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Acoustics — Guidelines for noise control by enclosures and cabins

Acoustique — Lignes directrices pour la réduction du bruit au moyen d'encoffrements et de cabines

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 3.

Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this International Standard may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

International Standard ISO 15667 was prepared by Technical Committee ISO/TC 43, *Acoustics*, Subcommittee SC 1, *Noise*.

Annexes A and B of this International Standard are for information only.

Introduction

Acoustic enclosures and cabins provide a reduction of airborne sound on the propagation path from the machine (or a set of machines) to nearby work stations or to the environment. This International Standard describes criteria which determine the acoustic performance of enclosures and cabins with consideration of operational aspects.

Acoustics — Guidelines for noise control by enclosures and cabins

1 Scope

This International Standard deals with the performance of enclosures and cabins designed for noise control. It outlines the acoustical and operational requirements which are to be agreed upon between the supplier or manufacturer and the user of such enclosures and cabins. This International Standard is applicable to two types of acoustic enclosures and cabins, as follows.

a) Cabins for noise protection of operators: free-standing cabins and cabins attached to machines (e.g. vehicles, cranes).

b) Free-standing enclosures covering or housing machines: enclosures with a fraction of acoustically untreated open area of less than 10 % of the total surface are the main subject of this International Standard.

In this International Standard, emphasis is put on lightweight constructions. However, thick, massive structures as, for example, brick walls, are not excluded.

Enclosures and cabins with more than 10 % open and untreated area belong to the category of partial enclosures. They are not the subject of this International Standard.

A third type of enclosure, integrated enclosures which form a part of the machine and are firmly attached to it, is not the subject of this International Standard.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this International Standard. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies. Members of ISO and IEC maintain registers of currently valid International Standards.

ISO 140-3, *Acoustics — Measurement of sound insulation in buildings and of building elements — Part 3: Laboratory measurements of airborne sound insulation of building elements*.

ISO 717-1, *Acoustics — Rating of sound insulation in buildings and of building elements — Part 1: Airborne sound insulation.*

ISO 3740 series, *Acoustics — Determination of sound power levels of noise sources using sound pressure*.

ISO 9614 (all parts), *Acoustics — Determination of sound power levels of noise sources using sound intensity*.

ISO 11200 series, *Acoustics — Noise emitted by machinery and equipment.*

ISO 11546-1:1995, *Acoustics — Determination of sound insulation performance of enclosures — Part 1: Measurements under laboratory conditions (for declaration purposes)*.

ISO 11546-2:1995, *Acoustics — Determination of sound insulation performance of enclosures — Part 2: Measurements* in situ *(for acceptance and verification purposes)*.

ISO 11957:1996, *Acoustics — Determination of sound insulation performance of sound protecting cabins — Laboratory and* in situ *measurements*.

ISO 14163, *Acoustics — Guidelines for noise control by silencers*.

3 Terms and definitions

For the purposes of this International Standard, the following terms and definitions apply.

3.1
enclosure
structure covering or housing a sound source (machine) for protection of the environment from this sound source (machine)

NOTE The shape may be box-like or follow the contour of machine parts. Box-shaped enclosures consist of walls and a roof. The enclosure may have openings for doors, windows, ventilation, material flow, etc.; see Figure 4.

3.2
cabin
construction specially designed for the protection of human beings (e.g. machine operators) from environmental noise, consisting of a fully enveloping structure

NOTE 1 Adapted from ISO 11957:1996.

NOTE 2 A floor is not always a component of the cabin.

3.3
sound power insulation of the enclosure
insertion loss of the enclosure
D_W
difference between the levels of the sound powers emitted from the sound source (machine) with and without the enclosure, in one-third-octave bands or octave bands, measured according to ISO 11546-1 or ISO 11546-2

NOTE 1 The sound power insulation (or insertion loss) is expressed in decibels, dB.

NOTE 2 This spectrum of values is useful for general planning of environmental noise control for locations at some distance from the source, e.g. in the reverberant field of an industrial hall or in the neighbourhood of a plant.

3.4
weighted sound power insulation of the enclosure
$D_{W,\mathrm{w}}$
single-number value determined in accordance with the method stated in ISO 717-1, except that the sound reduction index (or transmission loss) is replaced by the insertion loss, D_W

NOTE 1 The weighted sound power insulation is expressed in decibels, dB.

NOTE 2 The single-number value is useful for a rough comparison of different enclosures and for general acoustical planning inside buildings without detailed knowledge of the source spectrum.

NOTE 3 Adapted from ISO 11546-2:1995.

3.5
panel transmission loss
R
sound reduction index (or transmission loss) of individual panels from which the enclosure is made, in accordance with ISO 140-3

NOTE 1 The panel transmission loss is expressed in decibels, dB.

NOTE 2 In a limited range of medium frequencies (typically 250 Hz to 1 000 Hz), the insertion loss, D_W, of a completely sealed enclosure is approximately related to the panel transmission loss, R, by

$$D_W \approx R + 10 \lg(\alpha) \text{ dB} \quad (1)$$

where α denotes the average absorption coefficient of the internal side of the panels. While spectral information on R and α is often provided, the relation (1) primarily gives an upper limit and is not a reliable foundation for predicting the actual insertion loss, D_W. Leakages, insufficiently acoustically treated openings, and flanking transmission of structure-borne sound result in smaller values of the actual insertion loss.

NOTE 3 For measurements of the airborne sound insulation of small building elements with openings, see ISO 140-10 [11].

3.6 Sound pressure insulation, D_p

3.6.1
sound pressure insulation for enclosures
D_p
difference between the levels of the sound pressures at a specified position with and without an enclosure, in one-third-octave bands or octave bands

NOTE 1 The sound pressure insulation is expressed in decibels, dB.

NOTE 2 This spectrum of values is useful for the detailed analysis of the acoustic performance of an enclosure in different directions.

NOTE 3 For measurements of the sound pressure insulation of an enclosure, see ISO 11546-1 and ISO 11546-2.

3.6.2
sound pressure insulation for cabins
D_p
difference between the levels of the sound pressures in an external diffuse sound field and in a cabin located in this field, in one-third-octave bands or octave bands

NOTE 1 The sound pressure insulation is expressed in decibels, dB.

NOTE 2 For measurements of the sound pressure insulation of a cabin see ISO 11957.

NOTE 3 Adapted from ISO 11957:1996.

3.7
apparent sound pressure insulation of a cabin
D'_p
difference between the levels of the sound pressures in a room with arbitrary sound field distribution and in a cabin located in the room, in one-third-octave bands or octave bands

NOTE 1 The apparent sound pressure insulation of a cabin is expressed in decibels, dB.

NOTE 2 The sound field in the room may not necessarily be diffuse.

NOTE 3 For measurements of the apparent sound pressure insulation of an enclosure, see ISO 11957.

NOTE 4 Adapted from ISO 11957:1996.

3.8
A-weighted sound pressure insulation
D_{pA}
single-number value determined for the actual sound source spectrum, describing the reduction in the A-weighted sound pressure level at a specified position due to the enclosure or in a cabin located in a diffuse sound field

NOTE 1 The A-weighted sound pressure insulation is expressed in decibels, dB.

NOTE 2 This single-number value is most relevant for describing the actual acoustic performance of an enclosure for a particular machine, e.g. at a distance of 1 m from a machine enclosure or at any position inside a cabin.

3.9
estimated noise insulation due to the enclosure
$D_{pA,e}$
single-number value determined for a specific sound source spectrum, describing the reduction in the A-weighted sound pressure level at a specified position due to the enclosure

NOTE 1 The estimated noise insulation due to the enclosure is expressed in decibels, dB.

NOTE 2 This single-number value is most relevant for estimating the acoustic performance of an enclosure without detailed knowledge about the source spectrum.

3.10
leak ratio
θ
ratio between the area of all acoustically untreated openings of the enclosure and the total interior surface area of the enclosure (including openings)

NOTE Adapted from ISO 11546-1:1995 and ISO 11546-2:1995.

4 General principles and operational considerations

4.1 Sound source

The sound source (or sources) to be acoustically treated by an enclosure shall be clearly identified. The radiated airborne sound shall be measured according to the relevant International Standards of the ISO 3740, ISO 9614 or ISO 11200 series.

The provision of an enclosure will result in a build-up of internal heat. Air-moving devices and auxiliary equipment supplied with the enclosure for removing the heat and for air-conditioning shall be considered as additional sound sources.

4.2 Sound propagation paths

Several paths of sound propagation from a sound source in an enclosure to the environment can be grouped into four categories as shown in Figure 1.

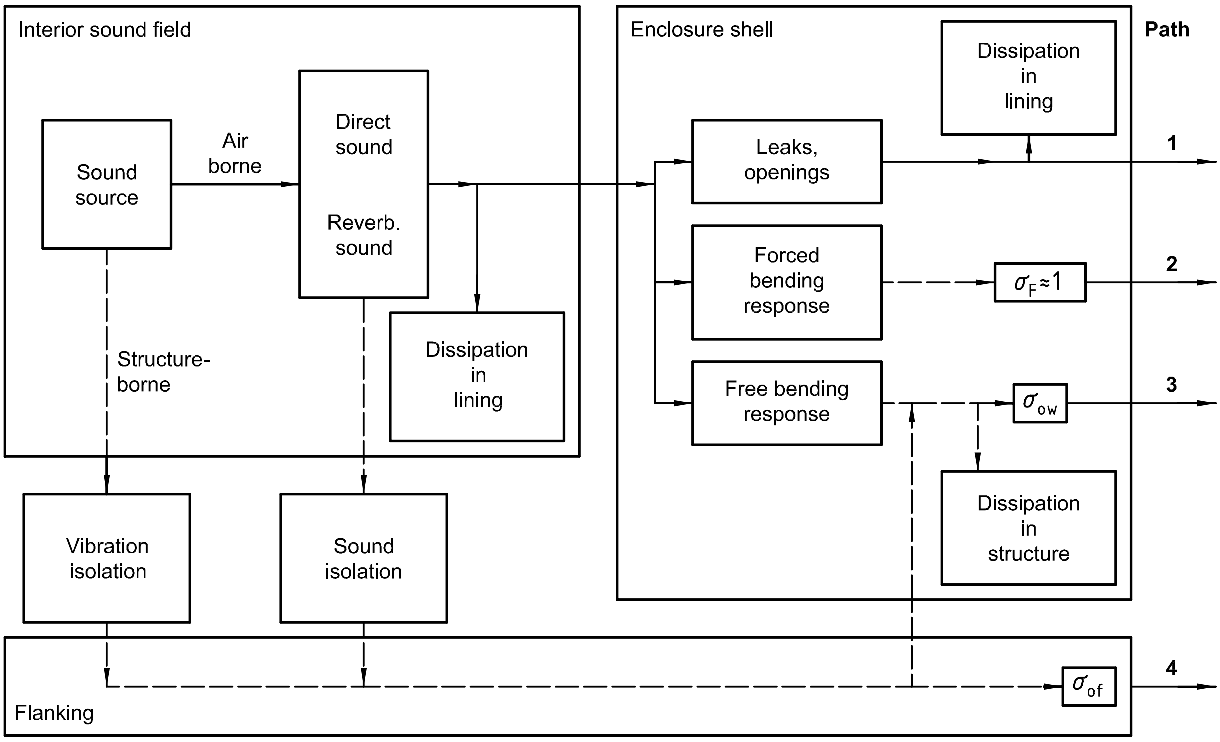


Figure 1 — Block diagram of sound propagation paths

a) **Path 1** for airborne sound through openings (or leaks) of the enclosure requires most attention. At very low frequencies, where the dimensions of the enclosure are small when compared to the wavelength and where there is little or no absorption by the enclosure lining, the volume of the enclosure and the constriction of the openings form a Helmholtz resonator, which may result in a negative insertion loss of the enclosure. At high frequencies, where the enclosure provides for substantial dissipation, the leak ratio θ and the dissipation of sound in linings close to the openings determine the transmission of sound along path 1. For acoustically untreated openings, the high frequency sound reduction index (or transmission loss) R_1 along path 1 is estimated from:

$$R_1 \approx -10 \lg(\theta) \text{ dB} \quad (2)$$

b) **Path 2** for sound propagation through the enclosure walls is typically controlled by laboratory tests on well-sealed enclosures without flanking transmission of structure-borne sound. At very low frequencies, the ratio of the compliance of the air inside the enclosure and the volume compliance of the enclosure walls determines the insertion loss of the enclosure [see equation (3)]. At low frequencies, the compliance of the air between the machine and a nearby enclosure wall may resonate with the mass of the wall, which results in a minimum of the insertion loss.

At intermediate and higher frequencies, the panel transmission loss is effective. It is determined by the impedance of the impervious shell and the attenuation on the propagation path through the inside lining. Single-wall constructions exhibit a sound reduction index (or transmission loss) which is mass controlled up to a panel weight of about 15 kg/m^2 and frequencies of about 2 kHz. Double-wall constructions are used to improve the sound reduction index (or transmission loss) at intermediate frequencies above the double-wall resonance frequency. Minima of the sound reduction index (or transmission loss) due to coincidence of the incident sound with free bending waves on the panel are mostly avoided by sound damping by the lining at frequencies above 2 kHz. At all but very low frequencies where the perimeter of the enclosure is smaller than the wavelength of airborne sound, the radiation efficiency of forced bending response $\sigma_F \cong 1$.

NOTE The radiation efficiency is defined in ISO/TR 7849 [14].

c) **Path 3** contains the radiation of free bending waves from the enclosure walls. Since mostly thin panels are used for the enclosure, the radiation efficiency σ_{ow} of limp panels is small and predominantly determined by their clamped edges or attachment points. Free bending waves are largely caused by flanking transmission of structure-borne and airborne sound. Damping of the panels provides for dissipation of such waves. Free bending waves on the enclosure frame may need to be considered at frequencies above 1 kHz.

d) **Path 4** is for the radiation with efficiency σ_{of} of structure-borne and airborne sound from flanking components which is unaffected by the enclosure. The floor, unenclosed parts of the machine, material supplied to the machine, and pipework connected to the machine are examples of flanking components. The contribution from this path finally limits the acoustic performance of an otherwise well-designed enclosure.

In critical cases, the sound transmission via all the different paths needs to be considered. The individual contributions may be determined from appropriate measurements or calculations. The distinction between contributions from path 2 and path 3 is the most difficult. In addition, if possible, the background sound pressure level $L_{p\mathrm{b}}$ should be determined for the case where the sound source to be enclosed is turned off.

4.3 Efficient noise control

NOTE For concerns to be addressed for efficient noise control by enclosures and cabins, see also references [1], [2], [6], [9].

4.3.1 Select an enclosure or cabin which is matched to the particular task of housing a machine or protecting a work station under general operating criteria, including availability of space, safety aspects, material flow, etc.

4.3.2 Generally, the acoustic performance of panels mounted on a mechanically stable frame is sufficient in terms of absorption and sound reduction index (or transmission loss) if common materials are used. Typical components shown in Figure 2 are

— outer shell: 1,5 mm steel sheet metal; where material other than steel is used for the outer shell, the thickness should be selected so as to result in a minimum mass per unit area of 10 kg/m^2 to 15 kg/m^2;

— absorbent lining on the inside: 50 mm mineral wool;

— perforated plate covering the absorbent lining: $\geqslant$ 30 % open;

— safety glass pane for windows: 6 mm thick.

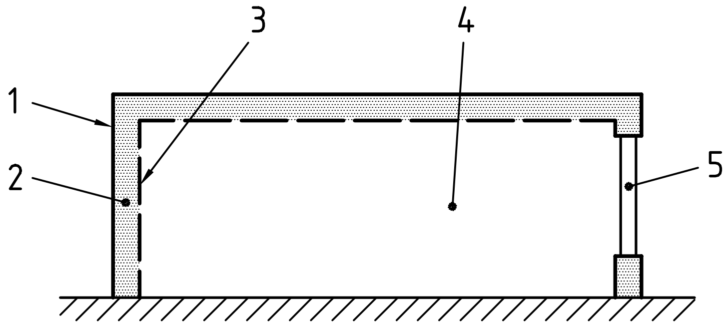
NOTE For the sake of brevity, the term "mineral wool" has been chosen throughout this International Standard to denote "mineral wool or fibre glass".

A typical spectrum of the sound pressure level close to a machine with and without such an enclosure is shown in Figure 3. The maximum A-weighted sound emission around 500 Hz determines the A-weighted sound pressure insulation.

Special requirements for enhanced low-frequency insertion loss, protective covers on the mineral wool, use of particular shapes and materials for the impervious surface, and the absorbing material, etc. need detailed investigations.

4.3.3 Devote full attention to leaks and openings. Avoid leaks between panels by making use of special single or double sealing constructions, depending on the acoustic requirements. If the panels are frequently removed, make sure that the sealing constructions can be used repeatedly. Where leaks are unavoidable, as in sliding doors, use absorbing linings or slot silencers. Minimize all openings for ventilation, cables, pipes, transport of material, etc. and equip them with silencers or sound-absorbent lined tunnels. Openings for maintenance purposes shall be closed carefully during operation.

4.3.4 To avoid flanking transmission of structure-borne sound, the sound source should be mounted on resilient elements. Panels making up the enclosure should not make contact with the sound source. Where this is unavoidable, the number of mounting points should be kept to a minimum and these should be provided with resilient elements between the sound source and contact points.



Key

1 Outer shell

2 Absorbent lining

3 Perforated cover

4 Space for sound source of work station

5 Window

Figure 2 — Acoustic enclosure or cabin (schematic)

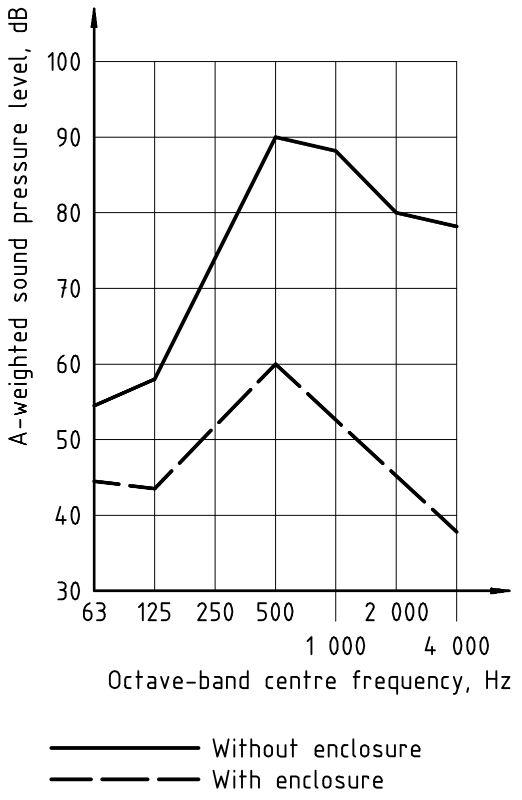


Figure 3 — Typical example of A-weighted octave-band spectrum of sound pressure level close to a machine

4.3.5 To avoid flanking transmission of airborne sound via the floor, use enclosures fully enveloping the machine, if necessary for a particularly high acoustical performance.

4.3.6 Coat the panels with damping material to increase the weight-dependent sound reduction index (or transmission loss) and the attenuation of free bending waves, if necessary for special applications.

5 Types of enclosures and cabins and particular requirements

5.1 Enclosures

5.1.1 Small enclosures (hoods)

Enclosures may be considered as being small for low-frequency sound when the largest dimension is less than one-quarter of the wavelength of airborne sound. Low-mass walls and transparent walls allow for easy handling, appropriate use and long life. The supporting structure is often the frame of the machine.

At low frequencies, the insertion loss of an airtight enclosure is

$$D_W = 20 \lg \left(1 + \frac{C_v}{\sum_{i=1}^{n} C_{wi}} \right) \text{dB} \quad (3)$$

where

$C_v = V_0/(\kappa P_0)$ is the compliance of the gas volume inside the enclosure, in metres to the fifth power per newton, m^5/N;

V_0 is the volume of the gas inside the enclosure, in cubic metres, m^3;

κ is the ratio of the specific heats of the gas inside the enclosure; for air $\kappa = 1,4$;

P_0 is the static pressure of the gas inside the enclosure, in pascals, Pa; for air under ambient conditions $P_0 = 10^5$ Pa;

$C_{wi} = \Delta V_{pi}/p$ is the volume compliance of the *i*th enclosure panel in response to the sound pressure inside the enclosure, in metres to the fifth power per newton, m^5/N;

Δv_{pi} is the volume displacement of the *i*th enclosure panel in response to the sound pressure inside the enclosure, in cubic metres, m^3;

p is the uniform sound pressure inside the enclosure, in pascals, Pa;

n is the number of panels forming the enclosure.

For the special case of a cubical enclosure with clamped flat panels, the insertion loss is

$$D_W = 20 \lg \left[1 + 41 \left(\frac{h}{a} \right)^3 \frac{E}{\kappa P_0} \right] \text{dB} \quad (4)$$

where

h is the panel thickness of the enclosure, in metres, m;

a is the edge length of the enclosure, in metres, m;

E is Young's modulus for the panel material in pascals, Pa;

κ, P_0 are as in equation (3).

For simply supported rather than clamped panel edges, the insertion loss is typically 10 dB lower. For small enclosures of the same mass, equation (4) indicates that aluminium and glass are superior to steel by more than 10 dB in insertion loss, while lead is a very poor choice for low-frequency sound [1].

Except for special constructions, all small enclosures are likely to have leaks and do not provide a positive insertion loss at frequencies below 1,4 f_L, where for a cubicle enclosure with a round opening

$$f_L = \frac{c}{2\pi} \sqrt{\frac{\theta}{(h + \Delta h) a \left(1 + \frac{\sum_{i=1}^{n} C_{wi}}{C_v} \right)}} \quad (5)$$

where

c is the speed of sound in the air volume inside the enclosure, in metres per second, m/s;

θ is the leak ratio;

a, h are as in equation (4);

$\Delta h \approx 1{,}6 a_L$ is the end correction for both ends of the opening in the enclosure, in metres, m;

a_L is the radius of the opening in the enclosure, in metres, m;

C_{wi}, C_v are as in equation (3).

At frequencies above f_L, the insertion loss of the leaky enclosure approaches that of the sealed enclosure. Leaks between the enclosure and the frame should be sealed by resilient strips suitable for frequent use. Since efficient silencers cannot be installed due to lack of space, openings should be kept as small as possible. Flanking transmission of structure-borne sound (e.g. via paper from a mechanical printer) shall be controlled, preferably by vibration damping.

5.1.2 Enclosures for single stationary machines

5.1.2.1 In workshops

The size of an enclosure is often determined by the available space around the machine. In some cases it may be considered that a partial enclosure, surrounding the dominant sound source, is more suitable.

The size and construction of the enclosure needs to be chosen by taking into consideration many aspects including the need for access, maintenance, adjustments, or removal/replacement of tools, etc. In some cases the size and mass of individual panels may require stiffening and the provision of hooks to accommodate lifting and removal.

Additionally, enclosures may need to be treated externally to resist the effects of the environment, e.g. the effects of oil and water. They should also be capable of being cleaned. The internal surfaces of the enclosure and all openings should be provided with absorbent linings. These linings can be protected from the ingress of oil and water by the provision of plastic films or metal foils. Where these coverings are used, it must be appreciated that in some cases the coverings may affect the acoustical performance of the absorbent linings, especially at high frequencies.

NOTE 1 For an area-related mass of film or foil of more than 50 g/m^2, or a thickness of plastic film of more than 50 µm, reduced absorption occurs at frequencies above 2 kHz.

For protection of the absorptive lining from mechanical damage, sound-transparent covers are necessary.

NOTE 2 Sufficient sound transparency is generally obtained by use of aluminium mesh or perforated steel plate, 30 % open area, and with holes of 3 mm to 5 mm diameter.

When films or foils are used together with perforated plate, care is needed to avoid reduced sound absorption due to sticking of the film or foil to the perforated plate. This can be achieved by having a thin, open mesh between the perforated plate and the film. Care is needed to ensure that burrs on the inside of the perforated plate do not puncture the thin film.

For acoustic enclosures designed for a weighted sound power insulation of at least 20 (30) dB, all leaks resulting in a leak ratio of more than 0,01 (0,001) shall be sealed, for example by elastomeric strips and bushings (see Figures A.3 to A.6 and A.17 to A.21). Doors require special attention (see Figures A.11 to A.13). Sound leakage due to resonance in an extended leak may result in reduced sound insulation over a narrow frequency range.

Depending on the required performance of the enclosure, silencers shall be provided for natural and forced draught ventilation systems and for openings needed for material flow (see Figures A.7 to A.10). For the specification and selection of silencers, see ISO 14163.

Relatively large openings are cut out in prefabricated panels for cables, mechanical transmissions, etc. After insertion of these elements, the openings are sealed with mineral wool between sheet metal covers and with elastomeric strips and bushings, if necessary (see Figures A.14 to A.16).

When the sound emission of the machine is mainly determined by structure-borne sound (e.g. for internal combustion engines, water-cooled electrical motors, generators, gear boxes, compressors, or transformers) the performance of the enclosure is often limited by flanking transmission of structure-borne sound via the supporting structure or connections between the source and the enclosure walls. Resilient mounts on a heavy foundation and resilient connections or bushings provide for improved noise control [10]. In critical cases, compound elastic mounts with an additional resilient element between the machine foundation and the building floor are employed (see Figure A.28). Then it is necessary to separate or isolate the machine foundation from the enclosure walls. In contrast to extended single elastic mounts (see Figure A.28), compact systems of compound elastic mounts consisting of a mass between two resilient elements may be used under a machine mounted on a stiff frame.

5.1.2.2 Outdoors

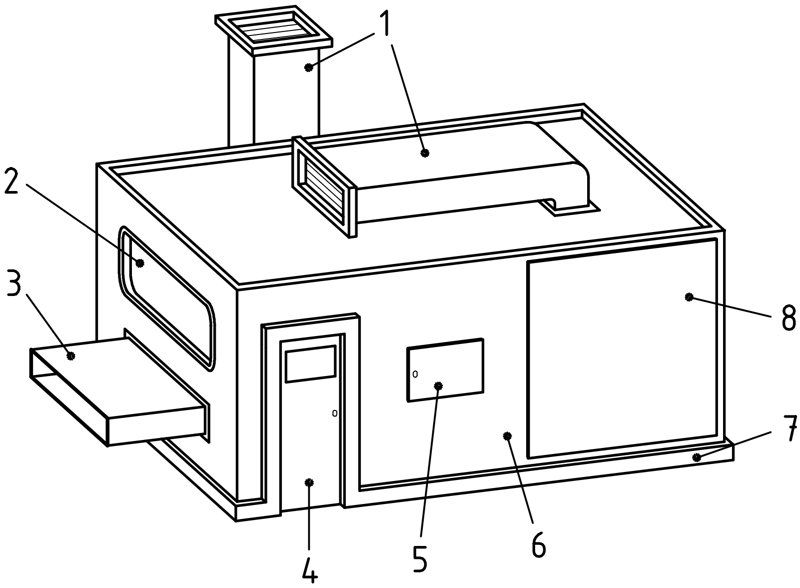
In addition to the requirements for acoustic enclosures in workshops, attention shall be paid to weather protection of materials (achieved by galvanized and/or painted steel) and openings (achieved by appropriately shaped sheet metal), to wind loads (achieved by increased thickness of the outer shell and/or stiffeners between the outer shell and the inner perforate) and to sea water protection (achieved by aluminium), if required.

NOTE Flow noise should be considered for deflector hoods for ventilation systems.

To inhibit flanking transmission via the foundation of machines mounted on elastic structures, the weight of the foundation may be increased by a concrete bedding, if structurally acceptable. Generally, there is no need for full absorbent lining or for limitation of windows. Special safety requirements (e.g. explosion hatches) shall be fulfilled.

5.1.3 Walk-in enclosures for large machines and groups of machines

The features of a typical machine enclosure are shown in Figure 4. In addition to the requirements for acoustic enclosures in workshops, ventilation and light inside should be available and appropriate safety features shall be provided [e.g. a cut-out switch so that the machine cannot be started by someone outside (see also 6.2.2)]. Applications with toxic gases, moving machine parts, etc. may require special safety devices. Different noise control may be specified in different directions resulting in different treatment of openings.



Key

1 Suitably attenuated cooling air supply/discharge
2 Inspection window
3 Workpiece entry/delivery via treated feed ducts
4 Personnel door (if necessary)
5 Routine access (hinged panel)
6 Inner lining of sound absorbent material, outer skin of insulating material
7 Airtight seal
8 Demountable panel to be sealed to form airtight seal for occasional access

Figure 4 — Typical machine enclosure

Frames of windows shall be well sealed and matched in sound insulation to the window panes (see Figures A.25 and A.26).

Particular attention shall be paid to the sound transmission through slits around doors. This depends on the type of door and the door lock. Three types of door can be distinguished:

a) sliding doors, folding doors and up-and-over doors;

b) hinged doors (with and without threshold);

c) force-activated doors.

A sliding door is used when local conditions do not provide sufficient space for the opening and closing of a hinged door, for example for safety reasons when a traffic path runs directly in front of a personnel door. The necessary slit of width h which is necessary to form a circumferential air gap shall be acoustically treated over a length $w \geqslant 20\,h$ (see Figure A.13) as a replacement of a seal.

Hinged doors of an enclosure shall open outwards if the door is on an emergency route. For hinged doors without threshold, elastic (rubber) seals are applied on three sides of the frame. The air gap between the door and the floor should be kept as small as possible to avoid an impaired sound reduction index (or transmission loss) of the door. Additional measures (e.g. a brush seal) provide just a marginal improvement of the sound reduction index (or transmission loss). A slightly better performance is obtained by using sliding rubber seals on bump thresholds. The latter are mounted on the floor and can be crossed by wheels without providing a high risk of tripping (see Figure A.20). The main disadvantage of such seal results from wear by friction and the need for frequent maintenance. Depending on the frequency of use, the floor seal becomes ineffective.

Better acoustical performance is achieved by hinged doors with a threshold. The seals are effective on all four edges of the door and avoid acoustical leaks. The disadvantage comes from the high risk that this may cause someone to trip.

Force-activated doors for very high acoustical requirements are equipped with pneumatically or electrically operated pressure devices for exactly controlled and equally distributed compression of the door seals which operate after closing of the door. The process is reversed for opening of the door. First, the pressure is released from the seals, and then the door can be opened.

Hinged doors are commonly equipped with regular latch locks. The pressure acting on the door seals depends on the mounting precision of hinges and latch plate. For greater pressure, snail locks are employed which allow for additional compression of the seals by a mechanical device activated from turning the door handle by another 90°.

5.1.4 High-performance enclosures

High-performance enclosures (see 6.1) are used for example, in engine test cells, transformers, compressors and corrugating machines.

When used outdoors, enclosures (e.g. for plant equipment or complete plants) require careful weather protection, also storm protection. For large enclosures, this is generally provided by stiffened panels strongly attached to the supporting structure.

Flanking transmission of structure-borne sound may determine the upper limit for the insertion loss of the enclosure. In order to meet high requirements on noise control, the flanking transmission shall be reduced, preferably at the vibration sources if possible, or alternatively in the propagation path by means of special resilient elements holding the panels, and finally by means of a damping layer attached to the outer shell. Double walls with mass per unit area m_1''' and m_2'' of the two shells at a distance t and intermediate sound absorbent material (with density of not more than 125 kg/m^3) increase the sound reduction index (or transmission loss) in the frequency range above 1,4 f_d, where f_d is the frequency of double-wall resonance:

$$f_\mathrm{d} = a\sqrt{\left(\frac{1}{m_1''}+\frac{1}{m_2''}\right)\frac{1}{t}} \qquad (6)$$

where

$a = 60\ \mathrm{Hz}\sqrt{\mathrm{kg/m}}$;

m_1'' and m_2'' are expressed in kilograms per square metre (kg/m^2), and t is expressed in metres (m).

NOTE For two steel plates of 1 mm and 1,5 mm thickness at a distance of 100 mm, filled with mineral wool, the resonance frequency is about 80 Hz.

5.1.5 Mobile and vehicle-mounted enclosures

Vehicle-mounted machinery (e.g. generators of electric power and compressed air, pumps and hydraulic systems) requires enclosures for operation on construction sites and other temporary installations. Whilst the basic acoustic features of such enclosures remain the same as described in 5.1.2, certain constraints lead to special considerations.

The panel system will often be fitted to a frame which would itself flex as the vehicle passes over undulating terrain. However, the fixture of the sheet panel system adds very considerably to the rigidity of the assembled enclosure. The resulting stress needs to be transferred to the frame. To ensure this, many more fixing screws, bolts or anchors are employed.

Also it is useful to make continuous sheets as large as possible and even adhesively bond them to the frame. Sizes of such sheets exceeding 10 m in length and 3 m in height can be achieved from coils of metal, usually aluminium alloy. Controls should be accessible without opening any panels. If possible, the machine should only run if all panels and doors are closed.

Mobile enclosures need to be waterproof. This requires careful attention to the panel joints and their ability to remain watertight in service.

As mobile trailers are required to be as light as possible, the traditional trend to increase mass for noise control is less appropriate. Instead very thick (300 mm) layers of acoustic infill, most appropriately of glass-fibre with density around 30 kg/m^3, are often used. The extra mass of mechanically protective perforated metal is usually avoided. Elastic mounts of the machinery to inhibit the propagation of structure-borne sound are important for the acoustical performance of the enclosure.

High-performance systems have been developed with double-wall enclosures, where the lined gap between the enclosures acts as the ventilation air silencer. Ventilation may be needed both during operation and after shut-down of the machinery.

5.2 Cabins

5.2.1 Cabins for general control and supervision

Walls with windows and doors, the roof and, if specified, the floor come as prefabricated elements. Adjustments to industrial-user conditions are mostly marginal. Doors need seals suitable for frequent use. Air-conditioning is recommended.

The weighted sound pressure insulation of an acoustic cabin is typically about 30 dB. If a higher insertion loss is needed in a particular direction, heavier wall elements or double-wall constructions may be specified for this side.

Special cabins with high insertion loss needed for broadcasting studios, measurements of hearing thresholds and simultaneous interpreters, are the subject of different standards; see references [12], [13].

5.2.2 Stationary cabins for operators

Enclosing the work station requires a minimum volume and proper regard for ventilation and seating arrangements. To minimize a build-up of dust, the cabin should contain an extractor fan rather than a supply fan. Artificial lighting may also be necessary. Controls shall be brought into the cabin in order to reduce the need to enter noisy areas.

5.2.3 Vehicle-mounted cabins

Both noise and vibration control are required. In addition to the general requirements for stationary cabins, wide-angle visibility, weight and size limitations, air conditioning and particular safety aspects need to be considered.

Most low-frequency sound is transmitted through the cabin walls and its mounting points. Lightweight walls provide a low sound reduction index (or transmission loss) for airborne sound and are easily excited by structure-borne sound. The absorption of low frequency sound in the cabin and the insertion loss of resilient cabin mounts are rather small. Active control systems involving controlled auxiliary sound sources can be very effective. They reduce the interior sound by interference and absorption.

6 Acoustic requirements, planning and verification of noise control

6.1 Target data

Based on existing sound pressure levels without enclosure or cabin, users or planners of acoustic enclosures and cabins require, as a rule, maximum permissible

a) A-weighted overall sound pressure levels or octave-band data at specified positions, such as

— at 1 m distance from the enclosure,

— averaged over an enveloping surface,

— at a work station,

— inside the cabin,

— at a specified reference point in the neighbourhood; or

b) A-weighted overall sound power levels or octave-band data of sound emission from the enclosure (or enclosed equipment).

Octave-band data of the sound emission from the enclosure or the sound source to be enclosed are preferred.

The difference in A-weighted overall sound pressure levels with and without the enclosure or (to a first approximation) the difference in the octave band centred at 500 Hz indicates the acoustic requirements for the enclosure. Five groups of enclosures may be distinguished on the basis of such a level difference:

a) up to 10 dB: no particular requirements;

b) 10 dB to 20 dB: typical enclosures without major leakages;

c) 20 dB to 30 dB: typical enclosures with carefully sealed leaks and elastic mounts of the machine;

d) 30 dB to 40 dB: carefully designed and assembled high performance enclosures;

e) more than 40 dB: special constructions.

Without detailed knowledge about the sound source, manufacturers should provide the following for acoustic enclosures:

— the insertion loss, and, at least,

— the weighted sound power insulation.

6.2 Planning

6.2.1 Procedure

The typical procedure followed by a user employing enclosures for noise control involves the following steps.

a) A request is sent out to a manufacturer (see 7.1).

b) The user invites the manufacturer for a first general discussion of the project at the plant.

c) The user collects all the technical data required for planning, including dimensions, ventilation, material flow, permissible materials, safety requirements, etc.

d) The user invites the manufacturer for a second detailed discussion of the project.

e) The manufacturer develops a draft drawing (general arrangement) of the enclosure.

f) The user of the machine (and his maintenance and safety departments) accept the draft.

g) The user starts the tender action.

h) The chosen manufacturer submits an exact measured drawing of the enclosure.

i) Structural requirements and penetrations are included in the design.

j) The user accepts the design and gives a commission to the manufacturer.

k) The manufacturer starts by prefabricating the elements.

l) The manufacturer assembles the enclosure.

m) The construction work is accepted by the user.

n) An independent acoustical consultant verifies the acoustical performance, if necessary.

If more than one enclosure is needed for several machines of the same type, it has been found useful to build a prototype first and to test it acoustically and with respect to usability, durability, problems with operation and maintenance, etc.

6.2.2 Dimensions

Minimum dimensions of an enclosure result from the requirement that no part of the machine shall touch the enclosure wall. In addition, electromagnetic fields can determine minimum dimensions.

In order to avoid a reduced acoustical performance of enclosure walls due to resonance with the stiffness of the air between the wall and the machine surface, the width d of the air gap shall meet the condition

$$\frac{d}{d_0} \geqslant \frac{2 \times 10^4}{\frac{m''}{m''_0}\left(\frac{f}{f_0}\right)^2} \quad (7)$$

where

d is the width of the space between the machine surface and the outer shell of the enclosure, in metres, m; d_0 = 1 m;

m'' is the mass per unit area of the outer shell, in kilograms per square metre, kg/m^2; $m''_0 = 1\ \text{kg/m}^2$;

f is the lowest frequency for which a panel transmission loss is required, in hertz, Hz; f_0 = 1 Hz;

NOTE For sheet metal of 1,5 mm steel and a frequency of 63 Hz, the minimum distance would be about 400 mm.

For walk-in enclosures, the accessible free space between the machine and the enclosure wall shall be 500 mm at least, preferably 600 mm to 700 mm. Safety standards also specify the distance between routine access panels and rotating or power-driven machine parts. (See references [18] through [26].)

6.2.3 Ventilation and air-conditioning

Ventilation is required for

— removal of heat,

— exchange of air in case of potential gas leakages (to prevent toxical hazards and danger of explosion),

— air supply for burners or internal combustion engines.

It is necessary that all openings for inlet and exhaust air be acoustically treated.

The insertion loss of treated openings should be comparable to that of the enclosure or cabin walls.

Natural draught ventilation requires inlets at the floor and exhausts at the roof. Forced draught ventilation may be accomplished occasionally by means of cooling fans of electric motors which are part of the enclosed machine (see Figure A.7). In general, special exhaust fans are installed at positions where circulation of dust from the floor is to be avoided (see Figures A.8 and A.9).

The air flow rate is often chosen so as to limit the temperature rise of the cooling air to about 15 °C. In the case of potential leaks of gases lighter than air, the exchange rate is typically 60 per hour, and for heavier gases 120 per hour, and special safety regulations shall be observed for the positioning of the exhaust duct.

Air-conditioning of cabins is often necessary to avoid the opening of doors or windows which impairs the acoustical performance of the enclosure. The forced draught ventilation from such equipment may need additional silencers.

6.2.4 Other requirements

Safety requirements determine the selection of sound-absorbing materials. With respect to fire hazards, mineral wool materials are generally superior to open cell plastic foams. However, cutting of mineral wool materials at the construction site should be avoided and cut edges of mineral wool blankets should be sealed to avoid contamination of the enclosure and its environment with loose particles.

Access doors for personnel should seal well to frame. It shall be possible to open them from inside the enclosure.

Large openings of the enclosure may be needed for changing parts or reloading the machine inside. For this purpose, various solutions are in use including hinged/sliding/rise-and-fall doors, roll-away boxes, lift-off roofs and others. Electrical connections between movable parts need special attention.

Full access to the machine often requires dismantling of the enclosure. If this is regularly needed, provisions should be taken to identify the various parts for easy reassembly. Marks, numbers, patterns or different colours have been found useful for such purposes. In addition, the type of connection shall be specified which ensures multiple reassembly (e.g. type of screw, quick-release clips).

The expected life of the enclosure should be matched to the life of the machine. Since rubber gaskets and other resilient elements may not last that long, they should be renewable. The outside shell of the enclosure may be repeatedly painted, but not the inner perforate without separation from the sound-absorbing material and its protective cover. Otherwise, the absorption may be substantially reduced.

6.3 Measurements

6.3.1 Overview

The following measurement methods are in use:

— laboratory measurements of small enclosures for declaration purposes as specified in ISO 11546-1,

— *in situ* measurements of enclosures for acceptance/verification purposes as specified in ISO 11546-2,

— laboratory and *in situ* measurements of cabins as specified in ISO 11957,

— combined vibration measurements on the outer shell and sound measurements close to leaks and openings of enclosures *in situ*,

— advanced measurement procedures, e.g. use of maximum length sequence (MLS) signals.

The method to be chosen for a given machine enclosure is determined by the size of the enclosure, its application and the environmental conditions.

6.3.2 Measurements according to ISO 11546-1

Measurements under laboratory conditions are carried out for declaration purposes on free-standing enclosures with volumes generally less than 2 m^3. Three types of measurements with and without the enclosure, or inside and outside of the enclosure are specified.

a) Measurements with the actual sound source are preferred and provide the most accurate values of the sound insulation performance of the enclosure. They may be carried out in various laboratory environments by means of sound pressure measurements to determine the insertion loss D_W (or the A-weighted sound power insulation $D_{W\text{A}}$) conforming with the ISO 3740 series, or by means of sound intensity measurements conforming with ISO 9614, or by means of sound pressure measurements at specified positions to determine the sound pressure insulation D_p (or the A-weighted sound pressure insulation $D_{p\text{A}}$).

b) If the actual sound source cannot be used, an external sound source and a reciprocity method are preferred to determine the sound pressure insulation. This method does not take into account the flanking transmission of sound, and it is not applicable if the enclosure includes active elements such as fans.

c) In cases where neither the actual sound source method nor the reciprocity method is applicable, the sound insulation performance in terms of the insertion loss D_W can be obtained using a special artificial sound source inside the enclosure. This method may not fully take into account the flanking transmission of sound and it is not applicable if the enclosure includes active elements such as fans. It may be strongly affected by environmental disturbances.

6.3.3 Measurements according to ISO 11546-2

Measurements under given conditions *in situ* are specified for free-standing machine enclosures. Two types of measurements with and without the enclosure are specified.

a) Measurements with the actual sound source are preferred. The insertion loss D_W (or the A-weighted sound power insulation $D_{W\text{A}}$) is determined from sound pressure measurements depending on the acoustic environment conforming with the ISO 3740 series, or by means of intensity measurements conforming with ISO 9614. In addition, sound pressure measurements at specified positions may be carried out conforming with the ISO 11200 series to determine the sound pressure insulation D_p (or the A-weighted sound pressure insulation $D_{p\text{A}}$) for work stations.

b) An artificial sound source may be used instead in some specific cases, for example when the actual sound source cannot operate without noisy auxiliary equipment outside the enclosure, or when it is impossible to achieve identical operating conditions for the machine with and without the enclosure.

Problems with the specifications arise from the fact that

— industrial environments are often too noisy to measure airborne sound outside an enclosure, either for the actual sound source or for the artificial sound source specified in the standard, and

— large enclosures may be put into relatively small rooms so that the accuracy of measurements may not reach engineering grade.

6.3.4 Measurements according to ISO 11957

An external sound field generated either in a reverberation room as specified in ISO 3741 or in any type of room *in situ* is used to determine the cabin sound pressure insulation. In the laboratory, no particular measure is taken to avoid flanking transmission via the floor. Ventilating fans shall be shut off. *In situ* measurements may be carried out with a loudspeaker (preferred for comparison with laboratory data) or with the actual noise (preferred for evaluation of the actual sound pressure insulation).

Field measurements shall not be carried out directly after installation of the cabin but after some time of usage. There shall not be any significant contribution to the measured sound pressure levels from ventilating fans and possible other sources in the cabin. The difference in sound pressure levels outside and inside the cabin observed *in situ* is called the apparent sound pressure insulation.

6.3.5 Combined sound and vibration measurements

Where extraneous noise inhibits sound measurements on an enveloping surface, the following different types of measurements may be successful for determining the sound radiated from a machine enclosure *in situ*.

a) Lightweight accelerometers are mounted on the outer shell to determine the structure-borne sound [14]. The measured data are converted into one-third-octave-band or octave-band levels of radiated sound pressure after integration and weighting with frequency-dependent radiation efficiencies assumed or known for the construction.

   In critical situations with very high extraneous noise, additional measurements should be carried out to ascertain that the vibrations are not caused by the extraneous noise. For this purpose, sound intensity measurements are suitable which also allow for the determination of the direction of sound propagation.

b) In addition to the vibration measurements, sound pressure (or possibly intensity) measurements shall be carried out close to all openings and leaks. If the levels exceed those from more remote positions by more than 3 dB, they may be used to determine partial sound powers.

Reliable data for the radiation efficiency require laboratory measurements on similar constructions with comparable sound fields on the source side and undisturbed conditions on the receiver side. When such data are not available, it is recommended that the user and manufacturer agree on assumed octave-band data of the radiation efficiency.

The total sound power radiated from the enclosed machine is the sum of the partial sound powers determined from sound and vibration measurements.

If more than one enclosure is needed for several machines of the same type, it has been found useful to build a prototype first and to test it acoustically before further effort is spent.

6.3.6 Maximum length sequence (MLS) measurement procedure

Under conditions where measurements with a loudspeaker according to ISO 11546-2 or ISO 11957 fail due to a high environmental noise level, so-called maximum length sequence (MLS) signals may be used which allow for an improvement of the signal-to-noise ratio by typically up to 30 dB [7]. High improvements require careful control of the linearity of the loudspeaker and receiver system, stability of temperature conditions and negligible air flow.

7 Information on enclosures

7.1 Information to be provided by the user

Where procedures similar to those described in 6.2.1 cannot be followed, the following minimum information, if applicable, shall be provided by the user/purchaser in order to specify the requirements for an enclosure:

a) kind of machine or plant (rated power, information concerning representative modes of operation);

b) size of the enclosure (length, width and height) or, at least, of the machine;

c) enclosure with or without floor panel;

d) application indoors or outdoors, with or without shelter, or on a vehicle;

e) mounting conditions (type and quality of floor);

f) type of construction (completely or partially liftable, capable of being dismantled, provision for partial or complete walk-in);

g) number, size and position of doors, windows, access panels (visual and physical), feed and delivery openings;

h) acoustical performance (see 6.1);

i) amount of heat to be removed;

j) material for outside shell and type of finish (pattern, treatment, colour);

k) structural requirements, such as strength and durability;

l) permissible absorbent materials and covers;

m) safety and hygienic aspects;

n) ventilation and air-conditioning;

o) electrical installation (lighting, outlets);

p) maximum permissible weight and dimensions of enclosure elements;

q) further specific information.

7.2 Information to be provided by the manufacturer

For the specification of the operational properties of an enclosure, the supplier/manufacturer shall provide at least the following information, if applicable:

a) acoustical performance in terms of

   — insertion loss in octave bands of the enclosure,

   — or weighted sound power insulation of the enclosure,

   — or apparent sound pressure insulation of the cabin;

b) temperature rise of cooling air;

c) geometry of the enclosure or cabin (drawing);

d) materials used, type of confinement for absorbent materials, and type of gaskets;

e) suitability for outdoor use;

f) weight, dimensions, mounting, inspection and maintenance conditions;

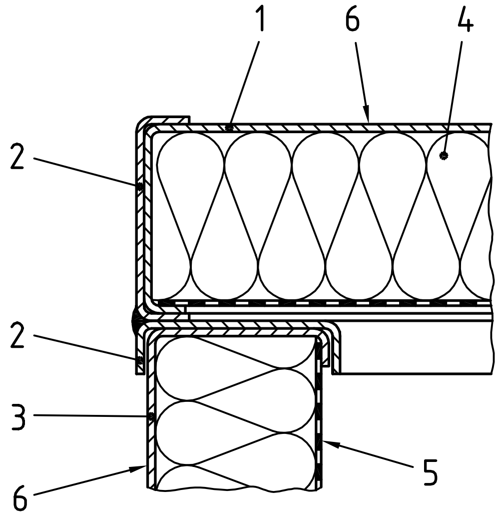
g) further specific information.

Annex A
(informative)

Examples of construction

A.1 Panels

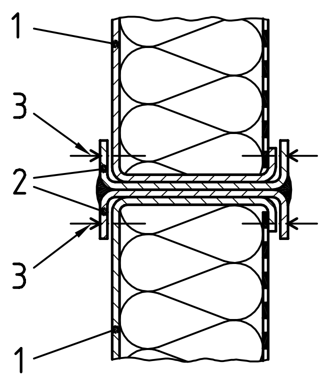
A.1.1 Mounting of panels in a stiff frame



Key

1 Enclosure roof element
2 U-profiles welded together
3 Enclosure wall element
4 Absorbent lining
5 Mechanical protection (perforated cover)
6 Impervious outer shell

Figure A.1 — Example of connection of enclosure roof elements



Key

1 Enclosure wall element
2 U-profiles welded together
3 Screw connection

Figure A.2 — Example of vertical connection of enclosure wall elements

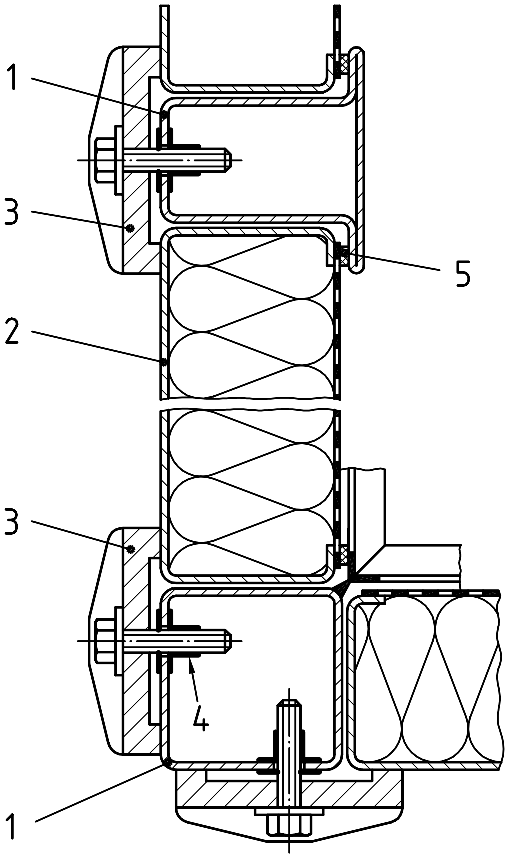
a) **On a smooth floor**

b) **On a rough (concrete) floor**

Key

1 Enclosure wall element
2 U-profile
3 Self-adhesive rubber seal
4 Plasticine-like seal
5 Mastic fillet

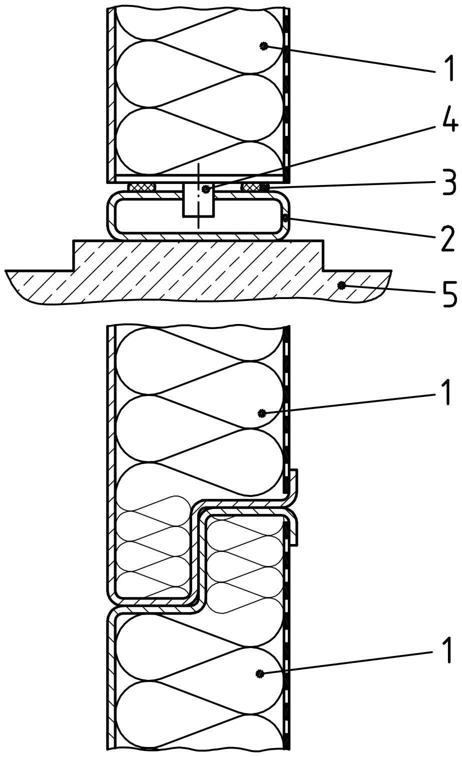
Figure A.3 — Examples of mounting the enclosure wall



Key

1 Enclosure frame
2 Enclosure wall element
3 Clamp
4 Blind rivet nut
5 Rubber seal

Figure A.4 — Examples of connection of removable enclosure wall elements to enclosure frame



Key

1 Enclosure wall element

2 Enclosure frame

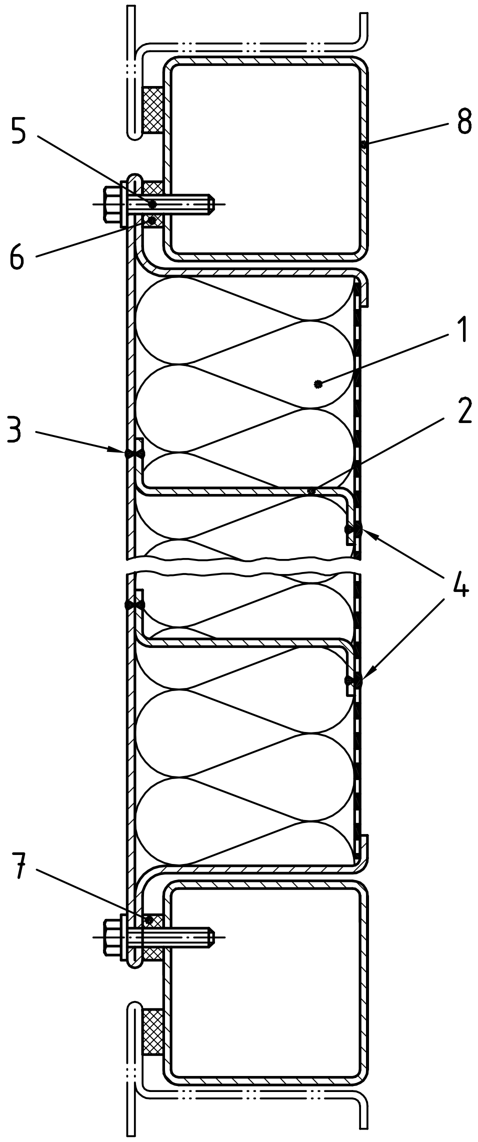
3 Rubber seal

4 Socket and locating pin

5 Concrete up-stand

Figure A.5 — Examples of precision enclosure wall elements mounted on a floor frame and connected without seal

A.1.2 Panels with stiffeners



Key

1 Enclosure wall element

2 Stiffener

3 Welding spot on outer shell

4 Welding spots on perforated cover

5 Screw connection

6 Self-adhesive rubber seal with holes

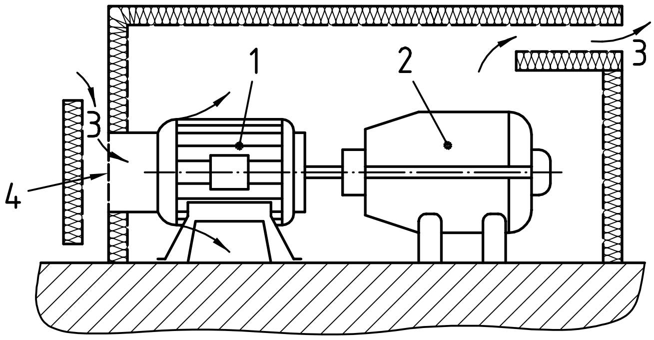
7 Rubber seal (alternative)

8 Enclosure frame

Figure A.6 — Example of removable panels with stiffeners reinforcing the enclosure frame; for use in areas with explosion hazard and outdoors

A.2 Silencers

A.2.1 Ventilation of machine enclosures



Key

1 Electric motor

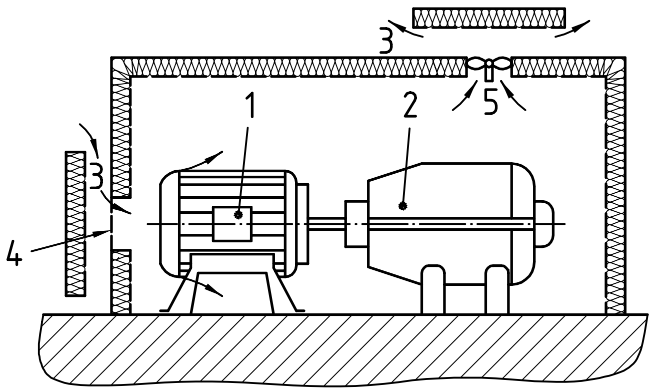
2 Turbo compressor

3 Acoustically treated intake and exhaust ducts

4 Protective grid

NOTE The fan of the electric motor is used for forced draught ventilation of the enclosure.

Figure A.7 — Enclosure for air-cooled electric motor and turbo compressor (schematic)



Key

1 Electric motor

2 Turbo compressor

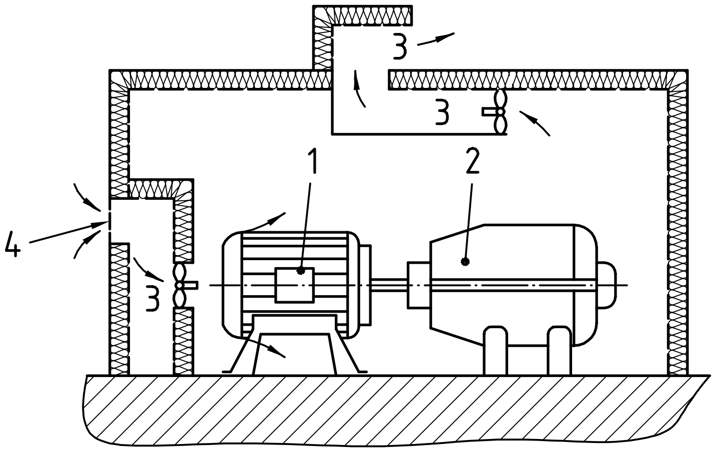
3 Acoustically treated intake and exhaust ducts

4 Protective grid

5 Fan

NOTE For large enclosures a duct may be provided between the protective grid and the electric motor as shown in Figure A.7.

Figure A.8 — Enclosure for electric motor and turbo compressor (schematic) with separate fan for forced draught ventilation



Key

1 Electric motor

2 Turbo compressor

3 Acoustically treated intake and exhaust ducts

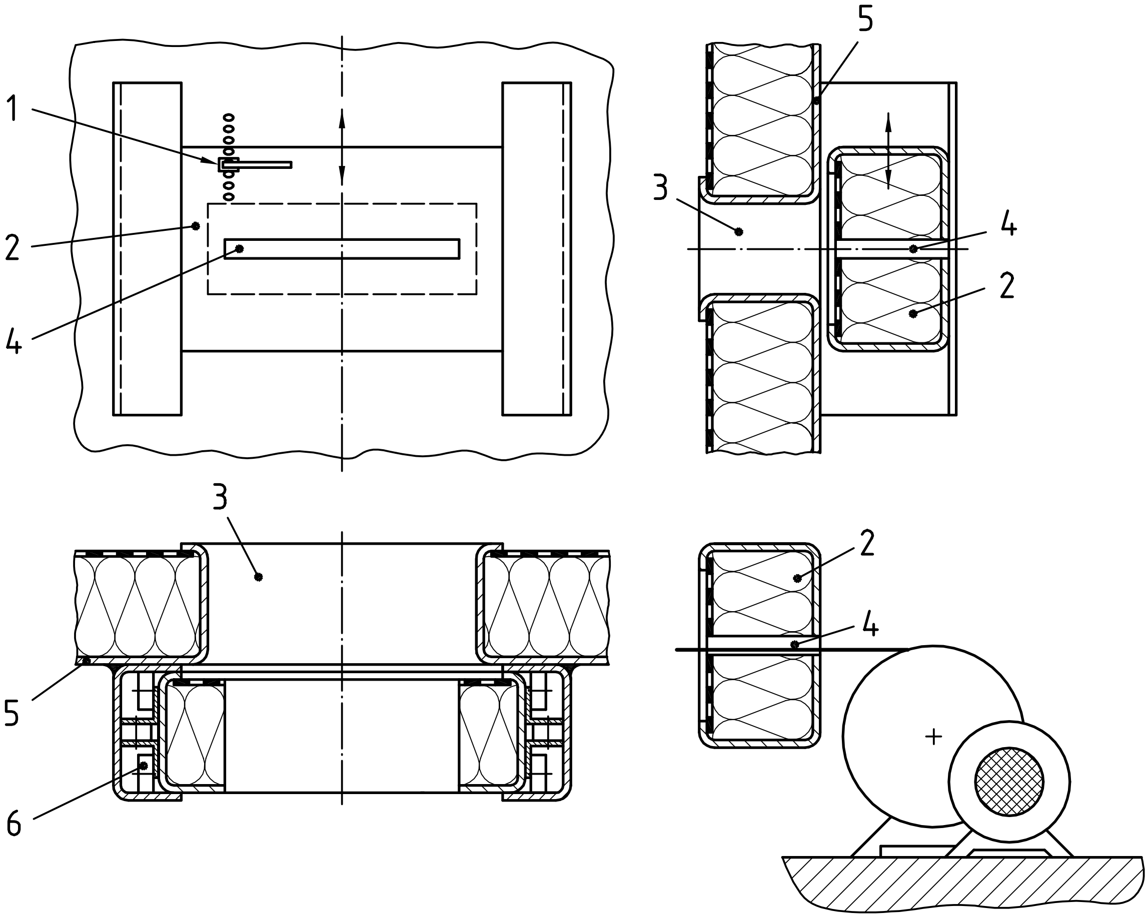
4 Protective grid

NOTE 1 Exhaust side extraction results in under-pressure in the enclosure.

NOTE 2 The intake and exhaust fans may be used alternatively or in combination.

Figure A.9 — Examples of incorporation of the silencer in the wall element (exhaust side) and, alternatively, of enhanced supply of cooling air to sensitive machinery (intake side)

A.2.2 Treated feed ducts



Key

1 Adjustment

2 Cover

3 Opening in enclosure wall

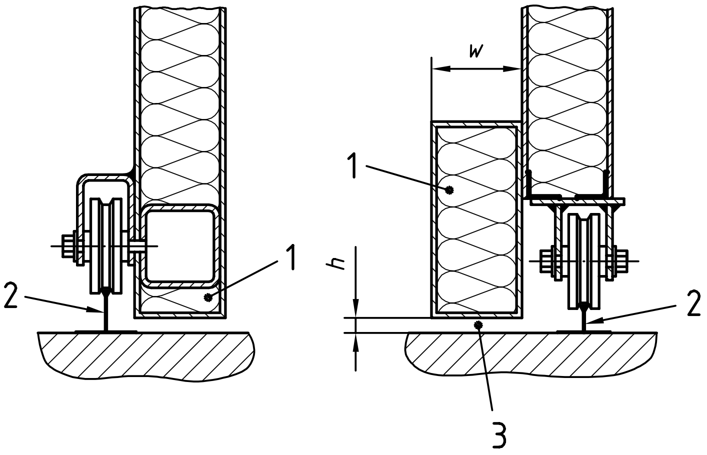
4 Feeding slot

5 Enclosure wall element

6 Roller guiding system

Figure A.10 — Adjustable feeding slot in enclosure wall

A.2.3 Sliding doors with slit silencers and seals



Key

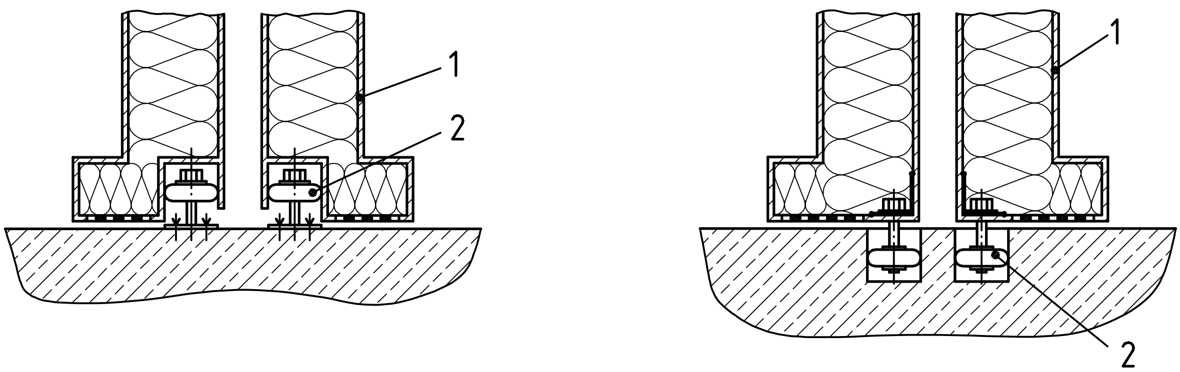
1 Boot with sound absorbing material

2 Running rails

3 Slit of width h and length $w \geqslant 20h$

NOTE For safety reasons, the running rails may be sunk in the floor in marked passageways.

Figure A.11 — Examples of acoustically treated slits under movable enclosure walls



a) **Over floor**

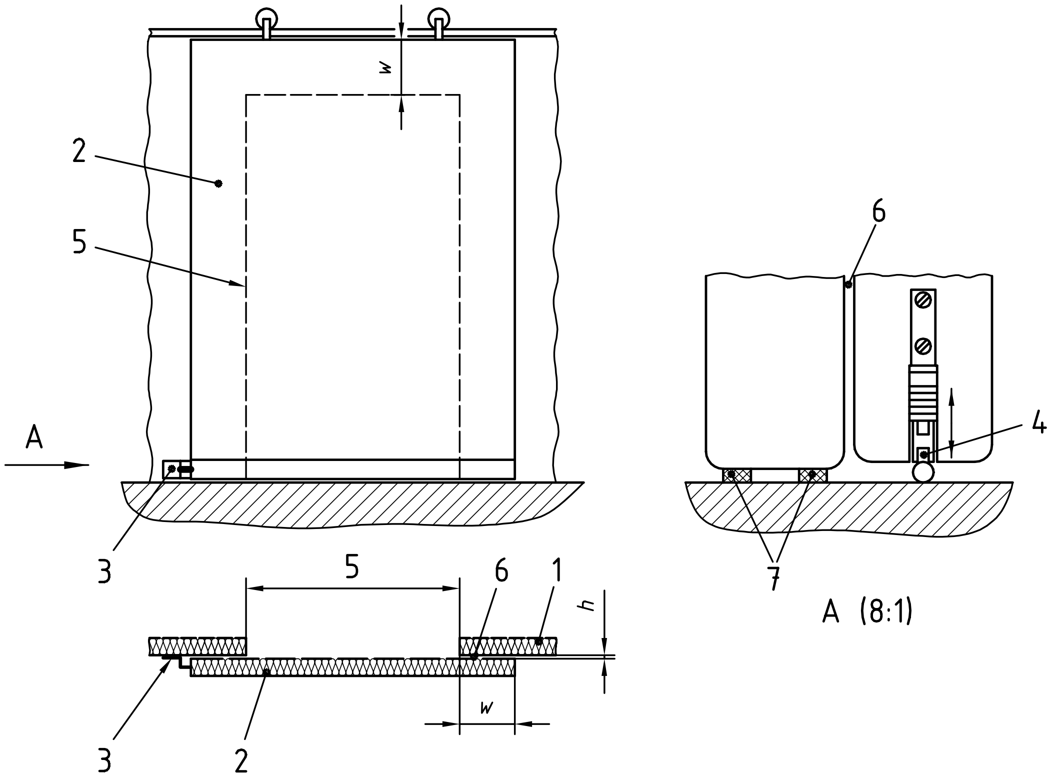
b) **Under floor**

Key

1 Sliding door

2 Guide rollers

Figure A.12 — Example of hanging telescopic sliding doors



Key

1 Enclosure wall element

2 Sliding door

3 Lever for activating floor seal

4 Falling floor seal

5 Opening in enclosure

6 Slit of width h and length $w \geqslant 20h$

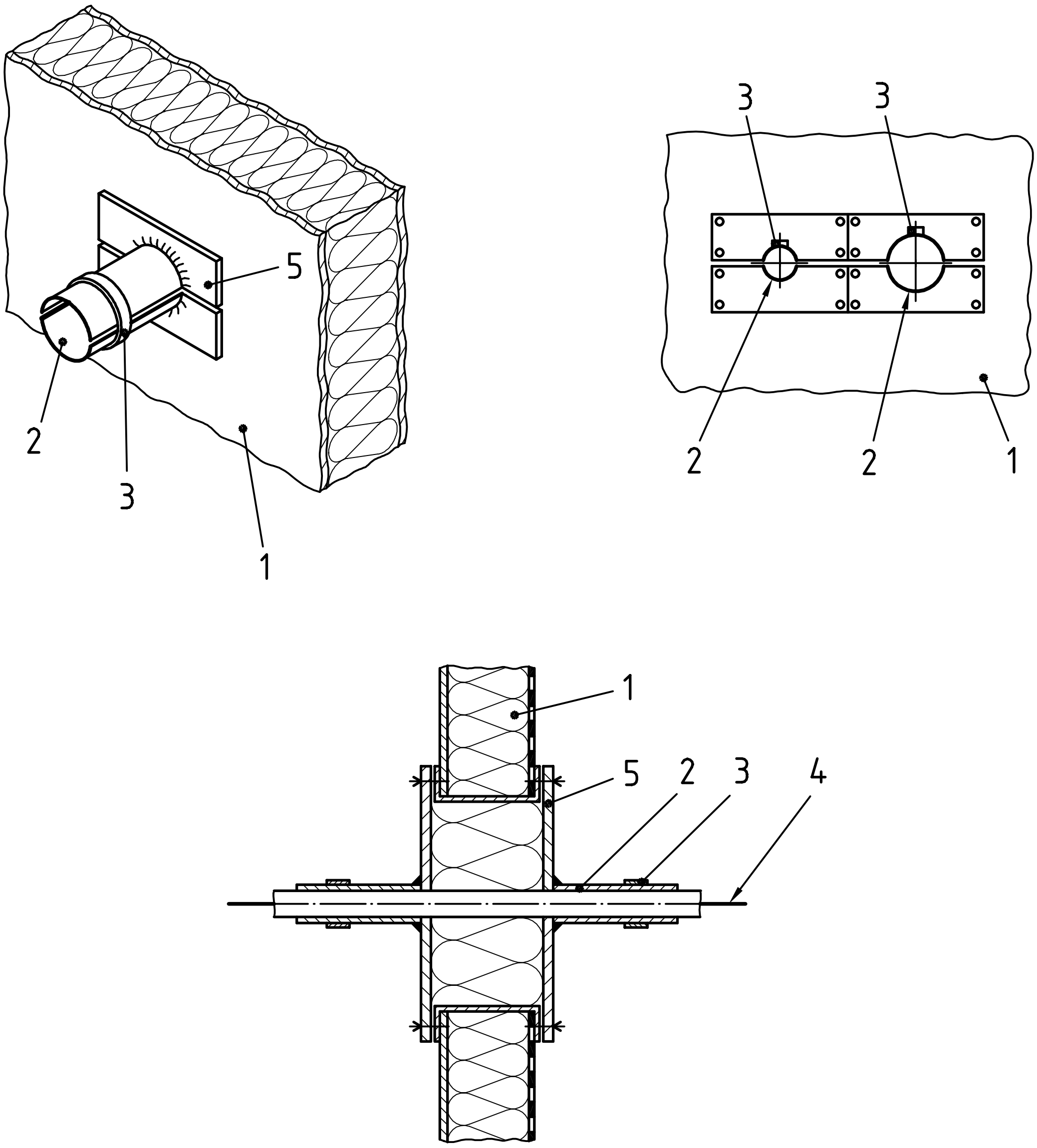
7 Rubber seal

NOTE Typically h = 10 mm.

Figure A.13 — Example of large sliding door with sufficient overlap and floor seal effective in closed position

A.3 Sealing

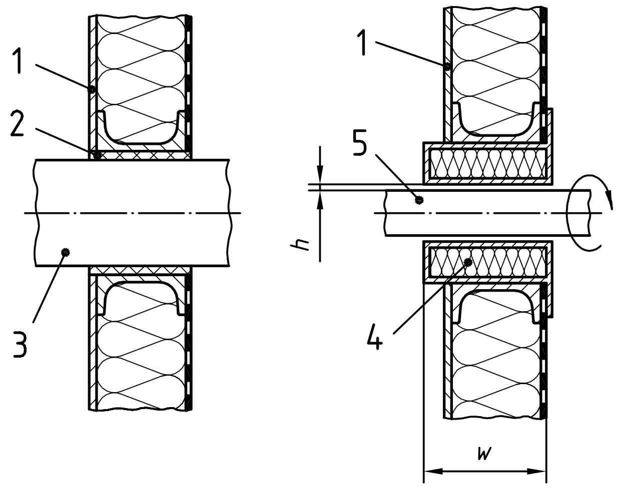
A.3.1 Penetrations of enclosure walls



Key

1 Enclosure wall element
2 Halfpipes welded on patch plate
3 Connecting clamp
4 Cable
5 Patch plate

Figure A.14 — Example of wall penetration for a cable



Key

1 Enclosure wall

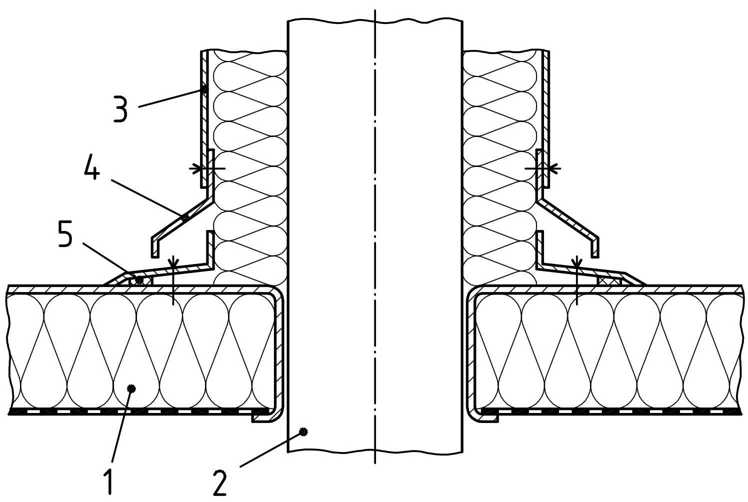
2 Seal

3 Tube

4 Silencer of length $w \geqslant 20h$

5 Shaft

Figure A.15 — Examples of acoustic treatment of wall penetrations for tubes, shafts, handles, etc.



Key

1 Enclosure roof element

2 Exhaust stack

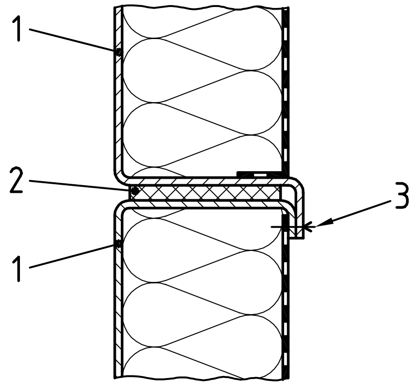
3 Thermal lagging

4 Inclined cover

5 Rubber seal

Figure A.16 — Example of acoustic treatment of roof penetration with thermal expansion joint

A.3.2 Seals between panels, betwen enclosure and floor, on hinged doors and access panels



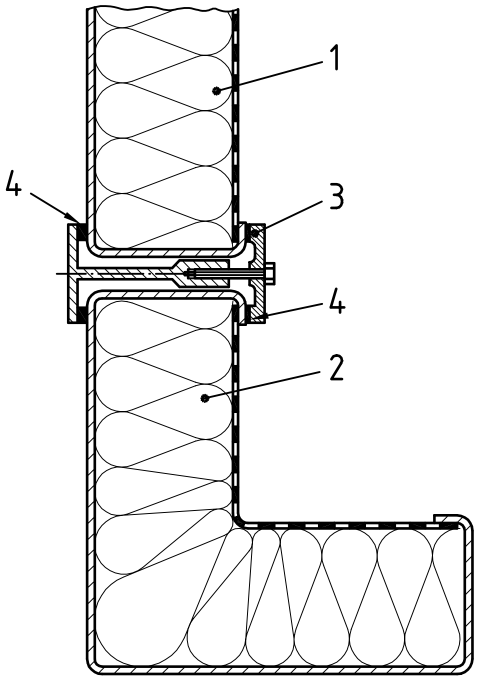
Key

1 Enclosure wall element

2 Self-adhesive rubber seal

3 Screw connection

Figure A.17 — Example of vertical connection of enclosure wall elements



Key

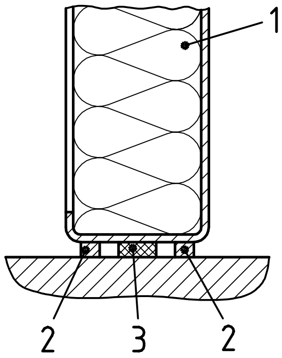
1 Enclosure wall element

2 Enclosure corner element

3 Adjustable connection element (long profiles)

4 Rubber seal

Figure A.18 — Example of connection of enclosure wall and corner elements by extended profiles with adjustable elements



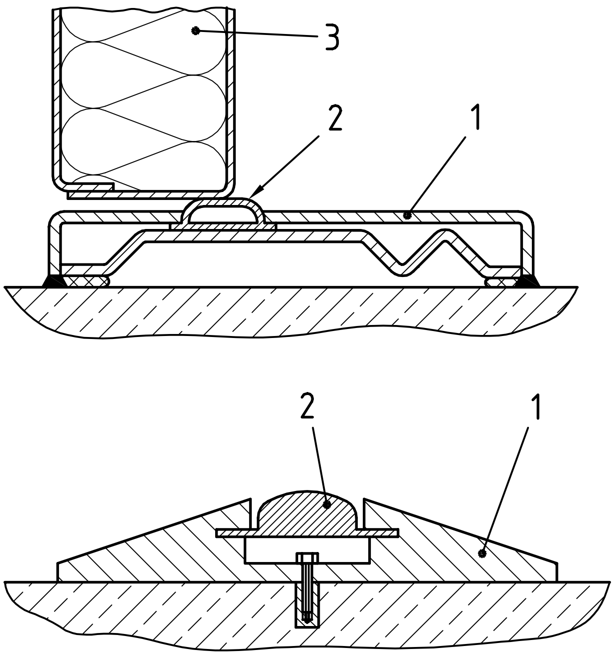
Key

1 Enclosure wall element

2 Solid steel profiles

3 Rubber seal

Figure A.19 — Example of a seal between enclosure wall element and floor



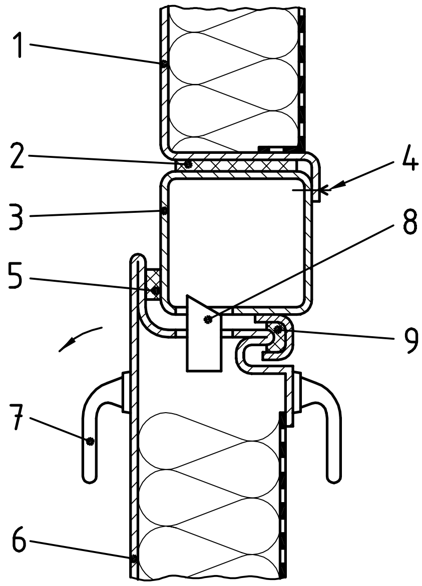
Key

1 Metal floor threshold/seal carrier

2 Replaceable rubber bump strip

3 Door element

Figure A.20 — Examples of a seal between hinged door and floor



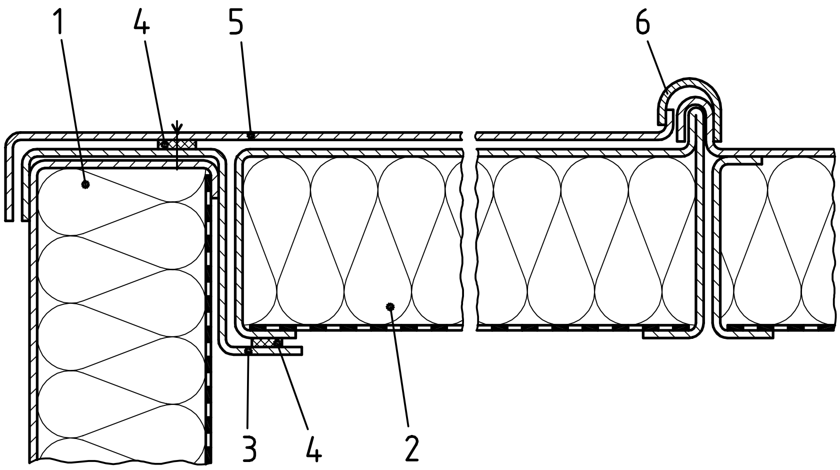
Key

1 Enclosure wall element
2 Self-adhesive rubber seal
3 Door frame
4 Screw connection
5 First door seal
6 Door element
7 Door handle
8 Latch
9 Second door seal

NOTE The second door seal is used for high-performance doors

Figure A.21 — Example of vertical connection of enclosure wall elements to door frame

A.3.3 Weather protection for demountable enclosures



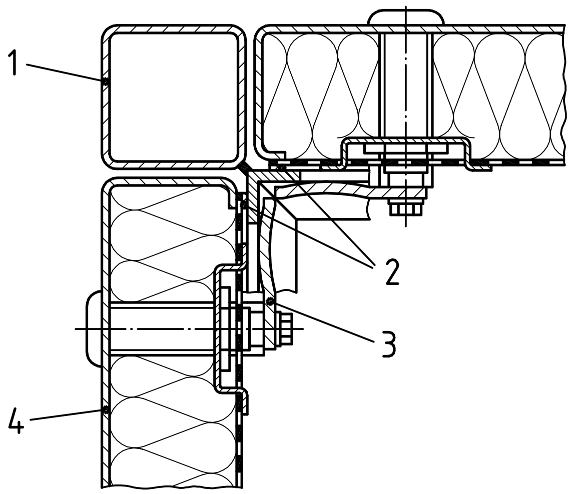
Key

1 Enclosure wall element
2 Enclosure roof element
3 Supporting profile
4 Rubber seal
5 Weather protection skin
6 Weather protection cap

NOTE Roof elements benefit from a gentle slope.

Figure A.22 — Example of connection of enclosure wall and roof elements by special supporting profile

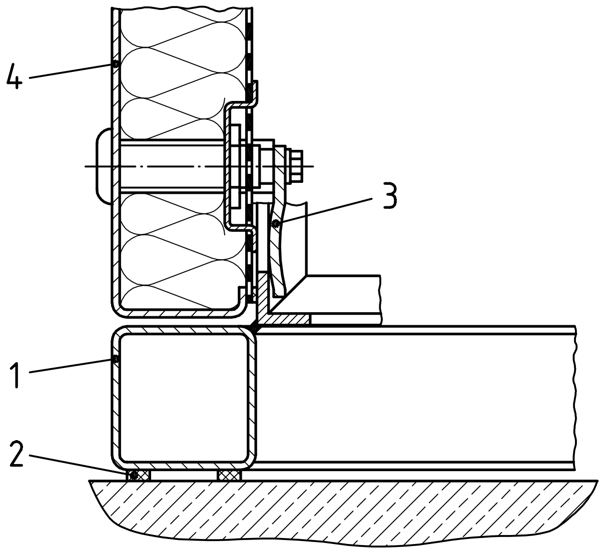
A.3.4 Seals for demountable elements



Key

1 Frame element
2 Rubber seal
3 Square bolt clamp
4 Enclosure roof element

Figure A.23 — Example of connection of enclosure wall and roof elements to enclosure frame by square bolt clamps

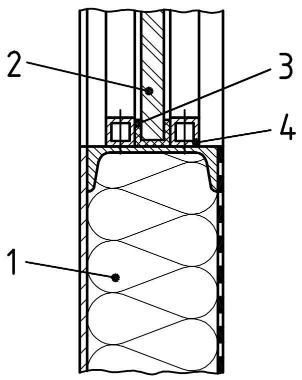


Key

1 Floor frame
2 Rubber seal
3 Square bolt clamp
4 Enclosure wall element

Figure A.24 — Example of vertical connection of enclosure wall elements to enclosure frame by square bolt clamps

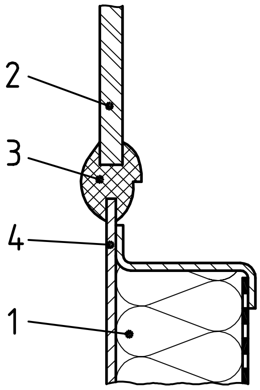
A.3.5 Seals for windows



Key

1 Enclosure wall element
2 Pane, thickness ⩾ 6 mm
3 Rubber seal
4 Mounting profile

Figure A.25 — Example of sealed rectangular pane in windows



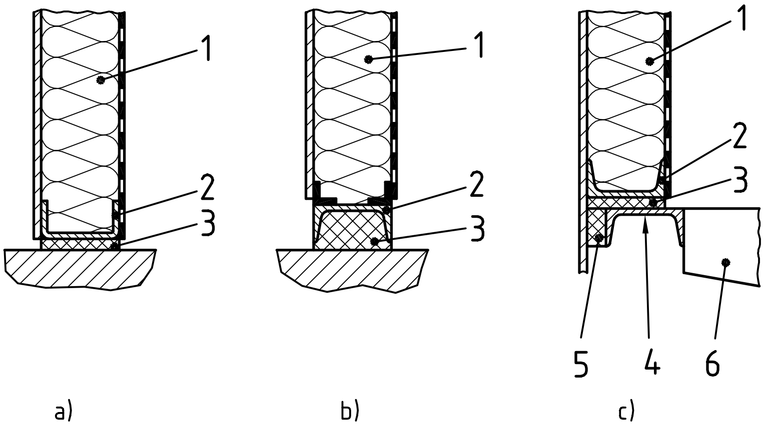
Key

1 Enclosure wall element
2 Pane, thickness ⩾ 6 mm
3 Rubber seal
4 Metal lip

Figure A.26 — Example of sealed contoured window

A.4 Elastic mounts

A.4.1 Single elastic mounts



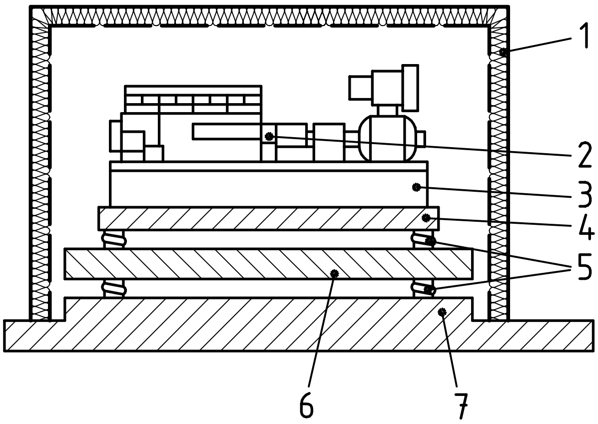
Key

1 Enclosure wall element
2 Mounting profile
3 Soft resilient mounts
4 Supporting element
5 Rubber mount for lateral positioning
6 Main frame

NOTE Example c) is less efficient because of the resilience of the supporting element.

Figure A.27 — Examples of airtight and resilient mounts of enclosure walls

A.4.2 Compound elastic mounts



Key

1 Acoustic enclosure

2 Source of sound and vibration

3 Machine frame

4 Heavy foundation

5 Elastic elements

6 Secondary foundation

7 Floor

Figure A.28 — Example of extreme vibration isolation by compound elastic mounts

Annex B
(informative)

Case studies

B.1 Punch press

A manually fed 60-ton eccentric press is used for producing 0,3 m × 1 m blanks out of 0,28 mm sheet metal. Noise from air-driven blow-off of blanks and impulses from the punch press resulted in an equivalent A-weighted sound pressure level of 101 dB at the operator's ear. The spectral distribution is shown in Figure B.1.

An enclosure was built in two stages. The first stage with a relatively open front provided an A-weighted sound pressure insulation of 11 dB. The second stage with a close shielding in front of the operator improved the insulation to 15 dB. No significant effect on the overall working efficiency of the machine was observed.

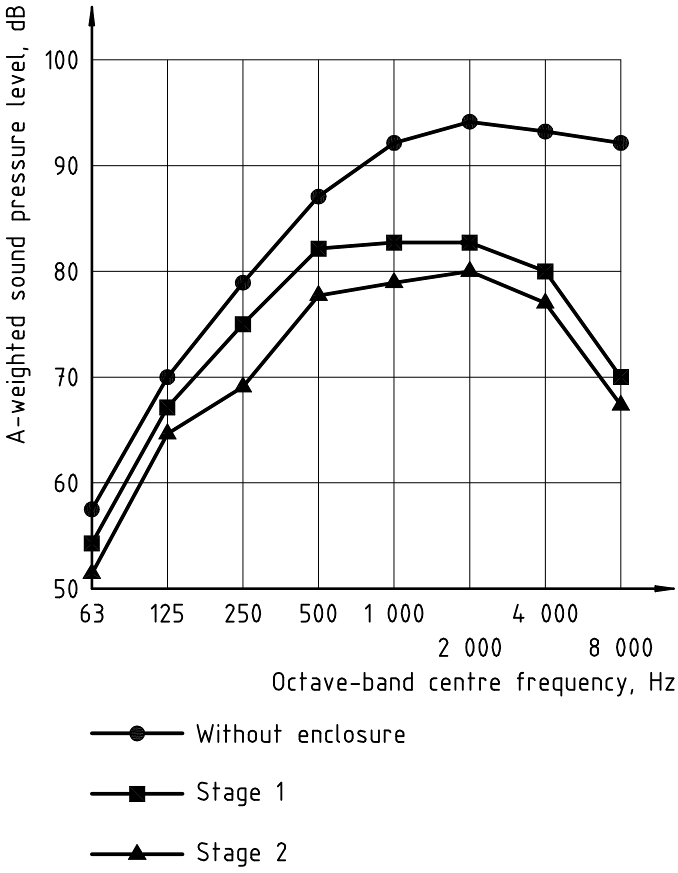
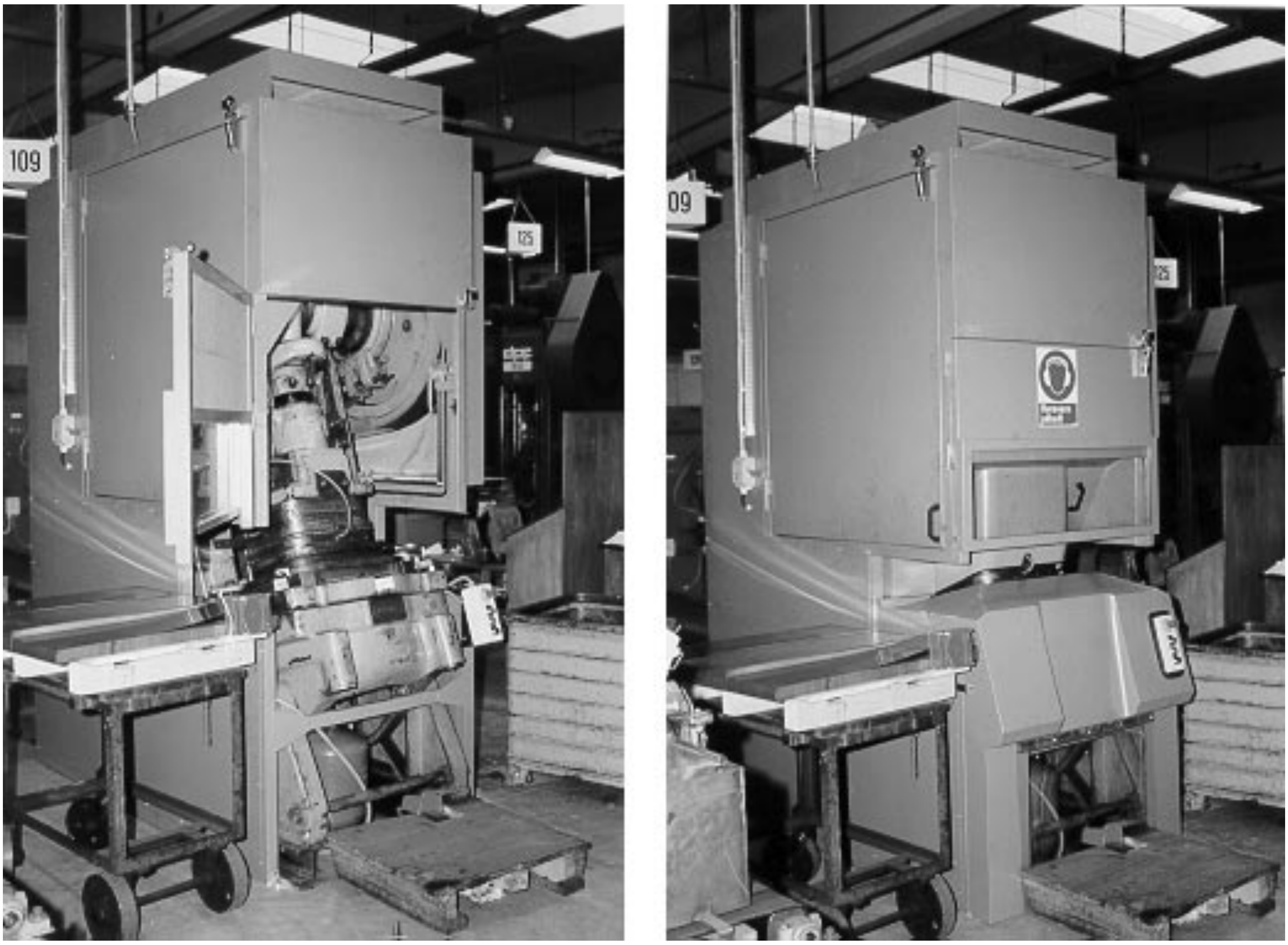


Figure B.1 — Sound pressure level at operator's ear in front of a punch press



NOTE Stage 1 (left) with partially open access doors and final stage 2 (right).

Figure B.2 — Punch press with enclosure

B.2 Outdoor transformer

The enclosure walls are equipped with access doors and panels for inspection and silencers for cooling air openings (centre of Figure B.3). The spectral distribution (fundamental tone at 100 Hz and higher-order harmonics) is shown in Figure B.4. The A-weighted sound power insulation is only 21 dB due to low-frequency sound transmission.

Figure B.3 — Outdoor transformer in enclosure

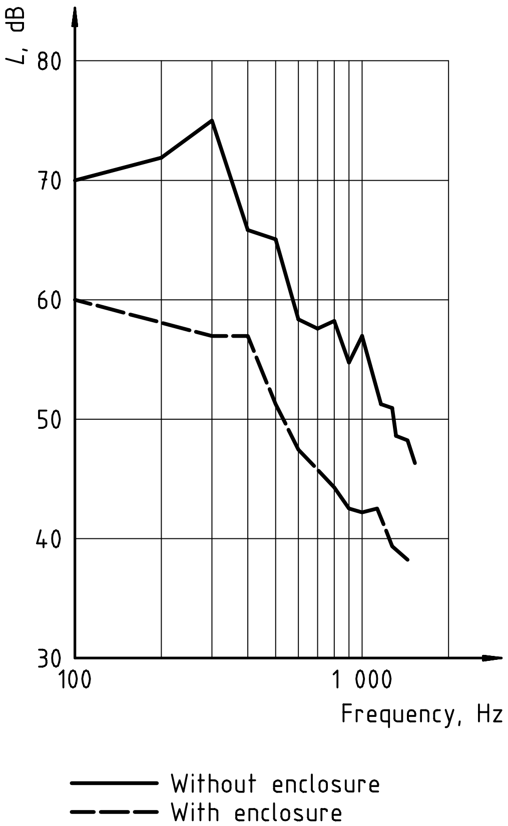


Figure B.4 — A-weighted narrow-band spectra of transformer noise level L

B.3 Saws for long profiles

One common enclosure houses two blade saws cutting aluminium profiles of adjustable length for awnings (see Figure B.6). A rise-and-fall front panel with three windows is electrically driven from the top. The cutting noise is dominated by high-frequency components (see Figure B.5). The A-weighted sound pressure insulation at the work station is 27 dB.

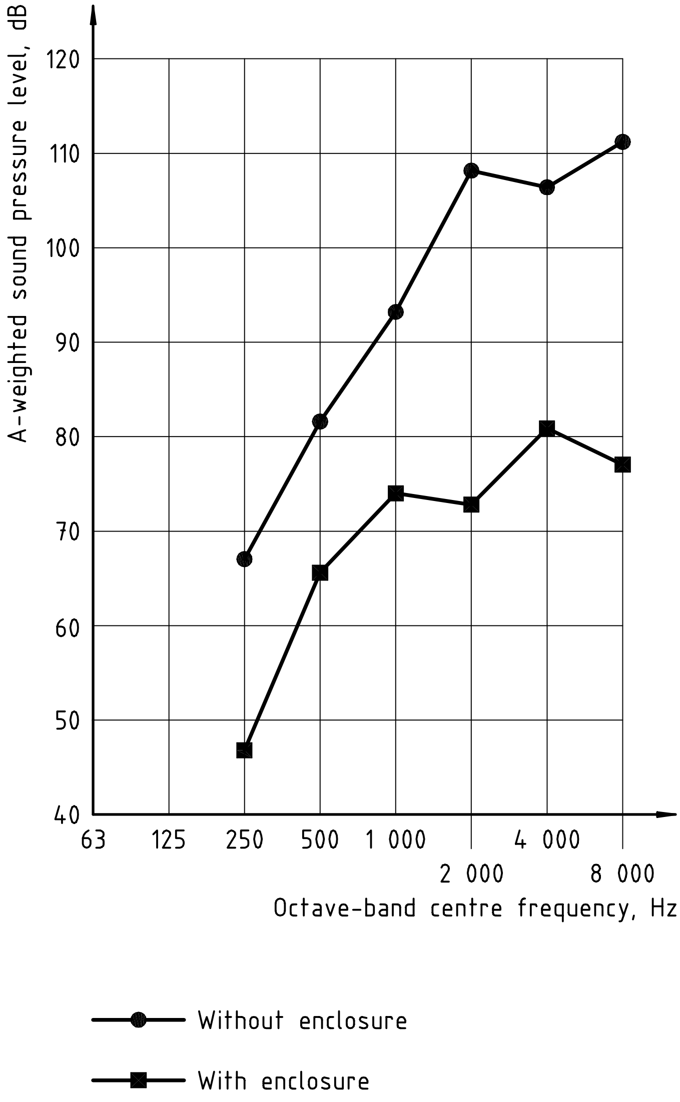


Figure B.5 — Sound pressure level at operator's ear in front of two profile-cutting blade saws

Figure B.6 — A set of two blade saws without (top) and with (bottom) enclosure

B.4 Corrugating machine

The enclosure was built to house machines for cutting, folding, glueing and labelling of cartons. Large openings on both ends of the production line limited the A-weighted sound pressure insulation to 11 dB (see Figures B.7 and B.8).

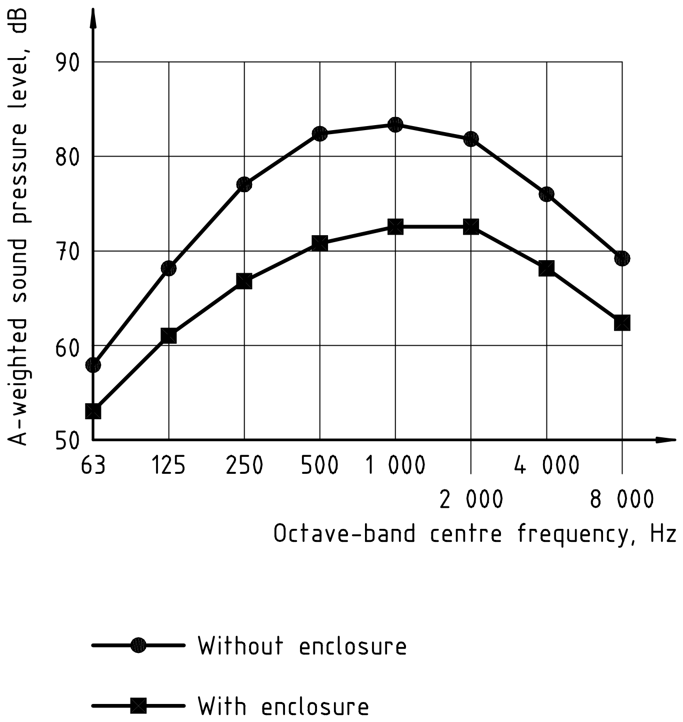


Figure B.7 — Sound pressure level at operator's position close to corrugating machine

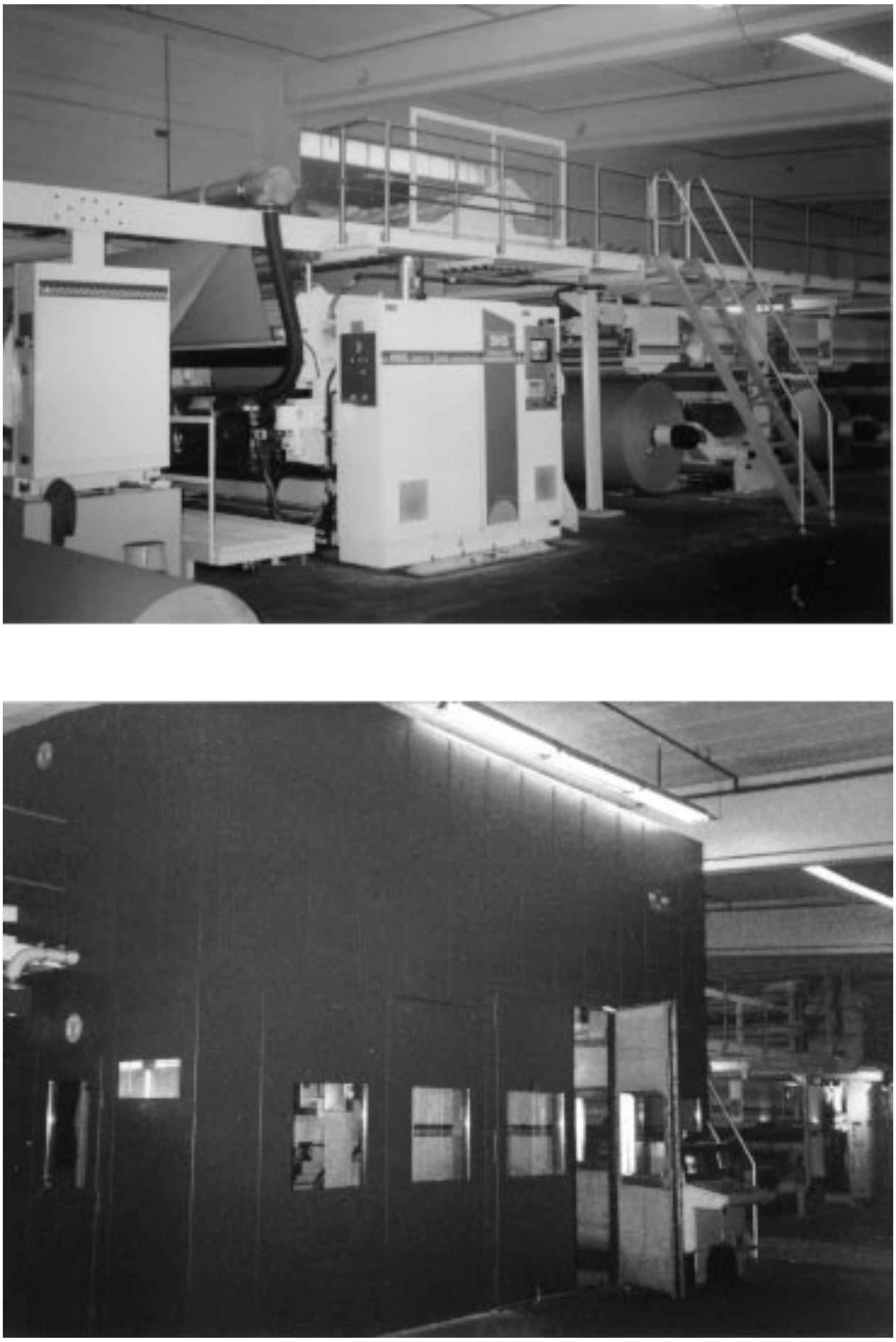


Figure B.8 — Corrugating machine without (top) and with (bottom) enclosure

B.5 Corrugated cardboard production line

In the production line for corrugated cardboard three machines (corrugated module, cassette facer, splicer, and corrugated module facer) were covered by an enclosure (see Figure B.10). Because of sections of the machinery were outside the enclosure, the apparent A-weighted sound pressure insulation achieved was limited to 19 dB (see Figure B.9).

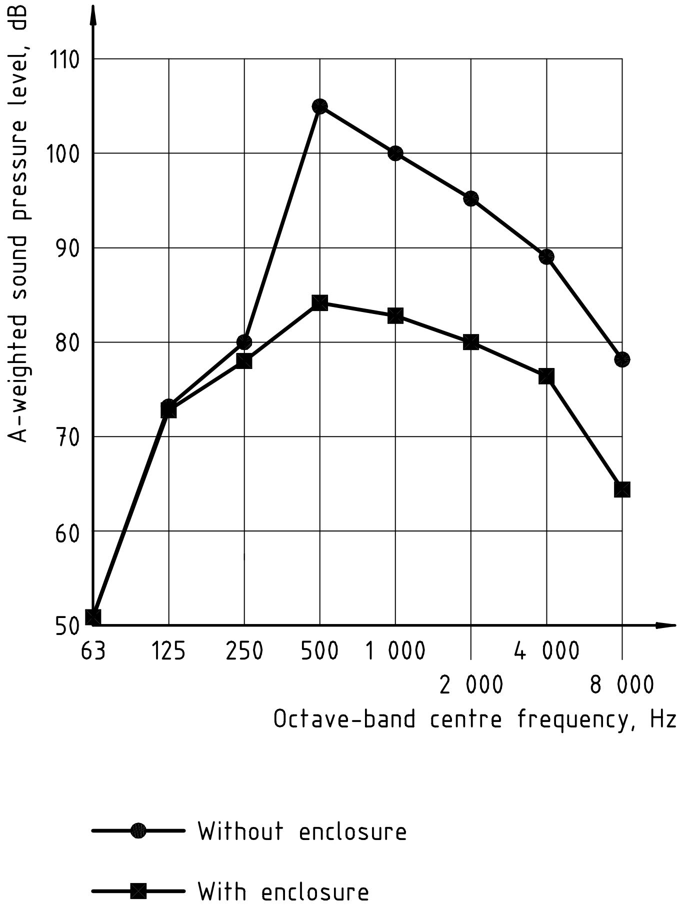


Figure B.9 — Sound pressure level at the operator's position close to the production line for corrugated cardboard

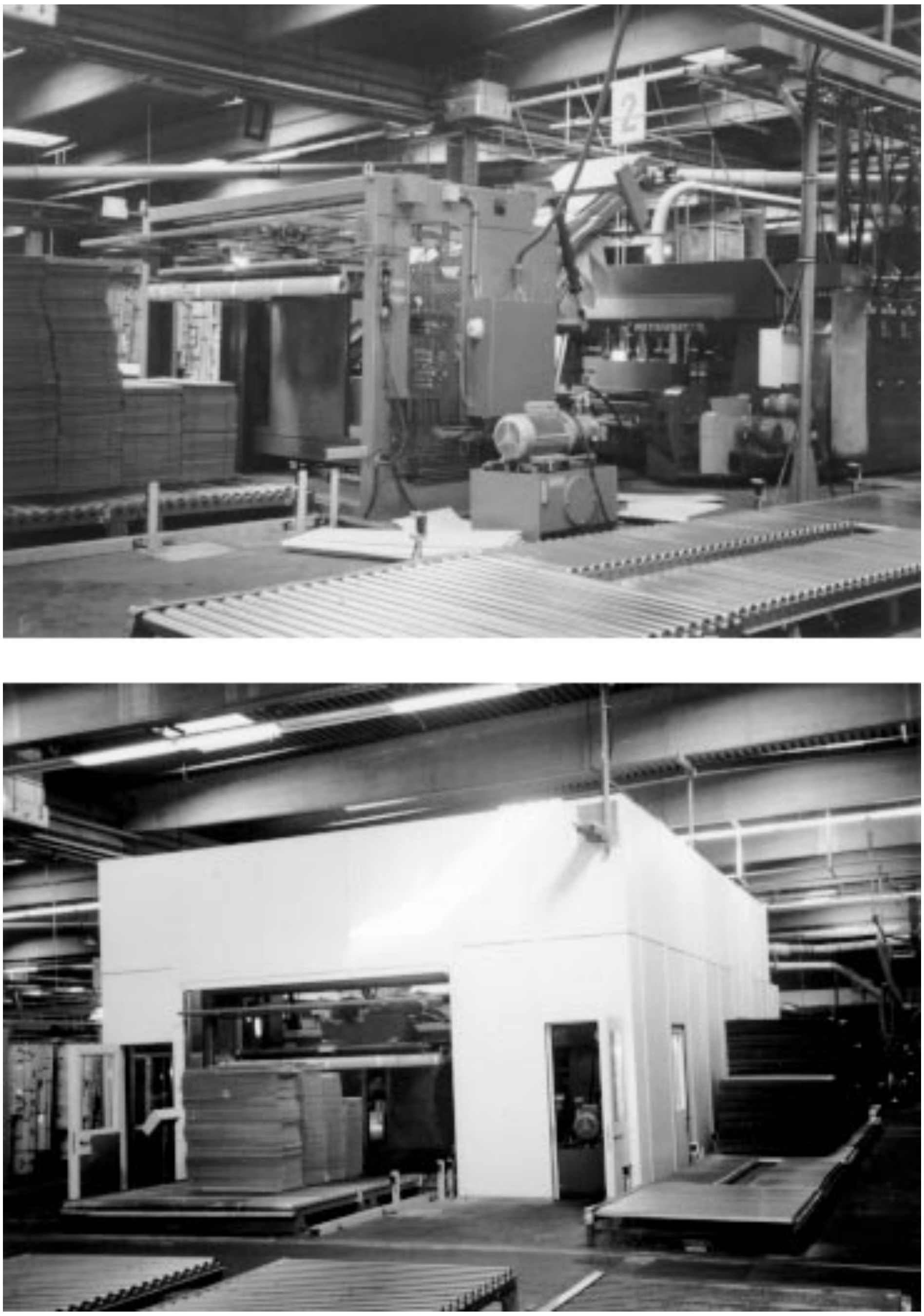


Figure B.10 — Production line for corrugated cardboard without (top) and with (bottom) enclosure

B.6 Gas turbine enclosure

The gas turbine shown in Figure B.11 is mounted on an iron girder frame known as a "skid". The unit is employed mainly for shaft driving an electricity attenuator or a fluid compressor. An intermediate gearbox is mounted on this skid, yielding its own contribution to sound and vibration. The acoustic enclosure sits on this skid with a simple strip of vibration isolation. The sound radiated from the skid sets a limit to the achievable insertion loss of the enclosure.

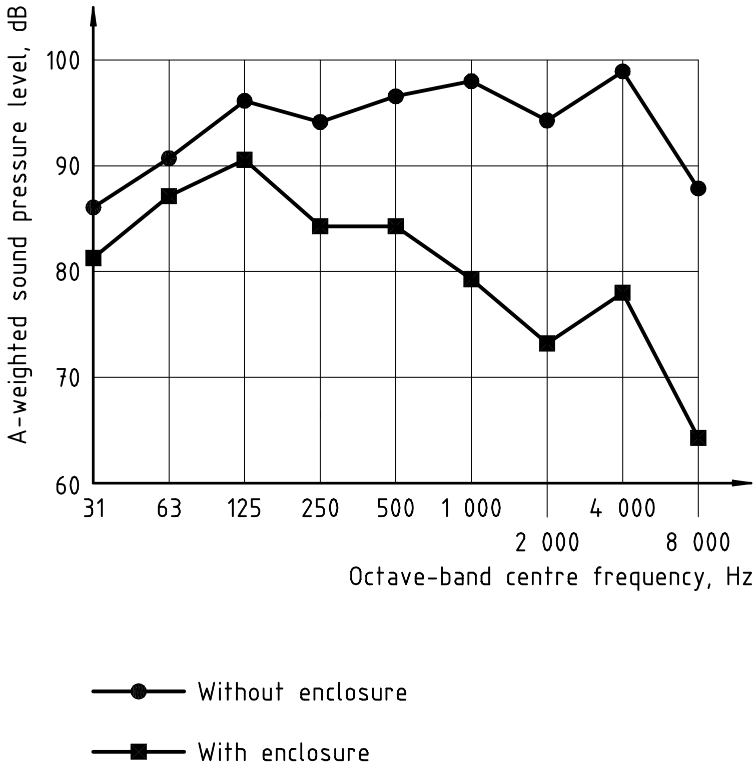
Figure B.11 — Gas turbine with enclosure, access panel open

The construction of the enclosure is based on an outer 1,5 mm steel skin, 100 mm of low-density acoustic infill (35 kg/m^3 resin-bonded glass fibre) and an inner protective sheet of 38 % open-area perforated metal. Since oil spill and mist are considered a risk, the acoustic infill has a thin layer of plastic film immediately behind the perforated metal which is bonded to the infill.

For reasons of easy access, many of the panels are hinged with appropriate rubber seals and compression latches. This functional feature limits the potential performance of the panel.

Heat from the turbine is removed with an attenuated forced ventilation system which forms an integral part of the enclosure. The ducted hot exhaust and inlet aspirated air are interfaced through the enclosure skin via flexible connectors. Special attention has been paid to the inlet air junction as there is a very strong high-frequency tone (in the 4 kHz band) from the inlet compressor blade passage frequency.

The net insertion loss obtained from such an enclosure can be seen from Figure B.12.



NOTE Determined at 1 m distance from the engine before enclosing and from the enclosure wall after enclosing..

Figure B.12 — Space average sound pressure levels determined from measurements

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