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INFLUENCE OF THE EXTERNAL WALL ON THE AIRBORNE SOUND INSULATION IN BUILDINGS

B. SZUDROWICZ and A. IŻEWSKA

Building Research Institute
(00-950 Warszawa, ul. Filtrowa 1)

The external wall, just as all the other partitions in the building, takes part in the sound transmission by the flanking structural path. Depending on the construction of the external wall, its influence on the total value of the airborne flanking transmission may be different. The papers presents two different solutions of the external walls: 1) walls which may be considered as panels and 2) multi-layer partitions, where the direct sound insulation is clearly lowered near the resonance frequency existing in the range of the frequencies found in buildings. The analysis considered both the calculation formula according to the EN standard [1] as well as the results of our own measurements performed in the building.

1. Introduction

From the acoustic point of view, the external wall is treated as a construction element protecting the room the penetration of external noise. Standards depending on the level of external noise and the destination of a room determine the value of the required direct airborne sound insulation of its external wall.

The external wall, just as all the other partitions in the building, also takes part in transmitting noise in the building through the flanking structural paths. Depending on the construction of the external wall, its influence on the total value of the flanking transmission in the building may be different.

The flanking airborne insulation of some structural and construction solutions of external walls used in practice is so small that it determines the airborne sound insulation between rooms.

Such solution include certain types of multi-layer partitions where the direct airborne sound insulation is clearly lowered near the resonance frequency existing in the important range of frequencies found in the building.

The European Standard being developed at the moment gives precise and simplified methods which enable the evaluation of the influence of the external wall on the value of the flanking sound transmission in the building. Nevertheless, these methods cannot be used directly for determination of the flanking sound transmission of many massive multilayer partitions used in practice. It is therefore necessary to evaluate this type of structures on the basis of empirical tests.

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2. General principles

The apparent sound reduction index R' of the internal partition in the building results from its direct sound reduction index R_{Dd} and the flanking sound reduction indices R_{ij}.

The separation of the influence of the external wall in the general calculation formula may be presented as follows:

$$R' = -10\log\left[10^{-0.1R_{Dd}} + \sum_{k_{ext}}\sum_{ij} 10^{-0.1R_{ij,k_{ext}}} + \sum_{k_{int}}\sum_{ij} 10^{-0.1R_{ij,k_{int}}}\right], \tag{2.1}$$

where:

R_{Dd} sound reduction index of the separating element (direct transmission), dB

$R_{ij,k_{ext}}$ sound reduction index of the flanking path ij of the external wall, dB

$R_{ij,k_{int}}$ sound reduction index of the flanking path ij of the internal partitions, dB

ij following flanking paths ij at a given junction,

k_{ext} number of junctions at the separating partition with external walls in a given room,

k_{int} number of junctions at the separating partition with internal partitions in a given room.

In practice we usually have $k_{ext}=1$ and $k_{int}=3$. If $k_{ext}>1$, then the influence of the external wall on the total flanking transmission increases.

If we assume that the structural reverberation time of the partition in an actual field situation and in the laboratory is approximately the same ($T_{s,situ}=T_{s,lab}$) we can assume for separating elements without additional layers:

$$R_{Dd}=R_s \tag{2.2}$$

where R_s — direct sound reduction index of the separating element determined on the basis of laboratory measurements or calculations.

With assumption that $T=_{s,\ situ}=T_{s,\ lab}$ and the equivalent absorption leng one may, according to EN, determine the insulation of the flanking paths by the expression:

$$R_{ij}=\frac{R_i+R_j}{2}+\Delta R_i+\Delta R_j+K_{ij}+10\log\frac{S_s}{l_f\cdot l_0}, \tag{2.3}$$

where:

R_i sound reduction index for the element i in the source room, dB,
R_j sound reduction index for the element j in the receiving room, dB
ΔR_i sound reduction index improvement by additional layers for the element i, dB
ΔR_j sound reduction index improvement by additional layers for the element j, dB
K_{ij} junction transmission index for each transmission path ij over a junction, dB
S_s area of the separating element, m^2,
l_f common coupling length between the flanking element f and the separating one, m,
l_0 reference length, (=1 m).

The influence of every flanking partition including the external wall on the value of flanking transmission in the building may be described on the basis of the resulting from the insulation of flanking paths at the edge "k".

If the rooms are not displaced with respect to each other, than the resultant insulation of flanking paths with the given edge k may be presented, considering formula (2.3), as follows:

$$R_{(Ff+Df+Fd)k} = -10\log\left(\frac{l_f\cdot l_0}{S_s}\sum_{ij}10^{-0.1R_{ij,o}}\right), \tag{2.4}$$

where

$$R_{ij,o} = \frac{R_i+R_j}{2} + \Delta R_i + \Delta R_j + K_{ij}. \tag{2.5}$$

For further analysis a more useful form of formula (2.4) is the following one:

$$R_{(Ff+Df+Ed)k} = R_{(Ff+Df+Fd)k,o} + 10\log\frac{S_s}{l_f\cdot l_o}, \tag{2.6}$$

where

$$R_{(Ff+Df+Fd)k,o} = -10\log\left[10^{-0.1R_{Ff,o}} + 10^{-0.1R_{Fd,o}} + 10^{-0.1R_{Df,o}}\right]. \tag{2.7}$$

Introducing formulas (2.2) and (2.7) in (2.1), it is possible to write the latter in a form allowing for a relatively simple analysis of the influence of various partitions on the flanking transmission in the building

$$R' = -10\log\left[10^{-0.1R_s} + \sum_{k_{ext}}\frac{l_{f,ext}\cdot l_o}{S_s}10^{-0.1R_{(Ff+Df+Fd)k,o,ext}} + \sum_{k_{int}}\frac{l_{f,int}\cdot l_o}{S_s}10^{-0.1R_{(Ff+Df+Fd)k,o,int}}\right] \tag{2.8}$$

where

$R_{(Ff+Df+Fd)k,o,ext}$ — expressed by the (2.7) unit is the resultant sound insulation of flanking paths at the edge common for the separating partition and external wall,

$R_{(Ff+Df+Fd)k,o,int}$ — expressed by the (2.7) unit is the resultant sound insulation of flanking paths at the edge common for the separating wall and internal partitions.
Calculation of the insulation of the partition, expressed by (2.8) may be conducted for various frequency bands or by referring to the weighted indices R_w.

3. Buildings with panel structures

In the case of panel structures without additional insulation layers, the weighted direct sound reduction index from airborne transmissions of the separating partition may be presented as a function of its unit mass.

The prEN 12354-1 : 1996 gives the so-called european mass law which for partitions with an area mass m' > 150 kg/m², has the form:

$$R_w = 37.5 \cdot \log m' - 42, \tag{3.1}$$

where m' — surface mass of the partition, kg/m².

In Poland such dependencies have been worked out for various construction materials. For concrete panels with a mass m' > 100 kg/m²

$$R_w = 27.1 \cdot \log m' - 15.6. \tag{3.2}$$

The differencies between these dependencies, (3.1) and (3.2), are relatively small.
If we consider the fact that K_{ij} for panel partitions is a function of the ratio of masses (m_i/m_j) and it is not influenced by the frequency, $R_{(Ff+Df+Fd),k,o,w}$ may be presented in the form

$$R_{(Ff+Df+Fd)k,o,w} = f\left(\frac{m_s'}{m_f'}\right), \tag{3.3}$$

where m_s' — surface mass of the separating partition, kg/m²,
m_f' — surface mass of the flanking partition, kg/m².

Calculations of the dependency (3.3) were performed taking into consideration the mass law according to (3.2) and using formulas describing K_{ij} given in the draft of EN standards. The results of those calculations for the cross junction are presented in Fig.1. Similar curves may be set for the T junction.

Using data according to Fig. 1 greatly simplifies both the calculations according to formula (2.8), as well as the analysis of the influence of various flanking partitions including the external wall on the total value of flanking transmission in the building.

The curves given in Fig. 1 were verified by numerous measurements in buildings. In most cases, the results of those tests did not differ by more than ±1 dB from the calculated values.

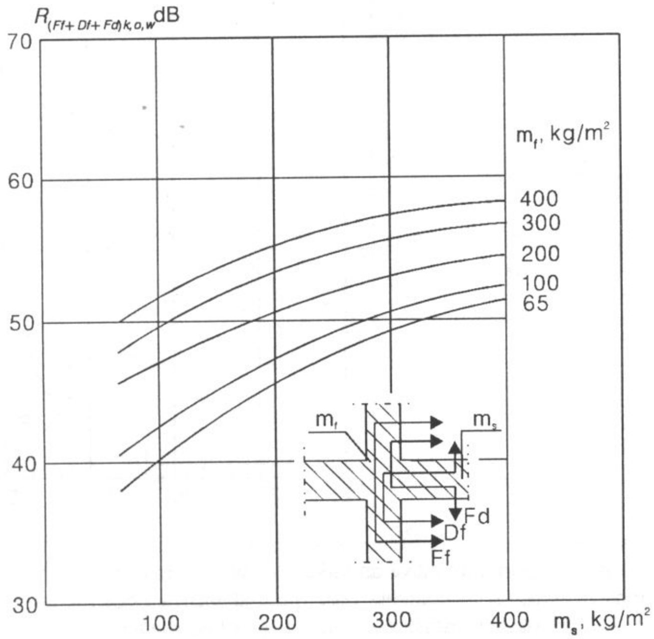

Fig. 1. Weighted index of unit flanking airborne sound insulation $R_{(Ff+Df+Fd)k,o,w}$ of panel partitions (cross junction).

4. Buildings with massive layered walls

Massive external walls are relatively frequently used in multi-family buildings. Such solutions include some types of massive layered walls, in which thermal insulation is made of foamed polystyrene.

Due to the relativity large dynamic rigidity of styrofarm panels the resonance frequency of the layered system is in the mid-frequency band. In the vicinity of this frequency there is an evident decrease of the direct sound reduction index. Examples of such walls are given in Figs. 2 and 3.

On the basis of numerous measurements in buildings, it was found that this phenomenon also causes the deterioration of airborne insulation between rooms in that such walls are used as flanking partitions. Examples of the results of tests made in two buildings are presented in Figs. 4 and 5. The airborne insulation of the ceilings R' was tested using standards methods as well as the resultant insulation of two flanking paths $R_{(Ff+Df)}$ at very edge of the ceilling with side walls, including the external wall. An evident similarity was found between the characteristics of the insulation, R' of the separating partition and $R_{(Ff+Df)}$ of the external wall.

The flanking sound insulation $R_{(Ff+Df)}$ was determined on the basis of the following formula

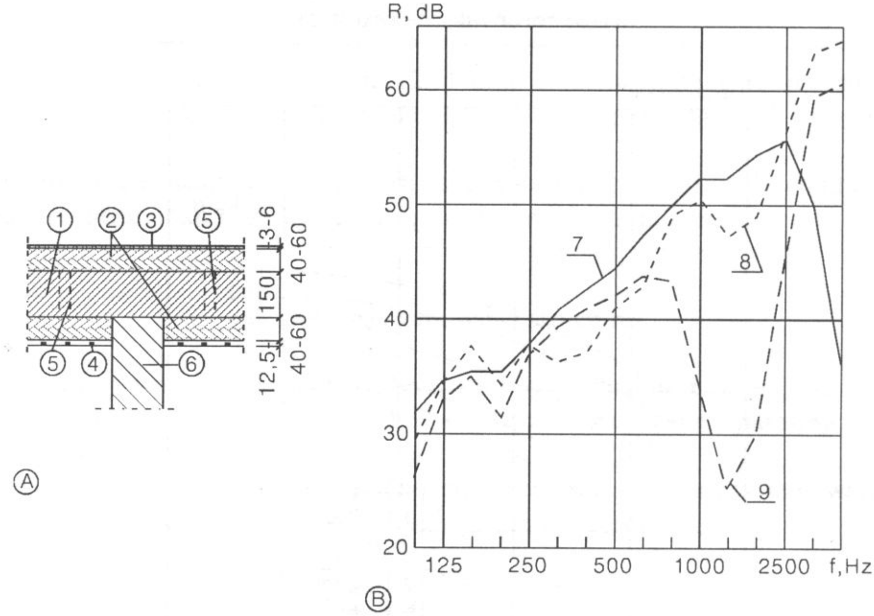

Fig. 2. External massive multi-layer wall — example no. 1

A. Diagram (dimensions in mm): *1* — concrete core (poured on the construction site), *2* — foamed polystyrene panels, *3* — thin plaster mass, *4* — plaster-cardboard panel, *5* — foamed polystyrene connections, *6* — massive internal partition.

B. Direct sound reduction index: *7* — wall without finishing layers according to the diagram, *8* — wall with finishing layers according to the diagram, *9* — wall with finishing layers on both sides made of thin plaster mass.

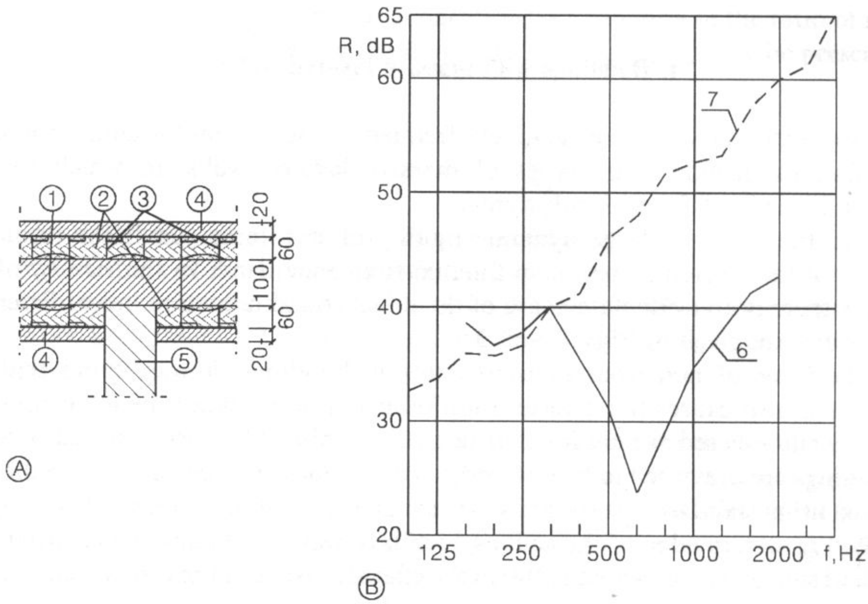

Fig. 3. External massive multi-layer wall — example no. 2

A. Diagram (dimensions in mm): *1* — concrete core poured on the construction site, *2* — foamed polystyrene, *3* — reinforcing net, *4* — gunite (concrete panel shot under presusre), *5* — internal partition.

B. Direct airborne sound insulation: *6* — wall according to diagram, *7* — concrete core.

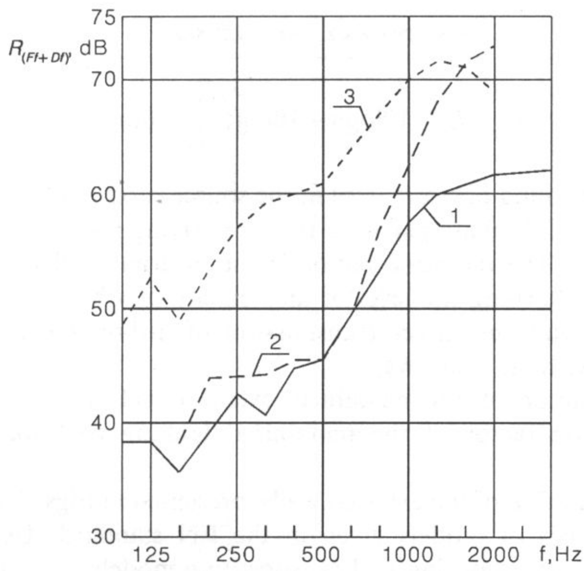

Fig. 4. Airborne sound insulation between rooms in building with an external wall according to Fig. 2. *1* — apparent sound reduction index R' of floor, $S_s = 12.9$ m², measured by the standard method, *2* — flanking airborne sound insulation $R_{(Ff+Df)}$ of external wall measured according to formula (4.1), $S_f = 7.2$ m², *3* — flanking sound insulation of internal wealls (brick wall of 25 cm thickness), $S_f = 24.4$ m² measured according to formula (4.1)

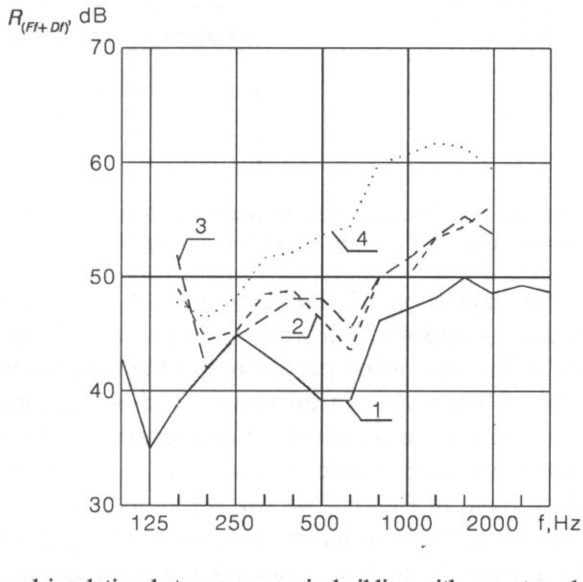

Fig. 5. Airborne sound insulation between rooms in building with an external wall according to Fig. 3. *1* — apparent sound reduction index R' of floor, $S_s = 11.9$ m², measured by the standard method, *2* — flanking sound insulation of external wall $R_{(Ff+Df)}$ measured according to formula (4.1), $S_f = 7.0$ m², *3* — flanking sound insulation $R_{(Ff+Df)}$ of internal cellular brick wall of 12.5 cm thickness, $S_f = 16.0$ m² measured according to formula (4.1)

$$R_{(Ff+Df)}=L_1-L_v-10\log\sigma+10\log\left(\frac{S_s}{S_f}\right)10\log\frac{1}{\sigma}+27.5, \tag{4.1}$$

where: L_1 — average sound pressure level in the source room, dB, L_v — average level of vibration velocity of flanking partition in the receiving room ($v_0=10^{-9}$ m/s, dB), σ — radiation factor. The radiation factor of the external wall was determined by measurement, by establishing the level of the velocity of vibrations and that of the sound intensity L_1 with the direct transmission of airborne energy through the external wall (part without windows).

The radiation factor of the examined external wall is significantly greater than 1. The radiation factor of the remaining flanking partitions was assumed to be equal to 1.

The flanking insulation of the external walls, presented in Figs. 2 and 3, cannot be calculated on the basis of models given in the EN standard. Using the general principles of calculation according to EN, substitute models were used in that was assumed that the influence of external layers on the insulation between rooms will be determined empirically. The models for the external walls presented in Figs. 4 and 5 are given in Fig. 6.

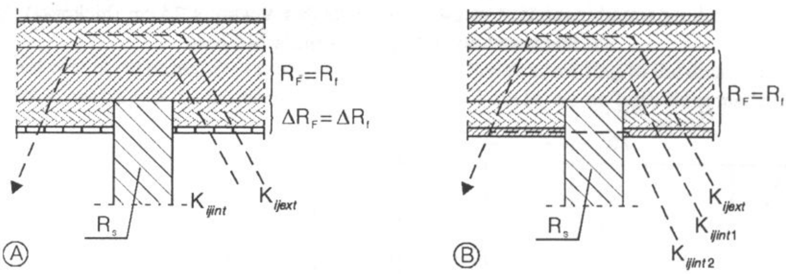

Fig. 6. Models of paths of flanking sound transmission for external walls according to Figs. 2 and 3. A. for wall according to Fig. 2, B. for wall according to Fig. 3.

Measurements of the insulation of flanking paths $R_{(Ff+Df)}$ at the edge of the external wall with the ceiling and internal walls were performed for several pairs of rooms of the same size of the separating partition and the external wall omitting the window area. Examples of test results mean values from several measurements are presented in Figs. 7 and 8. Taking into consideration the structural reverberation time T_s and assuming K_{ij} according to EN, calculations of $R_{(Ff+Df)}$ for the measured cases were made using models given in Fig. 6. The shaded areas in Fig. 7 and 8 show the influence of external layers of the external wall on its flanking insulation $R_{(Ff+Df)}$.

Analyzing the data in Figs. 7 and 8, we must take into consideration the fact that the dispersion of the results of measurements in situ of the sound insulation of flanking paths were quite large and reached ± 4 dB in the low and high frequency bands and slightly lower, (± 2 dB) in the medium one. This may be caused both by different quality of the execution, as well as by the difficulties in measuring the parameters included in formula particularly the radiatoin factor of partitions.

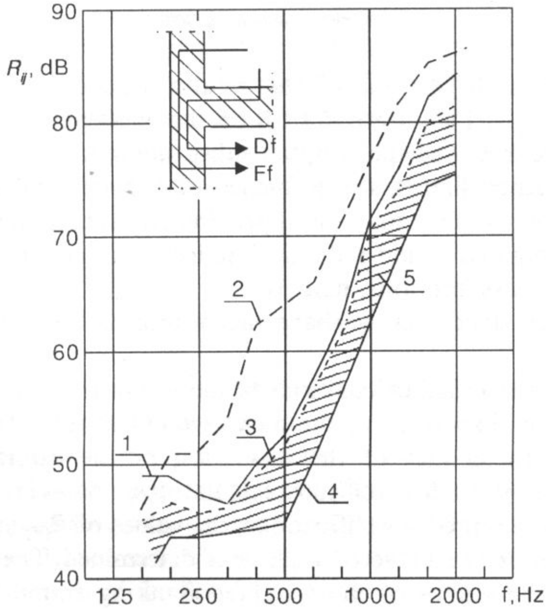

Fig. 7. Comparison of the measured and calculated flankig sound insulations $R_{(Ff+Df)}$ of the external wall according to Fig. 2. *1* — insulation R_{Ff} calculated with omission of external layers of the wall, *2* — insulation R_{Df} calculated with omission of external layers of the wall, *3* — insulation calculated as above $R_{(Ff+Df)}$, *4* — insulation $R_{(Ff+Df)}$measured in the building (mean values), *5* — influence of external layers on flanking airborne sound insulation $R_{(Ff+Df)}$ of the external wall.

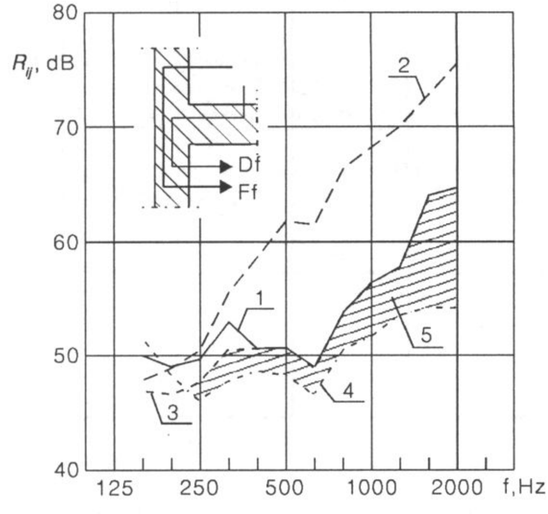

Fig. 8. Comparison of the measured and calculated flankig sound insulation $R_{(Ff+Df)}$ of the external wall according to Fig. 3. *1* — insulation R_{Ff} calculated with omission of external layers of the wall, *2* — insulation R_{Df} calculated with omission of external layers of the wall, *3* — insulation calculated as above $R_{(Ff+Df)}$, *4* — insulation measured in the building (mean values), *5* — influence of external layers on flanking sound insulation $R_{(Ff+Df)}$ of the external wall.

Significantly smaller dispersions of the results were obtained in the case of weighted indices $R_{(Ff+Df),w}$. They were ± 1 dB on the average.

On the basis of the tests and the adopted substitute model we cannot determine, for the various frequency bands, the influence of a given flanking paths on the insulation between rooms. This may be approximately determined by calculations with respect to the weighted sound reduction indices. This requires nevertheless the adoption of additional assumptions, namely:

• for the examines structures we have, according to the general assumption, $R_{Fd,w} = R_{Df,w}$,

• the error in the performed calculations of the values of the indices R_w does not exceed the value of the dispersion of the measurement results, despite the fact the difference in the characteristics of the insulation of the external wall and the saparating partition do not allow for such calculations.

Being aware of the adopted simplifications, the values of $R_{(Ff+Df+Fd),k,o,w}$ for the examined structures of external layered walls were determined. They are given in Fig. 9. For comparison, the values of the weighted flanking sound reduction indices $R_{(Ff+Df+Fd),k,o,w}$ determined on the basis of the diagram in Fig. 2, have also beenincluded. This comparison demonstrates that the discussed external walls cause a significant lowering of the weighted sound reduction index of the ceilings and the internal walls in the building as proved by direct measurements.

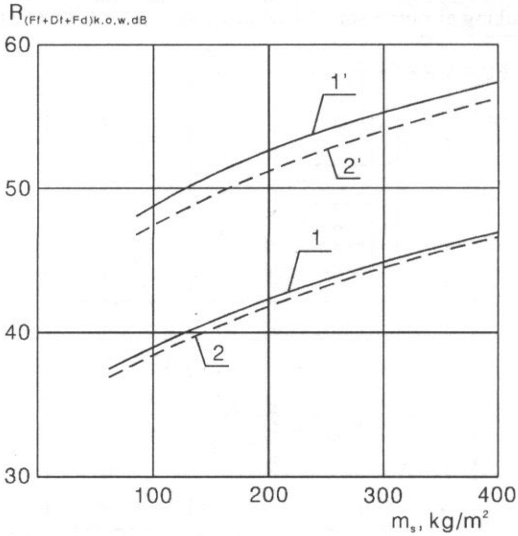

Fig. 9. Weighted unit flanking airborne sound insulation of external walls: *1* — of the wall according to diagram in Fig. 2, *2* — of the wall according to diagram in Fig. 3, *1'* — of the concrete core of the wall according to Fig. 2, *2'* — of the concrete core of the wall accoridng to Fig. 3.

The curves shown in Fig. 7 may be used for a preliminary estimation of the influence of the external walls on the value of the flanking transmission in the building in which the internal partitions may be treated as panels. If this condition is not fulfilled e.g. the internal partitions are double structures then, depending on the structures, the connection between the external wall and the internal partitions, i.e. the values of indices $R_{(Ff+Df+Fd),k,o,w}$, differ significantly from those given in Fig. 7. We see from the tests performed that it does not refer to the case when floating floors are used on the massive ceilings.

5. Conclusions

In the sound evalution of the external wall we should consider both its direct as well as flanking airborne sound insulation.

The influence of the external panel wall on the flanking sound transmission in the building may be evaluated approximately on the basis of its surface mass.

In practice there are several solutions for external walls which clearly increases the flanking sound transmission in the building. An example of such a wall was discussed in this paper on the basis of the results of measurements and calculations.

The influence of external walls of the structure described in this paper on the value of the flanking airborne transmission in the building may be temporarily estimated on the basis of data found in Fig. 7.

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