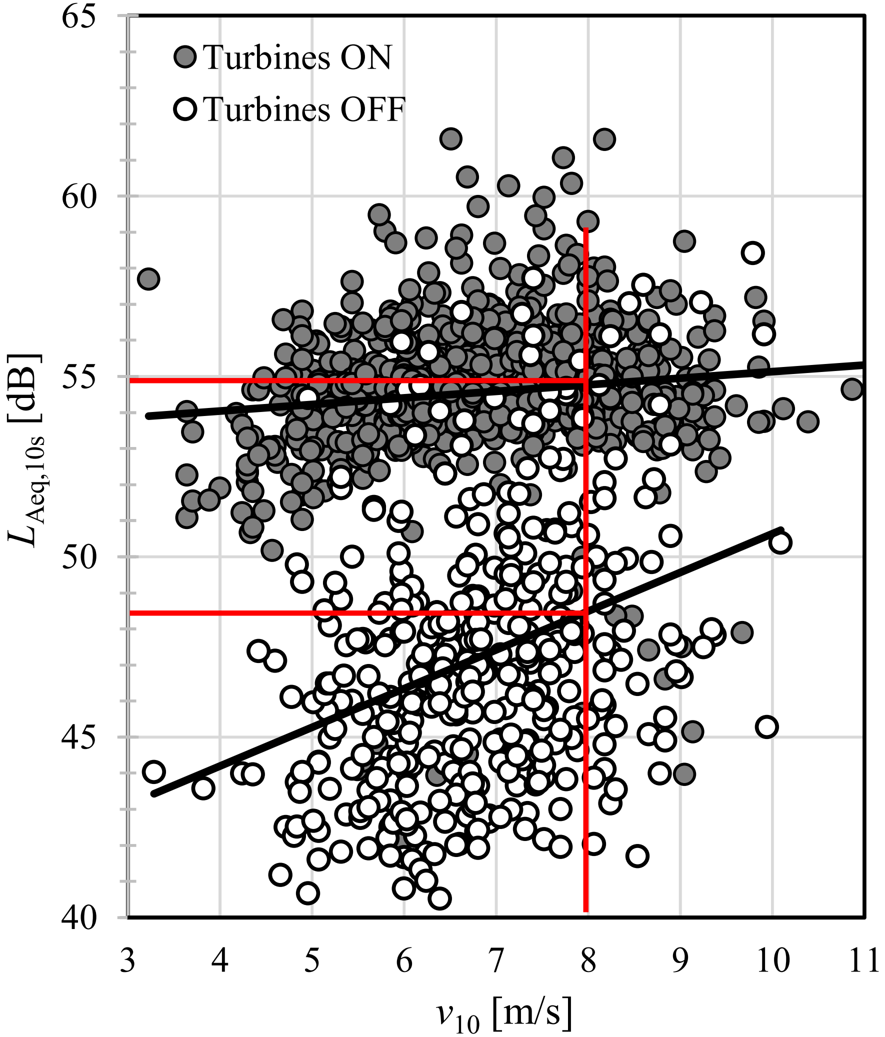
Noise emission measurement Example

- The clock of the weather mast and noise level meter are synchronized
- Measurements are conducted in 10 s periods
- Equivalent A-weighted SPL, $L_{Aeq,10s}$, is plotted as a functio of 10-second mean wind speed at 10 m height, v_{10}.
- Here, wind speed was measured in the hub height and v_{10} was obtained using equation

$$v_{10} = v_h \cdot \left[\ln(10/z_0)/\ln(h/z_0)\right]$$

v_{10}	Wind speed at hub height normalized to 10 m height [m/s].
v_h	Wind speed at hub height [m/s].
h	Hub height [m].
z0	Roughness of ground [m]. Value 0.20 m used.

- ON: 55 dB ($L_{p,tot}$, total). OFF: 48 dB ($L_{p,2}$, background).
- RESULT: 54 dB (after background noise correction)



$$L_{p,1} = 10\lg\left(10^{L_{p,tot}/10} - 10^{L_{p,2}/10}\right)$$

Results – Measured vs. predicted level

- The predicted and measured sound levels, L_{Aeq}, were in very good agreement
- The differences were within the measurement uncertainty (3 - 5 dB) in each point.

Point	d [m]	$L_{Aeq,M}$ [dB]	$L_{Aeq,P}$ [dB]
A/M1	660	44.8	44.1
A/K1	630	45.9	44.6
B/M1	447	41.0	43.0
B/K1	244	47.6	46.6
B/K2	600	39.1	41.3
B/K3	383	46.6	44.7
C/M1	772	44.2	43.2
C/K1	889	44.7	42.0

M = Measured

P = Predicted

Difference of predicted and measured L_{Aeq}