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RECORDING

Ljud i byggnad och samhälle (VTAF01) – Traffic noise

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Traffic noise

City Traffic Sounds for Sleep. What?!

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Socialstyrelsens miljörapport (2009)

- Trend from 1999 – 2007
  - Reported hearing loss → Increased by 24%
  - Annoyed by road traffic noise → Increased by 40%
  - Difficulties sleeping due to noise → Increased by 31%

	Amount of people exposed to $L_{Aeq,24h}$ >55 dB(A)
Road traffic	1.2 – 1.8 *milj.*
Railway noise	400 000 – 600 000
Flight noise (civ/mil)	15 000-25 000 / 25 000-35 000
Outside	1.6 – 2.4 *milj.*

Health effects due to exposure to (traffic) noise

- Auditory effects
  - Acoustic trauma
  - Tinnitus (ringing ears)
  - Temporary and permanent threshold shift (TTS/PTS)
  - Interference with communication
- Non-auditory effect
  - Annoyance
  - Cardiovascular disease
  - Sleep disturbance
  - Disturbed cognitive functioning
  - Cancer
  - Diabetes
  - Mental health

Few studies (Cancer, Diabetes, Mental health)

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Overview

The source

Anti-propagation measures

Traffic volume
Traffic speed
Tyre type
Road surface
Type of vehicle
…

→ Noise emissions →

Distance
Ground
Noise barriers
Building properties
…

→ Noise exposure →

Effect on humans

Environmental sound pollution

- Road traffic noise
  - Most disturbing
  - Depends on: vehicles per hour, speed, inclination, vicinity to buildings, percentage of heave vehicles, road surface, type of tires, aerodynamics…
  - Mainly from engine and frictional contact road/tire
- Railway noise
  - Less disturbing than road traffic for the same sound level
  - Depends on: train frequency, type of rolling stock, roughness, train load, length and speed
- Aircraft noise
  - Generates noise, vibrations and rattle
  - Depends on: plane size/model, type of engine, flight paths, number of aircraft, atmospheric conditions…

Traffic noise control strategies

Minimise noise levels

- Source (vehicle) controls
  - » Maintenance
  - » Traffic design controls (e.g. speed/load limits, diverting traffic)
- Path controls
  - » Sound barriers
  - » Non-residential buildings
  - » Earth embankments
  - » Buffer zones
  - » Distance

- Receiver-side controls
  - » Insulation and absorption (façade & indoors)

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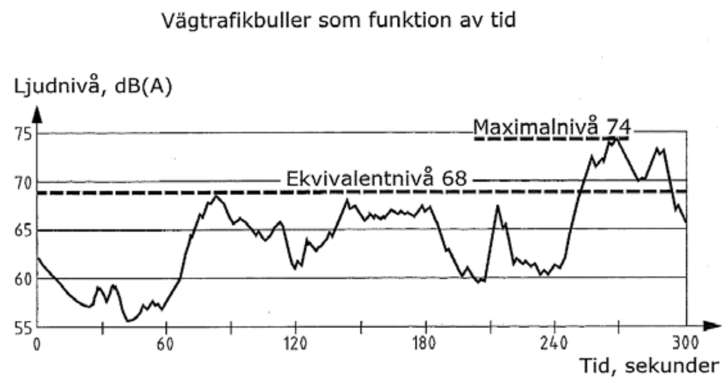
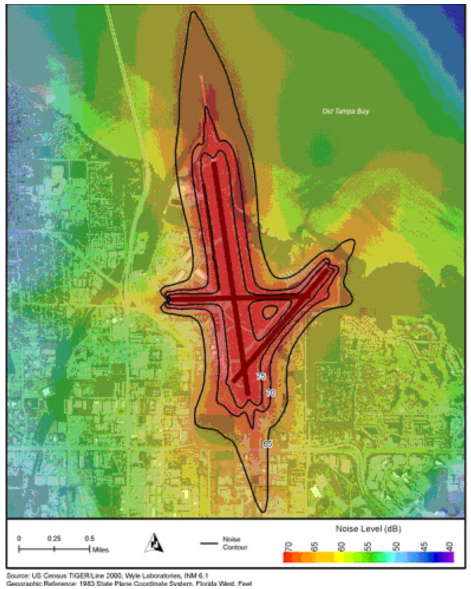
Cumulative environmental noise descriptors

- Traffic noise levels vary quickly over time → Many descriptors
  - Equivalent continuous A-weighted SPL

$$L_{Aeq,T} = 10\log\left(\frac{1}{\Delta T}\int_{T_1}^{T_2}\frac{p_A^2(t)}{p_{ref}^2}dt\right) = 10\log\left(\frac{1}{\Delta T}\int_{T_1}^{T_2}10^{\left(\frac{L_{p,A}(t)}{10}\right)}dt\right)$$



Figur 4:9. Ljudnivåns variation under 5 minuter på en livligt trafikerad innerstadsgata. Ekvivalentnivå 68 dB(A), maximalnivå 74 dB(A).



Ex: Calculate the $L_{Aeq,8h}$ that corresponds to 105 dBA for 15 min.

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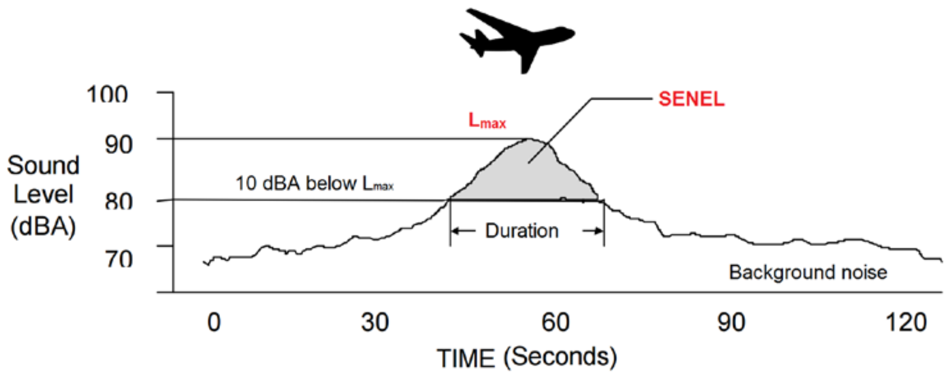
Cumulative environmental noise descriptors

- Day and night average sound level (DNL or L_{den})
  - Average SPL over 24-hour periods
  - Weighting factors for evening and night times (country-dependent)
  - L_{den}=$L_{Aeq,24h}$ [dBA] (with +10dB from 22:00 to 7:00)
- …

Single event environmental noise metrics

- Maximum/minimum sound level (L_{max} / L_{min}):
  - Greatest/lowest RMS sound amplitude [dB/dBA…] for the measurement period
  - NOTE: L_{peak}: maximum value of SPL (no time-constant applied and signal not passed through an RMS circuit or calculator, i.e. $\neq L_{max}$)
- Sound exposure level (SEL/L_{AE}) & Single event noise exposure level (SENEL)
  - Total "noisiness" of an event. It takes duration into account
  - If SENEL is measured for the period when the level is within 10 dB of the L_{max}, it will be essentially the same as SEL

$$L_{AE} = L_{Aeq,T} + 10\log(t_2 - t_1)$$



Workflow

- Measurement / calculation according to standard
- Evaluation according to standard / regulations
- Counter-measures

Regulations – Traffic noise

- Trafikbullerförordningen SFS 2015:216, med förordningsändring SFS 2017:359.
    - trädde i kraft 1 juli 2017
- Riktvärdena i förordningen ska tillämpas i detaljplaneärenden, i ärenden om bygglov och i ärenden om förhandsbesked påbörjade från och med 2 januari 2015.
- Om riktvärdet för ekvivalent ljudnivå vid en bostadsbyggnads fasad ändå överskrids bör minst hälften av bostadsrummen i en bostad vara vända mot en sida där 55 dBA ekvivalent ljudnivå inte överskrids vid fasad och minst hälften av bostadsrummen vara vända mot en sida där 70 dBA maximal ljudnivå inte överskrids nattetid vid fasad. Om 70 dBA maximal ljudnivå på uteplats ändå överskrids får den göra det högst fem gånger per timme under perioden kl. 06-22 och då med högst 10 dB.

Location	Measure	dB(A)
Outside (façade)	L_{Aeq}	60
Outside (uteplats)	L_{Aeq}	50
Outside (uteplats)	L_{AFmax}	70
Outside (façade) för bostad ≤ 35 kvm	L_{Aeq}	65

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Regulations – Traffic noise

- *Infrastrikturprop. 1996/97:53* – projects initiated before 2/1/2015 or involving new or large rebuilding of infrastructure

Location	Measure	Road	Track	Flight
Indoors	$L_{Aeq,24h}$	30	30	30
Indoors	L_{AFmax}	45	45	45
Outside (façade)	$L_{Aeq,24h}$	55	60	55
Outside	L_{AFmax}	70	70	70

  - Sets guidelines, which are indications but not binding
  - *"Vid tillämpning av riktvärden i trafikinfrastruktur-propositionen bör hänsyn tas till vad som är tekniskt möjligt och ekonomiskt rimligt. I de fall som utomhusnivån inte kan reduceras till riktvärdesnivåerna bör inriktningen vara att inomhusvärdena inte överskrids."*

Regulations indoor noise – *Boverkets byggregler – föreskrifter och allmänna råd, BBR*

Tabell 7:21c Dimensionering av byggnadens ljudisolering mot yttre ljudkällor.

	Ekvivalent ljudnivå från trafik eller annan yttre ljudkälla, $L_{pAeq,nT}$ [dB] [2]	**Maximal ljudnivå nattetid, $L_{pAFmax,nT}$ [dB]** [3]
Ljudisolering bestäms utifrån fastställda ljudnivåer utomhus så att följande ljudnivåer inomhus inte överskrids [1]		
i utrymme för sömn, vila eller daglig samvaro	30	45
i utrymme för matlagning eller personlig hygien	35	-

1) Dimensionering kan göras förenklat eller detaljerat enligt SS-EN 12354-3. För ljud från exempelvis blandad gatutrafik och järnvägstrafik i låga hastigheter kan förenklad beräkning genomföras med $D_{nT,A,tr}$ värden för byggnadsdelarna. Detaljerade beräkningar väger samman byggnadsdelarnas isolering mot ljud vid olika frekvenser med hänsyn till de aktuella ljudkällorna.

2) Avser dimensionerande dygnsekvivalent ljudnivå. Se Boverkets handbok *Bullerskydd i bostäder och lokaler*. För andra yttre ljudkällor än trafik avses ekvivalenta ljudnivåer för de tidsperioder då ljudkällorna är i drift mer än tillfälligt.

3) Avser dimensionerande maximal ljudnivå som kan antas förekomma mer än tillfälligt under en medelnatt. Med natt menas perioden kl. 22:00 till kl. 06:00. Dimensioneringen ska göras för de mest bullrande vägfordons-, tåg- och flygplanstyper, samt övrigt yttre ljud, exempelvis från verksamheter eller höga röster och skrik, så att angivet värde inte överstigs oftare än fem gånger per natt och aldrig med mer än 10 dB.

Regulations indoor noise – General advice

- Maximum sound level: L_{AFmax} = 45 dB
- Equivalent sound level: $L_{Aeq,T}$ = 30 dB
- Sound with audible tone components: $L_{Aeq,T}$ = 25 dB
- Sound from music systems: $L_{Aeq,T}$ = 25 dB
- Values for low third octave bands (31.5-200 Hz)

Folkhälsomyndigheten

f [Hz]	31.5	40	50	63	80	100	125	160	200
L [dB]	56	49	43	42	40	38	36	34	32

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Regulations indoor noise – *SS 25267:2015*

Tabell 5 – Dimensionerande inomhusljudnivå från trafik tillsammans med andra yttre ljudkällor, $L_{inom\text{-}hus}$, i dB

Typ av utrymme	Storhet	Ljudklass[a]		
		A	B	D
I utrymme för sömn, vila eller daglig samvaro	Dygnsekvivalent A-vägd ljudnivå, $L_{A,eq,24h}$	22	26	30
	Nattekvivalent ljudnivå, L_{night}	18	22	-
	Maximal A-vägd ljudnivå, $L_{A,Fmax}$	37	41	45
I utrymme för matplats och matlagning eller i utrymme för personlig hygien	Dygnsekvivalent A-vägd ljudnivå, $L_{A,eq,24h}$	27	31	40

[a] Krav för ljudklass C är redovisade i Boverkets byggregler BBR avsnitt 7:21.

Implications of regulations

- Outdoor noise regulations expressed as *riktvärden*
  - A certain amount of exceedance may be tolerated.
- Indoor noise regulations expressed as *ljudkrav*
  - Levels shall be met.
- Acoustic studies and accordingly acoustic counter-measures are performed and proposed to address two different kinds of problems:
  - Aim to have outdoor noise levels that are low enough and that fulfils how regulations are written (*minst hälften av bostadsrummen*)
  - Design a building that has a structure that gives enough sound insulation to meet indoor requirements
- Fulfilling one set of rules does not imply fulfilling the other.
  - One set of rules addresses outdoor acoustic climate – let people enjoy their outdoor area, balcony or getting fresh air in the room.
  - One set of rules addresses indoor acoustic climate.

Three different investigations

- Outdoor noise
  - At the façade
  - Outdoor spaces (balconies, gardens)
- Indoor noise i.e. acoustic dimensioning of the façade

Predictions and measurements of traffic noise

- Both are useful and are used in different situations.
    - Kind of investigation
    - Building phase
- Both have limitations and difficulties
    - Calculations are based on models with assumptions and simplifications of reality.
    - Measurements may be biased by measurement errors, measurement conditions, traffic and weather conditions.

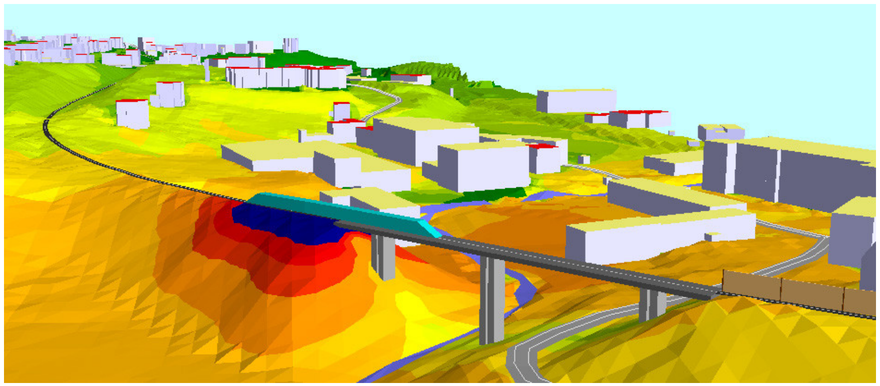
Road traffic noise prediction methods

- Nordic prediction method (from 1978; last update 1996)
  - Account for differences between light and heavy vehicles
  - Total equivalent sound pressure level during a period of time
  - Implemented in *SoundPlan* and other commercial software

- New method: *Nord2000* (simulations)
  - Equivalent sound pressure levels ($L_{A,eq}$) in 1/3-octave bands
  - Maximum sound pressure level for individual vehicles ($L_{A,Max}$)
  - L_{den} / L_{night} to use in European directives on environmental noise
  - Handles various weather conditions
  - Distinction between tyre/road noise and engine noise
  - …
  - Implemented in *SoundPlan* and other commercial software

Road traffic noise prediction methods (II)

- Commercial software (e.g. *Soundplan*)
  - Example: railway noise animation



NOTE: It is the results from the prediction methods that count and not measured levels in the case of road traffic noise related legal disputes. This is based on the idea that measurements may have too large variations and do not represent the average behaviour.

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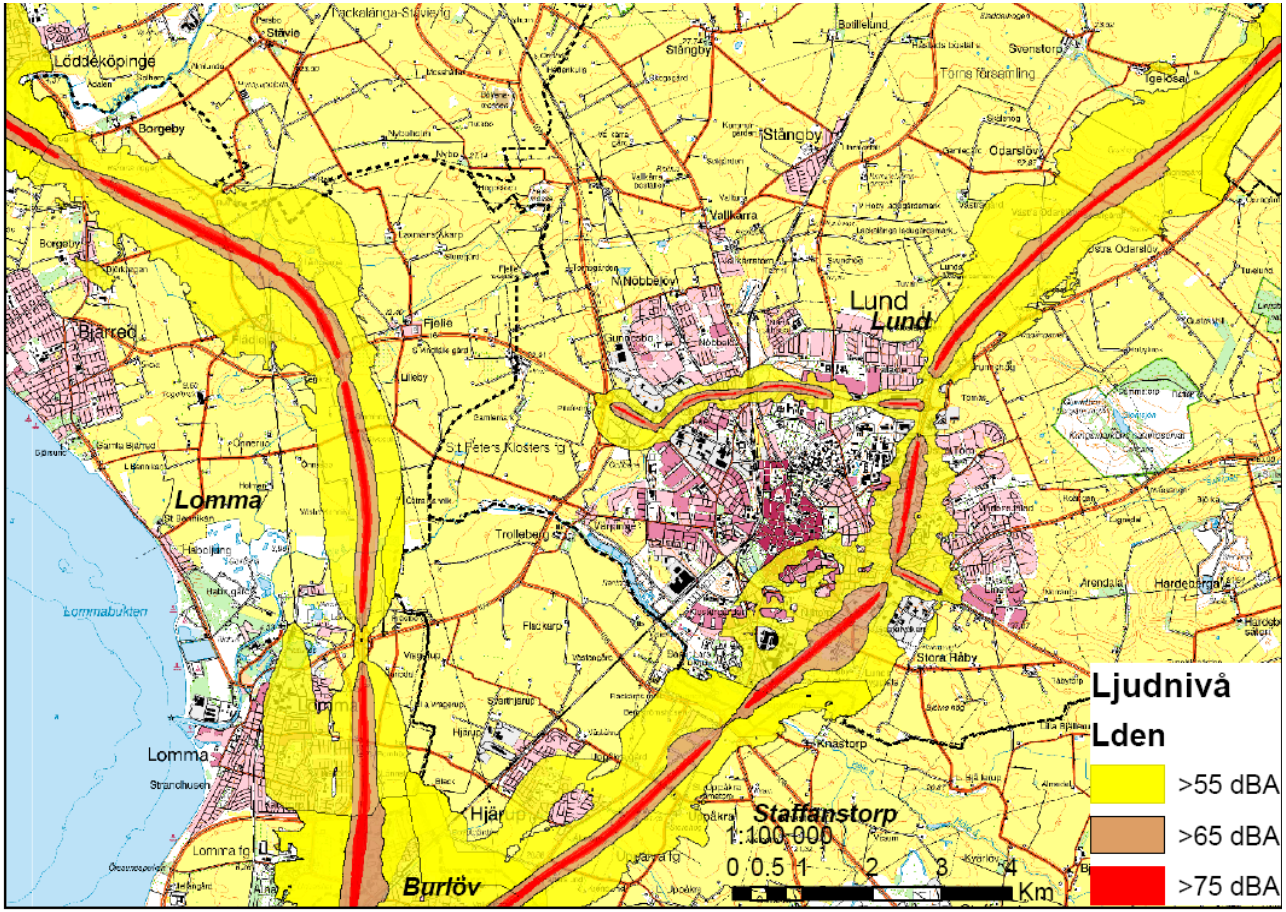
Road traffic noise prediction methods (III)

- Noise map (Lund)

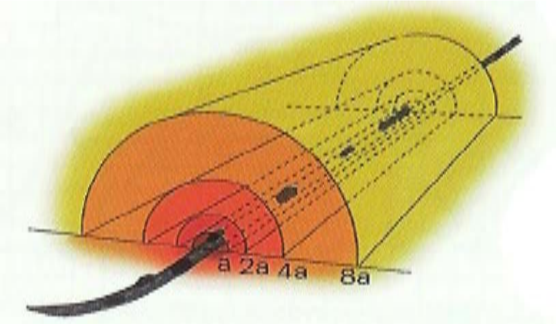


Sound propagation – General equation (1996)

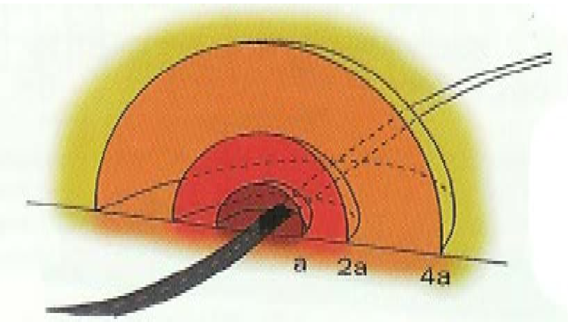
- $L_{Aeq} = L_1 + \Delta L_2 + \Delta L_3 + \Delta L_4 + \Delta L_5$
- L_1: starting value. At 10 m from centreline, dependent on speed and number of light and heavy vehicles during the period of observation.
- ΔL_2: distance correction.
- ΔL_3: extra damping due to hard or soft ground, barriers.
- ΔL_4: other correction (exceptions in previous steps)
- ΔL_5: fasade correction to calcualte indoor value.

- Nord2000 is based on the concept of propagating sound rays – with option to bend for taking care of atmosphering conditions and diffraction.

Sound propagation – Distance



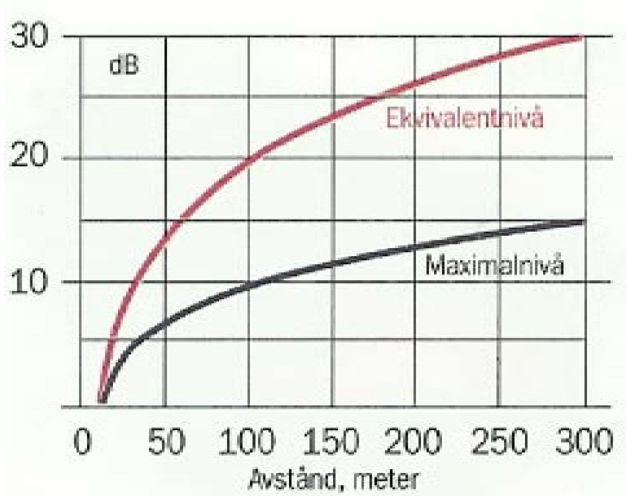
Halvcylindrisk utbredning av ekvivalent ljudnivå från vägtrafik och från spårburen trafik. a = avstånd.



Halvsfärisk utbredning av maximal ljudnivå från vägtrafik.

- Equivalent level (cylindrical propagation):

  -3 dB with doubling the distance



- Maximum level (spherical propagation):

  -6 dB with doubling the distance

Traffic noise decreases with increasing distance → a corridor problem

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Sound propagation – Some data

- Intensity: doubling of vehicles → + 3dB
- Heavy vehicles cf. with light → +10dB
- Speed:
  - 50-70 km/h → +4dB
  - 70-90 km/h → +3dB
  - 90-110 km/h → +3dB
- Tire noise dominates from 40-50 km/h
- Intersections and connections provide increased annoyance
- Rules of thumb from *Vägverket* (current *Trafikverket*)
  - Any increase in noise level by 1dB gives an annoyance increase of 20%
  - 3dB increase in noise level will double the disturbance
- Psychoacoustics: 10dB increase is perceived as a noise level doubling

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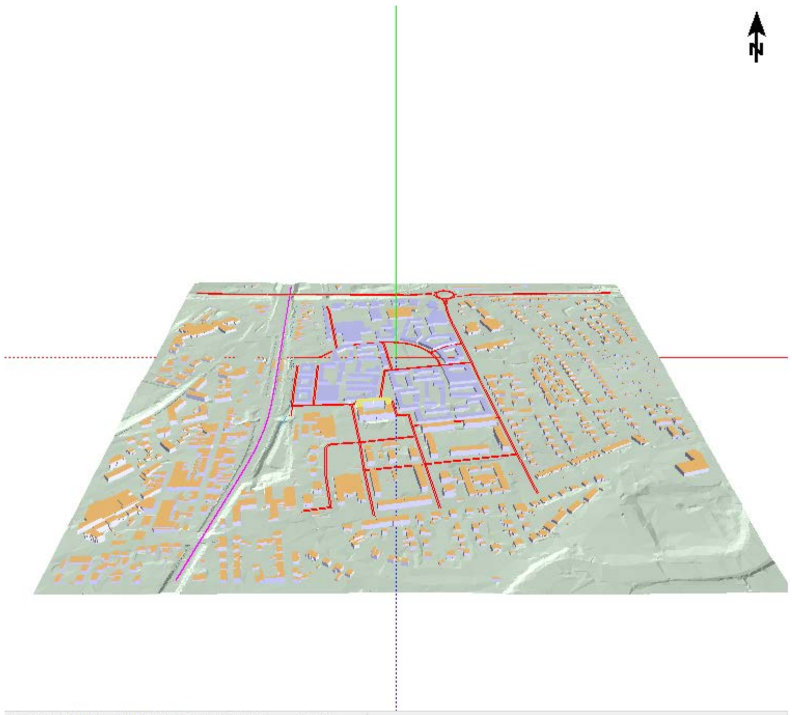
What a model looks like

- Soundplan, 3D model



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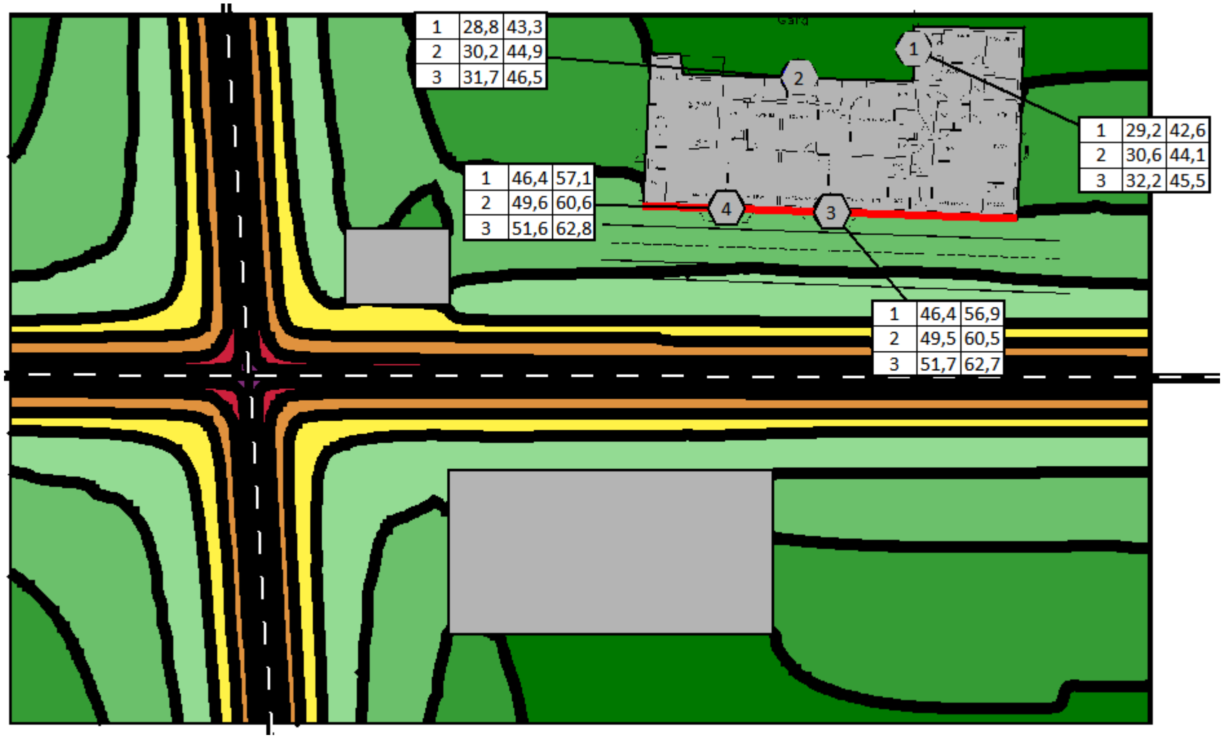
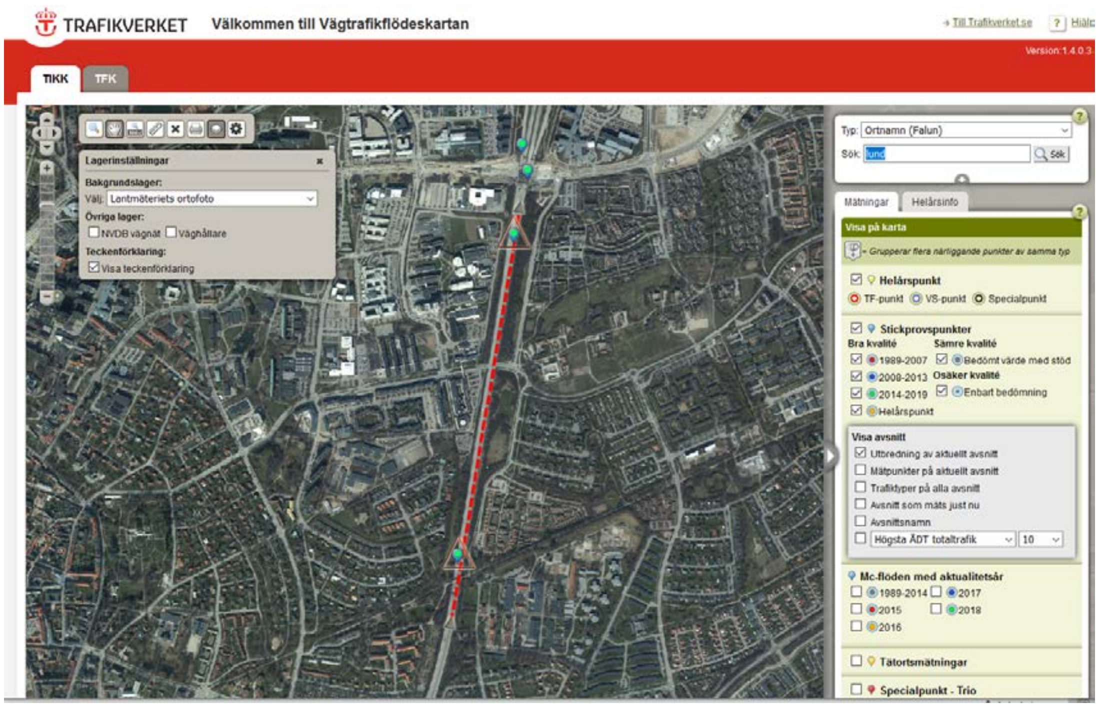
What a model looks like

- Sound map, Leq



What a model looks like

- Traffic information: http://vtf.trafikverket.se/SeTrafikinformation



What a model looks like

- Traffic information: http://vtf.trafikverket.se/SeTrafikinformation

TRAFIKVERKET

Avsnitt: 2240152 Län: M Vägnummer: 22

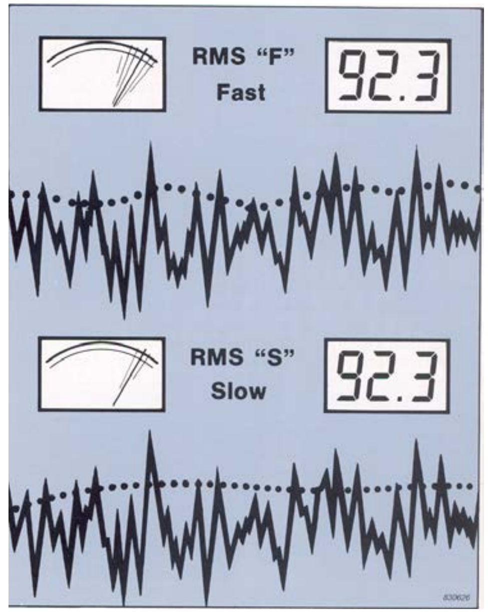
Årsmedeldygnstrafik

Avsnitt	Fr o m	Till	Mätkod	Mätår	Mätriktning	ÅDT(OS) Samtliga fordon	ÅDT(OS) Lastbilar	ÅDT(OS) Axelpar
2240152	1994-01-01	1998-01-01	2	1993	1	10980±(8%)	710±(14%)	11610±(8%)
2240152	1997-01-01	1998-01-01	2	1993	2	11010±(8%)	830±(14%)	11780±(8%)
2240152	1998-01-01	2002-01-01	2	1998	1	12280±(6%)	910±(8%)	13120±(6%)
2240152	1998-01-01	2002-01-01	2	1998	2	12140±(6%)	960±(8%)	13100±(6%)
2240152	2002-01-01	2006-01-01	2	2002	1	14490±(6%)	1160±(8%)	15520±(6%)
2240152	2002-01-01	2006-01-01	2	2002	2	14550±(6%)	1280±(8%)	15730±(6%)
2240152	2006-01-01	2011-01-01	2	2006	1	16490±(6%)	1460±(7%)	17760±(6%)
2240152	2006-01-01	2011-01-01	2	2006	2	16660±(6%)	1540±(7%)	18040±(6%)
2240152	2011-01-01	2015-01-01	2	2011	1	15540±(8%)	1600±(7%)	16750±(8%)
2240152	2011-01-01	2015-01-01	2	2011	2	16260±(12%)	1600±(9%)	17550±(12%)
2240152	2015-01-01	9999-12-31	2	2015	1	19190±(5%)	1830±(6%)	20460±(5%)
2240152	2015-01-01	9999-12-31	2	2015	2	19360±(5%)	1940±(6%)	20760±(5%)

- Count up to today and a future scenario (2040) using specific methods

Measurement of traffic noise

- Sound level meter
  - Microphone measures acoustic levels omni-directionally
  - Sampling:
    - » *Fast* (*F* - 0.125 s)
    - » *Slow* (*S* - 1 s)
    - » *Peak* (*P* - impulse value 35 ms)
  - Weighting filters (A, C…) built-in
  - Calculation of:
    - » $L_{eq,T}$, $L_{Aeq,T}$, SENEL…
    - » Building acoustic indicators
    - » …
  - Calibrated



… more about this during the course labs & measurement technique lecture

Traffic noise measurements – *Nordtest* methods

- Nordtest method NT ACOU 039, *Road traffic: noise – engineering method*
    - LAeq and LAmax
    - Measurements in third-octave band
    - Higher accuracy (engineering grade)
- Nordtest method NT ACOU 056, *Road traffic: noise – survey method*
    - LAeq
    - Lower accuracy (survey grade)
    - Up to 100 m from the road (if more, use 039).
- Both of them:
    - Measure during shorter intervals – then correct measured values with traffic
    - Count number of heavy/light vehicles
    - Both indoor and outdoor measurements

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Traffic noise measurements – *NT Acou 039/056*

Heavy vehicles:

$$L_{AE}\ (10\ \text{m}) = \begin{cases} 80.5 + 30\ \log\left(\frac{v}{50}\right);\ 50 \le v \le 90\ \text{km/h} \\ 80.5\ ;\ 30 \le v < 50\ \text{km/h} \end{cases} \quad \text{(A.1)}$$

Light vehicles:

$$L_{AE}\ (10\ \text{m}) = \begin{cases} 73.5 + 25\ \log\left(\frac{v}{50}\right);\ v \ge 40\ \text{km/h} \\ 71.1;\ 30 \le v < 40\ \text{km/h} \end{cases} \quad \text{(A.2)}$$

Traffic flow

$$L_{Aeq,1h}(10\ \text{m}) = 10\ \log\ \frac{1}{3600}\left[n_{heavy} \cdot 10^{\frac{L_{AE,heavy}}{10}} + n_{light} \cdot 10^{\frac{L_{AE,light}}{10}}\right] \quad \text{(A.3)}$$

$$L_{Aeq,meas,YDT} = L_{Aeq,meas,MTT} + (L_{1,YDT} - L_{1,MTT}) \quad \text{(A.4)}$$

$L_{Aeq,meas,YDT}$ = Measured equivalent noise level converted to yearly average traffic conditions

$L_{Aeq,meas,MTT}$ = Equivalent noise level measured during the measurement time interval

$L_{1,YDT}$ = value L_1 of equivalent noise level, calculated by Equation (A.3) for yearly average traffic conditions

$L_{1,MTT}$ = value L_1 of equivalent noise level, calculated by Equation (A.3) for measurement time interval traffic conditions.

Example:

MTT	*Measured during 30 minutes* $L_{Aeq,30\ min.}$ = *67.3 dB with 600 vehicles, including 22% heavy vehicles, average speed 54 km/h* *Calculation:* $L_{1,MTT}$ = *72.5 dB*
YDT	*16,000 vehicles, including 16% heavy vehicles, average speed 52 km/h* *Calculation:* $L_{1,YDT}$ = *68.8 dB*

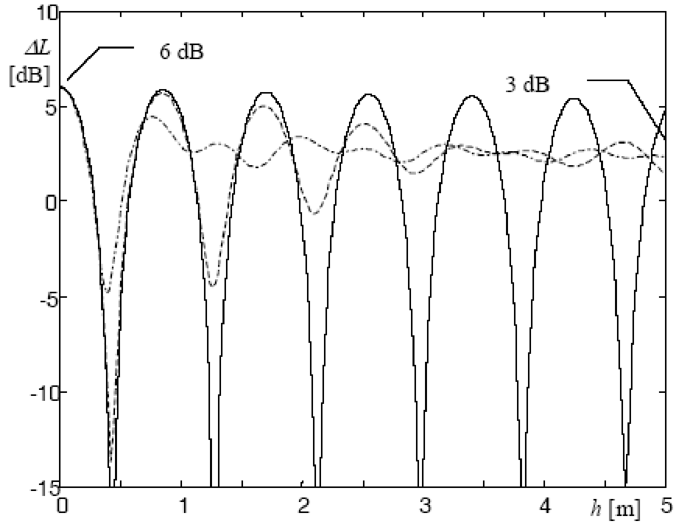
$L_{Aeq,meas,YDT}$ = *67.3 + (68.8 – 72.5) = 67.3 – 3.7 dB = 63.6 dB*

$$L_{1,MTT} = 10\log\frac{1}{3600}\left[2*600*0{,}22*10^{\frac{80.5+30\log\left(\frac{54}{50}\right)}{10}} + 2*600*(1-0{,}22)*10^{\frac{73.5+25\log\left(\frac{54}{50}\right)}{10}}\right] = 72{,}5\ \text{dB}$$

$$L_{1,YTT} = 10\log\frac{1}{3600}\left[\frac{16000}{24}*0{,}16*10^{\frac{80.5+30\log\left(\frac{52}{50}\right)}{10}} + \frac{16000}{24}*(1-0{,}16)*10^{\frac{73.5+25\log\left(\frac{52}{50}\right)}{10}}\right] = 68{,}8\ \text{dB}$$

Outdoor measurements

- Both 039 and 056 allow for +0 dB, +3 dB and +6 dB outdoor measurements. +6 dB is a safer bet than +3 dB though.
- Flat façade, away from edges.
- Background noise 10 dB lower than traffic.



Interference by a facade for narrow band (solid line), third octave band (dashed line) and octave band (dotted/dashed line). Midfrequency: 200 Hz (wavelenght 1.7 m).

Indoor measurements

- Three microphone positions in the room, away from sources of noise (windows, vents).
- Absorption in rooms (reverberation time, introduced in next lecture) .
- Background noise 10 dB lower than traffic.

Max sound pressure level

- Measured following NT 039 – LAFMax i.e. time constant 125 ms.
- A max SPL is registered every 125 ms. Series of samples. Calculation of mean and standard deviation *s*.
- When calculating max SPLs acousticians speak about LAFmax,5% i.e. the estimate of the 5th percentile of the distribution of SPLs – the maximum SPL exceed by the 5% of the vehicles in a given category.
- $L_{AFmax,5\%} = L_{AFmax,avg} + 1.65s$
- If other percentiles, substitute 1.65:

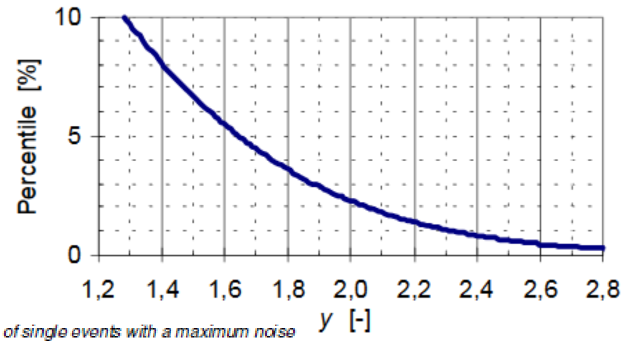


Figure 1. Percentage of single events with a maximum noise level exceeding – by a certain number y of standard deviations – the (arithmetic) mean of a normal distribution of maximum noise levels.

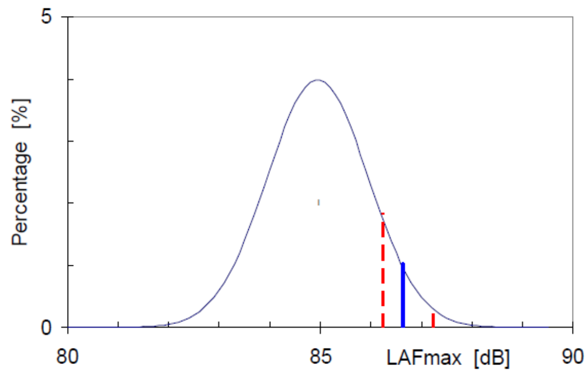


Figure 5
Normal distribution with illustration of the 5th percentile (full vertical line) and confidence limits calculated according to Equations (8)–(10) with n = 30.

Max sound pressure level

- If it is not possible to record maximum noise level from 30+ vehicles, then,

Heavy vehicles

$$\begin{cases} s = 4.1\text{dB};\ 30 \le v \le 50 \ \text{km/h} \\ s = 10 \cdot e^{-0.9 \cdot \frac{v}{50}} \ \text{dB};\ v \ge 50 \ \text{km/h} \end{cases}$$

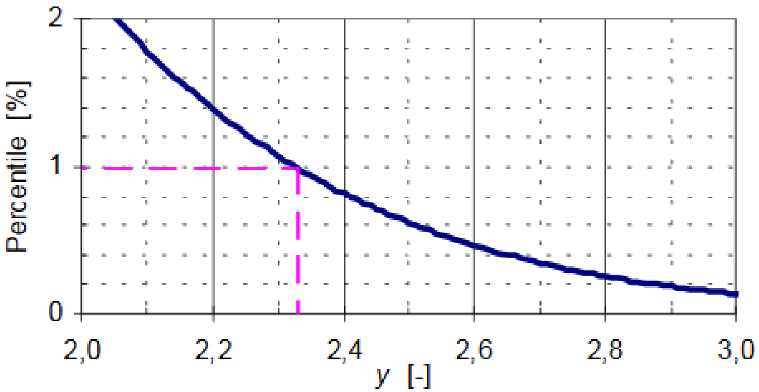
Light vehicles

$$s = 5.5 \cdot e^{-0.7 \cdot \frac{v}{50}} \text{dB}; \quad v \ge 30 \ \text{km/h}$$

Max sound pressure level

- Sometimes in Sweden we speak also about the 5th highest maximum noise level, $L_{AFmax,5th}$
- $L_{AFmax,5\%}$ more conservative but easier to calculate (risk of over dimensioning façades); 5th needs info/assumptions on time distribution of traffic.

*Example: If the fifth highest maximum noise level is wanted out of 500 vehicles passing, then the percentile is (5/500) * 100 = 1 and as shown in the bottom part of Figure 1 the factor to replace the factor 1.65 in Equation (8) is y = 2.33 ≅ 2.3.*



- $L_{AFmax,5th} = L_{AFmax,avg} + 2.3s$

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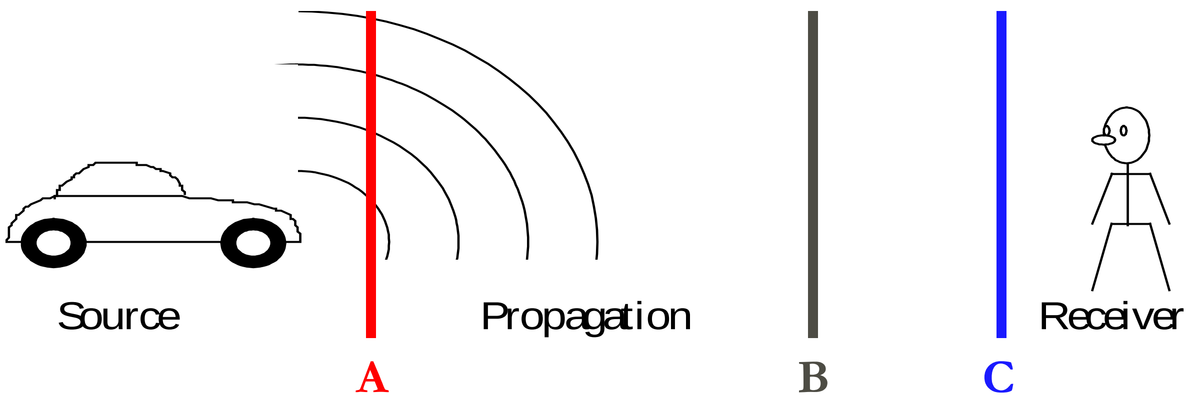
Noise barriers

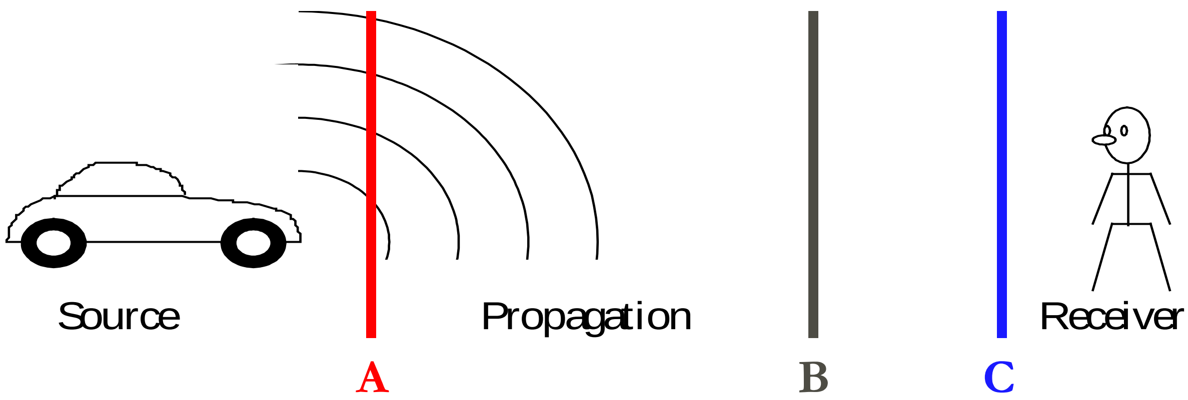
- Noise barriers
  - Protect people living near busy roads
  - More effective than distance when reducing noise
  - Amount of diffracted noise reaching the receiver depends on the frequency



DISCUSS: Intuitively, what is the best place to place a noise barrier? **A? B? C?**

Noise barriers

- Noise barriers
  - Both sound absorption and sound insulation
  - Sound absorption: 10dB higher than the damping that is needed.



DISCUSS: Intuitively, what is the best place to place a noise barrier? **A? B? C?**

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Noise barriers

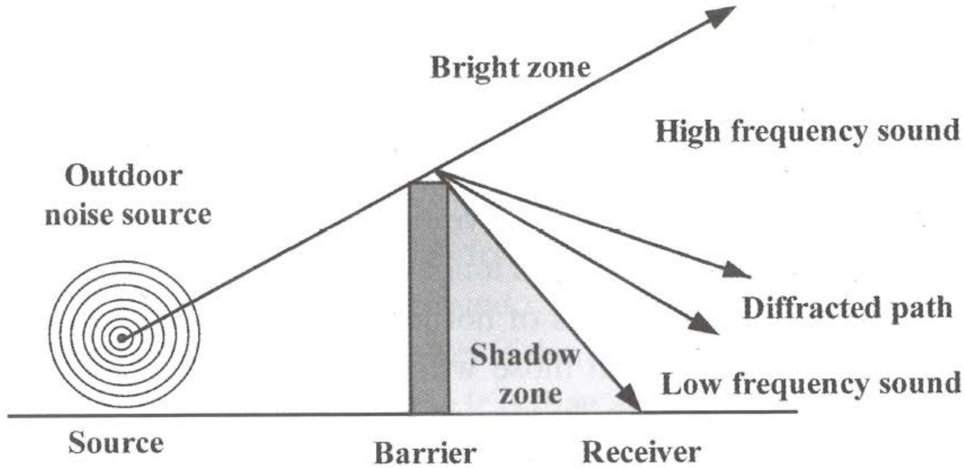

Fig. 8.7 Diffraction of sound around noise barrier. Sound waves have a tendency to bend or scatter from the top edge of the barrier (diffraction) and around the sides of a barrier wall particularly in the lower frequencies. In the higher frequencies, sound waves diffract less and are much more directional in nature. The shielding effect of the acoustical barrier and resultant noise shadow area beyond it are determined by the geometric relationship between the source, the receiver and the barrier height. Directly behind the noise barrier more low-frequency noise (low rumbling sound) is heard; while farther out, both low and high frequencies are observed. As one moves away from the barrier, the higher frequencies become more noticeable.

O. A. B. Hassan (2009)

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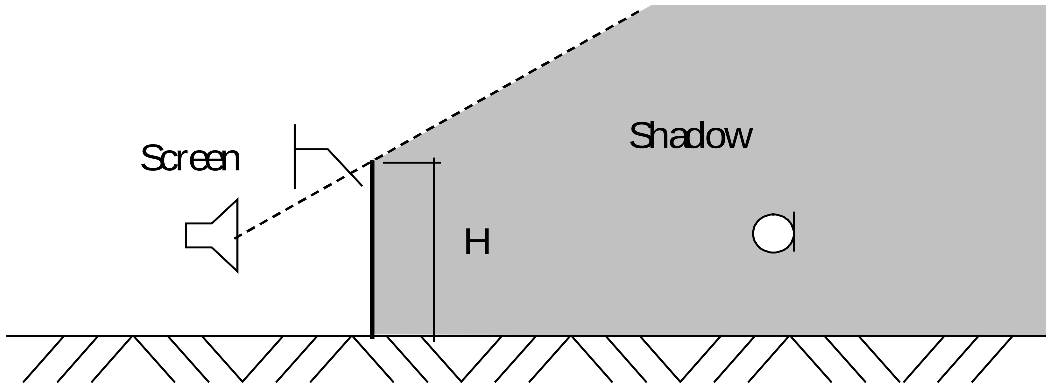
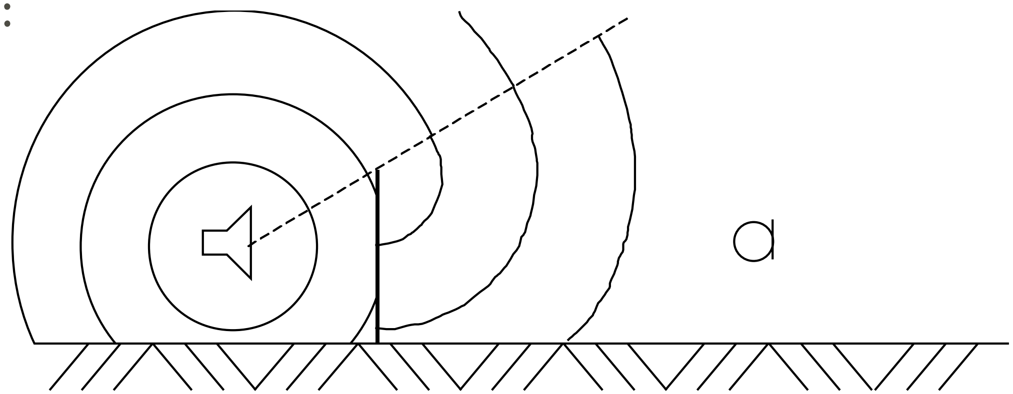
Noise barriers

- High frequencies:
  $\lambda << H$



- Low frequencies:
  $\lambda >> H$



Noise barriers

- Factors influencing effectiveness of barriers:
  - Transmitted sound << diffracted over its edge
  - Max. efficiency: placed as close as possible to the source or receiver
  - Attenuation increases with barrier height
    - » High enough to break the line of sight (2-3 m reduce 10-15dB)
  - Scattering due to turbulences can reduce barrier's efficiency
  - Foliage/different materials can affect the efficiency
  - Atmospheric conditions
  - Should be >10 kg/m^2 and completely sealed
  - …

Noise barriers

- Non-acoustic considerations:
  - Maintenance
  - Withstand loads
  - Good-looking
  - Vandal-proof
  - Take into consideration receivers downwind the barrier

- Cost*
  - 2 m high screen in pressure-treated wood
    - » 10 000 kr/m (+ 10 kr/m^2 and year of maintenance)
  - Noise barrier, 3-5 m high: about 5000 kr/m

*Source: *Vägverket* -actual *Trafikverket*-

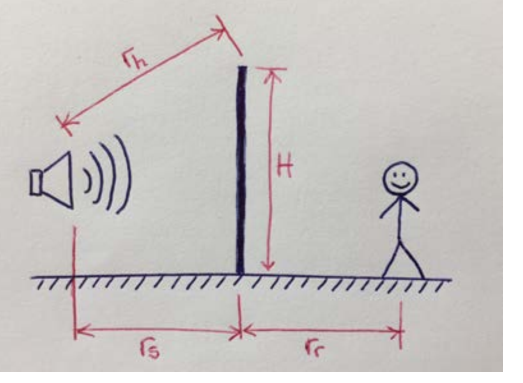
Noise barriers

- Insertion loss (IL) = Attenuation barrier (A_{barr}) = $L_{p,NoBarr}$ - $L_{p,Barr}$

- Many empirical models to predict barrier attenuation
  - Equation
  - Plots…

- A practical expression: Model (Fehr, 1951)
  - $r_r >> r_s$
  - $r_s > H$
  - $r_h \geq 2r_s$

$$A_{barr} \approx 10 \log\left(\frac{20H^2}{\lambda r_s}\right)$$

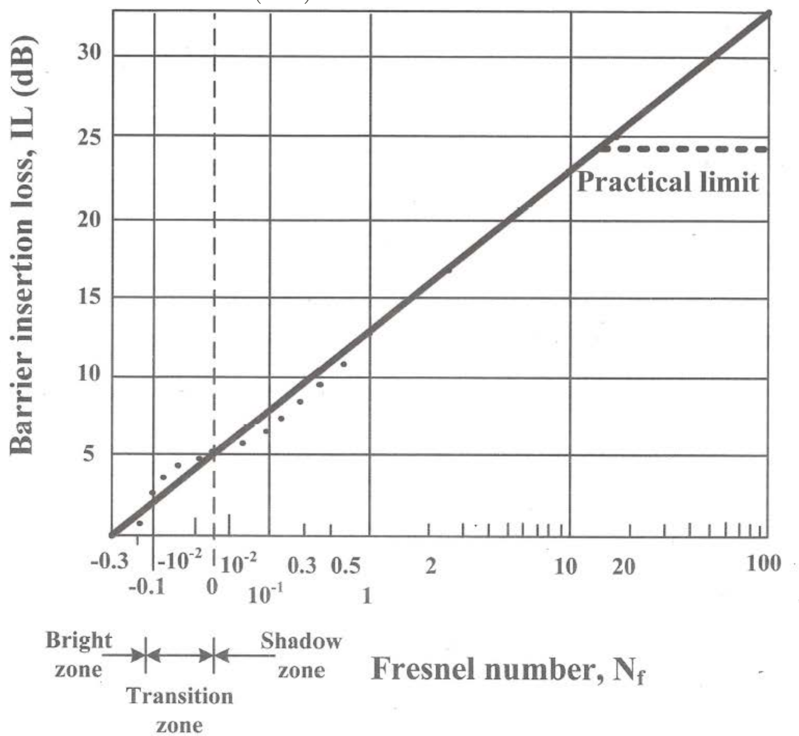


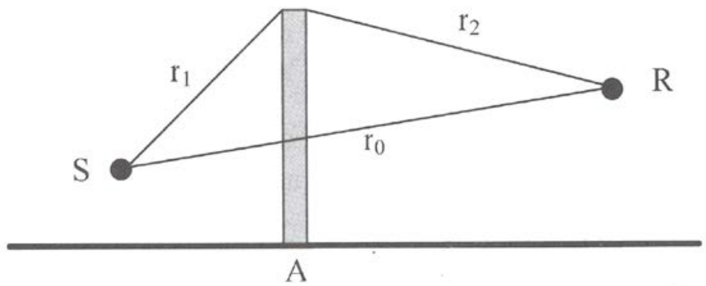
- In practice, barrier attenuations are limited to 10-15dB

Noise barriers

- Semi-infinite half-space, i.e. for open air above a hard flat ground
- Accounts for the effect of diffraction of sound over the top

O. A. B. Hassan (2009)





$$\delta = r_1 + r_2 - r_0$$

$$N_f = \pm \frac{2\delta}{\lambda}$$

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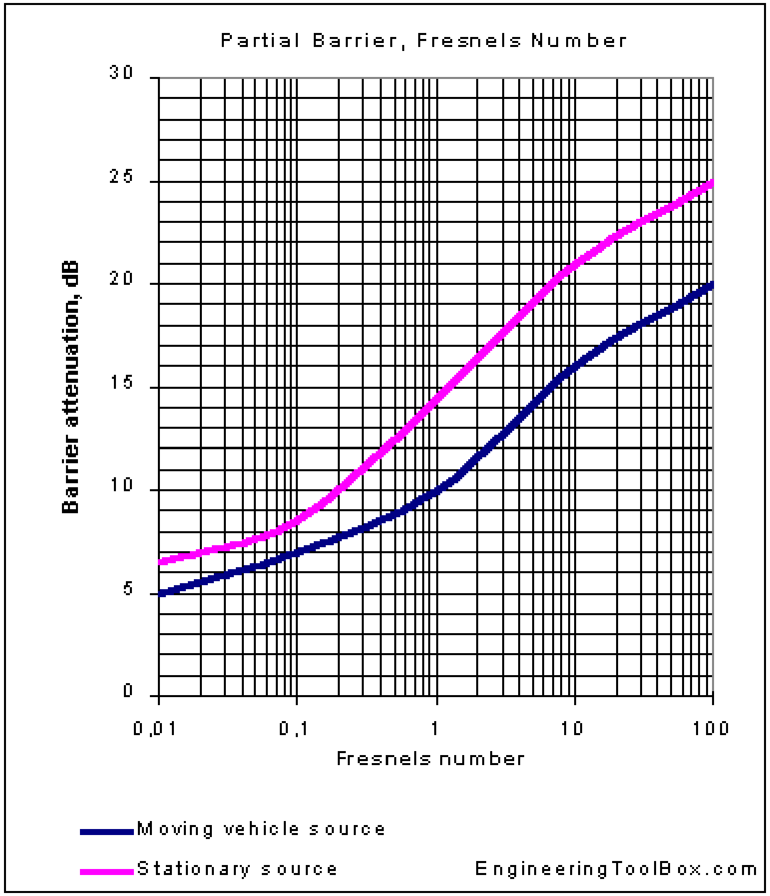
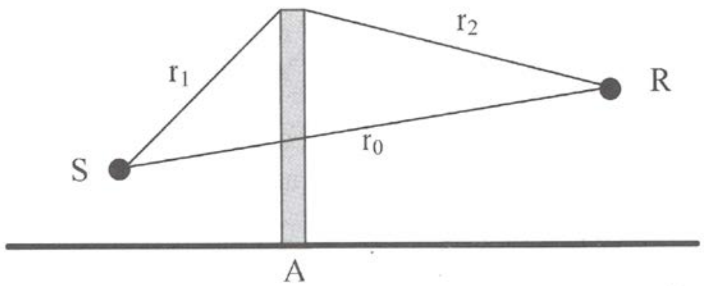
Noise barriers

- Semi-infinite half-space, i.e. for open air above a hard flat ground
- Accounts for the effect of diffraction of sound over the top





$$\delta = r_1 + r_2 - r_0$$

$$N_f = \pm \frac{2\delta}{\lambda}$$

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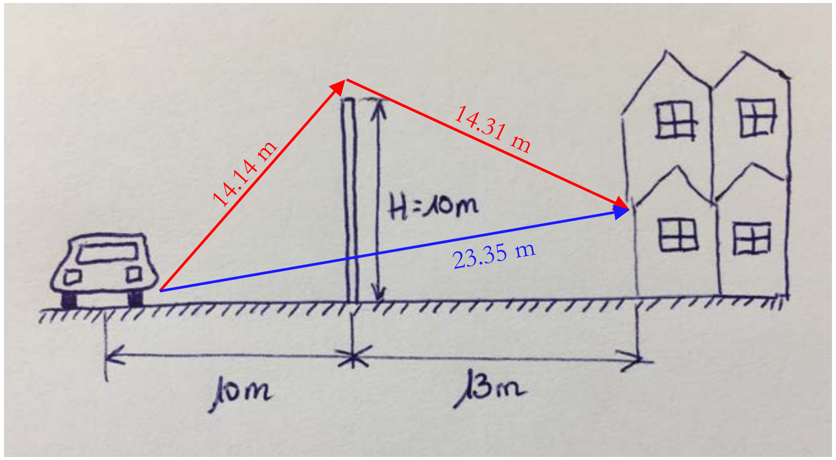
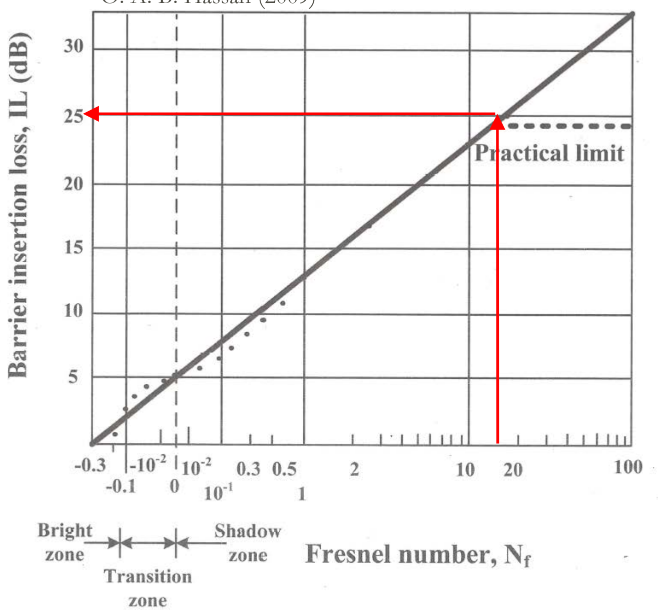
Noise barriers – Example

A 10 m tall noise barrier is installed in front of a house, 10 m away from the nearest tire. A 12 m house is built 13 m from the barrier. How much sound reduction can this wall yield at 550 Hz by the window located 4 m above the ground?



O. A. B. Hassan (2009)



1) $\delta = 5.1;\ N_f = 16.5 \rightarrow A_{barr} \approx 25\ \text{dB}$

2) $$A_{barr} \approx 10\log\left(\frac{20H^2}{\lambda r_s}\right) = 10\log\left(\frac{20\cdot 10^2}{\left(\frac{340}{550}\right)\cdot 10}\right) = 25\ \text{dB}$$

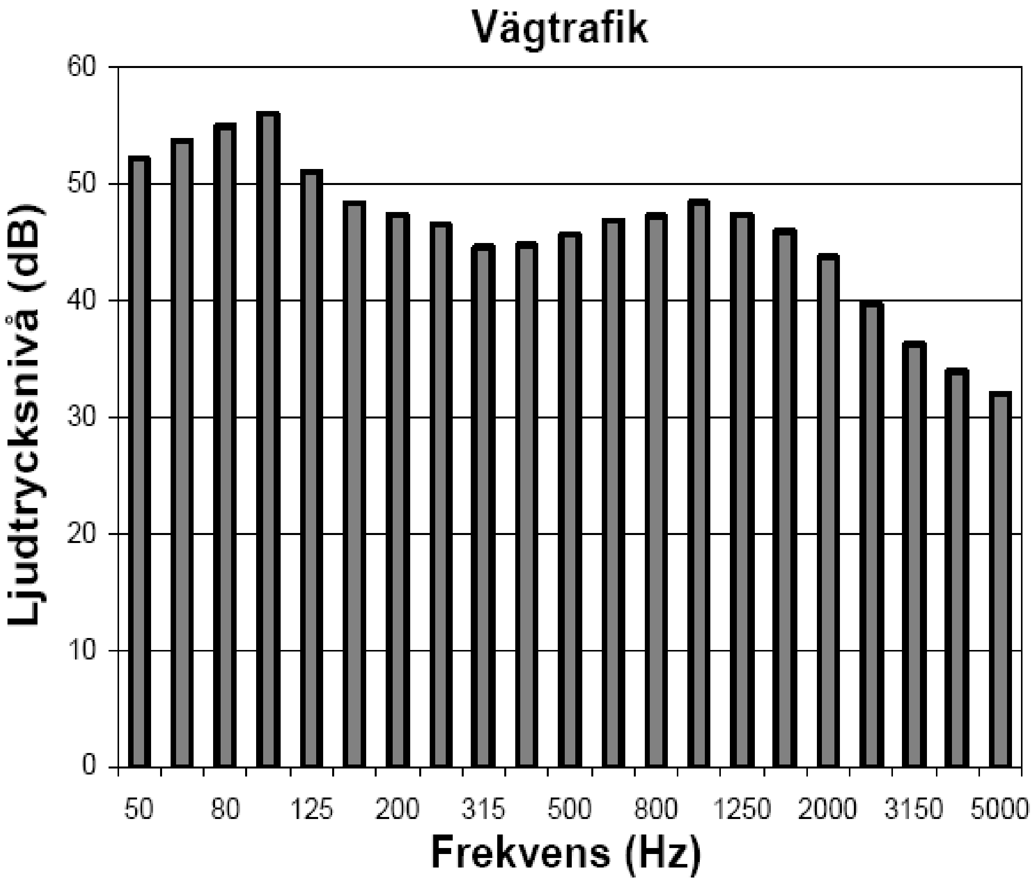
A practical attenuation that can be reached is 20 dB. On top of that and to be in the conservative side, 5 to 8 dB should be further discounted from the IL to account for e.g. reflection surfaces and car movement.

Noise barriers – ISO norms

ISO 9613-1:1993: Acoustics - Attenuation of sound during propagation outdoors - Part 1: Calculation of the absorption of sound by the atmosphere

ISO 9613-2:1996: Acoustics - Attenuation of sound during propagation outdoors - Part 2: General method of calculation

Traffic noise spectrum – Example



Traffic noise spectrum – Example

Road traffic

Exempel på frekvensspektrum för vägtrafik. Ljudtrycksnivå i oktavbanden 63–4 000 Hz då ljudnivån är 55 dB(A).

Railway traffic

Exempel på frekvensspektrum för spårburen trafik. Ljudtrycksnivå i oktavbanden 63–4 000 Hz då ljudnivån är 55 dB(A).

Aircraft traffic

Exempel på frekvensspektrum för flygtrafik. Ljudtrycksnivå i oktavbanden 63–4 000 Hz då ljudnivån är 55 dB(A).

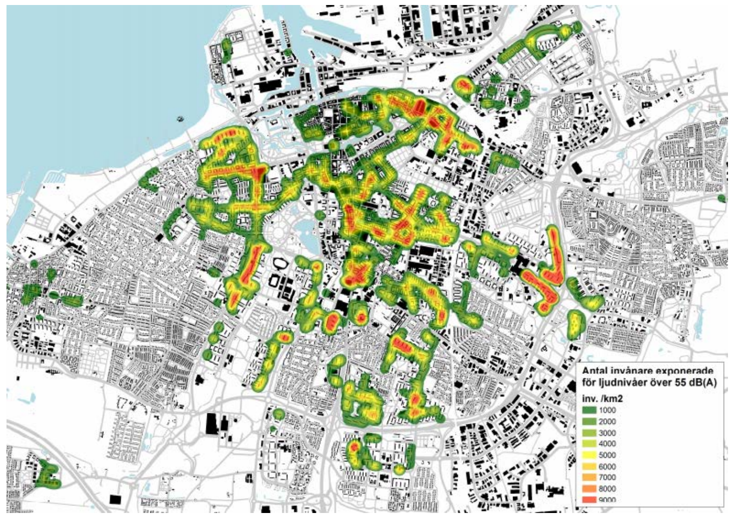
Malmö – Actions for noise exposure 2014

- Citizens exposed to > 30 dBA indoors: 48 000

  > 55 dBA outdoors: 126 000

- Estimated cost (incl. health care and loss of work): 1100 MSEK

- Proposed long term measures (250 MSEK):
  - Source: Lower speed limit, silent asphalt, driving style and silent car/tires
  - Sound reduction: Noise barriers, allowance for improvement of reduction at dwellings
  - Focus on sensitive places, e.g. schools, pre-schools and parks



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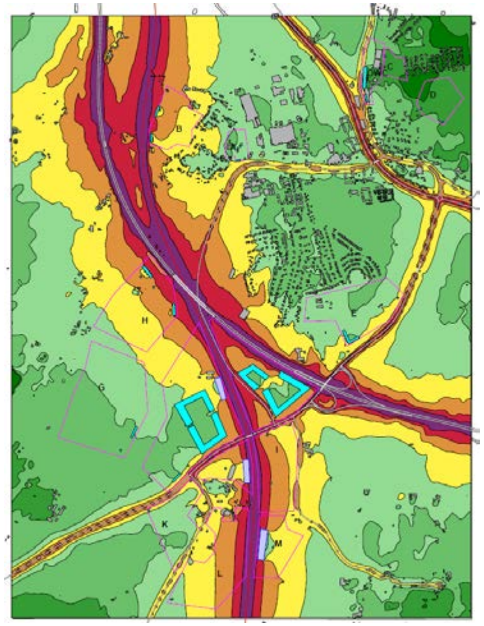
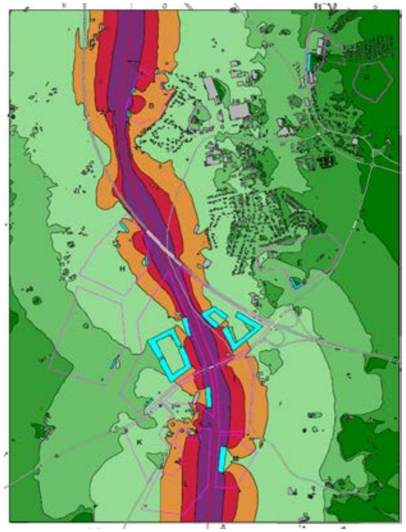
Study of a large area

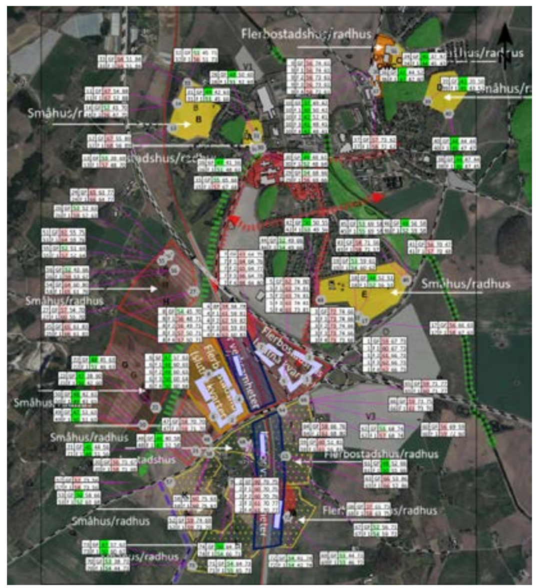


LAeq



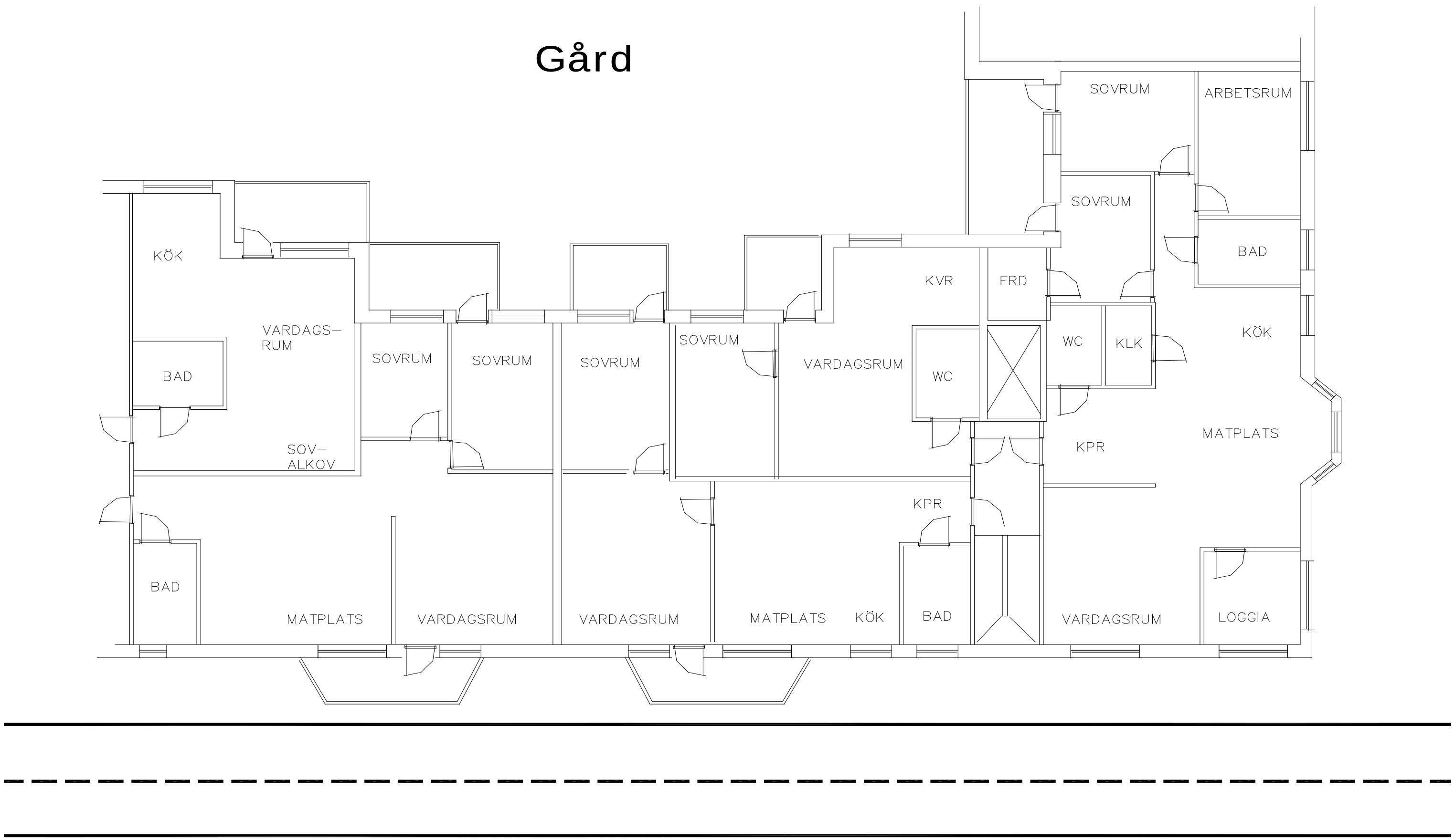
LAmax train

LAmax road



Façades

Example


Gård
SOVRUM
ARBETSRUM
SOVRUM
BAD
KÖK
VARDAGS–
RUM
BAD
SOV–
ALKOV
SOVRUM
SOVRUM
SOVRUM
SOVRUM
KVR
FRD
VARDAGSRUM
WC
WC
KLK
KÖK
MATPLATS
KPR
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MATPLATS
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VARDAGSRUM
MATPLATS
KÖK
BAD
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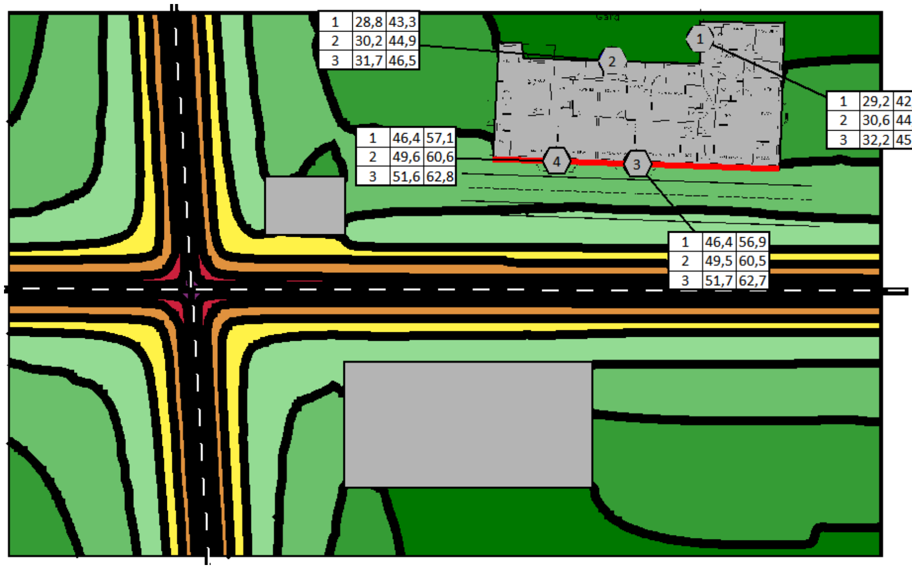
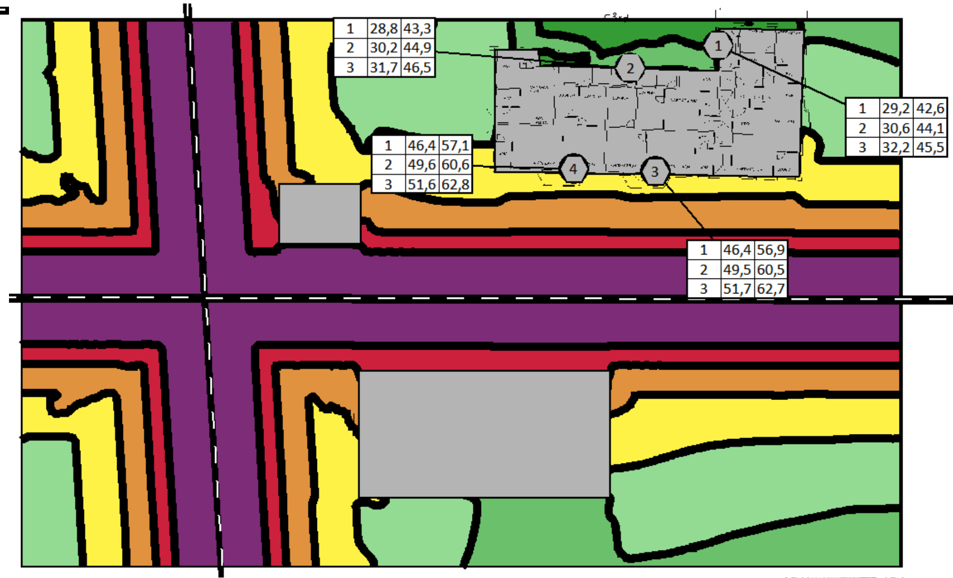
LOGGIA

Example

LAeq



LAmax



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Example

LAeq

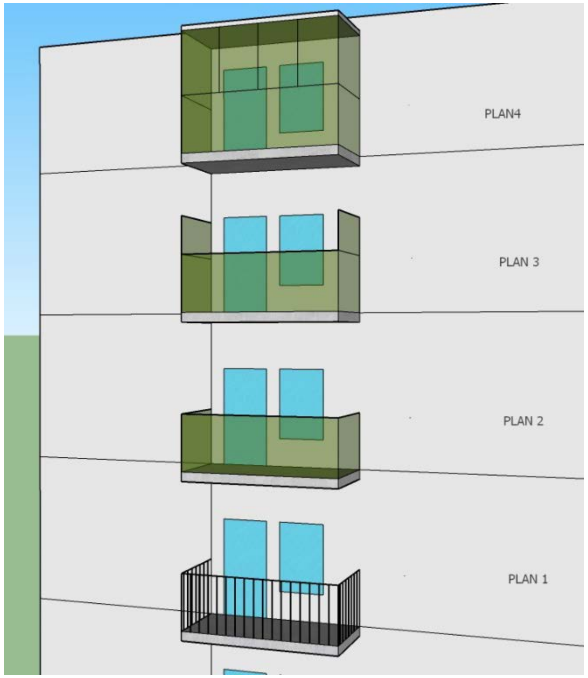
LAmax

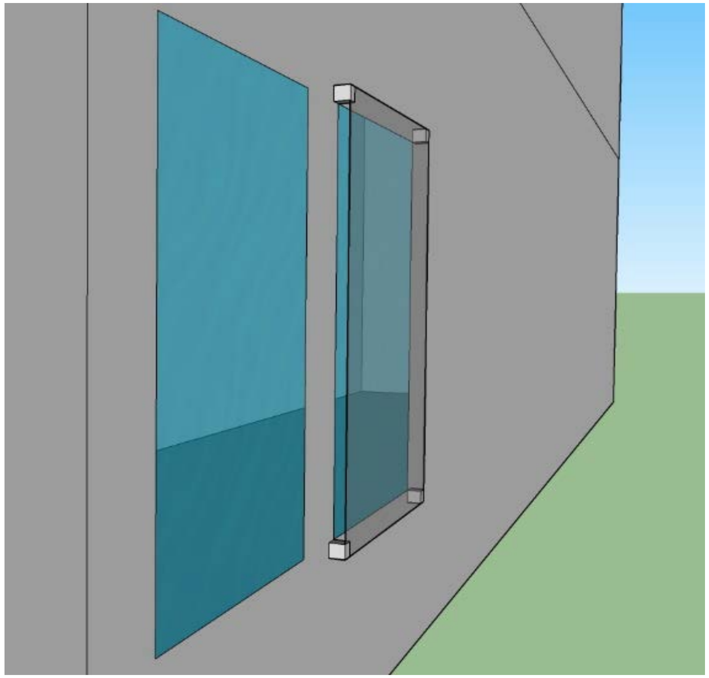
Example – Silent sides

- *Tyst sida* → definition of *Boverket*:

"Tyst sida i urban bostadsbebyggelse är en sida med en dygnsekvivalent ljudnivå som är lägre än 45 dBA (frifältsvärde) som en totalnivå från trafik, fläktar och liknande och i förekommande fall industri. Den tysta sidan bör därutöver vara visuellt och akustiskt attraktiv att vistas på."

Counter-measures at the façade





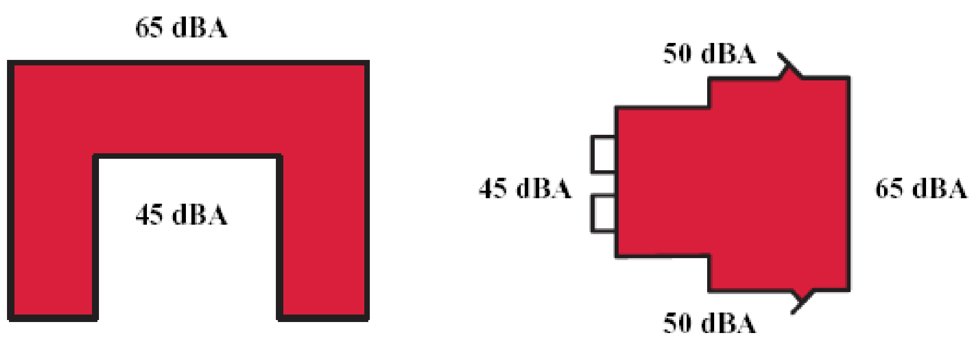
- Semi-closed balcony plus absorbent in the ceiling: -2/3/5 dB
- Completely closed balcony -15 dB

- Glass-pane outside window: -4/6 dB.

Deviations accepted

Exempel Grön

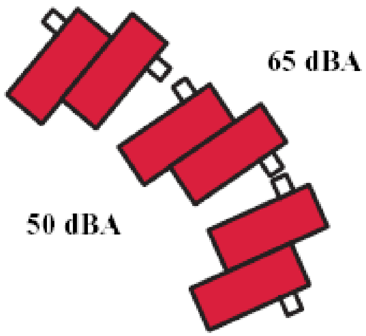
- Bebyggelsen konsekvent utformad och placerad för att minska bullret.
- Samtliga balkonger och uteplatser mot gård.
- Flertalet boningsrum (samtliga sovrum) mot gård.
- Centralt läge.
- Hög fasadisolering. Ljudklass B, enligt Svensk standard, vad avser ljudtrycks-nivå från trafik och andra yttre ljudkällor, uppfylls inomhus.
- Exponering för en bullerkälla; väg eller spårtrafik.
- Väl genomtänkta lägenhetslösningar, även i hörn och gavlar.
- Bebyggelsen minskar bullret för bakomliggande befintliga bostäder eller om-råden.
- Bullerskärm mot trafiken om det är tekniskt genomförbart.
- Vid behov vinklade burspråk för minskat buller och för att möjliggöra öppet fönster.

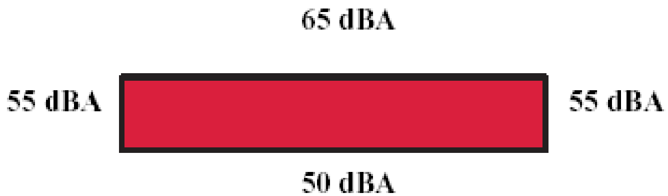


Deviations could be accepted

Exempel Gul

- Ej centralt läge.
- Bebyggelsen ej optimalt utformad med hänsyn till omgivande buller.
- Helt eller delvis inglasad balkong för att minska bullret.
- Buller från flera håll.
- Vissa lägenheter uppfyller inte kravet att minst hälften av boningsrummen ligger mot tyst sida.
- Obefintlig eller liten gårdsyta.
- Bullrig sida 55-65 dBA
- Ljuddämpad sida 45-50 dBA.
- Lägenheter i hörn har flera boningsrum mot bullrig sida.
- Planbestämmelser med lågt ställda krav, t.ex. "minst ett rum per lägenhet orienteras mot tyst sida eller ljuddämpad sida."
- Kompensationsåtgärder vidtas.





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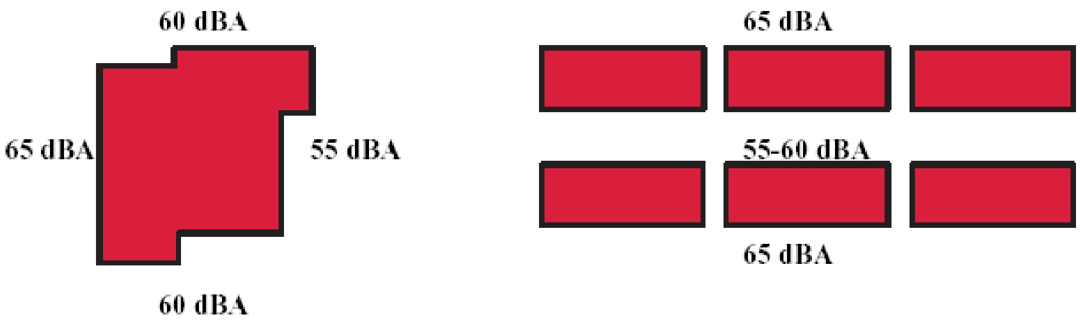
Deviations not accepted

Exempel Röd

- Viss andel enkelsidiga lägenheter mot trafiksidan, eller lägenheter som inte får tillgång till tyst sida eller ljuddämpad sida.
- Exponering för flera trafikslag.
- Bristfällig bullerutredning.
- Planbestämmelser om buller saknas eller anger endast krav på fasadisolering.
- Vissa balkonger mot sidor med >55 dBA.
- Bebyggelsen ej optimalt utformad med hänsyn till omgivande buller.
- Lägenhetslösningar redovisas inte.
- Buller från flera håll.

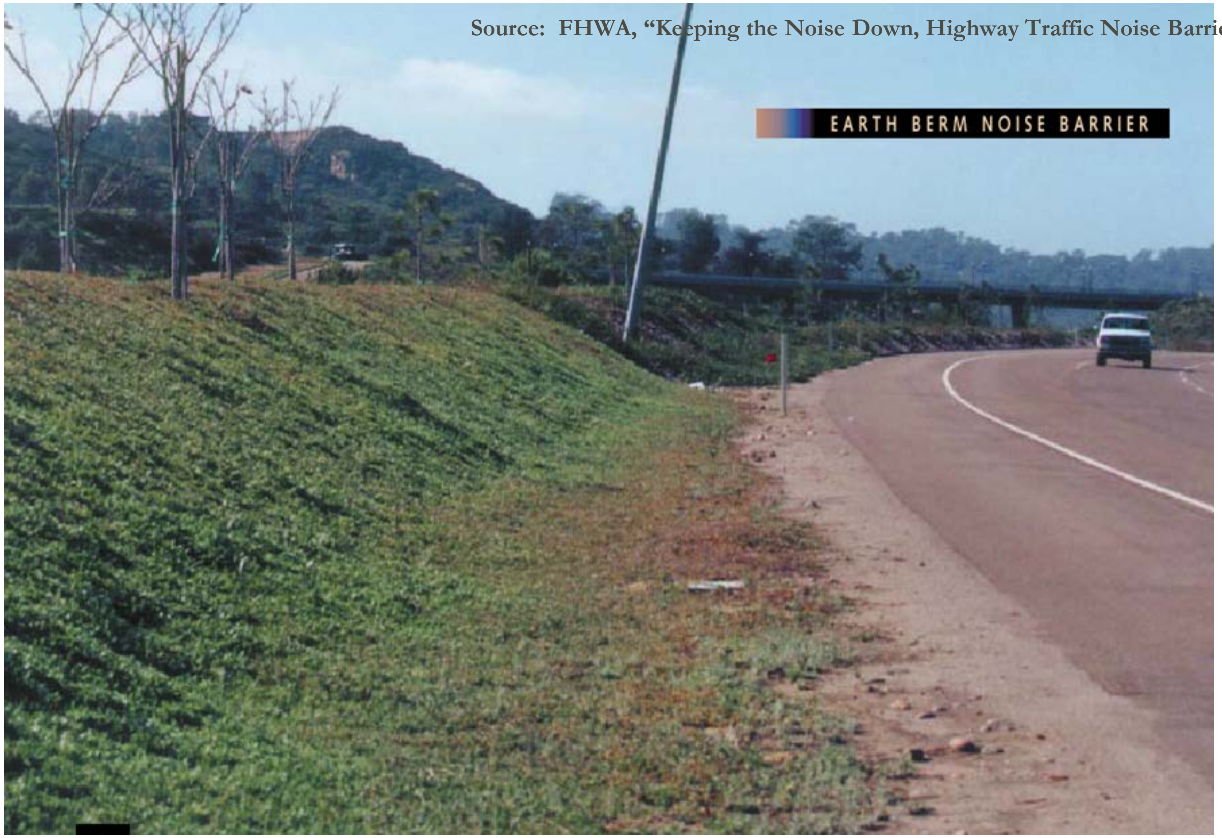


Possible measures:

- The noise source
- Distance
- Barrier / shield
- Sound insulation (facade)
- Sound absorption (inside)

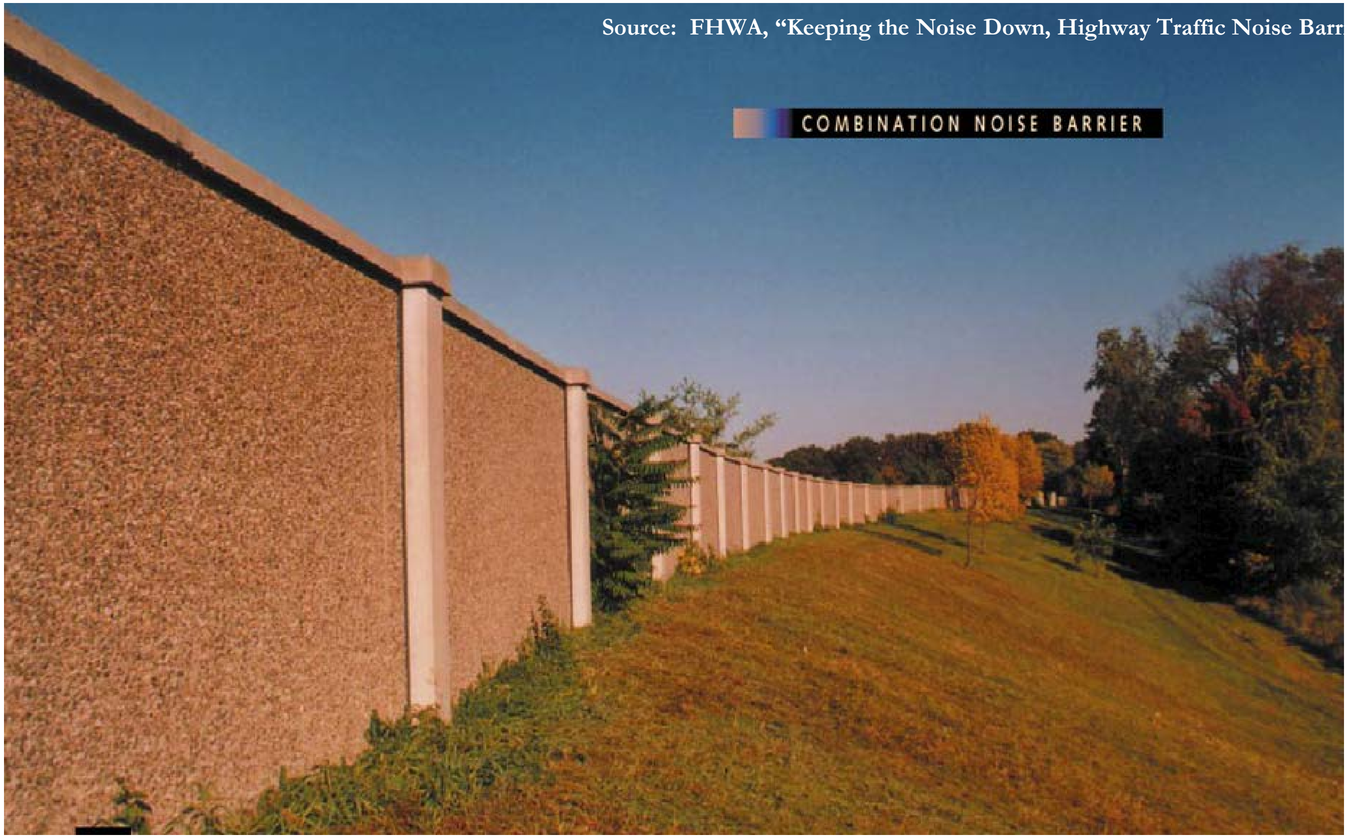
Noise barrier examples

Noise barrier examples



Source: FHWA, "Keeping the Noise Down, Highway Traffic Noise Barriers"

Noise barrier examples



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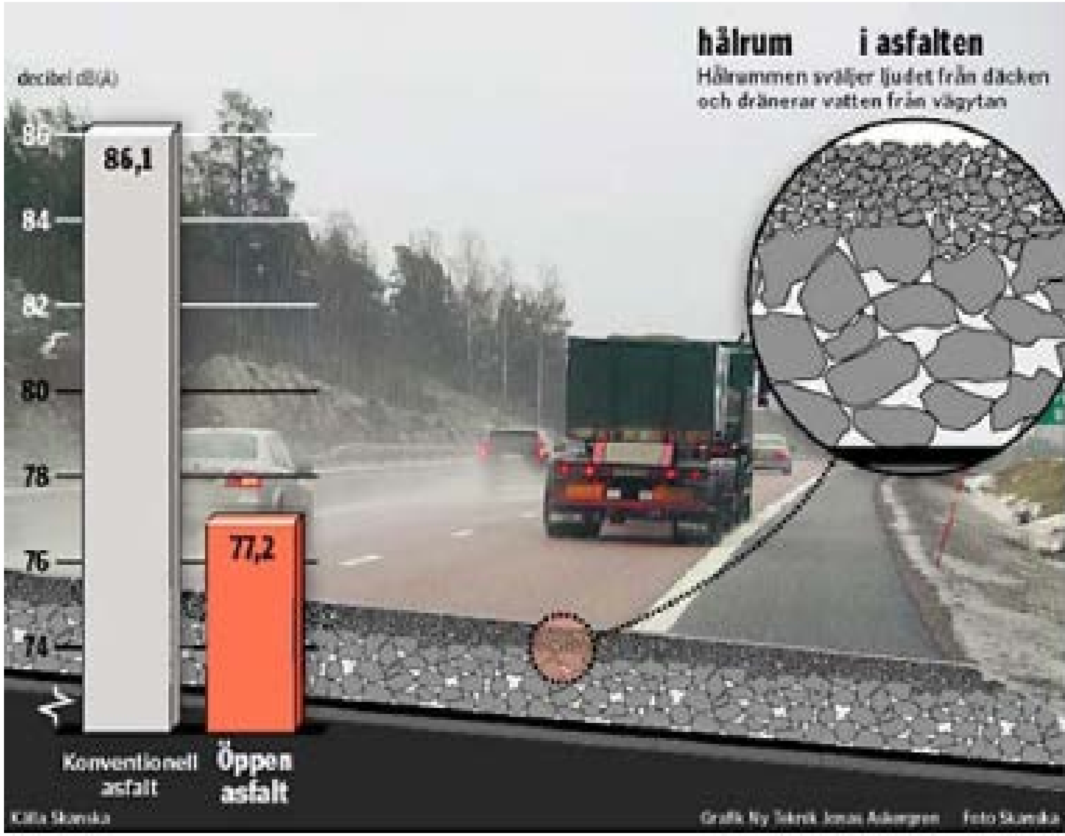
Silent asphalt



Thank you for your attention!

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