8 Noise

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8.1 General aspects

Noise is unwanted sound that causes a nuisance, disruption, impaired performance, specific accident hazards and harm to health. Behind this general definition lies a wide range of impacts that exposure to noise can have on humans, which are classified as either auditory or non-auditory effects.

Auditory effects of noise take the form of temporary hearing loss (also known as temporary threshold shift, TTS) or irreversible damage to hearing following long-term exposure to noise at high sound pressure levels (SPLs) or a single, intense impulse sound (e.g. a bang). The exposed person's subjective perception has no bearing on the auditory effect of the noise.

The term "non-auditory" refers to all of the other effects of noise. Examples include impaired speech intelligibility, diminished concentration and physical reactions such as stress and cardiovascular problems. The non-auditory effects of noise are at least partly linked to the subjective perception of the exposed person.

Workplace noise assessments must cover both the auditory and non-auditory effects. The ordinances and guidelines currently applicable are outlined in Section 8.2.

8.2 Ordinances

Section 3.7 of the Annex to the Arbeitsstättenverordnung (Ordinance on Workplaces) [1] stipulates the following requirements for noise protection in the workplace:

"The sound pressure level (SPL) in workplaces must be kept as low as is possible for the type of organisation concerned. The SPL in workrooms must be reduced, in line with the room use and the tasks to be performed, to a level that does not impair employees' health."

Though worded in general terms, this is a relatively strict workplace design requirement. It places the employer under an obligation to ensure that employees' health is not impaired by noise in any way, using state-of-the-art methods. It is thus particularly aimed at the potential non-auditory effects of noise.

The Lärm- und Vibrations-Arbeitsschutzverordnung (Occupational Health and Safety Ordinance on Noise and Vibrations) of 6 March 2007 [2] stipulates that employers must identify and evaluate the workplace noise exposure as part of their risk assessment. To protect employees from noise hazards and thus the auditory effects of noise, the ordinance cites action values for the daily noise exposure level and the peak SPL. It also gives maximum permissible exposure values, which relate to the noise level under hearing protectors and must not be exceeded under any circumstance.

Neither the Occupational Health and Safety Ordinance on Noise and Vibrations nor the associated technical rules [3] are expanded on in the following as they merely outline the steps to be taken to provide protection against the auditory effects of noise if the lower exposure action value of $L_{EX,8h}$ = 80 dB(A) is exceeded. This is unlikely to happen in indoor workplaces.

8.3 Non-auditory effects of noise

Non-auditory, i.e. physiological, vegetative and psychological, effects of noise impact upon employees' health, safety and performance in the following ways:

- Noise affects the central nervous system and triggers physiological responses. Depending on the intensity, duration and frequency levels of the noise exposure and the individual's disposition, these responses can lead to noise-stress reactions. The consequences include, for example:
  - narrowing of blood vessels,
  - increase in blood pressure,
  - increase in heart rate,
  - reduction in electrical skin conductance,
  - acute increase in muscle tone,
  - increased release of stress hormones,
  - decrease in stomach and intestinal activity,
  - restriction of field of vision and
  - delayed signal processing in the brain.
- Noise can trigger psychological reactions such as
  - irritation,
  - tension,
  - resignation,
  - fear and
  - nervousness.
- Furthermore, noise can
  - reduce attentiveness and concentration,
  - impair voice communication and thus cause misunderstandings, leading to incorrect decisions,
  - increase error rates and
  - decrease responsiveness.

Since such non-auditory noise effects cannot be assumed to be subject to a simple dose-effect relationship, the daily noise exposure level is not a suitable means of assessing them.

8.4 Parameter and guide values for non-auditory effects of sounds in the workplace

The rating level defined in DIN 45645 [4] is commonly used as the parameter for assessing the non-auditory effect of sounds in the workplace. The rating level is composed of the equivalent continuous sound exposure level L_{pAeq} of the activity being assessed plus any necessary adjustments for the degree of the impulse and the tonality and information content of the sound. It is calculated as shown in equation (1)

$$L_r = L_{pAeq} + K_I + K_T \quad (1)$$

where

L_r: Rating level

L_{pAeq}: Equivalent continuous sound exposure level

K_I: Adjustment for degree of the impulse

K_T: Adjustment for tonality and information content

The following preconditions must be considered when conducting the assessment:

- activities that occur during a single shift and pose different requirements must be assessed separately;
- work sub-intervals with significantly different sound exposures must be assessed separately if the phase lasts at least one hour;
- inherent sounds, such as a person's own voice, the voice of the person they are talking to, the ringing of a person's own telephone or the sound of a person's own typing must be blocked out;
- an adjustment of up to 6 dB maximum must be applied for the degree of the impulse where impulsive sound is subjectively perceived as an annoyance and the degree of the impulse is at least 3 dB;
- an adjustment of 3 dB or 6 dB can be applied for the tonality and information content depending on how extreme they are; and
- the total adjustments must not exceed 6 dB.

The rating level therefore differs from the daily noise exposure level in that the latter refers to the total exposure during an eight-hour shift and does not include any adjustments.

In addition to the above-mentioned influencing parameters, which can be measured acoustically, the Guideline VDI 2058, Part 3 [5] also cites the non-measurable factors listed in Table 12 for use in sound assessment.

The activity-specific requirements listed in Table 12 are the essential characteristics in determining the rating level that can reasonably be applied to a given workplace. The Guideline VDI 2058, Part 3 distinguishes between three level ranges with rating levels of

- 55 dB(A) maximum,
- 70 dB(A) maximum and
- more than 70 dB(A)

and assigns them to the following three activity-based categories:

Table 12:
Acoustically non-measurable factors in the assessment of the non-auditory effect of sound [6]

Person-specific factors	• Attitude towards sound or sound source • Attitude towards activity • Amount of practice/experience • Physical and psychological prerequisites (e.g. state of health or potential to cope with stress)
Activity-specific factors	• Attentiveness and concentration requirements • Memory • Ability to learn • Responsiveness • Stamina • Creativity • Voice communication
Other factors	• Prominence of the sound • Usualness of the sound in the given location • Preventability of the sound • Spatial change in the acoustic source

- *Predominantly mental activities – rating level 55 dB(A) maximum*

  These are highly complex activities requiring creative thinking, far-reaching decisions, problem-solving and good speech intelligibility, e.g.

  – meetings or teaching activities,
  – scientific work or software development,
  – medical investigations or operations and
  – drafting, translation or correction of demanding texts.

- *Simple or predominantly automated office activities and similar activities – rating level 70 dB(A) maximum*

  These are well-practised office activities and activities of medium complexity, requiring moderate or temporary concentration/strain and a satisfactory level of speech intelligibility, or activities involving similar, repetitive tasks, e.g.

  – communicative activities, e.g. in a call centre,
  – surveillance and controlling activities, e.g. at a control centre,
  – testing and monitoring activities,
  – serving customers or selling and
  – difficult, precision assembly activities.

- *Rating level higher than 70 dB(A)*

  Where the rating level is higher than 70 dB(A), only low-complexity activities should be carried out. These are activities requiring only low or brief concentration/strain and a low level of speech intelligibility. They are mainly routine tasks or activities with repetitive content, e.g.

  – technical and industrial tasks,
  – work using production machinery and
  – repair and maintenance of technical equipment.

8.5 Guidance on performing measurements

As a rule, the rating level should be determined at the specific workplace of the person exposed to the sound. The measurements are taken at ear height, without the person being present if possible. Ear height is defined as

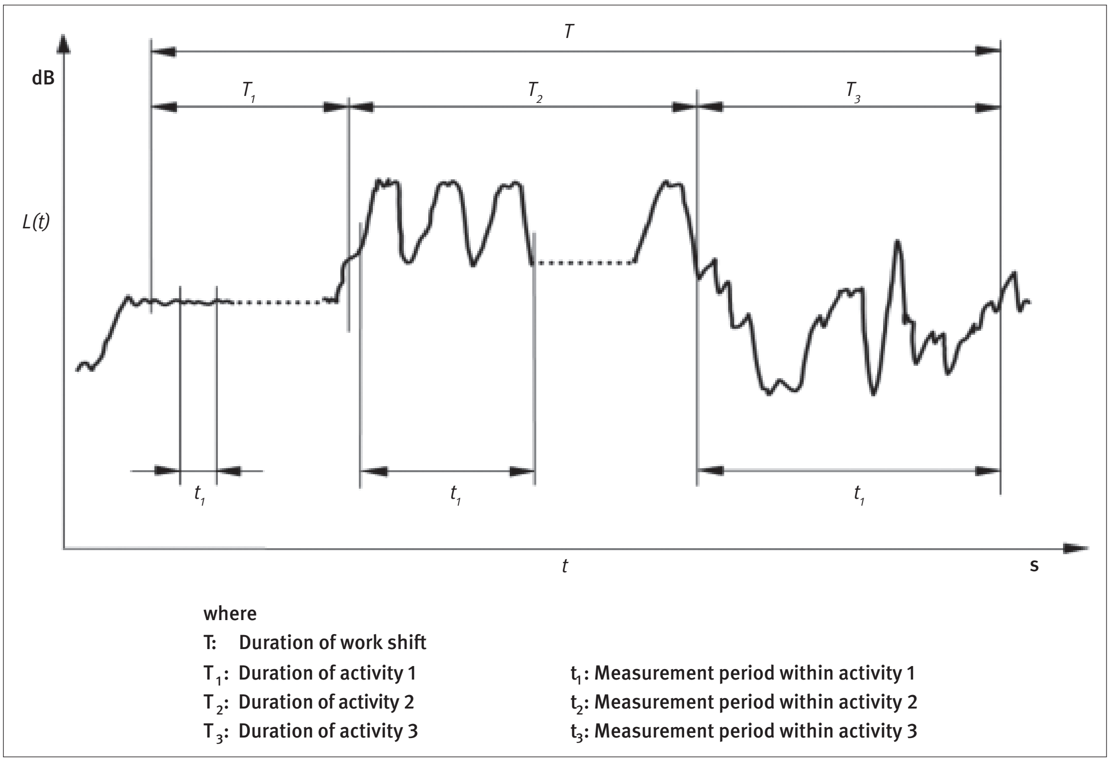
- for standing persons: 155 cm above the surface on which they stand
- for seated persons: 80 cm above the surface on which they sit

As far as possible, the microphone should point in the direction in which the person faces at their workplace. If the employee has to be present at their workplace during the measurement, the microphone should be positioned at their ear height (at a distance of 0.1 to 0.4 m from the ear) in such a way as to ensure the employee's body does not impede the microphone's exposure to the sound.

The measurements are performed using sound level meters of DIN EN 61672-1 [7] accuracy class 1 or 2, preferably the former. Where class 2 meters are used, a measurement uncertainty of ±3.0 dB(A) must be applied (see also Section 8.7, "Measurement uncertainty").

It is usually not necessary for the rating level to be determined by measuring sound levels throughout the entire period of exposure. If the averaging time (working time) can be split into subintervals that have their own typical sound, suitable periods can be defined for measuring the sound exposure for each period. A measurement period of approximately 20 seconds can suffice in the case of constant sounds. For periodic processes, the measurement period should last for at least one typical sound cycle (see Figure 10, page 48).

Figure 10:
Breakdown of a work shift into several sub-intervals with selected measurement periods as examples, based on DIN EN ISO 9612 [8]



8.6 Calculating the rating level based on measurements for sub-intervals

Rating level L_r [4] is calculated based on the A-weighted equivalent continuous sound exposure levels $L_{eq,m}$, determined for the individual sub-intervals T_m including any adjustments and the sub-interval lengths T_m in accordance with equation (2).

$$L_r = 10 \lg \left(\frac{1}{T} \sum_{m=1}^{M} T_m \cdot 10^{0,1 \cdot L_{p,m}} \right) \text{ dB(A)} \qquad (2)$$

where

$$L_{p,m} = L_{pAeq,m} + K_I + K_T$$

A-weighted equivalent continuous sound exposure level $L_{pAeq,m}$ for sub-interval m plus the adjustments for the degree of the impulse and tonality and information content

and

T_m: time interval of sub-interval m

T: time period of all sub-intervals T_m

M: total number of m sub-intervals

If the individual sub-intervals are calculated as a percentage of the overall duration of the activity concerned, equation (3) can be used as an alternative method of calculating the rating level

$$L_r = 10 \lg \left(\sum_{m=1}^{M} \frac{x_m}{100} \cdot 10^{0,1 \cdot L_{p,m}} \right) \text{ dB(A)} \qquad (3)$$

where

$$L_{p,m} = L_{pAeq,m} + K_I + K_T$$

A-weighted equivalent continuous sound exposure level $L_{pAeq,m}$ for sub-interval m plus the adjustments for the degree of the impulse and adjustment for tonality and information content

and

x_m: sub-interval m as a percentage of the overall duration of the activity, T

M: total number of m sub-intervals

8.7 Measurement uncertainty

As mentioned in Section 8.5, a measurement uncertainty factor must be included when determining the rating level. This factor depends both on the quality of the measuring equipment used (accuracy class) and the quality of the measurement (representativeness). Measurement uncertainty is particularly important when rating levels are close to prescribed sound level values (e.g. guide values given in VDI 2058, Part 3 [5]) because it determines whether it is possible to say that the actual values are higher or lower than the guide values.

DIN 45645-2 [4] lays down the following methods for simplifying the process of comparing values with prescribed sound level values and establishing a convention for doing so:

a) The calculated rating level is compared directly with the prescribed sound level value, i.e. an uncertainty factor of 0 dB is applied for the comparison, if

- *a class 1 sound level meter was used and*
- *the uncertainty during the measurement of the typical long-term (representative) sound exposure during the activity can be estimated as lower than 3 dB.*

b) An uncertainty factor of 3 dB is applied to the calculated rating level when comparing it with the prescribed sound level value if

- *a class 2 sound level meter was used and/or*
- *the uncertainty during the measurement of the typical long-term (representative) sound exposure during the activity can be estimated as lower than 6 dB.*

If an uncertainty factor of 0 dB can be achieved, as in case a), it is possible to decide with certainty whether the prescribed sound level value is complied with.

If it is only possible to achieve an uncertainty factor of 3 dB, as in case b), the prescribed sound level value must be checked to determine whether it is lower than, within or higher than the level range described by the uncertainty factor determined (L_r – 3 dB) to (L_r + 3 dB) when comparing the calculated rating level with prescribed sound level values.

If the prescribed sound level value is lower than this level range, the allowance is exceeded; if the prescribed sound level value is higher than the level range, it goes below allowance. If the prescribed sound level value is within the limit range, it is not possible to decide with certainty.

8.8 Noise in educational establishments

Implementing the assessment method presented here in educational establishments is not always a simple matter. It is sometimes difficult to block out inherent noise because, for example, teachers' own voices and their communication with the pupils need to be blocked out in order to assess teachers' noise exposure during lessons. In these cases, it can be difficult or even impossible to draw a clear distinction between inherent and extraneous noise. The procedure is simpler in teaching set-ups in which various groups work separately within one classroom. In such cases, measurements would have to be taken at a table that was not being used in order to assess the sound level generated by the other groups.

Besides noise exposure, another key criterion in educational establishments is speech intelligibility. If the reverberation times for a room are too long, intelligibility will be greatly impaired, which is why reverberation time is also an important factor when assessing rooms in educational establishments. The main requirements in this respect are set out in DIN 18041, "Hörsamkeit in kleinen bis mittelgroßen Räumen" (Acoustical quality in small to medium-sized rooms) [9]. For teaching situations in rooms with a volume of approximately 200 to 250 m³, the standard recommends a reverberation time of 0.5 to 0.6 seconds maximum when the rooms are occupied. In unoccupied rooms, the recommendation is that the reverberation time should not be more than 0.2 seconds higher than for occupied rooms. If rooms are to be used by people with impaired hearing, the recommendation is that the reverberation time should be reduced by up to 20%.

8.9 Room acoustic measures

Reflection on rooms' boundary surfaces (ceilings, walls and floors) reinforces sound. The extent of that reinforcement greatly depends on the size of the room and the nature of the room's boundary surfaces. Hard, solid surfaces (such as concrete, brick, glass or wood) reflect sound to a considerable extent. Porous materials (such as mineral fibre and acoustic foam panels and numerous special acoustic materials) absorb the sound and thus prevent up to 100% of the reflection. Equipping rooms with sound-absorbing materials such as these reduces employees' noise exposure and also decreases the reverberation time.

A brochure produced by the German Social Accident Insurance Institution for the administrative sector, entitled "Akustik im Büro" (Office acoustics) [10], provides detailed information on how to ensure good acoustics in office rooms and the results that can be achieved using different measures.

8.10 References

[1] Verordnung über Arbeitsstätten (Arbeitsstättenverordnung – ArbStättV) vom 12. August 2004. BGBI. I (2004), p. 2179-2189; last revision BGBl. I (2010), S. 960-967

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[3] Technische Regeln zur Lärm- und Vibrations-Arbeitsschutzverordnung: Lärm (TRLV Lärm). GMBl. (2010) No. 18-20, p. 359-405

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[5] VDI 2058 Blatt 3: Beurteilung von Lärm am Arbeitsplatz unter Berücksichtigung unterschiedlicher Tätigkeiten (02.99). Beuth, Berlin 1999

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[8] DIN EN ISO 9612: Akustik – Bestimmung der Lärmexposition am Arbeitsplatz – Verfahren der Genauigkeitsklasse 2 (Ingeneurverfahren) (09.09). Beuth, Berlin 2009

[9] DIN 18041: Hörsamkeit in kleinen bis mittelgroßen Räumen (05.04). Beuth, Berlin 2004

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Further reading

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