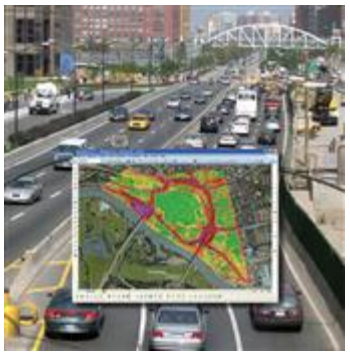
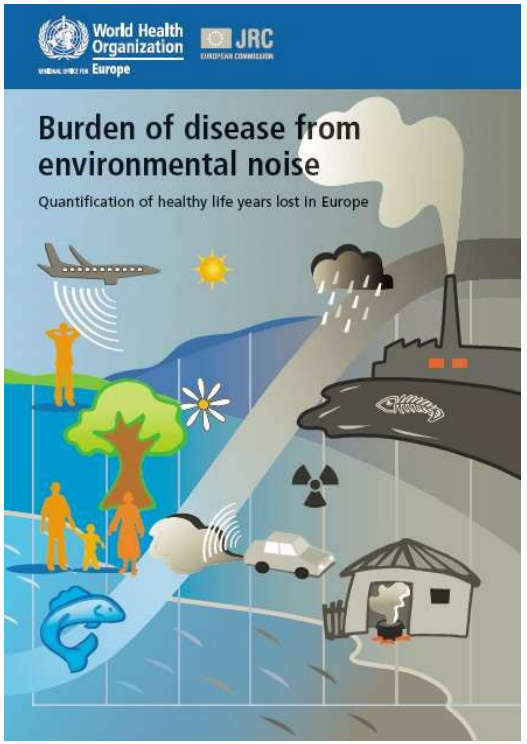
Noise and its effects





Noise

- A noise is a sound that induces annoyance or disagreement, in a more general sense a refusal attitude; each undesired sound is a noise
- A noise is prejudicial to health, corresponding to a state of physical, psychical and social well-being, after the WHO definition
- Main effects of noise are troubles and disturbances of:
  - sleep,
  - entertainment activities, leisure and rest,
  - conversations,
  - professional, intellectual, and manual activities (loss of concentration, lowering of rendement),
  - physiological et psychological (stress, disruption of sociability, agressiveness),
  - audition (auditory damages).

Noise

- annoyance and inconvenience are important long before direct effects on audition, or indirect effect (physiological, psychological) do arise

- It is not always possible to determine strictly medical criteria in view of determining if a noise is admissible or not.

Noise exposure situations

Noise effects are manifold:

- **comfort:**

noise exposure should be limited in order to respect the conditions of comfort for inhabitants, in services locals such as offices, shops, schools, and in transportations.

- **intelligibility and security:**

Instructions, or alarms, shall be heard and understood without any ambiguity in places where noisy activities are happening, in order to ensure peoples' security.

Intelligibility of speech in noise shall be guaranted

- **auditory damages**

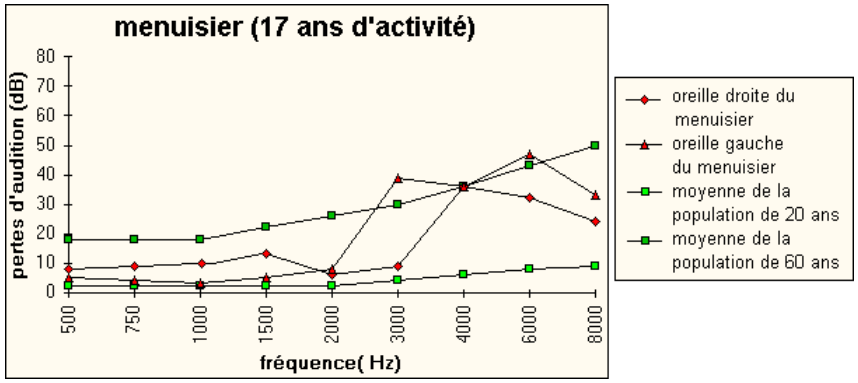
Sustained exposure to intense noises fastens the degradation of hearing.

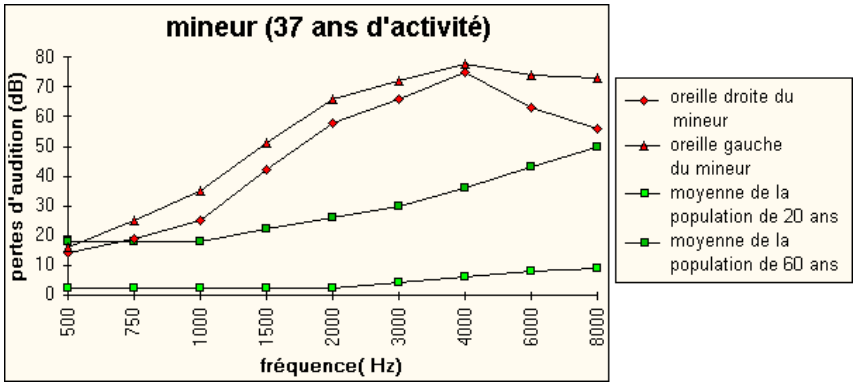
It can decrease the audition, even more induce total deafness. Adverse consequences of an auditory damage are quantified by the *auditory handicap*.

Extreme sound peaks are particularily dangerous, even if the are very fast, because the stapedius reflex does not happen quickly enough (such as shooting and percussions)

Auditory damages

original



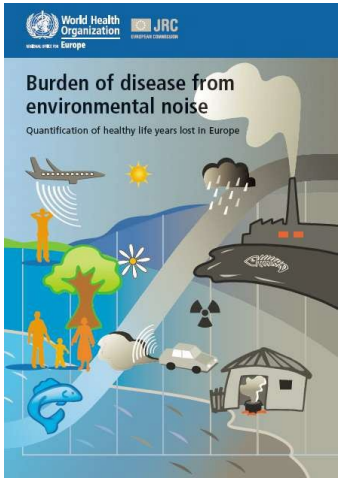


Carpenter's audition

Miner's audition

EPFL

Other health hazards



Certain indirect consequences of noise on health
(not necessarily affecting the hearing).

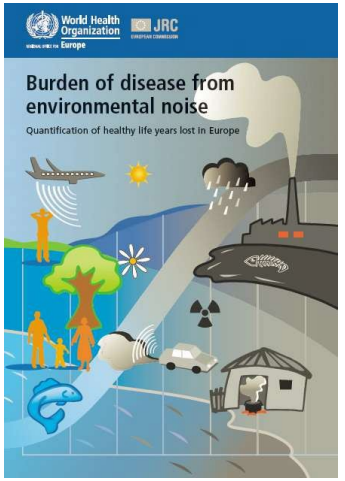
Physiological reactions:

- cardiovascular diseases (vasostriction, acceleration of cardiac rythm, modification of blood pressure, etc.)
- sleep disturbance,
- cognitive impairement (especially on children)
- tinnitus
- annoyance

that happen consecutively to long exposure to high noises, in particular in professional activities.

Some of these effects are mortal ! (Source WHO, *Burden of diesease from environmental noise* : " … at least one million healthy life years are lost every year from traffic-related noise in the western part of Europe")

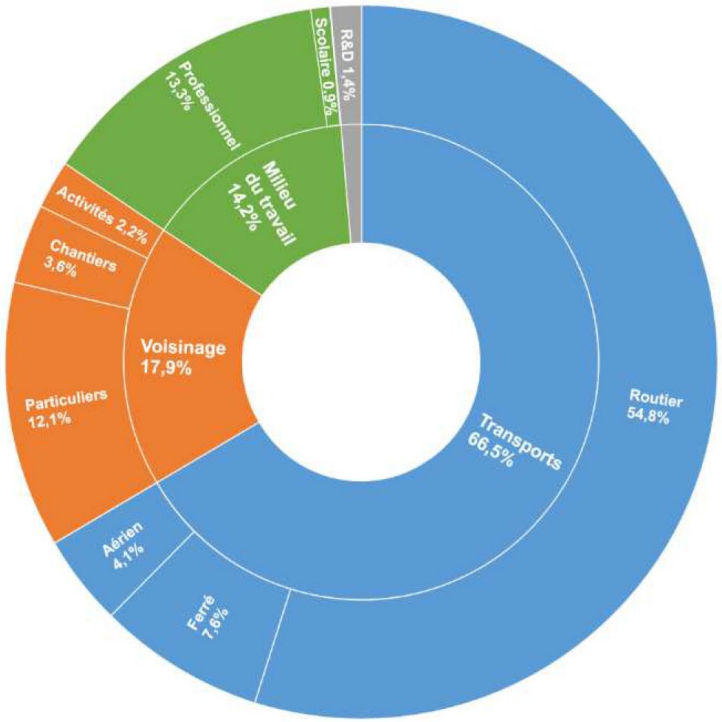
Other health hazards

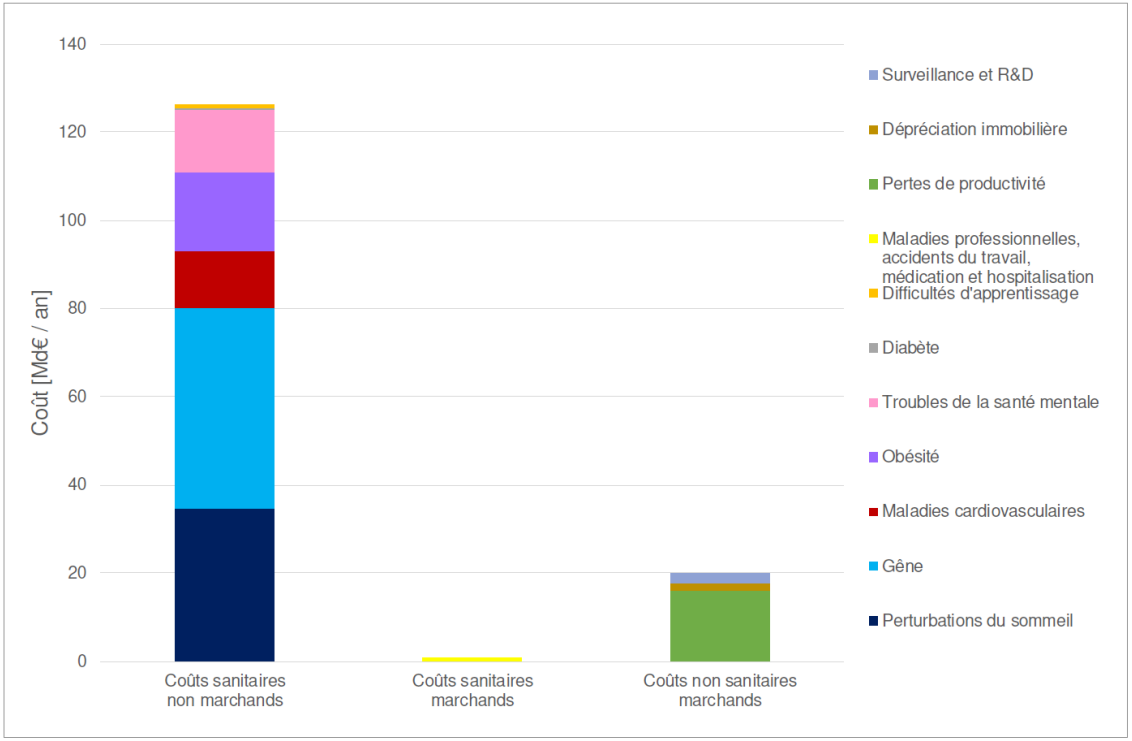


- According to the WHO, noise is the 2nd most important source of health problems
- Noise is a major cause of learning problems for children, sleep disturbance, cardiovascular diseases and mental health issues
  - 910'000 additional prevalent cases of hypertension,
  - 43'000 hospital admissions per year
  - At least 10'000 premature deaths per year related to coronary heart disease and stroke

- 1'700'000 healthy life years are lost every year in western Europe due to noise-related diseases

Social costs of noise

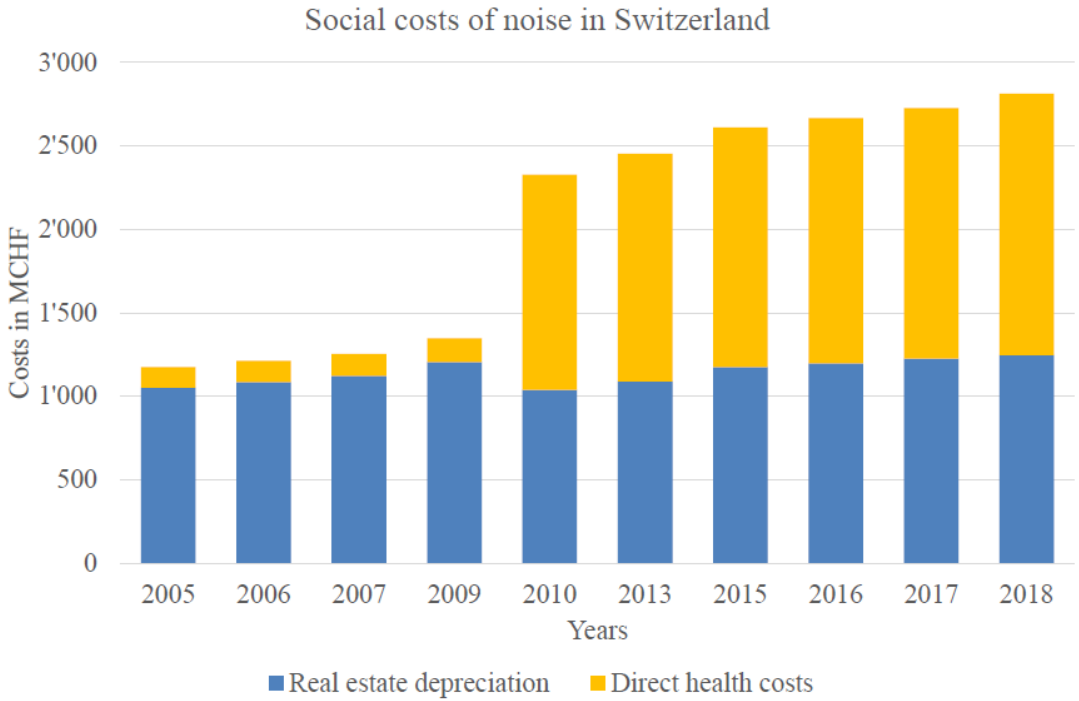




Annual social costs of noise pollution in France (source: ADEME report 10/2021)

The social costs of noise in France are estimated to amount 147,1 B€ per year, among which 97,8 B€ are due to transportation noise (92 B€ of health costs)

Social costs of noise



Source: Federal Office for the Environment, 2018

In Switzerland, the costs associated to mobility noise amount 2,8 billion CHF in 2018 (not accounting for loss of productivity, impact on tourism, etc.).
Health costs represented 1,5 billion CHF in 2018.
Real estate depreciation costs represented 1,3 billion CHF in 2018

Annoyance factors

- Experience shows that the degree of annoyance due to noise mainly depends on the following:
  - loudness
  - spectrum
  - temporal features
  - activities of people
  - moment of the day
  - exposure duration
  - individual behavior

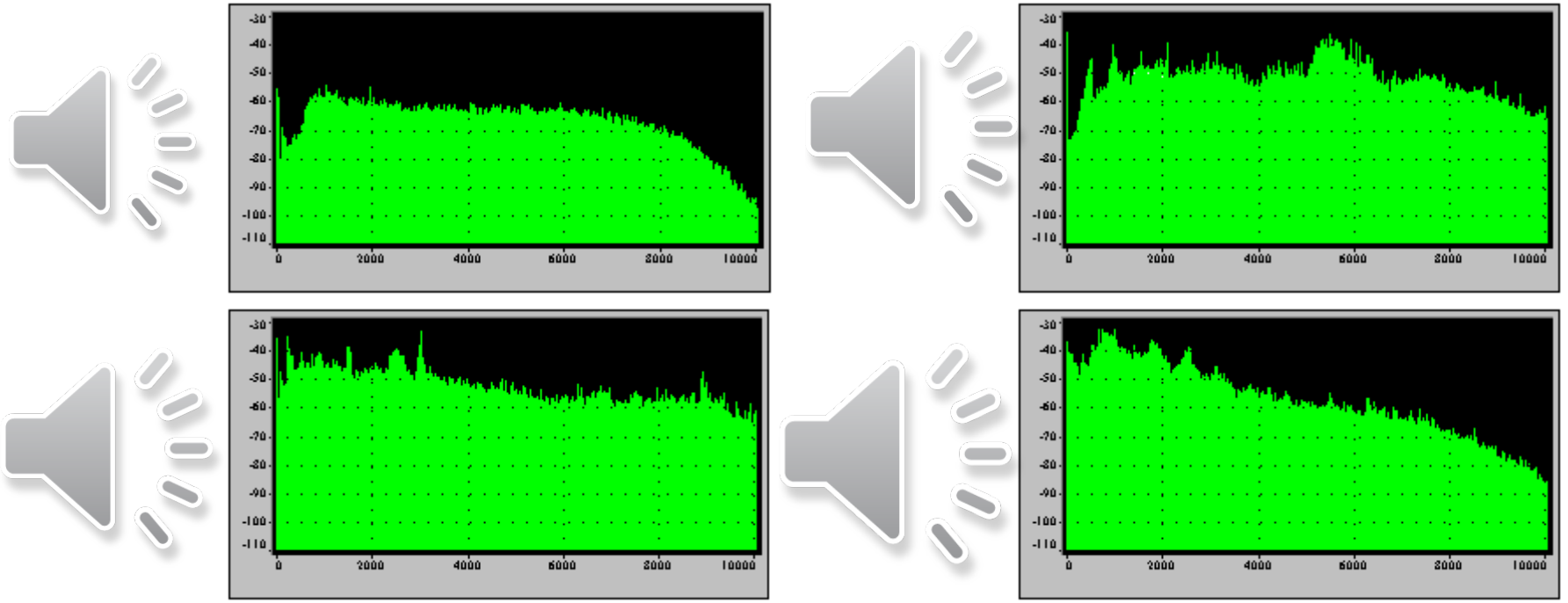
Loudness

- Loudness is the main factor of annoyance.
- In the early days, measurement of noise consisted in determining its loudness.

  It was processed by comparing noise to be assessed to a pure tone at 1000 Hz with variable level. The trained operator estimated the equal loudness point.
- Nowadays we use a sound-level meter

Spectrum

- Spectrum is associated to a certain tone, which can be more or less accepted.
- A noise with neutral tone, such as rain, is well accepted.

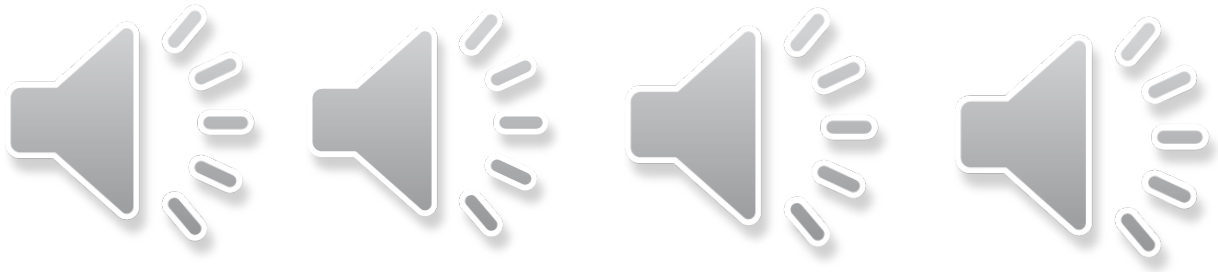


Spectrum

- Spectrum is associated to a certain tone, which can be more or less accepted.
- A noise with neutral tone, such as rain, is well accepted.
- Pure tones are less accepted than musical sound or wideband random sounds.
- More generally, the more the noise has a tonal character, the more annoying it is.
- Creaks and buzzs are particularily unwanted.
- The emergence of pure tones out of a uniform spectrum that is the cause of the annoyance

Temporal character

- Irregular noise, shocks and percussions are more annoying than stable or continous noise (such as rain), especially in case of random rythm.
- The impulse character of these noises accentuates the annoyance.



Activities of people

- After their activities, people subject to noise are more or less annoyed and their reaction more or less important. Ranking these activities by decreasing sensibilities to noise:
  - speech,
  - private sphere activities,
  - social activities,
  - professional intellectual activities,
  - professional manual activities.

Moment of the day

- Corresponding to the rythm of human activities, day is splitted into periods: work, relax, and rest.
- It is therefore natural to introduce criteria of annoyance differing for each moment of the day: early morning, morning, afternoon, evening and night.
- In view of simplification, only 3 (or even 2) moments are considered: day – (evening) – night, with level limits depending on the type of noise.

- Noise index: the « day-evening-night » level (L_{den})

$$L_{den} = 10 \log \frac{1}{24} \left(12.10^{L_{day}/10} + 4.10^{(L_{evening}+5)/10} + 8.10^{(L_{night}+10)/10} \right)$$

Exposure duration

- Total exposure duration is a determining factor with respect to people's perceived annoyance and their reactions.
  - Annoyance induced by construction noise on a period of 2 days is much better accepted than on a period of 2 months.

- In a same way, a noise happening each working day on a short time period
  - For example: a daily half-hour noise is better accepted than a daily 8 hours noise

- Exposure duration is determining for the auditory damages in the frame of professional activities (see Leq, noise dose,…)

Individual behavior

- Psycho-socio-cultural factors condition the individual behavior to a noise source, determining more or less extreme reactions:
  - a biker is not annoyed by the noise of his own vehicle, and is very tolerant with other bikers,
  - a classic-music lover does not accept often rock,
  - old people do not bear childs' shouting.

Noise measurement – evaluation level

- The objective of noise measurement is to determine the annoyance due to the noise:

➔is the measured noise acceptable or not, within the assessed situation?

- In order to qualify the annoyance of a particular situation, and not only the loudness, it is necessary to define specific quantities, to which measurement will be compared

➔ *evaluation level* (incl. correction factors K)

- These quantities are set as a function of indivual reactions, and depend on different criteria such as living environment, type of noise, etc.

Noise measurement – limit values

- The comparison of the *evaluation level* with *limit values*, fixed by guidelines, standards or laws, allows to appreciate the situation and to decide which decision to take.
- For example, the annoyance due to train traffic is the combination of the pass-by noise of one single train, and the number of vehicles in a given period.

Emission and immission limit values

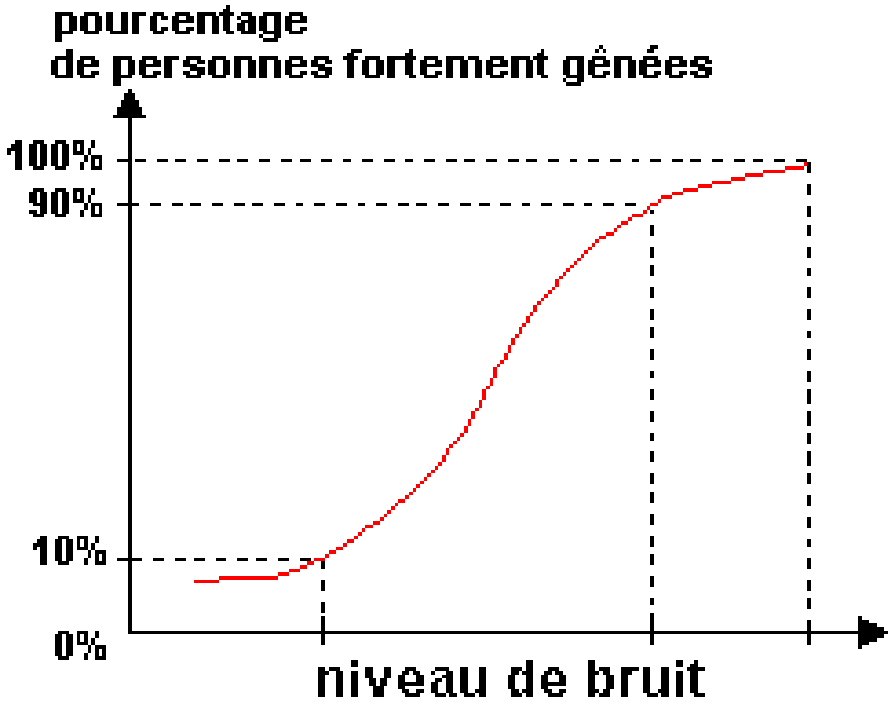
- It is necessary to distinguish limit values:
  - of *emission*, relative to the sources,
  - of *immission*, relative to people exposed to noise.

Setting immission limit values

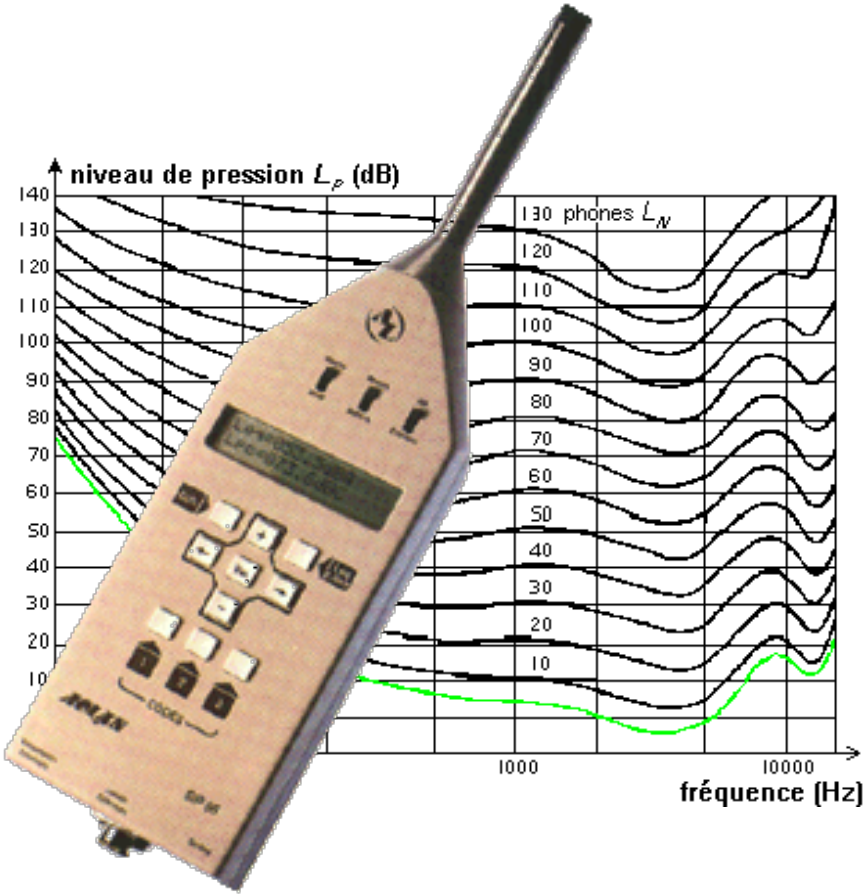
It is mainly based upon the percentage of people that are highly disturbed, as a function of noise levels.

No lower limit value: even low noise are susceptible to highly disturb a small percentage of people.

Above a threshold, the percentage quickly increases with the level, up to a point where everybody's annoyed.



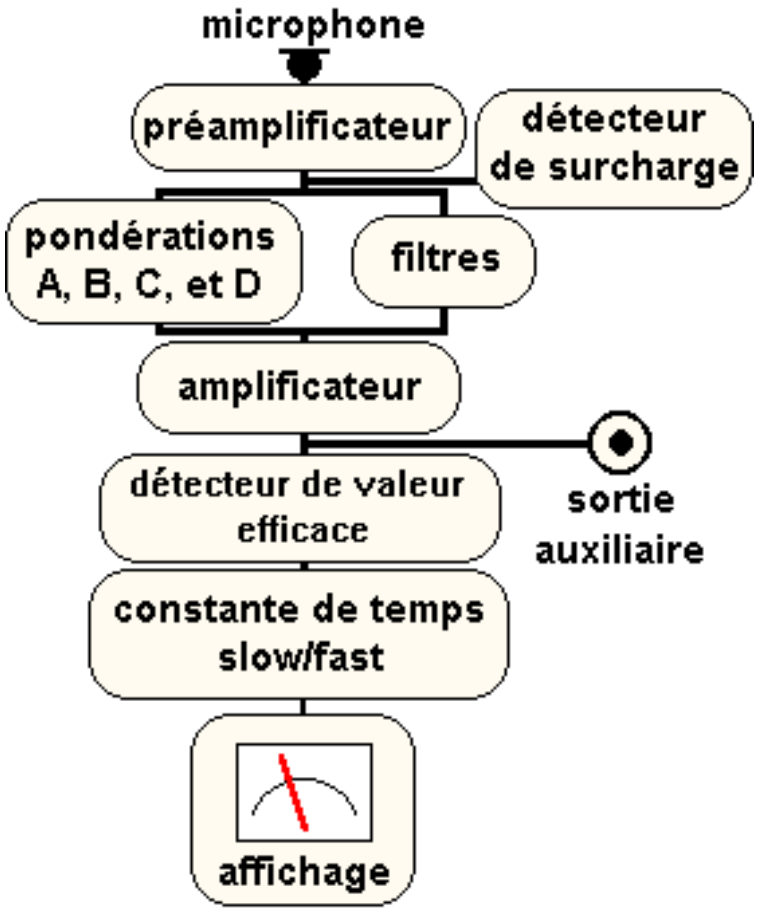
Sound-level meter



- Noise loudness is the main disturbing factor.
- The most straightforward way to evaluate noise annoyance is to assume that it mainly depends on **loudness**.
- Since the early days of noise abatment, the instrumentation to assess loudness has been investigated: the sound-level meter mimics the equal-loudness lines.

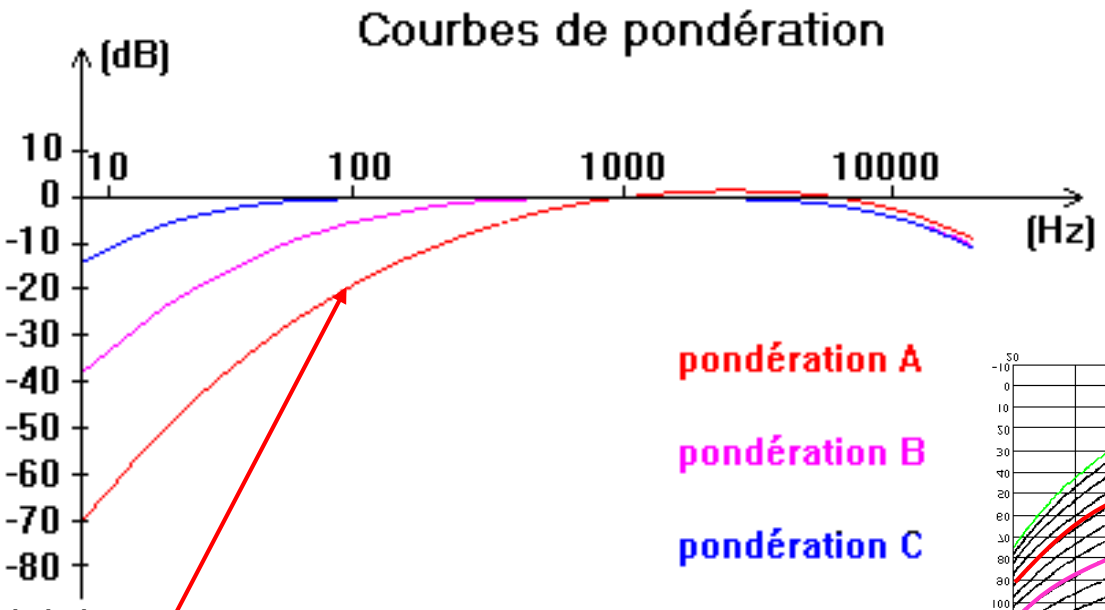
Sound-level meter

- It is an instrument that senses sound pressure, including weighting filters, dedicated to mimic the frequency response of the ear.
- The rms value detector should mimic the temporal behavior of the ear. Temporal weighting are then defined.

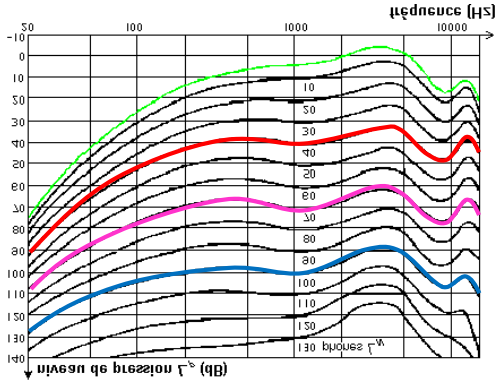


Frequency weighting

The 3 main weightings, A, B and C, correspond more or less to the inverse of the equal-loudness lines 40, 70 and 100 phones



ex: A-weighting:
@ 100 Hz, reduction of 20 dB



A-weighting

In practice, A-weighting is the more used.

The measurement result with A-weightig is a A-weighted sound pressure level, denoted "L_A" or "L(A)" and expressed in A decibels, dB(A).

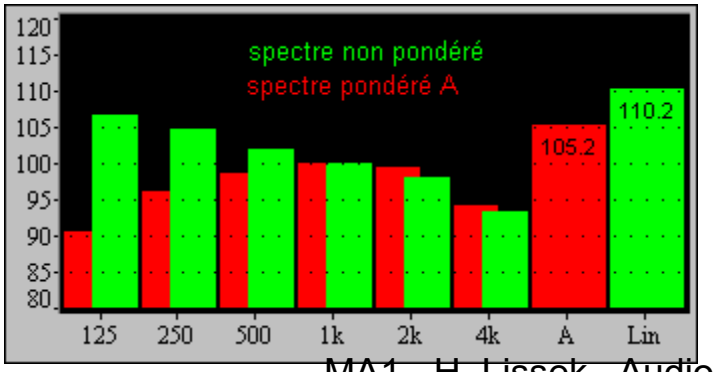
fréquence centrale en octave		63			125			250	
tiers d'octave	50	63	80	100	125	160	200	250	315
pondération (A)	-30.2	-26.2	-22.5	-19.1	-16.1	-13.4	-10.9	-8.6	-6.6

fréquence centrale en octave		500			1000			2000	
tiers d'octave	400	500	630	800	1000	1250	1600	2000	2500
pondération (A)	-4.8	-3.2	-1.9	-0.8	0	0.6	1	1.2	1.3

fréquence centrale en octave		4000			8000	
tiers d'octave	3150	4000	5000	6300	8000	10000
pondération (A)	1.2	1	0.5	-0.1	-1.1	-2.5

Computation of the weighted level

fréquences (Hz)	spectre de bruit rose (dB)	pondération (A)	spectre de bruit rose dB(A)
125	80	-16.1	63.9
250	80	-8.6	71.4
500	80	-3.2	76.8
1000	80	0	80
2000	80	1.2	81.2
4000	80	1	81
niveau résultant somme énergétique	87.8 (dB)		86.25 dB(A)



ambiances sonores	niveau pondéré dB(A)
Petit avion à réaction. Banc d'essai de moteur.	100
Atelier mécanique. Téléphonie difficile.	80
Grand restaurant. Salle bruyante. Trafic urbain.	60
Restaurant calme. Secrétariat.	50
Appartement calme (jour).	40
Chambre sur cour.	30
Studio de radiodiffusion.	20

Temporal weighting

- In order to provide a temporal response of the sound-level meter, similar to the human ear, different temporal weighting of the detector are used:
  - "Fast" F, corresponding to integration constant of 125 ms,
  - "Slow" S, corresponding to integration constant of 1 s,
  - "Impulse" I of time constant of 35 ms for the attack, and 1'500 ms for the release,
  - a peak value detector, with attack time constant from 20 to 40 μs, sustaining the reached value in order to read the sound pressure peaks.

Average energetic level

- When the sound pressure levels show high temporal fluctuations (trafic noise), or high dynamics, an *average energetic level* L_{em} is defined , level of a stable noise of **same A-weighted energy** than the considered noise.

$$L_{em} = 20.\log\left(\frac{\tilde{p}_A}{\tilde{p}_0}\right) = 10.\log\frac{1}{T.\tilde{p}_0^2}\int_{t_1}^{t_2} p_A^2.dt$$

$Pa^2.s$

- It is determined during the observation duration *T*, chosen with respect to temporal fluctuations of the A-weighted level obtained with temporal characteristic F.
- Level of the rms value of the A-weighted sound pressure.

Average energetic level

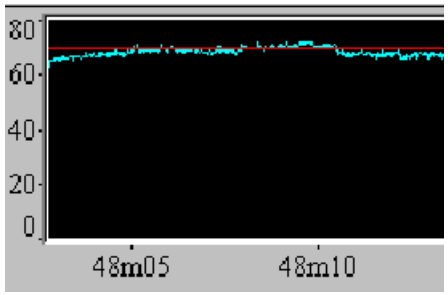
- In practice, we measure L_{em} during n consecutive identical intervals of time – for example 24 periods of 1 hour – and compute the resulting L_{em} :

$$L_{em} = 10.\log\frac{1}{n}\sum_{i=1}^{n}10^{L_{emi}/10}$$

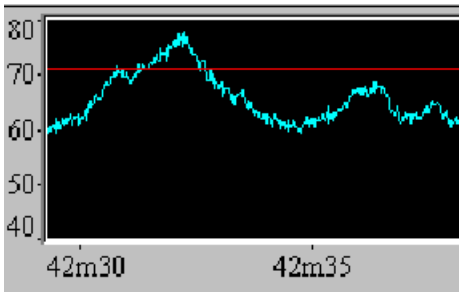
Equivalent level

- Similar to the average energetic level: the *equivalent level* L_{eq} is the level of a stable noise of **same annoyance** than the considered noise.
- The equivalent level has the double advantage of a **simple measurement**, thanks to integrating sound-level meters, and an **immediate computation** of the equivalent level on several consecutive periods of observation.

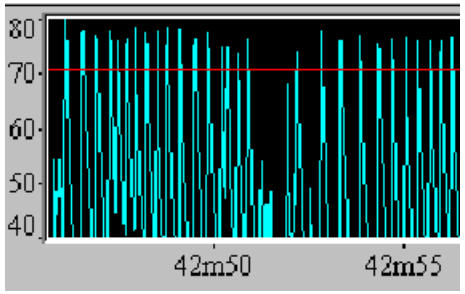
Equivalent level



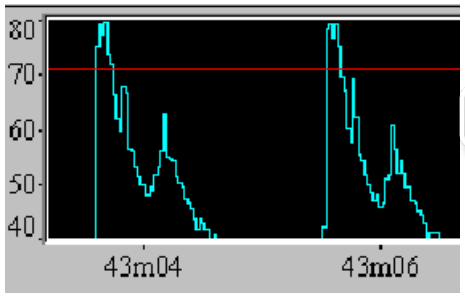
rain



trafic



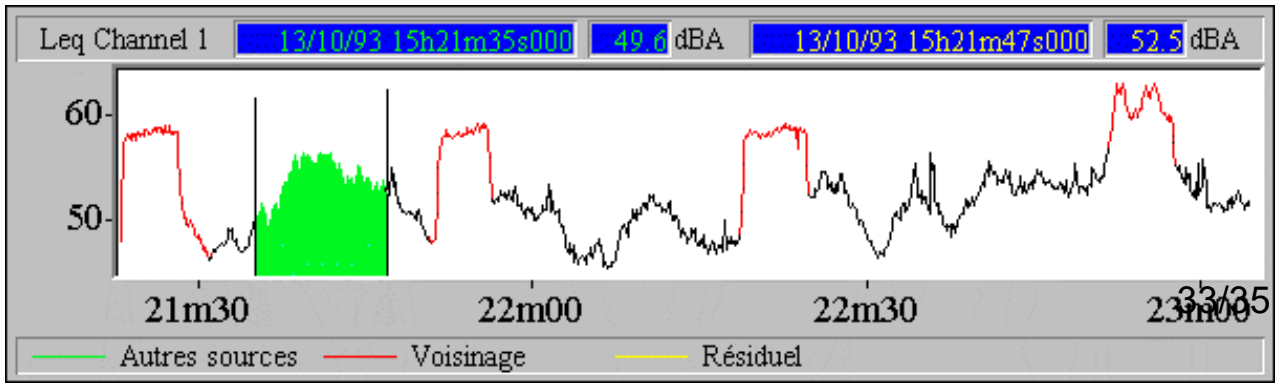
hammering



shoot

Short equivalent level

- It is simply a Leq which observation duration is of the order of a fraction of second up to few seconds.
- The short Leq is used to obtain an accurate repartition of sound events during the measurement duration.
- We can compute the Leq for any duration, after consecutive short Leq's.
- The short Leq method, which is now standardized and used worldwide, has numerous advantages among which:
  - identification and quantification of actual noise sources,
  - computation of Leq for any duration,
  - Statistical computation after bounded and perfectly defined samples



EPFL

Exposure sound level

- The exposure sound level "LAE" (or "LAX") is an equivalent level normalized to a **reference duration** of one second, whatever the actual duration of the measurement.
- In other words, referring to expression of Leq, we always integrate on a duration *T* equal to t_2 - t_1, but dividing by a reference time equal to one second.
- It yields to the relationship:

$$L_{em} = 10.\log \frac{1}{T.\tilde{p}_0^2} \int_{t_1}^{t_2} p_{A,\mathrm{eq}}^2 .dt$$

$$L_{AE} = L_{eq} + 10.\log_{10} T$$

Noise dose

- For assessing exposure to workplace noise, due to risks of auditory damages, both noise level and exposure duration are of importance.
- To account for that, the « *noise dose* » $E_{\mathrm{A,T}}$ has been introduced, as a A-weighted energy during a certain exposure duration.

$$E_{A,T} = \int_{t_1}^{t_2} p_A^2(t)dt$$

- At work, a limit is imposed by the law: the max weekly noise dose should not exceed a value corresponding to an exposure of 40 weekly hours at an equivalent level Leq of 87 dB(A) (28'800 $Pa^2.s$)

$$E_{A,\text{limit for a week of 40 h}} = \underbrace{(20.10^{-6})^2.10^{\frac{87}{10}}}_{p_A^2 \text{ corresponding to 87 dB(A)}} . \underbrace{(40.3600)}_{\text{40 hours in seconds}} = 28800 \text{ Pa}^2.s$$

(or 5'700 $Pa^2.s$ for a working day of 8 hours)

- There exist noise dosimeters – individual instrumentation for noise exposure monitoring – daily or weekly.

Evaluation level

- In order to account that the noise annoyance does not depend only on loudness, we determine an evaluation level ***Lr***, defined as the level of a stable noise, neither an impulsive nor a pure tone, inducing the same annoyance than the considered noise.
- In most of the cases, it can be computed by adding correction factors to Leq – positive or negative – accounting for various annoyance factors.
- In particular, for very irregular noises, with highly tonal character, a correction of +5 dB(A) is added.