* If heat conductivity of heat insulation material depends on the temperature in accordance with formula (4.5a), then equation $\frac{\partial}{\partial x}\left(e^{f_T(T-T_{10})}\frac{\partial T}{\partial x}\right)=0$, has to be solved and limiting states $-\lambda\frac{\partial T}{\partial x}\Big|_{x=0}=\frac{1}{R_i}\left(T_i-T\Big|_{x=0}\right)$ and $-\lambda\frac{\partial T}{\partial x}\Big|_{x=d}=\frac{1}{R_e}\left(T\Big|_{x=d}-T_e\right)$. have to be observed. The solution of the problem is expressed as transcendent equations, and can be solved only numerically. Calculations show that values of heat permeability coefficient obtained in this way do not differ from the data of table 4.4 within rounding-off limits of ±0,01 W/(m^2 . K).

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5. Construction Acoustics

5.1. General Description

Noise is a factor that has a negative impact on people, lowering their capacity to work and even harming their health. Thus one of the tasks of construction acoustics is not only designing acoustics for various public concert halls and theatres, but also protecting people against everyday noise in different kinds of buildings. The developed European countries have national standards ensuring protection of people against a definite noise. A national standard is currently being developed in Latvia. It is planned that in the future more or less uniformed standards will be developed in the European Union.

Types of noises in the buildings are divided according to their cause and its transmission:

1. If the noise emerges in one of the rooms of a building and is transmitted by air through the wall to adjacent room, then the insulation of transmission of this sound can be described as "airborne sound insulation index" or "weighted sound reduction index" – R'w(measured in dB, decibels). This is a number characterising the sound insulation of internal enclosure of the building, taking into consideration both the transmission of sound through the enclosure, as well as through adjacent structures – flanking transmission. In laboratory conditions, excluding flanking transmission possibilities, the sound insulation of internal enclosure of the building is characterised as "airborne sound insulation index" or "weighted sound reduction index" – Rw(dB)".
2. If the noise emerges in the result of impact of various objects with the enclosure of the building, (impact noise), then the insulation of this noise is characterised as "weighted normalized impact sound pressure level $L'_{n,w}$ (dB)." This amount characterises the impact noise insulation in real conditions, including also flanking sound transmissions. In laboratory conditions, excluding flanking transmission possibilities, we get the "weighted normalized impact sound pressure level$L'_{n,w}$ (dB)."
3. If the noise penetrates the building from outside through the external envelope of the building, then it is characterised as "airborne sound insulation index $R'_{fr,\,s,\,w}$ (dB)", describing the insulation between the room and external area.

The described characteristics of building envelope or enclosure depend largely on the frequency, and these dependencies can be measured experimentally both in a particular building, as well as in laboratory conditions (in cases 1 and 2).

5.2. Sound Measurement

The human ear can detect noise pressure from 2 . 10^{-5} – 20 Pa. In order to characterise such a wide range, it is useful to introduce a non-systematical measurement unit decibel (dB) with a formula

$$L = 20 \cdot \lg \frac{p}{p_0} = 10 \cdot \lg \frac{I}{I_0} \qquad (5.1)$$

where p – sound pressure, Pa;

p_0 – hearing threshold, $2 \cdot 10^{-5}$ Pa;

I – sound intensity, W/m^2;

I_0 – zero level sound intensity, $I_0 = \frac{{p_0}^2}{\rho}$ W/m^2;

ρ – air density, 1,2 kg/m^3;

v – velocity of sound transmission in air 343 m/s.

The hearing function of the human ear (human hearing being frequency dependant) is used for determination of the value L. When sound waves fall on the building enclosure, the sound is partially reflected and partially absorbed. The intensity of absorbed sound is determined by sound absorption coefficient

$$\alpha = \frac{I_{abs}}{I_{krit}}, \qquad (5.2)$$

where I_{abs} – sound intensity absorbed;

I_{krit} – sound intensity falling on the construction.

Value α can vary between 0 – 1 and depends largely on the frequency. The equivalent absorption area of the room is calculated by multiplying the areas of surfaces of the separate elements in the room with the sound absorption coefficients of their materials.

$$A = \sum_i \alpha_i \cdot S_i , \qquad (5.3)$$

where S_i – surface areas of the separate elements, m^2;

Equivalent absorption area is equal to an imaginary surface area, which absorbs the sound completely.

If a sound is created within a room, then after shutting it down, the sound dies away gradually. The time needed for the sound level to drop for 60dB is called reverberation time (T). The relationship between reverberation time, absorption area A(m^2) and volume of the room is called Sabine formula

$$T = 0{,}16 \frac{V}{A}. \qquad (5.4)$$

When the sound is transmitted through the building enclosure from one room to another, the sound insulation is characterised by sound insulation index R_w vai R'_w

$$R_w = 10 \cdot \lg \frac{I_1}{I_2} \qquad (5.5a)$$

$$R'_w = 10 \cdot \lg \frac{I_1}{I'_2} \qquad (5.5b)$$

where I_1 – intensity of the sound falling on the enclosure;

I_2 – intensity which has passed through the enclosure without flanking transmissions (in laboratory conditions)

I'_2 – including flanking sound transmissions through other constructions.

As it is more difficult to measure sound intensity than sound pressure, sound level L measurements are used for measuring sound insulation indexes. A sound source is placed in one (primary) room and a receiver in the second (secondary) room. After measuring the reverberation time in the secondary room, it is possible to determine the equivalent absorption area (A2) of the room using Sabine formula, and then sound insulation indexes using formulas

$$R'_w = L_1 - L'_2 + 10 \cdot \lg \frac{S}{A_2}. \quad (5.6a)$$

$$R_w = L_1 - L_2 + 10 \cdot \lg \frac{S}{A_2}. \quad (5.6b)$$

where L_1, L_2 – average sound levels in the rooms; L'_2 – including flanking transmissions;

S – surface area of the enclosure, m^2.

As R'_w and R_w values are frequency dependent, then a standardized frequency curve is used for determination of the average index.

The weighted normalized impact sound pressure level is measured similarly as sound insulation index. The difference is that the impact sound is generated by a special impact sound generator. This generator has five counterweights (500 g each), which one by one fall on the ground from 4 cm height 10 times a second, generating an impact sound in the primary room. Index $L'_{n,w}$ is determined using formula

$$L'_{n,w} = L_2 + 10 \cdot \lg \frac{A_2}{A_0} \; ; \; A_0 = 10 \; m^2. \quad (5.7)$$

Similar as for R'_w values, a standardized frequency curve is used for determining the average $L'_{n,w}$ value.

5.3. Sound Absorption and Insulation

The sound absorption qualities of different materials are used in practice for creating sound insulation layers. The sound insulation values set in the currently elaborated Latvian Construction Regulations – Construction Acoustics are sound insulation index R'_w, weighted standardized impact sound pressure level $L'_{n,w}$, and minimal airborne sound insulation index $R'_{tr,s,w}$ depending on the level of external noise. Airborne sound insulation indexes must not be lower than indicated in the tables of Appendixes [2] 2 and 3, but the weighted standardized impact sound pressure level must not exceed the levels indicated in the tables. Appendixes [2] 2 and 3 of the Construction Regulations are shown in Tables 5.1 and 5.2.

Table 5.1 Sound insulation for internal building enclosures

Table 5.1

No.	Type of buildings and rooms	Sound insulation requirements	Notes
1.	**2.**	**3.**	**4.**
	Medical and health care institutions	**sound insulation index R'_w(dB)**	
1.	Between residential rooms within apartments	54	Requirements apply to all types of dwelling houses
2.	Between residential rooms within apartments and common premises, office premises	54	Common premises are staircases, lobbies, corridors and available attic and basement premises

3.	Between apartments and premises with noise sources with the maximal noise level of: • up to 80 dBA • 81 – 90 dBA • 91 – 100 dBA	 56 66 76	 Ventilation cameras, engine-rooms, garage Cafes, bars, shops, etc. Restaurants, sports arena, etc.
4.	Between rooms within an apartment	45	Ceilings between the rooms in two-level apartment, partitions without doors between the rooms, between the kitchen and rooms
5.	Apartment entrance doors or door systems: a) leading directly to a stairway b) leading to a foyer separated from the stairway with a wall	 35 27	
		weighted standardized impact sound pressure level $L'_{n,w}$(dB)	
6.	Between apartments	54	Requirements do not apply to the bathroom, toilet, sauna, and similar premises
7.	Between the balcony, stairway, corridor, toilet and apartment	 58	
8.	Between apartment and premises with noise sources	48	Additional measures for reducing the transmission of structural noise should be taken if necessary
9.	Between residential rooms of a two-level apartment	63	
	2. Temporary accommodations	**sound insulation index R'_w(dB)**	**Temporary accommodations are hotels, camping places, guest houses, tourism and recreation centres**
10.	Between bedrooms (hotel rooms)	52	
11.	Between bedrooms (hotel rooms) and common premises (stairways, corridors, lobbies, lunchrooms)	52	
12.	Between bedrooms (hotel rooms) and premises with noise sources with maximal noise level of: • up to 80dBA • 81 - 90 dBA • 91 -100 dBA	 56 66 76	 Ventilation cameras, engine-rooms, garage Cafes, bars, shops, etc. Restaurants, sports arena, etc.
13.	Between separate rooms within a hotel apartment	44	
14.	Doors or door systems between bedroom (hotel room) and stairway or common corridor	32	
		weighted standardized impact sound pressure level $L'_{n,w}$(dB)	
15.	Between bedrooms (hotel rooms)	57	Requirements do not apply to balconies, bathrooms and toilets of dwelling premises

16.	Between common premises (balcony, stairway, lobby, corridor, lunchroom) and bedroom (hotel room)	55	
17.	Between premises with noise source (technical service and maintenance, restaurant, kitchen premises) and bedroom (hotel room)	50	Additional measures for reducing the transmission of structural noise should be taken if necessary
	Social care and rehabilitation institutions		
	It is advisable to apply the requirements of apartments to residential rooms of rehabilitation institutions and old people's homes. Minimal sound insulation requirements should be chosen according to points 10-17 (temporary accommodation)		
	Medical and health care institutions	**sound insulation index R'_w(dB)**	
18.	Between wards, as well as between wards and similar rooms	52	
19.	Between wards, similar rooms and common premises (stairways, corridors, lobbies, lounges, canteens)	53	Rooms similar to wards are examination and procedure rooms, as well as doctors' consulting rooms
20.	Between operating rooms; between operating rooms and other premises (except premises with equipment causing noise)	55	
21.	Between intensive therapy wards, between intensive therapy ward and corridor	37	If they have windows
22.	Between wards, similar premises and kitchen, technical service and maintenance premises	60	
23.	Between special premises (e.g. hearing examination room) and other premises	62	
24.	Doors, windows or their systems a) between wards and corridor b) between intensive therapy and corridor c) between hearing examination rooms and other	 32 27 36	
		weighted standardized impact sound pressure level $L'_{n,w}$ (dB)	
25.	From wards and similar rooms to other premises	57	In points 25 to 27 operating rooms are also included in wards and similar rooms
26.	From common premises (stairways, corridors, lounges) to wards and similar rooms	57	
27.	From premises with a noise source (kitchens, technical service and maintenance premises) to wards and similar rooms		Additional measures for reducing the transmission of structural noise should be taken if necessary
	5. Buildings of educational and science establishments	**sound insulation index R'_w (dB)**	
28.	Between classrooms in a school, between classrooms and similar rooms, between above-mentioned rooms and common premises (stairways, corridors, foyers, lobbies)	54	Requirements of points 28 – 37 do not apply to educational establishments for children with hearing problems. Rooms similar to classrooms are studies, and other similar study rooms

29.	Between large auditoriums (more than 100 places), between large auditoriums and other study rooms	57	
30.	Between large auditoriums and common premises (stairways, corridors, foyers, lobbies)	55	
31.	Between classrooms, studies, auditoriums and special classrooms	60	
32.	Between special classrooms and common premises (stairways, corridors, foyers, lobbies)	57	Special classrooms are music rooms, workshops and sports halls
33.	Between classrooms, studies, auditoriums and kitchens, canteens	55	
34.	Doors, windows or their systems: a) between classrooms, similar rooms and corridors b) between classrooms and similar rooms (except music rooms)	 30 32	
35.	Between group rooms and sleeping rooms in pre-school institutions	50	
36.	Between group rooms, sleeping rooms and kitchen in pre-school institutions	52	
37.	Between group rooms, sleeping rooms and music room or sports hall in pre-school institutions	55	
38.	Doors from pre-school group rooms or sleeping rooms to corridor	30	
		weighted standardized impact sound pressure level $L'_{n,w}$ (dB)	
39.	From classroom (study) to another classroom (study)	60	Additional measures for reducing the transmission of structural noise should be taken if necessary
40.	From common premises (stairways, corridors, foyers, lobbies) to classrooms (studies)	58	
41.	From special classroom to classroom (study, auditorium) or another special classroom	50	
42.	From a large auditorium to study room or another auditorium	48	
43.	From pre-school group-room, sleeping room to other group rooms and sleeping rooms	60	
44.	From common premises (corridor, stairway, foyer) to group rooms and sleeping rooms, from kitchen to group rooms and sleeping rooms in pre-school institutions	55	
45.	From pre-school music rooms, sports halls to group rooms and sleeping rooms	53	
	6. Administration buildings	**sound insulation index R'_w(dB)**	
46.	Between offices, between offices and stairways, corridors, foyers, lobbies	50	

47.	Doors, windows or their systems: a) from offices to stairways, corridors,foyers, lobbies; b) from halls to stairways, corridors, foyers, lobbies.	 30 36	
48.	Between offices and premises with noise sources with the maximal noise level of: • up to 80 dBA • 81 – 90 dBA • 91 – 100 dBA	 52 62 72	 Kitchens, technical, staff premises Cafes, bars, shops, etc. Restaurants, sports arenas, etc.
		weighted standardized impact sound pressure level $L'_{n,w}$ (dB)	
49.	Between court, meeting rooms and corridors, stairways, foyers, lobbies, office and technical premises	55	
50.	From office to office, from common premises to offices	60	
51.	From premises with a noise source (kitchens, technical service and maintenance premises) to halls	50	
	7. Culture and entertainment establishments	**sound insulation index R'_w(dB)**	
52.	Between halls, library reading rooms and foyers or hallways	57	
53.	Between halls, library reading rooms and unused attics, basements and warehouses	52	
54.	Between halls, library reading rooms and premises with noise sources with the maximal noise level of: • up to 80 dBA • 81 – 90 dBA • 91 – 100 dBA	 60 70 80	Additional measures for reducing the transmission of structural noise should be taken
55.	Between halls, library reading rooms and offices	55	
56.	Between auditoriums and conference halls	62	
57.	Between theatre and concert halls	69	
58.	Between cinema halls	75	
		weighted standardized impact sound pressure level $L'_{n,w}$ (dB)	
59.	From premises with noise sources (technical, engine rooms, etc.) to hall	48	
60.	From foyer, lobbies, hallways and offices to halls	53	
61.	From hall to hall	50	
62.	From halls to offices	63	

	8. Sports buildings		
63.	Between sports halls, swimming pools and foyer, lobbies or hallways	45	
64.	Between sports halls, swimming pools and bars, cafes	48	
65.	Between sports halls, swimming pools and offices	52	
66.	From sports halls, swimming pools to cafes, bars and offices	63	

Optional values of sound insulation indexes $R'_w/L'_{n,w}$ (dB) for building enclosures

Table 5.2

Acoustic regimes of bordering premises	Protection level of insulated premises		
	low	medium	high
1. silent	42/65	47/60	52/55
2. low noise level	47/60	52/55	57/50
3. noisy	52/55	57/50	62/45
4. very noisy	57/50	62/45	67/45

The R'_w index values given in the table indicate the necessary sound insulation between premises in vertical and horizontal direction. $L'_{n,w}$ index values indicate the necessary impact sound insulation in all directions (vertically, horizontally, diagonally). The compliance with impact sound insulation requirements is determined for premises with floor area of at least 2.5 m^2. Information sources [1] describe 4 types of border constructions, which can be used to reach the needed sound insulation level. Forth of these types corresponds to panels where heat insulation material (at the same time being sound insulation material) is from both sides covered with light facing – plasterboard or metal sheets. The sound insulation index R'_w of these constructions can exceed 50 dB with mineral wool core and 40 dB with polystyrene foam core, if the thickness of insulation layer >100 mm. Similar experimental measurements for samples with glass wool core are shown in information sources [3].

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