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ACOUSTIC PROBLEMS IN MULTI-STOREY RESIDENTIAL BUILDINGS RAISED BY MEANS OF INDUSTRIALIZED TECHNOLOGY METHODS

JERZY SADOWSKI

Building Research Institute (ITB) Warsaw, Filtrowa 1

The paper comprises results of subjective (social survey) and objective tests (measurements) of the acoustic climate in multi-storey buildings raised by industrialized methods. On the basis of performed tests the paper also discusses factors influencing the sound insulation in dwellings, as well as opinions concerning designing.

1. Introduction

People's desire to own a dwelling has recently become very common in almost all countries despite of their social status. The problem, however, is solved differently in different countries. The most essential task is to build a great number of dwellings in the possibly shortest time. It is such an urgent problem that sometimes even economic factors become less important. The number of new dwellings built in Europe in 1975 exceeded a number of 8 dwellings/1000 inhabitants. In Poland – 5.8 dwellings/1000 inhabitants. This certainly does not satisfy the growing demand of the population. That is why in Poland it was planned to build in 1979 340000 dwellings, index – 9.5 dwellings (1000 inhabitants). The realization – 274000. Population's demands are however greater, about 400000 dwellings every year. It requires further speeding-up of the tempo of rising buildings. According to specialists' opinions it is possible only in such a case, when buildings are built by means of industrialized methods as multi-storey residential buildings. At this point it is essential not to worsen the quality of buildings with such a big tempo of building rising.

By quality we also mean a proper acoustic climate which depends on many factors discussed further in this paper.

All multi-storey residential buildings raised by industrialized technology can be divided into five groups:

a) multi-block buildings built from blocks having with from 90 to 120 cm (or wider with a mode of 30 cm) and with length such as the length of a storey and in case of partitions — with of a bearing tract of a building;

b) framework buildings built from concrete frames — prefabricated or poured, or steel frames filled with light block walles or partitions;

c) monolithic, performed from poured concrete in climbing shuttering;

d) multi-block buildings performed from concrete large blocks having the dimensions of the whole room;

e) multi-spatial element buildings formed from spatial elements comprising one or two rooms (walls and partitions), completely equipped.

The above specification does not include buildings raised according to traditional methods which are not a subject of this description.

2. Subjective and objective tests on the acoustic quality of dwellings

As it is well known there are large discrepancies between the walls and partitions, insulation values measured in a laboratory and in a building. These discrepancies are caused by flanking transmission and very often by bad quality of assembling leakages at joints, bad fillings of assembly apertures partitions, small damages of elements. The value of acoustic insulation of partitions in buildings is always smaller than measured in a laboratory. Considering a common construction of buildings by means of industrialized methods it is necessary to have not only concerning measured transmission loss of these partitions but also a subjective evaluation of the insulation by inhabitants. Also, it is necessary to know to what extent a given partition meets the standard requirements and how far this is accepted by the inhabitants. In order to explain all these questions the Department of Acoustics, ITB [1] has performed tests on objective and subjective acoustical insulation of partitions in residential buildings which are raised according to the most common industrialized systems (Figs. 1–4), namely:

a) multi-block systems: “Szczeciński” and W-70,

b) monolithic system,

c) ferroconcrete frame system.

Objective tests (measurements) performed according to PN-68/B-02154 and ISO R 140 in many buildings of the above mentioned systems have proved that partitions and interdwelling walls satisfy the standard requirements ($E_L \geqslant -1$, $E_T \geqslant 0$). Solely, in the frame system (“Rama H”) the insulation index of inter-dwelling partitions E_L was lower by about 4 dB from the required values. The following values were measured: transmission loss of floors and ceilings and interdwelling partitions R, and insulation D_N between kitchens, bathrooms, ante-chambers (with installation pipes)

$$R'_w = L_1 - L_2 + 10 \log S/A \quad [\mathrm{dB}], \tag{1a}$$

while

$$D_N = L_1 - L_2 + 10 \log A/A_0 \quad [\mathrm{dB}], \tag{1b}$$

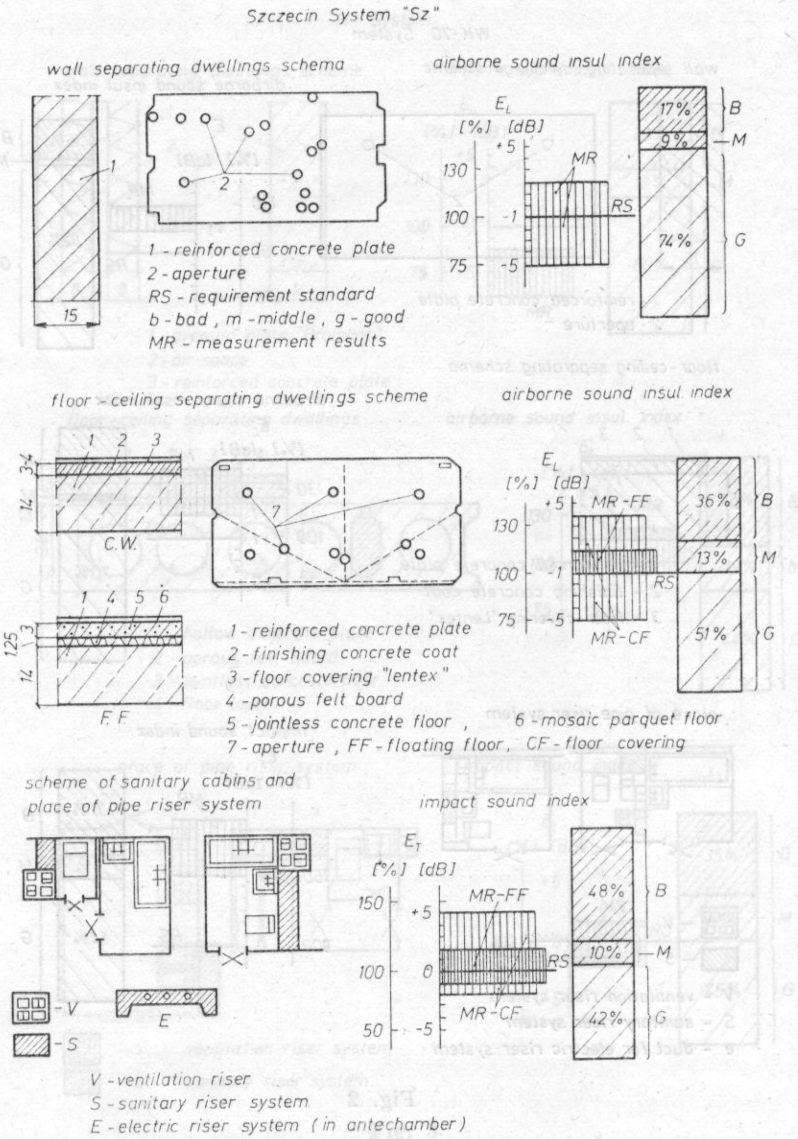

Szczecin System "Sz"
wall separating dwellings schema
airborne sound insul index
1 - reinforced concrete plate
2 - aperture
RS - requirement standard
b - bad , m - middle , g - good
MR - measurement results
E_L
[%] [dB]
MR
RS
17%
9%
74%
B
M
G
floor - ceiling separating dwellings scheme
airborne sound insul index
C.W.
F.F.
1 - reinforced concrete plate
2 - finishing concrete coat
3 - floor covering "lentex"
4 - porous felt board
5 - jointless concrete floor , 6 - mosaic parquet floor
7 - aperture , FF - floating floor, CF - floor covering
MR - FF
MR - CF
36%
13%
51%
scheme of sanitary cabins and
place of pipe riser system
impact sound index
E_I
48%
10%
42%
V - ventilation riser
S - sanitary riser system
E - electric riser system (in antechamber)

Fig. 1

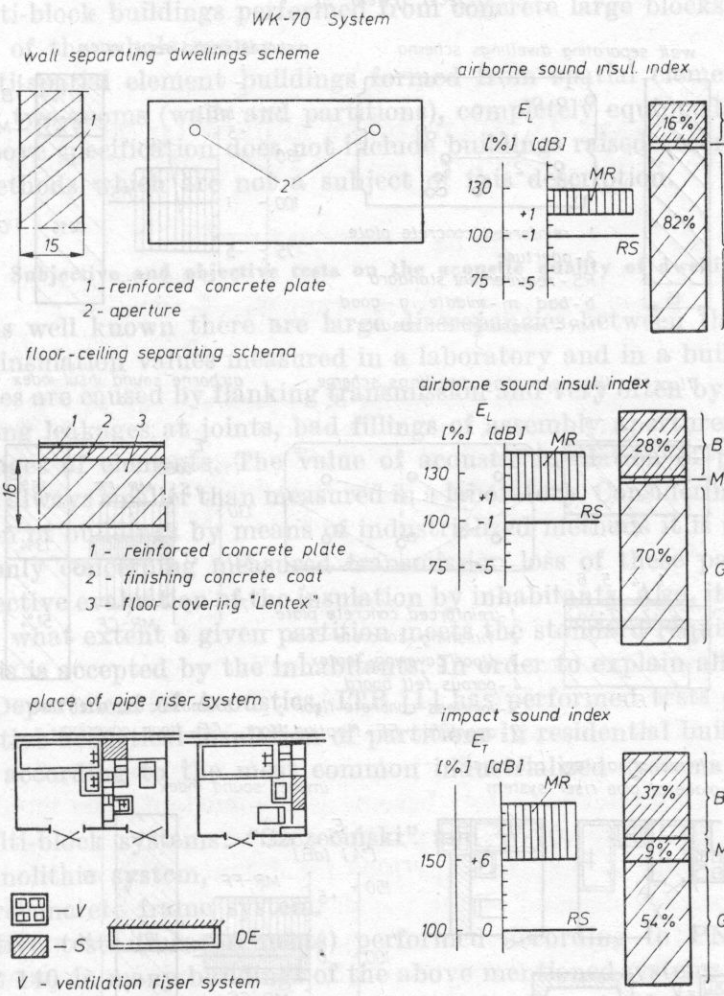

WK-70 System
wall separating dwellings scheme
airborne sound insul. index
15
E_L
[%] [dB]
130
100
75
+1
-1
-5
MR
RS
16%
82%
B
M
G
1 - reinforced concrete plate
2 - aperture
floor-ceiling separating schema
airborne sound insul. index
1 2 3
16
E_L
[%] [dB]
130
100
75
+1
-1
-5
MR
RS
28%
70%
B
M
G
1 - reinforced concrete plate
2 - finishing concrete coat
3 - floor covering "Lentex"
place of pipe riser system
impact sound index
E_T
[%] [dB]
150
100
+6
0
MR
RS
37%
9%
54%
B
M
G
– V
– S
DE
V ventilation riser system
S sanitary riser system
e - duct for electric riser system

Fig. 2

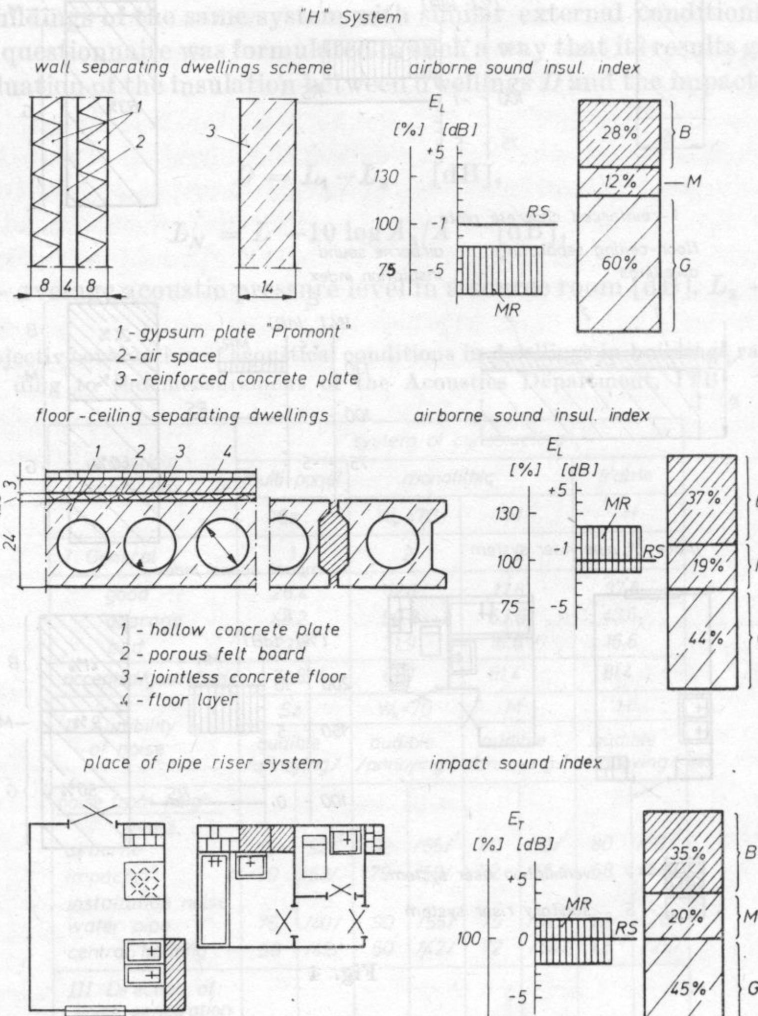

"H" System
wall separating dwellings scheme
airborne sound insul. index
1
2
3
8 4 8
14
E_L
[%] [dB]
+5
130
100 -1
75 -5
RS
MR
28%
12%
60%
B
M
G
1 - gypsum plate "Promont"
2 - air space
3 - reinforced concrete plate
floor-ceiling separating dwellings
airborne sound insul. index
1 2 3 4
125
3
24
E_L
[%] [dB]
+5
130
100 -1
75 -5
MR
RS
37%
19%
44%
B
M
G
1 - hollow concrete plate
2 - porous felt board
3 - jointless concrete floor
4 - floor layer
place of pipe riser system
impact sound index
E_T
[%] [dB]
+5
100 0
-5
MR
RS
35%
20%
45%
B
M
G
-V ventilation riser system
-S sanitary riser system

Fig. 3

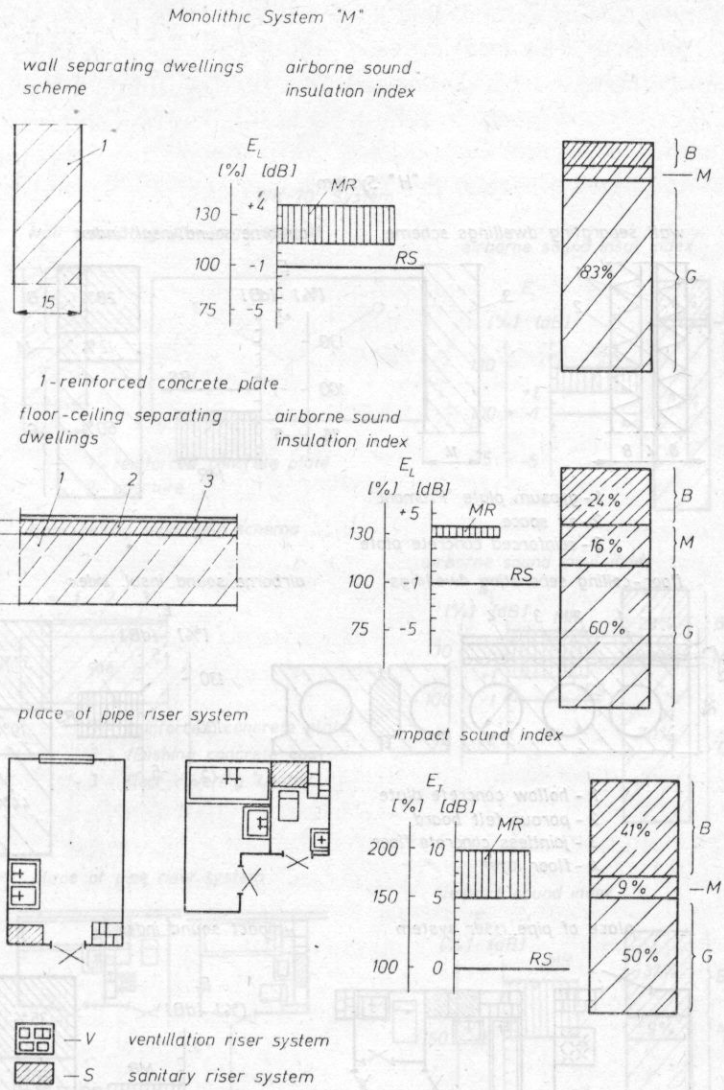


Fig. 4

where L_1, L_2 — average acoustic pressure levels in source and receiving rooms in dB, A — acoustic absorption of a room [m²], S — partiti onarea [m²], A_0 — 5 m² for kitchen and antechamber, 3 m² for bathroom (correction 10 log A/A_0 was neglegibly small).

The measurement results were presented according to PN-70/B-02151 as indices E_L (partitions, walls), E_T (floors, ceilings), E_{LE} (places with installation pipes) and at the same time there are the following dependances between these indices and the old indices in ISO R 717 for laboratory measurements $-I_a =$

$=54+E_L$; for field measurements $-I_a=52+E_L$, $I_a=52+E_{LE}$; despite of a measurement point $-I_i=68-E_T$.

In the same buildings in which the insulation of partitions was measured subjective measurements were performed according to a special social survey, initially checked in some buildings. And so, 160–200 dwellings were tested in different buildings of the same system with similar external conditions. The social survey questionnaire was formulated in such a way that its results gave a statistical evaluation of the insulation between dwellings D and the impact level L_N, and

$$D = L_1 - L_2 \quad [\text{dB}], \tag{2a}$$

$$L_N = L - 10 \log A_0/A \quad [\text{dB}], \tag{2b}$$

where L_1 – average acoustic pressure level in a source room [dB], L_2 – average

Table 1. Subjective evaluation of acoustical conditions in dwellings in buildings raised according to the measurement of the Acoustics Department, ITB

acoustical condicions	system of constructing							
	multi-panel		monolithic				frame	
	Sz		W_k=70		M		H	
I. General	1		2		3		4	
good	26.4		17.6		17.8		37.8	
avarage	48.2		50.3		63.6		43.6	
bad	23.4		31.9		16.6		16.6	
accepted/good+bad/	74.6		68.1		81.4		81.4	
II. Audibility of noise	Sz		W_k=70		M		H	
	audible	/annoying/	audible	/annoying/	audible	/annoying/	audible	/annoying/
noise from neighbours								
airborne	75	/52/[1]	92	/65/[1]	80	/52/[1]	80	/50/[1]
impact	70	/53/	79	/59/	72	/55/	68	/58/
installation noise								
water pipe	76	/40/	90	/55/	75	/52/	52	/26/
central heating	58	/42/	60	/42/	72	/56/	48	/25/
III. Direction of noise penetration								
airborne noise								
vertical	70	/47/	88	/62/	75	/48/	70	/42/
horizontal	31	/22/	31	/25/	22	/11/	42	/31/
impact noise								
vertical	66	/51/	70	/55/	66	/55/	60	/35/
horizontal	20	/14/	30	/22/	20	/17/	21	/14/
installation noise								
vertical	71	/38/	89	/50/	76	/50/	46	/21/
horizontal	13	/9/	21	/13/	7	/5/	17	/7/

1/ numbers in brackets denote % of inquired /surveyed/ people describing noise as annoying pressure level of the noise coming from neighbours [dB], A — absorption of a room [m²], A_0 — reference acoustic absorption, $A_0 = 10$ m².

Also the L_N values were measured in buildings.

Table 1 illustrates subjective evaluation of the acoustic conditions in buildings representing each system. Acceptable conditions (a sum of good and average evaluations) occur from 68 % for system WK-70, to 81 % for system H. Surveyed people evaluate 17.8 % of the dwellings in the WK-70 system as good and 37.8 % for system H. The inquired (surveyed) people stated that 14 % of the dwellings in the "Rama H System" and 32 % for the WK-70 system had bad conditions. The vertical direction is a dominating direction of noise penetration from dwelling to dwelling. It clearly shows that floors, ceilings and installation ducts are the greatest problem considering acoustic insulation. Analysis of measurement results (partially shown in Table 1) has proved that system WK-70 was evaluated negatively in view of intensive noise exposure of the dwellings adjacent to installation lines. The best subjective evaluation was attained by ferroconcrete walls 15 cm, particulary in the M and WK-70 systems (Tab. 2).

Table 2. Number of inquired people in %, complaining of audiobility of noise annoyance penetrating into residential rooms along partitions or walls, according to measurements of Dep. of Acoustics, ITB

constructing system	construction of floor, ceiling panels	construction of floor	audibility (noise annoyence) %		construction of walls	noise audibility (annoyence) %
			airborne	impact		
Sz	ferroconcrete panel 14 cm	30% of panels-cement setting coat + floor covering and 50% floating floor	49/35/[1]	59/49/[1]	ferroconcrete panel 15 cm	26/19/[1]
W_k-70	ferroconcrete panel 16 cm	cement setting coat + floating floor	30/28/[1]	45/35/[1]	as above	18/16/[1]
M	as above	as above	40/24/[1]	50/40/[1]	as above	15/10/[1]
H	ferroconcrete channel 24 cm /Żerań/	floating floor	56/38/[1]	56/38/[1]	ferroconcrete panel 14 cm or 2 gypsum boards in 6 cm distance	40/27/[1]

1/ numbers in brackets denote % inquired people describing the noise as annoying

Worse evaluation was attained by the same walls in the Sz system, what is clearly evidenced by large discrepancies in the indices E_L measured for these walls (from −5 to +2). This is caused by insufficient quality of performance (bad placing of concrete at joints and assembly apertures). Measurements show that properly built ferroconcrete walls of 15 cm have the index E_L values from +1 to +4 dB and are accepted by 80–90 % of the inhabitants. Faulty performance worsens the insulation of these walls even to $E_L = -5$ dB and the % of people satisfied with the conditions falls below 70. Double gypsum walls 7 cm with distance of 7 cm and a ferroconcrete wall of 14 cm have the index E_L value from -2 to -7 dB. Only 52 % of the inquired inhabitants evaluated these walls positively. The negative evaluations increased up to 28 % after carrying measurements for the walls and it results that at index $E_L \simeq -1 (I_a \simeq 51$ dB) $-$ 20 to 25 % of the inquired persons evaluated these walls as decidedly bad. The analysis has shown that in order to decrease the number of unsatisfied inhabitants to 15 % the index E_L for an inter-dwelling wall would have to be equal $+2$ dB ($I_a = 54$ dB). Inter-dwelling floor and ceiling panels were evaluated subjectively considerably tower than the walls (Tab. 2), from 9 to 13 % negative evaluations more than for the walls in relation to the airborne noise insulation; 29–48 % negative evaluations due to the penetration of impact noise. Best subjective evaluation in view of airborne noise insulation was attained by ferroconcrete

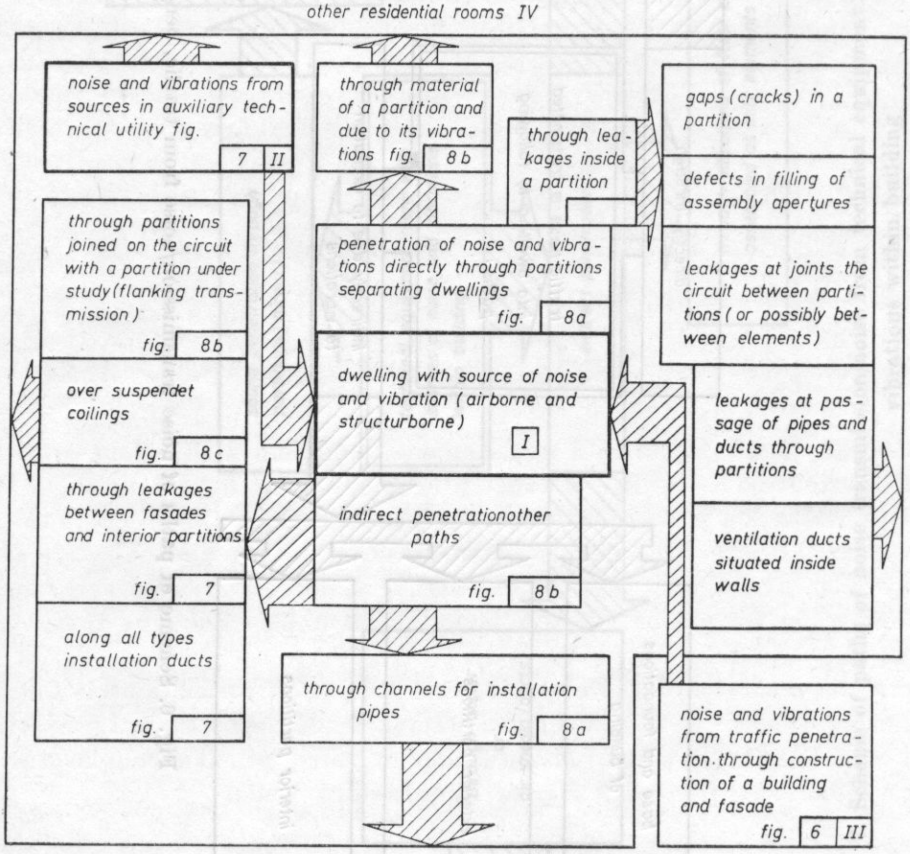


Fig. 5. Collective scheme of sound energy penetration. Sound energy emission from airborne, structure-borne noises sources into residential rooms. I, II, III – position of noise and vibration sources, I – residential dwelling, II – technical utility space in building, III – street with heavy traffic, I, IV – residential rooms protected against noise

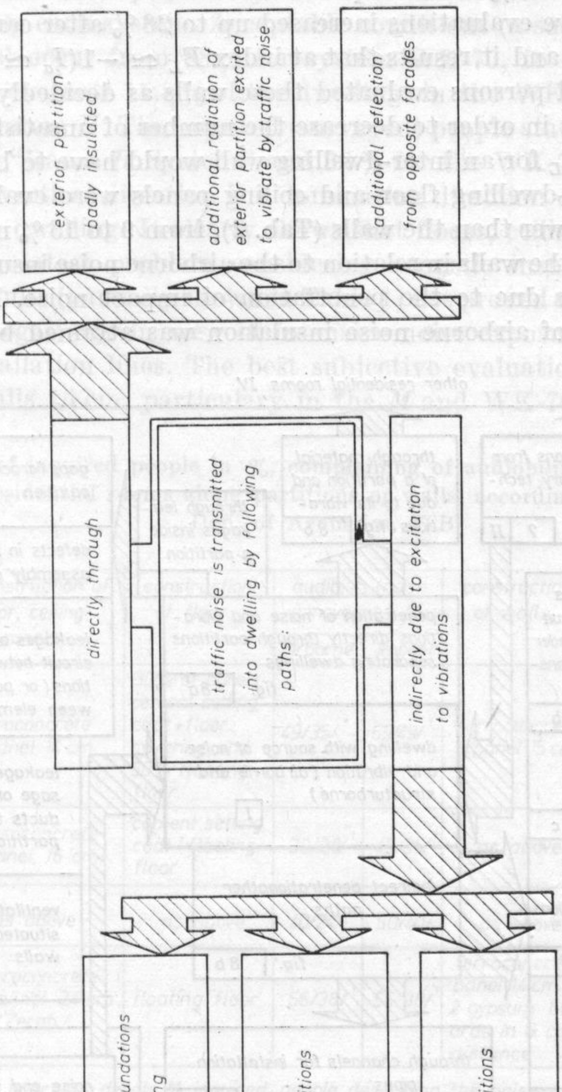


Fig. 6. Scheme of paths of noise transmission/noise from traffic, penetrating into dwellings

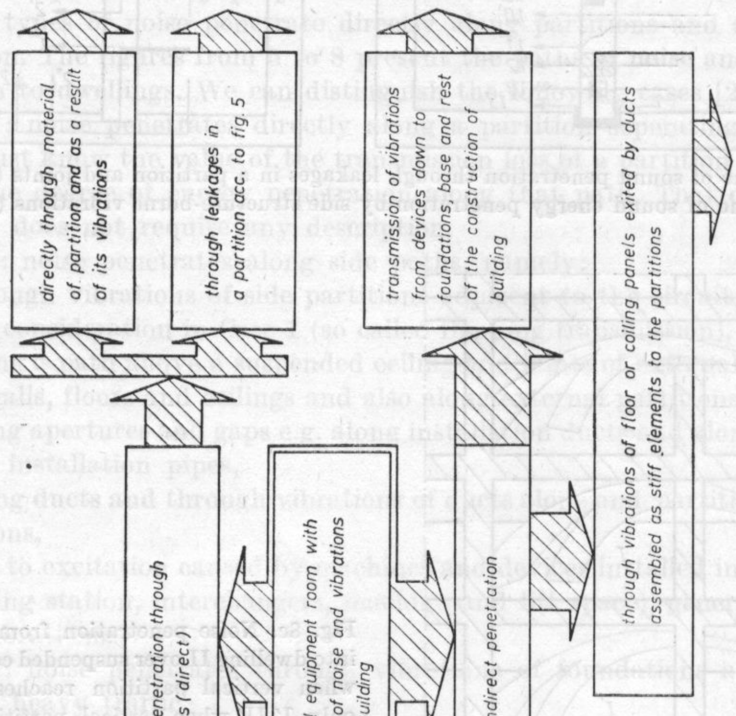
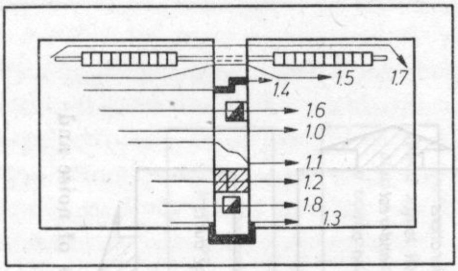


Fig. 7. Scheme of paths of noise transmission noise from technical equipment rooms with sources of noise and vibrations within building

a



b

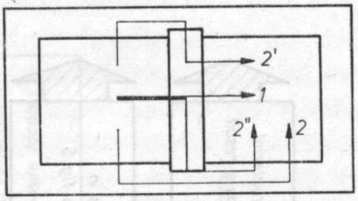


Fig. 8a. Scheme of sound penetration through leakages in a partition and joints (see Fig. 5)
Fig. 8b. Scheme of sound energy penetration by side structure-borne vibrations (see Fig. 5)

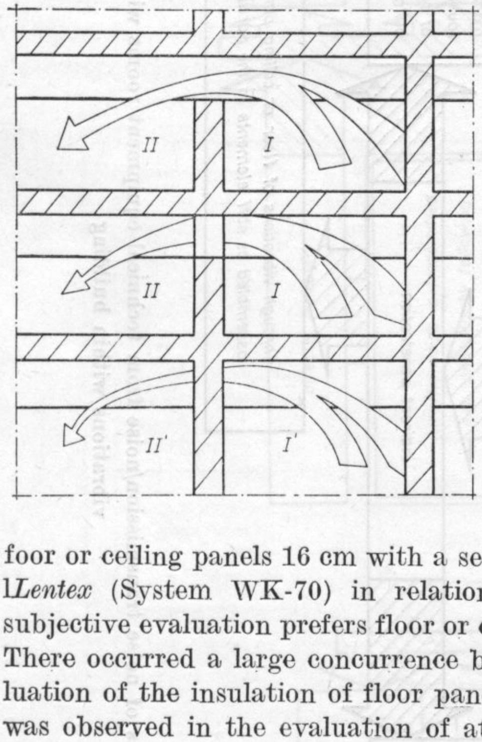


Fig. 8c. Noise penetration from dwelling I into dwelling II over suspended ceilings. I-II when vertical partition reaches a ceiling only, I′-II′ when vertical partition reaches a ceiling panel (better solution)

foor or ceiling panels 16 cm with a setting coat 3 cm and with a floor covering l*Lentex* (System WK-70) in relation to attenuation of impact noise. A the subjective evaluation prefers floor or ceiling panels with floating floors (Tab. 2). There occurred a large concurrence between the subjective and objective evaluation of the insulation of floor panels due to airborne noise. No accordance was observed in the evaluation of attenuation of impact noise by floors and ceilings.

From the analysis of the objective and subjective evaluations it follows that in order to gain the same degree of acceptance of the acoustical properties of floor or ceiling panels, the index E_L for floor or ceiling panels should be greater by 2 to 3 dB than the index E_L for interdwelling walls.

3. Paths of noise penetration

The following types of noise penetrate residential rooms:
outdoor noise (traffic, industry),

from technical utility space within buildings (noise permanently connected with buildings),

from adjacent dwellings (noise from household appliances, radio and TV), the noise produced by people themselves.

These types of noise penetrate directly along partitions and as flanking transmission. The figures from 5 to 8 present the paths of noise and vibration penetration to dwellings. We can distinguish the following cases [2]:

Case 1: noise penetrates directly along a partition seperating dwellings.

We must know the value of the transmission loss of a partition in order to evaluate the degree of energy penetration along that path. That case is well tested and does not require any description.

Case 2: noise penetrates along side paths, namely:

a) through vibrations of side partitions adjacent to the circuit of a partition under consideration in Case 1 (so called flanking transmission),

b) along a path above a suspended ceiling and joints of external walls with partition walls, floors and ceilings and also along external partitions,

c) along apertures and gaps e.g. along installation ducts and along channels containing installation pipes,

d) along ducts and through vibrations of ducts alone and partitions excited by vibrations,

e) due to excitation caused by machines and devices installed in a building (transforming station, interchangers, machine and lift space), generating construction vibrations.

Case 3: noise penetrates through vibrations of foundations and facades excited by heavy traffic.

If we consider noise control within dwellings the most essential for precast buildings are Cases 2a and 2e (they are most common).

4. Principles of noise control in dwellings in precast residential buildings

In order to ensure proper protection from noise in rooms it is indispensable to:

limit the transmission of noise and vibrations from outside the buildings to their interior what is connected with a proper, with respect to acoustics, solution of town-planning around the building (settlement);

limit the transmission of noise and vibrations created inside the building to the rooms. This is connected with the choise and employment of proper — as regards acoustics;

construction and elements of the building, the distribution of rooms in the building and the employment of machines, appliances and installations making the least noise.

As for machines, appliances and installations creating excessive vibrations and noise the use of appropriate devices protecting from vibrations and noise is essential [3].

4.1. Protection from noise in rooms with the aid of town-planning solutions

Protection from noise in rooms consists in the employment of one or more of the following means:

1. Correct, with respect to acoustics, location within urban areas of noise creating projects and those requiring quietness and, where possible, grouping noise creating projects in especially delimited and acoustically isolated zones in a given city;

2. Neutralization of noise sources, for instance by situating transportation routes in tunnels or excavations, or the use of partitions with required acoustic insulation around the source of noise (an industrial building for instance);

3. Realization of protection from the vibration of roads and tramlines and realization of proper roads with respect to acoustics;

4. Keeping a safe distance between a building and the source of noise;

5. The use of objects screening buildings requiring quietness. These night be trade pavillions, storehouses or special *wall-screens* adequate land shaping (earth embankments), strips of dense and high trees;

6. Use of exterior walls and windows with acoustic insulation suited to the noisiness of the surroundings of a given building.

4.2. The influence of architectural-construction solutions of a building and its elements on the acoustic climate in dwellings

As it results from the tests described in Section 2 the most important role in the shaping of the acoustic climate is played by the construction partitions. The acoustic insulation of a partition against air sounds and impact sounds depends on the following factors:

a) the properties of the material used for the partition and its structure;

b) the system of construction of the building and the employed method of industrialization;

c) the quality of used materials and workmanship.

4.2.1. General dependences concerning the insulation efficiency of partitions against air soands

As it is known the standard acoustic insulation efficiency of individual uniform and pseudo-uniform partitions depends on sound frequency, mass of the partition and the physical properties of the material used for its construction. Thus, it is different for partitions with the same mass but made from materials with different physical properties such as porosity, rigidity and others (Fig. 9). The characteristic curve of standard insulation efficiency as a function of frequency depends on the phenomenon of coincidence which is influenced by the physical properties of the material. For construction practice the fact that the value of the standard acoustic insulation efficiency of vertical and horizontal partitions with the same mass is different (generally greater for horizontal partitions) is very important. This is influenced by the direction of action and distribution of the mass of the partition as well as by different values of lateral transmission in walls and floors. This problem demands detailed justification and future theoretical investigation.

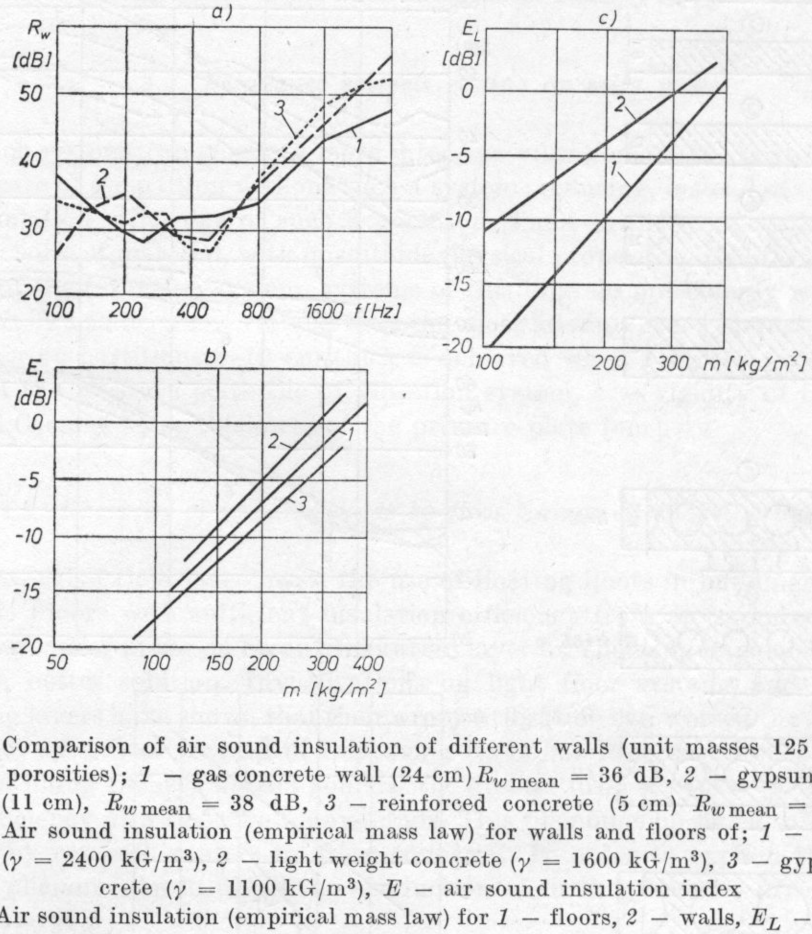


Fig. 9a. Comparison of air sound insulation of different walls (unit masses 125 kg/m but different porosities); *1* — gas concrete wall (24 cm) $R_{w\,\mathrm{mean}} = 36$ dB, *2* — gypsum concrete wall (11 cm), $R_{w\,\mathrm{mean}} = 38$ dB, *3* — reinforced concrete (5 cm) $R_{w\,\mathrm{mean}} = 38$ dB

Fig. 9b. Air sound insulation (empirical mass law) for walls and floors of; *1* — reinforced concrete ($\gamma = 2400$ kG/m^3), *2* — light weight concrete ($\gamma = 1600$ kG/m^3), *3* — gypsum concrete ($\gamma = 1100$ kG/m^3), E — air sound insulation index

Fig. 9c. Air sound insulation (empirical mass law) for *1* — floors, *2* — walls, E_L — air sound insulation index

4.2.2. The acoustic insulation efficiency of channaled slab partitions

A separate case is a partition with cylindrical holes also called a channel partition (the length of the cavity is much greater than its diameter). The standard acoustic insulation efficiency R of a partition with cylindrical holes is, in the band of 100–3200 Hz, much higher than the standard acoustic insulation efficiency of uniform slab partitions with the same mass made from the same kind of material (Fig. 10).

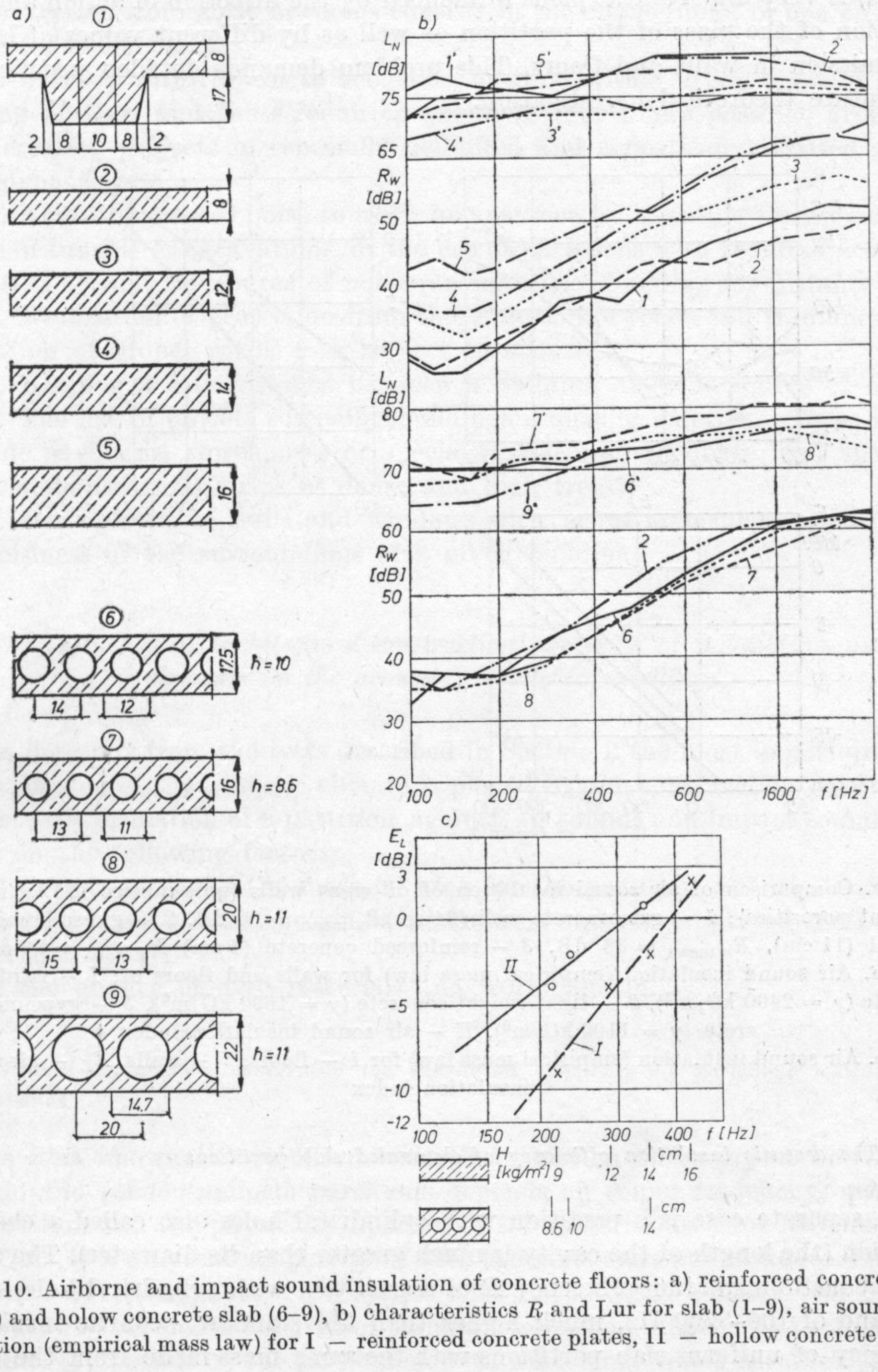


Fig. 10. Airborne and impact sound insulation of concrete floors: a) reinforced concrete slab (1–5) and holow concrete slab (6–9), b) characteristics R and Lur for slab (1–9), air sound insulation (empirical mass law) for I — reinforced concrete plates, II — hollow concrete slabs

Unlike partitions with rectangular air chambers, channel partitions display lesser deterioration of the insulation efficiency due to the phenomenon of coincidence and do not display negative action of the resonant frequencies of cylindrical chambers. This has been confirmed by the results of detailed investigations carried out on two floors from both groups. As can be easily proved the increase in the insulation efficiency of a channel floor in comparison with a slab floor with the same mass results from the greater rigidity of a channel floor.

4.3. Resonance systems resting on solid walls

Such systems can generate more intensive vibrations in the partitions than in the case of a partition without such a system; reducing, instead of increasing, the insulation efficiency of such a partition. Thus, in many cases, because of wrong choise of material, with unsuitable physical properties, used for individual layers of the vibration system, systems of this kind do not comply with requirements. It has been ascertained that the most advantageous increase of ΔR_{wu} for concrete partitions 8–10 cm thick is achieved when $((M_3/s)\,h_3 \geqslant 28)$, M_3 — mass of the pressure plate the of vibration system, s — rigidity of the elastic layer [kG/cm³], h_3 — thickness of the pressure plate [cm].

4.4. Damping of impact sounds by floor linings on silencing layers

Because of their large mass, the use of floating floors in buildings is inconvenient. Floors with sufficient insulation efficiency from air sounds and light floor systems or lining on an anti-vibration layer for silencing impact sounds are a much better solution. Investigations on light floor systems and lining on silencing layers have shown that their wrong utilization can worsen the insulation efficiency of a floor instead of improving it. It has been ascertained that the better a lining silences impact sounds, the greater drop it causes in the insulation efficiency of a floor from air sounds. This phenomenon has also been confirmed by research centers in other countries. In order to explain the theory of this phenomenon in detail the conduction of further acoustic investigations is necessary.

4.5. Influence of the construction system of a building and method of industrialization on the acoustic insulation efficiency of a partition

The choice of construction of a building and technology of its erection exerts particular influence on the acoustic conditions in rooms. The height of a building creates additional difficulties as regards the use of vertical and horizontal partitions with required acoustic insulation, because of limitations concerning the mass of the partitions and difficulties with ensuring sound-tight joints between partitions.

Also in buildings with skeleton constructions difficulties occur in the ensurance of adequate damping of vibrations transmitted by the skeleton.

Additional installations, such as hydrophores ensuring the flow of water to top storeys, elevators for quick transportation, air conditioning or mechanical ventilation, because of the height of a tall building, create additional difficulties as regards proper insulation of the sources of vibrations from the construction of a high-rise building as well as the ensurance of sufficient silencing of air sounds. Particularly difficult problems arise in the design of:

acoustic insulation of elevator devices — resulting from difficulties in the dilatation of engine and elevator hoistways, because of the height of the building,

insulation from sound and vibrations caused by hydrophores and ventilators mounted on middle storeys,

acoustic insulation of joints between exterior walls and floors of interior walls,

acoustic insulation of chutes, as well as water-sewage pipes, central heating pipes; the acoustic insulation of whole ducts for the passage of these pipes.

The construction of a tall building influences to a great extent the acoustic parameters of partitions. It has been ascertained that the coefficients of sound insulation of concrete partitions with the same thickness and surface display considerable differences in buildings with different construction systems what also testifies to various degrees to lateral transmission. It has also been determined that worse acoustic insulation efficiency of floors is accompanied by worse acoustic insulation efficiency of walls and vice versa. In order to determine the degree of sound transmission along the construction of a building, the acoustic insulation between rooms above each other and diagonally on one or more storeys was investigated in several buildings. In turn different sources of sound were used:

creating air sounds only, such as a loudspeaker,

creating both air and material sounds (e.g. a standard sounder, jack mounted firmly on the construction, piano).

Also, measurements of acceleration of vibrations near partition joints on different storeys were made, making use of the listed sources of vibrations in turn in a building with the same type of floors on all storeys and walls made on all storeys of the same material, but with various thickness (mass). Measurement conditions in all cases were identical. The results of the measurements show that sound energy to a considerable extent is transmitted "side" — ways and the worse the acoustical properties of "side" partitions the greater the transmission. When the source causes material vibrations in the partition, then more intensive transmission of energy to the receiving room takes place, what confirms the thesis concerning the participation of acoustic energy transmission from the sending room to the receiving room by material vibrations.

References

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