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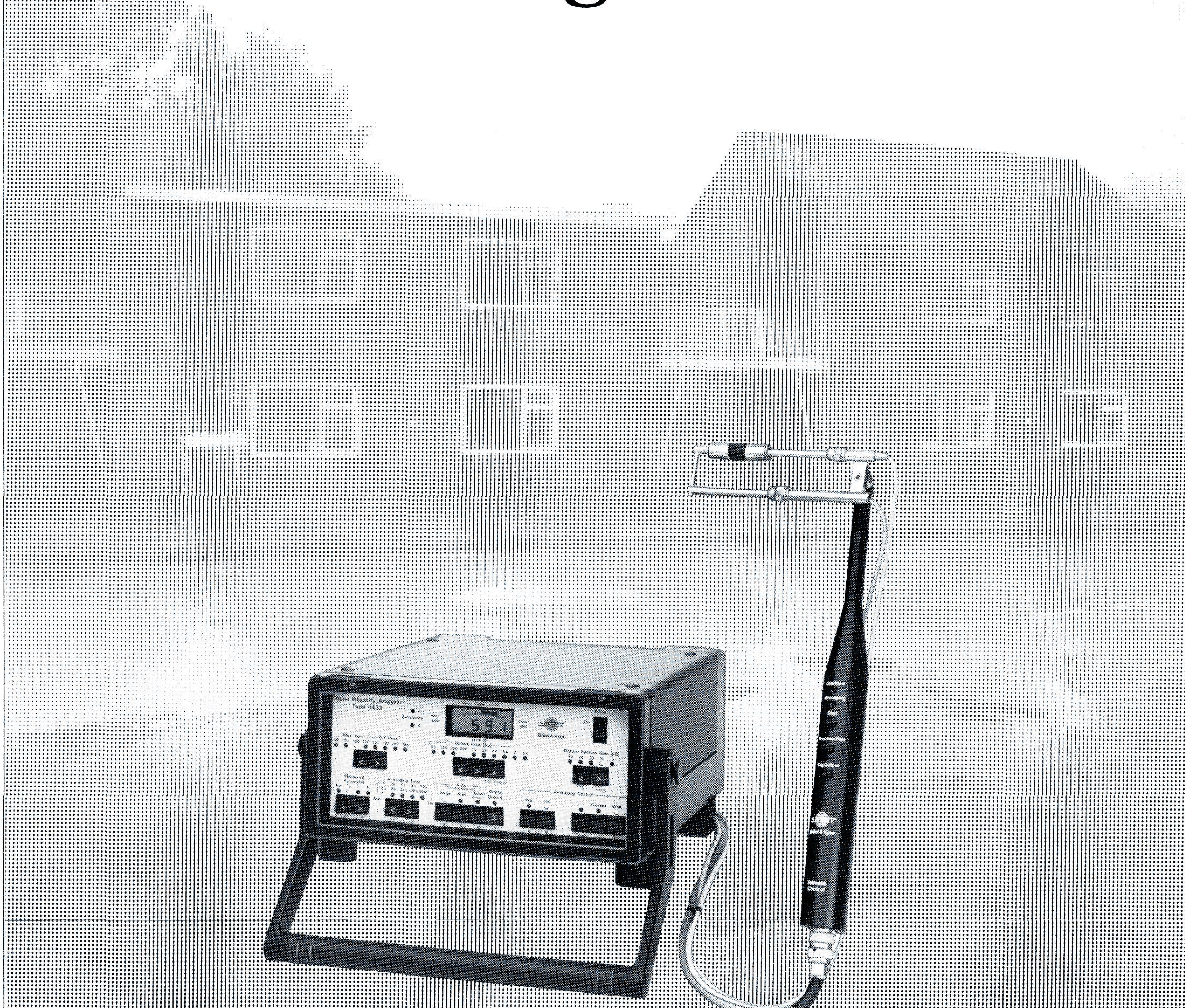
Intensity Measurements in Building Acoustics



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Intensity Measurements in Building Acoustics

by *Torben G. Nielsen*, Brüel & Kjær

Introduction

The procedure outlined in the ISO 140 standards for measurement of sound insulation rests on relationships between incident and transmitted sound power (Ref.[1]). The sound powers are estimated from measurements of spatially averaged sound pressures, and it is assumed that the sound fields are either diffuse or free. Sound intensity is a measure of sound power per m^2, so with an Intensity Analyzer it is possible to measure the sound power directly. The intensity method has some inherent advantages compared to traditional methods:

- Contributions from various flanking paths can be quantified
- Individual contributions from parts of composite elements may be determined
- Sound leaks can be traced
- The method uses a non contacting transducer

In this note, the classical method of measuring apparent sound reduction index (transmission loss) is first reviewed briefly. The intensity method is then outlined, and in the following section the battery operated intensity analyzer and its probe are described. After an outline of the general measurement procedure the last two sections give details of in-situ measurements in buildings carried out with the portable intensity system. In References [2, 3, 4, 5, 6] more information on Sound Intensity measurements in building acoustics are found.

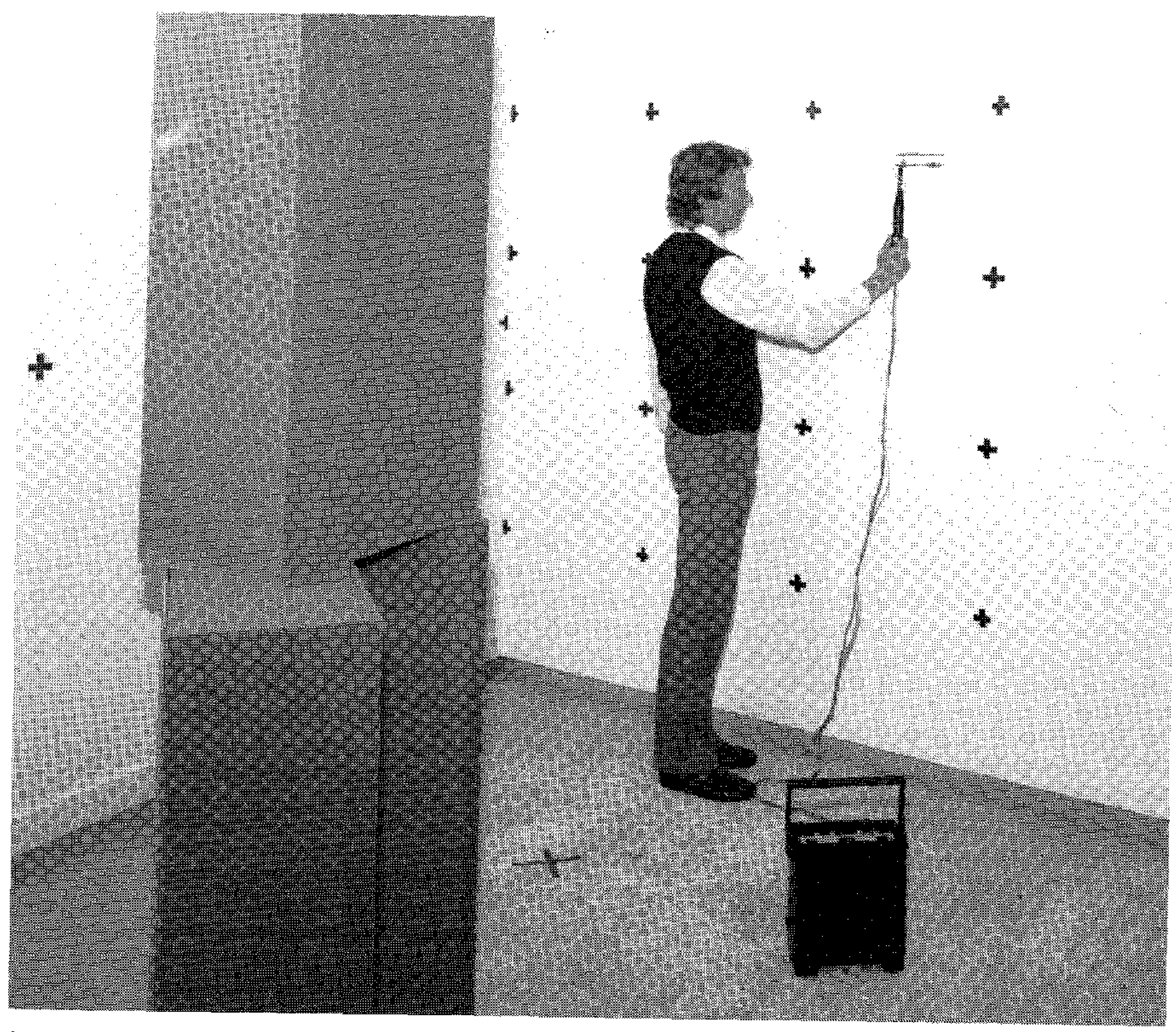
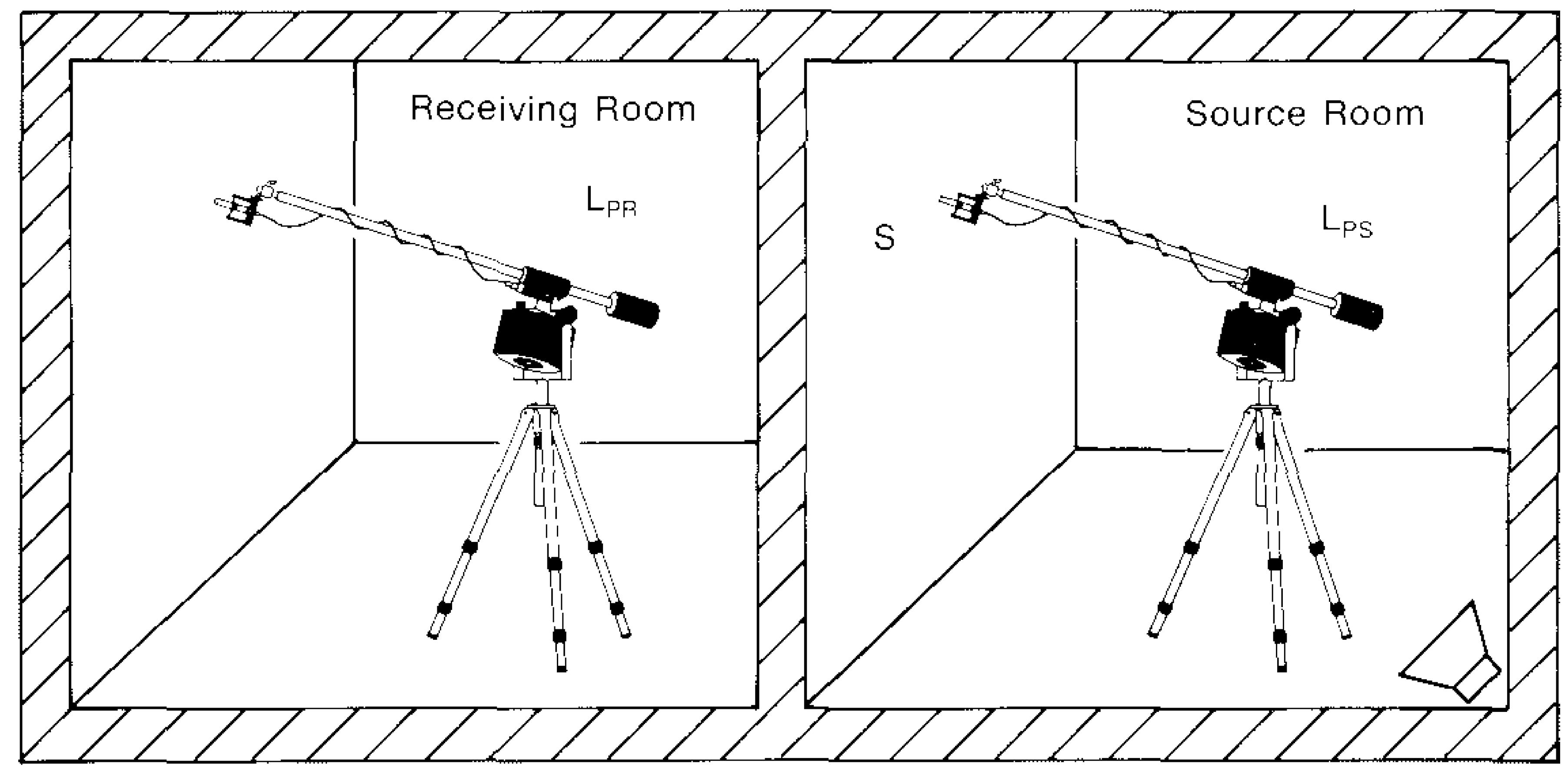


Fig. 1. Sound Intensity Analyzer Type 4433 being used to measure the sound power emitted from a wall

Apparent Sound Reduction Index

The Classical Approach

Apparent sound reduction index (apparent transmission loss) is defined in terms of the difference between the power incident on the partition in the transmitting room and the total power transmitted into the receiving room (Fig. 2). If it is assumed that the sound fields in the source and receiver room are diffuse and that the power entering the receiving room is absorbed by the absorption area A in the receiving room, then the index can be expressed in terms of the difference between the averaged sound pressure levels in the two rooms. A correction is made for the absorption area A in the receiving room. The procedure according to ISO 140 is to measure the sound pressure levels in both rooms, using a rotating microphone boom for example to provide the spatial averaging. The absorption area of the receiving room is determined by measurement of the reverberation time T. The apparent sound reduction index can be measured in the field to check on insulation specifications and work practices. In the event of the insulation specifications not being met, it is useful to identify the faulty building components; this is however not an easy procedure using the traditional methods.



Apparent Sound Reduction Index

$$R' = L_{PS} - L_{PR} + 10 \log S/A$$

$$\text{where } A = \frac{0.163\,V}{T}$$

S: Party wall area (m^2)
V: Volume of receiving room (m^3)
T: Reverberation time (s)

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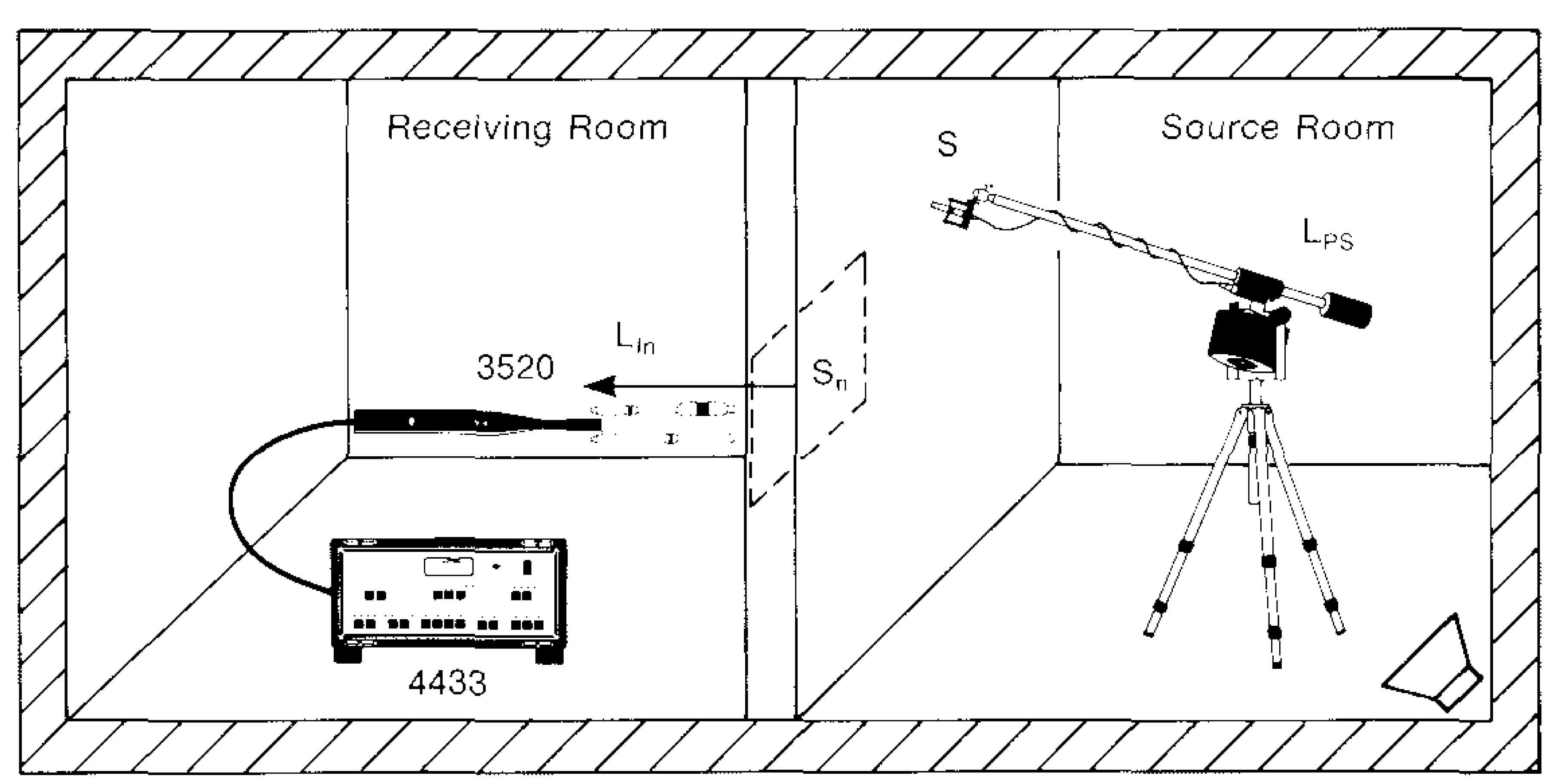
Fig. 2. The classical method of measuring sound insulation is based on pressure level measurements in the transmitting room and the receiving room. The sound fields in both rooms should be diffuse

The Intensity Approach

In the intensity approach (Fig. 3) the sound power incident on the partition on the transmitting side is measured in exactly the same way as in the classical method, by measuring the average sound pressure in the transmitting room. The power transmitted into the receiving room is however measured directly using a sound intensity analyzing system. Measurement of reverberation time T is not necessary, and one does not have to rely on a diffuse field assumption in the receiving room. The intensity analyzer measures the net sound power/m^2. The sound power emitted from a given surface is therefore the average sound intensity measured over the surface, multiplied by the surface area. In this way the partial contributions of power injected into the room from the different boundaries (walls, floor, ceiling) may be determined. It is also possible to measure contributions from windows, doors, etc. Sound leaks reveal themselves as spots with high levels of intensity. All contributions may be added up to give an apparent sound reduction index that can be compared with the result of a classical measurement.



Apparent Sound Reduction Index for surface n

$$R'_n = L_{PS} - 6\,\text{dB} - L_{In} + 10 \log S/S_n$$

L_{In} : Average intensity over surface area S_n

$$R' = -10 \log \sum_{n=1}^{N} 10^{\frac{-R'_n}{10}}$$

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Fig. 3. Sound insulation measured using the intensity technique. The sound field in the transmitting room should be diffuse, but this is not necessary in the receiving room, nor is it desirable

Instrumentation

The Sound Intensity Analyzer Type 4433 is ideal for use in on-site building acoustics investigations. The 4433 weighs less than 6 kg and runs for more than 7 hours continuously on its internal batteries. Its small size (138 mm × 251 mm × 300 mm) allows it to be brought right to the measurement site even when space is restricted.

The analyzer allows measurement of pressure, particle velocity and intensity to be done in octaves from 63 Hz to 8 kHz as well as broadband measurements (linear and A-weighted). It is also possible to A-weight the octave measurements directly. Automatic scanning of the filters and setting of the input and output amplifiers makes the instrument easy to use. Stored spectra may be transferred to external equipment via the built-in serial and IEEE interfaces.

The analyzer is designed to be used with a probe consisting of two phase matched microphones. For measurements at low and medium frequencies half-inch matched microphone pair Type 4177 or Type 4183 can be used.

The distance between the two microphones in a pair may be changed to accommodate different parts of the frequency range. Details on this are found in the data sheet for the 4433 analyzer and the probe 3520 (Refs. [7, 8], and in Appendix A. The Portable Sound Intensity Analyzer Type 4433 is shown along with the Intensity Probe Type 3520 in Fig. 4.

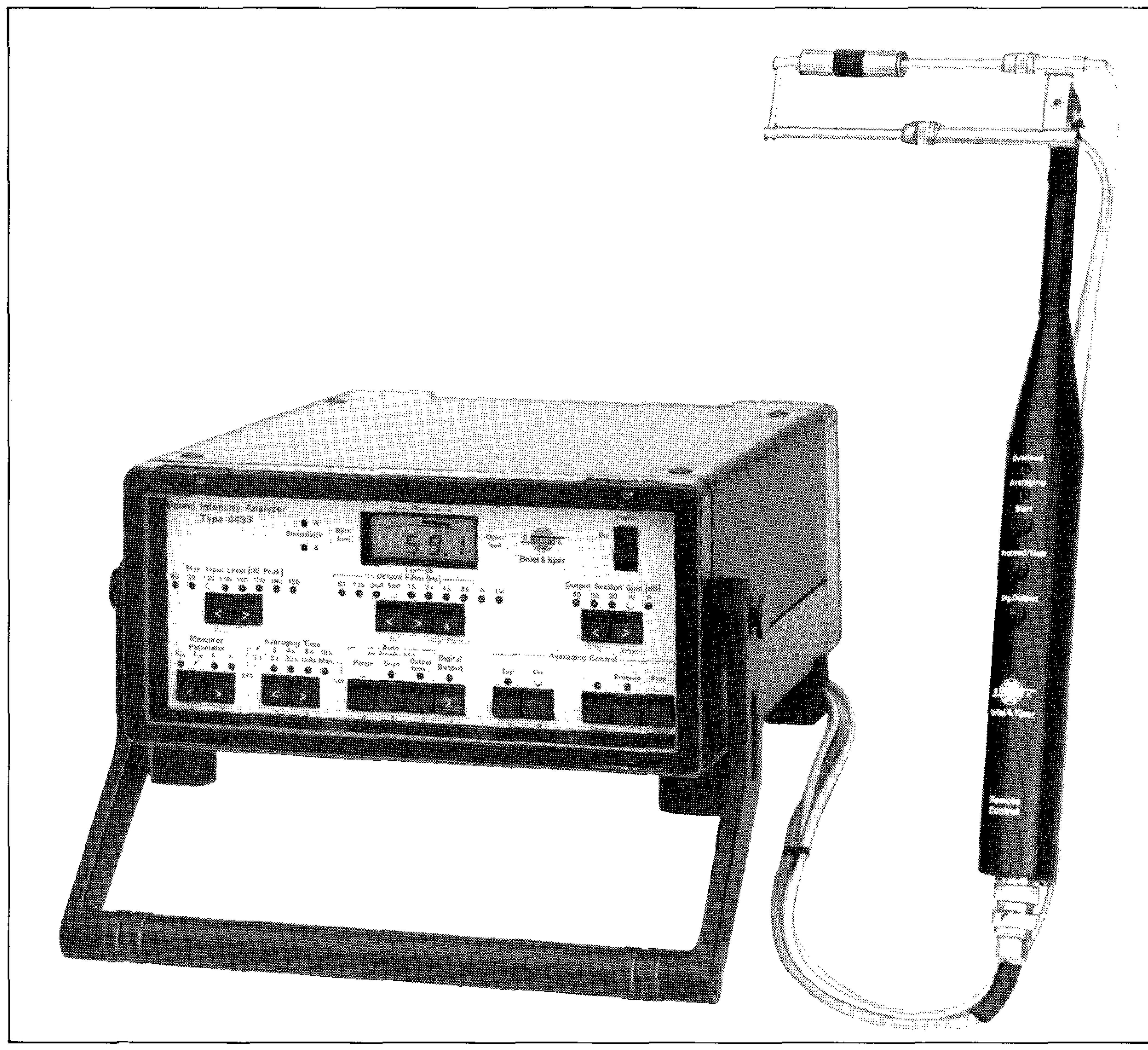

Fig. 4. Sound Intensity Analyzer Type 4433 and Probe Type 3520

General Measurement Procedure

Whereas the classical measurement of Sound Reduction Index or Transmission loss only allows one spectrum representing all the different transmission paths to be determined, the intensity method makes possible a quantification of the individual transmission paths that contribute to the sound field in the receiving room. The transmission through party walls and flanking walls are measured separately thus allowing an evaluation of the relative importance of the transmission paths. Also, in facade insulation measurements, doors, windows, window frames, ventilating units etc. can be measured separately.

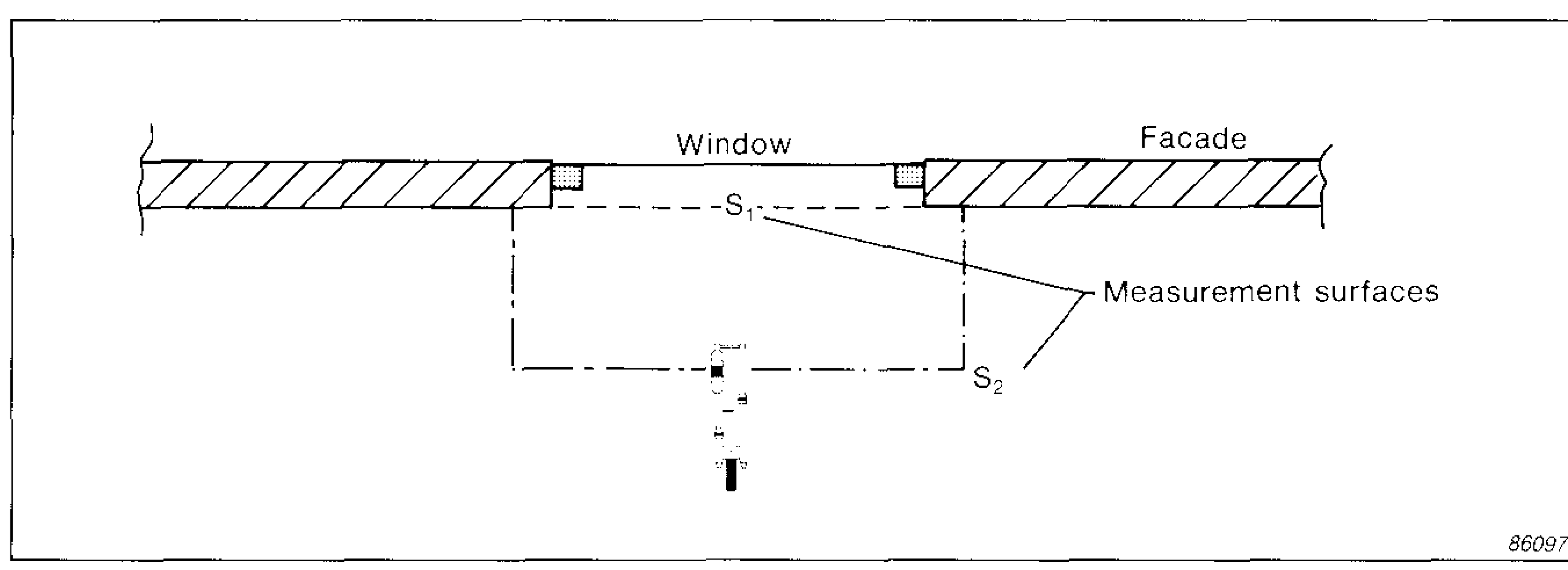

Fig. 5. Possible measurement surfaces for determining sound power transmitted through a window

Measurement Surface

Common to all these measurements is the determination of the sound power radiated from a surface. The sound power is found by measuring the average intensity normal to a measurement surface enclosing the radiating surface and then multiplying this average intensity I_{av} by the area of the measurement surface.

In Fig. 5 the procedure is illustrated with the measurement of the sound power radiated from a window in a measurement of facade insulation, where two possible measurement surfaces (S_1 and S_2) are shown. The choice of surface is determined from practical considerations. S_1 is obviously the simplest surface to measure on since it consists of only one plane, whereas S_2 consist of 5 planes. On the other hand, since it is rather close to the window the sound field may vary considerably with position making the determination of the average intensity normal to the surface difficult. In practice, the measurement distance is determined in a preliminary investigation where the probe is swept along the window at different distances with its axis normal to the window. Small changes in intensity levels indicate a suitable distance. Typically a distance of 10 – 20 cm will be adequate. In some cases, where the measurement surface parallel to the window is much larger than the other four surfaces and the sound energy is believed to propagate mainly perpendicular to the wall, these four areas may be omitted.

The average intensity is determined by first subdividing the measurement surface into a number of areas and then measuring the normal intensity level within each area by holding the probe in the middle of the area or by slowly sweeping the probe as if painting the area. Choice of area size and probe technique will depend on how much the sound field varies with position along the wall and how detailed information is required. The fixed point technique has high repeatability whereas the sweeping approach is faster, and inaccuracies due to nonsteady probe motion can be minimized by selection of a manageable area size. As shown later, an area of approximately 1 m^2 gives almost identical results with point and sweep measurements of the sound power radiated from a concrete party wall.

Check on Accuracy

The repeatability may be checked by comparison of a number of "identical" measurements at one point or over one area. Just as in measurements of sound pressure an increase in the averaging time will improve repeatability. A good averaging time to start with is 8 sec.

A possible bias error may be checked by comparing measurements where the probe has been turned 180°. The results should be the same but with opposite sign (opposite direction). If the results show a difference of e.g. 2 dB the measurement has a bias error of 1 dB (Ref. [9]). Other bias errors in the intensity estimates are caused by two factors: The absorption of the radiating surface and the reverberant field in the receiving room. The absorption coefficient α of the radiating surface should be low and the reverberation time T should be kept small ($T < 0,5$ s) in order to facilitate the measurements. If T is too high initially, it may be reduced by placement of absorbent material in the middle of the receiving room. Details on these precautions are found in Appendix B.

Computation of Apparent Sound Reduction Index

In the ISO standard ISO 140, part IV, an apparent Sound Reduction Index R' is defined. It is called "apparent" because the equation for R', as shown in Fig. 2, defines the Sound Reduction Index as if the whole transmission takes place through the party wall.

A similar equation may be set up for the apparent sound reduction index based on intensity measurements. When all contributions are added the result should be similar to the classical result.

The partial apparent sound reduction index R_n' for wall n with area S_n is given by the equation shown in Fig. 3:

$$R_n' = L_{ps} - 6\,\text{dB} - L_{In} + 10\log(S/S_n) \qquad (1)$$

R' is now found by proper addition of all the R_n':

$$R' = -10\log\sum_{n=1}^{N} 10^{\frac{-R_n'}{10}} \qquad (2)$$

In the laboratory, where there is only transmission through the partition with area S the equations reduce to:

$$R' = R_n' = L_{ps} - 6\,\text{dB} - L_{In} \qquad (3)$$

Case Studies

Measurements of sound insulation in two different houses will be described. The first set of measurements was done in a two storey building belonging to the Building Research Establishment in Watford, England. Measurements of sound insulation were made using both the classical method and the intensity method so that a comparison could be made. The other measurements were carried out on a party wall and an adjoining flanking wall in a newly built two storey apartment house in Denmark.

Case I: Measurement of apparent Sound Reduction Index

A ground plan drawing of the building belonging to BRE, Watford, UK is shown in Fig. 6. The party wall, consisting of 225 mm bricks with plaster on both sides, extends up to the roof, so no significant transmission was estimated to take place via the ceiling. Neither the concrete floor nor the backwall were likely to contribute very much either so it was decided to measure only the party wall and the two flanking walls.

Measurement Procedure

The significance of wall absorption and Reactivity Index were first investigated. The absorption coefficient of the walls was estimated to be around 0,01. The average reverberation time in the receiving room with 3 persons present was 1,4 sec. Expecting that one quarter of the total power is emitted from each of the flanking walls, ϵ_n (error due to absorption) and L_K (reactivity Index) for these walls were found to be −0,5 dB and −19 dB (using equations B1 and B2 in Appendix B). Wall absorption could then be neglected but it was necessary to introduce additional absorption in the room to decrease the magnitude of L_K. From Fig. 10 it is seen that the 4433/Probe combination allows measurements with less than 1 dB error to be done with $L_K > -14$ dB at 2 kHz. Foam blocks were now placed in the room and the average reverberation time decreased to 0,5 sec and $L_K \simeq -15$ dB was found to be close enough for a start. During the measurement the foam was placed along the wall behind the operator to efficiently provide more absorption. The Reactivity Index L_K was noted while measurements were being made and was found to be −8 to −10 dB for the party wall, and −10 to −13 dB for the flanking walls.

The sound power passing through the party wall was first determined. The wall was divided up in 30 areas,

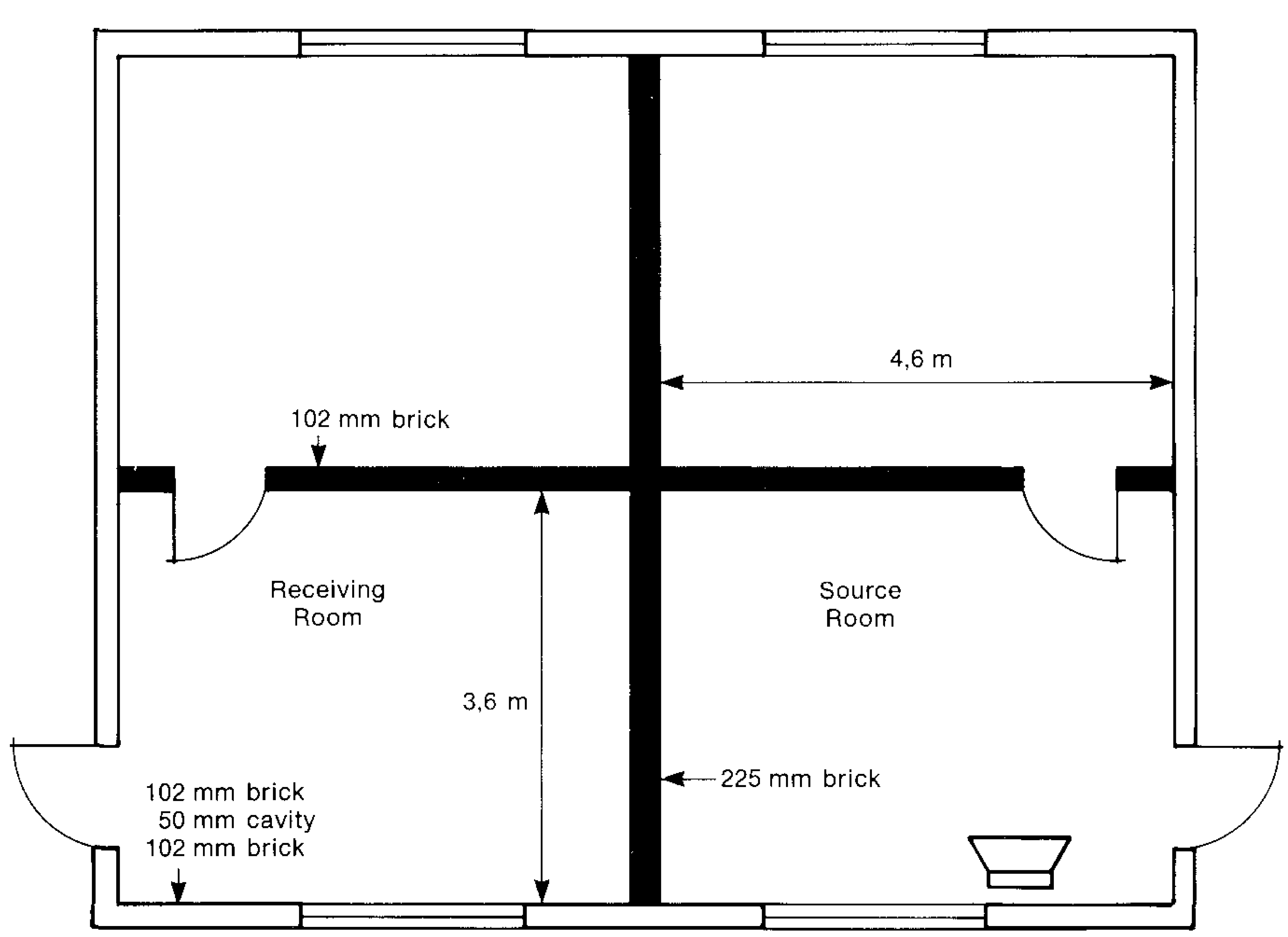

Fig. 6. Ground plan drawing of building where measurements were made

0,3 m^2 each, and the normal intensity was measured at 30 points about 20 cm from the wall. The distance was not critical and it turned out that there was very little variation of the intensity level along the surface, so much less than 30 points could have been used. The flanking walls were then divided in 10 and 11 segments respectively, and the segments were laid out to follow the door and the window. With segments of approximately 1 m^2 in size it was decided to move the probe in a circle instead of doing a point measurement. The level in the receiving room was very low and a true sweep measurement tended to create too much background noise from the operator. The frequency range from 125 Hz to 250 Hz was measured with a microphone spacing Δr = 50 mm whereas Δr = 12 mm was used for the rest of the frequency range (Refs. [8, 9]).

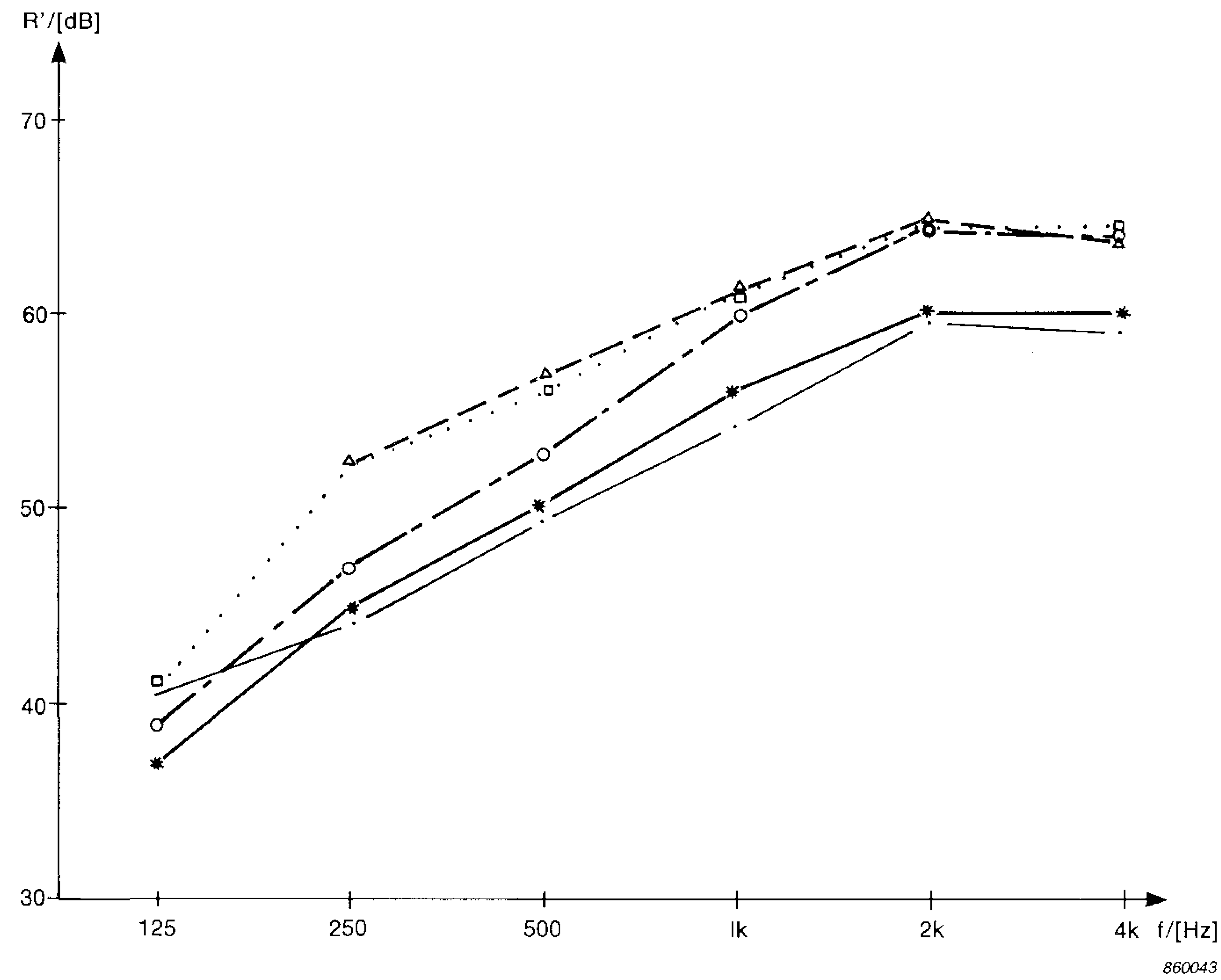

Fig. 7. Measurements of apparent sound reduction index R'.
*·—· Classical measurement. *—* Intensity measurement (party wall + 2 flanking walls) ○-·-○ Intensity measurement, party wall. △---△ Intensity measurement, flanking wall with window. □· · ·□ Intensity measurement, flanking wall with door*

Discussion of Measurement Results

The measurement results are shown in Fig. 7. It is seen, that there is very good agreement between the classical measurement and the sum of the contributions from the party wall and the two flanking walls from 250 Hz up to 4 kHz, as determined using the intensity method. In the bands around 250 Hz and 500 Hz the major contribution comes from the party wall whereas the flanking walls are just as important at higher frequencies. The discrepancy between the two sets of measurements in the 125 Hz octave band is probably due to measurement inaccuracy of the classical method. The uncertainty is known to be about 2 dB at 125 Hz in this building.

Conclusion

The portable 4433 Sound Intensity Analyzer has been used to measure sound insulation between two rooms in a house. The information obtained about the relative importance of flanking transmission, and the overall apparent sound reduction index shows very good agreement with results obtained by the classical method.

Acknowledgement

I would like to thank the staff at BRE, acoustics department for their assistance with the sound insulation measurements.

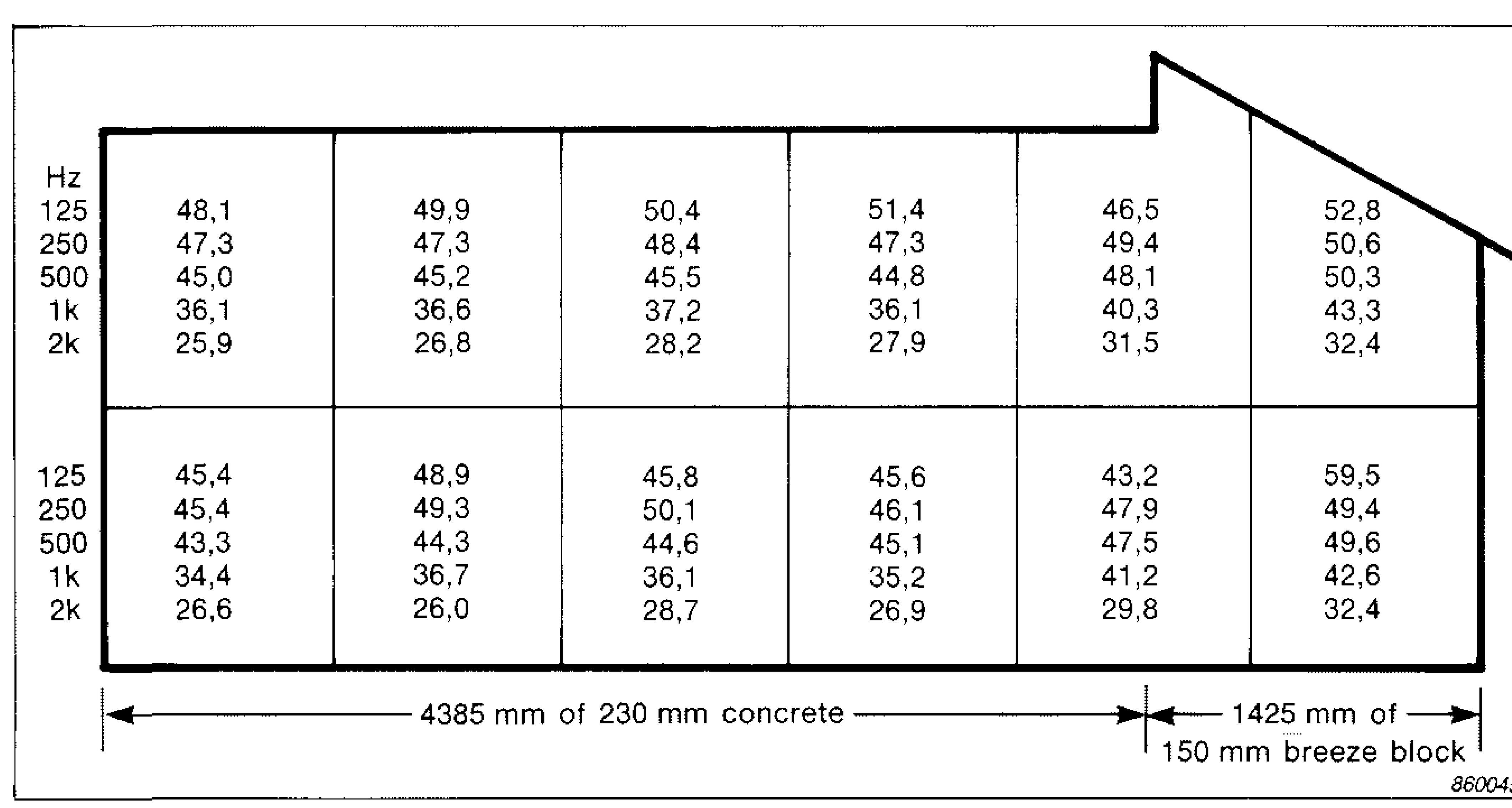

Fig. 8. Sound intensity levels on party walls in dB re 1 pW m^{-2}

Case II: Sound Insulation Measurement on party wall and flanking wall

The sound insulation measurements were performed in two adjacent terraced houses. The party wall separating the two houses had an area of 14 m^2 on the receiving room side, of which only 10 m^2 was common to both the transmitting and receiving rooms. The common area was made of 230 mm concrete. The remaining area, made of lighter materials (wood clad breezeblock) extended beyond the outer wall of the transmitting house and faced out into the garden. The reverberation time in the empty receiving room was approximately 1,5 sec. Placement of absorptive bales of Rockwool decreased the reverberation time to about 0,5 sec, which made the measurement condition better by decreasing the reactivity Index L_K (see also Appendix B).

Intensity Measurements

The sound intensity measurements on the party wall were measured using the sweep technique in 12 sub-areas with an averaging time of 32 s (Fig. 8).

The sweep rate was about 0,5 m/s. The intensity levels at that end of the wall closest to the garden were marketedly higher in certain octaves. The situation is detailed for the 1 kHz octave band in Fig. 9.

The sound pressure level in the garden near the breeze block wall was too low to generate significant airborne sound transmission into the receiving room, so the high intensity levels on this part of the wall were due to flanking transmission.

Sweep and Point Measurement Technique

Comparison was made between sweep and point measurements of intensity over the party wall in 12 subareas using the portable octave Sound Intensity Analyzer. The resulting sound reduction indices are shown in Table 1. The sweep speed was about 0,5 m/s.

Hz	R point	R sweep
125	47,2	47,9
250	52,1	52,8
500	58,4	58,8
1 k	63,9	63,6
2 k	74,2	73,9
A	61,4	61,4

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Table 1. Sound reduction indices, point and sweep measurement techniques over 12 subareas on the party wall

Conclusion

Using intensity measurements the sound power injected into the receiving room from a party wall and an adjacent flanking wall have been determined. It has been shown that the power/m^2 (the intensity) produced by the flanking wall is higher than the intensity produced by the party wall, and the flanking wall is excited by structure-borne transmission.

The portable intensity system is a very convenient tool for in situ investigations in building acoustics. The analyzer, being battery operated, is silent, which can be of crucial importance in measurement in well insulated houses where the sound level in the receiving room can be very low.

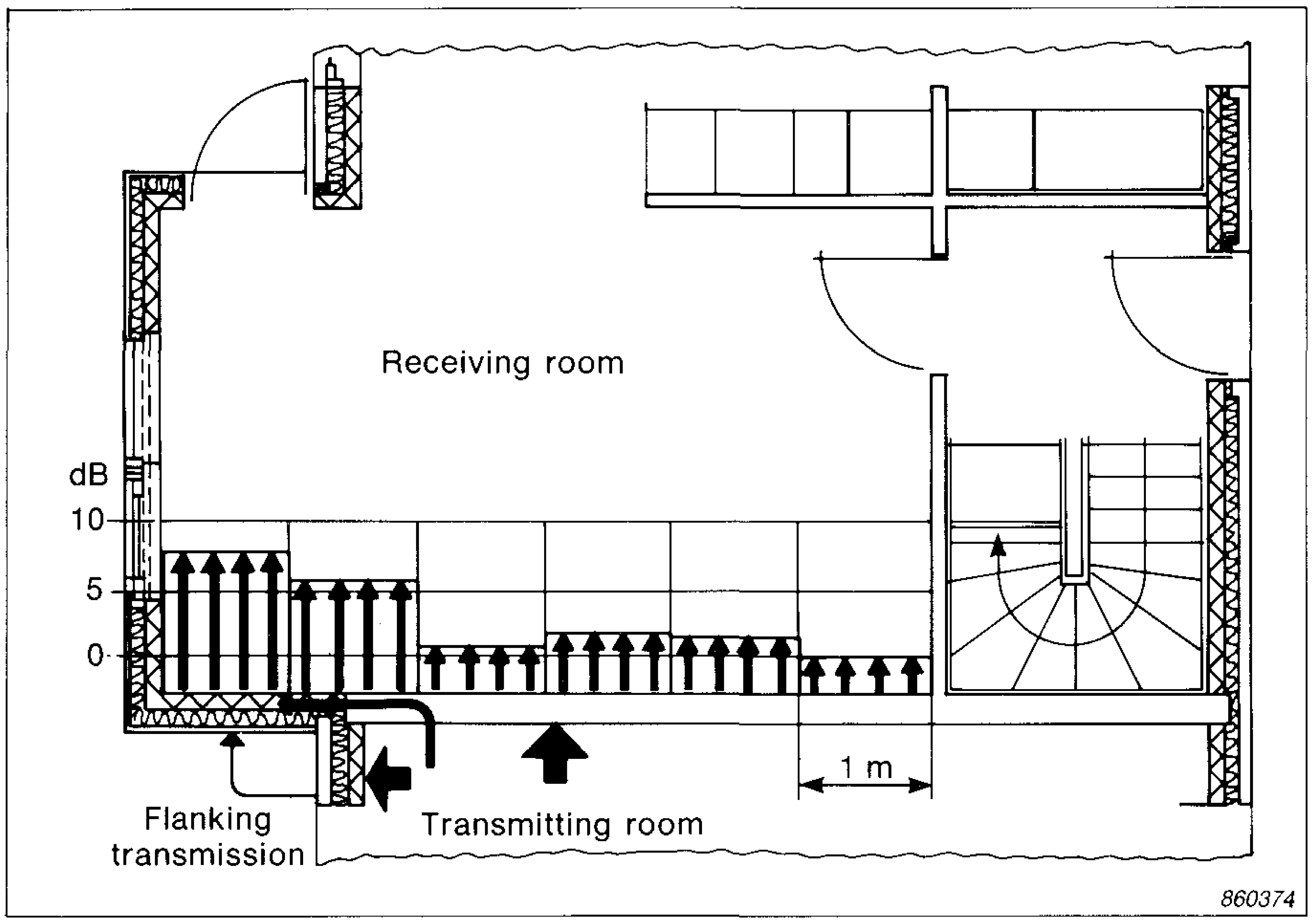

Fig. 9. Sound transmission in the 1 kHz octave band (0 dB corresponds to 35 dB Sound Intensity level

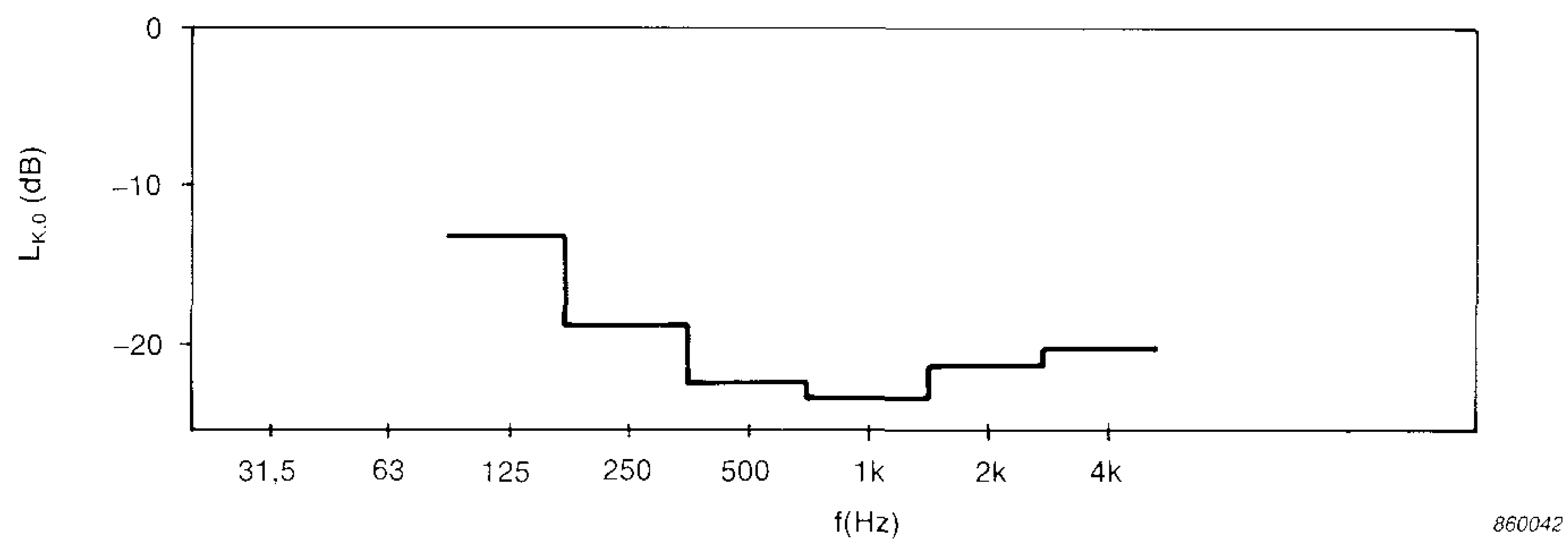

Fig. 10. The measured Residual Intensity Index for the 4433/Probe for a microphone spacing of 12 mm

Appendix A

Measurement Accuracy: The reactivity index L_K and the residual intensity index, $L_{K,0}$

An intensity system's ability to measure in sound fields is mainly determined by the phase mismatch between the two channels. This phase mismatch is conveniently expressed as the *Residual Intensity Index* $L_{K,0}$ (Ref.[9]), which determines the lowest intensity level which can be detected by the system for a given sound pressure level. This is an important parameter when measuring sound transmission through walls, as very often the intensity level which the system is required to detect lies much lower than the pressure level. The measured Residual Intensity Indices $L_{K,0}$ for the 4433 and the ½″ microphone pair used in the measurements are shown in Fig. 10.

For an accuracy of ±1dB in the measured intensity, the difference between the measured intensity and pressure levels (termed *Reactivity Index*, L_K) should be numerically 7 dB smaller than $L_{K,0}$ (Ref.[9]). This defines the dynamic capability of a sound intensity analysing system. For example if $L_{K,0}$ for the analyzer is −20 dB, then for an accuracy of ± 1 dB, measurements can be made in a sound field where the sound intensity level is no lower than 13 dB under the sound pressure level ($L_K > L_{K,0}$ + 7 dB, i.e. $L_K > -13$ dB).

The residual intensity index $L_{K,0}$ for an intensity system may be determined from the calibration chart of the probe and a simple measurement of $L_{K,0}$ of the analyzer.

Appendix B

Measurement Accuracy: Influence of absorption coefficient α of the radiating wall and influence of the reverberant field

When using the intensity approach to measure sound insulation between two rooms it is desireable that the reverberant sound field in the receiving room should be as low as possible. This is required for two reasons. The first concerns the fact that the analyzer will measure the net power coming from the wall, that is the power emitted by the wall minus the power absorbed by the wall from the reverberant sound field in the receiving room. In these circumstances there is an underestimate of the emitted power. The magnitude of this error, ϵ_n, can be estimated using a simple formula, Fig. 11 (Ref. [6]). If the error is unacceptably large, it can be reduced by distributing absorptive material in the receiving room to reduce the reverberant field.

The second reason for desiring a low level reverberant field in the receiving room is that a sound intensity analyzer may have difficulty in detecting the low intensity levels in the presence of a high level reverberant sound field. The Reactivity Index L_K therefore needs to be estimated or measured to check that the dynamic capability of the sound intensity analyzer is not exceeded. L_K can be estimated using the formula in Fig. 11 (see also Ref.[6]), and it can be measured directly. The magnitude of L_K can be reduced if necessary by introducing absorbing materials into the room which act to lower the reverberant sound field.

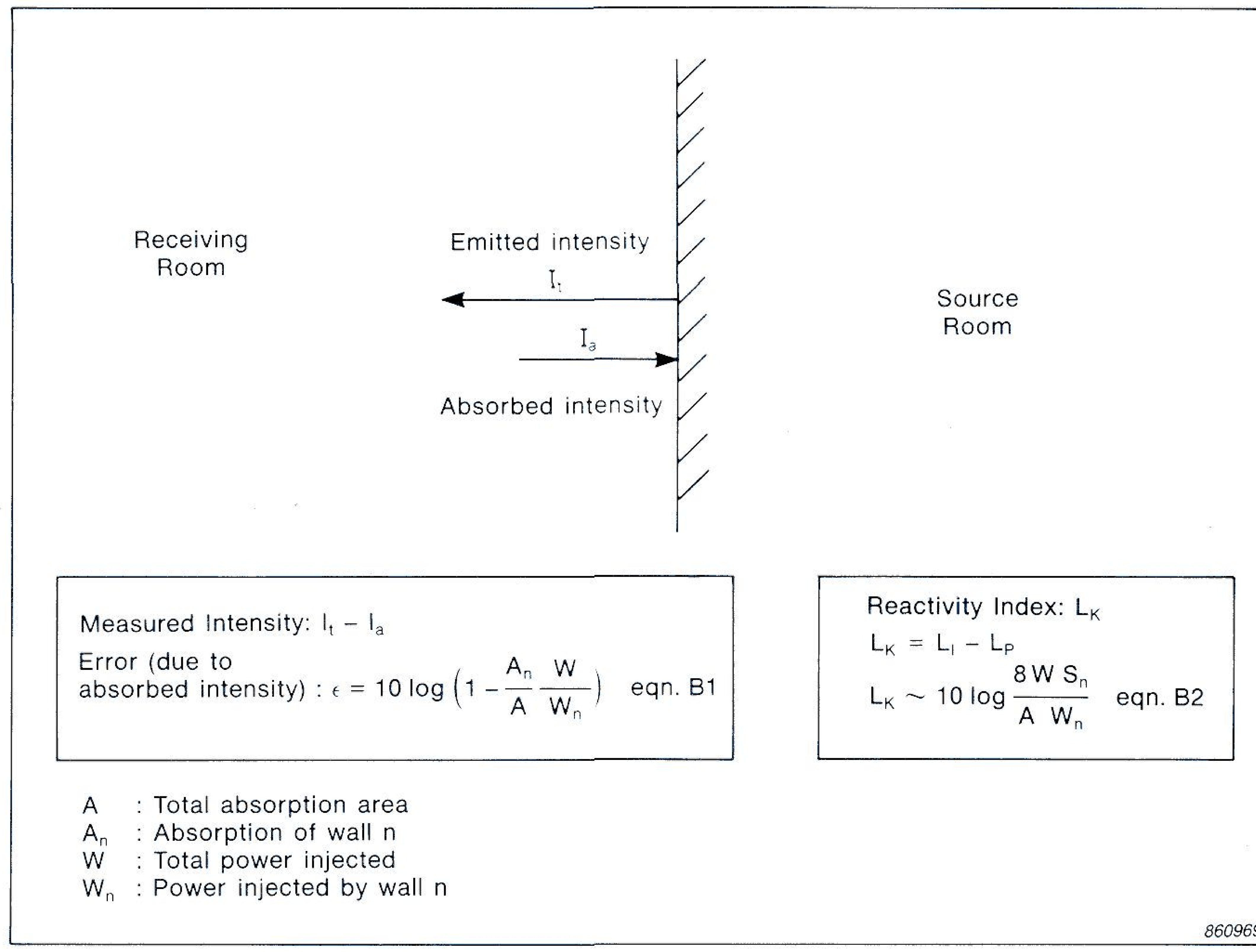

Fig. 11. Two factors which could affect the accuracy of sound intensity measurements: (a) absorption of sound power at the wall from the reverberant field in the receiving room, (b) Reactivity Index L_K of the sound field (Intensity Level minus Pressure Level). See also Ref. [6]

References

[1] ISO 140 "*Measurement of sound insulation in buildings and of building elements*". Part IV: Field Measurements of airborne sound insulation between rooms

[2] MACADAM, J.A. "*The measurement of sound powers radiated by individual room surfaces in lightweight buildings*", Building Research Establishment Current Paper CP 33/74, 1974

[3] KIHLMAN, T. "*Measurements of sound radiation into rooms*" 11th ICA, LYON, 1983

[4] COPS, A., MINTEN, M., "*Comparative study between the sound intensity method and the conventional two room method to calculate sound transmission loss of wall constructions*" Noise Control Engineering Journal, May – June 1984

[5] CAUBERG, J.J.M., "*Determination in situation of the transmission loss of various components of a building facade with the aid of sound intensity measurements*", FASE Proceedings, 1984

[6] ROLAND, J., "*Room to room transmission: What is really measured by intensity*" Proceedings of 2nd congress on acoustic intensity, CETIM, Senlis, 1985

[7] Sound Intensity Analyzer Type 4433, Product Data

[8] Sound Intensity Probe Type 3520, Product Data

[9] GADE, S., "*Validity of Intensity measurements*", 1985 B & K Technical Review, No. 4

[10] Sound Intensity, B & K booklet

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