AIRBORNE SOUND INSULATION FROM BUILDING PARTITIONS: POINT SOURCE AND PLANE SOURCE MODEL

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1 INTRODUCTION

The method for measuring the sound reduction index R of a partition element is described in the standards. The standard method is based on the point source radiation model.

However, it can be experienced that this transmission model does not exist in general, especially in those cases where the dimension of the radiating partition is large compared to the volume of the receiving room like for instance the floor or the ceiling in a living room. In those cases the partition acts on the principle of a plane source radiator and not as a point source.

By applying the point source model on a large partition element, the outcome of R is not a unique value but biased by the room dimensions. In these cases, a plane source model provides a more reliable result.

Flanking transmission, as it can interfere and degrade the sound insulation, will be left out of consideration in the next discussion.

2 THE POINT SOURCE AS A STANDARD

The sound radiation from a point source, based on Statistical Energy Analysis (SEA), is well known and established analytically. The method is used for the prediction of the sound transmission index and also for the measurement of the airborne sound insulation between rooms[1,2,3].

The sound transmission index resulting from the measurements in a reverberation room, according to ISO 140, is given by the equation:

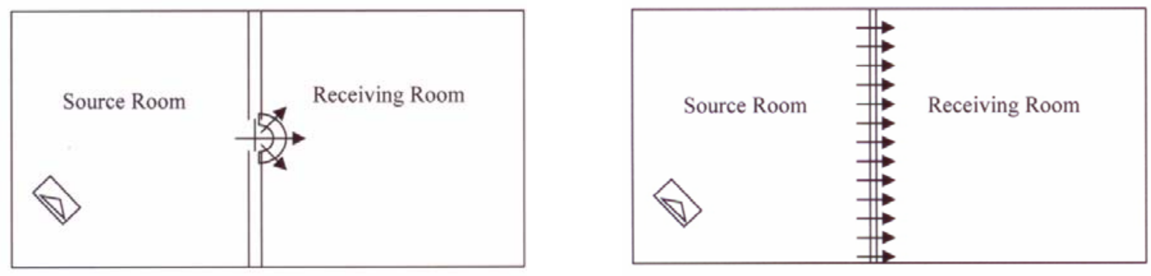
$$R = D + 10 \log S_p - 10 \log A \qquad (1)$$

Where:

- D the sound pressure level difference , $L_{p1} - L_{p2}$
- L_{p1} the sound pressure level in de source room [dB]
- L_{p2} the sound pressure level in the reverberant field in the receiving room [dB]
- S_p the surface of the partition [m²]
- A the absorption in the receiving room
  $= S.\overline{\alpha}$, with S = the total wall surface in the receiving room; and,
  $\overline{\alpha}$ = the average absorption coefficient in the receiving room.

Above equation is based on the condition that the partition is excited by a diffuse sound field on the source side and on the condition that a diffuse sound field exists in the receiving room and that L_{p1} and L_{p2} are the sound pressure levels measured in the diffuse sound fields on both sides of the partition.

These conditions are easily fulfilled in a laboratory situation where the surface of the partition element is small compared to the volumes of the test rooms. But, this is rarely the case in the field and it is neither the case in test facilities where the tested element makes up the complete partition wall. The difference between situations is illustrated by the sketches in Figure 1.



a) (b)

Figure 1. Transmission of sound energy from the source room to the receiving room: a) small partitions function as a point source in de receiving room; b) large partitions function as a plane source radiator.

3. THE PLANE SOURCE MODEL

3.1 Plane Source Radiation

Assumed that the partition is homogeneous and radiates the sound energy uniformly over its surface into the room, then an infinite number of mirror sources can be imagined as shown in Figure 2. The room depth in the figure equals L.

In the figure, the radiating wall in the room is at the origin of the length-axis and the radiation goes in the positive direction. The first mirror source can be imagined at the origin of the length-axis, on the back side of the radiating wall. It forms with the real source a plane source that radiates in both directions. This makes it possible to eliminate the partition and consider the room with depth 2L, with in its centre the double sided plane source.

Mirror sources are produced by the four side walls and build up an infinite plane source at the origin, perpendicular to the length-axis. Finally, one can imagine the next series of infinite plane mirror sources in positive and negative direction occurring at a distance interval of 2L.

The infinite plane sources radiate the energy rectilinear in positive and negative direction. It allows considering a tube along the length axis with the section equal to the cross section of the room. The energy is conserved in the tube, i.e. without transmission through the side walls, and the tube can be separated without disturbance of the sound field.

The strength of the successive mirror sources in the separated tube is reduced by absorption of the reflecting wall and also by absorption in the air. In this model, only the wall opposite to the radiating wall of the room contributes to the wall absorption.

At first, only the positive side of the l-axis is considered. The radiated sound power can be written as the product of intensity and surface, $W = I \times S_p$, with $I = p^2/\rho c$ and S_p the surface of the partition, or:

$$W = \frac{p^2}{\rho c} S_p \qquad (2)$$

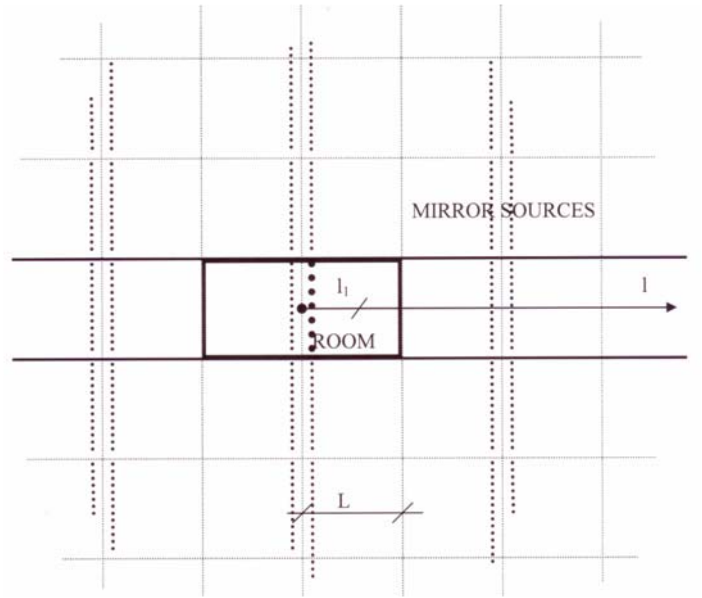


Figure 2. The room has depth L and the sound energy is radiated by the partition at the origin of the l-axis. The mirror sources build up infinite plane sources at intervals of 2L on the l-axis. A tube of infinite length, with the cross section of the room, can be separated with conservation of energy in the separated tube.

Let P_0^2 be called the direct sound radiated by the source, i.e.:

$$P_0^2 = \frac{\rho c}{S_p} W \tag{3}$$

The successive reflections, reduced in strength by the wall absorption α and by the air absorption β, can be written as follows:

1st reflection: $P_{refl,1}^2 = P_0^2 \left(1-\alpha\right) e^{-\beta l_1}$

…..

Nth reflection: $P_{refl,n}^2 = P_0^2 \left(1-\alpha\right)^N e^{-\beta l_N}$

As many reflections from the positive side arrive from the negative side, meaning that the number of reflections has to be doubled when the summation on the reflected sound is performed. The sum of direct and reflected sound then results in:

$$p^2 = P_0^2 + 2\sum_{1,N}[(1-\alpha)^N .e^{-\beta l}]\ P_0^2 \tag{4}$$

Assuming that the energy is evenly spread over the volume of the room cells in the tube, or:

$$P_0^2 = \frac{S.\Delta l}{V} P_0^2 ;$$

And knowing that the number of reflections, N, equals l/2L, and letting $\Delta l \rightarrow 0$, one can replace the summation by an integral, as follows:

$$p^2 = P_0^2 + 2\int_{L_1}^{\infty} (1-\alpha)^{l/2L} \frac{S}{V} e^{-\beta l} P_0^2 \, dl$$

$$= P_0^2 + 2 \frac{S}{V} P_0^2 \int_{L_1}^{\infty} e^{[\ln(1-\alpha)/2L - \beta] l} \, dl \qquad (5)$$

In the limit, when $L_1 \to 0$, the integral works out to:

$$p^2 = P_0^2 + \frac{2S}{V} P_0^2 \frac{2L}{-\ln(1-\alpha)+2\beta L}$$

S in above equations equals S_p, the surface of the partition. Substitution of V by the product $S_p.L$ and rearranging terms, gives:

$$p^2 = P_0^2 \left[1+\frac{4L}{-\ln(1-\alpha)+2\beta L}\right] \qquad (6)$$

Substitution of P_0^2 in above equation by (3) and after transformation of both sides to sound levels, equation (6) becomes:

$$L_p = L_w + 10\log\left[\frac{1}{S_p} + \frac{4}{-S_p\ln(1-\alpha)+2\beta S_p L}\right] \qquad (7)$$

When air absorption is neglected, above equation reduces to:

$$L_p = L_w + 10\log\left[\frac{1}{S_p} + \frac{4}{-S_p.\ln(1-\alpha)}\right] \qquad (7')$$

Equations (7) and (7') show the sound pressure level in a room, due to plane source radiation of the partition. The equations indicate that the sound pressure level is independent of distance and constant over the volume of the room.

It should also be noticed that the absorption term is similar in form to Eyring's absorption[4], although the parameters S_p and α differ in meaning.

3.2 Plane Source Transmission

The sound power level transmitted by a partition, excited by a diffuse sound field in the source room, is given by the relation:

$$L_{w2} = L_{p1} – R + 10 \log S_p – 6 \text{ dB} \qquad (8)$$

The sound pressure level in the receiving room, by plane source radiation from the partition, was derived in eq. (7') and reads in terms of the receiving room:

$$L_{p2} = L_{w2} + 10\log[\frac{1}{S_p} + \frac{4}{-S_p.\ln(1-\alpha)}] \quad (9)$$

Substitution of (8) into (9) and rearranging terms, leads to the equation:

$$L_{p2} = L_{p1} - R - 6 + 10 \log S_p + 10 \log 4 + 10 \log\left[\frac{1}{4S_p} + \frac{1}{-S_p \ln(1-\alpha)}\right]$$

That further reduces to:

$$L_{p2} = L_{p1} - R + 10 \log S_p + 10 \log\left[\frac{1}{4S_p} + \frac{1}{-S_p \ln(1-\alpha)}\right] \quad (10)$$

In above equation, the term $10\log S_p$ cancels and by replacing ($L_{p1} - L_{p2}$) by D, eq.(10) can be rearranged for R, and reduces to:

$$R = D + 10 \log\left[\frac{1}{4} + \frac{1}{-\ln(1-\alpha)}\right] \quad (11)$$

It is understood that in the derivation of the plane source equation, the radiating surface fills up the section of the room and equals S_p. This condition is generally fulfilled when the considered radiating partition is a partition wall or floor between two rooms.

When the average absorption coefficient is smaller than 0,4, the term (1/4) in eq. (11) can be neglected within an error of less than 0,5 dB. The equation then reduces further to:

$$R = D + 10 \log\left[\frac{1}{-\ln(1-\alpha)}\right] \quad (11')$$

The difference between R and D, expressed by the term 10 log [1/-ln(1-α)], is shown in Figure 3. The difference term has a large value in highly reverberant spaces but reduces to nearly 5 dB when the average absorption coefficient becomes 0,25. In highly dead rooms, the difference term tends to zero.

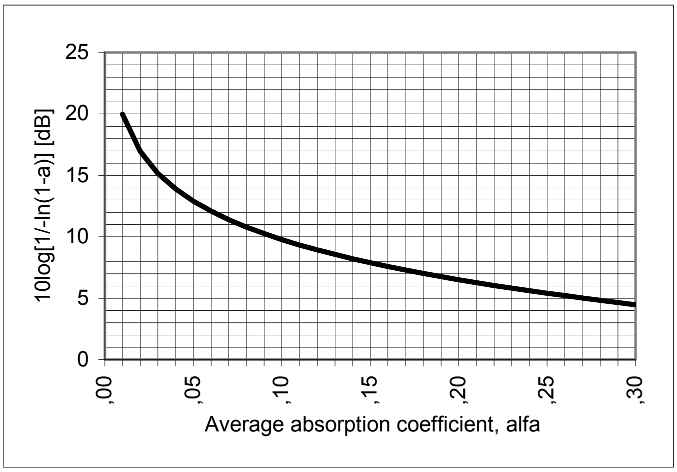


Figure 3. Difference between R and D from a partition with plane source radiation as a function of the average absorption coefficient, α .

It is worth noting that in eq.(11) and eq.(11'), the relation between D and R is only a function of the average absorption coefficient α, strictly speaking of the reflecting (back) wall in the receiving room. However, when the absorption is evenly spread over the wall surfaces in the room, α here can be replaced by the average absorption coefficient $\overline{\alpha}$ of the room.

4. POINT SOURCE AGAINST PLANE SOURCE

In order to distinguish in what follows between both transmission models, the sound transmission index R for the point source model will be called R_P and that for the plane (Flat) source model, R_F. There will be no distinction for a between both models.

From eq.(1) we recall that the point source transmission index $R_P = D + 10 \log S_p - 10 \log A$. Herein is A the Sabine absorption that can be replaced, without any negative consequence, by the Eyring absorption. Then eq.(1) is rewritten as:

$$R_P = D + 10 \log (S_P/S) + 10 \log [1/-\ln(1-\alpha)] \qquad (12)$$

From eq.(11') we recall that the plane source transmission index R_F is found from:

$$R_F = D + 10 \log [1/[-\ln(1-\alpha)]] \qquad (13)$$

In a given situation for which D is known, the difference in the result when either the point source model or the plane source model is applied, is found from the difference between eq.(12) and eq.(13). By calculating the difference, the terms in D and α cancel and the difference between R_P and R_F is found from:

$$R_P - R_F = 10 \log (S_P/S) \qquad (14)$$

where S_P is the surface of the partition wall and S the total surface of the room.

The ratio S_P/S is not a constant but will vary from one space to another. However, the variation range is rather restricted to values, say, from 0,1 to 0,3 and therefore the difference between R_P and R_F will be situated between 5 dB and 10 dB, and is graphically presented in Figure 4. It shows, in a situation where the transmission occurs by plane source transmission, that the standard method produces a bias of -5 dB to -10 dB on the result for the sound transmission index.

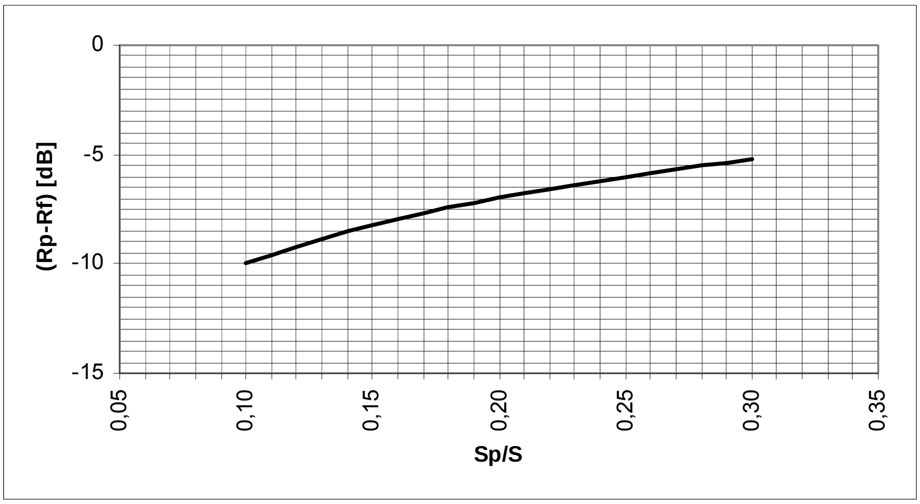


Figure 4. Difference between R_P and R_F as a function of the surface ratio S_p/S.

5. CONSEQUENCES

In situations where the partition between rooms is large compared to the volume of the receiving room, it is obvious to consider plane source transmission rather than point source transmission. The discussion so far has shown that, in a given situation with a given partition, the standard method (point source model) will underestimate the sound transmission index by 5 dB to 10 dB.

5.1 Laboratory Measurements

The purpose of laboratory measurements on partition elements is to provide data for R that characterizes a specific material or a specific wall construction. These data must not be biased.

5.2 Field Measurements

In general, the meaning of field measurements is to check the quality of the sound insulation and eventually find the cause when the requirements are not fulfilled.

When the design of a partition wall is based on point source transmission, but real life dictates plane source transmission, then there will be a problem: the requirement will not be fulfilled! An example may illustrate this.

Example. Given a room with the following characteristics:

- Volume, V = 2,8 m x 5 m x 7 m = 98 m³;
- Total wall surface, S = 137,2 m²;
- Partition wall surface, S_p = 2,8 m x 7 m = 19,6 m²;
- Required level difference, D ≥ 55 dB;
- Required reverberation time, T = 0,5 s;

Design: the required reverberation time requires an average absorption coefficient,
α = 0,161 V / S.T = 0,23; and a total absorption in the room,
A = S. α = 31,6 m²; the calculated sound reduction index for the partition will then be, eq.(1):
R = D + 10 log (S_p/A) = 52,9 dB, and specified to the builder;
Construction check: as it is assumed that the builder has managed to realize the construction with a and R exactly as required, then field measurements - plane source transmission does exist - will show according to eq.(13) that,
D = R – 10 log [1 / -ln(1 – α)] = 52,9 – 5,8 = 44,1 dB.
Conclusion: the deficiency in the result is nearly 11 dB.
Notice: In order to fulfil the requirement, in contradiction with the standard, a construction with a sound transmission index R ≥ 60,8 dB is needed.

This deficiency is the result of a wrong quantification for R, although based on the standard.

6. CONCLUSIONS

The standard method does not allow quantifying the sound reduction index correctly for large partition walls.

When the sound transmission takes place by plane source radiation, the standard method produces a bias on the measured and calculated results. The bias depends on the configuration of the receiving room and more specifically on the ratio S_p/S. In current spaces where the surface of the partition is large compared to the volume of the room, the value of the bias amounts from 5 dB to 10 dB.

At present, there exists only one standard method while the basics of this method do not comply with all real situations. Therefore, there is a need for an adaptable standard method. The presented plane source model can be helpful.

7. REFERENCES

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4. C.F. Eyring, Reverberation time in “dead” rooms. JASA 1, 217-241 (1930).