Sound transmission rooms : a comparison

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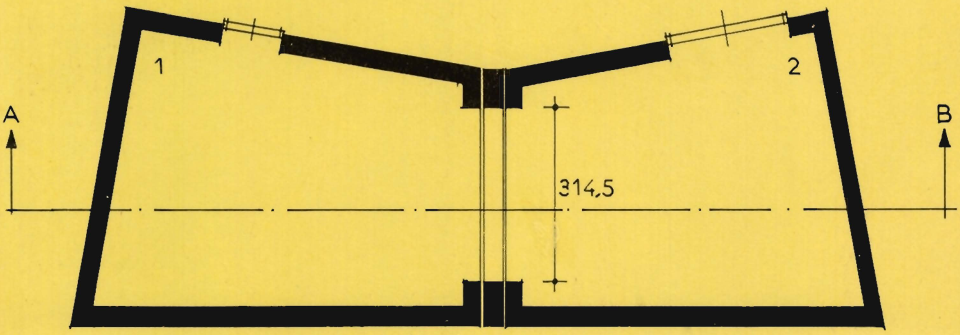

HEIKO JAN MARTIN

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PROEFSCHRIFT

TER VERKRIJGING VAN DE GRAAD VAN DOCTOR AAN DE TECHNISCHE UNIVERSITEIT EINDHOVEN, OP GEZAG VAN DE RECTOR MAGNIFICUS, PROF. DR. F. N. HOOGE, VOOR EEN COMMISSIE AANGEWEZEN DOOR HET COLLEGE VAN DECANEN, IN HET OPENBAAR TE VERDEDIGEN OP DINSDAG 9 SEPTEMBER 1986 TE 16.00 UUR

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HEIKO JAN MARTIN

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Voor Eipie, Anneke en Gert.

Preface

The sound reduction index of a building element is an important quantity in noise abatement. It is determined in sound transmission rooms of which there are six in The Netherlands. These rooms all differ in size, shape and construction. These differences affect the test results.

The idea for an inter-laboratory investigation arose from the many questions we encountered during the design and the construction of the Acoustics Laboratory at Eindhoven University of Technology. In the same period of time the cooperation started between the Institute of Applied Physics TNO at Delft and the group Physical Aspects of the Built Environment at Eindhoven University of Technology; it gave us another reason to carry out the investigation.
The idea was worked out by my TNO-colleague Renz van Luxemburg and myself in the usual good understanding.
This thesis which deals with the uncertanties that occur in laboratory sound insulation measurements gives some recommendations to improve the precision of this type of measurement.

An inter-laboratory investigation like this has no chance to succeed without the full cooperation of all participating laboratories. Therefore I would like to express my thanks to the people in charge of the laboratories who put their transmission rooms at the disposal of this investigation. This includes also each measuring team and the people we met on our tour along the laboratories who gave us a friendly reception.

A few names have to be mentioned: Renz van Luxemburg with his organizing talents, Wieger Cornelissen and Martijn Vercammen assisting during the measuring tours. I owe them a lot. I feel obliged to my colleagues of the group Physical Aspects of the Built Environment who gave me the opportunity to write this thesis. Without the mental support of my promotor and copromotor this thesis would never have been written.
I also thank our secretary Marianne Hafmans for her fast and accurate typing.

Heiko Martin
September 1986

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CHAPTER 1. GENERAL INTRODUCTION

The model SOURCE-PATH-RECEIVER is often used for describing the propagation of sound in existing and new situations.
Although every situation can be described using this model, in practice it suffices to distinguish three cases:

1. transmission of sound from outside to inside;
2. transmission of sound between two adjacent rooms;
3. transmission of sound from inside to outside.

The distinction is based on the character of the sound field near source and receiver.

1.1. Transmission of sound from outside to inside

Outside, where the noise is caused by traffic, railways or aeroplanes, propagation takes place in a free field. Inside, in the receiving room, in general the sound field is assumed to be diffuse. The facade of the building is the separation between outside and inside. The sound pressure level in front of the facade can be determined from the emission of the source and the distance between the source and the facade (refs.1.1 en 1.2). The emission of the source can be calculated from theoretical models developed for different source types.
Corrections can be made for the influence of barriers, air and ground absorption, meteorological conditions and the geometry of the situation.
The sound pressure level inside, in a certain frequency band, can be calculated according to regulations (refs.1.3, 1.4 and 1.5) from eq.(1.1):

$$L_2 = L_{2m} - G + 10 \lg (T_2/T_n) \qquad (1.1)$$

where: L_2 = the sound pressure level inside in dB re 20 μPa

L_{2m} = the sound pressure level outside at a distance of 2 m from the facade, in dB re 20 μPa

G = the sound reduction of the facade in the frequency band concerned, in dB

T_2 = the reverberation time in the receiving room in s

T_n = a reference reverberation time: $T_n = 0.5$ s for dwellings; $T_n = 0.8$ s for rooms in other buildings

(To avoid indices, every quantity is considered in the frequency band concerned.)

The sound reduction G of the facade can be determined from eq.(1.2):

$$G = R - C_r + 10 \lg (V_2/6\ T_n S) \qquad (1.2)$$

where: R = the laboratory sound reduction index of the facade in the frequency band concerned (dB)

C_r = a correction term for the reflection of sound against the facade, depending on the surface structure of the facade (dB)

V_2 = the volume of the receiving room (m^3), and

S = the total area of the facade with the highest level of incident sound, seen from inside (m^2).

The sound reduction index R of the facade can be calculated from eq.(1.3):

$$R = -10 \lg (\Sigma\ (S_j/S)\ 10^{(-R_j/10)} + K) \qquad (1.3)$$

where: S_j = the area of element j (m^2)

R_j = the laboratory sound reduction index of element j (dB)

K = a term indicating the transmission of sound through slits and cracks.

1.2. Transmission of sound between two adjacent rooms

The sound is produced in one room, the source room, by human activities or machines and transmitted to another room in the same building, the receiving room. In general, the sound field in both rooms is assumed to be diffuse.

The sound pressure level in the receiving room in a certain frequency band is the sum of the contributions of all possible paths of sound transmission from the source room to the receiving room:

- direct transmission through the partition (wall or floor);
- flanking transmission: transfer of sound and vibrational energy along the flanking structures;
- sound leaks;
- indirect transmission of sound, not being direct or flanking transmission.

The contribution of the direct and each flanking path to the total sound pressure level in the receiving room, in a certain frequency band, can be determined from eq.(1.4) (ref.1.6):

$$L_{2ij} = L_1 - R_i/2 - R_j/2 - D_{vij} + 5 lg(S_i . S_j) - 10 lg A_2 \qquad (1.4)$$

where: L_1 = the sound pressure level in the source room in dB re 20 µPa

L_2 = the total sound pressure level in the receiving room in dB re 20 µPa; $L_2 = \Sigma L_{2ij}$

L_{2ij} = the sound pressure level in the receiving room in dB re 20 µPa as a result of transport of sound energy along path ij: structure i in the source room, structure j in the receiving room

R_i, R_j = the respective sound reduction indices of structures i and j (dB)

D_{vij} = the reduction in vibration level going from structure i to structure j, caused by reflection at the junction of both structures (dB)

S_i, S_j = the areas of structures i and j respectively (m^2)

A_2 = the total amount of absorption in the receiving room (m^2).

Also in the case of indirect sound transmission the sound reduction index of building elements like suspended ceilings, roofs, air terminal devices, etc. plays an important role.

1.3. Transmission of sound from inside to outside

In a room, the source room, sound is produced by human activities or machines, e.g. by a concert or a process in a factory. The sound is transmitted through all surfaces of the room.
Theoretical models (refs.1.7, 1.8 and 1.9) have been developed to calculate the sound pressure level in a certain frequency band outside at a certain distance to the source room (eq.1.5):

$$L_2(r) = L_1 - R - C_d + 10 \lg S + DI(\Phi) - D_{geo} - \Sigma D_i \qquad (1.5)$$

where: $L_2(r)$ = the sound pressure level outside as a result of radiation of sound from a certain surface, at a distance r from that surface, in dB re 20 µPa

L_1 = the sound pressure level inside near the surface concerned, in dB re 20 µPa

R = the laboratory sound reduction index of the surface considered, in dB

C_d = a correction for the character of the sound field and the absorption of the surface at the inside, in dB

S = the area of the surface, in m^2

D_{geo} = the reduction caused by spherical expansion of the sound (dB)

$DI(\Phi)$ = the reduction caused by spherical expansion of the sound, in dB

Φ = the angle of the direction of radiation

ΣD_i = the reduction caused by ground and air absorption, barriers and meteorological influences, in dB

1.4. Aim of this thesis

As seen in the practical cases mentioned above, the sound reduction index of the partition between two 'rooms' is an important step in noise abatement. The sound reduction index of individual building elements can be predicted from theory, complemented by empirical formulae; good results

have been obtained especially for glazing and single-leaf constructions. Another way to obtain the sound reduction index of a building element is to make use of laboratory measurements. Firstly, because complex constructions cannot be modelled accurately and secondly, because in practice there is a need for an acoustical qualification of elements by means of carrying out measurements under well defined conditions.
As will be seen in § 2.3 an acoustical laboratory for measuring the sound reduction index consists of at least two rooms, the transmission rooms, between which a building element is mounted. The combination of the two transmission rooms is called a transmission suite.
Of course errors of a statistical nature occur during laboratory measurements. However, it has been shown by different research-workers in the FRG and Scandinavia that results of sound insulation measurements are not independent of the laboratory chosen. The sound reduction index of a building element, as a result of measurements in one laboratory, can differ considerably from the results of measurements in another laboratory.
This thesis contains the results of an investigation after the influences of laboratories on the measured sound reduction index of building elements. The investigation has been carried out in the period from 1982 to 1985 in 8 laboratories, of which 2 are in Belgium and 6 in The Netherlands. It has been sponsored by the Ministry of Housing, Physical Planning and Environment.

In Chapter 2 a short historical review of transmission suites in Belgium and The Netherlands will be followed by the requirements for transmission suites and the standardized measuring method. Also a second measuring method in which the intensity technique is used, is introduced in this chapter.
The factors which can affect the sound reduction index, measured in the laboratory, are dealt with in Chapter 3, including the statistical model for determining the repeatability and the reproducibility of the test methods.
Chapter 4 outlines the organization of the investigation, specifying in detail the test objects and the participating laboratories.
Chapter 5 presents the results of the investigation.

CHAPTER 2. TRANSMISSION ROOMS: HISTORY, STANDARDIZATION AND TEST METHODS

2.1. Introduction

In acoustical laboratories, transmission rooms are used to qualify building elements.
The definition of the sound reduction index R of a building element is given by eq.(2.1):

$$R = 10 \lg (W_i / W_\tau) \qquad (2.1)$$

where: W_i = the sound power, incident on the building element in watts
W_τ = the sound power, transmitted through the element in watts.

To determine the sound reduction index from measurements, the building element is mounted in a test opening between two rooms, the transmission rooms. The whole of the transmission rooms and the test opening between them is called the transmission suite. The transmission suite should be constructed in a special way so that transport of sound energy from one room to the other is possible only through the test object, i.e. the building element. For that purpose a number of requirements for transmission suites are given in an international standard. Other international standards specify test procedures. The past 25 years have shown a certain development in standardization. Besides, new measuring techniques have been introduced.

2.2. History of transmission suites in Belgium and The Netherlands

The first attempts to investigate systematically the sound insulation of building constructions on a laboratory scale date from the thirties.
At Delft, in the Laboratory of Applied Physics at the Mijnbouwplein, the so called 'kistenmethode' (box method) was used before World War II.

We cite ref.2.1:

"A sample of the test object with an area of about 1 m^2 is constructed. Two wooden boxes with double walls and thus a high sound insulation, are clamped on both sides of this sample. On one side a 'source box', containing a loudspeaker; on the other side a 'receiving box', in which the microphone of the sound level meter. By employing felt at the edges of the boxes, there are no sound leaks so that sound can only be transmitted from the 'source box' to the 'receiving box' through the sample. By means of a sine generator and an amplifier the loudspeaker produces a pure tone, the frequency of which is increased in 200 Hz steps from 200 Hz to 2000 Hz. Sometimes warble tones are used. By measuring the sound levels in the source box and the receiving box the sound insulation at that frequency is obtained:

$$iL = L_1 - L_2 - B \qquad (2.2)$$

where: iL = sound insulation in dB
L_1 = sound level in the source box in dB
L_2 = sound level in the receiving box in dB
B = correction term, accounting for the absorption of the receiving box (= 4dB).

End of quotation.

Before long it was seen that, for a better understanding of the matter, sound insulation measurements in situations, practice alike, were needed. In fact, measurements according to the 'kistenmethode' were very unreliable.

So, in 1946 plans were made to create a building, consisting of several rooms, in which it was possible to place different types of walls and floors between the rooms. This building, the so-called 'proefhuisje' (test rig) of the 'Geluidcommissie TNO' (Acoustics Committee TNO), has been erected in 1948 in the attic of the old Laboratory of Applied Physics (refs. 2.2 and 2.3). In it were 4 small rooms, two beside each other and two on top of the former two, with a volume of 15.6 m^3 each. The walls

were made of bricks with a thickness of 110 mm. The floor of the lower two rooms was the existing concrete floor with a thickness of 250 mm. The separation between the lower and the upper rooms was a cassette floor, made of concrete, with a thickness of 100 mm. On top of the upper rooms there was a concrete floor with a thickness of 100 mm (construction data from ref.2.4).
In this 'proefhuisje' two walls and two floors could be tested within a short period of time. This test rig allowed test objects with larger areas than the boxes. Besides, essential changes were introduced in the test methods: broad band noise was used instead of warble tones and by using band pass filters the desired quantities could be determined as a function of frequency. Indeed, this laboratory proved a better approximation of practice than the 'kistenmethode'.

From the design of these first 'laboratories' we see, that at that time the important part, played by the wavelength in propagation of sound in building constructions, was not realised. It is not surprising, since only in 1942 Cremer (ref.2.5) demonstrated that bending waves in a building construction can have a strong influence on its sound insulation. The wavelengths of those bending waves can be calculated from the bending stiffness. They are responsible for radiation of sound from a vibrating construction and hence for the sound insulation of it, at least in a certain frequency range.
Not until the late forties Cremer's ideas were used in experiments in The Netherlands.
In the same period of time, in 1947, deliberations were started between England, Denmark, France and The Netherlands about unification and later on about standardization of test methods. Among other things, this led to the first edition of ISO 140 (ref.2.6): 'Field and laboratory measurements of airborne and impact sound transmission'.

As a consequence of this standardization the results of sound insulation measurements in different countries and institutes became comparable.
The first 'real' transmission suites also date from this time. The volumes of the transmission rooms are larger than those of the 'proefhuisje', at least 50 m^3 but often more. Source and receiving rooms were separated

structurally. Their walls and floors often consist of heavy homogeneous constructions. Hence, sound is only transmitted from the source room to the receiving room through the test object mounted in a test opening between both rooms.

In 1962 the Acoustics Laboratory of the Faculty of Applied Physics at Delft University of Technology was built under the supervision of prof.dr. C.W.Kosten. Its four transmission rooms have also been used ever since by the Institute of Applied Physics TNO.

In 1967 Leuven University (KUL-Belgium) got its acoustics laboratory, in which four transmission rooms are present; it was an important step forward for the known Laboratory of Acoustics and Heat Conduction, led by prof.dr.H.Myncke and dr.A.Cops (ref.2.7).

Not long after that, in 1968, the Institute of Health Engineering TNO (IG-TNO, born from the 'Geluidcommissie TNO', later called the TNO Environmental Research Institute) built its six transmission rooms with J.van den Eijk in control.

Transmission suites were also built by private firms: in 1972 Peutz & Associé's and in 1975 Van Dorsser b.v., both acoustic consulting firms, got their transmission suites in Nijmegen and The Hague respectively.

In 1978 the Scientific Centre for Building Technology (Wetenschappelijk en Technisch Centrum voor het Bouwbedrijf WTCB, or 'Centre Scientifique et Technique de la Construction' CSTC) put their transmission suites into use in Limelette near Brussels.

Youngest member of the family is the Acoustics Laboratory of the Faculty of Architecture and Building Technology at Eindhoven University of Technology. Its three transmission rooms were completed in 1981 (ref.2.8).

The construction of the different laboratories will be discussed in chapter 4.

2.3. Requirements for transmission suites

The first, internationally agreed, requirements for transmission suites are given in ISO R/140-1960 (ref.2.6). The developments in acoustics and the need for further standardization led to a revision of this document in 1978. This resulted in ISO 140-1978, parts I to IX (refs.2.9 to 2.17).

Table 2.1. summarizes the requirements of ISO R/140-1960 and ISO 140/I-1978 as to laboratories meant for airborne sound insulation measurements. Apart from these international standards, almost every country has its own, somewhat adapted, requirements, derived from the ISO documents.

2.4. Test procedures

2.4. Conventional 'pressure' method according to ISO 140/III-1978 (ref. 2.11)

The definition of the sound reduction index R has already been given by eq.(2.1):

$$R = 10 \lg (W_i/W_\tau) \tag{2.1}$$

If the sound fields in the source room and the receiving room are diffuse and if the sound is transmitted only through the specimen, the sound reduction index for diffuse incidence may be evaluated from:

$$R = L_1 - L_2 + 10 \lg (S/A_2) \tag{2.3}$$

where: L_1 = the average sound pressure level in the source room in dB re 20 μPa

L_2 = the average sound pressure level in the receiving room in dB re 20 μPa

S = the area of the test specimen which is normally equal to the area of the free test opening, and

A_2 = the equivalent absorption area in the receiving room in m^2

The sound generated in the source room should be steady and have a continuous spectrum in the frequency range considered.
The loudspeaker enclosure should be placed to give a sound field as diffuse as possible and at such a distance from the test specimen that the direct radiation upon it is not dominant.

Table 2.1. Requirements for laboratories with respect to airborne sound insulation measurements.

	ISO R/140-1960 (ref.2.6)	ISO 140/I-1978 (ref.2.9)
laboratory type	flanking transmission excluded	suppressed radiation from flanking elements
transmission rooms	two reverberant rooms with a test opening between them	two reverberant rooms with a test opening between them
. volumes	>50 m^3 desirable: 100 m^3	>50 m^3 difference in room volumes of at least 10%
. shape	chosen so as to give an adequately diffuse sound field	not exactly the same for both rooms; ratios of dimensions chosen so that natural frequencies in the low frequency region are spread as uniformly as possible
. background level	--	sufficiently low
test object	--	structurally isolated from both rooms or connected to one or both rooms
. area	10 m^2 min. 2.5 m; smaller size may be used if the wavelength of free bending waves is smaller than the minimum dimension	10 m^2 minimum dimension 2.3 m; smaller size may be used if the wavelength of free bending waves is smaller than the minimum dimension and for doors, windows and other small building elements
. edge conditions	as near to practical conditions as possible	careful simulation of normal connections and sealing conditions at the perimeter.

The average sound pressure level may be obtained by using a number of fixed microphone positions or a continuously moving microphone with an integration of the squared rms sound pressure.
The sound pressure levels should be measured using third-octave band filters, of which the centre frequencies in hertz should be at least: 100, 125, 160, 200, 250, 315, 400, 500, 630, 800, 1000, 1250, 1600, 2000, 2500 and 3150.

The correction term in eq.(2.3) containing the equivalent absorption area may preferably be evaluated from the reverberation time measured using Sabine's formula:

$$A = 0.163 \times (V/T) \tag{2.4}$$

where: A = the equivalent absorption area, in m^2
V = the receiving room volume, in m^3
T = the reverberation time, in seconds.

2.4.2. The intensity method

The power W_i of the incident sound (eq.(2.1)) is the product of the intensity I_i of the incident sound and the area S of the test object:

$$W_i = I_i \times S \tag{2.5}$$

The intensity of the incident sound can be calculated under the assumption of a diffuse sound field from:

$$I_i = p^2/(4\rho c) \tag{2.6}$$

where: p^2 = the average squared rms sound pressure in the source room in Pa
ρ = the density of air in kg/m^3
c = the speed of sound in air in m/s

The intensity level of the incident sound is related to the averaged sound pressure level by:

$$L_{Ii} = L_1 - 6\text{dB} \tag{2.7}$$

where: L_{Ii} = the intensity level of the incident sound in dB re $10^{(-12)}$ watts/m^2

L_1 = the averaged sound pressure level in the source room in dB re 20 µPa

Also, the transmitted acoustic power W_τ for a homogeneous test object can be calculated from:

$$W_\tau = I_\tau \, . \, S \tag{2.8}$$

where: I_τ = the intensity of the sound transmitted through the test object in watts/m^2

S = the area of the test object in m^2

The transmitted acoustic intensity is measured by a two-microphone probe directly behind the test object. The axis through the two microphones is perpendicular to the surface of the object. The measured intensity is the component of the intensity in the direction of the axis and is given by:

$$I_\tau = (1/T) \, . \, {}_0\!\int^T p(t) \, . \, v(t) \, dt \tag{2.9}$$

where: $p(t)$ = the instantaneous pressure in Pa

$v(t)$ = the instantaneous particle velocity in the direction of the axis in m/s

T = the averaging time in seconds

The sound pressure $p(t)$ in eq.(2.9) is obtained from the sound pressures $p_A(t)$ and $p_B(t)$, measured by the two microphones A and B:

$$p(t) = (p_A(t) + p_B(t))/2 \tag{2.10}$$

and the particle velocity v(t) is determined by the pressure gradient between the two microphones:

$$v(t) = (1/\rho) \cdot \int (p_A(t) - p_B(t))/\Delta x \;\; dt \tag{2.11}$$

where: ρ = the density of air in kg/m^3

Δx = the distance between the microphones in m

The method involving eqs.(2.9), (2.10) and (2.11) is known as the direct method for determining the sound intensity (refs.2.18 and 2.19).

The acoustic intensity can also be obtained by transformation to the frequency domain by using a two-channel FFT analyser (ref.2.20 and 2.21):

$$I_\tau(\omega) = Im(S_{AB}(\omega))/(\omega\rho\Delta x) \tag{2.12}$$

where: $Im(S_{AB}(\omega))$ = the imaginary part of the cross-spectrum of the two microphone signals $p_A(t)$ and $p_B(t)$

ω = the angular frequency, 2π times the frequency

The method involving eq.(2.12) is called the indirect method to determine the sound intensity (refs.2.18 and 2.20 to 2.22).

The sound reduction index Ri then follows from:

$$Ri = L_1 - L_{I\tau} - 6 \text{ dB} \tag{2.13}$$

where: L_1 = the average sound pressure level in the source room in dB re 20 µPa

$L_{I\tau}$ = the level of the transmitted acoustic intensity in $watts/m^2$ measured according to the direct or the indirect method directly behind the object

(Ri is used here instead of R to distinguish the results of the intensity method from those of the pressure method.)

The sound field in the source room is generated in the same way as in the case of conventional measurements. The receiving room is in fact not necessary for the intensity measurements. One wants to avoid sound being rejected from the boundaries of the receiving room at the probe. Therefore, a free field situation is perfect. In a normal transmission suite the receiving room is for this purpose made almost anechoic by bringing in a large amount of absorption material.
In literature the reactivity, or reactivity index RI, is often used as a measure for the reaction of the receiving room. It is defined by:

$$RI = L_p - L_I$$

where: L_p and L_I are the sound pressure level and the intensity level respectively, measured in the receiving room directly behind the test object.
For a free field, RI = 0dB
The transmitted intensity is measured at many fixed positions directly behind the object or by scanning the specimen with the probe.
As usual, the results are presented in third-octave bands.

2.4.3. Single-number quantities

To characterize the acoustical performance of a building element the frequency-dependent values of airborne sound insulation can be converted into a single number. These single number quantities are intended for simplifying the formulation of acoustical requirements in building codes.
Different single-number quantities for the sound reduction index are used. We will use some of them in this thesis:

1. R_w: the weighted sound reduction index:
   It is determined by comparing the measured sound reduction index in third-octave bands with the reference curve from ISO 717/1 (ref. 2.23). The method of comparison is given in the same document.
2. R_A: the sound reduction index in dB(A):
   With respect to the reference spectrum of standard outdoor noise (more or less the spectrum of traffic noise) (ref.1.3) R_A is calculated from:

$$R_A = -10\lg \sum_{i=1}^{5} (10^{-(R_i - C_i)/10}) \tag{2.15}$$

where: R_i = the sound reduction index in the ith octave band; the centre frequencies of the octave bands considered are 125, 250, 500, 1000 and 2000 Hz

C_i = a correction term for weighing the sound reduction index in octave band i to the reference spectrum; the values of C_i are -14, -10, -6, -5 and -7dB respectively for the octave bands considered

The sound reduction index R_i (ref.2.24) is calculated from:

$$R_i = -10\lg ((1/3) \sum_{j=1}^{3} (10^{(-R_{ij}/10)}) \tag{2.16}$$

where: R_{ij} = the sound reduction index in the third-octave band j, belonging to octave band i

3. R_m: the averaged sound reduction index in the frequency range 100-3150Hz:

$$R_m = (1/16) \sum_{k=1}^{16} R_k \tag{2.17}$$

where: R_k = the sound reduction index in the kth third-octave band

R_w is used in all laboratories, especially in the FRG. Its value is determined by the values of R in the mid- and high frequencies.
In France and The Netherlands R_A is used besides R_w, especially for characterizing glazing, although the reference spectra of both countries differ slightly. The value of R_A is often determined by the values of R at the low and midfrequencies.
Therefore the value of R_A is lower than the value of R_w for the same object. The value of R_m is lying between the values of R_A and R_w.

CHAPTER 3. FACTORS AFFECTING THE RESULTS OF LABORATORY SOUND INSULATION MEASUREMENTS

3.1. Introduction

The sound reduction index of a building element as defined by eq.(2.1) is of course determined by some properties of the element itself. The most important are:

- the surface mass in kg/m^2
- the bending stiffness, and as a derived quantity:
  the critical frequency f_c
- the internal loss factor
- the element type: single, laminated or double-leaved.

Many investigations have been dedicated to the influence of these properties on the sound reduction index. Therefore it is no subject of this thesis. Instead we will pay attention to the uncertainties that occur in laboratory measurements of the sound reduction index.

The results of measurements of the sound reduction index of a building element which is mounted between two transmission rooms, are influenced by:

1. the properties of the transmission suite;
2. the test method used;
3. statistical errors.

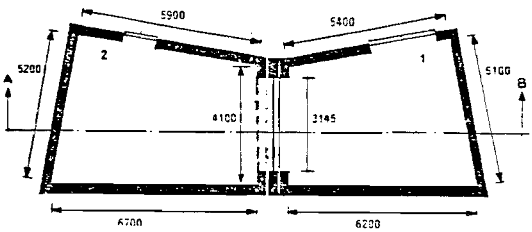
This chapter summarizes the factors affecting the results of laboratory measurements, as observed by other investigators.

3.2. Effects caused by the properties of the transmission suite

3.2.1. General

The volume of the source room and the receiving room should be at least 50 m^3. The main reason for that is to guarantee a certain degree of diffusivity of the sound field in both rooms, even at the lowest frequency of

interest, 100 Hz. Very often the rooms have bigger volumes: in The Netherlands the values lie between 50 and 120 m^3.
Besides, we have to take into account another ISO requirement: the area of the test object should be about 10 m^2. For the bigger rooms (100 m^3) this requirement implies that the test object can be smaller than the wall between the two rooms. In that case the rest of the wall between the rooms should have a very high sound insulation.
The test object is mounted in a frame in that wall (see figure 3.1). Often the frame is constructed in the same way as the walls and floors of the transmission rooms. Sometimes it is a double construction separated by an air gap, which is filled up with a flexible material. When the thickness of the wall and the frame is bigger than that of the test object a niche results or two smaller niches on both sides of the object. The test object can be placed at different positions in the frame. Small building elements like windows, doors, etc., are mounted in a construction which reduces the 10 m^2 area of the test opening to a prescribed area. This construction also should have a very high sound insulation, which almost always results in a thick wall. So also with small building elements niches may be present.



dimensions in mm

| centre position

¦ position at one end of the test opening

fig.3.1. Ground plan laboratory C.

The factors affecting the results of laboratory measurements, caused by the properties of the transmission suite are:
- the position of the test object in the test opening: the so-called niche effect;
- the shape and volume of the transmission rooms;

- the edge conditions of the test object;
- the measuring direction;
- the loudspeaker position;
- diffusing elements.

The factors have a rather frequency-dependent influence on the results. In the next paragraphes these effects will be explained.

3.2.2. The niche effect

Different workers have demonstrated the influence of the position of the test object within a deep test opening on the measured sound reduction index (refs.3.1 to 3.6).

When an object is placed in the centre of a deep test opening we get two equal niches, as to depth and area, on both sides of the object. This symmetry is disturbed when the specimen is placed away from the centre of the test opening. For frequencies below the critical frequency of the test object the centre position yields the lowest sound reduction index, while the position at one end of the test opening produces the highest values. This niche effect can be observed especially with lightweight constructions having a high critical frequency. That is why many investigations concerning the niche effect have been carried out on glazing. The differences in sound reduction index because of the niche effect may be up to 10dB. This effect is not fully explained by theory. Possible explanations are pointing in the direction of a strong coupling of resonant modes in the niches on both sides of the test object.

3.2.3. The effect of equal shape and volume of source and receiving room

As can be seen from theoretical models and experiments of many workers (refs.3.2 and 3.9 to 3.11) the measured sound reduction index depends on the shape and the volume of the source room and the receiving room. When the volumes of source and receiving room are equal, which almost always means that the rooms have the same shape, this will yield the lowest values of the measured sound reduction index. If there is a difference in volume of at least 10% then the measured results are higher. This effect is not depending on frequency.

The following explanation might be given:
In the source room a large number of room modes are excited by the loud-speaker. Some modes are coupled strongly with the bending wave modes of the test object. In turn these bending waves excite specific modes in the receiving room. If the receiving room is (exactly) identical with the source room, the modes of both rooms coincide. This results in a strong coupling of some specific modes in the source room with the same modes in the receiving room via the modes of the test object. The consequence of this is a reduced sound reduction index.
The differences in the measured sound reduction index due to this effect are seldom more than 3dB.
According to Kihlman (ref.3.9) it can only be observed in the absence of flanking transmission.

3.2.4. The effect of different edge conditions of the test object

In most laboratories the test specimen is always connected to only one transmission room. The character of this connection affects the vibrational behaviour of the object.
This may lead to two effects (ref.3.2):

1. For frequencies below the critical frequency the radiation of sound from a vibrating object with finite dimensions depends on the boundary conditions: more sound is radiated from a clamped test object than from a simply supported object. As a result of this the sound reduction index is higher for a simply supported object than it is for a clamped object.
2. For frequencies above the critical frequency edge losses occur in two ways: power flow from the vibrating object to the adjoining structures and dissipation by friction at the edges of the object. Both types of edge losses depend on the boundary conditions.

Ad.1. For frequencies below the critical frequency sound radiation is not possible for an infinite plate because of acoustic short circuit. For a finite plate this short circuit does not occur at the edges, so radiation of sound is possible even at frequencies below the critical frequency. Only a strip of the plate near the perimeter radia-

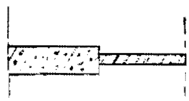
tes sound so the boundary conditions are very important. Theory and experiments have shown that a clamped panel radiates more sound than a simply supported panel. Therefore a flexible connection between the test object and the adjoining structures increases its sound reduction index for frequencies below the critical frequency.
For frequencies above the critical frequency vibrating panels are able to radiate sound from the entire surface. For frequencies above the critical frequency these boundary conditions -clamped or simply supported- are of no importance, unless edge losses occur.

Ad.2. The total loss factor of a vibrating panel, indicating which fraction of the vibrational energy is lost, is the sum of internal losses and edge losses (also called edge damping). These edge losses are very important for the sound reduction index, especially when the internal loss factor is low, i.e. for metal panels and glazing. The sound reduction index is increased by increasing edge losses for frequencies above the critical frequency. One part of edge losses, the power flow to the adjoining structures depends on the coupling between the test object and the adjoining structures. This coupling can be expressed in terms of a sudden change in impedance. For a rigid connection between the test specimen and the adjoining structures this sudden change in impedance depends firstly on the ratio of the surface masses of the object and the adjoining structures and secondly on the shape of the junction (fig.3.2): change in thickness (junction type 1) or a L- or T-junction (junction types 2 and 3) (ref.3.7). A flexible connection reduces the power flow to the adjoining structures.
Most transmission suites are constructed of heavy structures. As a consequence, the flow of power to the adjoining structures will be higher for rigidly mounted heavy objects than it is for lightweight objects. For lightweight constructions the sound reduction index may be increased for frequencies above the critical frequency by introducing friction at the edges.

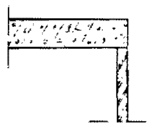
Both effects can lead to differences in the measured values of the sound reduction index of up to 4dB.

3.2.5. The effect of the measuring direction

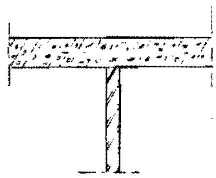
When a test object is mounted between two transmission rooms there are two possible measuring directions. Putting the loudspeaker in one room automatically makes this room the source room and the other room the receiving room. The functions of the rooms are switched by putting the loudspeaker in the other room. In literature one finds contradictory opinions about the effect of the measuring direction on the measured sound reduction index.
In ref.(3.6) the measured sound reduction index is said to depend on the measuring direction if source and receiving room are identical in geometry and if the absorption in the two rooms is quite different. It is not indi-



A.
Change in thickness
jt = 1



B.
L-junction
jt = 2



C.
T-junction
jt = 3

fig.3.2. Different types of junction between two structures.

cated which measuring direction yields the highest values.
Heckl and Seifert (ref.3.11) concluded from theory that for unequal transmission rooms the measured sound reduction index is higher when the smallest room is acting as the source room. Guy (ref.3.12) confirms this conclusion at first, but in later experiments (ref.3.16) he obtains the highest values when the smallest room is the receiving room. This effect gives differences of one or two decibels in the measured sound reduction index.

3.2.6. The effect of the loudspeaker position

The position of the loudspeaker in the source room determines which modes are being excited and to what extent. Since each mode is coupled in its own way with the modes of the test object the loudspeaker position will influence the measured sound reduction index. This is confirmed by experiments of different workers (ref.3.8). Especially for double-leaf constructions the effect of the loudspeaker position is pronounced. One of the characteristic properties of this type of construction is the mass-spring-resonance determined by the surface masses of the two leaves and the stiffness of the air gap between them. The loudspeaker position affects the measured sound reduction index in the region of this resonance frequency.

3.2.7. The effect of diffusers

If necessary diffusing elements should be installed in the rooms to obtain a diffuse sound field.
In symmetrical situations, i.e. for symmetrical niches and equal volumes of source and receiving room, the measured sound reduction index increases by bringing in diffusing elements in one of the rooms. This means that the niche effect or the effect of equal rooms will be diminished (refs.3.2 and 3.10). This may be explained by the disturbance of the symmetry by the diffusers. In that way the strong coupling between the modes of source room, object and receiving room is decreased.

3.3. The effect of the test method; the Waterhouse effect

As seen in chapter 2 (eq.2.12) it is possible to measure directly the sound intensity. This intensity technique is used mainly for determining the sound power of noise sources, but in recent years it is used more and more for determining the sound reduction index of partitions. Especially Crocker c.s. (refs.3.17 and 3.18) and Cops c.s. (refs.3.19 to 3.22) have carried out many sound insulation measurements using the intensity technique.

In their experiments and in those of other workers much attention is paid to the comparison of the results of the conventional method on the one hand and the results of the intensity method on the other hand.
Almost every experiment dealing with this comparison shows that:

i - for frequencies below 400 or 500 Hz the intensity method yields lower values than the conventional method;

ii- for frequencies above 1000 Hz the results from intensity measurements are higher than the results obtained with the conventional method.

The differences between the results of the two test methods may be up to 5 dB. Till now these effects have all been found from measurements on lightweight constructions with a high critical frequency. From measurements carried out on glazing Cops (ref.3.20) found that the sound reduction index at the critical frequency is about 2 dB higher when measured by means of the intensity technique. Halliwell and Warnock (ref.3.23) suppose that the so-called Waterhouse-effect is partly responsible for the difference between the results of the intensity method and the conventional method.
Waterhouse (ref.3.24) and others (ref.3.36) have shown that in a room the energy density near surfaces and corners is higher than in the centre of the room. Therefore an estimation of the total sound power brought into the room from a measurement of the sound pressure level averaged over the 'centre volume' of the room, is too low. (The 'centre volume' of the room is the volume enclosed by imaginary surfaces each being 1 m in front of the real surfaces.)
When carrying out sound power measurements according to ISO 3741 (ref. 3.25) the measured sound pressure level must be corrected for this error. This correction, the so-called Waterhouse correction, is given by:

$$L_p' = L_p + 10 \lg (1 + (S \lambda/8V)) \qquad (3.1)$$

where: L_p = the measured sound pressure level in the centre volume of the room in dB re 20 μPa

S = the total area of the surfaces of the room in m^2

λ = the wavelength at the centre frequency of the frequency band concerned in m

V_i = the room volume in m^3

L_p = the corrected sound pressure level in dB

The Waterhouse correction is no part of the standard test procedure for sound insulation measurements. As seen in chapter 2 (eq.2.3) in this standard procedure the transmitted sound power is estimated by measuring the sound pressure level in the centre volume of the receiving room, corrected for the amount of sound absorption in the room. When the transmitted sound power is measured with the intensity technique in the immediate vicinity of the test object this may result in different values. These differences may be explained partly by the Waterhouse correction.

If the Waterhouse correction should be applied to conventional sound insulation measurements it should be applied to the sound pressure level in the receiving room. This means that at low frequencies the sound reduction index is somewhat reduced.

Returning to the beginning of 3.3. the differences between the results of conventional and intensity measurements for frequencies below 400 Hz (i) are also reduced. In literature an explanation for the remaining differences in the frequency region below 400 Hz (i) is not given. The differences between the results of both test methods for frequencies above 1000 Hz (ii) are not explained either.

3.4. Statistical errors; repeatability and reproducibility

3.4.1. Introduction

Tests, performed on presumably 'identical materials' in presumably 'identical circumstances' do not, in general, yield identical test results. This is attributed to unavoidable random errors inherent in every test procedure; apart from these random errors there are other factors that may influence the outcome of a test. They may (apart from the inhomogeneity of samples) originate from, for example:

a. the operator;

b. the instruments and equipment used;

c. the calibration of the equipment;

d. the environment (temperature, humidity, air pollution, etc.).

Hence, many different measures of variability are conceivable according to the circumstances under which the tests have been performed. Two extreme measures of variability, termed repeatability and reproducibility have been found sufficient to deal with most practical cases.
Repeatability refers to tests performed at short intervals in one laboratory by one operator, using the same equipment each time. These conditions are called repeatability conditions. Under these conditions factors a to d are considered as constants and do not contribute to the variability. Then variability is determined only by remaining random errors. A quantative definition of the repeatability r is given by ISO 3534 (ref.3.26):

> The repeatability r is the value below which the absolute difference between two single test results obtained with the same method on identical test material, under the same conditions (same operator, same apparatus, same laboratory, and a short interval of time) may be expected to lie with a specified probability; in the absence of other indications, the probability is 95%.

Reproducibility refers to tests performed in different laboratories, which implies different operators and different equipment. The factors a to d vary under these reproducibility conditions; they contribute to the variability of test results. The ISO-document 3534 also gives a quantative definition of the reproducibility R:

> The reproducibility R is the value below which the absolute difference between two single test results obtained with the same method on identical test material, under different conditions (different operators, different apparatus, different laboratories and/or different time) may be expected to lie with a specified probability; again in the absence of other indications a probability of 95% is used.

As to building acoustics ISO 140/II (ref.2.10) deals with the statement of precision requirements concerning sound insulation measurements. Precision is a general term for the closeness of agreement between replicate test results. Thus the repeatability r and the reproducibility R describe the precision of a given test method under two different circumstances of replication. A series of interlaboratory trials organized with the specific purpose of determining the repeatability r and the reproducibility R is called a precision experiment. ISO 140/II states minimum values for the precision required when carrying out tests according to ISO 140. This means that requirements for the repeatability r are given in this document. Also a method for a standard check of the repeatability is presented.

Besides, in the second working draft of ISO 140/II (ref.3.27) requirements for the reproducibility and a method to check reproducibility are given. The seventh working draft (ref.3.28) of ISO 140/II states requirements for r and R concerning the single-number quantities. The requirements for r and R are based on precision experiments carried out in few laboratories on few types of test objects in England, the FRG and the United States. The procedure for determining the repeatability and the reproducibility is described in ISO 5725 (ref.3.29).

3.4.2. Procedure for determining the repeatability and the reproducibility

The ISO-document 5725 is primarily intended for the determination of the repeatability r and the reproducibility R of the results of standardized test methods used in different laboratories.

The test methods used in this thesis have been introduced in chapter 2:

- the standard test method according to ISO 140/III (ref.2.11);
- the intensity method.

The second method has not been standardized yet by any ISO procedure.

For laboratory measurements the sound reduction index R has to be determined as a function of frequency, i.e. in third-octave bands. This means that for laboratory sound insulation measurements the repeatability r as well as the reproducibility R is a function of frequency.

In the description of the statistical model in the next paragraph however for the sake of clearness we will not use an index indicating frequency dependence.

3.4.2.1. The statistical model:

In ISO 5725 (ref.3.29) a statistical model for estimating the precision of a test method is introduced. In this model it is assumed that every single test result y is the sum of three components:

$$y = m + B + e \tag{3.2}$$

where: m = the average

B = a term representing the deviation from m described to the specific laboratory, and

e = a random error occurring in every test

Suppose that p laboratories are taking part in a precision experiment and that in the ith laboratory n_i single test results are obtained under repeatability conditions. Then m can be calculated from:

$$m = \frac{\sum_{i=1}^{p} n_i \overline{y_i}}{\sum_{i=1}^{p}} \tag{3.3}$$

where: $\overline{y_i}$ = the average test result in the ith laboratory = $\sum_{k=1}^{n_i} \frac{y_{ik}}{n_i}$

n_i = the number of single test results in the ith laboratory

y_{ik} = the kth test result in the ith laboratory

The term e represents a random error occurring in every single test result. The distribution of this variable is assumed to be approximately normal.
Within a single laboratory its variance

$$\mathrm{var}(e)_i = \sigma^2_{wi} \tag{3.4}$$

is called the within-laboratory variance σ^2_{wi}
It may be expected that σ^2_{wi} will vary between laboratories.
In this thesis we will approximate σ^2_{wi} by:

$$S_i^2 = \frac{\sum_{k=1}^{n_i} (y_{ik} - \overline{y_i})^2}{n_i - 1} \tag{3.5}$$

where: S_i = the standard deviation of the test results in the ith laboratory

n_i = the number of single test results in the ith laboratory

y_{ik} = the kth test result in the ith laboratory

$\overline{y_i}$ = the average test result in the ith laboratory assuming that n_i and p are large enough to permit this approximation.

Besides, ISO 5725 assumes that when a test method has been properly standardized, the difference between laboratories should be small so that it is justifiable to establish a common value for the within-laboratory variance valid for all laboratories using the standard test method.
This common value, which is an average of the variances taken over the laboratories participating in the precision experiment, will be called the repeatability variance σ_r^2 and will be designated as:

$$\overline{\mathrm{var}(e)_i} = \sigma_r^2 \qquad (3.6)$$

Again, in this thesis we will approximate σ_r^2 by:

$$S_r^2 = \frac{\sum_{i=1}^{p} (n_i - 1)\, S_i^2}{\sum_{i=1}^{p} n_i - p} \qquad (3.7)$$

where: p = the number of laboratories taking part in the precision experiments

The term B in eq.(3.2) is considered to be constant during any series of tests performed under repeatability conditions, but to behave as a random variable in a series of tests performed under reproducibility conditions. The distribution of this variable is also assumed to be normal.
Its variance will be denoted by:

$$\mathrm{var}(B) = \sigma_L^2 \qquad (3.8)$$

and called the between-laboratory variance.

The quantity σ_L^2 includes the between-operator and the between-equipment variabilities. This between laboratory variance can be approximated by:

$$S_L^2 = \frac{1}{\bar{\bar{n}}}\left[\frac{\sum_{i=1}^{p} n_i\, (\overline{y_i} - m)}{p - 1} - S_r^2\right] \qquad (3.9)$$

$$\bar{\bar{n}} = \frac{1}{(p-1)} \left[\sum_{i=1}^{p} n_i - \frac{\sum_{i=1}^{p} n_i^2}{\sum_{i=1}^{p} n_i} \right] \tag{3.10}$$

3.4.2.2. The determination of the repeatability and the reproducibility:

Assuming normal distribution the repeatability r and the reproducibility R can be determined from:

$$r = 2.83 \sqrt{s_r^2} \tag{3.11}$$

$$R = 2.83 \sqrt{(s_L^2 + s_r^2)} \tag{3.12}$$

in which the term $(s_L^2 + s_r^2)$ is an approximation of the reproducibility variance σ_R^2:

$$\sigma_R^2 = \sigma_L^2 + \sigma_r^2 \tag{3.13}$$

Again it should be mentioned that these formulae may be used under the assumption that the number of measurements is not too small and that the distribution of the variables is normal.

It might also be worth repeating that a probability of 95% is used.

3.4.3. Survey of precision experiments

Different research-workers have carried out series of measurements on the same object in different laboratories. Precision experiments according to ISO 5725 and comparison of the calculated repeatability and reproducibility to the requirements of refs.2.10 and 3.27 have only been performed in the FRG and Scandinavia.

The first of these precision experiments took place in 1976 in 8 laboratories in the FRG (ref.3.30). The test object was a double-leaf lightweight wall consisting of a 100 mm chipboard frame of 22 mm thickness into which an 8 mm and a 16 mm chipboard panel were glued and nailed. The cavity was completely filled up with mineral wool. The size of this object was 1.6 m^2. In every laboratory 6 complete measurements according to ISO 140/III were carried out.

The repeatability calculated from these results was satisfying, compared to the requirements of ISO 140/II (figure 3.3). By all kinds of causes, which we will not discuss in this thesis, the resulting reproducibility did not fulfil the requirements of ISO 140/II at all (figure 3.4).
From this precision experiment many ideas have originated about a better organisation for such investigations.
In Scandinavia these ideas have been brought into practice. Two precision experiments have been carried out in 1984 (refs.3.31 and 3.32). The test object was a sound insulating double glazing, consisting of 4+4 mm laminated glass and 4 mm ordinary glass separated by a 15 mm air space. In each of the 5 participating laboratories 6 complete measurements according to ISO 140/III have been carried out in both precision experiments.
In the first experiment the objects were mounted in each laboratory in the test opening in such a way that the niches on both sides of the test objects had equal areas but not equal depths (the so-called flat test opening). The size of the objects in this experiment was 1.4 m^2.
In the second experiment the areas of the niches on both sides of the test object as well as their depths were unequal (the so-called staggered test opening). The size of the objects in this experiment was 1.1 m^2.
The ratio of the depths of the two niches was 1:2 in both experiments.
In the two experiments more or less the same values of the repeatability were obtained, fulfilling the requirements of ISO 140/II (figure 3.5).
The calculated reproducibility in the first experiment was much higher than the requirements of ref.3.27 (figure 3.6). In the second experiment the calculated reproducibility also exceeded the requirements, although to a much less extent (figure 3.6).
The precision experiments, which will be discussed in this thesis, have been performed between 1982 and 1985 in 7 laboratories, of which 2 in Belgium and 5 in The Netherlands. Three test objects have been used.
Apart from that, in 1985 a very large precision experiment has been started by the European Community: three objects will be tested in 14 European laboratories. This experiment is still going on.

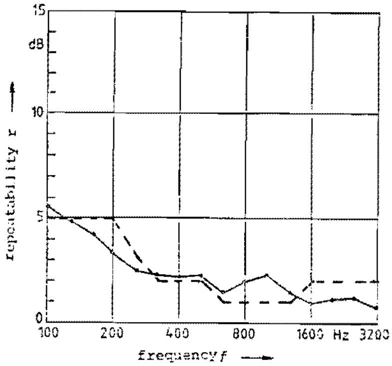


fig.3.3. Repeatability r as a function of frequency (ref.3.30). ———

Reference curve ISO 140/2-1978 - - - - -

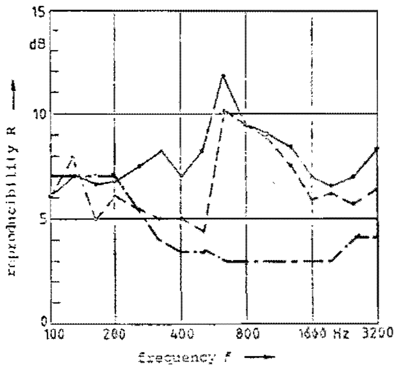


fig.3.4. Reproducibility R as a function of frequency (ref.3.30).

——— Laboratories No. 1 to 8

- - - - - Laboratories No. 1 to 6

—·—·—·— Proposed reference curve ISO/TC 43/SC 2/WG 8 N34

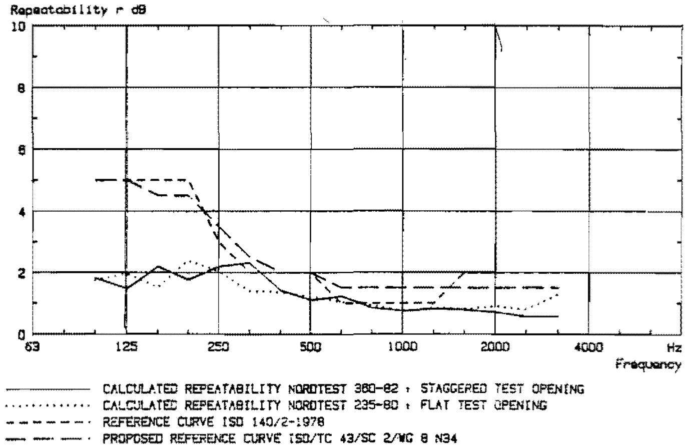


fig.3.5. The calculated repeatability values for measurements in a staggered test opening (NT 360-82) and comparison with other repeatability values (ref.3.32).

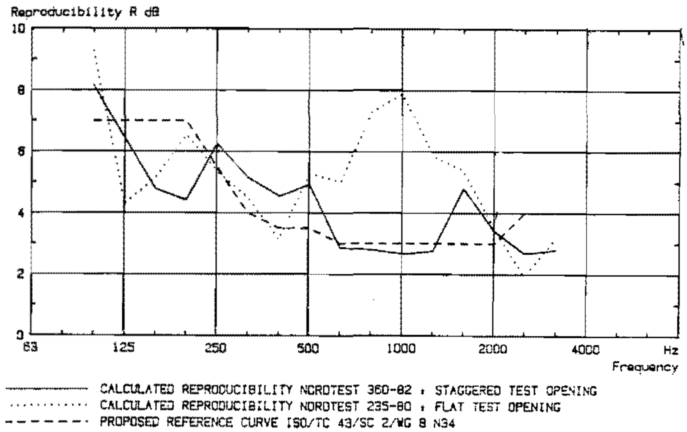


fig.3.6. The calculated reproducibility values for measurements in a staggered test opeing and comparison with other reproducibility values (ref.3.32).

CHAPTER 4. INVESTIGATIONS IN TRANSMISSION SUITES IN BELGIUM AND THE NETHERLANDS

4.1. The plan of the investigation.

In connection with the completion of the Acoustics Laboratory at the Faculty of Architecture and Building Technology of Eindhoven University of Technology an investigation has been started concerning the factors affecting the results of airborne sound insulation measurements.

At first the investigation comprised two themes:

1. A research in Dutch transmission suites concerning the effects mentioned in chapter 3;
2. A precision experiment according to ISO 5725 and a comparison of the obtained repeatability and reproducibility to the requirements.

When the intensity technique became available two more aspects have been added to the investigation:

3. The influence of the properties of a transmission suite on the difference between the results of conventional and intensity measurements, carried out on the same object.
4. A comparison of the precision of the intensity technique to the precision of the conventional method.

To carry out the investigation three test objects were chosen. The choice was based on the following considerations:

* The niche effect: at least one object with a high critical frequency should be chosen as the niche effect occurs for frequencies below the critical frequency.
* The edge conditions: the properties of transmission suites can affect edge losses, i.e. the power flow from the object to the adjoining structures, especially when the surface mass of the object equals more or less the surface mass of the adjoining structures. Therefore the choice should include a heavy test object.
* Flanking transmission: also in transmission suites flanking transmission occurs especially when the sound insulation of the test object is high; it will depend on the properties of the transmission suite. Therefore one highly insulating test object should be included.

* The level of m: in laboratory practice of sound insulation measurements the range of levels of m encountered is very wide, so the repeatability r and the reproducibility R should be studied for different values of m.
* The organization: in precision experiments each participating laboratory has to make tests on identical objects. This can be realized in two ways:
  i. by circulating one object along each participating laboratory, the so-called 'round robin';
  ii. by constructing as many objects as there are participating laboratories and testing these objects more or less simultaneously.

These considerations resulted in the choice of the following test objects:
- a lightweight single wall made of wood and chipboard with a surface mass of approximately 35 kg/m^2;
- a heavy single wall made of sand lime blocks with a surface mass of approximately 450 kg/m^2;
- a 'middleweight' single wall made of sand lime blocks with a mass per unit area of approximately 225 kg/m^2.

The investigation consisted three of three parts:
1: The experiments on the lightweight wall, including the investigation concerning the niche effect.
2: The experiments on the heavy wall, including some intensity measurements.
3: The experiments on the middleweight wall, including the precision experiment of the intensity method.

Part 1 has been completed in 1983, part 2 in 1984 and part 3 in 1985. In each part of the investigation a precision experiment according to ISO 5725 has been carried out. The test method used was the standardized 'pressure' method of ISO 140/III, meaning that each laboratory has to perform a number of tests on each object under repeatability conditions. The number of tests in each laboratory is based on Annex B of ref.2.10, which states that:

> "considering the frequency-dependency of the quantities measured in building acoustics (comparable to the levels of the test property according to ISO 5725 clause 2.5) from a statistical point of view there should be at least 5 participants (p>5) but it is preferable to exceed this number in order to reduce the number of replicate measurements

required. The number of laboratories p and the number of test results in each laboratory n_i should be so chosen that:

$$p \times (n_i - 1) > 35$$

However for each leaboratory at least five results are needed."

ISO 5725 states that:

"if the range of m is very wide then the use of 6 levels may be desirable. The number of laboratories should to some extent depend on the number of levels. It is recommended that p should never be less than 8 and if only a single level is of interest, p should preferably be higher, say 15 or more.
Regarding the value of n_i, the recommended figure is 2 except where it is customary to make a large number of replicates."

4.2. The participating laboratories

The laboratories that have taken part in the investigation are:

A. The Institute of Applied Physics TNO at Delft.
B. The TNO Environmental Research Institute at Delft (abbreviated in Dutch IMG-TNO).
C. The Acoustics Laboratory of the Faculty of Architecture and Building Technology at Eindhoven University of Technology.
D. Private Consultants in Acoustics Peuts & Associé's at Nijmegen.
E. Private Consultants in Acoustics Van Dorsser B.V. at The Hague.
F. Laboratory on Acoustics and Heat Conduction of the Katholieke Universiteit Leuven (Belgium).
G. Scientific Centre for Building Technology (WTCB or CSTC) at Limelette near Brussels (Belgium).
H. United Companies Bredero (VBB) at Maarssenbroek.

Part 1 of the investigation has been carried out in the laboratories A to F and H, whereas parts 2 and 3 have taken place in the laboratories A to G and laboratories A and C to G respectively. The plans and vertical sections of each laboratory are given in figure 4.1. Table 4.1 presents the essential data of the transmission rooms of each laboratory (from ref. 4.1).

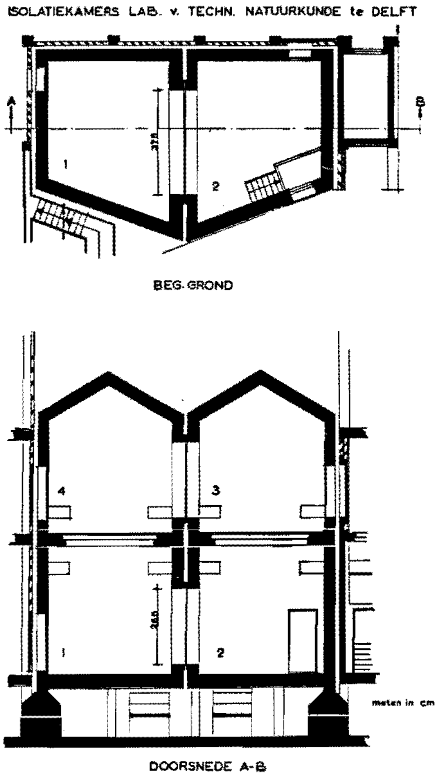


figure 4.1.a. Laboratory A

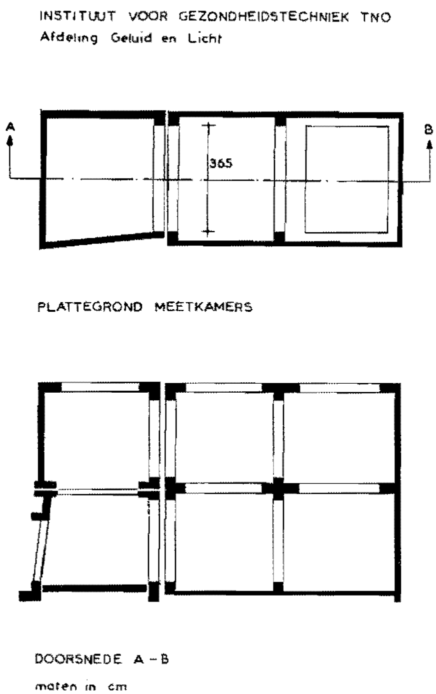
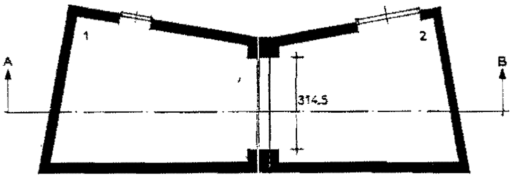


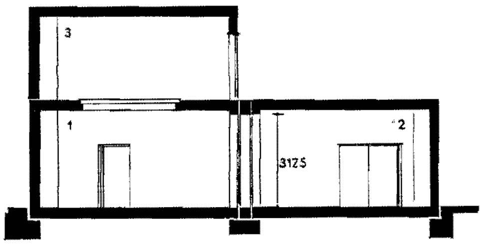
figure 4.1.b. Laboratory B.

LABORATORIUM VOOR AKOESTIEK
Afdeling der Bouwkunde
Technische Hogeschool Eindhoven



PLATTEGROND MEETKAMERS

maten in cm



DOORSNEDE A-B

figure 4.1.c. Laboratory C.

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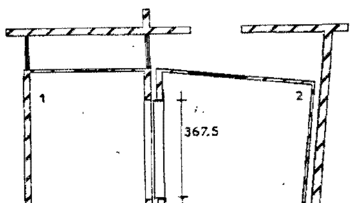


PLATTEGROND MEETKAMERS

maten in cm

figure 4.1.d. Laboratory D.

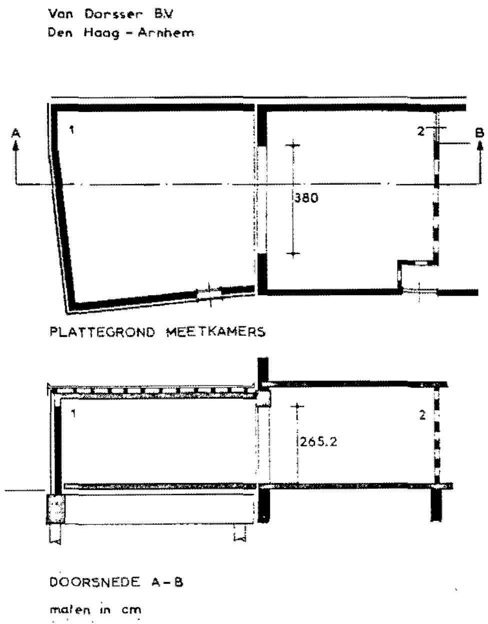


figure 4.1.e. Laboratory E.

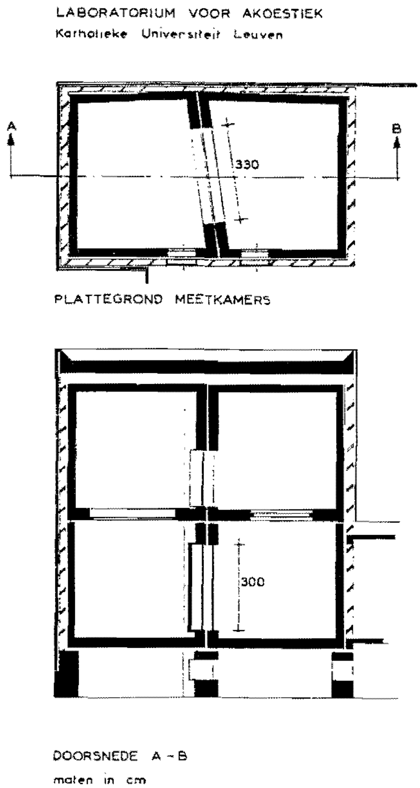


figure4.1.f. Laboratory F.

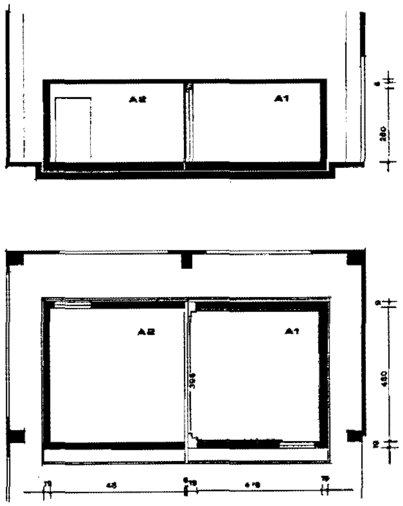


figure 4.1.g. Laboratory G.

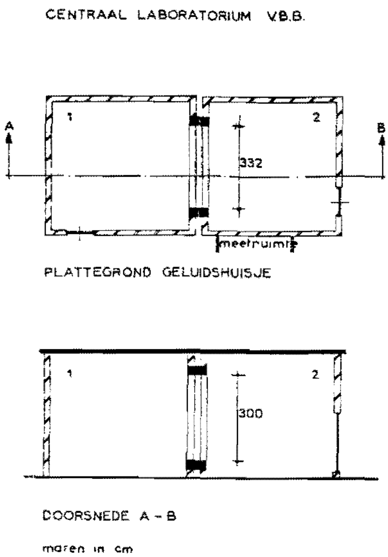


figure 4.1.h. Laboratory H.

Table 4.1. Essential data of the participating laboratories (from ref.4.1)

laboratory:	A	B	C	D	E	F	G	H
volume V (m^3):								
. room 1	104		88	73	123	87	46	91
. room 2	101		98	98	104	87	53	83
. room 3	100							
. room 4	100	42						
. room 5		46						
test opening:								
width (m)	3,75	3,65	3,15	3,68	3,80	3,27	3,95/4,22	3,32
height (m)	2,65	2,75	3,18	2,67	2,65	2,97	2,60	3,00
area (m^2)	9,9	10,0	10,0	9,8	10,1	9,7	10,3/11,0	10,0
depth (m)	0,95	0,90	1,0	0,65	0,33	0,80	0,30	0,61
$\Delta V/V$:								
. maximum (%)	12/9,4	30	20	43	21,4	9	22,1	17
. minimum (%)	0	0	2	25	15	0	8,1	2
laboratory type: suppressed flanking *	+	+	+	+	+	+	+	+
parallelism: object/ backwall (1)	+	+		+			+	+
(2)	+	+			+		+	+
side walls (1)				+			+	+
(2)		+			+		+	+
floor-ceiling(1)		+	+	+	+	+	+	
(2)		+	+		+	+	+	

(1) = first room
(2) = second room
* = to distinguish these laboratories from those with 'normal' flanking transmission ("bauähnlichen Nebenwegen").

Comparing the properties of these transmission suites to the requirements (table 2.1) some remarks can be made.
Laboratories A, C, D, E, F and H fulfil the requirements of ISO 140-1960; the volumes of the transmission rooms of laboratory B and G are too small compared to the required 50 m^3. However, the difference is small and even smaller if the volumes of the niches on both sides of the test object are added to the volumes of the respective rooms. The level of background noise in the rooms of laboratory H is varying because of the combination of heavy railway traffic nearby and a relatively low sound insulation between outside and the rooms.
Laboratories C, D, E and H meet the requirements of ISO 140/I-1978. In laboratories A (from 1962) and F (from 1967) source and receiving room have equal volumes; according to later requirements from 1978 there should be a difference in room volumes of at least 10%.

4.3. The test objects

4.3.1. The lightweight wall

The construction (refs.4.2 and 4.3):
This lightweight wall, which had to be sent from one participating laboratory to another, had to fulfil some conditions:
- in each laboratory 'the same wall' had to be mounted;
- in view of the niche effect it had to be possible to shift the wall without too much effort from the centre of the test opening to one end of it.

This was hampered by the variability in the dimensions of the different test openings; the width varied from 3.15 to 3.80 m, the height from 2.65 to 3.18 m.
We looked for a wall with a quadratic structure having the same stiffness in two directions, so that different dimensions of a test opening would have only a small effect on the stiffness. Besides, it was decided to construct the wall of small elements, easy to handle, so that the wall could be erected in a short time. In this way the conditions might be met.

The above mentioned considerations led to a wall consisting of a quadratic frame made of wooden studs of dimensions 50x100 mm^2 in two directions, spaced at 300 mm centres (fig.4.2). On this frame 20 mm chipboard has been applied. The seams always coincided with a stud. Thus, one side of the wall always showed a plain surface of chipboard, while the other side showed the quadratic structure. The remaining openings between the wooden frame and the test opening were filled up with solid wood. In that way the wall was more or less clamped in the test opening. The wall was erected in each laboratory by the same craftsmen who were well-informed of the purpose of the experiments.

Acoustical characterization:
For the type of wall described above the sound reduction index is determined by its surface mass, its stiffness and its loss factor. The surface mass of this wall is approximately 35 kg/m^2. Acoustically, this is a complex wall. Different acoustical phenomena may determine the sound reduction index, each in a specific frequency range:

a. the critical frequency of the 20 mm chipboard alone is 1250 Hz;
b. by the combination of the 20 mm chipboard and the wooden frame the stiffness of the chipboard is increased, which leads to a second critical frequency of 500 Hz;
c. the total area of the wall is subdivided into small square areas of dimensions 300x300 mm^2 in which panel resonances may occur; the lowest resonance frequency is 500 Hz (simply supported) or 900 Hz (clamped);
d. the panel resonances of the total wall with an area of 10 m^2 may start at the lowest frequency of 10 Hz (simply supported) or 20 Hz (clamped).

Because of this complex acoustical character prediction of the sound reduction index of this wall is difficult and probably inaccurate.

4.3.2. The heavy wall

The construction (ref.4.4):
The heavy wall was made of sand lime blocks type D35 with a thickness of 210 mm (fig.4.3). The same team of bricklayers erected the wall in each laboratory. To avoid sound leaks between the blocks and the test opening the blocks were sawn to measure beforehand on the basis of the dimensions of the test openings. The remaining slits and cracks were filled up with mineral wool and closed with elastic sealant. A layer of plaster with a thickness of about 1 cm was applied onto the wall.

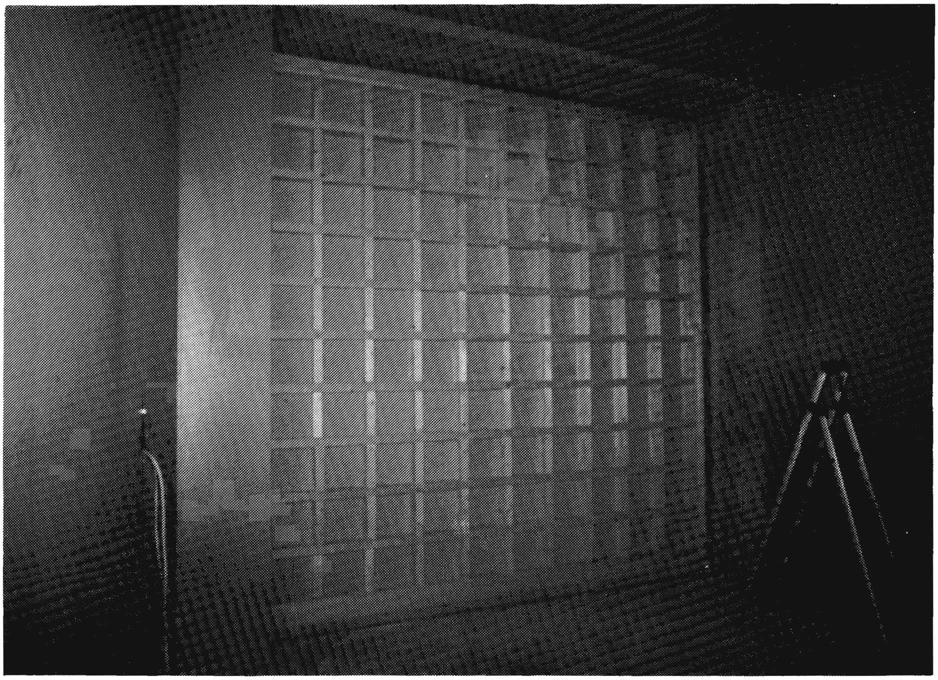
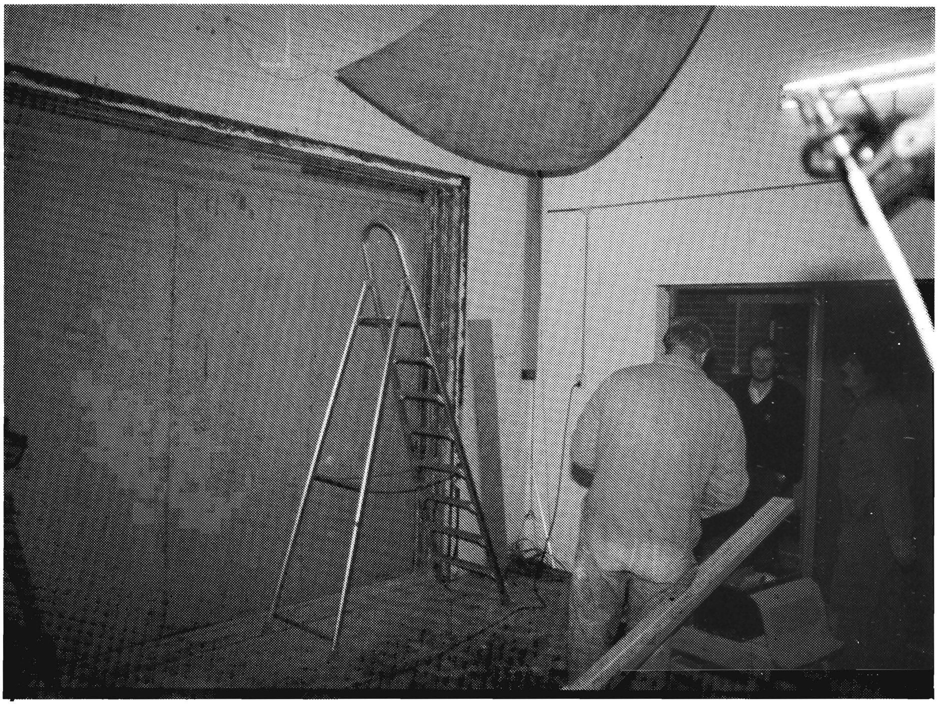


fig.4.2. The lightweight wall.



Acoustical characterization:

The mass per unit area of this single homogeneous wall is 450 kg/m^2. Its critical frequency is lying between 90 and 130 Hz, depending on the value of the speed of longitudinal waves used for the calculation of the critical frequency. The lowest resonance frequency has been calculated assuming a square with dimensions of 3.15 m. Its value is 62 Hz (simply supported) or 115 Hz (clamped).

4.3.3. The 'middleweight' wall

The construction (ref.4.5):

The middleweight wall was made of sand lime blocks type B33 with a thickness of 102 mm. Again, the same team of bricklayers built the wall in each laboratory. To avoid sound leaks the same procedure was followed as with the heavy wall. This wall too was plastered on one side in the same thickness.

Acoustical characterization:

The mass per unit area of this wall is approximately 225 kg/m^2. Its critical frequency is lying between 195 and 270 Hz, depending on the speed of longitudinal waves used in the calculation. The lowest resonance frequency of this wall with an area of 10 m^2 assuming a square, is 30 Hz (simply supported) or 53 Hz (clamped).

4.4. The tests performed on the lightweight wall

For the precision experiment described in ref.4.3 the lightweight wall has been mounted in the centre of the test opening as prescribed by ISO 140/III (ref.2.11).

The participating laboratories were requested to perform 8 complete tests according to ISO 140/III under repeatability conditions. Some variations in the position of the loudspeaker and the absorption or diffusivity of the rooms were allowed. Unfortunately, it turned out that these instructions had not been understood clearly. Firstly, some laboratories had performed more tests because they considered one test to be the average of two measurements in opposite directions. Secondly, some laboratories had not determined the reverberation time in the receiving room for every test anew. To cope with these troubles we decided to consider a test result to

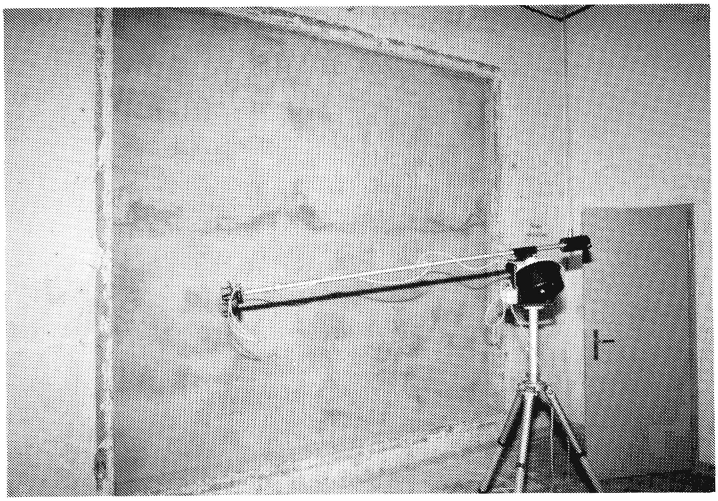
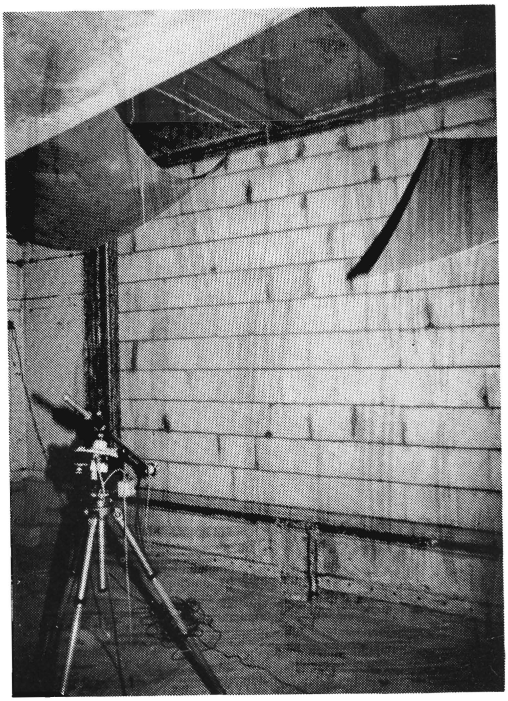


fig.4.3. The heavy wall.



be a complete measurement in one direction. Table 4.2a gives a survey of the measurements, whereas table 4.2b presents the number of loudspeakers and loudspeaker positions used in the precision experiment.

Table 4.2a. Measurements carried out on the lightweight wall (from refs. 4.2 and 4.3)

lab.	operator	wall position	measuring direction	number of tests
A	C	0 near 4	3-4	1
		4-3	1	
	A	0 near 4	3-4	1
		4-3	1	
	C	centre	3-4	1
		4-3	1	
	A	centre	3-4	5 *
		4-3	5 *	
B	C	0 near 5	4-5	2
		5-4	2	
	B	0 near 5	4-5	2
		5-4	2	
	C	centre	4-5	2
		5-4	2	
	B	centre	4-5	8 *
		5-4	8 *	
C	C	0 near 1	2-1	1
		1-2	1	
	C	centre	1-2	1
		2-1	1	
D	C	0 near 2	2-1	1
		1-2	1	
	C	centre	2-1	1
		1-2	1	
	D	centre	1-2	4 *
		2-1	4 *	
E	C	0 near 2	1-2	1
		2-1	1	
	C	centre	1-2	1
		2-1	1	
	E	centre	2-1	6 *
		1-2	2 *	
F	C	0 near 2	1-2	1
		2-1	1	
	F	0 near 2	1-2	2
		2-1	2	
	C	centre	1-2	1
		2-1	1	
	F	centre	1-2	6 *
		2-1	6 *	
H	C	0 near 1	1-2	1
		2-1	1	
	C	0 near 2	1-2	1
		2-1	1	
	C	centre	1-2	1
		2-1	1	

0 near 1 means: wall at one end of the test opening near room 1;
measuring direction 3-4 means: room 3 is source room, room 4 is receiving room;
* means: these measurements have been used in the precision experiment.

Table 4.2b. Number of loudspeakers and loudspeaker positions used in the precision experiment (from ref.4.3).

laboratory	A	B	C	D	E	F
number of loudspeakers:	2	1	1	2	1	1
number of loudspeaker positions:	2	1	1	4	5	8

4.5. The tests performed on the heavy wall

In this part of the investigation the precision experiment has also been carried out with the wall in the centre of the test opening (ref.4.4). Again the laboratories were requested to perform 8 complete tests according to ISO 140/III under repeatability conditions. This time it had been indicated that a measurement of the sound reduction index in one direction would be considered as one test. The measuring direction was not prescribed. Table 4.3 presents the essential data of the measurements as to the precision experiment.
Apart from the measurements carried out by each laboratory with respect to the precision experiment we also determined the sound reduction index of the heavy wall in almost every laboratory (ref.4.7).
We used two methods. Firstly, in each laboratory the sound reduction index was determined by means of the pressure method in two measuring directions. Secondly, the intensity technique has been used in each laboratory. On behalf of these measurements the amount of sound absorption in the receiving room had to be increased. Table 4.4 gives a survey of our measurements on the heavy wall.

Table 4.3. Measurement data of the precision experiment on the heavy wall (from ref.4.4).

laboratory	A	B	C	D*	E	F	G
number of tests:							
. direction 1-2	8		8	8	8	5	8
. direction 2-1						3	
. direction 4-5		4					
. direction 5-4		4					
reverberation measurements:	8	8	8	8	8	8	8
diffusing elements:							
. source room:				2		3	
. receiving room:				2	25	3	

Table 4.4. Survey of conventional and intensity measurements carried out by laboratory C in the participating laboratories (from ref. 4.7).

lab.	measuring method	measuring direction	wall connected to room	number of measurements
A	P	2-1	2	1
		1-2		1
	I	2-1		1
B	P	4-5	4	1
		5-4		1
	I	4-5		1
		5-4		1
C1	P	1-2	*	8
C1	I	1-2	*	1
C2	P	1-2	1	8
		2-1		8
C2	I	1-2		1
		2-1		1
D	P	1-2	1	1
		2-1		1
	I	1-2		1
		2-1		1
F	P	1-2	1	1
		2-1		1
	I	2-1		1
G	P	A1-A2	A1	1
		A2-A1		1
	I	A1-A2		1

P means: conventional (pressure) measuremments
I means: intensity measurements
* means: not connected to either room 1 or room 2 (see fig.4.4)

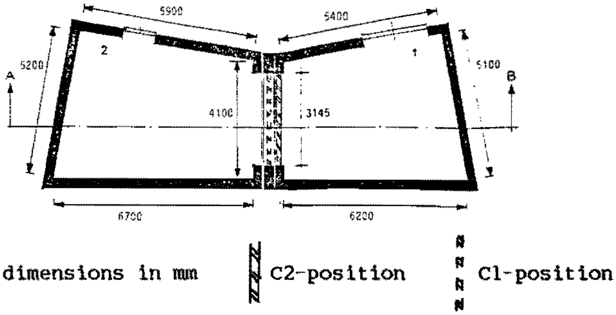


fig.4.4. Ground-plan laboratory C.

Both conventional and intensity measurements have been carried out in the period between the 4th and the 12th day after the wall had been erected.

For heavy walls the total loss factor may be different in each laboratory. This loss factor may be checked by measuring the reverberation time of the wall as a function of frequency. This has been performed in each laboratory by exciting the wall with a hammer and recording the decaying accelerations of the bending waves in the wall. The accelerations have been measured at several points in the direction perpendicular to the wall.

4.6. The tests performed on the middleweight wall

In this part of the investigation the 'middleweight' wall has not been mounted in the centre of the test opening for reasons of reducing the niche effect (ref.4.5). Therefore, in each laboratory the object is placed in the test opening in such a way that the ratio of the depths of the niches on both sides of the wall is 1:2. However, the wall was allowed to have a connection to only one transmission room. The depths of the niches resulting from these conditions are given in table 4.5.

As to the precision experiment this time the laboratories have been instructed to perform 10 complete tests according to ISO 140/III under repeatability conditions. The tests had to be divided equally over the two measuring directions. Our intention was to see if, when the average of measurements in two directions was considered being a single test result, this would yield a better repeatability and/or a better reproducibility.

Table 4.5. Niche depths on both sides of the middleweight wall (from ref. 4.5)

lab.	niche depth (m) room 1	room 2
A	0,575	0,26
C	0,190	0,70
D	0,240	0,10
E	0,22	0,10
F	0,225	0,495
G	0,08	0,10

Unfortunately this instruction led to misunderstanding in two of the laboratories. In laboratory E only 8 tests had been performed, of which 5 in the usual direction and 3 in the opposite direction. In laboratory G 10 tests were carried out. However, 6 of them in the usual direction and 4 in the opposite direction. Table 4.6 presents the measurements and some other relevant data.

A second precision experiment carried out on the middleweight wall concerned the precision of the intensity method (ref.4.8). Therefore in each laboratory we determined the sound reduction index of the wall 5 times in one measuring direction, using the intensity technique. Some variations in source and microphone position were applied. These intensity measurements have been carried out without adding extra absorption material to the receiving room. In some laboratories this may lead to a highly reactive sound field in the receiving room, thus causing errors. As usual the reactivity index is determined when performing an intensity measurement. In some laboratories a limited number of intensity measurements has been carried out with extra absorption material in the receiving room, to measure the effect on the sound reduction index.
From the first precision experiment on the middleweight wall we selected 5 tests in each laboratory. The measuring direction of these selected measurements had to be the same as used in the intensity measurements. These 5 test results of measurements in one measuring direction may be considered to be a third precision experiment in part 3 of this investigation. In this way the precision of both test methods as well as the average results of both test methods can be compared for the same number of tests. A survey of the measurements in this second and third precision experiment is given in table 4.7.

Table 4.6. Measurements carried out on the middleweight wall with respect to the precision experiment (from ref.4.5).

number of:	laboratory A	C	D	E	F	G
tests:						
. direction 1-2	5	5	5	5	5	6
. direction 2-1	5	5	5	3	5	4
loudspeakers	2	1	1	1	1	1
loudspeaker positions	2	1	2	1	1	1
diffusing elements:						
. room 1	-	3	2	-	2	
. room 2	-	-	4	25	2	

Table 4.7. Survey of pressure and intensity measurements concerning the second and the third precision experiment in part 3 of the investigation (from ref.4.8).

lab.	operator	measuring direction	wall connected to room	extra absorption	method	number of tests
A.	A	2-1	2	-	P	5
	C	2-1	2	-	I	5
C.	C	2-1	2	-	P	5
	C	2-1	2	-	I	5
	C	2-1	2	+	I	5
D.	D	1-2	1	-	P	5
	C	1-2	1	-	I	5
E.	E	2-1	2	-	P	5
	C	2-1	2	-	I	5
F.	F	1-2	1	-	P	5
	C	1-2	1	-	I	5
	C	1-2	1	+	I	1
G.	G	A1-A2	A1	-	P	5
	C	A1-A2	A1	-	I	5
	C	A1-A2	A1	+	I	1

CHAPTER 5. RESULTS AND DISCUSSION

5.1. Introduction

In this chapter the results of the investigation will be discussed on the basis of the four themes already mentioned in chapter 4:

1. the effects of the properties of a transmission suite on the results of sound insulation measurements;
2. the precision of the conventional test method, investigated on three test objects;
3. comparison of the results of conventional and intensity measurements;
4. comparison of the precision of the conventional and the intensity method.

The first theme will be discussed in §5.2. This discussion will be restricted to the niche effect and the effects of equal volumes, different edge conditions and, briefly, the measuring directions. The effect of the loudspeaker position will not be treated separately as it has not been investigated systematically, but the effect plays a part in the results of the precision experiments. The same is true for the effect of diffusing elements. The effect of a different test method is discussed in §5.4 and §5.5 together with the third and the fourth theme. The precision experiments concerning the conventional method will be treated in §5.3.

5.2. The effects of the properties of a transmission suite on the results of sound insulation measurements

5.2.1. The niche effect

The investigation concerning the niche effect has been carried out in part 1 of the investigation in the laboratories A, B, C, D, E, F and H (see §4.4). In each laboratory the sound reduction index of the lightweight wall has been determined for two wall positions: the centre of the test opening and at one end of the test opening (fig.3.1). For each wall position the sound reduction index has been determined in two measuring directions.

The sound reduction index of the lightweight wall averaged over the two measuring directions, will be denoted R_c when the wall is in the centre of the test opening and R_o when the wall is at one end of the test opening. In fig.5.1 R_c is compared with R_o for each laboratory; also the standard deviations of R_c and R_o are shown. A niche effect can be observed clearly in the results of the measurements in laboratories A, B and F. For these laboratories R_o is larger than R_c for frequencies below 500 Hz which is approximately the lowest critical frequency of this wall. In this frequency region the difference R_o-R_c is larger than expected from the standard deviations of R_o and R_c. This effect is confirmed by the investigations of other authors (refs.3.2, 3.3 and 3.5).
In laboratory B R_o is also larger than R_c in the frequency range above 500 Hz. Again the difference is larger than expected from the standard deviations. By moving the wall away from the centre to one end of the test opening the total loss factor may have changed. Measurements to confirm this have not been carried out.
The results in the laboratories C, D and E show no niche effect. The difference R_o-R_c has more or less the same value as the standard deviation. In laboratory C the sound reduction index R_c is somewhat higher than R_o for frequencies above 500 Hz, maybe because of a change in the total loss factor as a consequence of moving the wall.
This effect for frequencies above 500 Hz can also be observed in the results of laboratory H. However, in that case during the last measurements an increased humidity of the wall was observed, which may have resulted in a different loss factor and a slight variation in the value of the surface mass. In this laboratory a niche effect was not recognized. There are indications for R_c to be lower than R_o, but this does not occur in the whole frequency range below 500 Hz and it is not significant.

Those laboratories in which a niche effect has been observed, have the following characteristics in common:
- a deep test opening: a depth of 0.6 m or more;
- the shape of the test opening is rectangular;
- identical niches exist on both sides of the test object when the object is in the centre position;
- there is a niche at all four wall boundaries.

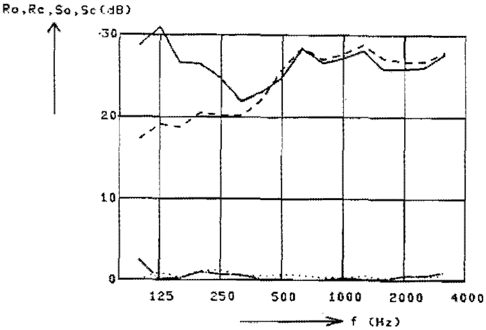


Fig.5.1A THE INFLUENCE OF THE POSITION OF THE LIGHTWEIGHT WALL IN THE TEST OPENING ON ITS SOUND REDUCTION INDEX, MEASURED IN LABORATORY A

Ro, WALL AT ONE END OF THE TEST OPENING
Rc, WALL IN THE CENTRE OF THE TEST OPENING
So, THE STANDARD DEVIATION OF Ro
Sc, THE STANDARD DEVIATION OF Rc

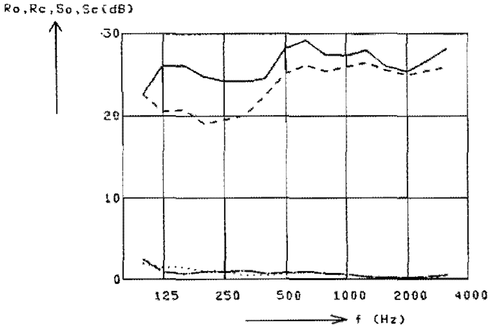


Fig.5.1B THE INFLUENCE OF THE POSITION OF THE LIGHTWEIGHT WALL IN THE TEST OPENING ON ITS SOUND REDUCTION INDEX, MEASURED IN LABORATORY B

Ro, WALL AT ONE END OF THE TEST OPENING
Rc, WALL IN THE CENTRE OF THE TEST OPENING
So, THE STANDARD DEVIATION OF Ro
Sc, THE STANDARD DEVIATION OF Rc

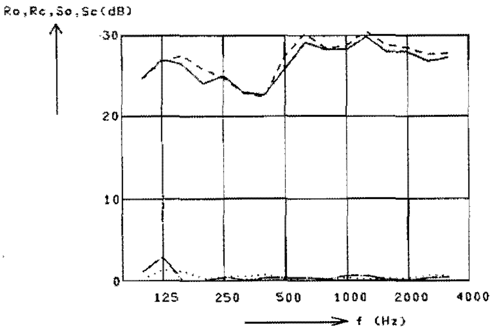


Fig.5.1C THE INFLUENCE OF THE POSITION OF THE LIGHTWEIGHT WALL IN THE TEST OPENING ON ITS SOUND REDUCTION INDEX, MEASURED IN LABORATORY C

Ro, WALL AT ONE END OF THE TEST OPENING
Rc, WALL IN THE CENTRE OF THE TEST OPENING
So, THE STANDARD DEVIATION OF Ro
Sc, THE STANDARD DEVIATION OF Rc

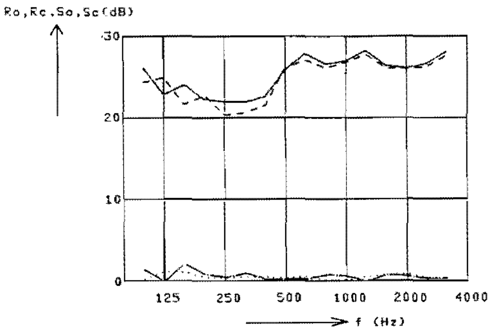
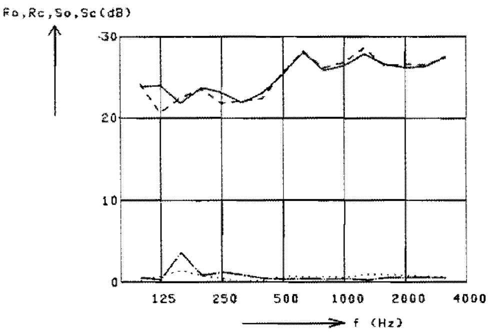


Fig.5.1D THE INFLUENCE OF THE POSITION OF THE LIGHTWEIGHT WALL IN THE TEST OPENING ON ITS SOUND REDUCTION INDEX, MEASURED IN LABORATORY D

Ro, WALL AT ONE END OF THE TEST OPENING
Rc, WALL IN THE CENTRE OF THE TEST OPENING
So, THE STANDARD DEVIATION OF Ro
Sc, THE STANDARD DEVIATION OF Rc



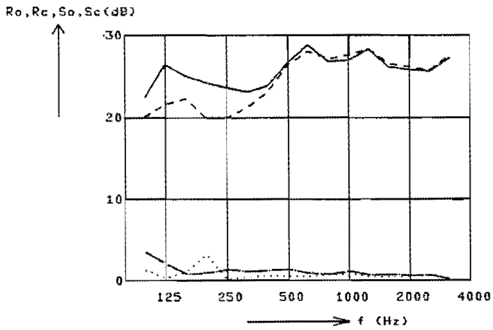


Fig.5.1E THE INFLUENCE OF THE POSITION OF THE LIGHTWEIGHT WALL IN THE TEST OPENING ON ITS SOUND REDUCTION INDEX, MEASURED IN LABORATORY E

———— Ro, WALL AT ONE END OF THE TEST OPENING
- - - - Rc, WALL IN THE CENTRE OF THE TEST OPENING
—·—·— So, THE STANDARD DEVIATION OF Ro
······ Sc, THE STANDARD DEVIATION OF Rc

Fig.5.1F THE INFLUENCE OF THE POSITION OF THE LIGHTWEIGHT WALL IN THE TEST OPENING ON ITS SOUND REDUCTION INDEX, MEASURED IN LABORATORY F

———— Ro, WALL AT ONE END OF THE TEST OPENING
- - - - Rc, WALL IN THE CENTRE OF THE TEST OPENING
—·—·— So, THE STANDARD DEVIATION OF Ro
······ Sc, THE STANDARD DEVIATION OF Rc

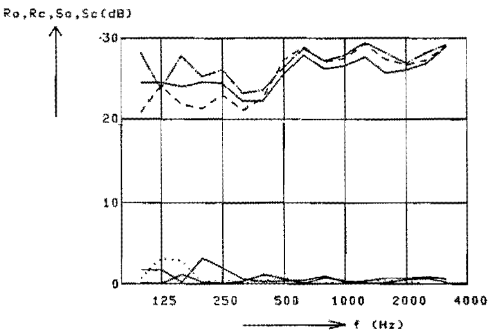


Fig.5.1G THE INFLUENCE OF THE POSITION OF THE LIGHTWEIGHT WALL IN THE TEST OPENING ON ITS SOUND REDUCTION INDEX, MEASURED IN LABORATORY H

———— Ro, WALL AT ONE END(AT ROOM 1) OF THE TEST OPENING
- - - - Rc, WALL IN THE CENTRE OF THE TEST OPENING
—·—·— Ro, WALL AT THE OTHER END OF THE TEST OPENING
······ So, THE STANDARD DEVIATION OF Ro(WALL NEAR ROOM 1)
———— Sc, THE STANDARD DEVIATION OF Rc
———— THE STANDARD DEVIATION OF Ro(WALL NEAR ROOM 2)

5.2.2. The effect of equal volumes of source and receiving room

In only two laboratories the volumes of source and receiving room are equal i.e. laboratories A and F, although they have a different type of symmetry.
To see if an effect of equal volumes is relevant measurements with rooms with unequal volumes should be carried out, for instance by diminishing the volume of one room with at least 10%. This has not been done in this investigation.
Another way to disturb the perfect symmetry in laboratories A and F is to move the object within the test opening. As seen in §5.2.1 this may result in a different sound reduction index which may be attributed to the niche effect.
The effect of equal volumes can be demonstrated in scale models in which niches can be avoided and the volumes can be made exactly equal. Michelsen (ref.3.5) showed the effect by means of such scale models. Figure 5.2 presents some results of our 1:4 scale model experiments showing also clearly a similar effect. The sound reduction index is increased when the perfect symmetry is disturbed by reducing the volume of one of the rooms.

5.2.3. The effect of the measuring direction

Theoretically (ref.3.11) the sound reduction index of an object mounted between two transmission rooms with different volumes should be higher when the small room is acting as the source room.
The laboratories B, C, D, E, G and H have rooms with different volumes. In all parts of the investigation sound insulation measurements have been carried out in two measuring directions. The number of replicate measurements for the two measuring directions is small for the lightweight wall and the heavy wall (see tables 4.2a and 4.3). More tests have been performed on the middleweight wall for both measuring directions: in each laboratory the sound reduction index of the middleweight wall has been determined 5 times for each direction. If there exists an effect of the measuring direction then this might be observed in the results of the measurements on the middleweight wall. Table 5.1 presents the differences between the average sound reduction index in one direction and the average sound reduction index in the opposite direction as a function of frequency. The average has been taken over 5 single tests.

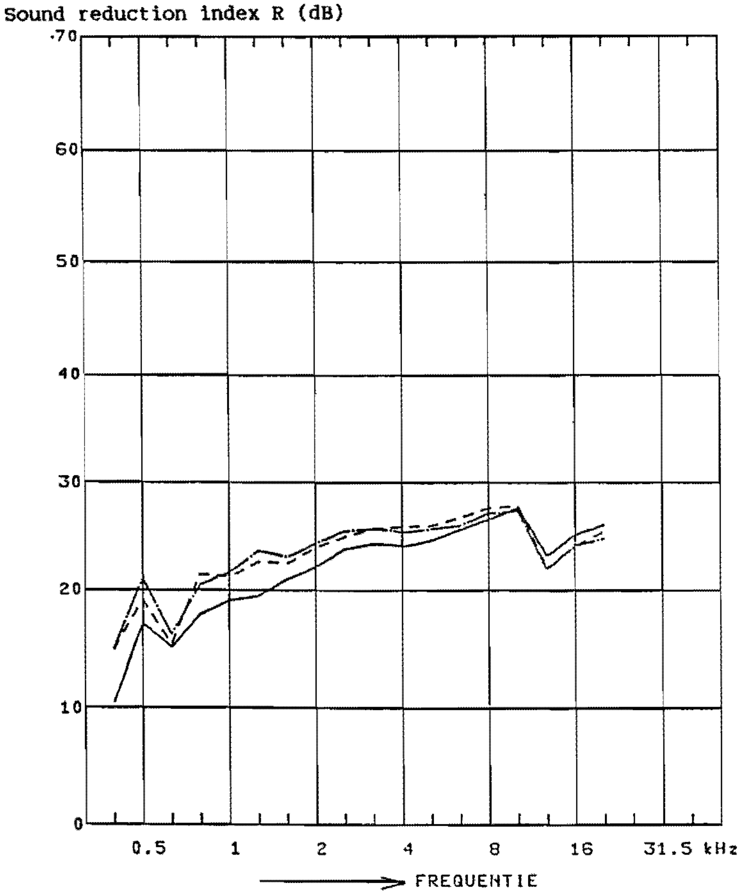


fig.5.2. The effect of equal volumes of source and receiving room (from scale model experiments).

———— $V_1 = V_2$: measuring direction 1-2

– – – – – $V_1 = V_2 - 10\%$: measuring direction 1-2

—·—·— $V_1 = V_2 - 20\%$: measuring direction 1-2

Table 5.1. The effect of the measuring direction on the sound reduction index of the middleweight wall.

freq. (Hz)	A $V_1>V_2$ $R_{21}-R_{12}$ (dB)	C $V_2>V_1$ $R_{21}-R_{12}$ (dB)	D $V_2>V_1$ $R_{12}-R_{21}$ (dB)	E $V_1>V_2$ $R_{21}-R_{12}$ (dB)	F $V_1=V_2$ $R_{12}-R_{21}$ (dB)	G $V_2>V_1$ $R_{12}-R_{21}$ (dB)
	laboratories					
100	-2.5	2.4	0.4	-1.6	-3.7	-0.7
125	2.2	5.9	-1.8	0	-1.2	-1.8
160	-0.2	1.3	-1.8	-0.8	1.8	0.2
200	-2	1.8	0.1	-0.5	2.8	1.2
250	0.9	0.5	1.3	-0.3	-1.6	-0.4
315	0.1	0.8	0.5	0	-1.8	-0.5
400	-0.7	0.3	0.3	0.4	-0.3	-1
500	-0.6	0.2	0.4	-0.7	0.2	-0.5
630	0	0.1	0.2	0	-0.2	0.2
800	0,3	0.2	0.3	-0.9	-0.3	0.1
1000	0,7	-0.1	0.5	0.1	-0.3	0.4
1250	0,2	0.4	1.1	-0.3	-0.4	0.4
1600	0	0.7	0.77	-0.6	-0.6	0.8
2000	0,5	0.2	0.8	-0.1	-0.7	0.7
2500	1	0.4	0.6	-0.3	-0.5	0.9
3150	0,9	0.3	0.6	-0.7	-0.8	0.6

R21-R12 means the difference of the sound reduction index in the direction room 2 to room 1 and R in the direction room 2 to room 1.

The standard deviations belonging to the average sound reduction indices are given by table 5.2. It can be seen from both tables that random errors as indicated by the standard deviations might as well be responsible for the differences as an eventual effect of the measuring direction.

In literature another effect related to the effect of the measuring direction has been mentioned. As shown in §3.2.5 Michelsen proved experimentally that the measuring direction can affect the sound reduction index when in the identical transmission rooms the amounts of absorption are quite different.

We did not perform investigations under these conditions.

Table 5.2. Standard deviations in dB of 5 measurements on the middleweight wall for each measuring direction in each laboratory.

	laboratories A		C		D		E		F		G	
freq.(Hz)	2-1	1-2	2-1	1-2	2-1	1-2	2-1	1-2	2-1	1-2	2-1	1-2
100	1.5	1.1	1.2	2.6	1.6	2.5	1.6	0.5	1.6	0.9	2.3	2.3
125	1.4	0.3	2.5	1.6	1.4	1.2	0.8	0.1	2.4	1.7	1.3	0.9
160	1.7	0.5	0.9	0.9	1.3	1.2	0.6	1.0	0.6	0.8	1.5	1.4
200	2.1	0.5	0.8	1.1	0.7	0.9	0.4	1.1	06.	1.5	1.1	2.8
250	0.5	0.5	0.4	0.4	0.9	0.5	0.7	0.4	0.6	0.5	0.7	0.9
315	0.8	0.7	0.6	0.5	1.0	1.0	0.6	0.5	0.6	0.9	0.4	0.5
400	1.2	0.7	0.8	0.3	0.8	0.5	0.1	0.5	0.2	1.0	1.3	0.4
500	1.4	0.4	0.4	0.4	0.6	0.5	0.3	0.3	0.3	0.3	1.0	0.4
630	0.3	0.5	0.3	0.3	0.4	0.2	0.3	0.4	0.6	0.1	1.0	0.8
800	0.9	0.6	0.3	0.4	0.9	0.2	0.6	0.6	0.6	0.5	0.2	0.2
1000	0.5	0.5	0.2	0.3	0.8	0.3	0.2	0.4	0.6	0.5	0.8	0.4
1250	0.6	0.3	0.2	0.2	0.8	0.3	0.3	0.1	0.3	0.6	0.8	0.3
1600	0.7	0.6	0.2	0.3	0.7	0.3	0.2	0.2	0.4	0.5	1.1	0.9
2000	0.7	0.5	0.5	0.5	0.6	0.2	0.2	0.1	0.5	0.4	0.9	0.2
2500	0.9	0.5	0.5	0.7	0.6	0.4	0.1	0.2	0.3	0.3	1.0	1.0
3150	0.9	0	0.5	0.5	0.6	0.3	0.1	0.33	0.3	0.5	0.8	0.9

2-1 means room 2 is source room, room 1 is receiving room.

5.2.4. The effect of different edge conditions of the test object

When we increase the total loss factor of a building element its sound reduction index for frequencies above the critical frequency will increase. The total loss factor can be calculated from the reverberation time of the object:

$$\eta = 2.2 / (f \cdot T) \qquad (5.1)$$

where: η = the total loss factor

f = the centre frequency of the frequency band concerned

T = the reverberation time of the object, being the time after which the acceleration level of the object has dropped 60 dB starting at the switching off of the excitation signal.

In literature values of the internal loss factor of 0.01 to 0.02 are given for masonry.

We determined the total loss factor of the heavy wall and the middleweight wall as a function of frequency. Octave bands have been used instead of 1/3-octave bands. Theoretically for these objects the power flow to the adjoining structures cannot be neglected and it will be different in each laboratory. Table 5.3 gives a survey of the total loss factors of the heavy wall, determined in each laboratory.

Table 5.3. Total loss factors $\eta(f)$ of the heavy wall, measured in each laboratory as a function of frequency.

lab.	$\eta(125)$	$\eta(250)$	$\eta(500)$	$\eta(1000)$	$\eta(2000)$	$\eta(4000)$	$\overline{\eta}$
A	0.018	0.015	0.013	0.010	0.008	0.007	0.012
B	0.028	0.015	0.013	0.012	0.011	0.006	0.014
C1*	0.073	0.044	0.029	0.028	0.016	0.008	0.033
C2**	0.016	0.016	0.010	0.008	--	--	0.013
D	0.068	0.055	0.028	0.022	0.016	0.011	0.033
E	0.093	0.068	0.044	0.028	0.022	0.011	0.044
F	0.018	0.014	0.013	0.012	0.010	0.006	0.012
G	0.020	0.019	0.029	0.022	0.016	0.011	0.02

* = test object on concrete frame with no connection to either room 1 or room 2

** = test object connected to room 1.

In this connection the ratios of the masses per unit area of the adjoining structures to those of the heavy wall are given in table 5.4. Also the junction type is indicated. According to Cremer/Heckl an L-junction will reflect more vibrational power than a sudden change in thickness, assuming a rigid connection between the object and the adjoining structures. This means that the power flow to the adjoining structures will be lower for an L-junction. It can be seen from table 5.3 that on the basis of the loss factors the 8 different edge conditions for the heavy wall can be divided into two categories:

a. laboratories A, B, C2, F and G;

b. laboratories C1, D and E.

In category a the loss factors are smaller than those in category b. This may be explained partly by table 5.4 from which it can be seen that in category a the mass per unit area of the adjoining structures on the average is bigger than in category b. This results in a bigger jump in impedance in category a and hence less power flow to the adjoining structures, assuming a rigid connection.

Table 5.4. Ratio of the mass per unit area m_a of the adjoining structures to the mass per unit area m_o of the test object. The type of the junction (see §3.2.4) jt is also indicated; jt=1 means change in thickness; jt=2 means an L-junction.

lab.	test object							
	lower edge		upper edge		left side		right side	
	m_a/m_o	j.t	m_a/m_o	j.t	m_a/m_o	j.t	m_a/m_o	j.t
A	2.3	1	2.3	1	2.3	1	2.3	1
B	1.8	1	1.8	1	1.8	1	1.3	2
C1*	1.5	1	1.5	1	1.5	1	1.5	1
C2**	1.5	2	1.5	2	1.5	1	1.5	1
D	1	1	0.8	2	1	1	1	1
E	0.7	2	2	1	1.5	1	1.5	1
F	1.9	1	1.9	1	1.9	1	1.9	1
G	1.3	2	0.8	2	1	2	1	2

j.t means junction type
*   test object on concrete frame
** test object connected to room 1.

This connection plays an important part. Although all the measurements have been carried out in the period between the fourth and the twelfth day after the wall had been erected, the speed of drying of the wall may have been different in each laboratory. This may have affected the rigidity of the connection, and so the edge losses.
There will usually be a difference in the edge conditions between upper and lower edge, because of the weight of the object. This difference will be influenced strongly by the way the object is erected. Thus a rigid connection cannot be assumed in each laboratory and at each edge of the wall. For instance, the edge losses in laboratory G should have been larger because of the ratio of surface masses. However, the bricklayers informed us that they had been given the wrong dimensions of the test opening so they had to improvise which may have reduced the rigidity of the connection. This may have resulted in smaller edge losses.

In laboratory C a test object can be placed in a concrete frame which has no connection to either source or receiving room. In this laboratory measurements have been performed on two heavy walls. The first one (C1 in tab 5.3) was built on the concrete frame. The second one (C2 in table 5.3) was connected to room 1 (see fig.4.4).

The highest loss factors were found with the first wall. As the concrete frame has the same surface mass as the walls of the rooms we expect the difference in impedance jumps in C1 and C2 to be caused only by the geometrical differences (juntion type 1 in the case of C1 and type 2 for the C2-situation, see §3.2.4), and the presence of flexible porous rubber layers which might involve frictional losses in the C1-situation.
A second difference between C1 and C2 concerns the flanking transmission: it may be neglected for the C1-situation whereas for C2 the measured sound reduction index will be slightly reduced because of flanking transmission. The average results for both wall positions are shown in fig.5.3. As would be expected wall position C1 yields the highest values of the sound reduction index in the frequency range above the critical frequency which is 100 Hz. Calculations on the basis of a simple theoretical model (ref.1.6) show an increase of 2 to 3 dB in the sound reduction index when the total loss factor is increased by a factor of 3. This is in reasonable accordance with fig.5.3.
The importance of the edge losses is illustrated once more in fig.5.4, which for each laboratory presents the laboratory averaged sound reduction index $\overline{y_i}$ as a function of frequency compared with the average sound reduction index m (see §3.4). As can be seen combining this figure with table 5.3 a big loss factor will cause $\overline{y_i}$ to be larger than m, while for a small loss factor $\overline{y_i}$ will be smaller than m.

A similar effect can be demonstrated from the measurements carried out on the middleweight wall, although the effect is not so pronounced as it was for the heavy wall and it is smaller than expected. Table 5.5 gives the loss factors calculated from the reverberation time.

Table 5.5. Total loss factors $\eta(f)$ of the middleweight wall measured in each laboratory as a function of frequency.

lab.	$\eta(125)$	$\eta(250)$	$\eta(500)$	$\eta(1000)$	$\eta(2000)$	η
A	0.115	0.056	0.029	--	--	0.067
C						
D	0.117	0.059	0.029	--	--	0.068
E	0.048	0.065	0.029	--	--	0.047
F	0.019	0.013	0.021	0.015	0.008	0.015
G	0.035	0.044	0.029	0.015	0.008	0.026

-- because of the weak excitation signal and the short reverberation time the loss factor could not be measured.

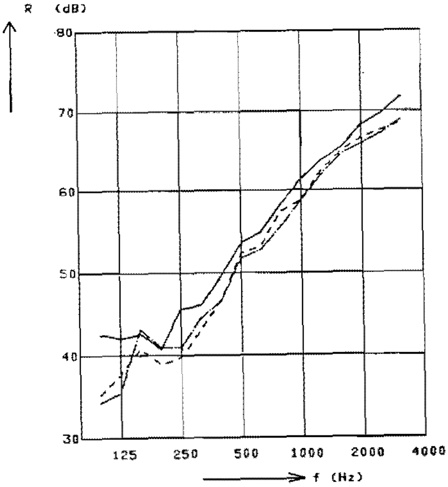


Fig.5.3 THE SOUND REDUCTION INDEX OF THE HEAVY WALL MEASURED IN LABORATORY C FOR TWO POSITIONS OF THE WALL IN THE TEST OPENING

———— CENTRE POSITION, MEASURING DIRECTION 2-1

- - - - - WALL CONNECTED TO ROOM 1, MEASURING DIRECTION 1-2

———— WALL CONNECTED TO ROOM 1, MEASURING DIRECTION 2-1

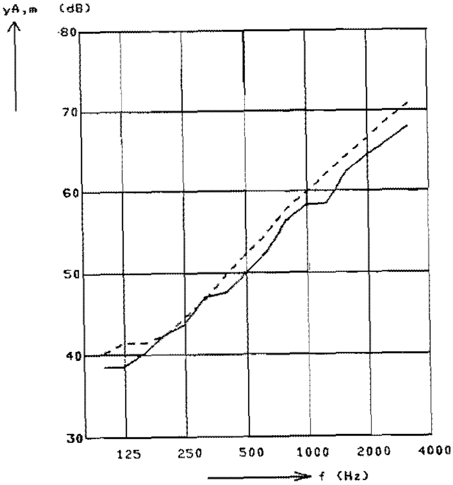


Fig.5.4A THE AVERAGE SOUND REDUCTION INDEX OF THE HEAVY WALL MEASURED IN LABORATORY A, COMPARED TO m

———— yA

- - - - - m

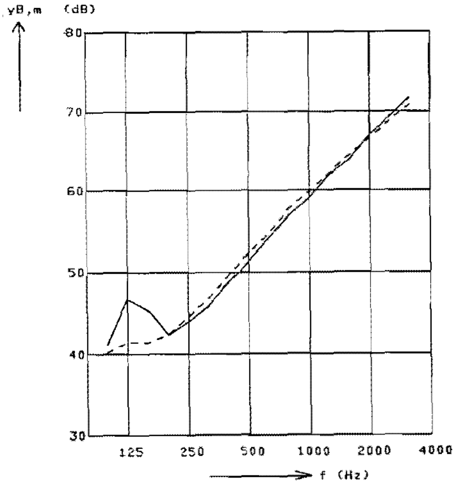


Fig.5.4B THE AVERAGE SOUND REDUCTION INDEX OF THE HEAVY WALL MEASURED IN LABORATORY B, COMPARED TO m

———— yB

- - - - - m

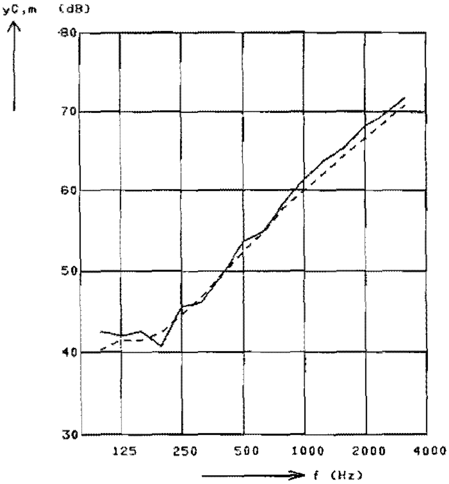


Fig.5.4C THE AVERAGE SOUND REDUCTION INDEX OF THE HEAVY WALL MEASURED IN LABORATORY C, COMPARED TO m

———— yC

- - - - - m

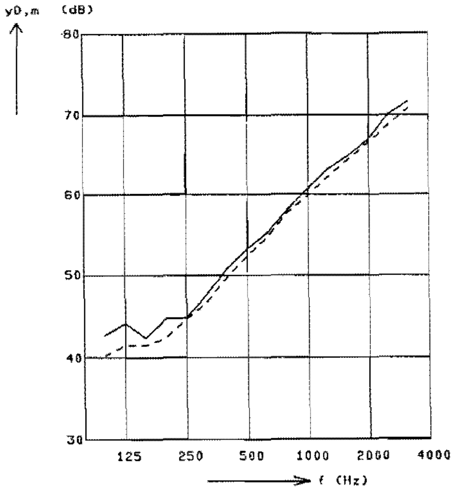


Fig.5.4D THE AVERAGE SOUND REDUCTION INDEX OF THE HEAVY WALL MEASURED IN LABORATORY D, COMPARED TO m

——— yD
- - - - m

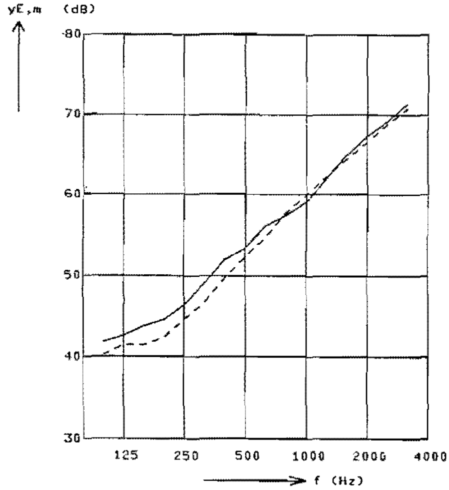


Fig.5.4E THE AVERAGE SOUND REDUCTION INDEX OF THE HEAVY WALL MEASURED IN LABORATORY E, COMPARED TO m

——— yE
- - - - m

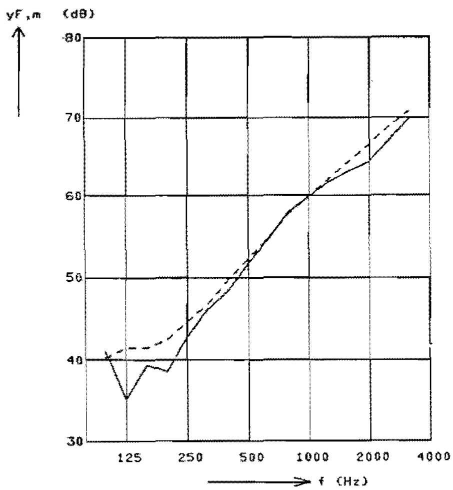


Fig.5.4F THE AVERAGE SOUND REDUCTION INDEX OF THE HEAVY WALL MEASURED IN LABORATORY F, COMPARED TO m

——— yF
- - - - m

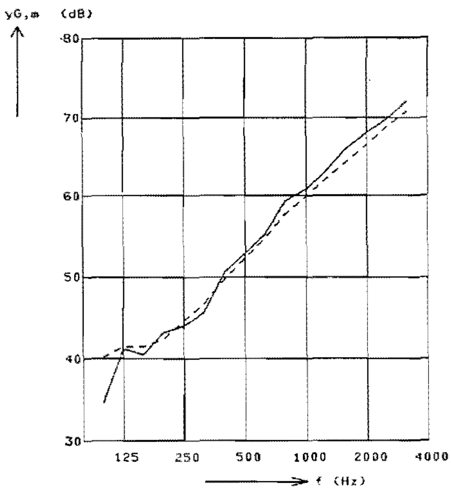


Fig.5.4G THE AVERAGE SOUND REDUCTION INDEX OF THE HEAVY WALL MEASURED IN LABORATORY G, COMPARED TO m

——— yG
- - - - m

For each laboratory the average sound reduction index $\overline{y_i}$ is compared with the average sound reduction index m in fig.5.5. The correlation between the value of the loss factor and the test results is not as satisfactory as for the heavy wall. In laboratory A the average sound reduction index $\overline{y_i}$ is lying 2 dB below the values of m for frequencies above 200 Hz, the critical frequency, although a big loss factor was measured. For the other laboratories the differences between $\overline{y_i}$ and m are smaller than expected from the loss factors.

5.2.5. Conclusions of §5.2

The results of airborne sound insulation measurements in laboratories in Belgium and The Netherlands may be affected by the properties of the laboratories. The biggest effects are:

1. the niche effect;
2. the effect of different edge conditions.

ad.1. For the lightweight wall used in the investigation the measured sound reduction index depends to a high extent on the position of the wall in the test opening. This effect was demonstrated in the frequency region below 500 Hz, the lowest critical frequency of the wall. In this frequency region the lowest values of the sound reduction index are obtained when the wall is placed in the centre position. By moving the wall away from the centre position to one end of the test opening variations on the sound reduction index up to 10 dB have been measured.

ad.2. As mentioned before, different edge conditions cause different edge losses. For both the heavy wall and the middleweight wall different edge losses, i.e. flow of vibrational energy from the test object to the adjoining structures, could be expected theoretically from one laboratory to another. We measured differences in the sound reduction indices as big as 4 dB for frequencies at and above the critical frequency of the objects. A correlation has been found between the measured values of the loss factors and the sound reduction indices in accordance with theory.

To reduce these effects, some recommendations are given:

* The position of the test object should be prescribed in international standards; more precisely, the ratio of the depths of the niches on both sides of the wall should differ from 1. For glazing, this ratio has already been standardized to a value of 1:2. The higher the critical frequency of the test object, the more important this standardization is.
* Both shape and mass of the test opening should be standardized in future requirements in order to normalize the edge losses, i.e. the energy flow from the test object to the adjoining structures. For new transmission suites the effect of different edge conditions should be reduced in this way. For existing transmission suites it might be considered to correct the test results for instance normalize them to a standard loss factor.

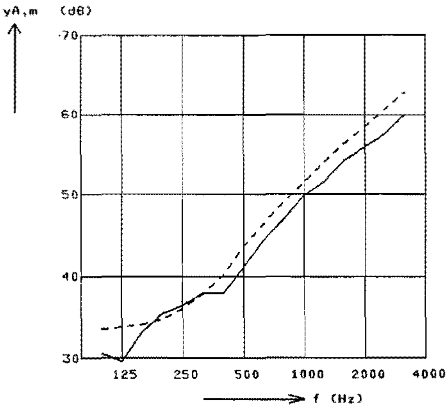


Fig.5.5A THE AVERAGE SOUND REDUCTION INDEX OF THE MIDDLEWEIGHT WALL MEASURED IN LABORATORY A, COMPARED TO m

——— yA
- - - - m

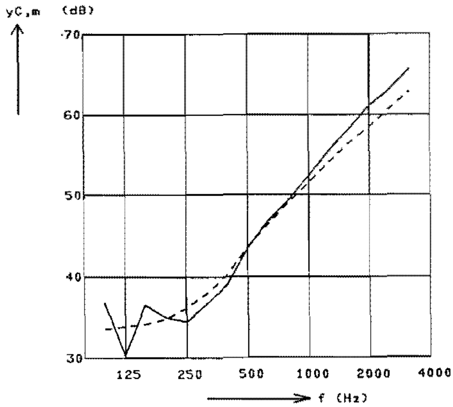


Fig.5.5B THE AVERAGE SOUND REDUCTION INDEX OF THE MIDDLEWEIGHT WALL MEASURED IN LABORATORY C, COMPARED TO m

——— yC
- - - - m

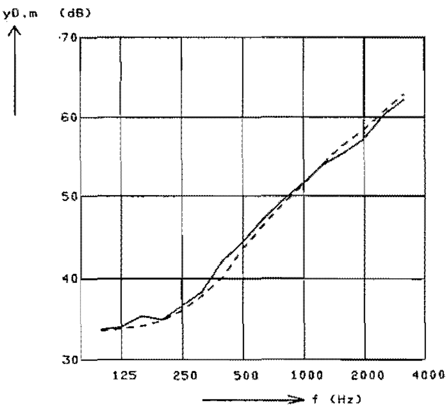


Fig.5.5C THE AVERAGE SOUND REDUCTION INDEX OF THE MIDDLEWEIGHT WALL MEASURED IN LABORATORY D, COMPARED TO m

——— yD
- - - - m

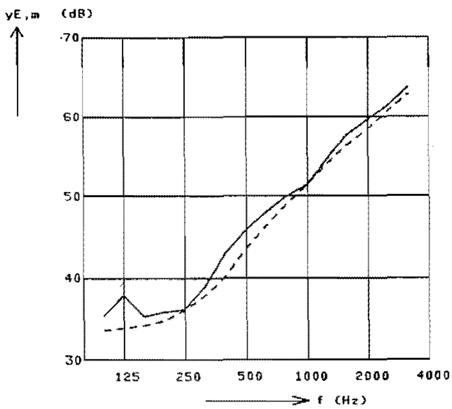


Fig.5.5D THE AVERAGE SOUND REDUCTION INDEX OF THE MIDDLEWEIGHT WALL MEASURED IN LABORATORY E, COMPARED TO m

——— yE
- - - - m

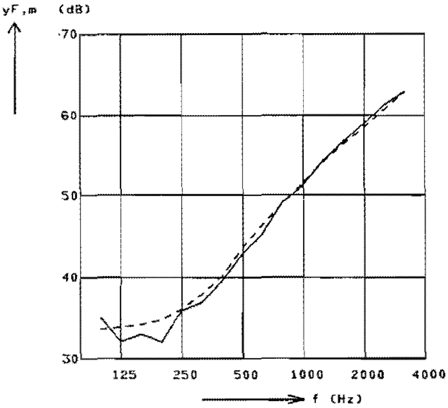


Fig.5.5E THE AVERAGE SOUND REDUCTION INDEX
OF THE MIDDLEWEIGHT WALL MEASURED IN
LABORATORY F, COMPARED TO m

——————— yF

- - - - - - - - m

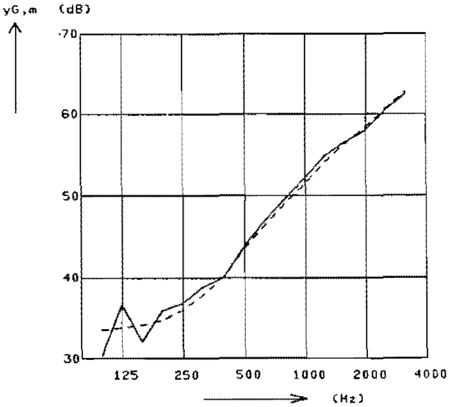


Fig.5.5F THE AVERAGE SOUND REDUCTION INDEX
OF THE MIDDLEWEIGHT WALL MEASURED IN
LABORATORY G, COMPARED TO m

——————— yG

- - - - - - - - m

5.3. The precision of the conventional test method

5.3.1. The lightweight wall

5.3.1.1. The average sound reduction index m:

Figure 5.6 shows the variations in the average sound reduction index $\overline{y_i}$ for each laboratory. This figure gives us a rough measure of the reproducibility R. As can be seen from this figure the biggest variations occur in the low frequency range.
For each laboratory the average sound reduction index $\overline{y_i}$ is compared with m in fig.5.7. Table 5.6 presents the $\overline{y_i}$-values of the single-number quantities R_w, R_A and R_m (see §2.4.3) for each laboratory together with the m-value of these quantities. The standard deviations s_i are also given in this table.

Table 5.6. The laboratory averaged sound reduction index $\overline{y_i}$, the average sound reduction index m of the single-number quantities R_w, R_A and R_m and the standard deviations s_i for each laboratory concerning the lightweight wall.

	R_w(dB)		R_A(dB(A))		R_m(dB)	
lab.	$\overline{y_i}$	s_i	$\overline{y_i}$	s_i	$\overline{y_i}$	s_i
A	26.72	0.51	24.19	0.55	23.71	0.56
B	26.78**	0.98	24.91**	1.08	24.71	0.72
C	28.23	0.15	26.56	0.18	26.23	0.12
D	26.64	0.44	25.17	0.26	24.84	0.31
E	26.72	0.49	25.25	0.43	24.81	0.48
F	27.50	0.23	25.53	0.36	24.76	0.37
m	27.17		25.31		24.84	

** outlier

5.3.1.2. The repeatability r:

The repeatability r as calculated on the basis of the results of the measurements on the lightweight wall is given in fig.5.8 as a function of frequency. This figure also contains the reference curves for the repeatability from ISO 140/II and ISO/TC-43/SC-2-N-267.

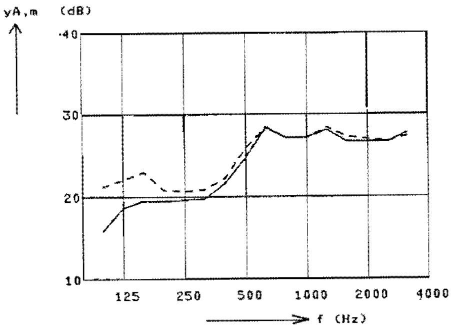


Fig.5.7A THE AVERAGE SOUND REDUCTION INDEX OF THE LIGHTWEIGHT WALL MEASURED IN LABORATORY A, COMPARED TO m

yA

m

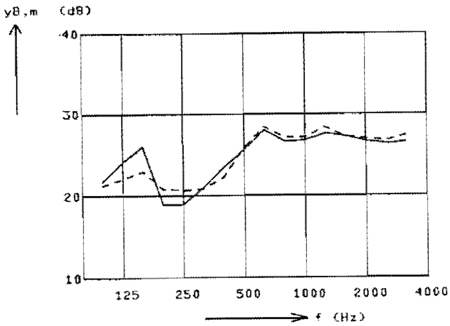


Fig.5.7B THE AVERAGE SOUND REDUCTION INDEX OF THE LIGHTWEIGHT WALL MEASURED IN LABORATORY B, COMPARED TO m

yB

m

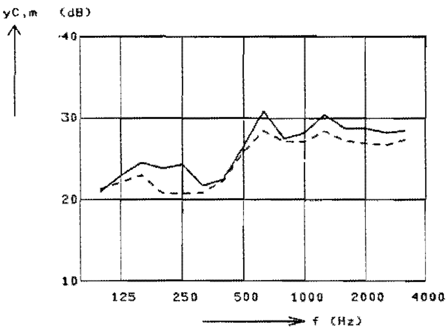


Fig.5.7C THE AVERAGE SOUND REDUCTION INDEX OF THE LIGHTWEIGHT WALL MEASURED IN LABORATORY C, COMPARED TO m

yC

m

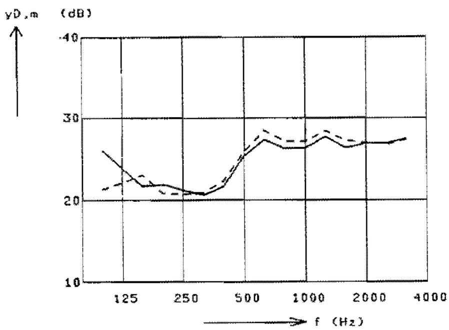


Fig.5.7D THE AVERAGE SOUND REDUCTION INDEX OF THE LIGHTWEIGHT WALL MEASURED IN LABORATORY D, COMPARED TO m

yD

m

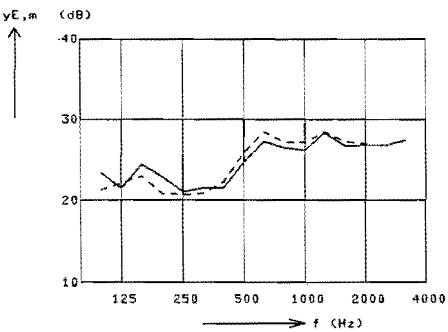


Fig.5.7E THE AVERAGE SOUND REDUCTION INDEX OF THE LIGHTWEIGHT WALL MEASURED IN LABORATORY E, COMPARED TO m

yE

m

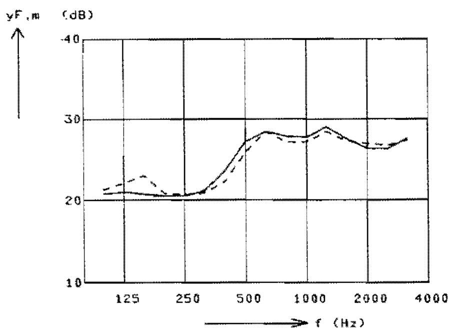


Fig.5.7F THE AVERAGE SOUND REDUCTION INDEX OF THE LIGHTWEIGHT WALL MEASURED IN LABORATORY F, COMPARED TO m

yF

m

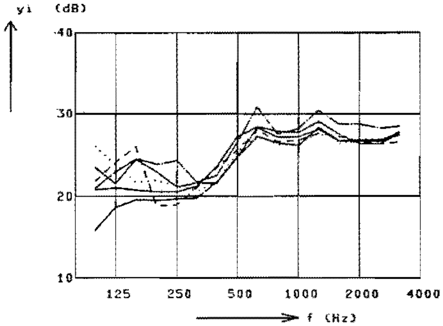


Fig.5.6 THE AVERAGE SOUND REDUCTION INDEX
OF THE LIGHTWEIGHT WALL
FOR EACH LABORATORY

- yA
- yB
- yC
- yD
- yE
- yF

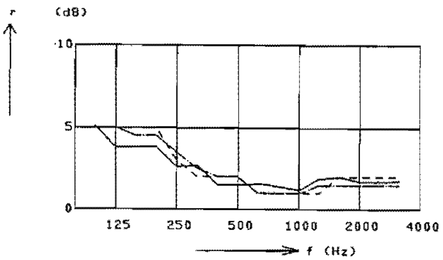


Fig.5.8 THE REPEATABILITY OF THE CONVENTIONAL METHOD
DETERMINED FROM THE MEASUREMENTS ON THE
LIGHTWEIGHT WALL, COMPARED TO THE REFERENCE CURVES

- r
- REFERENCE CURVE OF ISO 140/II (ref.2.10)
- REFERENCE CURVE OF ISO/TC 43/SC 2 N267 (ref.3.27)

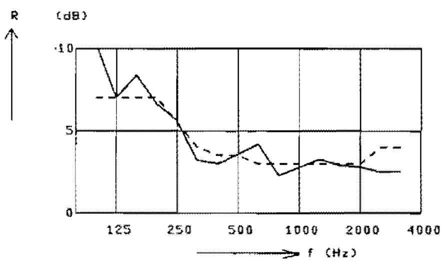


Fig.5.9 THE REPRODUCIBILITY OF THE CONVENTIONAL METHOD
DETERMINED FROM THE MEASUREMENTS ON THE
LIGHTWEIGHT WALL, COMPARED TO THE REFERENCE CURVE

- R
- REFERENCE CURVE OF ISO/TC 43/SC 2 N267 (ref.3.27)

The repeatability exceeds the reference curve of ISO 140/II in the frequency range 630 to 1250 Hz by a maximum of 0.9 dB. The reference curve of ISO/TC-43/SC-2-N-267 is exceeded for the frequencies above 630 Hz. Table 5.7 shows the repeatability of the single-number quantities R_w, R_A and R_m and compares them with the reference values of ISO/TC-43/SC-2-N-379.

Table 5.7. The repeatability of the single-number quantities R_w, R_A and R_m concerning the lightweight wall.

	r (dB)	reference value (ref.3.28)
R_w	1.10	1 dB
R_A	1.10	1 dB
R_m	1.44	1 dB

As the repeatability r is determined by the magnitude of the standard deviations in each laboratory these values are summarized in table 5.8. In this table the standard deviations can be compared to the 'within-laboratory standard deviation' s_r.
It can be seen from this table that the standard deviations do not differ much from one laboratory to another, with the exception of those of laboratory B. In this laboratory the standard deviations are much higher especially in the midfrequency range from 315 to 1000 Hz. This leads to the largest number of outliers which are left out of the calculation of the repeatability according to the rules in ISO 5725.
It may be concluded from the definition of the repeatability r (see 3.4.2) and from the reference values that if in the midfrequency range the repeatability should be smaller than 1 dB, the average standard deviation for the laboratories should be smaller than 0.35 dB. Comparing this value with the calculated standard deviations in each laboratory this seems to be a severe demand.

Table 5.8. The standard deviations s_i in dB for each laboratory and the 'within-laboratory standard deviation' s_r concerning the lightweight wall.

freq.(Hz)	s_A	s_B	s_C	s_D	s_E	s_F	s_r
100	1.74	2.10	1.22	1.73	1.00	2.12	1.80
125	1.60	1.05	1.19	1.37	0.68	1.85	1.34
160	1.32	1.42	1.18	1.13	1.35	1.38	1.33
200	1.03	1.71	1.08	0.42	0.92	1.63	1.32
250	0.89	1.28	0.32	0.41	0.63	1.01	0.92
315	1.10	1.36	0.50	0.52	0.96	0.31	0.94
400	0.62	1.99**	0.42	0.37	0.65	0.49	0.52
500	0.52	1.89**	0.42	0.41	0.55	0.63	0.53
630	0.39	1.79**	0.96*	0.37	0.59	0.37	0.56
800	0.64	1.66**	0.22	0.51	0.63	0.39	0.50
1000	0.31	1.79**	0.15	0.46	0.65	0.43	0.42
1250	0.89	0.80	0.37	0.63	0.75	0.29	0.67
1600	0.71	1.02	0.29	0.67	0.49	0.32	0.69
2000	0.74	0.55	0.44	0.55	0.93	0.38	0.61
2500	0.56	0.61	0.71	0.57	0.83	0.42	0.61
3150	0.78	0.70	0.22	0.74	0.87	0.33	0.65

** outlier * straggler

5.3.1.3. The reproducibility R:

Reference values for the reproducibility R are given by ISO/TC-43/SC-2-N-267 and ISO/TC-43/SC-2-N-379. Both documents state the same reference values.

The calculated reproducibility R for the lightweight wall is compared to these reference values in fig.5.9. The reference curves are exceeded for the third-octave bands of 100, 160, 630 and 1250 Hz. In the former two frequency bands the niche effect will of course play a part and perhaps it is the main cause for the discrepancy.

Although the reference curve is exceeded in some frequency bands the calculated reproducibility for the single-number quantities R_w, R_A and R_m fulfil the requirements of ISO/TC-43/SC-2-N-379 as can be seen in table 5.9.

In table 5.10 a survey of the difference $(\overline{y_i}-m)$ is given as a function of frequency for each laboratory. Again some outliers are indicated for laboratory B in the midfrequency range.

Table 5.9. The calculated reproducibility R of the single-number quantities R_w, R_A and R_m concerning the lightweight wall.

	R(dB)	reference value (ref.3.28)
R_w	2,16	3
R_A	2,59	3
R_m	2,52	3

Table 5.10. The difference (in dB) of the laboratory average $\overline{y_i}$ and the average sound reduction index m for the lightweight wall for each laboratory.

freq.(Hz)	$\overline{y}_A$-m	$\overline{y}_B$-m	$\overline{y}_C$-m	$\overline{y}_D$-m	$\overline{y}_E$-m	$\overline{y}_F$-m
100	-5.45	0.54	-0.31	4.73	2.05	-0.52
125	-3.38	2.03	0.84	1.68	-0.61	-1.15
160	-3.41	3.00	-1.55	-1.24	1.42	-2.32
200	-1.38	-1.92	2.99	1.02	2.10	-0.35
250	-0.92	-1.64	3.65	0.51	0.49	-0.14
315	-1.17	0.02	0.73	-0.39	0.65	0.30
400	-0.65	1.16**	0.15	-0.60	-0.66	1.30
500	-1.08	-0.17**	0.78	-0.50	-1.06	1.41
630	-0.10	-0.42**	2.43*	-1.13	-1.15	-0.01
800	0.05	-0.51**	0.45	-0.83	-0.72	0.68
1000	0.02	-0.30**	1.04	-0.88	-1.09	0.59
1250	-0.30	-0.83	1.95	-0.69	-0.09	0.59
1600	-0.56	0	1.51	-0.86	-0.46	0.35
2000	-0.29	-0.28	1.85	0.01	-0.05	-0.60
2500	-0.15	-0.43	1.46	0.14	0.10	-0.44
3150	0.34	-0.88	1.04	0.08	-0.05	0.19

** = outlier   * = straggler

5.3.2. The heavy wall

5.3.2.1. The average sound reduction index m:

In the same way as for the lightweight wall fig.5.10 shows the laboratory average sound reduction index $\overline{y_i}$ for each laboratory as a function of frequency. As usual the largest discrepancies occur at the low frequencies. A separate comparison between the laboratory averages $\overline{y_i}$ and m was

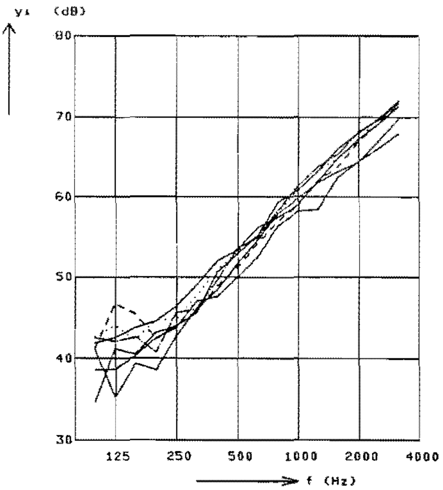


Fig.5.10 THE AVERAGE SOUND REDUCTION INDEX
OF THE HEAVY WALL
FOR EACH LABORATORY

- yA
- yB
- yC
- yD
- yE
- yF
- yG

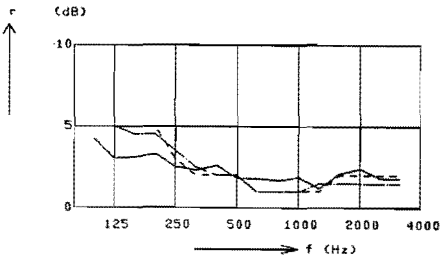


Fig.5.11 THE REPEATABILITY OF THE CONVENTIONAL METHOD
DETERMINED FROM THE MEASUREMENTS ON THE
HEAVY WALL, COMPARED TO THE REFERENCE CURVES

- r
- REFERENCE CURVE OF ISO 140/II (ref.2.10)
- REFERENCE CURVE OF ISO/TC 43/SC 2 N267 (ref.3.27)

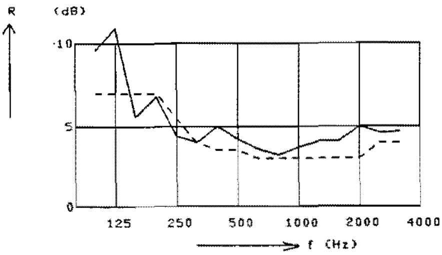


Fig.5.12 THE REPRODUCIBILITY OF THE CONVENTIONAL METHOD
DETERMINED FROM THE MEASUREMENTS ON THE
HEAVY WALL, COMPARED TO THE REFERENCE CURVE

- R
- REFERENCE CURVE OF ISO/TC 43/SC 2 N267 (ref.3.27)

shown in fig.5.4 when dealing with the effect of different edge conditions (see §5.2.4). The laboratory averages $\overline{y_i}$ and the average sound reduction index m concerning the single-number quantities can be found in table 5.11. The standard deviations S_i are given too.

Table 5.11. The laboratory averages $\overline{y_i}$, the average sound reduction index m and the standard deviations S_i concerning the single-number quantities R_w, R_A and R_m for the heavy wall (all quantities are expressed in dB).

	R_w(dB)		R_A(dB(A))		R_m(dB)	
lab.	$\overline{y_i}$	S_i	$\overline{y_i}$	S_i	$\overline{y_i}$	S_i
A	55.35	0.56	49.09	0.55	52.20	0.53
B	56.11	0.75	50.33	0.92	54.36	0.54
C	56.89	0.79	50.50	0.98	54.60	0.56
D	57.56	0.17	51.79	0.21	55.08	0.28
E	58.02	0.29	52.17	0.35	55.08	0.32
F	54.77	0.37	47.77	0.51	52.61	0.34
G	56.37	0.43	48.96	0.37	54.20	0.43
m	56.44		50.09		54.02	

5.3.2.2. <u>The repeatability r:</u>

A comparison of the repeatability and the reference values is shown in fig.5.11. This time the reference curves are exceeded in a large number of third-octave bands. The reference curve of ISO 140/II is exceeded in the frequency region of 350 to 2000 Hz whereas the second reference curve is exceeded for the frequencies above 400 Hz. The difference between the repeatability and the reference values never exceeds 0.92 dB.

For each laboratory the standard deviations of the measurements on the heavy wall are given in table 5.12.

The value of the 'within-laboratory standard deviation' S_r is given in the last column of this table.

This table more or less shows the same result as table 5.8. Again in laboratory B some outliers can be observed.

Tabel 5.12. The standard deviations S_i of the measurements on the heavy wall for each laboratory compared with S_r, the square root of the 'within-laboratory variance; all quantities in dB.

Freq.(Hz)	S_A	S_B	S_C	S_D	S_E	S_F	S_G	S_r
100	0.92	5.00**	0.99	1.91	0.89	2.14	1.56	1.48
125	1.32	1.49	0.90	0.77	0.59	0.85	1.20	1.06
160	0.48	3.35**	1.13	0.69	0.79	1.67	1.40	1.10
200	0.90	1.69	1.80	0.43	0.38	1.24	0.83	1.16
250	0.85	2.21**	0.75	0.79	0.72	1.07	1.10	0.89
315	1.01	0.73	0.67	0.71	0.61	0.82	0.94	0.79
400	0.88	1.47	1.39	0.37	0.38	0.53	0.73	0.92
500	0.67	0.80	0.53	0.58	0.29	0.42	0.88	0.63
630	0.86	0.90	0.50	0.30	0.37	0.48	0.75	0.63
800	0.80	0.46	0.59	0.33	0.63	0.67	0.52	0.59
1000	0.46	0.69	0.69	0.68	0.33	1.10	0.52	0.68
1250	0.64	0.39	0.28	0.41	0.39	0.32	0.48	0.42
1600	1.02	0.85	0.21	0.47	0.72	0.36	1.04	0.73
2000	1.16	1.39	0.25	0.41	0.49	0.32	1.07	0.85
2500	0.69	0.94	0.28	0.39	0.48	0.35	0.96	0.64
3150	0.51	1.68**	0.89	0.22	0.41	0.50	0.88	0.62

** = outlier * = straggler

For the heavy wall the calculated repeatability r as to the single-number quantities exceeds the reference values (see table 5.13).

Table 5.13. The repeatability r concerning R_w, R_A and R_m of the heavy wall.

	r (dB)	reference value (ref.3.28)
R_w	1,50	1 dB
R_A	1,74	1 dB
R_m	1,27	1 dB

5.3.2.3. <u>The reproducibility R</u>:

As can be seen from fig.5.12 the reproducibility only fulfils the requirements of ISO/TC-43/SC-2-N-267 in the third-octave bands 160, 200, 250 and 315 Hz. The biggest difference between the reproducibility and the reference values is 3.89 dB at 125 Hz. From these calculated values of the re-

producibility it may be concluded that for this type of test object the difference between two single test results obtained in different laboratories will not be more than 10 dB at the low frequencies.
At the mid- and high frequencies the reference curve is exceeded to a less extent: 1 or 2 dB. As a consequence it seems only logical that as to the single-number quantities the reference values for the reproduciblity are exceeded by the calculated reproducibility (see table 5.14).

Tabel 5.14. The reproducibility R concerning R_w, R_A and R_m for the heavy wall in comparison with the reference values.

	R(dB)	reference value (ref.3.28)
R_w	3,57	3 dB
R_A	4,78	3 dB
R_m	3,53	3 dB

Of course the reproducibility will depend on the repeatability variance s_r^2. Apart from this the different edge conditions will affect the reproducibility.
For instance, in laboratory A the curve of the laboratory average $\overline{y_i}$ is lying below the curve of the average m in almost the whole frequency range. To illustrate this table 5.15 presents the differences between the laboratory average $\overline{y_i}$ and the average m for each laboratory.
It also has to be mentioned that the test objects were not exactly identical in the different laboratories, because of variations in the quality of the masonry. This will also have had an effect on the reproducibility.

Table 5.15. The difference in dB between the laboratory average $\overline{y_i}$ and m for each laboratory as a function of frequency.

freq.(Hz)	$\overline{y_A}$-m	$\overline{y_B}$-m	$\overline{y_C}$-m	$\overline{y_D}$-m	$\overline{y_E}$-m	$\overline{y_F}$-m	$\overline{y_G}$-m
100	-1.56	0.98**	2.23	2.47	1.68	0.82	-5.58
125	-2.77	5.18	0.50	2.58	1.15	-6.33	-0.30
160	-1.23	3.92**	1.15	0.86	2.30	-2.10	-0.98
200	0.10	0.03	-1.72	2.32	2.21	3.74	0.77
250	-0.72	1.15**	1.03	0.23	1.83	-1.81	-0.54
315	0.30	-0.95	-0.63	0.83	2.22	-0.64	-1.10
400	-2.12	-0.80	-0.06	1.13	2.26	-1.29	0.89
500	-2.33	-1.09	1.32	0.95	1.15	-0.54	0.54
630	-2.15	-0.54	0.19	0.59	1.46	-0.08	0.51
800	-1.44	-0.87	0.60	0.32	0.30	0.70	1.55
1000	-1.61	-0.83	1.44	0.89	-0.82	0.02	0.94
1250	-2.65	-0.18	1.57	0.96	-0.31	-0.40	1.01
1600	-1.93	-0.58	0.97	0.54	0.49	-1.20	1.72
2000	-2.16	0.34	1.59	0.38	0.66	-2.26	1.47
2500	-2.53	0.54	0.98	1.30	0.40	-1.68	1.03
3150	-2.79	0.95**	0.96	0.86	0.64	-0.95	1.27

** = outlier * = straggler

5.3.3. The middleweight wall

5.3.3.1. The average sound reduction index m:

In this part of the investigation two precision experiments have been carried out on the same test object concerning the conventional test method:

1. from each laboratory 10 test results are used for the precision experiment; each test result is the result of a single sound insulation measurement in one measuring direction;
2. from each laboratory 5 test results are used for the precision experiment; each test result is the average of two sound insulation measurements on two opposite measuring directions.

Fig.5.13 presents the variation of the laboratory averages $\overline{y_i}$. For the single test results the laboratory averages $\overline{y_i}$ have already been compared with m for each laboratory separately in view to the total loss factor (see fig.5.5). The average sound reduction index m and the laboratory averages $\overline{y_i}$ regarding the single-number quantities R_w, R_A and R_m are presented in table 5.16a for the single test results and in table 5.16b for the averaged test results. Considering the standard deviations of the-

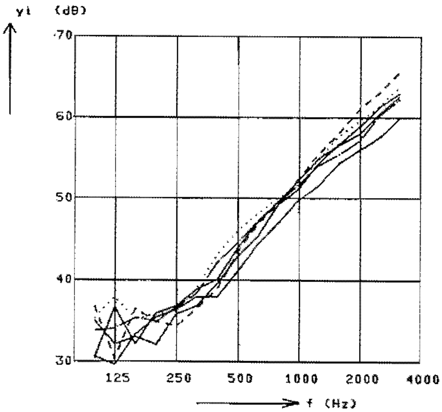


Fig.5.13 THE AVERAGE SOUND REDUCTION INDEX
OF THE MIDDLEWEIGHT WALL
FOR EACH LABORATORY

yA
yC
yD
yE
yF
yG

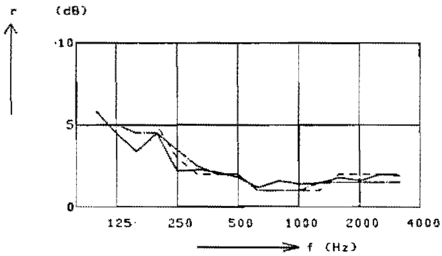


Fig.5.14A THE REPEATABILITY OF THE CONVENTIONAL METHOD
DETERMINED FROM 10 SINGLE TESTS ON THE
MIDDLEWEIGHT WALL, COMPARED TO THE REFERENCE CURVES

r
REFERENCE CURVE OF ISO 140/II (ref.2.10)
REFERENCE CURVE OF ISO/TC 43/SC 2 N267 (ref.3.27)

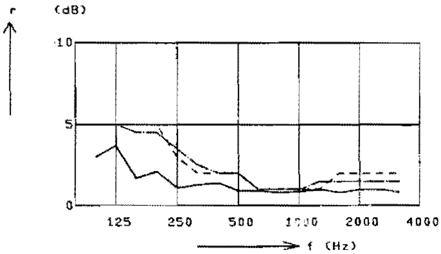


Fig.5.14B THE REPEATABILITY OF THE CONVENTIONAL METHOD
DETERMINED FROM 5 AVERAGED TESTS ON THE
MIDDLEWEIGHT WALL, COMPARED TO THE REFERENCE CURVES

r
REFERENCE CURVE OF ISO 140/II (ref.2.10)
REFERENCE CURVE OF ISO/TC 43/SC 2 N267 (ref.3.27)

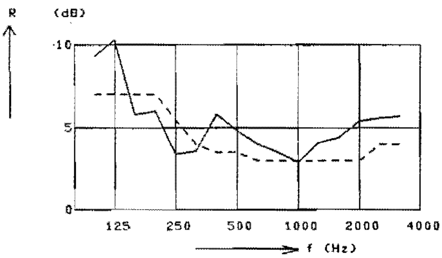


Fig.5.15A THE REPRODUCIBILITY OF THE CONVENTIONAL METHOD
DETERMINED FROM 10 SINGLE TESTS ON THE
MIDDLEWEIGHT WALL, COMPARED TO THE REFERENCE CURVE

R
REFERENCE CURVE OF ISO/TC 43/SC 2 N267 (ref.3.27)

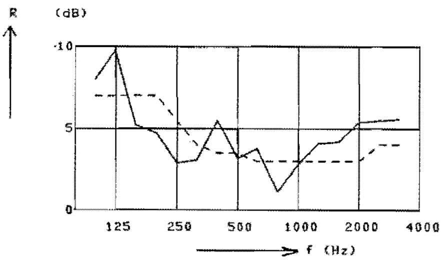


Fig.5.15B THE REPRODUCIBILITY OF THE CONVENTIONAL METHOD
DETERMINED FROM 5 AVERAGED TESTS ON THE
MIDDLEWEIGHT WALL, COMPARED TO THE REFERENCE CURVE

R
REFERENCE CURVE OF ISO/TC 43/SC 2 N267 (ref.3.27)

se quantities one can observe a systematically lower standard deviation for the averaged test results as could be expected.

Table 5.16. The laboratory averages $\overline{y_i}$, the standard deviations S_i and the average sound reduction index m concerning the middle-weight wall.

a. single test results:						
	R_w(dB)		R_A(dB(A))		R_m(dB)	
lab.	$\overline{y_i}$	S_i	$\overline{y_i}$	S_i	$\overline{y_i}$	S_i
A	46.91	0.44	40.72	0.48	43.94	0.40
C	47.56	0.66	41.50	1.14	46.17	0.57
D	48.96	0.51	42.93	0.54	45.95	0.68
E	49.55	0.30	43.87	0.37	47.21	0.29
F	47.20	0.18	41.09	0.47	45.47	0.36
G	48.48	0.43	42.17	0.88	46.03	0.25
mm	48.06		41.98		45.75	
b. averaged test results:						
lab.	$\overline{y_i}$	S_i	$\overline{y_i}$	S_i	$\overline{y_i}$	S_i
A	47.00	0.39	40.86	0.41	44.00	0.39
C	47.66	0.31	41.68	0.46	56.50	0.26
D	49.04	0.28	43.04	0.39	46.12	0.28
E	49.56	0.30	43.99	0.28	47.30	0.17
F	47.26	0.15	41.28	0.35	45.50	0.19
G	48.55	0.38	42.39	0.59	46.05	0.25
m	48.06		42.07		45.80	

<u>5.3.3.2. The repeatability r</u>:

In fig.5.14a the calculated repeatability r is given for the single test results whereas fig.5.14b presents the same quantity for the averaged test results, in both figures as a function of frequency. Both graphs also show the reference curves. The repeatability r with respect to the single-number quantities for the single test results as well as for the averaged test results can be found in table 5.17.

Table 5.17. The repeatability r concerning R_w, R_A and R_m for the middleweight wall when using 10 single test results and when using 5 averaged test results.

	r single test result (dB)	r averaged test results (dB)	reference value (dB) (ref.3.28)
R_w	1,27	0,89	1
R_A	2,02	1,20	1
R_m	1,30	0,80	1

As to the single test results the reference curve of ISO 140/II is exceeded at 100 and 315 Hz and from 630 to 1600 Hz. The maximum difference is 0.82 dB at 1600 Hz. This is confirmed by the standard deviations of the single test results which are compared with the values of s_r for each laboratory in table 5.18a. The frequencies at which the standard deviation is bigger than s_r are distributed randomly over the participating laboratories, although in laboratory G the values of s_r are exceeded in more frequency bands than in any other laboratory.

By calculating the repeatability on the basis of the averaged test results the requirements of both ISO 140/II and ISO/TC-43/SC-2-N-267 are met in every frequency band. The standard deviations of the averaged test results when compared with the values of s_r illustrate this clearly (see table 5.18b).

Apparently a big standard deviation in one frequency band in one laboratory is compensated for sufficiently by small standard deviations in other laboratories. This time the largest number of frequency bands in which the values of s_r are exceeded is found in laboratory A.

A condensed way to show the increase in precision by considering the average of two single measurements in opposite measuring directions as one test result is shown in table 5.17.

5.3.3.3. The reproducibility R:

For the middleweight wall two calculations of the reproducibility have been made. The figures 5.15a and 5.15b present the results concerning the single test results and the averaged test results respectively. For the single test results as well as for the averaged test results the reference value at 125 Hz is exceeded to a large extend: 3.27 dB and 2.79 dB respec-

Table 5.18a. Standard deviations s_i for the 10 single test results and the values of s_r calculated from them concerning the middleweight wall (all quantities in dB).

freq.(Hz)	s_A	s_C	s_D	s_E'	s_F	s_G	s_r
100	1.79	2.32	1.97	1.46	2.32	2.18	2.05
125	1.50	3.70**	1.55	0.62	2.06	1.62	1.57
160	1.18	1.08	1.54	0.80	1.15	1.30	1.21
200	1.76	1.31	0.78	0.72	1.79	2.32	1.58
250	0.65	0.49	0.99	0.61	1.02	0.72	0.77
315	0.70	0.66	0.97	0.50	1.17	0.50	0.80
400	0.98	0.58	0.66	0.31	0.73	0.95	0.75
500	1.02*	0.39	0.56	0.43	0.32	0.71	0.62
630	0.36	0.31	0.29	0.29	0.42	0.75*	0.44
800	0.70	0.33	0.61	0.76	0.59	0.23	0.57
1000	0.56	0.22	0.65	0.23	0.53	0.59	0.50
1250	0.47	0.30	0.83	0.28	0.47	0.65	0.54
1600	0.63	0.47	0.63	0.35	0.50	1.02	0.65
2000	0.63	0.50	0.57	0.15	0.57	0.78	0.57
2500	0.89	0.61	0.56	0.21	0.40	1.07	0.70
3150	0.76	0.49	0.55	0.44	0.55	0.95	0.66

' = 8 tests   ** = outlier   * = straggler.

Table 5.18b. The standard deviations s_i for the 5 averaged test results on the middleweight wall and calculated from them s_r (all quantities in dB).

freq.(Hz)	s_A	s_C	s_D	s_E'	s_F	s_G''	s_r
100	0.90	1.43	1.09	0.46	1.07	0.84	1.05
125	0.71	1.79	1.01	0.17	1.79	1.29	1.32
160	0.62	0.51	0.60	0.66	0.40	0.88	0.62
200	0.96	0.91	0.49	0.62	0.61	2.25**	0.76
250	0.41	0.36	0.52	0.17	0.40	0.24	0.39
315	0.51	0.38	0.44	0.35	0.57	0.34	0.45
400	0.77	0.29	0.54	0.25	0.48	0.00	0.48
500	0.85**	0.26	0.47	0.31	0.24	0.08	0.30
630	0.30	0.28	0.19	0.36	0.32	0.49	0.33
800	0.70**	0.20	0.40	0.25	0.30	0.15	0.28
1000	0.43	0.11	0.47	0.10	0.36	0.13	0.33
1250	0.44	0.18	0.48	0.25	0.31	0.29	0.35
1600	0.30	0.14	0.41	0.10	0.24	0.19	0.26
2000	0.54	0.26	0.34	0.12	0.30	0.33	0.37
2500	0.63*	0.36	0.35	0.06	0.18	0.14	0.36
3150	0.42	0.29	0.28	0.15	0.22	0.05	0.28

= 3 tests   " = 4 tests   ** = outlier   * = straggler

tively. The measure in which the reference values are exceeded at other frequencies is lower: 1 or 2 dB.
Although the reproducibility is better for the averaged test results, i.e. the values of the reproducibility R are smaller for the averaged test results, the improvement is not as big as was the case for the repeatability. This seems logical because of the still remaining differences in the properties of the participating laboratories such as edge losses, quality of the masonry, etc. As the 'within-laboratory variance' is only a part of the reproducibility variance a decrease of the within-laboratory variance will only have a limited effect on the reproducibility.
Again this is summarized by means of the reproducibility of the single-number quantities, shown in table 5.19. Only a small improvement occurs when the averaged test results are used in the calculation of the reproducibility instead of the single test results. As a result of this the reproducibility of R_w just fulfils the requirements.

Table 5.19. The reproducibility R as to R_w, R_A en R_m concerning the middleweight wall for the single test results as well as for the averaged test results.

	R single test results (dB)	R averaged test results (dB)	reference value (ref.3.28) (dB)
R_w	3,09	2,93	3
R_A	3,78	3,30	3
R_m	3,23	3,16	3

5.3.4. Conclusions of 5.3.

The investigation concerning the precision of the standardized test method has been carried out using three test objects of which the sound reduction index R_m differs quite explicitely:

- the lightweight wall : R_m = 25 dB
- the heavy wall : R_m = 54 dB
- the middleweight wall: R_m = 46 dB.

The repeatability r and the reproducibility R have been determined four times according to ISO 5725:

- for the lightweight wall on 8 single test results;
- for the heavy wall on 8 single test results;
- for the middleweight wall on 10 single test results;
- for the middleweight wall on 5 averaged test results.

The precision requirements concerning the repeatability are stated in ISO 140/II-1978 as a function of frequency. This standard is under revision by ISO. The working drafts also present reference values for the reproducibility R, apart from the requirements for the repeatability. In the seventh working draft reference values for single-numer quantities are added for the repeatability als well as for the reproducibilitu.
The reference values are not the same in all documents mentioned above (see table 5.20). Therefore statements about the repeatability meeting the requirements should be made in relation to the document used.

As to the lightweight wall the calculated repeatability fulfils the requirements at most frequencies. The frequency region in which the reference values are exceeded depends on the reference curve chosen:

- ISO 140/II-1978 : from 630 to 1600 Hz;
- ISO/TC-43/SC-2-N-267: above 630 Hz;
- ISO/TC-43/SC-2-N-379: above 1250 Hz.

The repeatability r concerning the single-number quantities exceeds the reference values of 1 dB for both R_w, R_A and R_m. The reference values in the midfrequency range from the same ISO-document are 1.5 dB or higher. One may wonder whether the calculated repeatability r should meet the requirements for every third-octave band so as to obtain a repeatability for single-number quantities smaller than 1 dB.

Table 5.20. The reference values for the repeatability r.

freq. (Hz)	ISO-140/II 1978 (ref.2.10)	ISO-TC43/SC2 N267, June'80 (ref.3.27)	ISO-TC43/SC2-N379 June'85 (ref.3.28)
100	5	5.0	5.0
125	5	5.0	5.0
160	5	4.5	4.5
200	5	4.5	4.5
250	3	3.5	3.5
315	2	2.5	2.5
400	2	2.0	2.0
500	2	2.0	2.0
630	1	1.0	1.5
800	1	1.0	1.5
1000	1	1.0	1.5
1250	1	1.5	1.5
1600	2	1.5	1.5
2000	2	1.5	1.5
2500	2	1.5	1.5
3150	2	1.5	1.5

As to the heavy wall the calculated repeatability exceeds the reference values for most frequencies. The frequency range in which the reference curves are exceeded does not depend much on the reference curve chosen. The repeatability for the single-number quantities exceed the reference value for both R_w, R_A and R_m.

As to the single test results of the middleweight wall in a number of frequency bands the repeatability r is larger than the reference values. When calculating the repeatability on the basis of averaged test results, as is common practice in laboratories B and F, the requirements for all three documents (refs.2.10, 3.27 and 3.28) have been met. The same is true for the repeatabilities of two of the single-number quantities which then are both smaller than 1 dB.

The definitions of the single-number quantities lead to a systematic difference in the precision with which the quantities can be determined. The standard deviations of R_A are bigger for all objects used leading to higher values of the repeatability whereas the standard deviations of R_w tend to be the smallest. If the low and midfrequency region is playing an important part in the determination of R_A and the mid- and high frequency region does the same for R_w then it might be considered to state different reference values for R_A and R_w, for instance 1.5 and 1 dB respectively.

For all precision experiments the calculated reproducibility exceeds the reference values but not for all test objects in the same measure and not in the same number of third-octave bands.
This is illustrated in table 5.21.

As to the single-number quantities the results are a bit more positive.
For the lightweight wall the reference values are not exceeded.
For the heavy wall and the middleweight wall (as to the single test results) the calculated reproducibility does not meet the requirements neither for R_w nor for R_A and R_m.
For the middleweight wall as to the averaged test results the reference values are exceeded to a less extent for R_A and R_m; they are met for R_w. Considering the calculated reproducibility of the single-number quantities one can again observe the highest values of the reproducibility R for R_A. Different reference values for different single-number quantities might also be considered.

Table 5.21. The number of frequency bands in which the reference curves for the reproducibility have been exceeded (the total number of frequency bands is 10).

the lightweight wall	6
the heavy wall	12
the middleweight wall:	
. single test results	11
. averaged test results	10

The conclusions of §5.3 can be summarized as follows:

* As long as single test results are used to determine the repeatability and the reproducibility, the reference values are not met in each frequency band.
* It is possible that the repeatability or the reproducibility concerning the single-number quantities fulfil the requirements, although the frequency-dependent reference values are exceeded in some frequency bands.

* The values of the repeatability and the reproducibility are lowered when using averaged test results instead of single test results; in this way the requirements can be met more easily.

Some recommendations may be given:

* To improve the precision of the standardized 'pressure' method of ISO 140/III, the measuring procedure should be prescribed more strictly. This may preferably lead to the use of averaged test results in test reports.
* Different single-number quantities should have different reference values for the repeatability and the reproducibility.
* Also in view of the precision of the standardized test method the standardization of both the position of the test object in the test opening and the shape and mass of the test opening should be recommended.

5.4. Comparison of the results of conventional measurements with the results of intensity measurements

In the investigations concerning the heavy wall and the middleweight wall (see §4.5 and §4.6) the sound reduction index of both test objects have been determined using the conventional 'pressure' method as well as the intensity method.

In the tests on the heavy wall two aspects were emphasized:

- a comparison of the results of both test methods for each measuring direction;
- the influence of the measuring direction on the results of intensity measurements.

These aspects have been studied in each participating laboratory at a low reactivity of the sound field in the receiving room. As shown in table 4.4 only one intensity measurement has been carried out for each measuring direction.

In the tests on the middleweight wall different aspects were accentuated (table 4.7):

- the Waterhouse correction;
- the influence of the reactivity.

For these purposes the sound reduction index of the middleweight wall has been determined in only one measuring direction i.e. with the wall connected to the source room. For each test method 5 single tests have been performed in every participating laboratory.

5.4.1. The tests performed on the heavy wall

The difference between the results of pressure and intensity measurements may depend on the measuring direction.
We will distinguish the two directions by the following descriptions:
- the object is connected to the source room;
- the object is connected to the receiving room.

5.4.1.1. Tests performed with the wall connected to the source room:

The results of both test methods concerning this measuring direction are shown in:
- figure 5.16A for laboratory A;
- figure 5.16B for laboratory B;
- figure 5.16F for laboratory C;
- figure 5.16I for laboratory D;
- figure 5.16M for laboratory G.

All figures have a few things in common:
- for low frequencies, approximately below 250 Hz, the intensity measurements yield the lowest values of the sound reduction index;
- for frequencies between 250 and 1000 Hz the results of the two test methods agree rather well;
- for frequencies above 1000 Hz the intensity technique yields the highest values.

An exception can be observed in the results of laboratory B where the curve of the intensity measurement is lying below the other curve for nearly every frequency.
For the measuring direction concerned one would expect the results of the two test methods to agree well as in the receiving room the same amount of sound power is measured with both methods i.e. the sound power radiated from the test object.

Besides we found that the reactivity index only exceeds the value of 10 dB for a few frequencies in a few laboratories:

- in laboratory B at 3150 Hz;
- in laboratory C at 125 Hz.

An extra measurement has been carried out:

- in laboratory C another heavy wall had been built on the concrete frame (the C1-situation in §5.2.4).

The results of the measurements as to this wall position are shown in fig. 5.16E. The same common characteristics as those mentioned above, when the wall is connected to the source room, can be observed in this figure.

<u>5.4.1.2. Tests performed with the wall connected to the receiving room</u>:

For this measuring direction the sound reduction index of the heavy wall has not been determined in each laboratory.

The results of the measurements for the laboratories concerned can be found in:

- figure 5.16C for laboratory B;
- figure 5.16G for laboratory C;
- figure 5.16J for laboratory D;
- figure 5.16L for laboratory F.

Also from the results of these measurements some common characteristics can be concluded:

- for low frequencies the intensity measurements yield the lowest values of the sound reduction index; this effect occurs approximately at frequencies below 250 Hz although this frequency is varying from one laboratory to another; in laboratories B and C large variations in the sound reduction index occur at low frequencies;
- for frequencies above approximately 250 Hz the curves resulting from intensity measurements are lying above the curves from the pressure measurements; differences of up to 5 dB can occur;
- the reactivity index exceeds the value of 10 dB only for a few frequencies:
  . in laboratory B at 125 and 160 Hz;
  . in laboratory F at 160 Hz.

Although the number of measurements in this paragraph is very limited we can conclude that the intensity measurements yield higher values of the sound reduction index for most frequencies. This may be explained from the difference in nature between the two test methods. When using the intensity technique the sound power radiated from the test object is determined whereas by using the pressure measurements one determines the total sound power radiated into the receiving room from all its surfaces. This means that the sound power directly transmitted through the test object is measured by the intensity technique while this power plus the power transmitted along flanking paths is determined by the pressure measurements. For the heavy wall, of which the mass per unit area is about equal to that of the adjoining structures, the flanking transmission cannot be neglected. This results in higher values of the measured sound reduction index when the intensity technique is used.

5.4.1.3. The effect of the measuring direction on the results of the intensity measurements:

Intensity measurements in two measuring directions have only been carried out in laboratories B, C and D.
The results of these measurements are given in:
- figure 5.16D for laboratory B;
- figure 5.16H for laboratory C;
- figure 5.16K for laboratory D.

These figures show that the lowest values of the measured sound reduction index are obtained when the object is connected to the source room. This occurs for nearly the whole frequency range but is mostly pronounced for frequencies above 500 Hz. For frequencies below 500 Hz the effect is not significant. In laboratory B the results of the measurements in the two directions agree from 250 to 500 Hz while for frequencies below 250 Hz large variations in both curves occur with on the average higher values for the direction in which the test object is connected to the receiving room.

A similar effect can be observed in the results of the measurements in laboratory C. For frequencies above 250 Hz the direction at which the wall is connected to the receiving room yields the highest values whereas for frequencies below 250 Hz the effect is again not significant because of large variations in both curves.
In §5.4.1.1 and §5.4.1.2 we already mentioned the frequencies at which the reactivity index concerning these measurements exceeds the value of 10 dB.

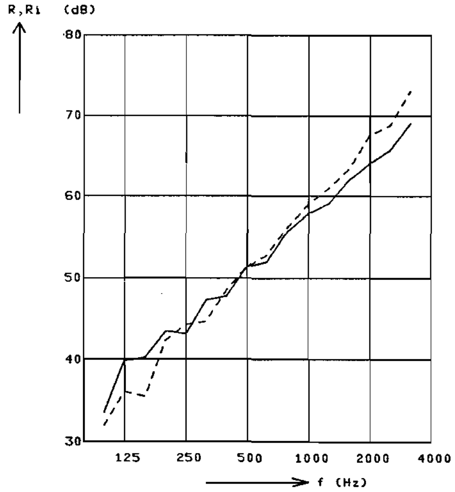


Fig.5.16A THE SOUND REDUCTION INDEX OF THE HEAVY WALL MEASURED IN LABORATORY A USING THE CONVENTIONAL METHOD AND THE INTENSITY METHOD

——————— R, WALL CONNECTED TO THE SOURCE ROOM

- - - - - - - - Ri, WALL CONNECTED TO THE SOURCE ROOM

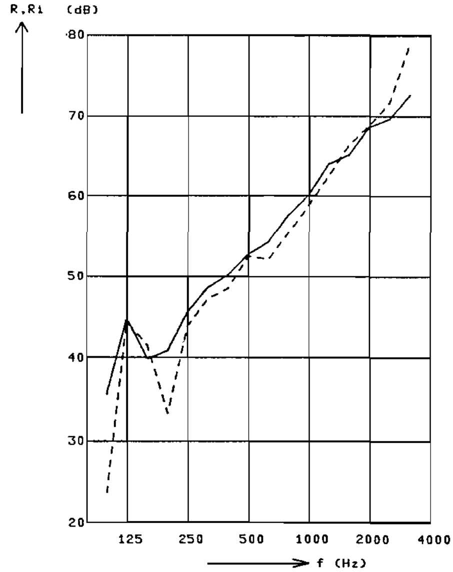


Fig.5.16B THE SOUND REDUCTION INDEX OF THE HEAVY WALL MEASURED IN LABORATORY B USING THE CONVENTIONAL METHOD AND THE INTENSITY METHOD

——————— R, WALL CONNECTED TO THE SOURCE ROOM

- - - - - - - - Ri, WALL CONNECTED TO THE SOURCE ROOM

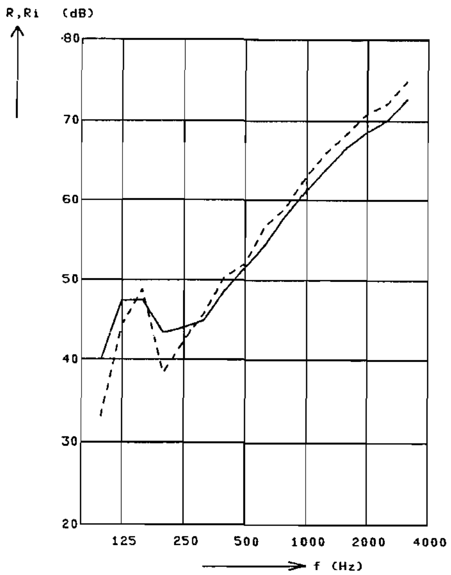


Fig.5.16C THE SOUND REDUCTION INDEX OF THE HEAVY WALL MEASURED IN LABORATORY B USING THE CONVENTIONAL METHOD AND THE INTENSITY METHOD

——————— R, WALL CONNECTED TO THE RECEIVING ROOM

- - - - - - - - Ri, WALL CONNECTED TO THE RECEIVING ROOM

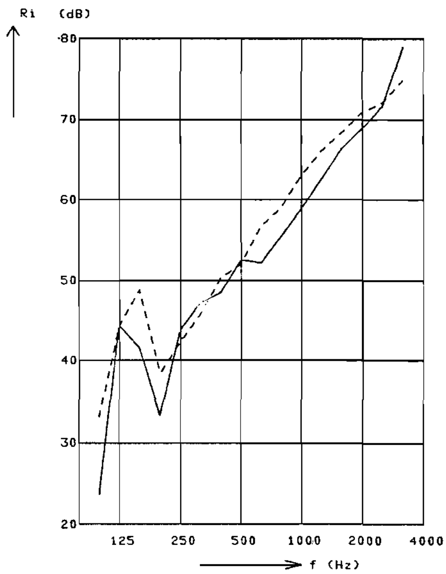


Fig.5.16D THE SOUND REDUCTION INDEX OF THE HEAVY WALL MEASURED IN LABORATORY B USING THE INTENSITY METHOD

——————— Ri, WALL CONNECTED TO THE SOURCE ROOM

- - - - - - - - Ri, WALL CONNECTED TO THE RECEIVING ROOM

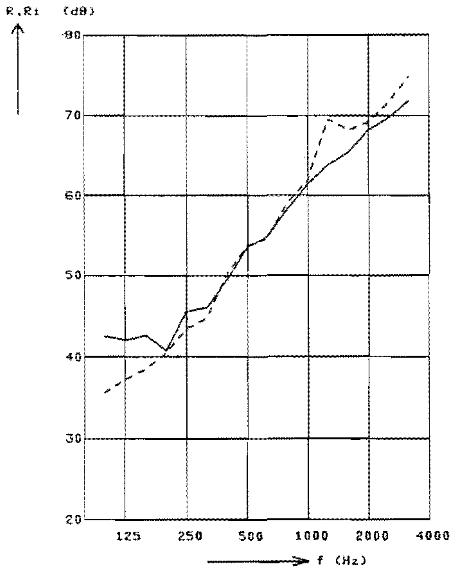


Fig.5.16E THE SOUND REDUCTION INDEX OF THE HEAVY WALL MEASURED IN LABORATORY C USING THE CONVENTIONAL METHOD AND THE INTENSITY METHOD

———— R, WALL NOT CONNECTED TO SOURCE OR RECEIVING ROOM

-------- Ri, WALL NOT CONNECTED TO SOURCE OR RECEIVING ROOM

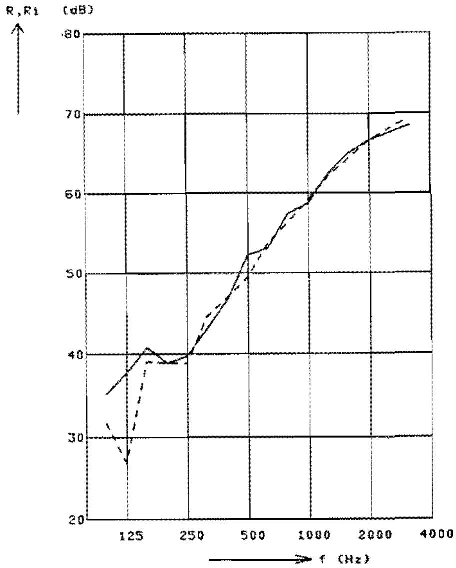


Fig.5.16F THE SOUND REDUCTION INDEX OF THE HEAVY WALL MEASURED IN LABORATORY C USING THE CONVENTIONAL METHOD AND THE INTENSITY METHOD

———— R, WALL CONNECTED TO THE SOURCE ROOM

-------- Ri, WALL CONNECTED TO THE SOURCE ROOM

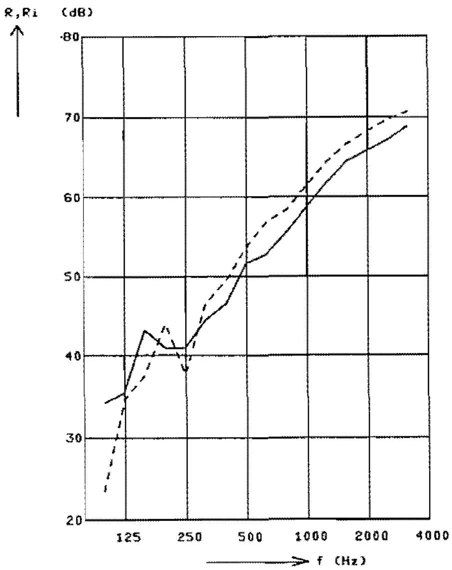


Fig.5.16G THE SOUND REDUCTION INDEX OF THE HEAVY WALL MEASURED IN LABORATORY C USING THE CONVENTIONAL METHOD AND THE INTENSITY METHOD

———— R, WALL CONNECTED TO THE RECEIVING ROOM

-------- Ri, WALL CONNECTED TO THE RECEIVING ROOM

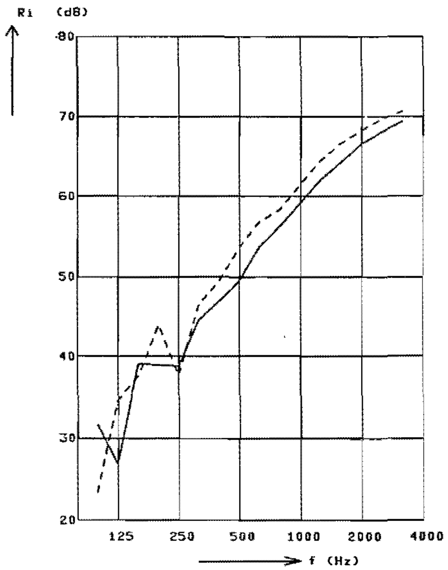


Fig.5.16H THE SOUND REDUCTION INDEX OF THE HEAVY WALL MEASURED IN LABORATORY C USING THE INTENSITY METHOD

———— Ri, WALL CONNECTED TO THE SOURCE ROOM

-------- Ri, WALL CONNECTED TO THE RECEIVING ROOM

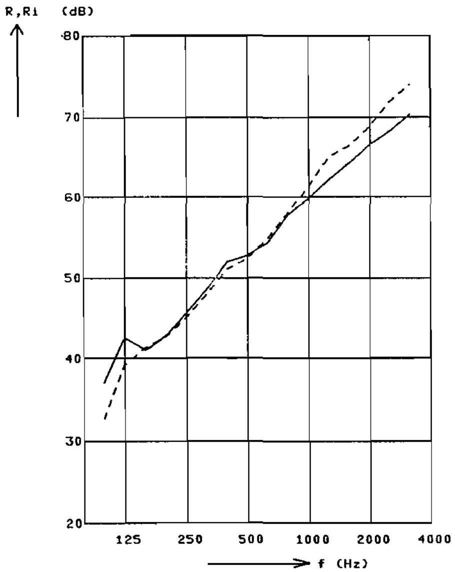


Fig.5.16I THE SOUND REDUCTION INDEX OF THE HEAVY WALL MEASURED IN LABORATORY D USING THE CONVENTIONAL METHOD AND THE INTENSITY METHOD

———— R, WALL CONNECTED TO THE SOURCE ROOM

-------- Ri, WALL CONNECTED TO THE SOURCE ROOM

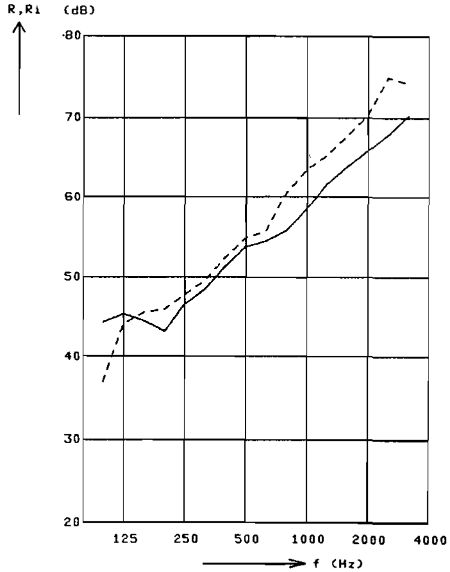


Fig.5.16J THE SOUND REDUCTION INDEX OF THE HEAVY WALL MEASURED IN LABORATORY D USING THE CONVENTIONAL METHOD AND THE INTENSITY METHOD

———— R, WALL CONNECTED TO THE RECEIVING ROOM

-------- Ri, WALL CONNECTED TO THE RECEIVING ROOM

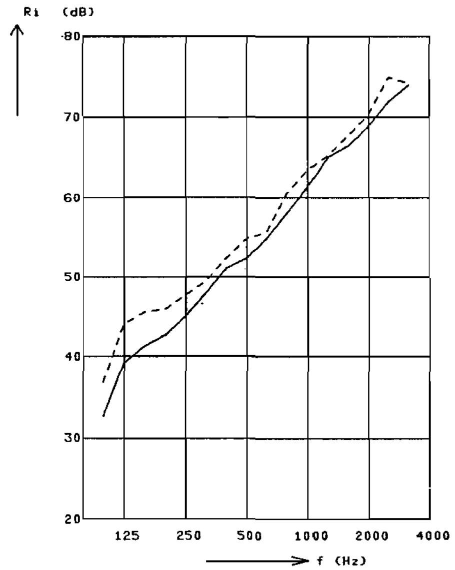


Fig.5.16K THE SOUND REDUCTION INDEX OF THE HEAVY WALL MEASURED IN LABORATORY D USING THE INTENSITY METHOD

———— Ri, WALL CONNECTED TO THE SOURCE ROOM

-------- Ri, WALL CONNECTED TO THE RECEIVING ROOM

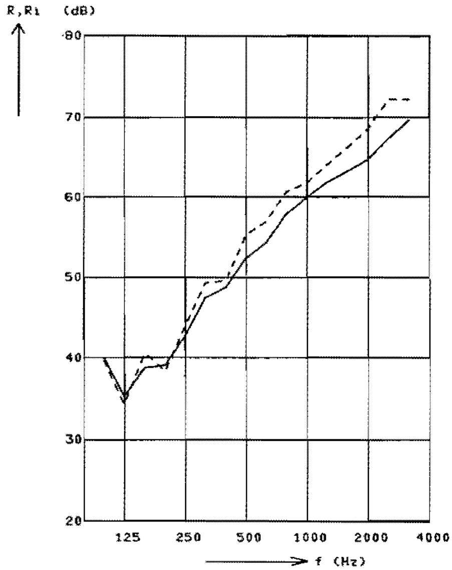


Fig.5.16L THE SOUND REDUCTION INDEX OF THE HEAVY WALL MEASURED IN LABORATORY F USING THE CONVENTIONAL METHOD AND THE INTENSITY METHOD

———— R, WALL CONNECTED TO THE RECEIVING ROOM

- - - - - Ri, WALL CONNECTED TO THE RECEIVING ROOM

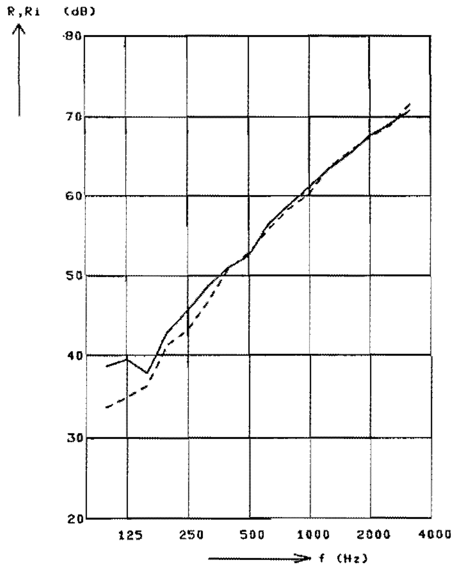


Fig.5.16M THE SOUND REDUCTION INDEX OF THE HEAVY WALL MEASURED IN LABORATORY G USING THE CONVENTIONAL METHOD AND THE INTENSITY METHOD

———— R, WALL CONNECTED TO THE SOURCE ROOM

- - - - - Ri, WALL CONNECTED TO THE SOURCE ROOM

The following explanation of the influence of the measuring direction can be given.

When the test object is connected to the source room it is receiving sound energy directly from the source room and vibrational energy from the flanking structures of the source room.

When the test object is connected to the receiving room it is only receiving sound energy directly from the source room. Then vibrational energy is flowing from the vibrating object to the adjoining structures in the receiving room. Thus the level of vibrations in the test object is lower than when the wall is connected to the source room.

For both measuring directions only the sound power radiated by the test object into the receiving room is determined when using the intensity technique. This results in higher values of the measured sound reduction index when the object is connected to the receiving room.

5.4.2. The tests performed on the middleweight wall

5.4.2.1. Comparison of the results of pressure and intensity measurements:

As summarized in table 4.7 for the measuring direction at which the wall was connected to the source room the sound reduction index has been determined five times with each test method. No extra absorption material had been added to the receiving rooms.

The averaged sound reduction indices of both methods are shown in:

- figure 5.17A for laboratory A;
- figure 5.17B for laboratory C;
- figure 5.17F for laboratory D;
- figure 5.17G for laboratory E;
- figure 5.17H for laboratory F;
- figure 5.17L for laboratory G,

with the reactivity indices to match:

- figure 5.17D for laboratory A;
- figure 5.17E for laboratory C;
- figure 5.17I for laboratories D and E;
- figure 5.17J for laboratory F;
- figure 5.17N for laboratory G.

From these figures a common property can be observed:

- for frequencies below approximately 500 Hz the intensity technique yields lower values of the measured sound reduction index; for laboratories C and D this frequency region is extended to 1000 Hz.

There is no clear connection between this property and the value of the reactivity index. For laboratories A, C and F the common property coincides with a reactivity index larger than 10 dB while for laboratories D, E and G the reactivity index hardly exceeds the value of 10 dB. Besides, at frequencies above 1000 Hz for this test object the intensity technique yields only higher values of the measured sound reduction index in laboratories A and G.

As in some laboratories the reactivity of the sound field in the receiving room was rather high, it was decided to carry out extra measurements after increasing the absorption in the receiving room. This was done in laboratories C, F and G. Only one extra test was performed in each of these laboratories using the intensity technique.

The results of these extra measurements are given in:

- figure 5.17B for laboratory C;
- figure 5.17H for laboratory F;
- figure 5.17L for laboratory G,

and the reactivity indices to match in:

- figure 5.17E for laboratory C;
- figure 5.17J for laboratory F;
- figure 5.17N for laboratory G.

By increasing the absorption in the receiving room the reactivity index in laboratories C and F was reduced to values smaller than 10 dB for the entire frequency range. However, the effect of the reduction of the reactivity index on the measured sound reduction index is not equal for both laboratories. In laboratory C (fig.5.17B) the sound reduction index increased for frequencies below 1000 Hz. As a consequence the differences between the results of both test methods became smaller. Contrary to this, in laboratory F hardly any change in the measured sound reduction index can be noticed. Only at 100 Hz and 125 Hz the measured sound reduction index is increased slightly after increasing the absorption (fig.5.17H).

In laboratory G the reactivity index was already smaller than 10 dB because the walls of the receiving room are made of non-plastered porous concrete blocks. The addition of extra absorption material reduced the reac-

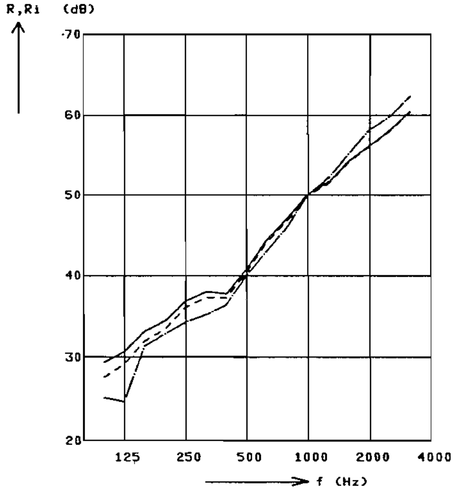


Fig.5.17A THE SOUND REDUCTION INDEX OF THE MIDDLEWEIGHT WALL MEASURED IN LABORATORY A USING THE CONVENTIONAL METHOD AND THE INTENSITY METHOD

———— R
- - - - - - - - R, CORRECTED FOR THE WATERHOUSE-EFFECT
—·—·— Ri

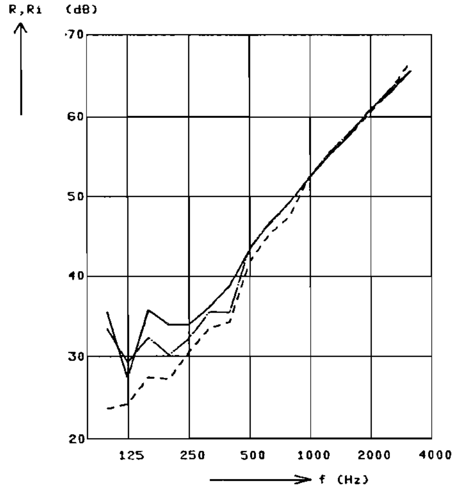


Fig.5.17B THE SOUND REDUCTION INDEX OF THE MIDDLEWEIGHT WALL MEASURED IN LABORATORY C USING THE CONVENTIONAL METHOD AND THE INTENSITY METHOD

———— R
- - - - - - - - Ri
—·—·— Ri, EXTRA ABSORPTION IN THE RECEIVING ROOM

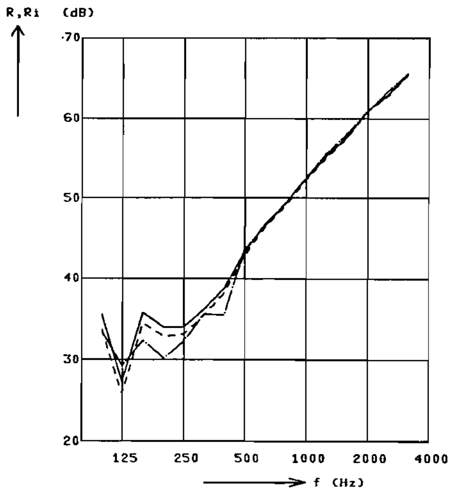


Fig.5.17C THE SOUND REDUCTION INDEX OF THE MIDDLEWEIGHT WALL MEASURED IN LABORATORY C USING THE CONVENTIONAL METHOD AND THE INTENSITY METHOD

———— R
- - - - - - - - R, CORRECTED FOR THE WATERHOUSE-EFFECT
—·—·— Ri, EXTRA ABSORPTION IN THE RECEIVING ROOM

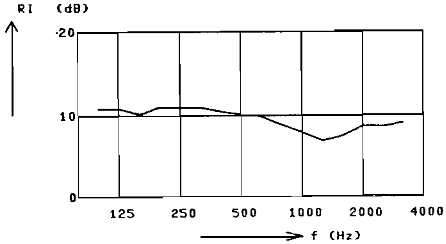


Fig.5.17D THE REACTIVITY INDEX OF THE SOUND FIELD IN THE RECEIVING ROOM CONCERNING THE INTENSITY MEASUREMENTS ON THE MIDDLEWEIGHT WALL IN LAB.A

———— RI

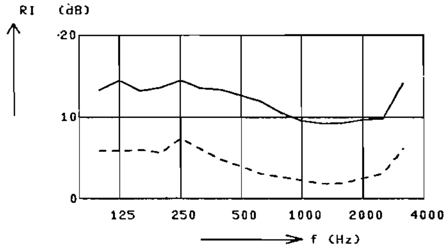


Fig.5.17E THE REACTIVITY INDEX OF THE SOUND FIELD IN THE RECEIVING ROOM CONCERNING THE INTENSITY MEASUREMENTS ON THE MIDDLEWEIGHT WALL IN LAB.C

———— RI
- - - - - - - - RI, EXTRA ABSORPTION IN THE RECEIVING ROOM

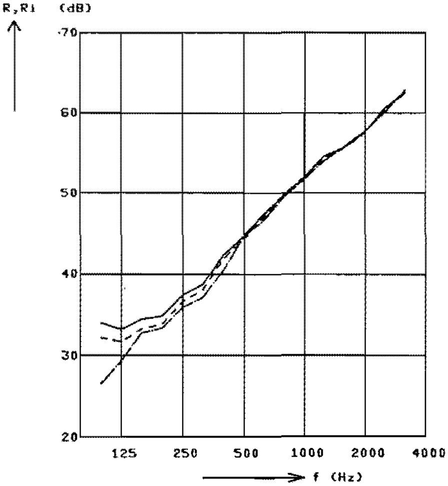


Fig.5.17F THE SOUND REDUCTION INDEX OF THE MIDDLEWEIGHT WALL MEASURED IN LABORATORY D USING THE CONVENTIONAL METHOD AND THE INTENSITY METHOD

———————— R
- - - - - - - - R,CORRECTED FOR THE WATERHOUSE-EFFECT
—·—·—·—· Ri

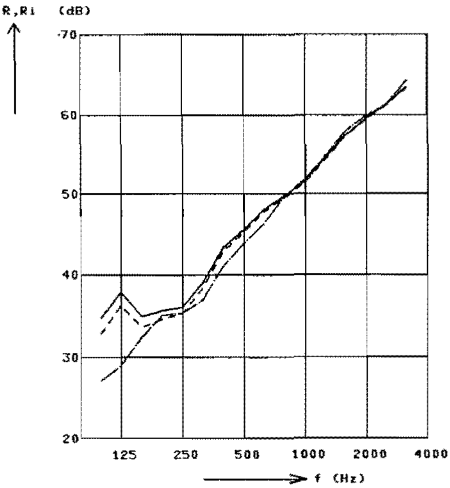


Fig.5.17G THE SOUND REDUCTION INDEX OF THE MIDDLEWEIGHT WALL MEASURED IN LABORATORY E USING THE CONVENTIONAL METHOD AND THE INTENSITY METHOD

———————— R
- - - - - - - - R, CORRECTED FOR THE WATERHOUSE-EFFECT
—·—·—·—· Ri

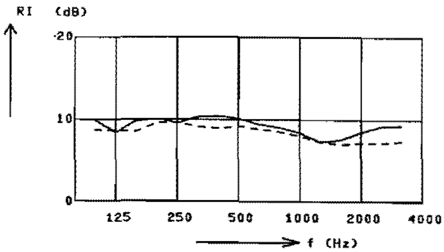


Fig.5.17I THE REACTIVITY INDEX OF THE SOUND FIELD IN THE RECEIVING ROOM CONCERNING THE INTENSITY MEASUREMENTS ON THE MIDDLEWEIGHT WALL IN LAB.D/E

———————— RI, LAB.D
- - - - - - - - RI, LAB.E

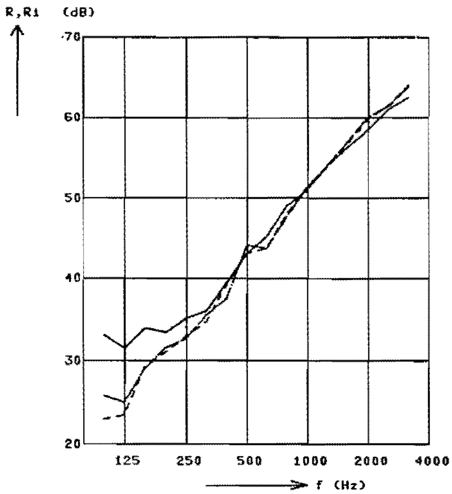


Fig.5.17H THE SOUND REDUCTION INDEX OF THE MIDDLEWEIGHT WALL MEASURED IN LABORATORY F USING THE CONVENTIONAL METHOD AND THE INTENSITY METHOD

——————— R
- - - - - - - - Ri
——————— Ri, EXTRA ABSORPTION IN THE RECEIVING ROOM

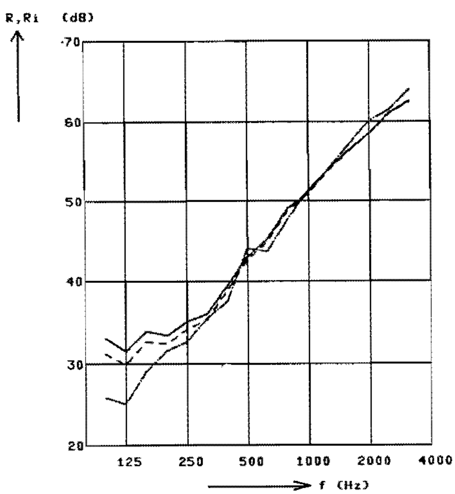


Fig.5.17K THE SOUND REDUCTION INDEX OF THE MIDDLEWEIGHT WALL MEASURED IN LABORATORY F USING THE CONVENTIONAL METHOD AND THE INTENSITY METHOD

——————— R
- - - - - - - - R, CORRECTED FOR THE WATERHOUSE-EFFECT
——————— Ri, EXTRA ABSORPTION IN THE RECEIVING ROOM

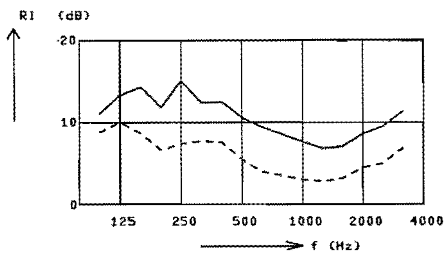


Fig.5.17J THE REACTIVITY INDEX OF THE SOUND FIELD IN THE RECEIVING ROOM CONCERNING THE INTENSITY MEASUREMENTS ON THE MIDDLEWEIGHT WALL IN LAB.F

——————— RI
- - - - - - - - RI, EXTRA ABSORPTION IN THE RECEIVING ROOM

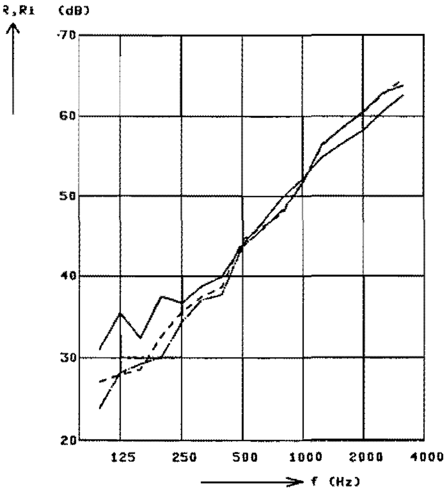


Fig.5.17L THE SOUND REDUCTION INDEX OF THE MIDDLEWEIGHT WALL MEASURED IN LABORATORY G USING THE CONVENTIONAL METHOD AND THE INTENSITY METHOD

——————— R

- - - - - - - - Ri

——————— Ri, EXTRA ABSORPTION IN THE RECEIVING ROOM

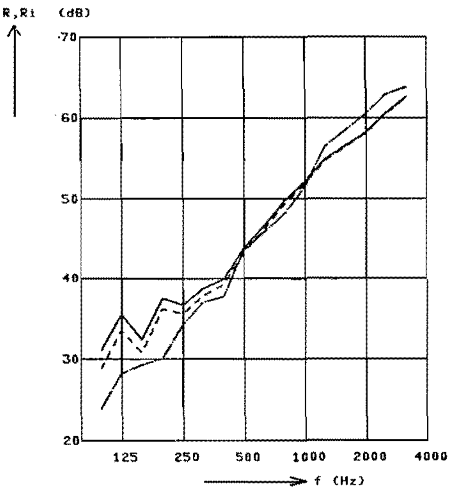


Fig.5.17M THE SOUND REDUCTION INDEX OF THE MIDDLEWEIGHT WALL MEASURED IN LABORATORY G USING THE CONVENTIONAL METHOD AND THE INTENSITY METHOD

——————— R

- - - - - - - - R, CORRECTED FOR THE WATERHOUSE-EFFECT

——————— Ri, EXTRA ABSORPTION IN THE RECEIVING ROOM

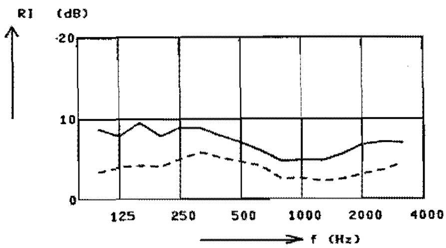


Fig.5.17N THE REACTIVITY INDEX OF THE SOUND FIELD IN THE RECEIVING ROOM CONCERNING THE INTENSITY MEASUREMENTS ON THE MIDDLEWEIGHT WALL IN LAB.G

——————— RI

- - - - - - - - RI, EXTRA ABSORPTION IN THE RECEIVING ROOM

tivity index still further (fig.5.17H). The effect of it on the measured sound reduction index is shown in fig.5.17L. The sound reduction index is reduced between 200 and 400 Hz instead of being increased as in laboratory C. However, the differences are small.

5.4.2.2. The Waterhouse correction:

The Waterhouse correction has been applied to the sound pressure level in the receiving room. Consequently the sound reduction index resulting from pressure measurements is reduced especially for low frequencies.
The corrected sound reduction indices are shown in:
- figure 5.17A for laboratory A;
- figure 5.17C for laboratory C;
- figure 5.17F for laboratory D;
- figure 5.17G for laboratory E;
- figure 5.17K for laboratory F;
- figure 5.17M for laboratory G.

These figures show that application of the Waterhouse correction to the pressure measurements reduces the differences between the results of pressure and intensity measurements.

5.4.3. Conclusions of §5.4

The conclusions of section 5.4, when confined to laboratory measurements, can be summarized as follows:

* The sound reduction index of an object obtained from intensity measurements is in reasonable agreement to the sound reduction index determined by the conventional pressure measurements. When flanking transmission occurs we only get this agreement when the object is connected to the source room.
* The best agreement between the results of both test methods is obtained when the reactivity of the sound field in the receiving room is low i.e. when extra sound absorbing material is added to the receiving room.
* The differences between the results of both test methods tend to be frequency dependent: for low frequencies the intensity method yields lower values of the sound reduction index whereas for high frequencies the intensity method yields higher values.

* The differences between the results of both test methods can be reduced by applying the Waterhouse correction to the results of the conventional measurements i.e. to the sound pressure level in the receiving room.
* The sound reduction index obtained from intensity measurements depends on the measuring direction especially when flanking transmission cannot be neglected. Then lower values are obtained for the direction at which the object is connected to the source room.
* The connection between the value of the reactivity index and the differences between the results of both test methods is not clear yet but values of the reactivity index larger than 10 dB should be avoided.

From these conclusions we give some recommendations:

* In future measuring procedures concerning the use of intensity measurements in laboratory sound insulation measurements, the measuring direction and the character of the sound field in the receiving room should be prescribed too.
* The Waterhouse correction should be applied to laboratory sound insulation measurements; the ISO standards concerning laboratory airborne and impact sound insulation measurements should be modified.

5.5. Comparison of the precision of the conventional method with the precision of the intensity method

Here we shall deal with a comparison of five tests for each test method performed on the middleweight wall in one measuring direction i.e. the direction at which the wall is connected to the source room.

5.5.1. The average sound reduction index m

The laboratory average $\overline{y_i}$ obtained from five pressure measurements in one measuring direction is shown in fig.5.18A for each laboratory. Fig.5.18B shows the laboratory averages $\overline{y_{ii}}$ obtained from five intensity measurements. Both figures give an indication of the reproducibility of the test methods. Apart from the usual rather large variations in the laboratory averages $\overline{y_i}$ at the low frequencies also an unusual large variation at the midfrequencies and the high frequencies can be observed. At

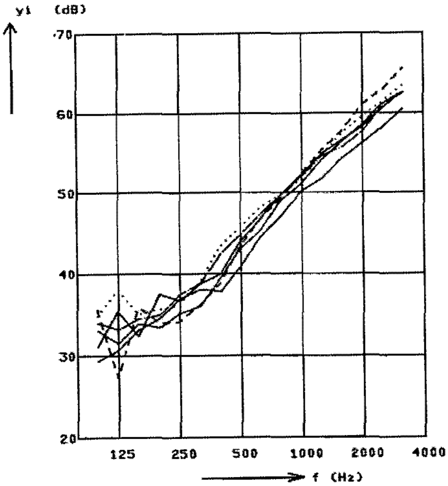


Fig.5.18A THE AVERAGE SOUND REDUCTION INDEX OF THE MIDDLEWEIGHT WALL OBTAINED FROM 5 SINGLE TESTS IN EACH LABORATORY USING THE CONVENTIONAL METHOD

yA
yC
yD
yE
yF
yG

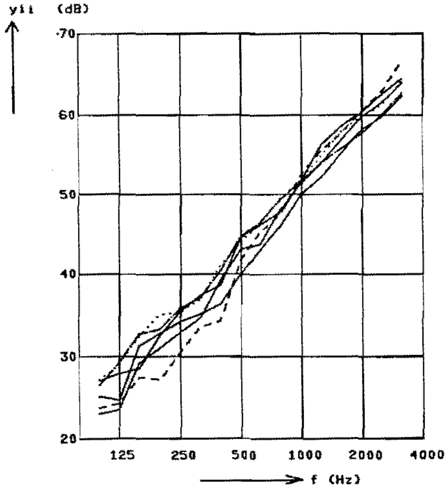


Fig.5.18B THE AVERAGE SOUND REDUCTION INDEX OF THE MIDDLEWEIGHT WALL OBTAINED FROM 5 SINGLE TESTS IN EACH LABORATORY USING THE INTENSITY METHOD

yiA
yiC
yiD
yiE
yiF
yiG

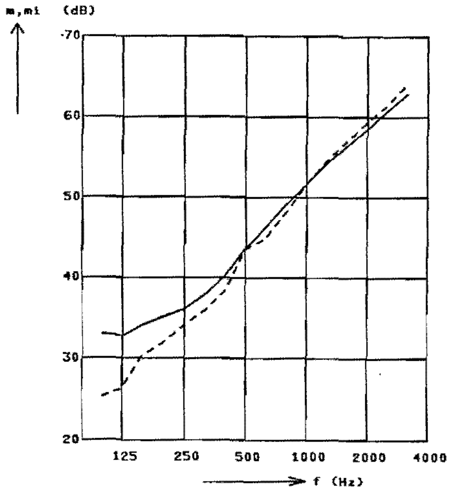


Fig.5.18C THE SOUND REDUCTION INDEX m OF THE MIDDLEWEIGHT WALL OBTAINED FROM 5 SINGLE TESTS IN EACH LAB. USING CONVENTIONAL AND INTENSITY MEASUREMENTS

m
mi

first sight the variations in $\overline{y_i}$ resulting from both test methods do not differ much.
In fig.5.18C the average sound reduction index m resulting from the pressure measurements is compared with the average sound reduction index m_i obtained from intensity measurements. This figure shows the same characteristics as those mentioned in §5.4: for frequencies below 500 Hz the intensity technique yields lower values of the sound reduction index whereas for frequencies above 500 Hz the two curves do not differ much.
In the figures 5.19 the laboratory average $\overline{y_{ii}}$ is compared with m for each laboratory separately concerning the intensity measurements. These figures resemble the fig.5.5 where the same presentation is given for the pressure measurements. The effect of different edge conditions is shown in about the same way as in fig.5.5 except for the results of the intensity measurements in laboratory C (fig.5.19B). For this laboratory the difference between the laboratory average $\overline{y_i}$ and the average m is larger for the intensity measurements than for the pressure measurements. As discussed in §5.4 this may be caused by a high reactivity of the sound field in the receiving room.

In table 5.22 the laboratory averages $\overline{y_i}$ and the average sound reduction index m concerning the single-number quantities R_w, R_A and R_m are given for five single pressure measurements as well as for five single intensity measurements. Besides, the standard deviations are given.

5.5.2. The repeatability r

In the figures 5.20A and 5.20B the repeatabilities r calculated on the basis of the results of the pressure and the intensity measurements are compared with the reference curves of ISO 140/II and ISO/TC-43/SC-2-N-267. The repeatability r concerning the pressure measurements exceeds the reference curves at 400 and 500 Hz and from 700 to 1600 Hz. In table 5.23a the standard deviation of the pressure measurements is given as a function of frequency for each laboratory. It can be compared to the value of s_r, the square root of the repeatability variance.
The repeatability determined from the results of the intensity measurements exceeds the reference curves at 100 Hz, 400 Hz, 800 Hz and 1000 Hz (fig.5.20B). The standard deviations of the results of the intensity mea-

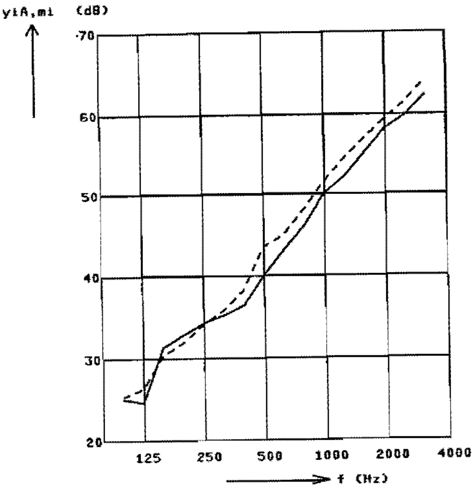


Fig.5.19A THE SOUND REDUCTION INDEX OF THE MIDDLEWEIGHT WALL
AVERAGED OVER 5 SINGLE TESTS IN LAB.A
USING THE INTENSITY METHOD, COMPARED TO mi

——————— yiA
- - - - - - - - mi

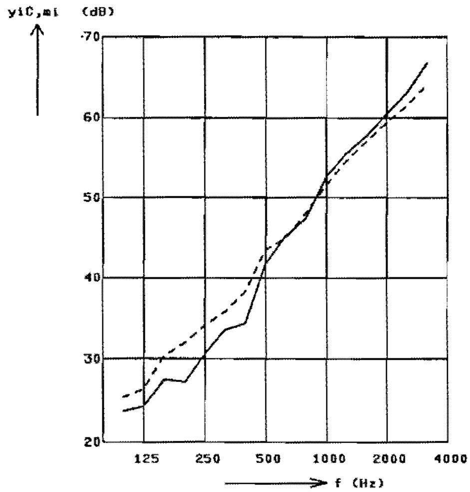


Fig.5.19B THE SOUND REDUCTION INDEX OF THE MIDDLEWEIGHT WALL
AVERAGED OVER 5 SINGLE TESTS IN LAB.C
USING THE INTENSITY METHOD, COMPARED TO mi

——————— yiC
- - - - - - - - mi

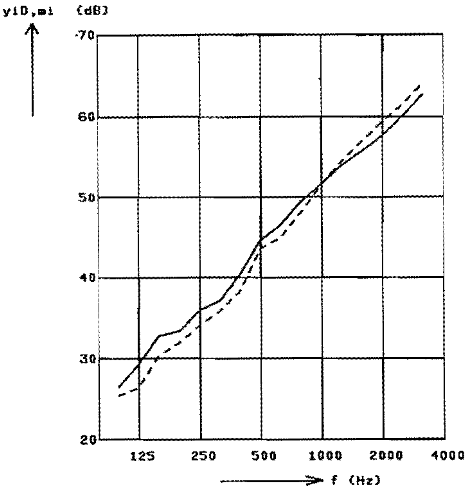


Fig.5.19C THE SOUND REDUCTION INDEX OF THE MIDDLEWEIGHT WALL
AVERAGED OVER 5 SINGLE TESTS IN LAB.D
USING THE INTENSITY METHOD, COMPARED TO mi

——————— yiD
- - - - - - - - mi

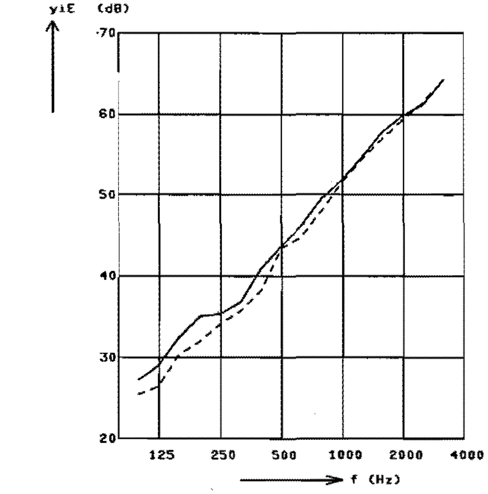


Fig.5.19D THE SOUND REDUCTION INDEX OF THE MIDDLEWEIGHT WALL
AVERAGED OVER 5 SINGLE TESTS IN LAB.E
USING THE INTENSITY METHOD, COMPARED TO mi

——— yiE
- - - - mi

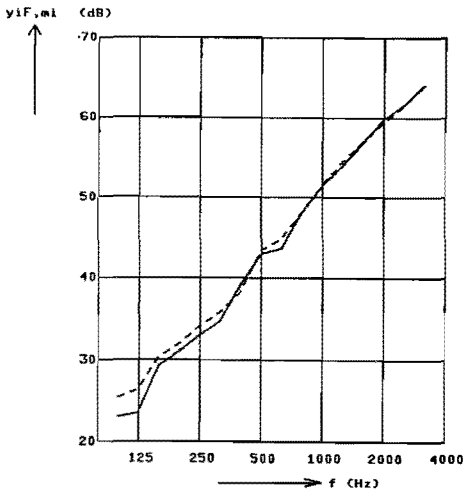


Fig.5.19E THE SOUND REDUCTION INDEX OF THE MIDDLEWEIGHT WALL
AVERAGED OVER 5 SINGLE TESTS IN LAB.F
USING THE INTENSITY METHOD, COMPARED TO mi

——— yiF
- - - - mi

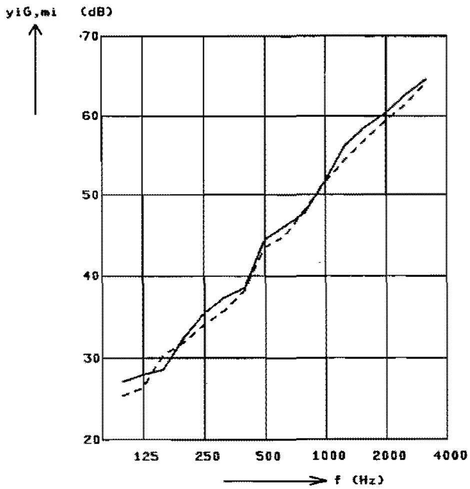


Fig.5.19F THE SOUND REDUCTION INDEX OF THE MIDDLEWEIGHT WALL
AVERAGED OVER 5 SINGLE TESTS IN LAB.G
USING THE INTENSITY METHOD, COMPARED TO mi

——— yiG
- - - - mi

Table 5.22. The laboratory averages $\overline{y_i}$ and the average sound reduction index m concerning the single-number quantities R_w, R_A and R_m calculated from the tests on the middleweight wall, with standard deviations.

a. 5 single pressure measurements

	R_w(dB)		R_A(dB)		R_m(dB)	
lab.	$\overline{y_i}$	s_i	$\overline{y_i}$	s_i	$\overline{y_i}$	s_i
A	46.88	0.56	40.53	0.58	43.97	0.48
C	47.00	0.30	40.54	0.63	45.99	0.16
D	49.08	0.69	42.99	0.69	46.23*	0.62
E	49.44	0.19	43.70	0.24	47.06	0.13
F	47.18	0.13	41.18	0.43	45.21	0.32
G	48.60	0.36	42.44	0.88	46.07	0.14
m	48.03		41.90		45.76	

b. 5 single intensity measurements

	R_w(dB)		R_A(dB)		R_m(dB)	
lab.	$\overline{y_{ii}}$	s_i	$\overline{y_{ii}}$	s_i	$\overline{y_{ii}}$	s_i
A	44.70**	0.97	37.52	0.84	42.93**	0.74
C	42.98	0.44	35.40	0.89	43.24	0.23
D	47.42	0.34	40.05	0.63	44.87	0.23
E	47.46	0.23	40.10	0.28	45.43	0.30
F	44.54	0.35	36.55	0.59	43.53	0.28
G	46.40	0.29	39.02	0.70	45.04	0.27
m_i	45.76		38.11		44.42	

** = outlier   * = straggler

The average sound reduction indices m of R_w, R_A and R_m obtained from pressure measurements are 2.3, 3.8 and 1.3 dB larger than those of R_w, R_A and R_m obtained from intensity measurements respectively.

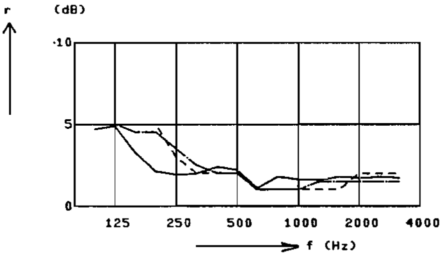


Fig.5.20A THE REPEATABILITY OF THE CONVENTIONAL METHOD DETERMINED FROM 5 SINGLE TESTS ON THE MIDDLEWEIGHT WALL, COMPARED WITH REFERENCE CURVES

——— r
- - - - - REFERENCE CURVE OF ISO 140/II (ref.2.10)
-·-·-·- REFERENCE CURVE OF ISO/TC 43/SC 2 N267 (ref.3.27)

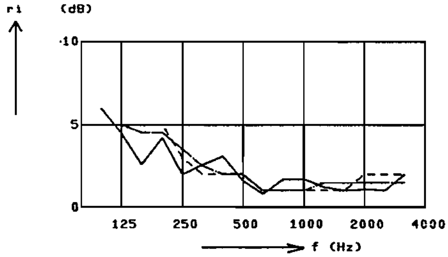


Fig.5.20B THE REPEATABILITY OF THE INTENSITY METHOD DETERMINED FROM 5 SINGLE TESTS ON THE MIDDLEWEIGHT WALL,COMPARED TO THE REFERENCE CURVES

——— ri
- - - - - REFERENCE CURVE OF ISO 140/II (ref.2.10)
-·-·-·- REFERENCE CURVE OF ISO/TC 43/SC 2 N267 (ref.3.27)

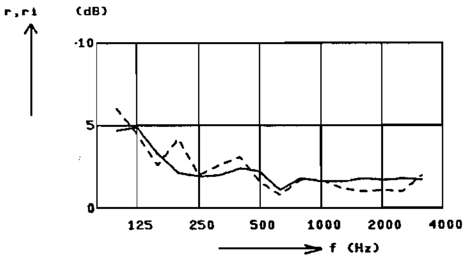


Fig.5.20C THE REPEATABILITY OF THE CONVENTIONAL METHOD AND THE REPEATABILITY OF THE INTENSITY METHOD, BOTH FROM 5 SINGLE TESTS ON THE MIDDLEWEIGHT WALL

——— r
- - - - - ri

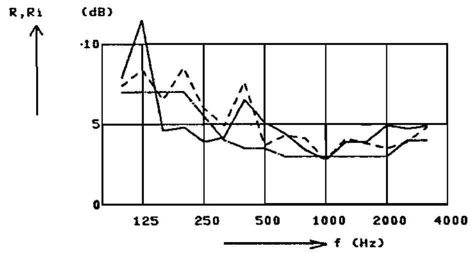


Fig.5.20D THE REPRODUCIBILITY OF THE CONVENTIONAL METHOD AND THE REPRODUCIBILITY OF THE INTENSITY METHOD, BOTH FROM 5 SINGLE TESTS ON THE MIDDLEWEIGHT WALL

——— R
- - - - - Ri
-·-·-·- REFERENCE CURVE OF ISO/TC 43/SC 2 N267 (ref.3.27)

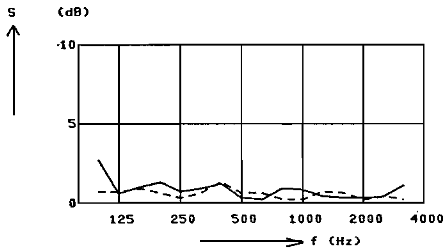


Fig.5.21 THE STANDARD DEVIATIONS OF THE SOUND REDUCTION INDEX USING THE INTENSITY METHOD IN THE CASE OF A BARE RECEIVING ROOM AND WITH EXTRA ABSORPTION

——— S, BARE RECEIVING ROOM
- - - - - S, EXTRA ABSORPTION ADDED

surements are given in table 5.23b together with the values of s_r.
The repeatability r of both test methods are compared with one another in fig.5.20C. This figure shows lower values of the repeatability determined from pressure measurements for frequencies below 500 Hz. For frequencies above 500 Hz the intensity measurements yield lower values of the repeatability.

Table 5.23a. Standard deviations and s_r, the square root of the repeatability variance of the results of five single pressure measurements on the middleweight wall (all quantities in dB).

freq.(Hz)	s_A	s_C	s_D	s_E	s_F	s_G	s_r
100	1.48	1.23	1.60	1.55	1.62	2.32	1.67
125	1.45	2.45	1.36	0.81	2.38	1.31	1.73
160	1.69	0.87	1.34	0.60	0.60	1.50	1.18
200	2.07**	0.78	0.74	0.39	0.55	1.06	0.74
250	0.47	0.44	0.91	0.72	0.57	0.72	0.66
315	0.79	0.60	0.99	0.57	0.64	0.42	0.69
400	1.16	0.77	0.80	0.09	0.23	1.33	0.85
500	1.40*	0.36	0.62	0.33	0.33	1.01	0.79
630	0.28	0.30	0.36	0.28	0.59	1.03**	0.37
800	0.85	0.29	0.85	0.62	0.64	0.22	0.63
1000	0.47	0.18	0.83	0.17	0.57	0.83	0.57
1250	0.60	0.22	0.84	0.29	0.29	0.82	0.57
1600	0.71	0.23	0.72	0.18	0.36	1.06	0.62
2000	0.72	0.50	0.58	0.17	0.52	0.92	0.62
2500	0.93	0.45	0.59	0.11	0.27	0.98	0.64
3150	0.89	0.48	0.61	0.13	0.30	0.82	0.60

* straggler; ** outlier

Table 5.23b. Standard deviations and S_r, the square root of the repeatability variance of the results of five single intensity measurements on the middleweight wall (all quantities in dB).

freq.(Hz)	S_A	S_C	S_D	S_E	S_F	S_G	S_r
100	1.56	2.69	1.48	2.63	1.29	2.55	2.12
125	1.37	0.58	0.66	2.79*	1.33	1.71	1.59
160	1.37	0.99	0.30	0.40	0.93	1.10	0.93
200	1.80	1.31	0.92	0.58	0.37	2.61*	1.48
250	0.86	0.68	0.32	1.01	0.69	0.46	0.71
315	1.53*	0.93	0.49	0.40	0.75	0.82	0.90
400	1.45	1.22	0.58	0.34	0.86	1.56	1.10
500	1.63**	0.31	0.25	0.50	1.00*	0.50	0.57
630	0.43	0.19	0.28	0.85**	0.19	0.23	0.28
800	0.66	0.88	0.37	0.75	0.35	0.30	0.60
1000	0.64	0.75	0.12	1.05*	0.25	0.28	0.61
1250	0.25	0.35	0.33	0.55	0.63	0.38	0.44
1600	0.47	0.27	0.13	0.20	0.58	0.16	0.35
2000	0.50	0.26	0.27	0.08	0.58	0.33	0.37
2500	0.50	0.37	0.27	0.21	0.40	0.30	0.36
3150	0.40	1.12	0.18	0.53	0.82	0.77	0.71

* straggler; ** outlier

As to the single-number quantities R_w, R_A and R_m the repeatability r of both test methods is given in table 5.24.

Table 5.24. The repeatability r concerning R_w, R_A and R_m of the conventional method (a) and the intensity method (b) determined for each test method from 5 single tests in each laboratory.

	r(dB): a	r(dB): b	reference values (dB) (ref.3.28)
R_w	1,20	0,94	1
R_A	1,72	1,94	1
R_m	0,75	1,10	1

It cannot be concluded neither from fig.5.20C nor from table 5.24 that one of the two test methods yields systematically lower values of the repeatability r.

In laboratory C the serie of five intensity measurements has been repeated after the addition of a large amount of absorption material in the receiving room resulting in lower values of the reactivity index (fig.5.17E). The standard deviations of the results from this serie are compared with those of the first serie in fig.5.21. It shows that the reduction of the reactivity of the sound field in the receiving room does not affect the standard deviations very much, except perhaps for frequencies below 400 Hz. In this frequency region the reactivity index is lowered beneath 10 dB as a result of the extra absorption material.

5.5.3. The reproducibility R

The reproducibility R concerning the pressure as well as the intensity measurements is shown in fig.5.20D together with the reference curve from ISO/TC-43/SC-2-N-267. The reference curve is exceeded for most frequencies. This is the case for both test methods. The reproducibility concerning the pressure measurements only meets the requirements at 160, 200, 250, 315 and 1000 Hz whereas the reproducibility as to the intensity measurements agree with the reference values only at 160, 1000 and 2500 Hz. It seems logical that the reproducibility of the intensity measurements does not differ much from the reproducibility of the pressure measurements. This might be explained as follows.

From the definition of the reproducibility R (eq.3.12) we see that it is calculated from the repeatability variance s_r^2 and the between-laboratory variance s_L^2. Firstly, the repeatabilities of both test methods have about the same value (fig.5.20C) and from eq.3.11 so do the repeatability variances of the two methods. Secondly, the between-laboratory variance is determined by the properties of the transmission suites and should not depend on the test method chosen.

The peaks of the repeatability r of the intensity measurements at 200 and 400 Hz lead to peaks in the reproducibility of the intensity measurements at the same frequencies.

We may conclude that under the conditions of this investigation the intensity technique does not yield a better reproducibility. One might consider the reproducibility of the conventional method as being slightly better. This is confirmed by the reproducibility concerning the single-number quantities as shown in table 5.25.

Table 5.25. The reproducibility R concerning the single-number quantities R_w, R_A and R_m of pressure measurements (a) and intensity measurements (b) determined from 5 tests for each method on the middleweight wall.

	R(dB)(a)	R(dB)(b)	reference values (dB) (ref.3.28)
R_w	3.41	5.60	3
R_A	4.09	5.74	3
R_m	3.03	2.83	3

5.5.4. Conclusions of §5.5.

The precision of the two test methods for the determination of the sound reduction index has been compared. The comparison concerned five single tests for each test method carried out in the same measuring direction on the same object in six laboratories. The pressure measurements have been carried out under reproducibility conditions. The intensity measurements have been carried out by the same operators in each laboratory so reproducibility conditions according to ISO 5725 were not relevant. In this way the variations in the measured sound reduction index due to different operators are left out.

The conclusions can be summarized as follows:

* The repeatability r of the intensity method is slightly higher than the repeatability of the conventional method, at least under the conditions of this investigation. This is illustrated best by looking at the repeatability concerning the single-number quantities.

* The reproducibility R of the intensity method is higher than the reproducibility of the conventional method under the conditions of this investigation. The reproducibilities of the single-number quantities illustrate this clearly.

* The results of the intensity measurements show the same characteristics as the results of the pressure measurements as to the effects of different edge conditions, etc.

* The sound reduction index obtained from intensity measurements is smaller than the sound reduction index obtained from pressure measurements. Especially when the reactivity index of the sound field in the receiving room is large, differences of 2 or 3 dB can occur between the results of the two test methods concerning the single-number quantities.

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Summary

This thesis describes an experimental investigation on the influence of the properties of sound transmission rooms on the results of airborne sound insulation measurements. This investigation took place in six Dutch and two Belgian laboratories.
The transmission rooms in these laboratories all differ in size, shape and construction, as a result of the rather wide margins of the requirements for these rooms.
It is known from literature that the results of airborne sound insulation measurements on building elements may depend on the properties of the transmission rooms. It is important to know these effects and, if possible, to reduce them in view of the acoustical qualification for building elements and the export trade.
Although test reports from different Dutch and foreign laboratories appear in The Netherlands, a comparative investigation has never been carried out in Dutch laboratories, contrary to West-Germany and Scandinavia.

Chapter 1 illustrates the important part played by the sound reduction index of building elements in noise abatement by means of three practical cases.
In chapter 2 a short historical survey of Dutch transmission rooms (§2.2) is followed by the requirements from ISO 140 for these rooms (§2.3). These requirements show rather wide margins for the designing of these rooms. Two methods for determining the airborne sound insulation of building elements are explained briefly in §2.4; firstly the standardized 'pressure' method from ISO 140/III and secondly the non-standardized 'intensity' method, both applied in the frequency range 100.....3200 Hz.
This chapter ends by introducing some single-number quantities for the sound reduction index. These quantities are often used to formulate acoustical requirements in building codes.

The causes which affect the results of laboratory airborne sound insulation measurements are explained in chapter 3. Firstly a short survey of literature of the effects caused by the properties of the transmission rooms is given in §3.2. Secondly the discrepancy between the results of the two test methods found by other authors is shown in §3.3.

Thirdly a method to determine the precision of a standard test method is given in §3.4. The statistical model from ISO 5725 for determining the repeatability and the reproducibility of a test method by inter-laboratory tests is introduced.
A summary of precision experiments concerning the standardized 'pressure' method carried out in West-Germany and Scandinavia concludes this chapter.

Chapter 4 deals with the organization of the investigation, described in this thesis. Three test objects were selected. They were used to investigate the effects mentioned in §3.2.
Four precision experiments according to ISO 5725 were carried out using the three objects with respect to the standardized 'pressure' method. The two test methods were used in each laboratory to determine the sound reduction index of two test objects. Finally the precisions of the two test methods were compared from measurements on one test object.
In §4.2 the participating laboratories are described whereas in §4.3 and §4.4, §4.5 and §4.6 the test objects and the tests are dealt with respectively.

In chapter 5 the results of the investigation are treated.
Two important effects were caused by the properties of the transmission rooms (§5.2).
Firstly the so-called niche effect may cause differences in the measured sound reduction index of as much as 10 dB for frequencies below the critical frequency of the test object. It is recommended that the recommendation of ISO for the central position of the object in the test opening is hanged in order to reduce this effect.
Secondly the different edge conditions met by heavy walls in the different laboratories caused differences of as much as 4 dB in the measured sound reduction index for frequencies around and above the critical frequency of the test object. It is recommended that both shape and mass of the test opening are standardized.

The results of the precision experiments (§5.3) show that the requirements for the repeatability and the reproducibility are not met for each frequency band when single test results, i.e. the result of one test in one measuring direction, are used. However, yet it is possible that the re-

quirements for the repeatability and the reproducibility concerning the single-number quantities are fulfilled.
When using averaged test results, i.e. the average result of two tests in opposite measuring directions, for the determination of the repeatability and the reproducibility, the reference values for the repeatability can be met in each frequency band. The reproducibility too is improved in that case.
It is recommended that, apart from the requirements for new sound transmission laboratories, the measuring procedure in ISO 140/III too is standardized more firmly. A second recommendation concerns the reference values for the repeatability and the reproducibility of the single-number quantities: different single-number quantities should have different reference values.

When using the intensity technique instead of the standardized pressure method considerable discrepancies may occur (§5.4), depending on frequency, the measuring direction and the reactivity of the sound field in the receiving room. A rather good agreement is obtained when the test object is connected to the source room and the receiving room has a very small reverberation time, i.e. made almost anechoic. For low frequencies the discrepancies between the results of the two test methods are reduced by applying the so-called Waterhouse correction to the results of the pressure method.
It is recommended that in future measuring procedures concerning the intensity method in laboratory measurements, the measuring direction and the character of the sound field in the receiving room are prescribed. The need for the application of the Waterhouse correction in standardized sound insulation measurements is a second recommendation.

The comparison of the precision of the two test methods in §5.5 shows a slightly better repeatability and reproducibility for the 'pressure' method. This is illustrated best by the repeatability and the reproducibility of both test methods concerning the single-number quantities.

Samenvatting

Dit proefschrift beschrijft een experimenteel onderzoek naar de invloeden van de eigenschappen van geluidtransmissiekamers op de resultaten van luchtgeluidisolatiemetingen aan bouwelementen; het onderzoek is uitgevoerd in zes Nederlandse en twee Belgische laboratoria. De transmissiekamers in deze laboratoria zijn alle verschillend qua grootte, vorm en constructie, als gevolg van speelruimte in de voorschriften voor deze meetkamers.
Uit de literatuur blijkt, dat de resultaten van luchtgeluidisolatiemetingen aan bouwelementen mede afhangen van de eigenschappen van transmissiekamers. Het is van belang deze effecten te kennen en zo mogelijk te minimaliseren met het oog op de toekenning van attesten aan bouwelementen en in breder verband de export van deze bouwelementen.
Hoewel in Nederland regelmatig meetrapporten van verschillende laboratoria verschijnen is een vergelijkend onderzoek in Nederlandse laboratoria niet uitgevoerd, in tegenstelling tot bijvoorbeeld West-Duitsland en Scandinavië.

In een algemene inleiding, beschreven in hoofdstuk 1, wordt de belangrijke rol die de luchtgeluidisolatie van bouwelementen in de praktijk van de lawaaibestrijding speelt, verduidelijkt aan de hand van drie gevallen.

Hoofdstuk 2 geeft een kort historisch overzicht van de transmissiekamers in Nederland (§2.2), gevolgd door de eisen uit ISO-140 die aan deze meetkamers worden gesteld (§2.3). Uit deze eisen blijkt de speelruimte voor het ontwerpen van deze meetkamers. Twee methoden ter bepaling van de luchtgeluidisolatie van bouwelementen worden kort toegelicht in §2.4, ten eerste de genormaliseerde 'druk'-methode uit ISO 140/III en ten tweede de niet-genormaliseerde 'intensiteits'-methode, beide van toepassing in het frequentiegebied 100.....3200 Hz.
Dit hoofdstuk besluit met het introduceren van enkele zogenaamde één-getals-grootheden voor de luchtgeluidisolatie. Deze worden veel gebruikt om akoestische eisen in bouwvoorschriften vast te leggen.

In hoofdstuk 3 wordt uiteengezet waardoor de resultaten van luchtgeluidisolatiemetingen in het laboratorium kunnen worden beïnvloed.
Op de eerste plaats (§3.2) betreft dit een kort overzicht van de in [illegible] 'i-

teratuur vermelde invloeden, veroorzaakt door de eigenschappen van de transmissiekamers.
Op de tweede plaats (§3.3) volgt een korte opsomming van de door anderen geconstateerde verschillen in de meetresultaten door het gebruik van de 'intensiteits'-methode in plaats van de 'druk'-methode.
Op de derde plaats (§3.4) wordt aangegeven hoe de nauwkeurigheid van een standaard-meetmethode kan worden bepaald. Het statistische model uit ISO 5725, waarmee uit metingen aan hetzelfde object in verschillende laboratoria de herhaalbaarheid en de reproduceerbaarheid van de meetmethode worden bepaald, wordt geïntroduceerd.
Tot besluit wordt een korte samenvatting gegeven van de in West-Duitsland en Scandinavië verrichte nauwkeurigheidsonderzoeken betreffende de genormaliseerde 'druk'-methode.

Hoofdstuk 4 beschrijft de opzet en de organisatie van het onderzoek, verricht in Nederlandse en Belgische laboratoria (§4.1). Drie meetobjecten zijn geselecteerd. Met deze objecten zijn de voornaamste invloeden, genoemd in §3.2, onderzocht. Vier nauwkeurigheidsonderzoeken volgens de methode uit ISO 5725 zijn uitgevoerd met de genormaliseerde 'druk'-methode. Tevens zijn vergelijkingen van de resultaten verkregen met de in §2.4 genoemde meetmethoden aan twee objecten gemaakt. Tenslotte is de nauwkeurigheid van de beide meetmethoden onderling vergeleken.

In hoofdstuk 5 worden de resultaten van het onderzoek behandeld. De eigenschappen van de transmissiekamers in de deelnemende laboratoria leiden tot twee belangrijke effecten (§5.2). Op de eerste plaats kan het zogenaamde niseffect voor frequenties beneden de grensfrequentie van het meetobject voor verschillende posities van het object in de meetopening verschillen tot 10 dB in de gemeten luchtgeluidisolatie veroorzaken. Aanbevolen wordt dat de voorkeur van ISO 140/III voor de centrale positie van het object in de meetopening dient te worden gewijzigd in een eenduidig omschreven positie, niet gelijk aan de centrale positie. Op de tweede plaats leiden de verschillende randcondities die met name zware meetobjecten in verschillende laboratoria ondervinden tot verschillen van maximaal 4 dB voor frequenties rond en boven de grensfrequentie van het meetobject. Uit dit laatste volgt de aanbeveling, dat ook de vorm en de omgevende massa van de meetopening nader dienen te worden genormaliseerd.

Uit de resultaten van de nauwkeurigheidsonderzoeken (§5.3) blijkt dat, zo lang een meetresultaat voortkomt uit één meting in één meetrichting, de herhaalbaarheid en de reproduceerbaarheid niet in elke frequentieband aan de referentiewaarden voldoen. Het blijkt echter voor te kunnen komen dat de herhaalbaarheid en/of de reproduceerbaarheid, bepaald voor de één-getals-grootheden, dan wel aan de daarvoor geldende referentiewaarden kunnen voldoen. Ten aanzien van de herhaalbaarheid wordt wel aan de referentiewaarden voldaan, indien een meetresultaat het gemiddelde is van twee metingen in tegengestelde meetrichting. Ook de reproduceerbaarheid wordt daardoor verbeterd.
Er wordt aanbevolen dat, naast de voorschriften voor de bouw van nieuwe laboratoria, ook de voorschriften voor de meetprocedure uit ISO 140/III dienen te worden bijgesteld. Een tweede conclusie is, dat verschillende één-getals-grootheden verschillende referentiewaarden voor de herhaalbaarheid en de reproduceerbaarheid dienen te hebben.

Door de intensiteitsmethode te gebruiken in plaats van de genormaliseerde drukmethode kunnen aanzienlijke verschillen in de meetresultaten optreden (§5.4). Deze verschillen zijn afhankelijk van de frequentie, de meetrichting en de reactiviteit van het ontvangvertrek. Een redelijke overeenstemming tussen de resultaten van beide meetmethoden wordt bereikt wanneer het meetobject gekoppeld is aan de zendruimte en het ontvangvertrek sterk geluidabsorberend is uitgevoerd tijdens de intensiteitsmetingen. Het toepassen van de zogenaamde Waterhouse-correctie op de resultaten van de drukmetingen verkleint de nog resterende verschillen voor de lage frequenties.
Aanbevolen wordt dat in toekomstige meetvoorschriften voor de intensiteitsmetingen in het laboratorium in elk geval de meetrichting en de inrichting van het ontvangvertrek voorgeschreven dienen te worden. Tevens wordt aanbevolen dat de Waterhouse-correctie bij 'druk'-metingen moet worden toegepast.

Uit de vergelijking van de nauwkeurigheid van de beide meetmethoden, uitgevoerd aan hetzelfde object onder dezelfde condities (§5.5) blijkt, dat de genormaliseerde drukmethode een iets hogere nauwkeurigheid bezit dan de intensiteitsmethode. Dit komt vooral tot uiting in de herhaalbaarheid en de reproduceerbaarheid van de één-getals-grootheden.

Curriculum vitae Heiko-Jan Martin

23 januari 1947	Geboren te Winschoten.
1953-1959	Lager Onderwijs te Winschoten.
1959-1960	Brugklas VHMO te Winschoten.
1960-1965	Middelbare schoolopleiding aan de Gemeentelijke HBS te Winschoten.
1965	Eindexamen HBS-B.
1965-1972	Studie voor natuurkundig ingenieur aan de Technische Hogeschool te Delft.
1969-1972	4e en 5e jaars werk in de onderzoekgroep Akoestiek onder leiding van Prof.dr.ir.C.W.Kosten en Lector ir.D.W.van Wulfften Palthe.
25 april 1972	Doctoraal examen natuurkundig ingenieur.
1972-1973	Akoestisch adviseur bij het Adviesbureau voor Bouwakoestiek te Delft.
1973-heden	Wetenschappelijk medewerker, respectievelijk wetenschappelijk hoofdmedewerker, respectievelijk universitair docent in de vakgroep Fysische Aspecten van de Gebouwde Omgeving van de Afdeling der Bouwkunde, Technische Hogeschool Eindhoven; onderwijs en onderzoek op het gebied van de bouwfysica.
1974-heden	Docent Geluidleer aan de Post-HTO-cursus Bouwfysica aan de HTS te 's-Hertogenbosch.

STELLINGEN, BEHORENDE BIJ HET PROEFSCHRIFT:

"SOUND TRANSMISSION ROOMS - A COMPARISON"

1. Bij luchtgeluidisolatiemetingen in het laboratorium dient het meetobject niet in het midden van de meetopening geplaatst te worden; de norm ISO 140/III dient op dit punt te worden herzien (dit proefschrift hoofdstuk 5.2).

2. Voor de luchtgeluidisolatie van een bouwelement dient het gemiddelde resultaat van twee qua bronpositie of meetrichting verschillende metingen te worden genomen (dit proefschrift hoofdstuk 5.3).

3. Wanneer aan een bouwelement de luchtgeluidisolatie als kwaliteitskenmerk wordt toegekend, dient de waarde hiervan uit het oogpunt van betrouwbaarheid het (rekenkundig) gemiddelde van twee meetresultaten te zijn (dit proefschrift hoofdstuk 5.3).

4. Het is bij geluidisolatiemetingen aan bouwelementen noodzakelijk de zogenaamde Waterhouse-correctie toe te passen (D.W.van Wulfften Palthe, G.Faber en D.de Vries 'Sound power radiated by a velocity monopole under reverberant and under free field conditiions'. J. Acoust. Soc. Am. 65(2), February 1979).

5. De bewering, dat het niseffect alléén in het frequentiegebied onder de grensfrequentie optreedt, is theoretisch zwak gefundeerd (o.a. T. Kihlman, A.C.Nilsson 'The effects of some laboratory designs and mounting conditions on reduction index measurements', Journal of Sound and Vibration, 24(3), 1972).

6. Het uitvoeren van nauwkeurigheidsonderzoeken in laboratoria, die kwaliteitskenmerken aan toestellen of materialen toekennen, dient te worden gestimuleerd, ook in internationaal verband, met het oog op de export van bedoelde toestellen en materialen.

7. Het onderwijs in de materiaalkunde aan aanstaande bouwkundig ingenieurs zou zeer gebaat zijn bij meer kennis van de VWO-abituriënten van de scheikunde (B.W.v.d.Vlugt, Diësrede, Technische Hogeschool Eindhoven, 1984).

8. Het onderwijs op basisscholen dient zo te worden ingericht, dat voorkomen wordt dat intelligente kinderen lui worden (W.B.Barbe and J.S. Renzulli, 'Psychology and education of the gifted', New York, 1981).

9. De vereiste nauwkeurigheid van één cent in de verhouding van de frequenties van grond- en boventonen van vibrafoonstaven is niet voldoende onderbouwd (J.L.Moore, 'Bar percussion instruments', Permus Publications, Columbus Ohio, 1978).

10. Het terugdringen van het onderwijs in de Romaanse talen leidt tot een verminderd inzicht in de schrijfwijze en uitspraak van woorden; dit kan er bijvoorbeeld toe leiden dat men bij het woord parameter gaat denken aan een apparaat voor het tellen van Joegoslavische munten.

11. Het musiceren in een groot orkest levert naast de muzikale beleving een aantal vaardigheden op, die overal tepas komen, zoals samenspelen, zuiver spelen, tellen en maathouden.

Eindhoven, 9 september 1986.

Heiko Martin.