Repeatability and reproducibility of sound insulation measurements

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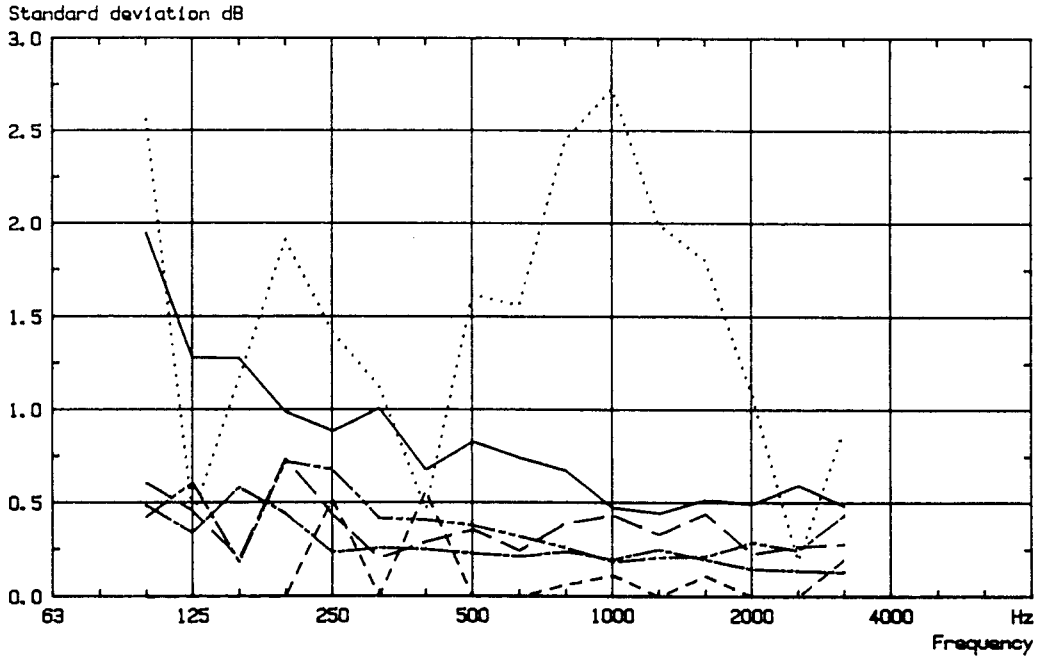

Danish Acoustical Institute

Report No. 118 1984

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TECHNICAL REPORT

Report No.	Date
118	July 1984 SDK/BR/lm
Title of Report Repeatability and Reproducibility of Sound Insulation Measurements	**Head of Institute** A. C. Nilsson
Client Sponsor of Project Nordtest	**Client/Sponsor Ref.** 235-80
Work carried out by Søren Damgaard Kristensen & Birgit Rasmussen	**Reporter's Sign.**

Summary

Results of a cooperative experiment are presented in the report. Five laboratories participated in the tests. The laboratories are located in Finland, Norway, Sweden, and Denmark.

The aim of the cooperative experiment is to determine the repeatability, r, and the reproducibility, R, of measurements of sound reduction index according to the International Standard ISO 140 part II.

The repeatability is found to be between 0.7 and 2.4 dB, depending on the frequency. The repeatability for the weighted sound reduction index R_W is found to be 0.7 dB.

The reproducibility is found to be between 1.9 and 9.3 dB, depending on the frequency. The reproducibility for the weighted sound reduction index R_W is found to be 3.3 dB.

The report also describes the sources of errors and their relative contributions to the total variance of the measurements.

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APPENDICES

1. INTRODUCTION

The international standard ISO 140-1978(E) "Acoustics - Measurement of sound insulation in buildings and of building elements" has been adopted as national standards in the Scandinavian countries with none or only a few minor changes of the recommendations.

In part II of the ISO 140 "Statement of precision requirements" certain requirements to the quality of the sound insulation measurements (airborne sound reduction index and impact sound pressure level) are stated. In the 1978 version of the standard the requirements to the repeatability are stated while similar requirements to the reproducibility have been postponed. This is due to insufficient experimental results.

The two concepts (repeatability and reproducibility) define quantities which are characteristic for a well defined measuring method. If a measurement is conducted in a laboratory with appropriate facilities and with a test procedure as prescribed in the international standard, then the test result could be reproduced with a certain degree of accuracy. If the measurement is repeated in the same laboratory, the repeatability r is used to describe the accuracy. If the measurement is repeated in another laboratory, the reproducibility R is used. The repeatability r and the reproducibility R have to be determined by experiments.

The international standard ISO 5725-1981(E) "Precision of test methods - Determination of repeatability and reproducibility" describes the determination of r and R. The ISO 5725 is not aimed at acoustic test exclusively; hence several strategies for determining r and R are described in this standard. However, the strategy in this particular project is to conduct a Round Robin test in which the participating laboratories are repeating measurements of sound reduction index one or several times.

Below the definitions in ISO 5725 for r and R are quoted.

"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%."

"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; in the absence of other indications, the probability is 95%."

This report describes a cooperative experiment conducted by five Scandinavian laboratories in order to achieve data on the repeatability and the reproducibility of the measurement procedures used for determining the sound reduction index of building elements. The project has been financially supported by Nordtest.

2. REPORT FROM THE PROJECT GROUP

In order to perform a Round Robin test concerning the reproducibility and repeatability factors discussed above, a project group was established within the Nordtest organization.

The members of the group have been:

Heikki T. Tuominen, later succeeded by Heikki Saario,
Statens Tekniska Forskningscentral (VTT), Finland

Tor Erik Vigran, Akustisk Laboratorium (ELAB), Norway

Kaj Bodlund, Statens Provningsanstalt (SP), Sweden

Nic Michelsen (project leader), later succeeded by
Birgit Rasmussen, Lydteknisk Institut (LI), Denmark

The major part of the data analysis and the reporting has been carried out by Søren Damgaard Kristensen, Lydteknisk Institut.

Henrik Spliid from IMSOR at the Technical University of Denmark has acted as a consultant concerning the statistical aspects of the investigation.

The participants in the cooperative experiment were the above-mentioned four laboratories and Jydsk Teknologisk Institut (JTI), Denmark.

The project group had two joint meetings.

At the first meeting 27th October, 1981, the type and mounting of the test objects were discussed, and a test programme was set up.

It was discussed whether walls or windows should be chosen as test objects. For several reasons it was decided to choose windows. The number of measurements on windows is rather large, and windows are export/import articles to a greater extent than walls. Further the largest differences in measurement results were found for windows. So the largest problems were connected to windows.

It was agreed that the cooperative experiment should include three types of test objects with different sound reduction index:

a) A double window construction with a very high sound reduction index
b) A typical sound insulating glazing
c) A single-glass pane

However, for economical reasons the number of test objects had to be limited to one. Hence the typical sound insulating glazing was chosen as the test object.

At the final meeting on 6th June, 1984, the results and the draft for the final report were discussed.

It was agreed that the relatively poor results for the reproducibility called for further investigations in order to reveal the cause.

The results were compared with the results from Nordtest 360-82, which showed better values for the reproducibility. Based on the results of the experiments it was concluded that further investigations should concentrate on the dividing wall between the measurement rooms, i.e. the wall with the test opening. It was noticed that some laboratories use a heavy construction wall, while others use a lightweight wall, thus defining different edge conditions.

3. COOPERATIVE EXPERIMENT

3.1 Description of Test Object

The test object is a 4/4-15-4 sound insulating pane. The pane consists of a 4 + 4 mm laminated glass and a 4 mm glass. The two glasses are separated by a 15 mm profile of steel and are sealed with butyl and thiocol. The laminated glass has a 1.14 mm plastic film (polyvinyl butural) embedded in it. The sound insulating pane has a total thickness of 28 mm and a weight of approximately 30 kg/m^2.

The panes were manufactured by Scanglas A/S, Denmark, with the trade name Scanofon.

The size of the panes are 1190 × 1190 mm, and they were mounted in test openings of 1210 × 1210 mm.

Six panes were delivered to Lydteknisk Institut where preliminary measurements of the sound insulation were carried out. Based on the results of the preliminary tests 5 panes were selected for further distribution. The sixth pane was kept as a spare.

The preliminary test above is described in Appendix A.

3.2 Measurement Programme

Each of the 5 participating laboratories were asked to perform 4 series of measurements. The test programme included the following tests:

Series 1: Influence of stochastic noise signal
Series 2: Mounting conditions (remounting)
Series 3: Repeatability/reproducibility
Series 4: Peproducibility within laboratories

The test series are described below. Instruction for the laboratories is shown in Apendix B.

Series 1: Influence of Stochastic Noise Signal

To investigate this parameter the laboratories were asked to conduct 5 measurements using the same loudspeaker positions and the same microphone positions or microphone paths for all the measurements.

Hence the intention was to keep all other parameters constant so that merely the variations due to the stochastic noise signal would appear.

Series 2: Mounting Conditions (Remounting)

It is known that the mounting conditions have an important effect on the measured sound insulation when measurements on the same type of pane is carried out in different laboratories; refer among others to "Laboratory Effects on the Measured Sound Reduction Index of Windows and Glazings" Lydteknisk Laboratorium, 1982 [3].

In this experiment the influence of remounting the pane using the same mounting instructions was investigated.

The laboratories were asked to unrig the pane, to clean it, and to remount it. Then one single measurement using the same loudspeaker positions and microphone position or microphone paths as in measurement series no. 1 was to be performed.

Series 3: Repeatability/Reproducibility

This is the main experiment of the project.

Each laboratory was asked to conduct 6 measurements under repeatability conditions. This implies that the rooms are kept unchanged and that the measuring equipment and the personnel are the same for all the measurements. Each measurement was to be carried out independently of the other 5. Therefore all changes normally included in the test procedure of the labora-

tory were supposed to be carried out. For instance, if the normal procedure of a laboratory is to remove microphones and/or loudspeakers between the measurements, this was also to be done in this test series.

Series 4: Reproducibility within Laboratories

The aim of this experiment is to estimate the influence of changes which are likely to occur within a laboratory over a long time period. For instance change of equipment, personnel, or test procedure.

Each laboratory was asked to conduct 5 measurement with the measurement procedure changed from measurement to measurement.

The instructions included suggestions how to change the procedure.

4. STATISTICAL ANALYSIS

In order to determine the repeatability r and the reproducibility R the statistical analysis is carried out according to the guidelines specified in ISO 5725. However, the design of the test programme allows for further analysis in order to estimate the variances of the various components contributing to the total variance of a single test result.

4.1 Statistical Model

In ISO 5725 a statistical model is assumed where a single test result, in this case a single measurement of the sound reduction index, is a sum of three components.

$$y = m + B + e \qquad (4.1)$$

where y is a single test result, m is the average of several test results from many laboratories, B is a term representing the deviation for a certain laboratory from m, and e is a random error occurring in every test.

Note: The statistics terminology in this section is adopted from ISO 5725.

4.1.1 The Average m

In ISO 5725 it is pointed out that the average m may differ from the "true" value for the test object, i.e. the true sound reduction index for the pane. The difference between m and the true value is called the bias of the test method.

The bias has no influence on the estimation of the repeatability r or the reproducibility R. Hence the bias will be ignored.

4.1.2 The Term B

The term B describes the uncertainty caused exclusively by the fact that the measurements are carried out by different laboratories with different measurement rooms, equipment, staff, and test procedure on different test objects.

The variance associated with the term B is called the between-laboratory variance.

$$\text{var}(B) = \sigma^2_L \tag{4.2}$$

σ^2_L is one of the terms needed for the calculation of the reproducibility R.

For further analysis B may be split into three individual components.

$$B = B_O + B_S + P \tag{4.3}$$

B_O is a random component describing the variations that may occur within a single laboratory during a relatively long period. That is, if the sound reduction index of a specific pane is measured twice with a relatively long period between the two measurements, then it is likely that the results will differ because one or more of the following items have changed: equipment, operator, test procedure, temperature, humidity, room absorption.

The attached variance is denoted $\sigma^2_{B_O}$

$$\text{var}(B_O) = \sigma^2_{B_O} \tag{4.4}$$

B_S, the systematic component, describes the differences between laboratories. Equipment, operator, and room will always be different from laboratory to laboratory. Normally the test procedure will also be different even though the same test standard is used.

Serious systematic differences may result from misreading the test standard or from the use of inadequate equipment. Such er-

rors should be investigated and corrected and are not considered as included in the term B.

The variance of the systematic component is

$$\text{var}(B_S) = \sigma^2_{B_S} \tag{4.5}$$

The last component P contributing to the term B accounts for the fact that the different laboratories do not measure on the same pane, although the panes are selected to be as identical as possible.

The variance is

$$\text{var}(P) = \sigma^2_P \tag{4.6}$$

Since the three terms are assumed to be independent, the following relation holds

$$\sigma^2_L = \sigma^2_{B_O} + \sigma^2_{B_S} + \sigma^2_P \tag{4.7}$$

4.1.3 The Term e

The third term in Eq. 4.1 is the random error component e, representing the unavoidable errors which will occur in every single test result.

Within a single laboratory its variance is called the within-laboratory variance σ^2_w

$$\text{var}(e) = \sigma^2_w \tag{4.8}$$

σ^2_w is expected to vary between laboratories due to differences in the skills of the operators or in the quality of the equipment used. However, it is assumed in the statistical model that the differences between σ^2_w for different laboratories are small so that it is certified to establish a common value, called the repeatability variance

$$\overline{\text{var}(e)} = \overline{\sigma^2_w} = \sigma^2_r \tag{4.9}$$

The repeatability variance is an average of the variances of the laboratories participating in the precision experiment. The repeatability variance is used for calculating both the repeatability r and the reproducibility R.

As for the term B, the term e may be subdivided into more individual components for further statistical analysis.

$$e = u + d + k \tag{4.10}$$

where:

u describes the uncertainty due to the stochastic noise signal used for the measurements, while d describes the other uncertainties such as microphone paths and short time variations in the sensitivity of the measuring system, background noise, etc. The term k describes the uncertainties due to the mounting of the pane.

The variances are

$$\mathrm{var}(u) = \sigma^2_u \tag{4.11}$$

$$\mathrm{var}(d) = \sigma^2_d \tag{4.12}$$

$$\mathrm{var}(k) = \sigma^2_k \tag{4.13}$$

Hence since u, d, and k were independent

$$\mathrm{var}(e) = \sigma^2_w = \sigma^2_u + \sigma^2_d + \sigma^2_k \tag{4.14}$$

By combining Eqs. 4.7 and 4.14 the total variance of a measurement may be expressed

$$\mathrm{var}(y) = \sigma^2_{B_O} + \sigma^2_{B_S} + \sigma^2_p + \sigma^2_u + \sigma^2_d + \sigma^2_k \tag{4.15}$$

From the expressions for σ^2_L and σ^2_r, Eqs. 4.2 and 4.9, respectively, the expressions for the repeatability and the reproducibility may be derived according to ISO 5725

$$r = F\sqrt{2}\ \sigma_r \tag{4.16}$$

$$R = F\sqrt{2}\ \sqrt{\sigma^2_L + \sigma^2_r} = F\sqrt{2}\ \sigma_R \tag{4.17}$$

where

$$\sigma^2_R = \sigma^2_L + \sigma^2_r \tag{4.18}$$

is called the reproducibility variance.

The coefficient $\sqrt{2}$ is derived from the fact that r and R refer to the difference between two single test results, and F is a factor, the value of which both depends on the number of test results and on the shape of the distributions of the random components B and e in the model.

In ISO 5725 it is stated that if the number of test results is not too small and if the probability level is 95%, the factor F will never differ much from the value 2.

Hence

$$r = 2.83\ \sigma_r \tag{4.19}$$

$$R = 2.83\ \sigma_R \tag{4.20}$$

4.2 Estimating the Variances

The aim of the cooperative experiment is to provide data on the repeatability, r, and the reproducibility, R. However, the measurement programme stated in Section 3 makes it possible to estimate nearly all the variances in Eq. 4.15 or at least to confine them to certain values. The results are stated in Section 5. For practical reasons the results are presented in terms of the standard deviation, i.e. the square root of the estimated variance.

The two standard deviations needed for estimating r and R are the repeatability variance s^2_r and the between-laboratory vari-

ance s^2_L. The estimation of these two variances are described in Sections 4.2.2 and 4.2.5, respectively.

4.2.1 The Term u

Referring to the programme it is seen that series no. 1, Influence of Stochastic Noise Signal, directly provides an estimate s^2_u of σ^2_u. Hence $s_u = \sqrt{s^2_u}$.

4.2.2 The Repeatability Variance and the Term d

Series no. 3, Repeatability/Reproducibility, provides an estimate s^2_w of σ^2_w. The repeatability variance s^2_r is estimated by taking the average over the 5 laboratories.

$$s^2_r = \frac{1}{5} \sum_{i=1}^{5} s^2_{w,i} \qquad (4.21)$$

By reversing Eq. 4.14 an estimate s^2_d of the variance for the random error component d can be made for the 5 laboratories.

$$s^2_d = s^2_w - s^2_u \qquad (4.22)$$

The term σ^2_k for the mounting conditions will vanish, because the pane is not demounted between the measurements. See Section 3.2.

Note: When estimating a variance by subtracting two other estimated variances, it may happen that the result has a negative sign. This is due to the limited number of data of course, but even though a result of such a subtraction may seem meaningless, it may give an indication of which of the two sources of errors is most important.

By common practice the result is set equal to zero if the results of the subtraction have a negative sign.

4.2.3 The Term P

It is a little more difficult to get an estimate s^2_P of the variance σ^2_P due to the different panes.

Before the panes were distributed to the participating laboratories, they were all tested at the same laboratory. A special test procedure was used for this preliminary test in order to minimize the variance, see Appendix A. The total variance of the preliminary test of the 5 panes distributed to the laboratories is denoted σ^2_O.

The variance of a single measurement in the preliminary test is denoted σ^2_1.

σ^2_1 accounts only for variations other than the panes. Hence

$$\sigma^2_O = \sigma^2_1 + \sigma^2_P \tag{4.23}$$

Since the preliminary test was designed to minimize the variances, it is assumed that the following unequalities are valid

$$\sigma^2_u \leq \sigma^2_1 \leq \sigma^2_w \tag{4.24}$$

$$\sigma^2_O - \sigma^2_w \leq \sigma^2_P \leq \sigma^2_O - \sigma^2_u \tag{4.25}$$

or

$$0 \leq \sigma^2_P \leq \sigma^2_O - \sigma^2_u \tag{4.26}$$

σ^2_u is the variance for the stochastic noise signal for the particulary laboratory.

Converting to the estimated variances Eq. 4.26 is changed to

$$0 \leq s^2_P \leq s^2_O - s^2_u \tag{4.27}$$

Note that σ^2_O also includes the effect of mounting conditions. Hence the upper limit for s^2_P may be regarded as the sum of the variance due to the different panes and the variance s^2_k due to mounting conditions.

4.2.4 The Term B_O

Series no. 4, Reproducibility within Laboratories, provides an estimate s^2_{IL} of σ^2_{IL}, which describes the within-laboratory reproducibility. σ^2_{IL} may be called the within-laboratory reproducibility variance.

σ^2_{IL} can be expressed as the sum of two components (see also Eq. 4.14 and 4.15)

$$\sigma^2_{IL} = \sigma^2_{B_O} + \sigma^2_w \tag{4.28}$$

Since s^2_w is already known for the individual laboratories, $s^2_{B_O}$ may be estimated by subtraction

$$s^2_{B_O} = s^2_{IL} - s^2_w \tag{4.29}$$

and $s_{B_O} = \sqrt{s^2_{B_O}}$

4.2.5 The Between-Laboratory Variance and the Term B_S

In ISO 5725 computational expressions are given for computing the between-laboratory variance s^2_L.

s^2_L may be found by subtracting the repeatability variance divided by 6 from the variance $s^2(\bar{y})$.

$$s^2_L = s^2(\bar{y}) - \frac{s^2_r}{6} \tag{4.30}$$

$s^2(\bar{y})$ is the empirical variance for the laboratory mean values.

The division by 6 is derived by the fact that s^2_r is determined from 6 measurements at each laboratory.

Using Eq. 4.7 an expression for the estimate $S^2_{B_S}$ may then be derived

$$s^2_{B_S} = s^2_L - \overline{s^2_{B_O}} - s^2_P \tag{4.31}$$

where $\overline{s^2_{B_o}}$ indicates the mean value of the variance for the randon components B_o of the between-laboratory variations.

4.2.6 The Term k

In the preceding part of Section 4.2 it has been assumed that the test pane was steadily mounted. However, when considering the concept of reproducibility the mounting conditions have to be taken into account.

In series no. 2, Mounting Conditions, a single measurement was conducted using the same loudspeaker positions and the same microphone positions or microphone paths as in series no. 1. Therefore an evaluation of the effects of the mounting conditions can be done by comparing the result of the single measurement in series no. 2 with the average of the 5 measurements in series no. 1.

If the difference between the two results is denoted Δy, then an estimate s^2_k of the variance due to the mounting conditions may be computed.

$$s^2_k = \frac{1}{2} \Delta y^2 - \frac{3}{5} s^2_u \qquad (4.32)$$

The estimate is rather rough because the number of test results are limited.

4.2.7 Calculating r and R

In ISO 5725 expressions for the numerical computation of r and R are given.

The experiment is a uniform-level experiment (only one type of test specimen). With p participating laboratories (i = 1 to 5), n tests in each laboratory (k = 1 to 6) and a measurement result called y, the basic expressions are:

$$r = 2.83\ s_r \tag{4.33}$$

$$R = 2.83\ s_R = 2.83\ \sqrt{s^2_L + s^2_r} \tag{4.34}$$

where

$$s^2_r = \frac{1}{p} \cdot \sum_{i=1}^{p} s^2_i \tag{4.35}$$

$$s^2_L = \frac{1}{p-1} \cdot \sum_{i=1}^{p} (\overline{y_i} - \bar{\bar{y}})^2 \ - \frac{s^2_r}{n} \tag{4.36}$$

and

$$s^2_i = \sum_{k=1}^{n} \frac{(y_{ik} - \overline{y_i})^2}{n - 1} \tag{4.37}$$

$$\overline{y_i} = \frac{1}{n} \cdot \sum_{k=1}^{n} y_{ik} \tag{4.38}$$

$$\bar{\bar{y}} = \frac{1}{p} \cdot \sum_{i=1}^{p} \overline{y_i} \tag{4.39}$$

The equations used for the numerical computation are found in ISO 5725 (Section 14.9.2).

4.3 Data Check

Before the variances were computed, the reported data were checked.

In ISO 5725 R.S. Gardner's version of Dixon's outlier test is specified.

In order to perform the test the data set at each frequency is arranged in the order of magnitude Z(h), h = 1, 2, 3, ... H.

H will be 5 or 6.

The ratios Q_{10low} and Q_{10high} are computed and compared with a table of critical values indicating probable outliers.

$$Q_{10low} = \frac{Z(2) - Z(1)}{Z(H) - Z(1)} \qquad (4.40)$$

$$Q_{10high} = \frac{Z(H) - Z(H-1)}{Z(H) - Z(1)} \qquad (4.41)$$

The 5% and 1% critical values for H = 5 and H = 6 are listed in Table 4.1.

H	5%	1%
5	0.710	0.821
6	0.628	0.740

Table 4.1 Critical values for the Dixon outlier test.

The test was performed on the data material, and the statistical outliers were carefully investigated.

It is obvious that due to the small number of data in each data-set the test will indicate many false outliers.

Example:

In a data-set at a certain frequency the test results are:

44.1 44.2 44.2 44.2 44.2

Performing Dixon's outlier test on the data-set will give answer $Q_{10low} = 1 > 0.821$, i.e. an outlier at the 1% level.

However, common acoustical sense will tell that the first result in the data-set is not an outlier.

All the possible outliers were checked under the supervision of the statistical expert, and it was finally decided that no test results should be rejected from the material.

4.4 Missing and Additional Data

4.4.1 Missing Data

Laboratory no. 1, Statens Tekniska Forskningscentral (VTT), reported that the pane was slightly damaged when unrigged. Therefore VTT decided to abandon the measurement of series no. 2, Mounting Conditions.

The incident took place after the measurements of series no. 1 had been completed. The measurements of series nos. 3 and 4 were performed with the slightly damaged pane. The nature of the damage is described in Appendix C.

4.4.2 Additional Data

Laboratory no. 3, Statens Provningsanstalt (SP), reported 8 test results for series no. 4, Reproducibility within Laboratories, while the measurement programme only assumed 5 test results.

In order to maintain the homogeneity of the data material it was decided to regard three of the test results as additional data.

Referring to the test results, Appendix E, the test results nos. 4.1, 4.2, 4.3, 4.4, and 4.8 were included in the statistical analysis, while nos. 4.5, 4.6, and 4.7 were regarded as additional data.

5. RESULTS

In this section the main results of the cooperative experiment are presented together with the results which can be derived from the total measurement programme.

5.1 Repeatability and Reproducibility

Figure 5.1 shows the calculated repeatability r. Also in Figure 5.1 the reference curve for repeatability from ISO 140 part II is plotted.

Figure 5.2 shows the calculated reproducibility R. In order to illustrate the concept of reproducibility Figure 5.3 shows the mean values of the measured sound reduction index for the 5 laboratories for series no. 3, Repeatability/Reproducibility. The poor reproducibility in the mid-frequency region is clearly reflected in Figure 5.3 and Figure 5.4, which show the derivations from the total mean.

Tables of the calculated repeatability and reproducibility values are found in Appendix H.

The repeatability for the weighted reduction index R_w is 0.7 dB.

The reproducibility for R_w is 3.3 dB.

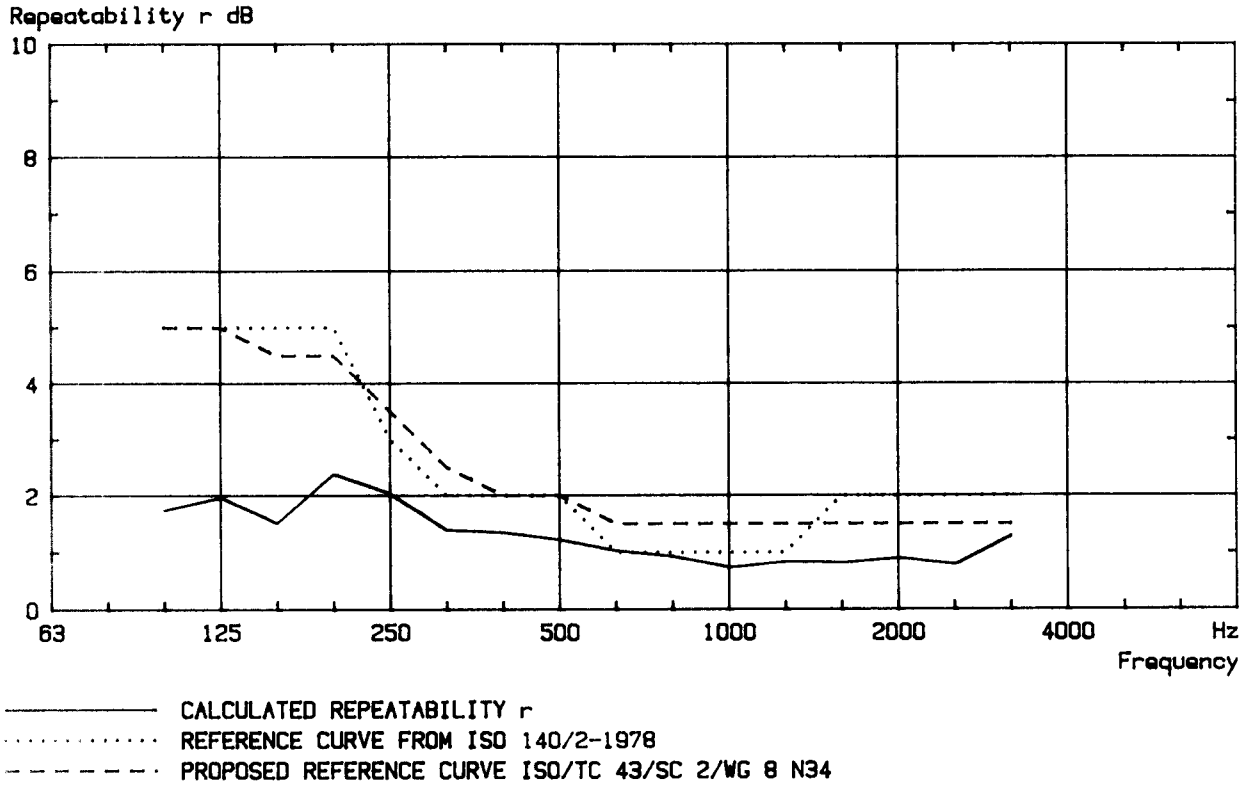


Figure 5.1 The calculated repeatability r and the reference curve from ISO 140 part II.

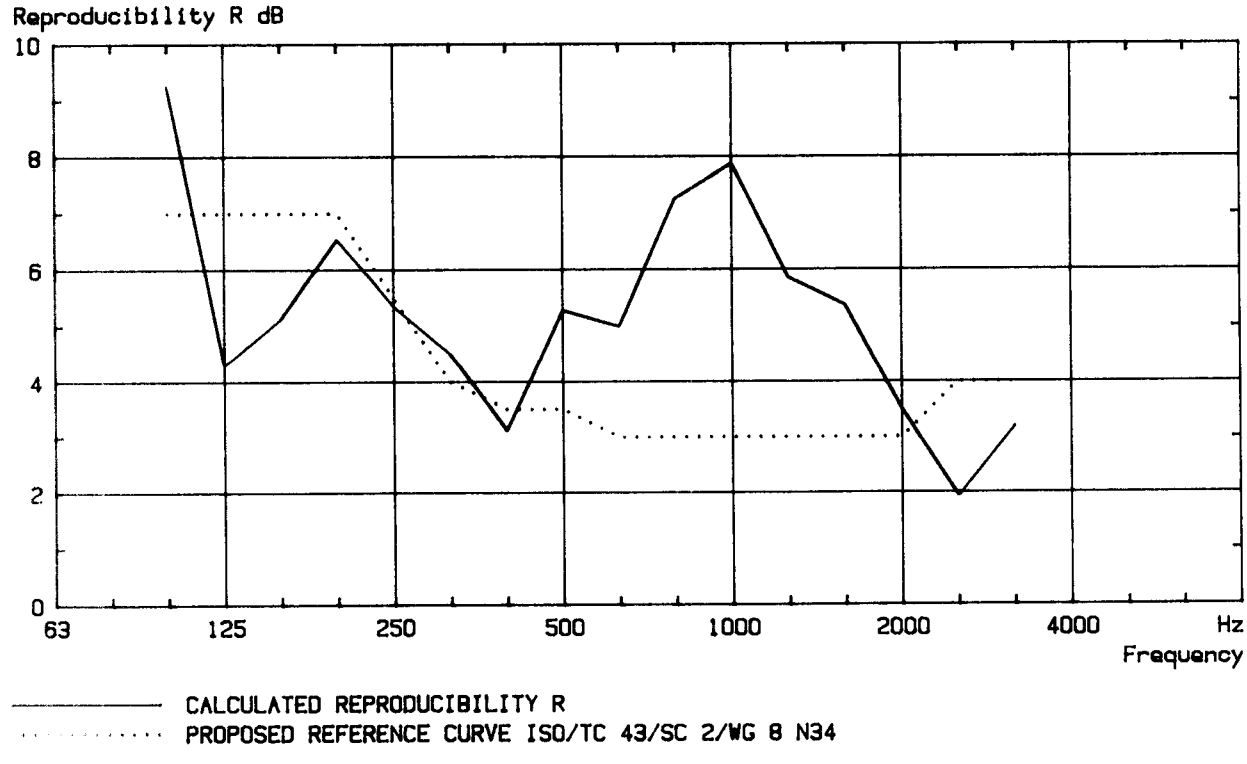


Figure 5.2 The calculated reproducibility R and the reference curve from ISO/TC 43/SC 2/WG 8 N34.

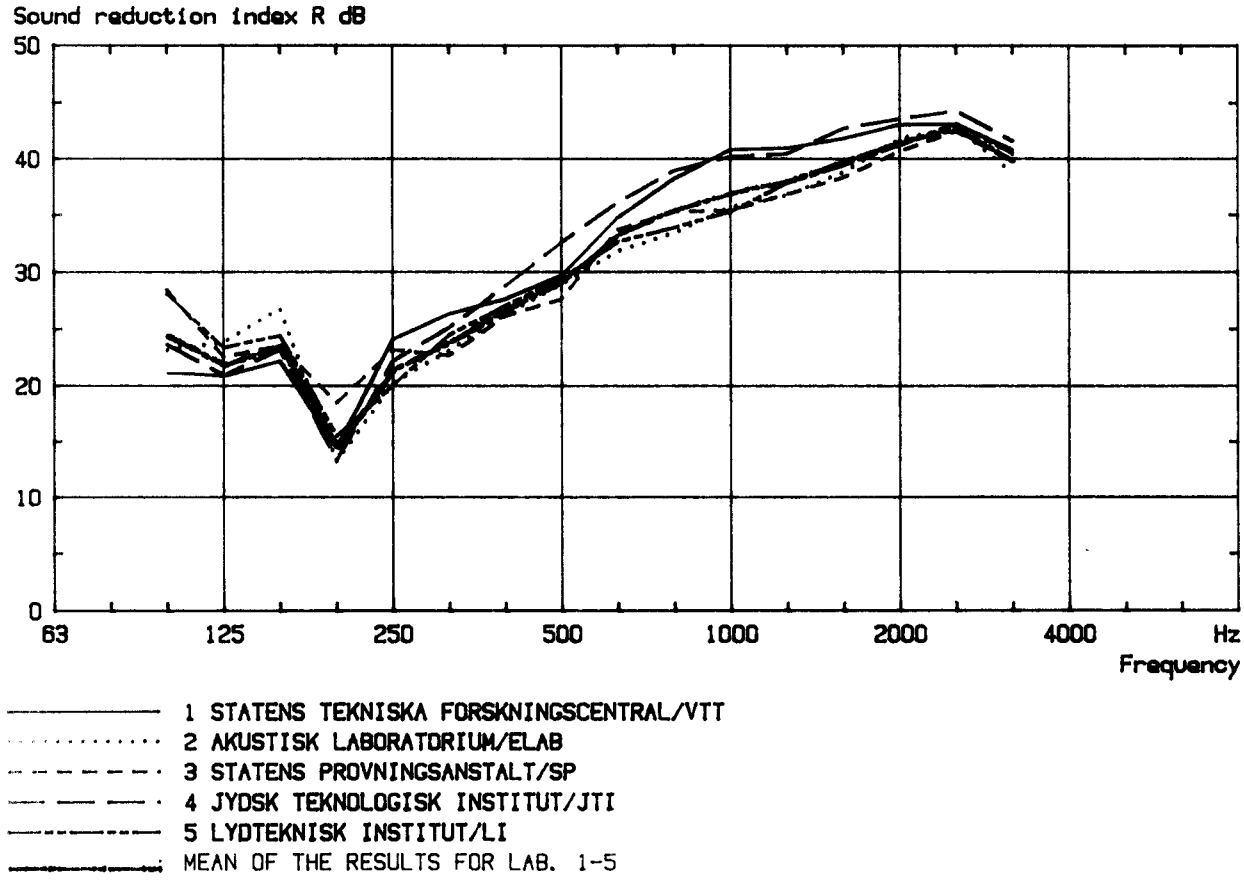


Figure 5.3 Comparison of measured sound reduction index from series no. 3, Repeatability/Reproducibility. Mean values for each laboratory.

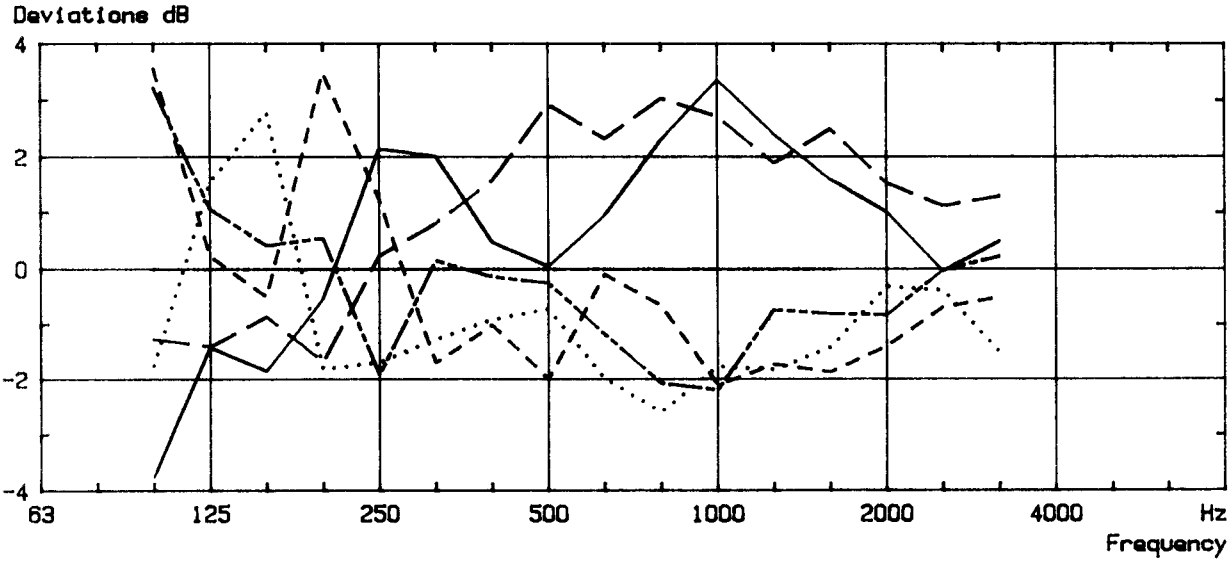


Figure 5.4 Series no. 3. Deviations from the total mean value. As to line types, see Figure 5.3.

5.2 Influence of Stochastic Noise Signal, the Term u

Figure 5.5 shows the estimated standard deviation s_u for the influence of the stochastic noise signal.

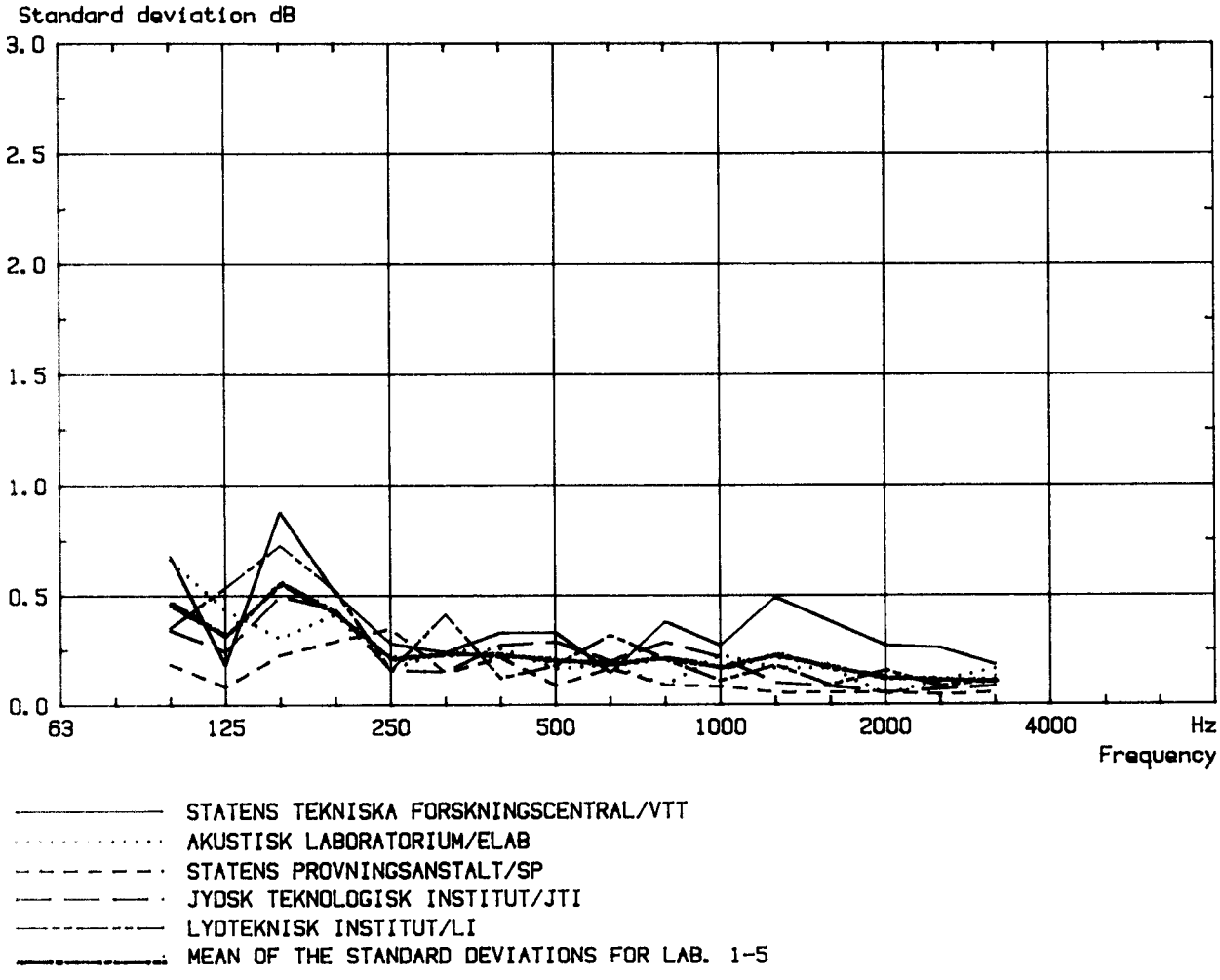


Figure 5.5 Estimate of the standard deviation s_u for the influence of the stochastic noise signal.

5.3 Random Error Component, the Term d

Figure 5.6 shows the estimated standard deviation s_d of the random error component d, accounting for random errors other than the stochastic noise signal.

The standard deviation is computed indirectly, see Eq. 4.22. The values of s_u and s_w needed for the computation are shown on Figures 5.5 and 5.10, respectively.

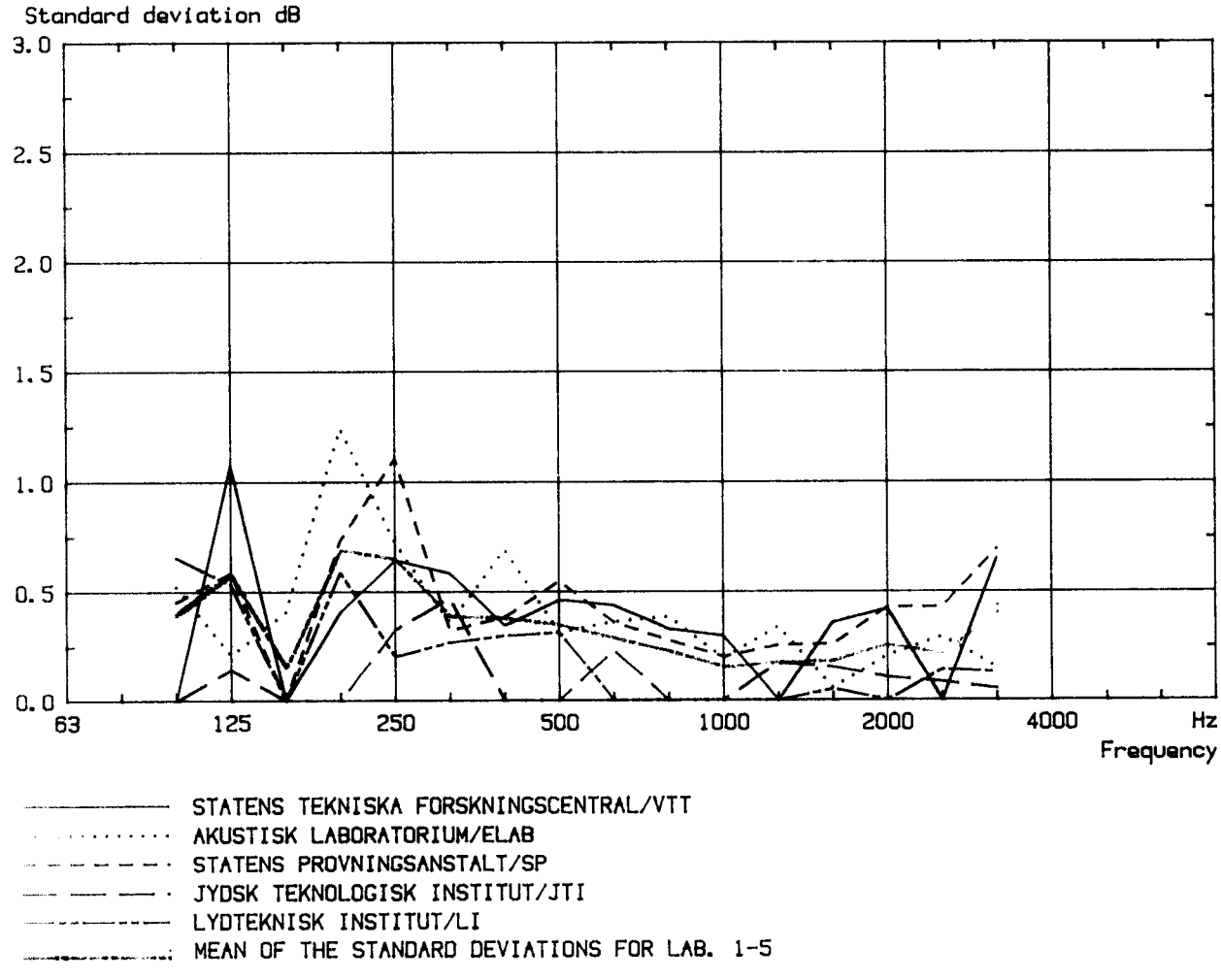


Figure 5.6 Estimated standard deviation s_d of the random error component d.

5.4 Influence of the Different Panes, the Term P

Figure 5.7 shows the estimated standard deviation s_P due to differences between the panes.

The values in Figure 5.7 represent an upper value for s_P as shown in Eq. 4.27.

The values of s_O and s_U needed for the computation of s_P are shown on Figures 5.8 and 5.9, respectively.

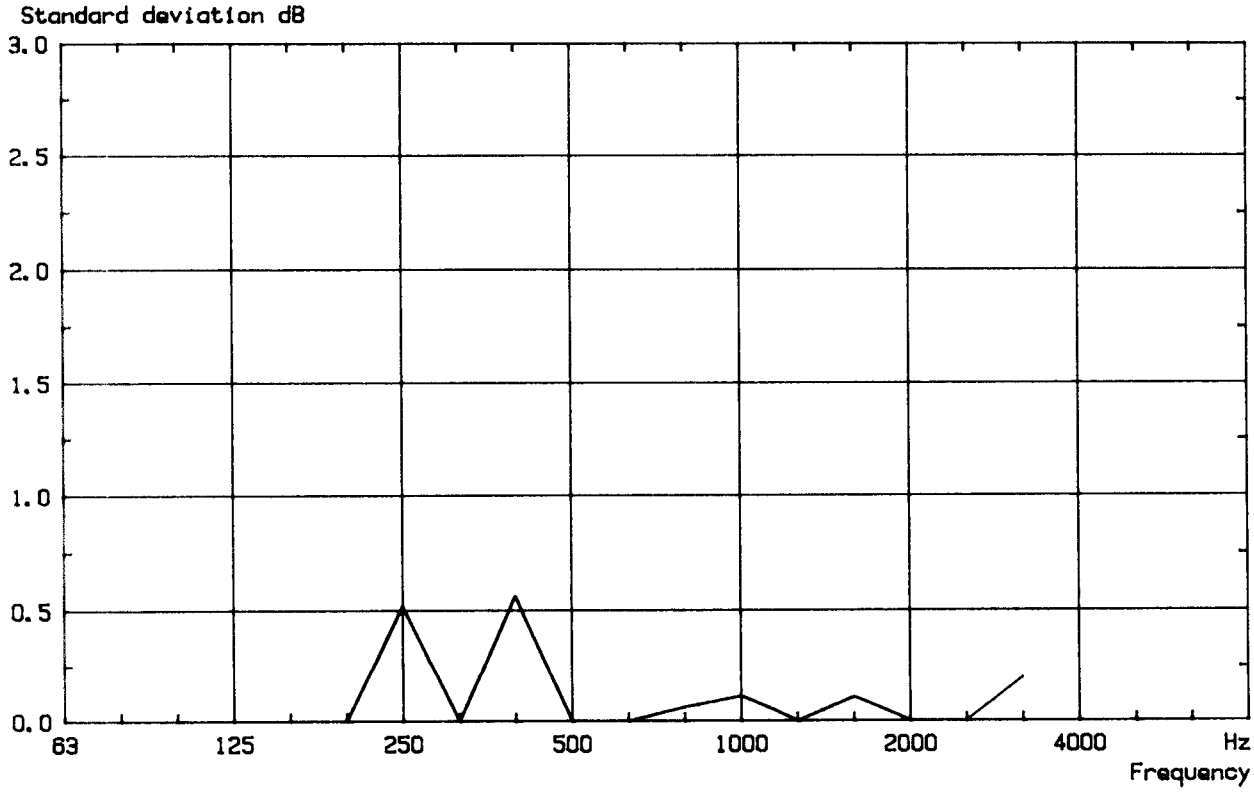


Figure 5.7 The estimated standard deviation sp due to differences between the panes.

It should be noted that the values in Figure 5.7 include the mounting. Hence it can be concluded that remounting has very little influence on the total variance. See also Section 5.8.

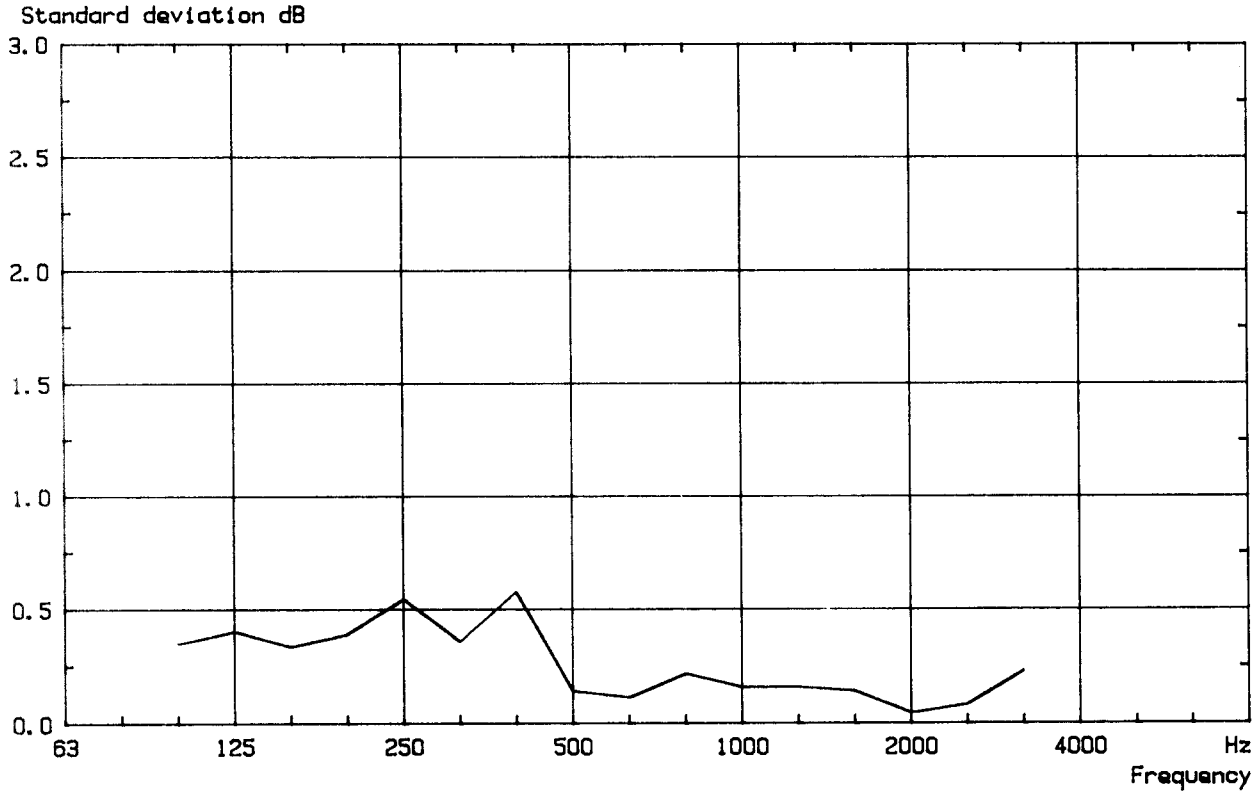


Figure 5.8 Estimated standard deviation s_o for the preliminary test of the 5 panes distributed to the participating laboratories.

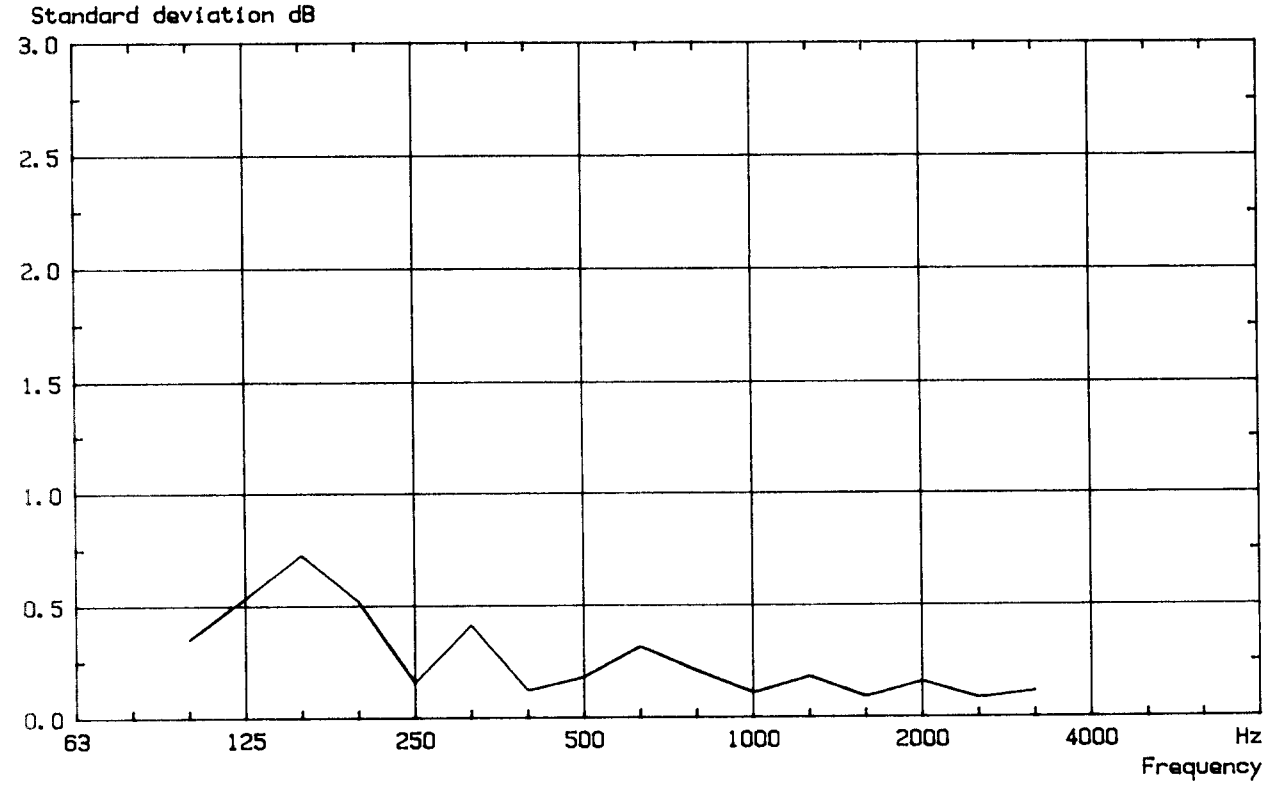


Figure 5.9 Estimated standard deviation s_u of the influence of the stochastic noise signal for laboratory no. 5 which also performed the preliminary tests on the panes.

5.5 The Within-Laboratory Variance and the Repeatability Variance

Figure 5.10 shows the square root s_w of the estimated within-laboratory variance s^2_w for the 5 laboratories. The square root s_r of the estimated repeatability variance $s^2_r = \overline{s^2_w}$ is also shown.

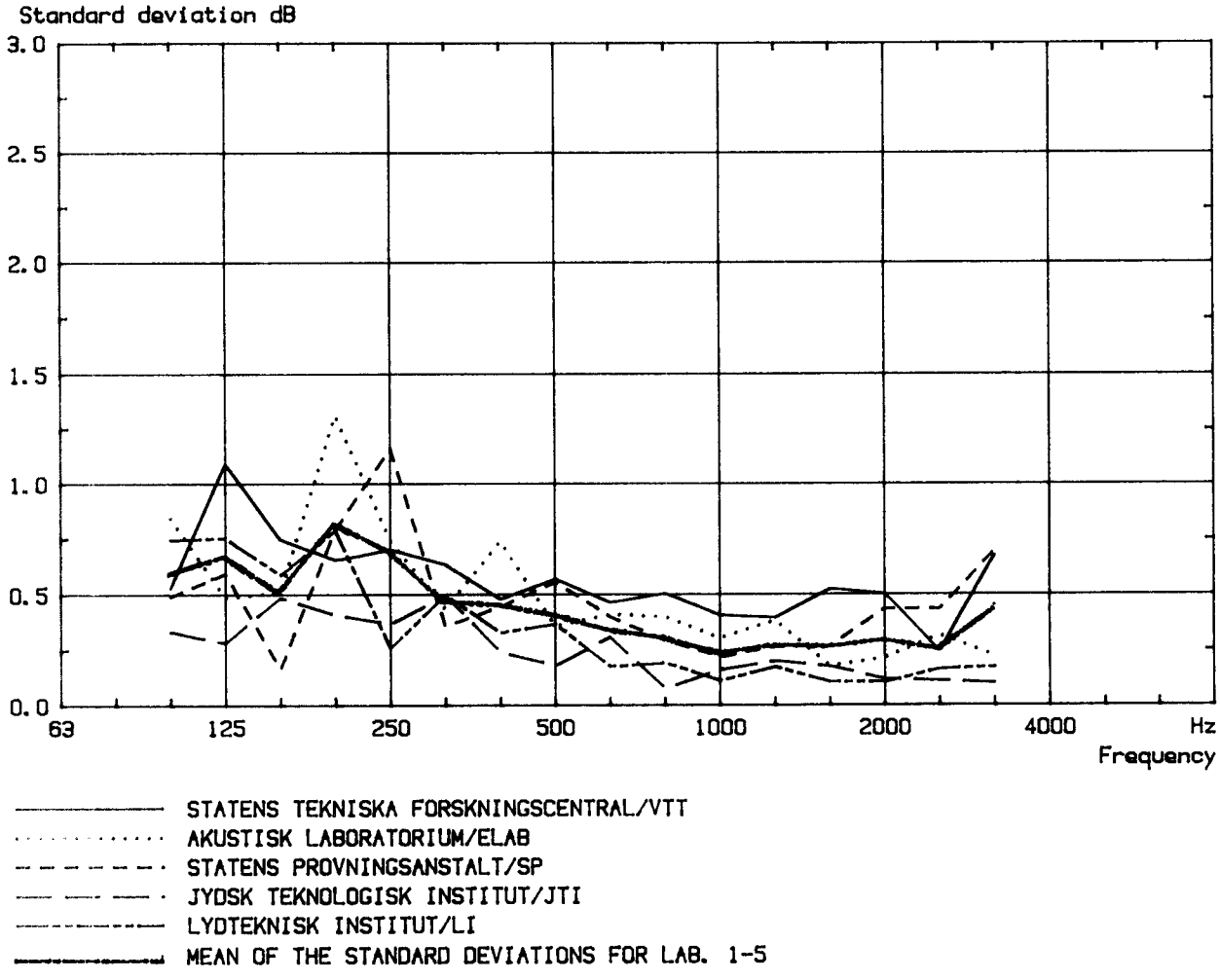


Figure 5.10 Square root s_w of estimated within-laboratory variances and the square root s_r of the estimated repeatability variance.

5.6 The Within-Laboratory Reproducibility Variance and the Term B_o

Figure 5.11 shows the square root s_{IL} of the estimated within-laboratory reproducibility variance, i.e. the results from series no. 4, Reproducibility within Laboratories.

Estimates for the standard deviation s_{B_o} of the within-laboratory variation component B_o are plotted in Figure 5.12. s_{B_o} is computed by means of Eq. 4.29.

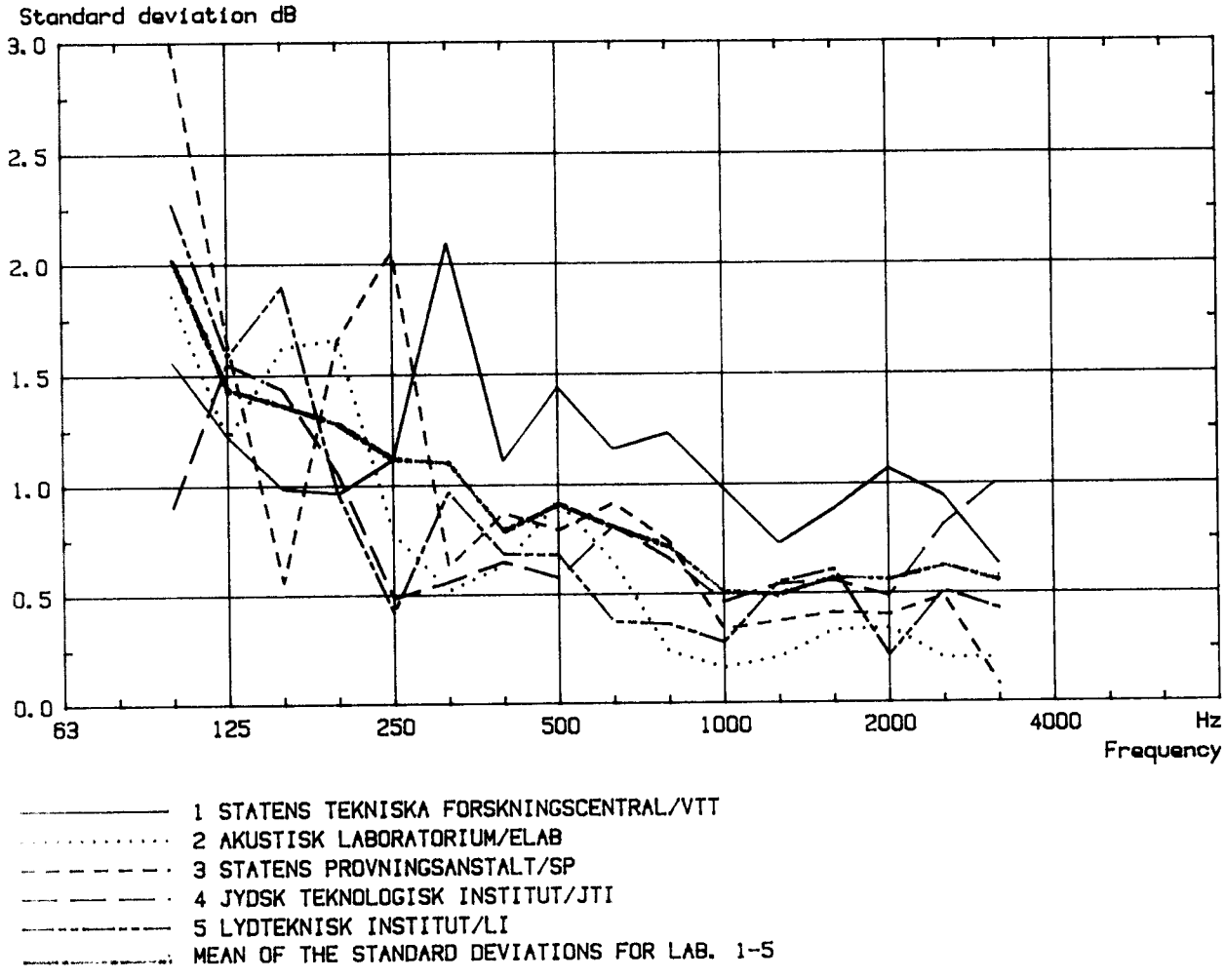


Figure 5.11 The square root s_{IL} of the estimated within-laboratory reproducibility variance.

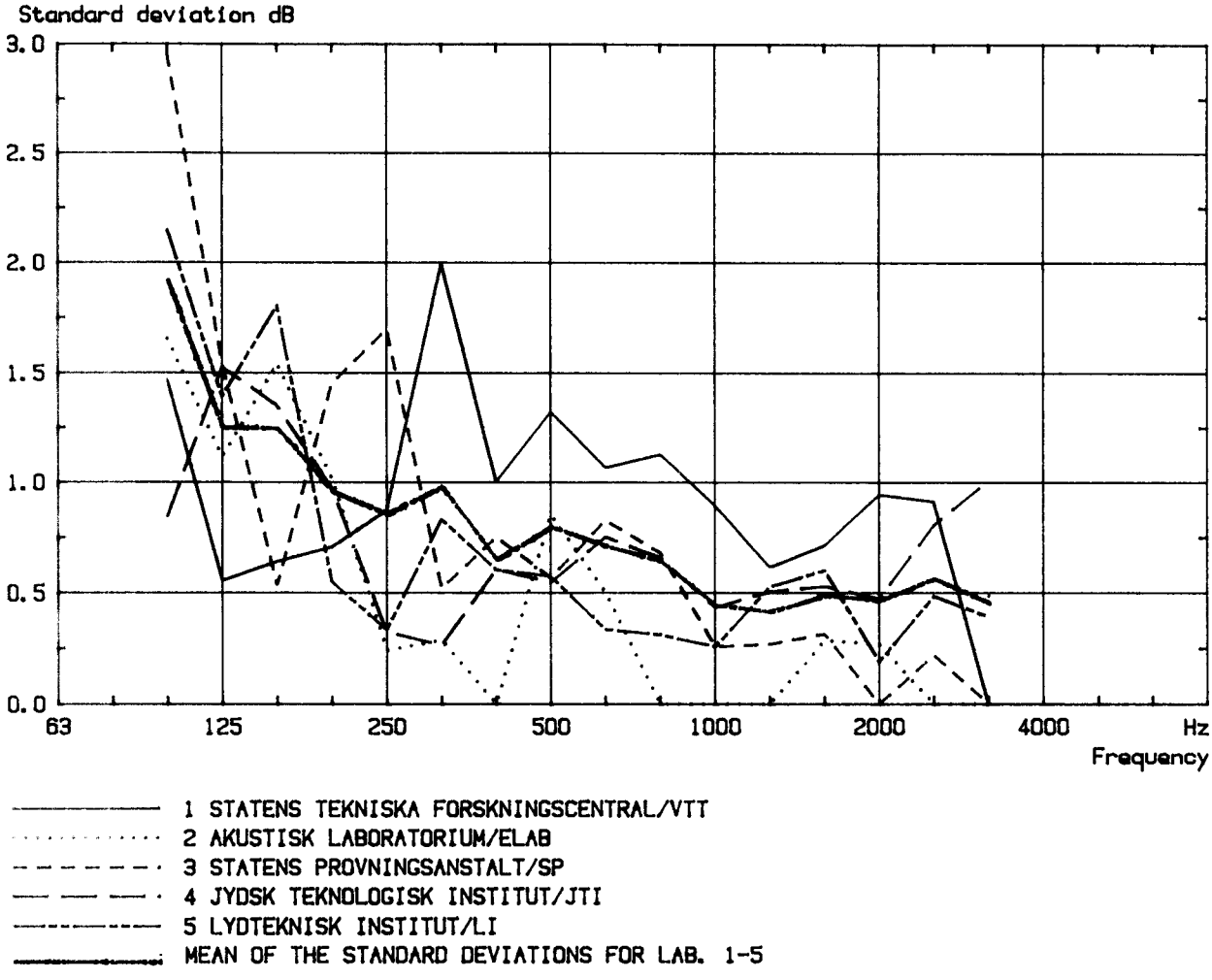


Figure 5.12 Estimated standard deviation s_{B_O} for the within-laboratory variation component B_O.

5.7 The Systematic Component B_s in the Between-Laboratory Variance

Figure 5.13 shows the estimated value s_L for the square root of the between-laboratory variance.

By using Eq. 4.31 the standard deviation s_{B_s} of the systematic component can be computed. This is shown in Figure 5.14.

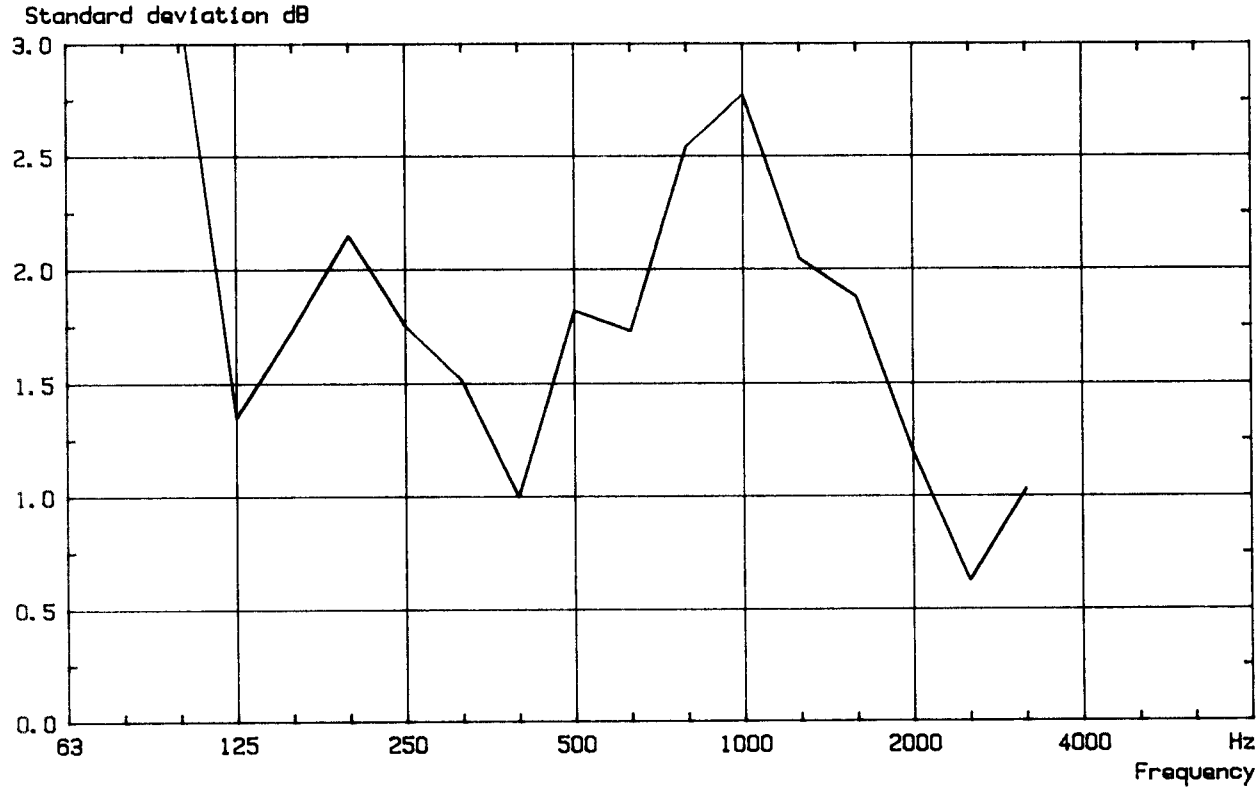


Figure 5.13 Estimate s_L of the square root of the between-laboratory variance s^2_L.

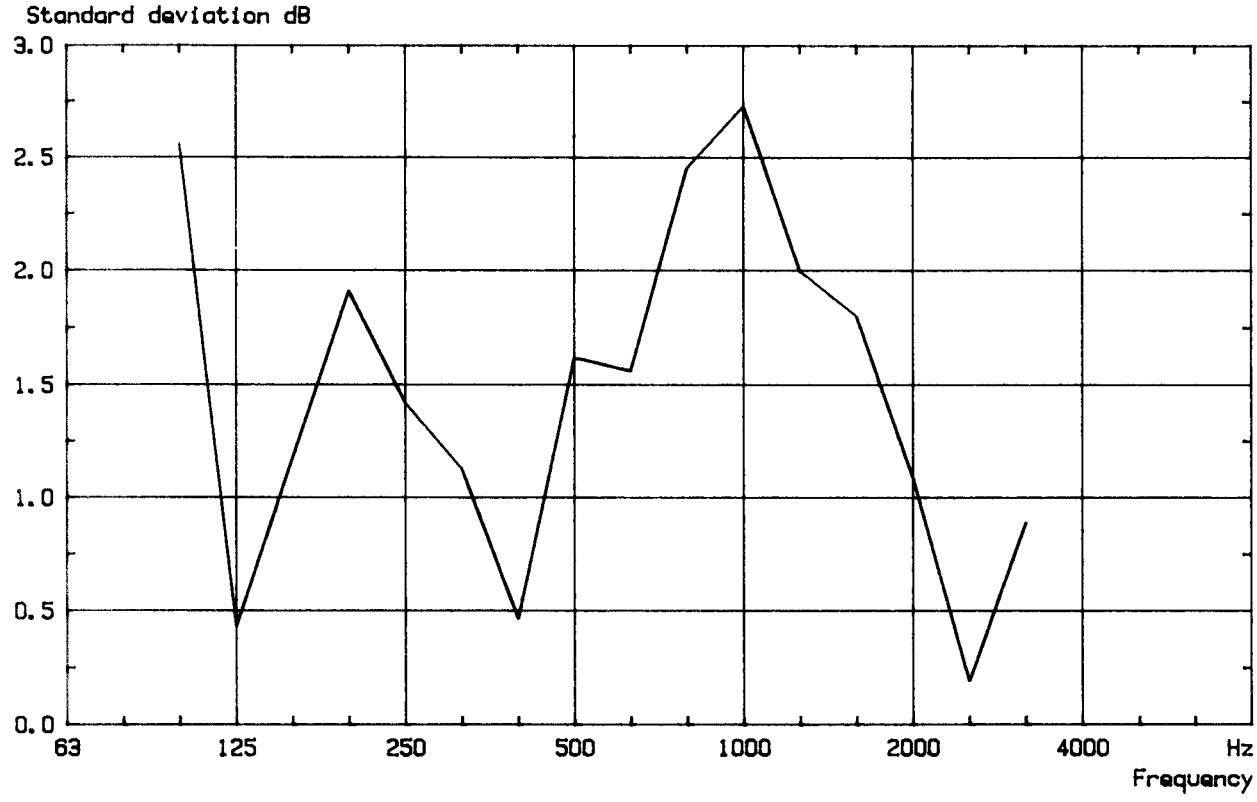


Figure 5.14 Estimated standard deviation s_{B_S} for the systematic component in the between-laboratory variance.

5.8 Remounting, the Term k

Figure 5.15 shows the differences between the results of the measurements in series no. 1 and series no. 2 for 4 laboratories. Laboratory no. 1 did not conduct the measurements in series no. 2.

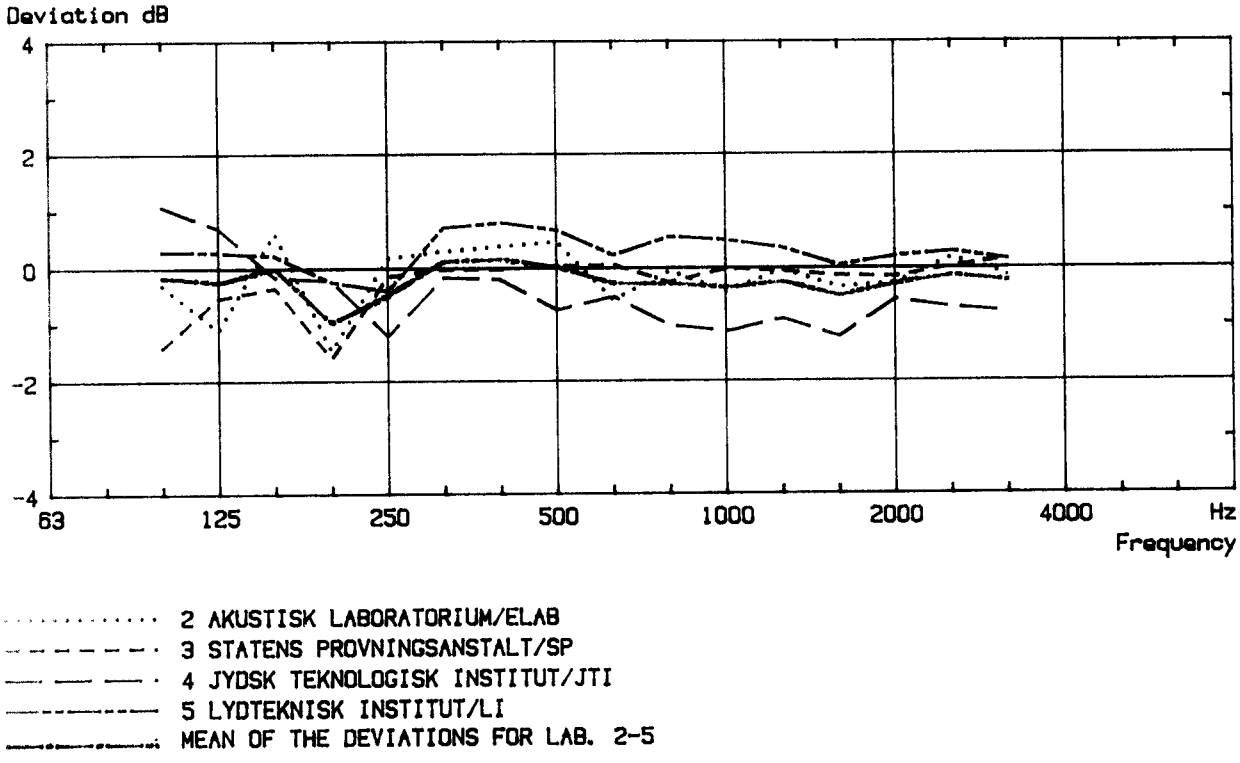


Figure 5.15 Plot of the results from series no. 2 versus the mean values of series no. 1.

By using Eq. 4.32 an estimate of the standard deviation s_k may be found. The results are shown in Figure 5.16.

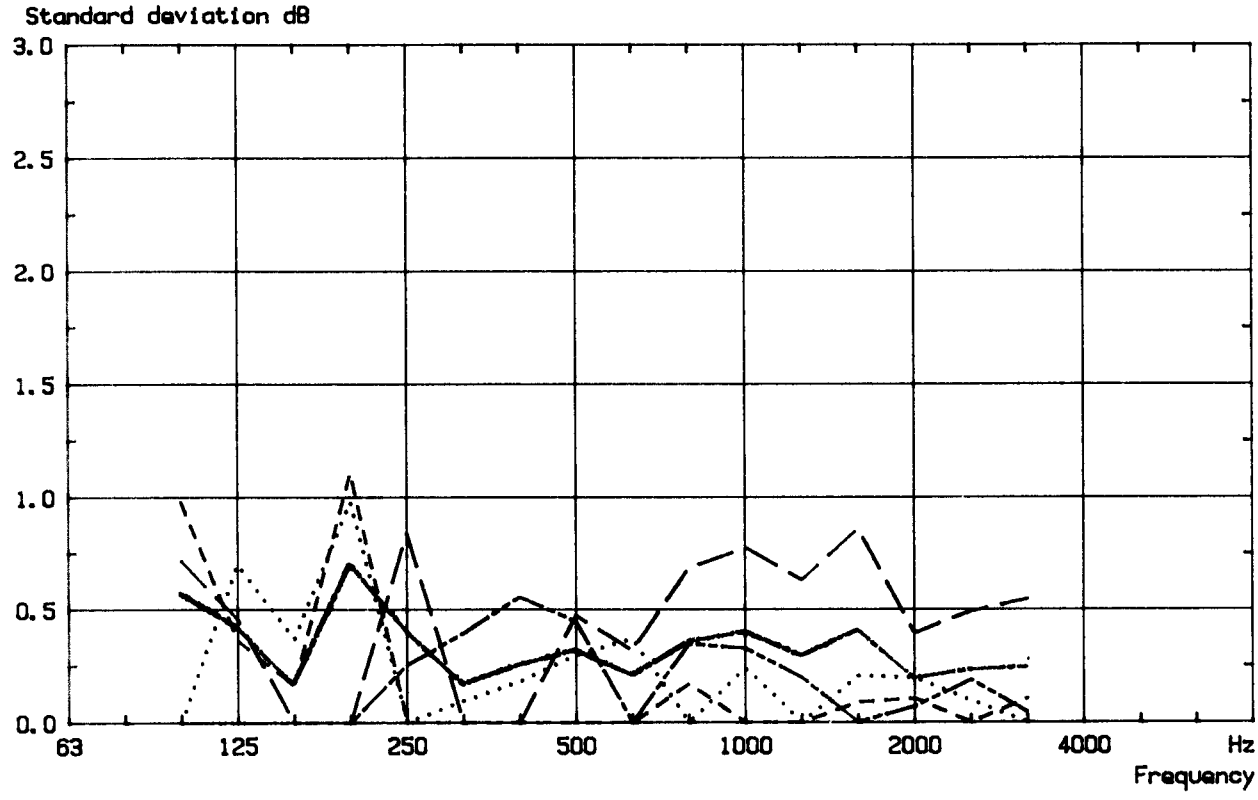


Figure 5.16 Estimated standard deviation s_K for the influence of the remounting.

5.9 Comments on the Results

From Figure 5.1 it is seen that the values for r are below or at the reference curve from ISO 140 part II and the proposed new reference curve from ISO/TC 43/SC 2/WG 8 N34.

The values for R are high in the low frequency range. This is expected because all the random variations in an acoustic experiment are normally expected to grow with decreasing frequency. However, it is seen that the values are also very high around 200 Hz and 1000 Hz.

In Figure 5.17 the mean values of the estimated standard deviations for the various error components are assembled. From Figure 5.17 it is seen that the term B_S, the systematic variations between laboratories, is the most important factor. B_S has maximum values around 200 Hz and 1000 Hz. It should be noted that Figure 5.17 shows the standard deviations corresponding to different error components. When calculating the total standard deviation, the variances - i.e. the square of the standard deviations - have to be used. Hence the importance of the term B_S is even more important than appearing from the figure.

The resonance frequency for the double glazing is within the 200 Hz 1/3 octave band. Therefore some variations in this frequency range are expected because unavoidable variations in the sound distribution from laboratory to laboratory will influence the measured sound reduction index near the resonance frequency.

The peak around 1000 Hz, where the sound reduction index is high, is due to specific laboratory effects (the term B in Eq. 4.1).

It is not the aim of this project to explain these variations. However, one possible clue to the explanation could be that the wall in which the pane is mounted is of a heavy construction in some laboratories and of a lightweight or mixed construction in others.

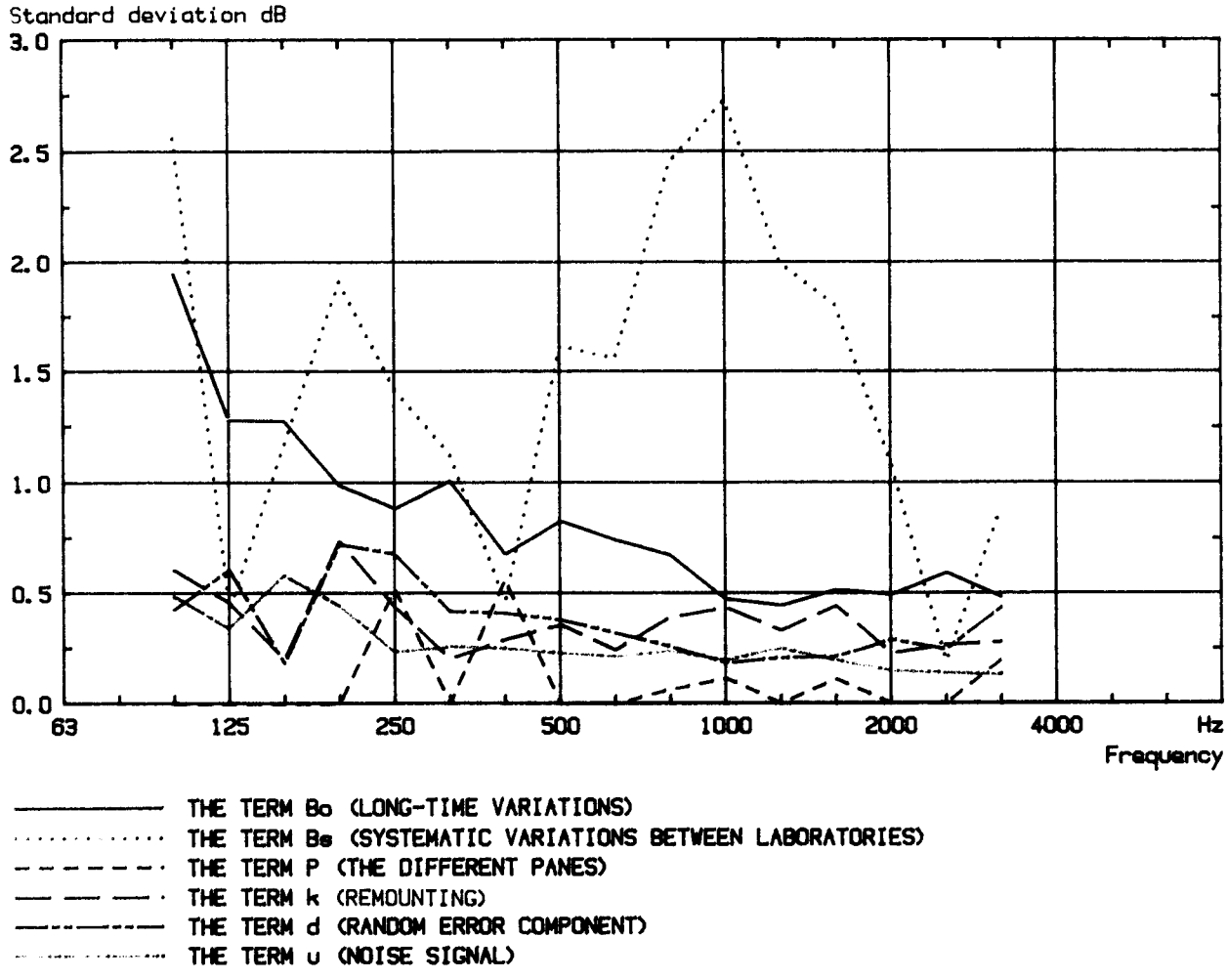


Figure 5.17 Mean values of the estimated standard deviations for the various error components.

Because only one measurement was conducted in series no. 2, Mounting Conditions, the estimate of the standard deviation is somewhat doubtful. From Figure 5.16 it seems that s_k is somewhat higher than s_d and s_u. However, from the preliminary measurements, where remounting was also included, it seems that s_k is smaller than s_p which is already very small.

6. COMPARISON WITH OTHER COOPERATIVE EXPERIMENTS

In Figures 6.1 and 6.2, respectively, the values for r and R are compared with the results of two other cooperative experiments.

6.1 Nordtest-Project NT 360-82

In parallel to this project a similar cooperative experiment was conducted in which the repeatability and the reproducibility were determined using a pane in a staggered test opening, see [5]. The same type of pane was used. However, due to the frame the panes were slightly smaller (1.09 m × 1.09 m). On Figure 6.1 it is seen that the repeatability found in the two Scandinavian experiments is nearly identical. On Figure 6.2 it is seen that the reproducibility is much better when measuring with a staggered test opening.

6.2 DIN-Project

Deutsches Institut für Normung e.V. (DIN) has submitted a report on a Round Robin test conducted by 8 German laboratories [6].

The test object simulated a double-window construction. Two chipboards of 16 and 8 mm thick were mounted on a frame made of 22 mm chipboard. The cavity between the plates had a width of 76 mm and was filled with mineral wool.

The weighted sound reduction index R_w was approximately 45 dB whereas R_w for the Nordtest 235-80 test panes is approximately 34 dB. Therefore it is not surprising that the repeatability and the reproducibility are poorer for the German experiment than for the Nordtest experiment. The influence of laboratory design will be more important in the German than in the Scandinavian experiments.

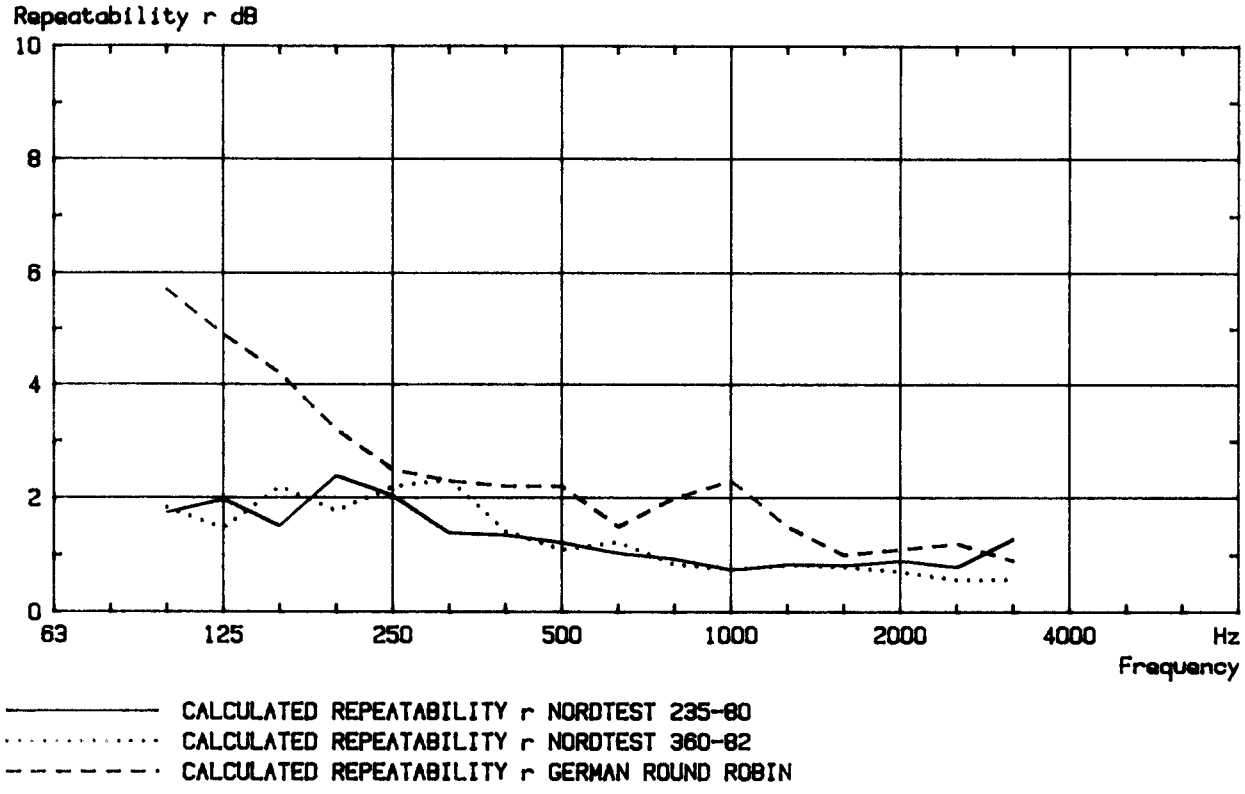


Figure 6.1 Comparison between Nordtest 235-80, Nordtest 360-82, and German results for repeatability.

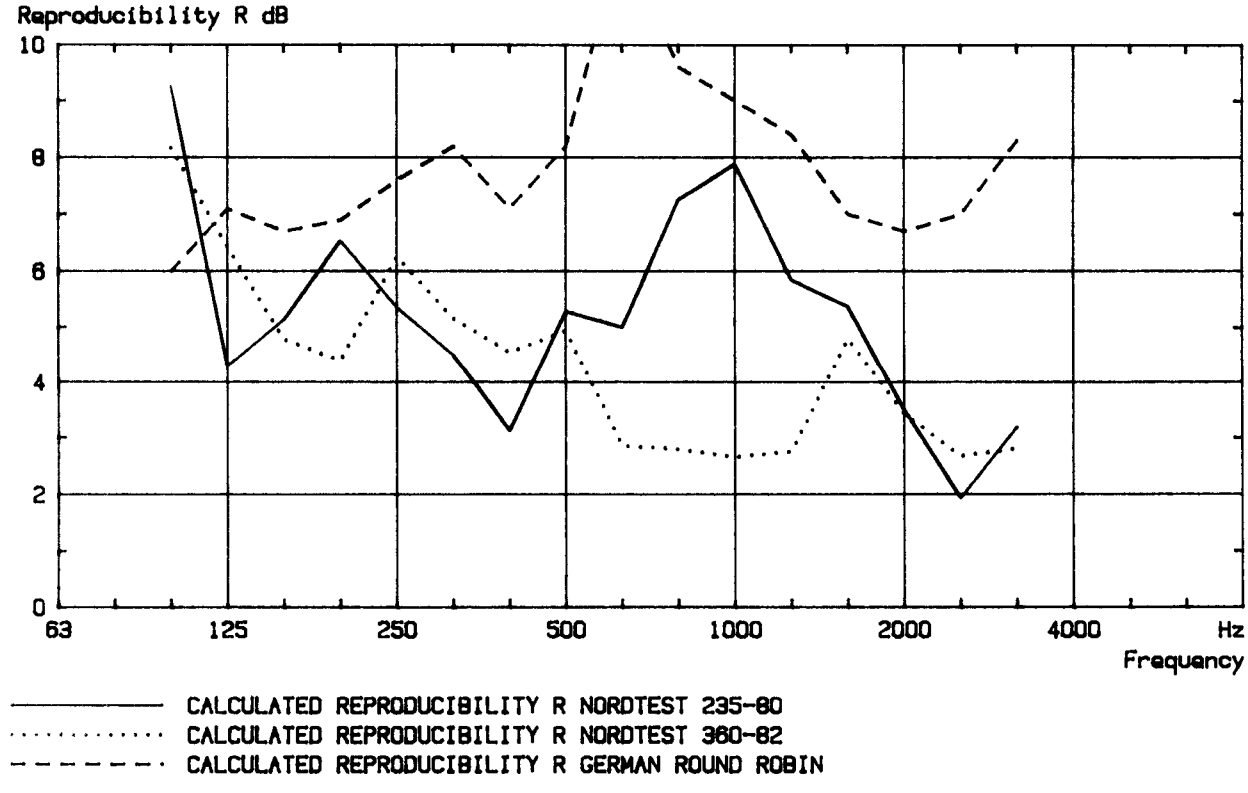


Figure 6.2 Comparison between Nordtest 235-80, Nordtest 360-82, and German results for repeatability.

6.3 Other Experiments

Two more projects including Round Robin measurements of sound reduction index may be mentioned [7] and [8]. The first project deals with doors and the second with walls.

In these projects the repeatability and the reproducibility were not calculated.

7. CONCLUSIONS

The repeatability r and the reproducibility R have been calculated from the results of the cooperative experiment. The test specimen was a sound insulating glazing with $R_w \approx 34$ dB.

The results for r are below or just at the reference curve for repeatability stated in ISO 140 part II.

The values for R are much higher than the values for r, primarily owing to the fact that the variance due to systematic differences between the laboratories is quite high.

The variances for the various components contributing to the total variance have been estimated. The results of the estimates show that variances due to other factors than the systematic differences between laboratories are relatively small.

Based on the experience from this project future investigations should include details concerning the wall with the test opening.

8. REFERENCES

[1] ISO 140-1978(E) "Acoustics - Measurements of sound insulation in buildings and of building elements".
Part 1: Requirements for laboratories
Part 2: Statement of precision requirements
Part 3: Laboratory measurements of airborne sound insulation of building elements

[2] ISO 5725-1981(E), Precision of test methods - Determination of repeatability and reproducibility by inter-laboratory tests.

[3] Nic Michelsen & Birgit Rasmussen, "Laboratory Effects on the Measured Sound Reduction Index of Windows and Glazings". Danish Acoustical Institute, Report No. 34, 1982.

[4] Nic Michelsen, "Repeatability of Sound Insulation Measurements". Danish Acoustical Institute, Report No. 36, 1982.

[5] Birgit Rasmussen, "Measurement of Sound Reduction Index for Glazings in a Staggered Test Opening" (Nordtest-project NT 360-82). Danish Acoustical Institute, Report No. 119, 1984.

[6] K. Bahlo Dittmann, P. Dämmig, A. Eisenberg, H. Schulze, "Bericht über den Ringversuch 'Kastendoppelfenster'. Deutsches Institut für Normung, 1978.

[7] Nic Michelsen, "Sammenlignende reduktionstalsmålinger for døre målt i laboratorium". Lydteknisk Laboratorium, rapport nr. 4, 1976.

[8] T. Kihlman and A.C. Nilsson, "The Effects of Some Laboratory Designs and Mounting Conditions on Reduction Index Measurements". Journal of Sound and Vibration (1972) 24 (3), p. 349-364.

APPENDIX A

Control of the Test Specimens

CONTROL OF THE TEST SPECIMENS

Six sound insulating panes were delivered to Lydteknisk Institut for preliminary measurements in order to check the homogeneity. The panes and the associated measurements are numbered 1-6.

A special test procedure was used in order to minimize the variations due to other factors than the panes.

The design of the test procedure was based on the experiences from [4].

The sound reduction index is evaluated from

$$R_{12} = L_1 - L_2 + 10 \log \frac{S \cdot T_2}{0{\cdot}16\ V_2} \quad dB$$

where

R_{12} denotes the sound reduction index measured from room no. 1 (source room) to room no. 2 (receiving room),

L_1 and L_2 are the sound pressure levels in the two rooms,

T_2 is the reverberation time in the receiving room,

V_2 is the volume of the receiving room, and

S is the area of the test specimen.

If the measuring direction is reversed, a similar expression can be written for R_{21}

$$R_{21} = L_2 - L_1 + 10 \log \frac{S \cdot T_1}{0{\cdot}16\ V_1} \quad dB$$

The resulting sound reduction index R was computed as the average between R_{12} and R_{21}.

The sound pressure levels in the rooms were measured with rotating microphones with an integration time of 32 sec.

The sound pressure levels in the receiving room were corrected for the influence of the background noise L_{B1} and L_{B2}. T_1 and

T_2 were determined by 9 excitations (abrupted noise) in each 1/3 octave band.

In order to minimize the variations L_B and T were only measured during the first measurement. For the remaining 5 panes the values for L_B and T from no. 1 were used.

To check the influence of L_B and T an additional measurement no. 7 was conducted on pane no. 6.

Here the values of L_1 and L_2 from no. 6 were used, and L_B and T were measured again.

In Table A.1 the differences between no. 6 and 7 are listed. The differences are very small.

	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	R_W
06	27,0	23,7	23,1	15,9	20,4	24,7	27,9	29,3	32,8	33,9	35,7	37,8	39,4	41,1	42,8	40,1	33,5
07	27,0	23,8	23,2	15,9	20,3	24,6	27,9	29,4	32,8	33,8	35,8	37,9	39,4	41,1	42,9	40,1	33,5
Δ6-7	0	-0,1	-0,1	0	0,1	0,1	0	-0,1	0	0,1	-0,1	-0,1	0	0	-0,1	0	0

Table A.1 Differences between measurements no. 6 and 7.

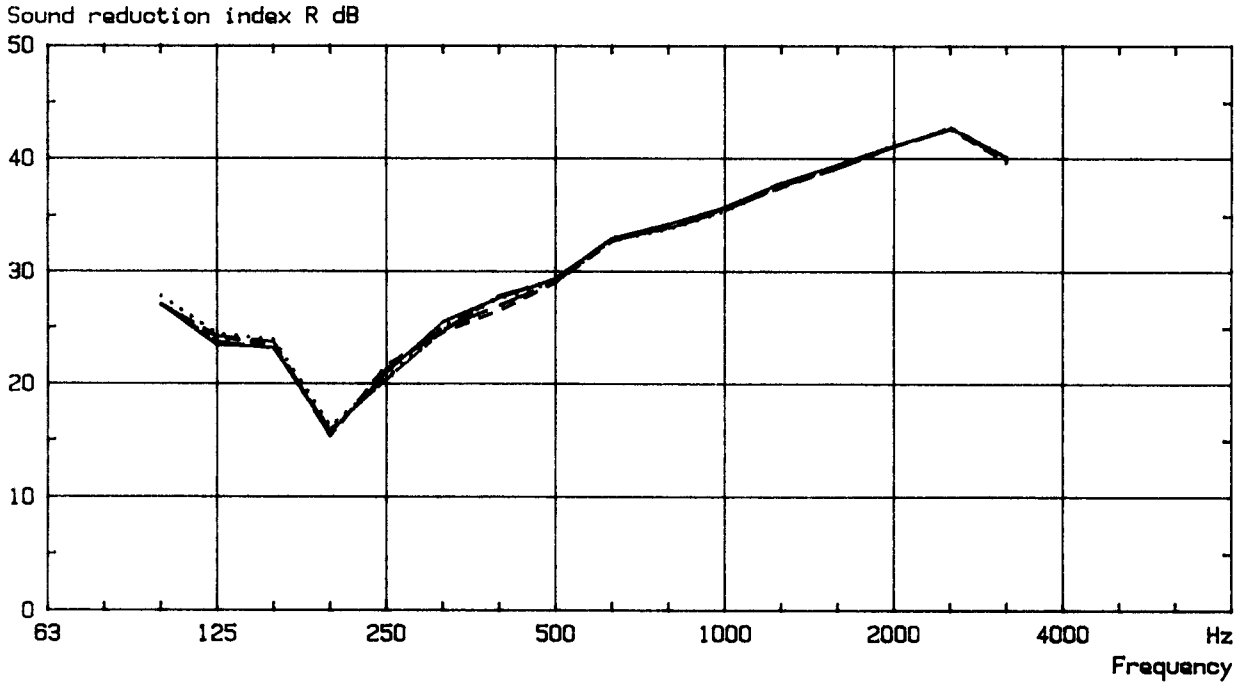
During all the preliminary measurements the loudspeaker positions and the microphone paths were kept unchanged.

The results were corrected for transmission through the surrounding wall according to Nordtest method NT ACOU 013-1979.

Dixon's outlier test was performed on the results for the six panes and showed a possible outlier for pane no. 5.

Therefore it was decided to keep pane no. 5 as a reserve and to distribute panes nos. 1, 2, 3, 4, and 6 to the participating laboratories.

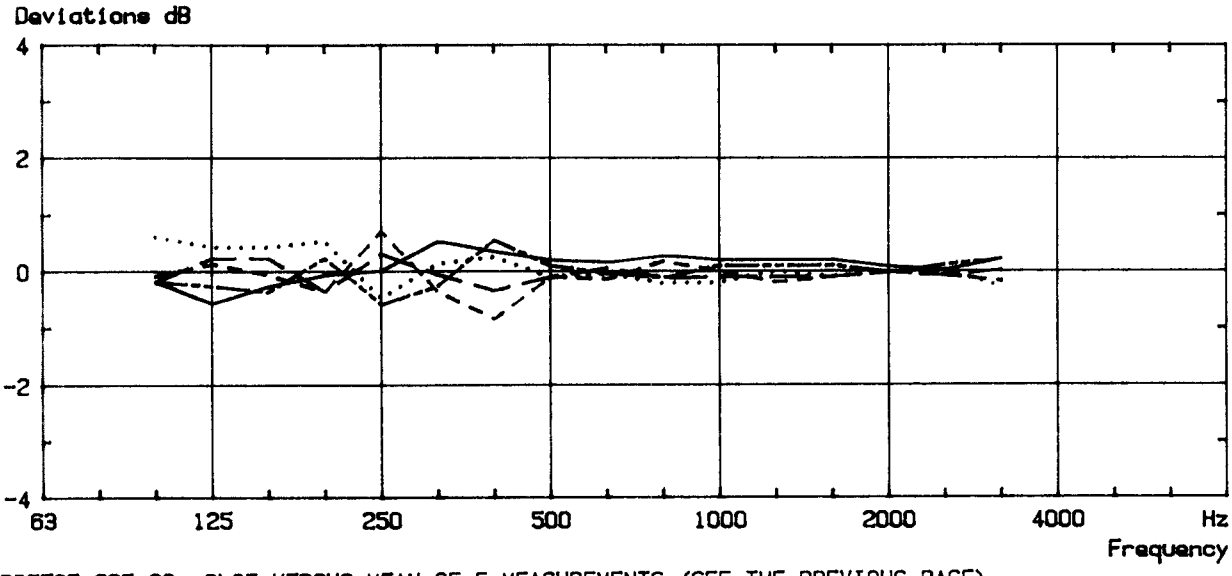
The results for these 5 panes are shown on the figures on the two following pages.



NORDTEST 235-80
LABORATORY : LYDTEKNISK INSTITUT
CONTROL OF TEST SPECIMEN

——————— 1
. 2
– – – – – – 3
— — — — 4
———·———· 6

Measurement Frequency Hz	1.0 dB	2.0 dB	3.0 dB	4.0 dB	6.0 dB	Mean dB
100	27.0	27.8	27.1	27.0	27.0	27.2
125	23.4	24.4	24.1	24.2	23.7	24.0
160	23.2	23.9	23.4	23.7	23.1	23.5
200	15.6	16.2	15.3	15.3	15.9	15.7
250	21.0	20.5	21.7	21.3	20.4	21.0
315	25.5	25.1	24.6	24.9	24.7	25.0
400	27.7	27.6	26.5	27.0	27.9	27.3
500	29.4	29.1	29.1	29.1	29.3	29.2
630	33.0	32.8	32.7	32.9	32.8	32.8
800	34.3	33.8	34.2	33.9	33.9	34.0
1000	35.8	35.4	35.6	35.5	35.7	35.6
1250	37.9	37.7	37.5	37.6	37.8	37.7
1600	39.5	39.2	39.2	39.2	39.4	39.3
2000	41.2	41.1	41.1	41.1	41.1	41.1
2500	42.7	42.7	42.6	42.6	42.8	42.7
3150	40.1	39.6	39.7	39.9	40.1	39.9
Rw	33.7	33.5	33.4	33.4	33.5	33.5
Δ_{max}	-8.1	-7.3	-8.1	-8.1	-7.6	



NORDTEST 235-80, PLOT VERSUS MEAN OF 5 MEASUREMENTS (SEE THE PREVIOUS PAGE)
LABORATORY : LYDTEKNISK INSTITUT
CONTROL OF TEST SPECIMEN

——————— 1
. 2
- - - - - - - 3
— — — — · 4
——— · — · — 6

		Deviations from mean:				
Measurement Frequency	Mean	1.0	2.0	3.0	4.0	6.0
Hz	dB	dB	dB	dB	dB	dB
100	27.2	-0.2	0.6	-0.1	-0.2	-0.2
125	24.0	-0.6	0.4	0.1	0.2	-0.3
160	23.5	-0.3	0.4	-0.1	0.2	-0.4
200	15.7	-0.1	0.5	-0.4	-0.4	0.2
250	21.0	0.0	-0.5	0.7	0.3	-0.6
315	25.0	0.5	0.1	-0.4	-0.1	-0.3
400	27.3	0.4	0.3	-0.8	-0.3	0.6
500	29.2	0.2	-0.1	-0.1	-0.1	0.1
630	32.8	0.2	-0.0	-0.1	0.1	-0.0
800	34.0	0.3	-0.2	0.2	-0.1	-0.1
1000	35.6	0.2	-0.2	0.0	-0.1	0.1
1250	37.7	0.2	0.0	-0.2	-0.1	0.1
1600	39.3	0.2	-0.1	-0.1	-0.1	0.1
2000	41.1	0.1	-0.0	-0.0	-0.0	-0.0
2500	42.7	0.0	0.0	-0.1	-0.1	0.1
3150	39.9	0.2	-0.3	-0.2	0.0	0.2
Rw	33.5	0.2	0.0	-0.1	-0.1	0.0

APPENDIX B

Instruction for Participating Laboratories

1982.09.17

NORDTEST 235-80

INSTRUCTION FOR COOPERATIVE EXPERIMENT FOR TEST ON REPEATABILITY AND REPRODUCIBILITY - FINAL VERSION

The aim of the experiment is to provide data on the repeatability and reproducibility of a sound reduction index measurement carried out according to ISO 140.

It is very important that instructions given are followed in all details and that data are reported in the way specified, preferably before 1st December, 1982.

The test specimen is a sound insulating pane 4/4-15-4 manufactured by Scanglas A/S, Denmark. Each participating laboratory will receive a pane (1190 mm x 1190 mm) together with other materials necessary for the mounting of the pane. After having carried out their measurements the laboratories are asked to keep their test object.

Measurement Facility

The measurement facility shall be in accordance with ISO 140/I.

The test aperture shall have a height of 1.21 m and a width of 1.21 m. Sound transmitted by other paths than via the test specimen shall be corrected for according to NT ACOU 013.

Test Method

The measurement procedure shall follow the instructions in ISO 140/III. As these instructions are, however, rather weak, the instructions in the example of test procedure in Annex B should be fulfilled, too. It should be noted that for the sound pressure level measurements Annex B prescribes two positions of the loudspeaker system.

The possibility exists to measure the sound reduction index in both directions using only one position of the loudspeaker system in each room.

The measurements are carried out using 1/3 octave filtering in the frequency range 100 Hz to 3150 Hz. Measurement results are rounded to one decimal place. R_w-values (ISO/DIS 717/3) are also to be calculated to one decimal place. Measurement are re-
./. ported on the enclosed sheets in clear handwriting.

The position of the test object in the aperture shall be chosen to give niches at both sides of the insulating pane with a ration in depths of 1:2. The laminated glass (4/4) shall face the niche with the smallest depth.

The pane is kept in place by 25 mm x 25 mm wooden lists mounted from both sides of the pane. The wooden lists are secured to the test aperture using 5 screws in each list. The procedure of installation will be as follows:

1. Find the position of the wooden lists on one side of the pane and mount these lists.
2. Use blocks with a thickness of 34 mm to find the position of the wooden lists on the other side of the pane and mount and demount these lists.
3. Mount the soft rubber band on the wooden lists in a position which will allow you to top-seal the pane in 2 mm depth.
4. The pane is to be placed in the aperture resting on two 25 mm x 70 mm blocks as shown in the figure. The height of the blocks should be adjusted in order to have a nominal 10 mm joint at all sides of the pane.
5. Stop the joint in the perimeter with mineral wool as tight as possible without bending the wooden lists already mounted.
6. Mount the soft rubber band on the loose wooden lists in a position which will allow you to top-seal the pane in 2 mm depth.
7. Mount the wooden lists at the other side of the pane.
8. Top-seal the pane at both sides with the elastic sealant.
9. Seal at both sides of the pane the joints between the wooden lists and the test aperture and the joints in the corners between the wooden lists.
10. Wait at least for 3 hours in order to let the sealing material change to an elastic material.

Measurement Programme

1. Influence of Stochastic Noise Signal

Conduct 5 measurements (1.1-1.5) using the same loudspeaker positions and microphone positions or microphone paths for all the measurements.

2. Mounting Conditions

Demount the test object and clean as well as possible the pane and the wooden lists for rubber band and sealing material. Remount the test object and conduct a single measurement (2.1) using the same loudspeaker positions and microphone positions or microphone paths as used for measurements 1.1-1.5.

3. Repeatability/Reproducibility

Conduct 6 measurements (3.1-3.6) under repeatability conditions. The same measurement procedure should be used for all the measurements and no changes should be made in the rooms. Each measurement should be carried out independently of the other 5. Before running this part of the measurement programme each laboratory definestheir measurement procedure. This procedure must fulfil the specifications in "Test Method", but still some questions are open concerning the loudspeaker system and microphone positions or microphone paths. Therefore each laboratory is asked to treat this as they would do running their normal tests.

If your loudspeakers are normally in the same position(s) and are not moved except on special occasions, you should not make any changes during this test. If your loudspeakers are normally in the same position(s), but are frequently moved between tests, you should use the same positions, but re-install the loudspeakers before each measurement with the degree of accuracy you normally use.

Considering the choice of microphone position or microphone path you must again consider how you normally run a test and what variations in positions or paths you would normally accept. If you normally use a path only defined by its radius, buth with

the centre position and inclination varying, you should re-install your rotating device before each test chosing a new centre position (including a new height) and chosing a new inclination. Doing this you should try to forget where the former path(s) were positioned. You should not choose paths oddly positioned just to obtain a deviation from former paths.

4. Reproducibility within Laboratories

Conduct 5 measurements, but not under repeatability conditions (4.1-4.5). This means that the normal procedure is changed from measurement to measurement. The following list of measurements are meant only as a guideline:

4.1 A measurement according to the normal test procedure

4.2 A measurement in the opposite direction

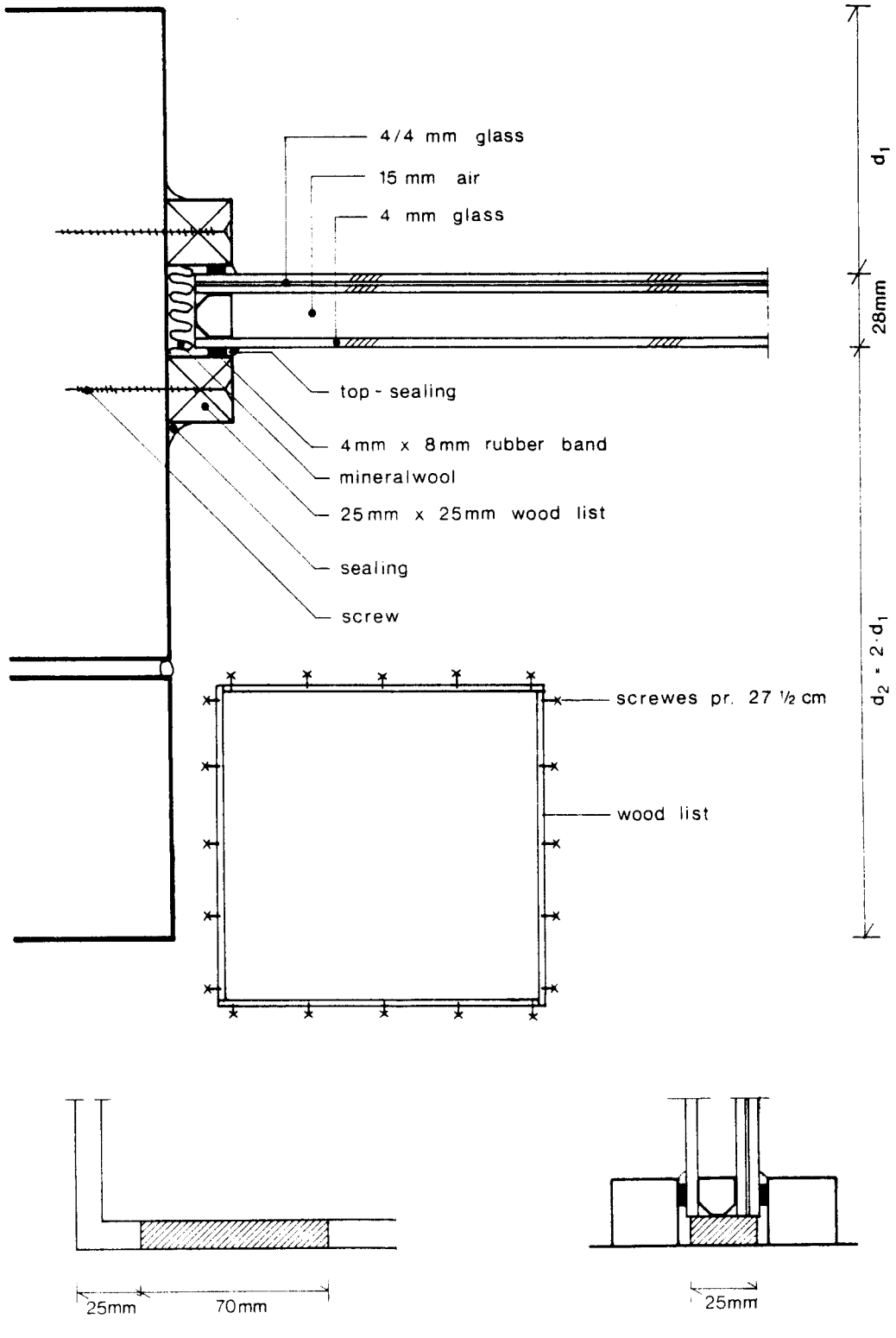
4.3 A measurement being the average of both directions

4.4 A measurement with the reverberation time in one or in both rooms changed

4.5 A measurement with loudspeakers in positions different from normal positions

4.6 A measurement in rooms with the configurations of diffusing elements changed

NORDTEST 235-80



NORDTEST 235-80

LABORATORY:

1. Influence of stochastic noise signal
2. Mounting conditions

	R measurement no.					5%: 0.710 1%: 0.821		<R>	s(R)	R
	1.1	1.2	1.3	1.4	1.5	Q 10 low	Q 10 high			2.1
100										
125										
160										
200										
250										
315										
400										
500										
630										
800										
1000										
1250										
1600										
2000										
2500										
3150										
R_W										
Date										

Sound reduction indices 100 Hz to 3150 Hz shall be rounded to one decimal place.

R_W (ISO/DIS 717/3) shall be calculated using steps of one tenth dB.

Mesurement results are reported in clear handwriting.

Date _____ Signed by _____

NORDTEST 235-80

LABORATORY:

3. Repeatability / reproducibility

	R measurement no						5%: 0.628 1%: 0.740		<R>	s(R)
	3.1	3.2	3.3	3.4	3.5	3.6	Q 10 low	Q 10 high		
100										
125										
160										
200										
250										
315										
400										
500										
630										
800										
1000										
1250										
1600										
2000										
2500										
3150										
R_W										
Date										

Sound reduction indices 100 Hz to 3150 Hz shall be rounded to one decimal place.

R_W (ISO/DIS 717/3) shall be calculated using steps of one tenth dB.

Mesurement results are reported in clear handwriting.

Date Signed by

NORDTEST 235-80

LABORATORY:

4. Reproducibility within laboratories

	R measurement no.					5%: 0.710 1%: 0.821		<R>	s(R)
	4.1	4.2	4.3	4.4	4.5	Q 10 low	Q 10 high		
100									
125									
160									
200									
250									
315									
400									
500									
630									
800									
1000									
1250									
1600									
2000									
2500									
3150									
R_W									
Date									

Sound reduction indices 100 Hz to 3150 Hz shall be rounded to one decimal place.

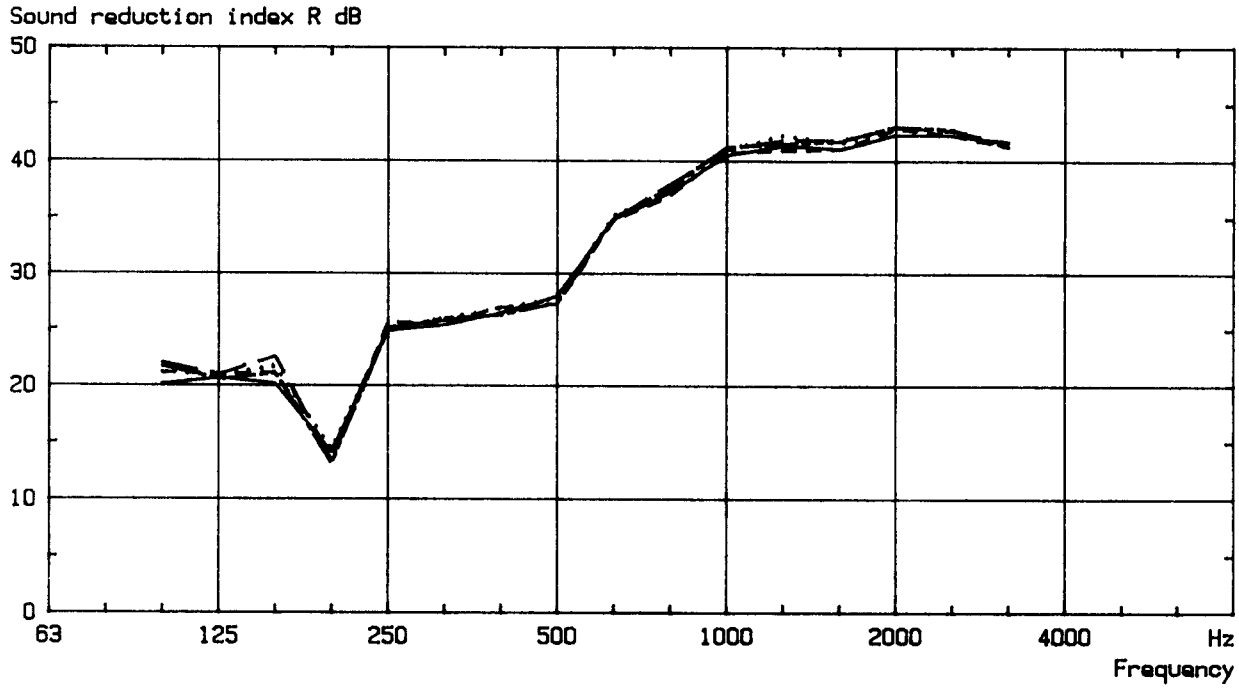
R_W (ISO/DIS 717/3) shall be calculated using steps of one tenth dB.

Mesurement results are reported in clear handwriting.

Date _____ Signed by _____

APPENDIX C

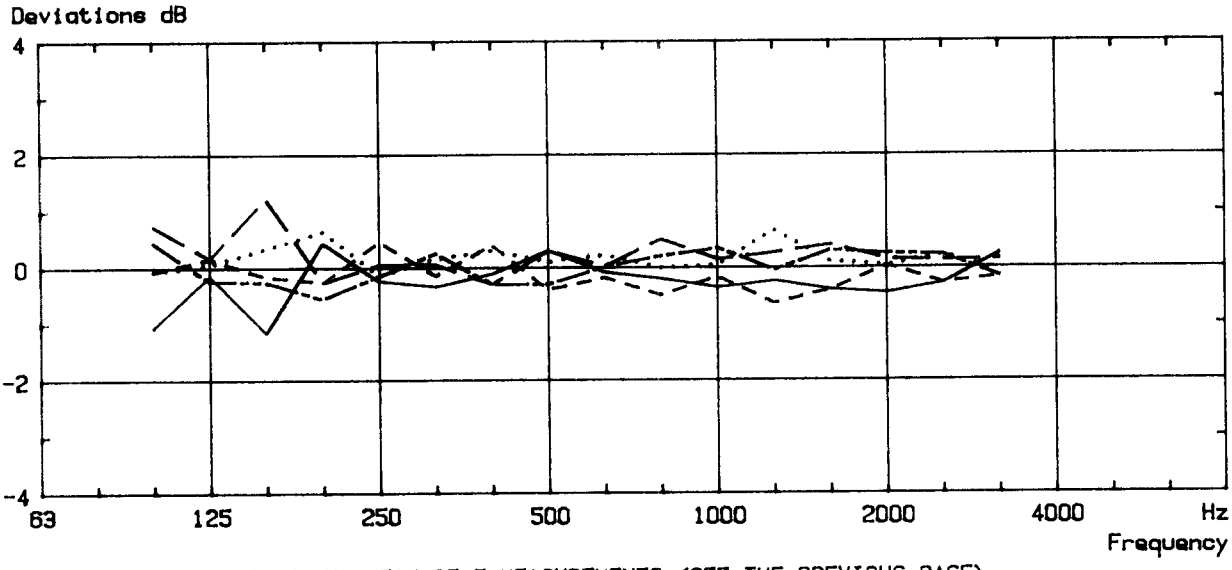
Results from Statens Tekniska Forskningscentral / VTT



NORDTEST 235-80
LABORATORY : STATENS TEKNISKA FORSKNINGSCENTRAL
1. INFLUENCE OF STOCHASTIC NOISE SIGNAL

———— 1.1
. . . . . 1.2
– – – – – – 1.3
— — — · 1.4
———·——— 1.5

Measurement Frequency	1.1	1.2	1.3	1.4	1.5	Mean
Hz	dB	dB	dB	dB	dB	dB
100	20.2	21.2	21.2	22.0	21.7	21.3
125	20.7	20.9	21.0	21.0	20.6	20.8
160	20.2	21.7	21.2	22.6	21.1	21.4
200	14.1	14.3	13.4	13.4	13.1	13.7
250	24.9	25.0	25.6	25.2	25.0	25.1
315	25.4	25.9	25.6	25.8	26.0	25.7
400	26.5	26.9	27.0	26.3	26.3	26.6
500	28.0	27.8	27.3	28.0	27.4	27.7
630	34.9	35.2	34.8	35.0	35.0	35.0
800	37.3	37.5	37.0	38.0	37.7	37.5
1000	40.6	41.0	40.8	41.1	41.3	41.0
1250	41.4	42.3	41.0	41.9	41.6	41.6
1600	41.1	41.6	41.1	41.9	41.8	41.5
2000	42.4	42.9	42.9	43.0	43.1	42.9
2500	42.3	42.8	42.3	42.7	42.8	42.6
3150	41.7	41.4	41.3	41.6	41.3	41.5
Rw	34.2	34.6	34.4	34.4	34.2	34.4
Δ_{max}	-10.1	-10.3	-11.0	-11.0	-11.1	



NORDTEST 235-80, PLOT VERSUS MEAN OF 5 MEASUREMENTS (SEE THE PREVIOUS PAGE)
LABORATORY : STATENS TEKNISKA FORSKNINGSCENTRAL
1. INFLUENCE OF STOCHASTIC NOISE SIGNAL

——————— 1.1
. . . . . 1.2
– – – – – – 1.3
— — — — 1.4
———— 1.5

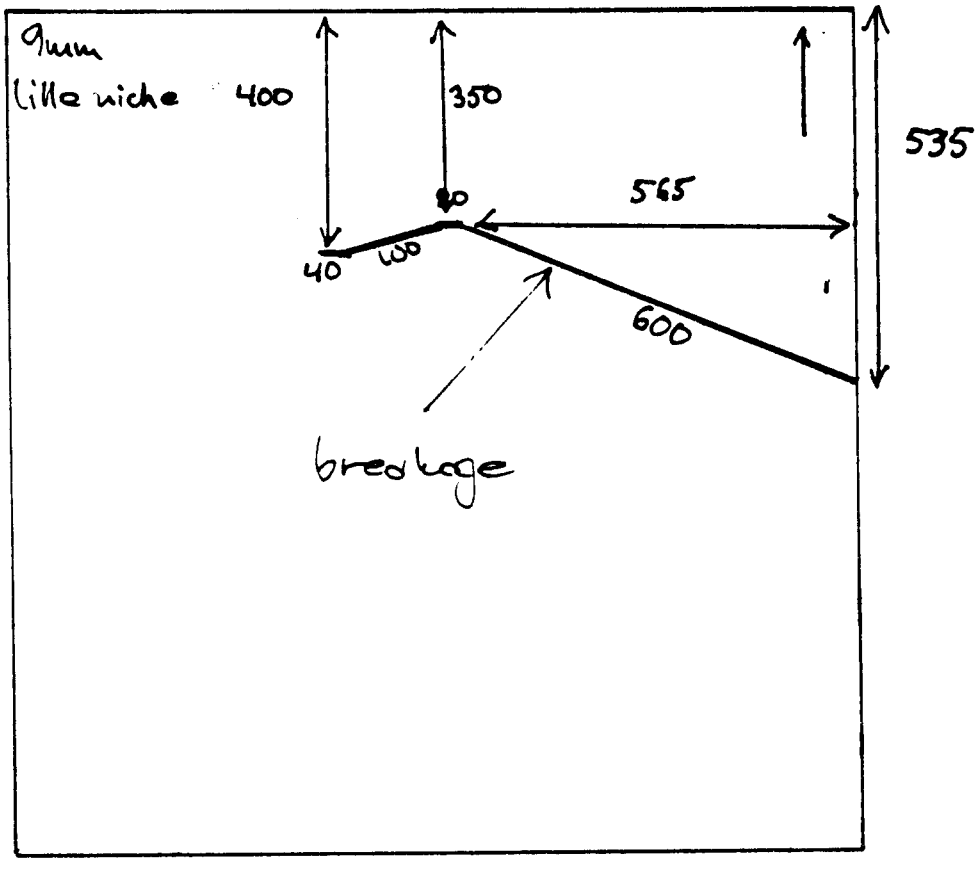
		Deviations from mean:				
Measurement Frequency	Mean	1.1	1.2	1.3	1.4	1.5
Hz	dB	dB	dB	dB	dB	dB
100	21.3	-1.1	-0.1	-0.1	0.7	0.4
125	20.8	-0.1	0.1	0.2	0.2	-0.2
160	21.4	-1.2	0.3	-0.2	1.2	-0.3
200	13.7	0.4	0.6	-0.3	-0.3	-0.6
250	25.1	-0.2	-0.1	0.5	0.1	-0.1
315	25.7	-0.3	0.2	-0.1	0.1	0.3
400	26.6	-0.1	0.3	0.4	-0.3	-0.3
500	27.7	0.3	0.1	-0.4	0.3	-0.3
630	35.0	-0.1	0.2	-0.2	0.0	0.0
800	37.5	-0.2	0.0	-0.5	0.5	0.2
1000	41.0	-0.4	0.0	-0.2	0.1	0.3
1250	41.6	-0.2	0.7	-0.6	0.3	-0.0
1600	41.5	-0.4	0.1	-0.4	0.4	0.3
2000	42.9	-0.5	0.0	0.0	0.1	0.2
2500	42.6	-0.3	0.2	-0.3	0.1	0.2
3150	41.5	0.2	-0.1	-0.2	0.1	-0.2
Rw	34.4	-0.2	0.2	0.0	0.0	-0.2

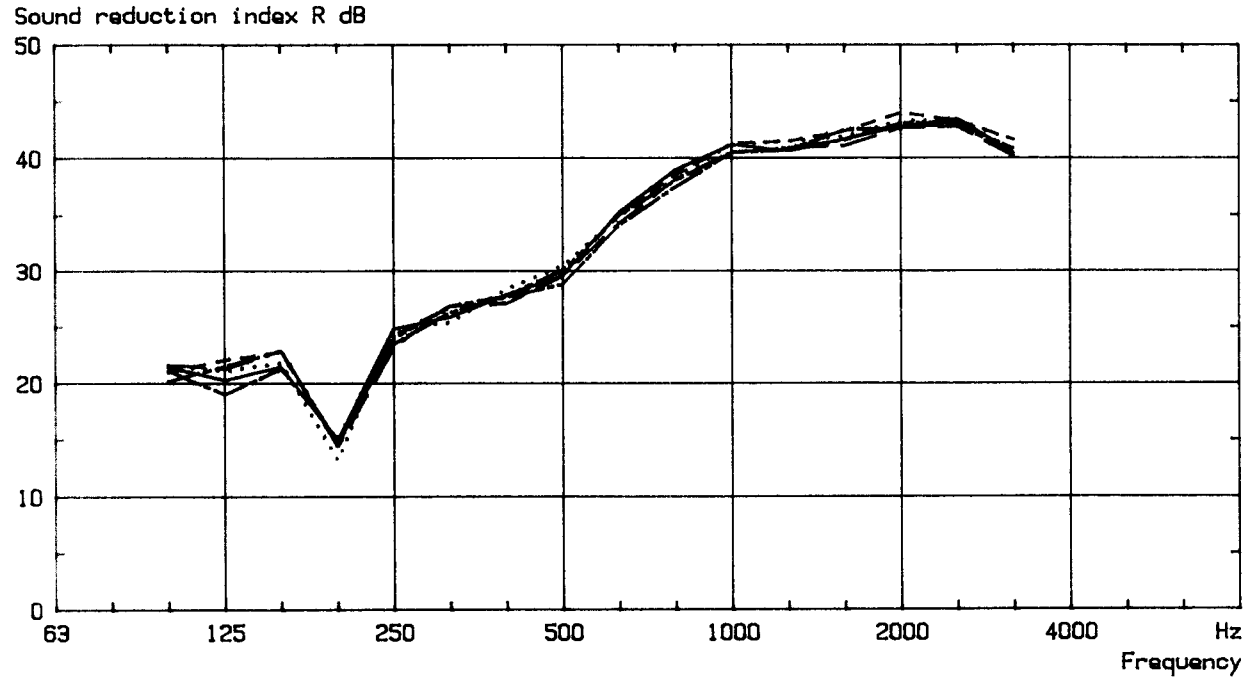
VTT

note concerning measurement no. 2.1.

The measurement no. 2.1. was abandoned because the pane was slightly broken during the demounting (see the picture below). An adhesive tape was fitted on the breakage. The remaining measurements were carried out according to the test scheme.

the side of single layered glass

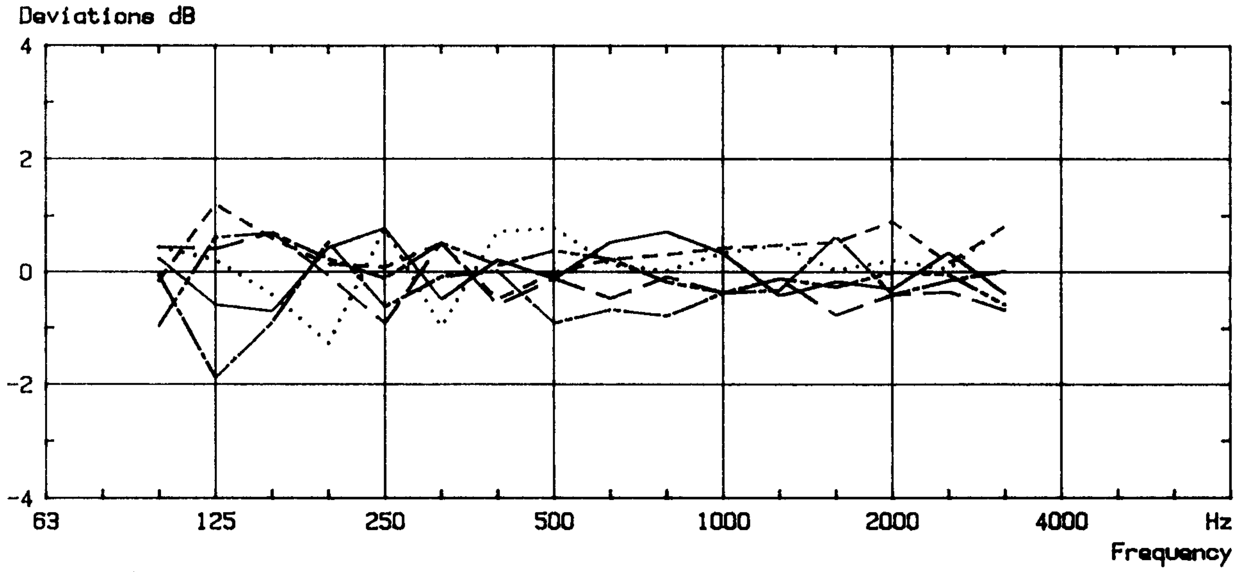




NORDTEST 235-80
LABORATORY : STATENS TEKNISKA FORSKNINGSCENTRAL
3. REPEATABILITY/REPRODUCIBILITY

——————— 3.1
. . . . . 3.2
– – – – – – – 3.3
— — — — · 3.4
——— - ——— 3.5
——— ·· ——— 3.6

Measurement Frequency Hz	3.1 dB	3.2 dB	3.3 dB	3.4 dB	3.5 dB	3.6 dB	Mean dB
100	21.4	21.6	21.0	21.6	20.2	21.1	21.2
125	20.3	21.1	22.1	21.3	21.5	19.0	20.9
160	21.5	21.8	22.8	22.9	22.9	21.3	22.2
200	14.9	13.2	14.6	14.4	14.7	15.0	14.5
250	24.9	24.9	24.2	23.2	24.0	23.5	24.1
315	25.9	25.4	26.9	26.9	26.9	26.3	26.4
400	27.9	28.4	27.2	27.1	27.8	27.7	27.7
500	29.6	30.5	29.7	29.6	30.1	28.8	29.7
630	35.3	34.9	35.0	34.3	35.0	34.1	34.8
800	39.0	38.3	38.6	38.2	38.1	37.5	38.3
1000	41.2	41.2	41.3	40.5	40.5	40.5	40.9
1250	40.6	41.5	41.5	40.9	40.9	40.7	41.0
1600	41.7	41.9	42.4	41.1	41.6	42.5	41.9
2000	42.8	43.3	44.0	42.7	43.1	42.7	43.1
2500	43.5	43.2	43.3	42.8	43.1	43.0	43.2
3150	40.4	41.6	41.6	40.1	40.2	40.8	40.8
Rw	35.1	35.0	35.1	34.7	35.2	34.6	35.0
Δ_{max}	-10.2	-11.8	-10.5	-10.3	-10.5	-9.6	



NORDTEST 235-80, PLOT VERSUS MEAN OF 6 MEASUREMENTS (SEE THE PREVIOUS PAGE)
LABORATORY : STATENS TEKNISKA FORSKNINGSCENTRAL
3. REPEATABILITY/REPRODUCIBILITY

- ———— 3.1
- ············ 3.2
- – – – – – – 3.3
- — — — 3.4
- –·–·–·– 3.5
- –··–··– 3.6

Deviations from mean:

Measurement Frequency Hz	Mean dB	3.1 dB	3.2 dB	3.3 dB	3.4 dB	3.5 dB	3.6 dB
100	21.2	0.3	0.5	-0.2	0.5	-1.0	-0.1
125	20.9	-0.6	0.2	1.2	0.4	0.6	-1.9
160	22.2	-0.7	-0.4	0.6	0.7	0.7	-0.9
200	14.5	0.4	-1.3	0.1	-0.1	0.2	0.5
250	24.1	0.8	0.8	0.1	-0.9	-0.1	-0.6
315	26.4	-0.5	-1.0	0.5	0.5	0.5	-0.1
400	27.7	0.2	0.7	-0.5	-0.6	0.1	0.0
500	29.7	-0.1	0.8	-0.0	-0.1	0.4	-0.9
630	34.8	0.5	0.1	0.2	-0.5	0.2	-0.7
800	38.3	0.7	0.0	0.3	-0.1	-0.2	-0.8
1000	40.9	0.3	0.3	0.4	-0.4	-0.4	-0.4
1250	41.0	-0.4	0.5	0.5	-0.1	-0.1	-0.3
1600	41.9	-0.2	0.0	0.5	-0.8	-0.3	0.6
2000	43.1	-0.3	0.2	0.9	-0.4	0.0	-0.4
2500	43.2	0.4	0.1	0.2	-0.4	-0.1	-0.2
3150	40.8	-0.4	0.8	0.8	-0.7	-0.6	0.0
Rw	35.0	0.2	0.1	0.2	-0.3	0.3	-0.4

VTT

Measurements Procedures in Series no. 4

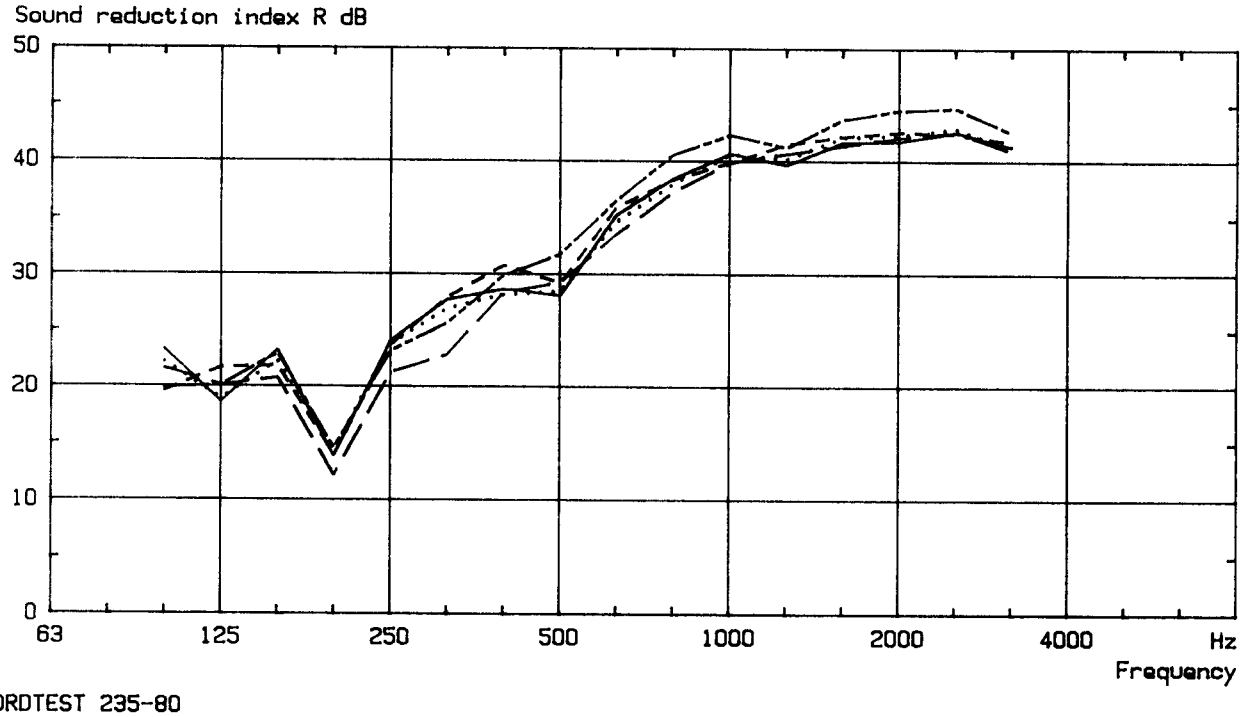
4.1. A measurement in the opposite direction

4.2. A measurement being the average of both directions (the other measurement used in the calculation was no. 3.6.)

4.3. A measurement with the lousdpeaker facing outwards from the corner instead of towards the corner

4.4. A measurement with two loudspeakers (both different from the one used in all other measurements) situating in the back corners

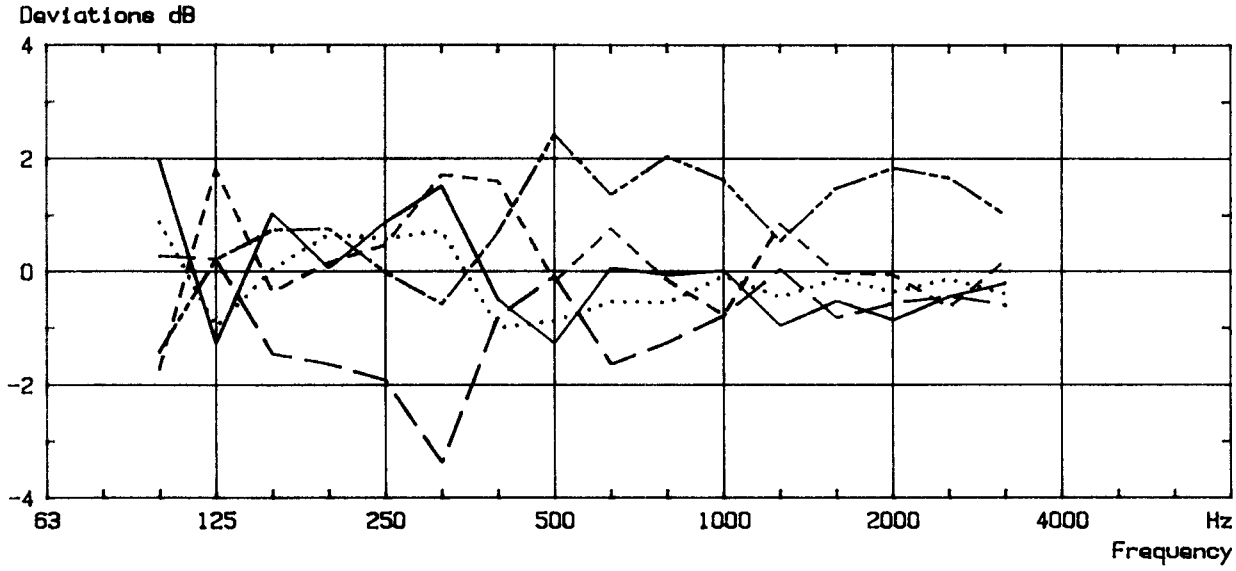
4.5. A measurement with the reverberation time of the receiving room diminished



NORDTEST 235-80
LABORATORY : STATENS TEKNISKA FORSKNINGSCENTRAL
4. REPRODUCIBILITY WITHIN LABORATORIES

——————— 4.1
. . . . . 4.2
– – – – – – 4.3
—— — —— — 4.4
———— 4.5

Measurement Frequency	4.1	4.2	4.3	4.4	4.5	Mean
Hz	dB	dB	dB	dB	dB	dB
100	23.3	22.2	19.6	21.6	19.9	21.3
125	18.6	18.9	21.7	20.1	20.1	19.9
160	23.3	22.3	21.9	20.8	23.0	22.3
200	13.8	14.4	13.9	12.1	14.5	13.7
250	24.1	23.8	23.7	21.3	23.2	23.2
315	27.8	27.0	28.0	22.9	25.7	26.3
400	28.7	28.2	30.8	28.4	29.9	29.2
500	28.1	28.5	29.2	29.3	31.8	29.4
630	35.3	34.7	36.0	33.6	36.6	35.2
800	38.5	38.0	38.4	37.3	40.6	38.6
1000	40.7	40.6	39.9	39.9	42.3	40.7
1250	39.7	40.2	41.5	40.7	41.2	40.7
1600	41.7	42.1	42.2	41.4	43.7	42.2
2000	41.8	42.3	42.6	42.1	44.5	42.7
2500	42.6	42.9	42.4	42.6	44.7	43.0
3150	41.3	41.1	41.7	40.9	42.5	41.5
Rw	35.0	34.9	35.6	33.4	35.7	34.9
Δ_{max}	-11.2	-10.5	-11.7	-11.3	-11.2	

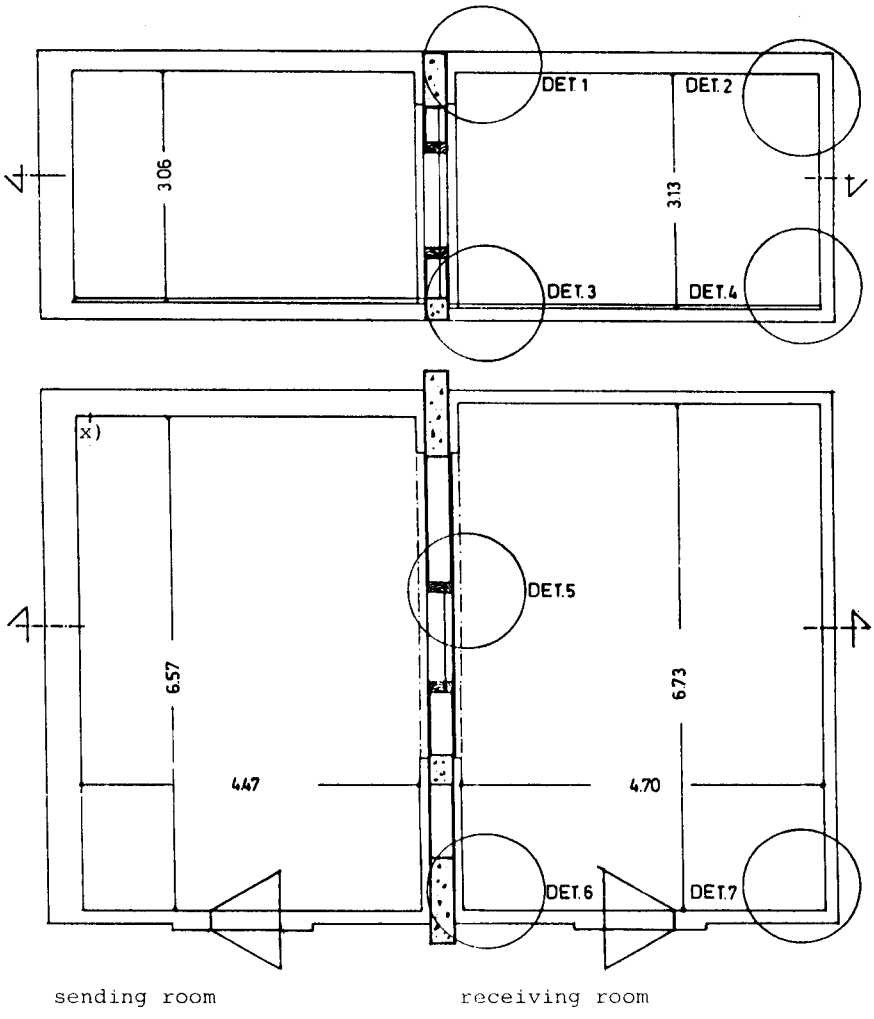


NORDTEST 235-80. PLOT VERSUS MEAN OF 5 MEASUREMENTS (SEE THE PREVIOUS PAGE)
LABORATORY : STATENS TEKNISKA FORSKNINGSCENTRAL
4. REPRODUCIBILITY WITHIN LABORATORIES

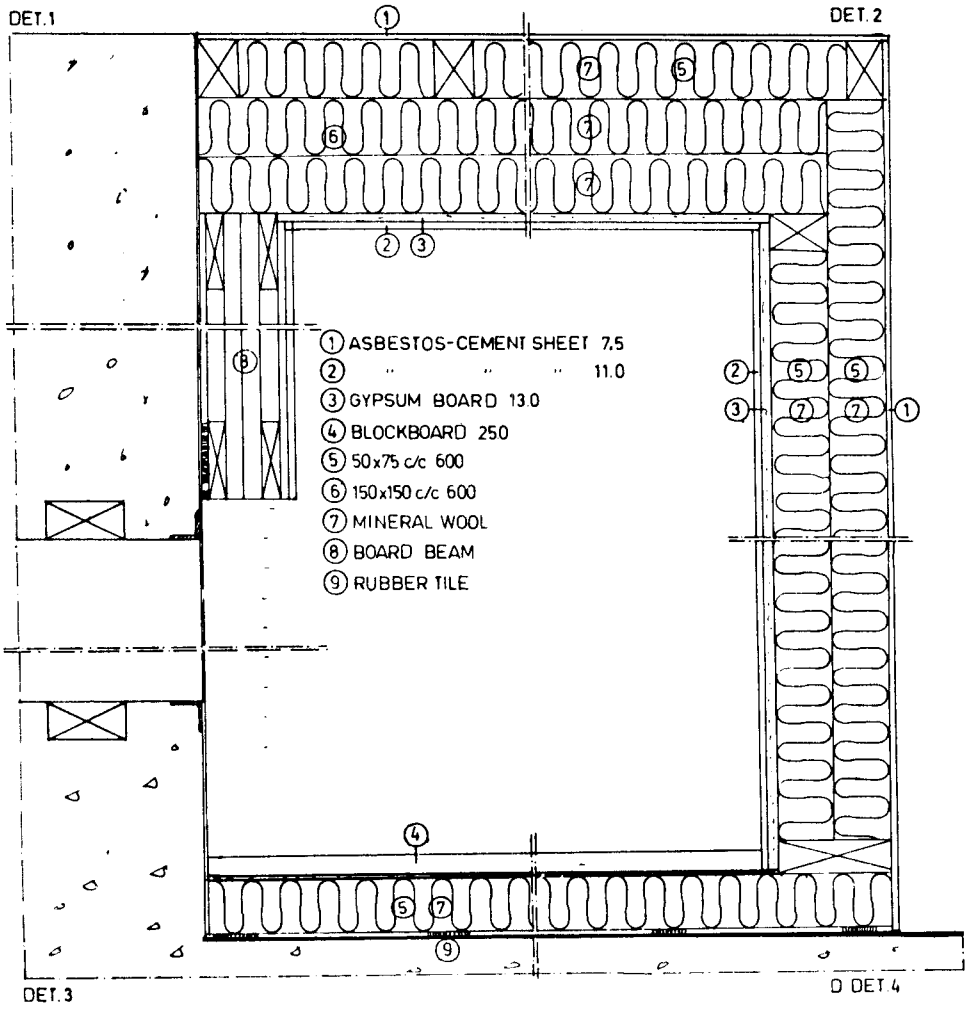
———— 4.1
. . . . . 4.2
– – – – – 4.3
— — — · 4.4
———— 4.5

		Deviations from mean:				
Measurement Frequency	Mean	4.1	4.2	4.3	4.4	4.5
Hz	dB	dB	dB	dB	dB	dB
100	21.3	2.0	0.9	-1.7	0.3	-1.4
125	19.9	-1.3	-1.0	1.8	0.2	0.2
160	22.3	1.0	0.0	-0.4	-1.5	0.7
200	13.7	0.1	0.7	0.2	-1.6	0.8
250	23.2	0.9	0.6	0.5	-1.9	-0.0
315	26.3	1.5	0.7	1.7	-3.4	-0.6
400	29.2	-0.5	-1.0	1.6	-0.8	0.7
500	29.4	-1.3	-0.9	-0.2	-0.1	2.4
630	35.2	0.1	-0.5	0.8	-1.6	1.4
800	38.6	-0.1	-0.6	-0.2	-1.3	2.0
1000	40.7	0.0	-0.1	-0.8	-0.8	1.6
1250	40.7	-1.0	-0.5	0.8	0.0	0.5
1600	42.2	-0.5	-0.1	-0.0	-0.8	1.5
2000	42.7	-0.9	-0.4	-0.1	-0.6	1.8
2500	43.0	-0.4	-0.1	-0.6	-0.4	1.7
3150	41.5	-0.2	-0.4	0.2	-0.6	1.0
Rw	34.9	0.1	-0.0	0.7	-1.5	0.8

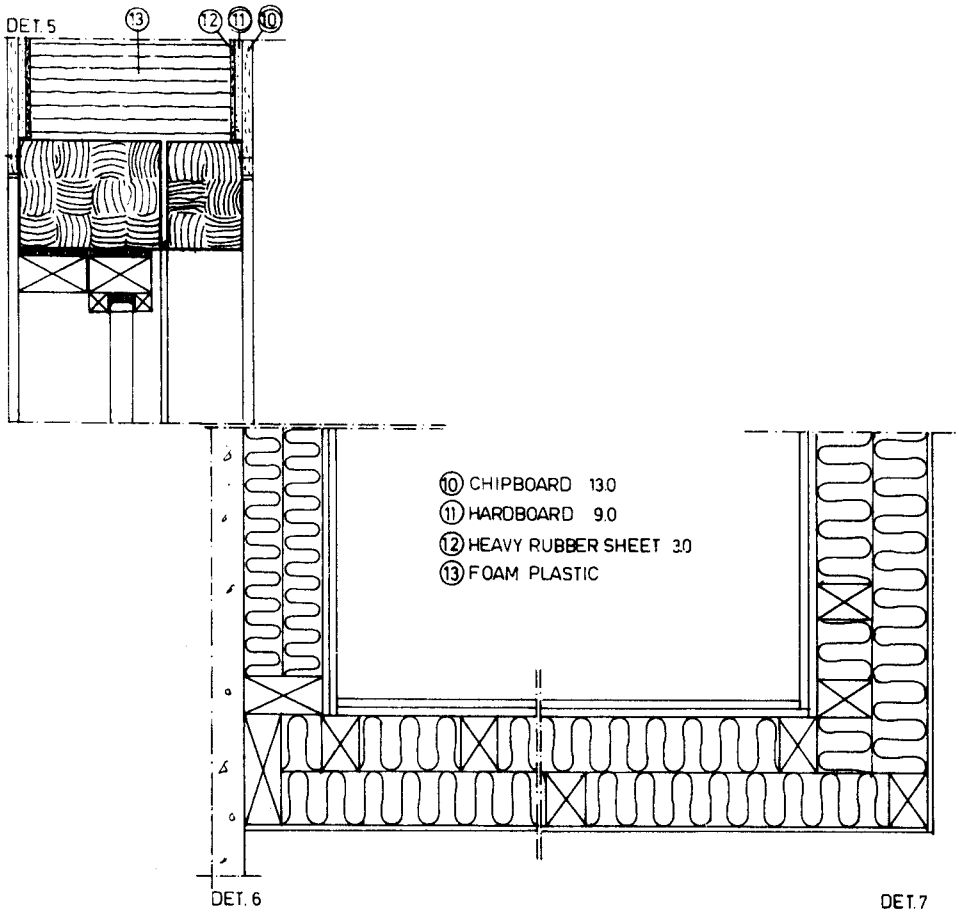
REVERBERATION ROOMS OF THE TECHNICAL RESEARCH CENTRE OF FINLAND (VTT)



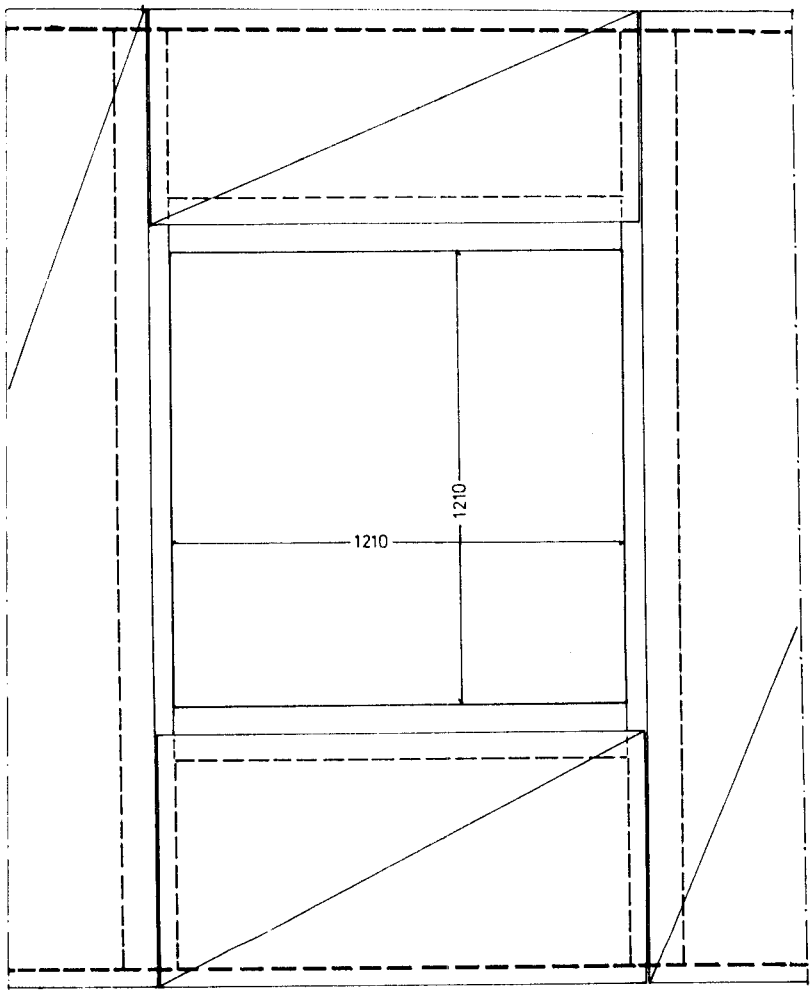
x) loudspeaker position in the sending room


DET. 1
DET. 2
DET. 3
DET. 4
1 ASBESTOS-CEMENT SHEET 7.5
2 " " " 11.0
3 GYPSUM BOARD 13.0
4 BLOCKBOARD 25.0
5 50x75 c/c 600
6 150x150 c/c 600
7 MINERAL WOOL
8 BOARD BEAM
9 RUBBER TILE

DETAILS OF THE TEST OPENING



GENERAL VIEW OF THE TEST OPENING

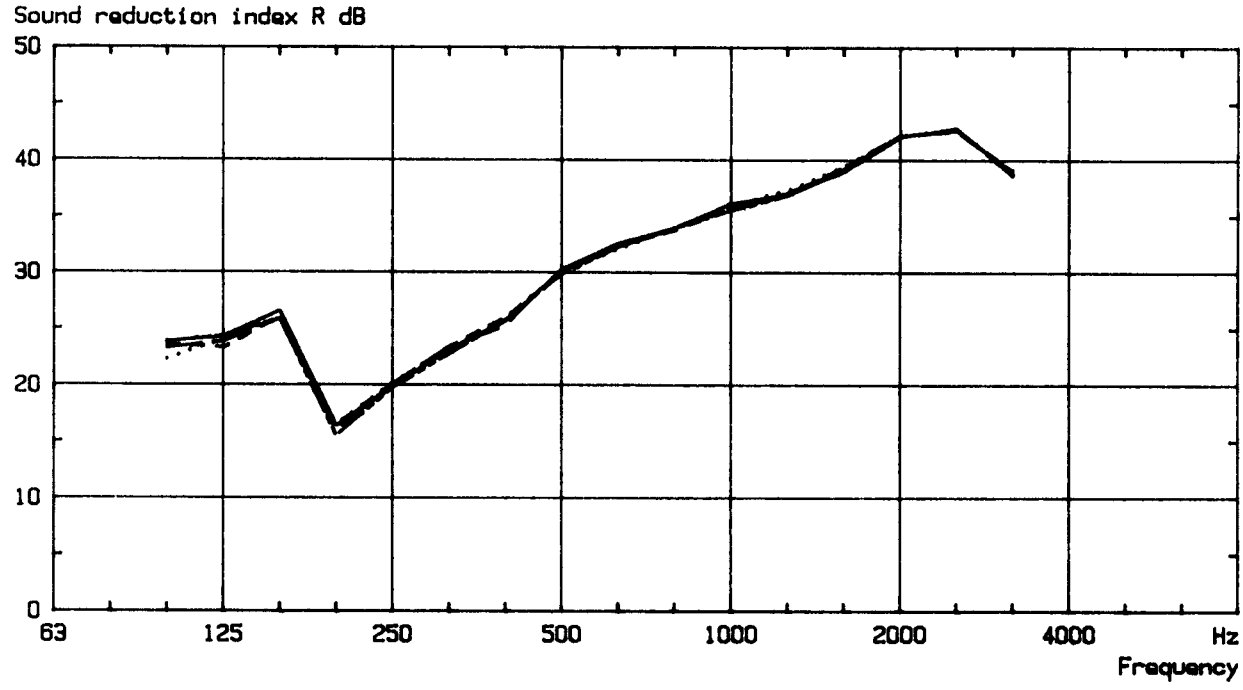


3. MEASUREMENT PROCEDURE

The measurement equipment consists of the Nortronik 811 analyzer and two AKG C451E microphones. The smaller one (90 m^3) of the reverberation rooms is used as a sending room and the larger one (100 m^3) as a receiving room. The loudspeaker is placed in the farthermost corner of the sending room, facing towards the corner, opposite to the test opening. The microphone stand is erected to the approximate center point of the room. The microphone is moved along its circular trajectory whose radius is about 1.0 m and whose center point is situated 1.3 m above the floor. The circle forms an inclination of 15° with the floor. 8 microphone positions along the circle are used for the measurement of each third octave. The microphone positions are not exactly the same on each third octave and on each measurement because the microphone rotation system is not accurate and the starting point of rotation varies from measurement to measurement.

APPENDIX D

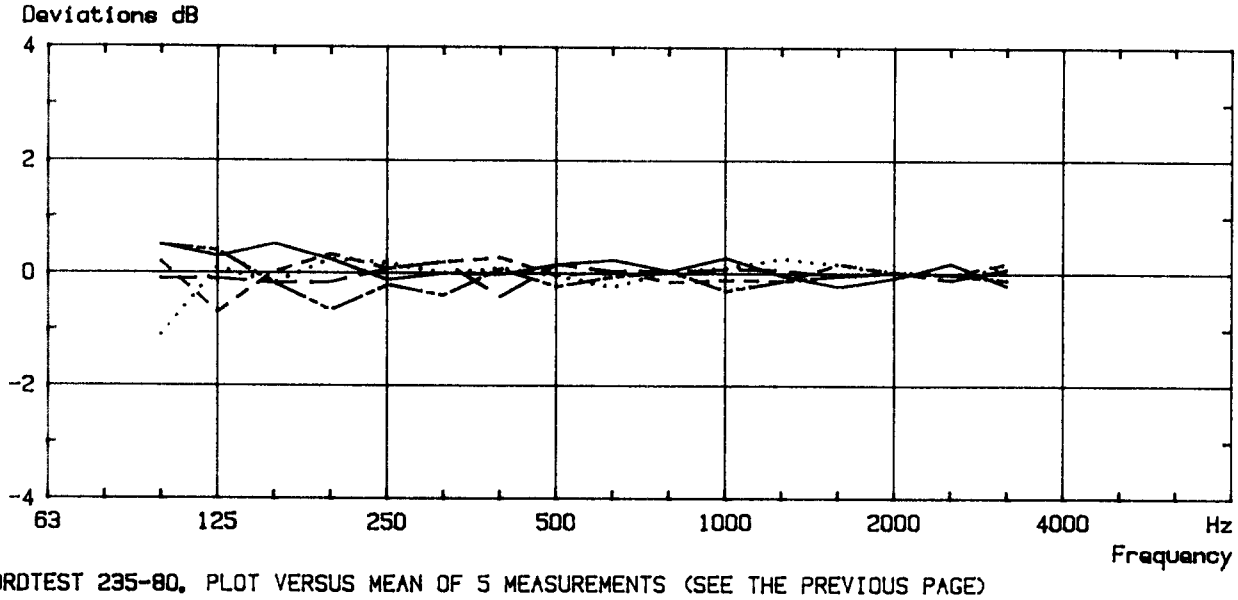
Results from Akustisk Laboratorium / ELAB



NORDTEST 235-80
LABORATORY : AKUSTISK LABORATORIUM/ELAB
1. INFLUENCE OF STOCHASTIC NOISE SIGNAL

——————— 1.1
. . . . . 1.2
– – – – – – – 1.3
— — — — · 1.4
———·———·— 1.5

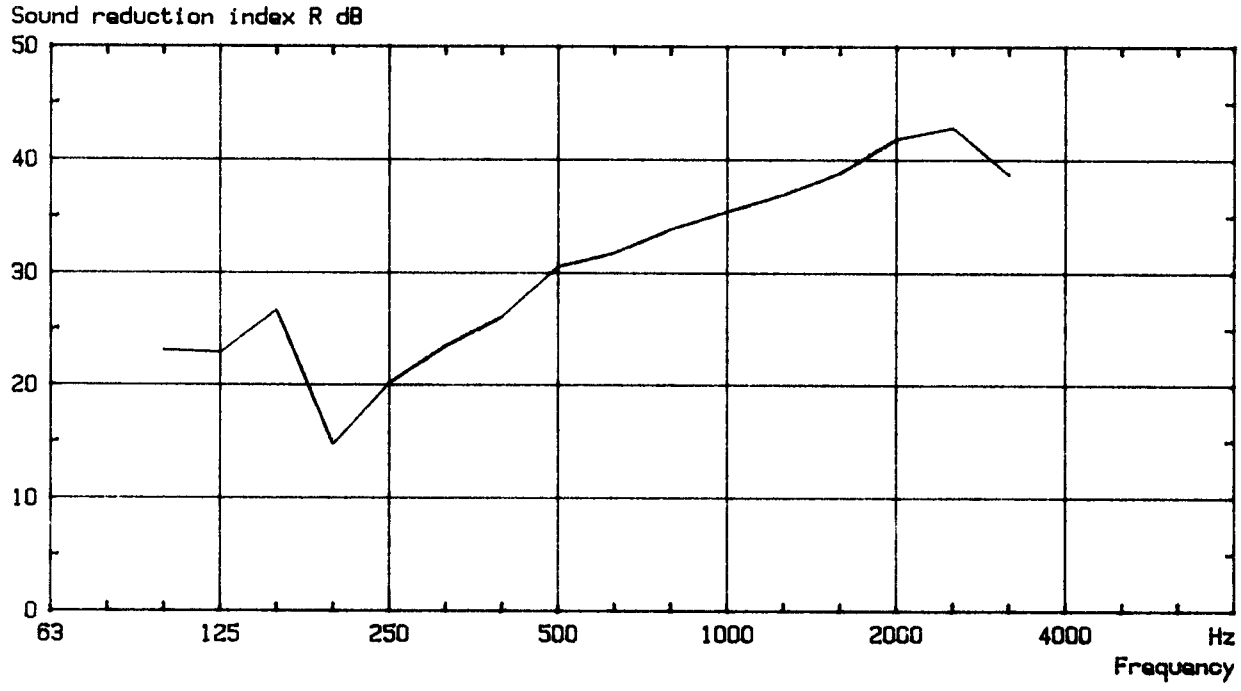
Measurement Frequency	1.1	1.2	1.3	1.4	1.5	Mean
Hz	dB	dB	dB	dB	dB	dB
100	23.9	22.3	23.6	23.3	23.9	23.4
125	24.3	24.1	23.3	23.9	24.4	24.0
160	26.6	25.9	26.1	25.9	25.9	26.1
200	16.4	16.4	16.5	16.0	15.5	16.2
250	19.9	20.2	20.1	20.1	19.8	20.0
315	23.2	23.2	23.4	23.4	22.8	23.2
400	25.7	25.8	26.0	25.3	25.8	25.7
500	30.3	30.1	30.1	30.3	29.9	30.1
630	32.6	32.1	32.4	32.4	32.3	32.4
800	34.0	34.0	33.8	34.0	34.0	34.0
1000	36.2	36.0	35.8	36.0	35.6	35.9
1250	37.0	37.3	36.9	37.1	36.9	37.0
1600	39.0	39.4	39.4	39.2	39.2	39.2
2000	42.1	42.2	42.2	42.2	42.2	42.2
2500	42.9	42.7	42.7	42.6	42.7	42.7
3150	38.6	38.9	39.0	38.9	38.7	38.8
Rw	33.2	33.2	33.2	33.1	32.9	33.1
Δ_{max}	-6.8	-6.8	-6.7	-7.1	-7.4	



NORDTEST 235-80. PLOT VERSUS MEAN OF 5 MEASUREMENTS (SEE THE PREVIOUS PAGE)
LABORATORY : AKUSTISK LABORATORIUM/ELAB
1. INFLUENCE OF STOCHASTIC NOISE SIGNAL

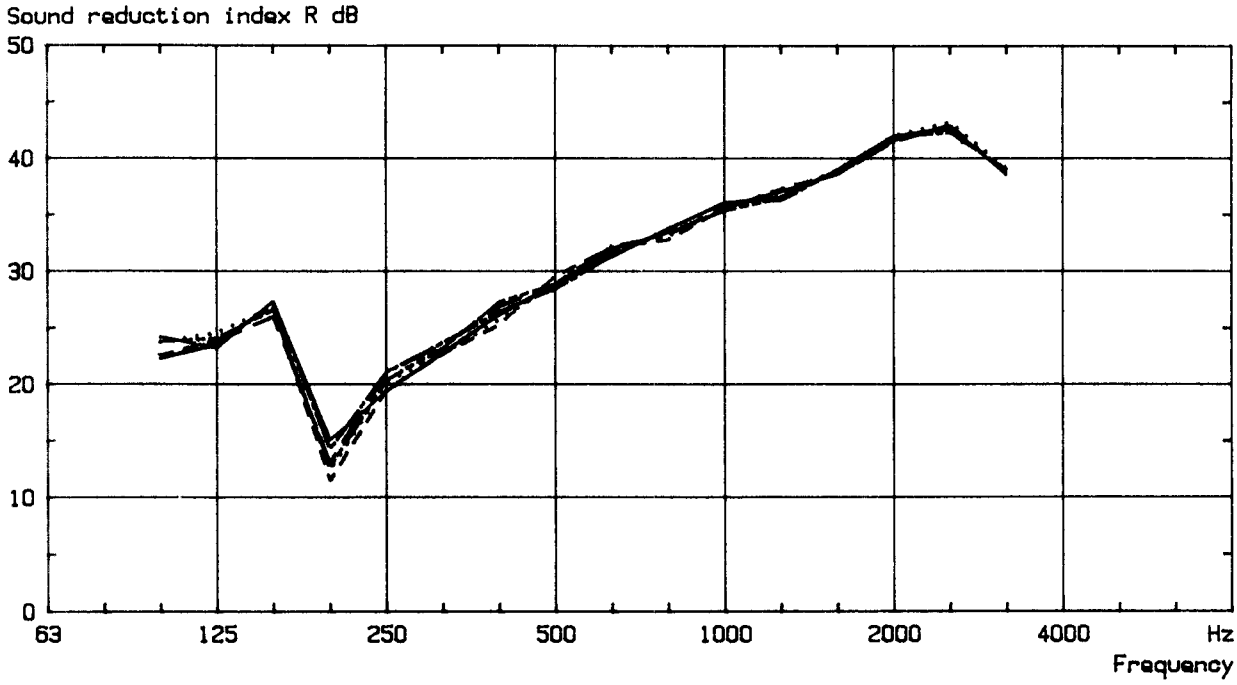
———— 1.1
. . . . . 1.2
– – – – – – 1.3
— — — · 1.4
—— – —— 1.5

		Deviations from mean:				
Measurement Frequency	Mean	1.1	1.2	1.3	1.4	1.5
Hz	dB	dB	dB	dB	dB	dB
100	23.4	0.5	-1.1	0.2	-0.1	0.5
125	24.0	0.3	0.1	-0.7	-0.1	0.4
160	26.1	0.5	-0.2	0.0	-0.2	-0.2
200	16.2	0.2	0.2	0.3	-0.2	-0.7
250	20.0	-0.1	0.2	0.1	0.1	-0.2
315	23.2	0.0	0.0	0.2	0.2	-0.4
400	25.7	-0.0	0.1	0.3	-0.4	0.1
500	30.1	0.2	-0.0	-0.0	0.2	-0.2
630	32.4	0.2	-0.3	0.0	0.0	-0.1
800	34.0	0.0	0.0	-0.2	0.0	0.0
1000	35.9	0.3	0.1	-0.1	0.1	-0.3
1250	37.0	-0.0	0.3	-0.1	0.1	-0.1
1600	39.2	-0.2	0.2	0.2	-0.0	-0.0
2000	42.2	-0.1	0.0	0.0	0.0	0.0
2500	42.7	0.2	-0.0	-0.0	-0.1	-0.0
3150	38.8	-0.2	0.1	0.2	0.1	-0.1
Rw	33.1	0.1	0.1	0.1	-0.0	-0.2



NORDTEST 235-80
LABORATORY : AKUSTISK LABORATORIUM/ELAB
2. MOUNTING CONDITIONS

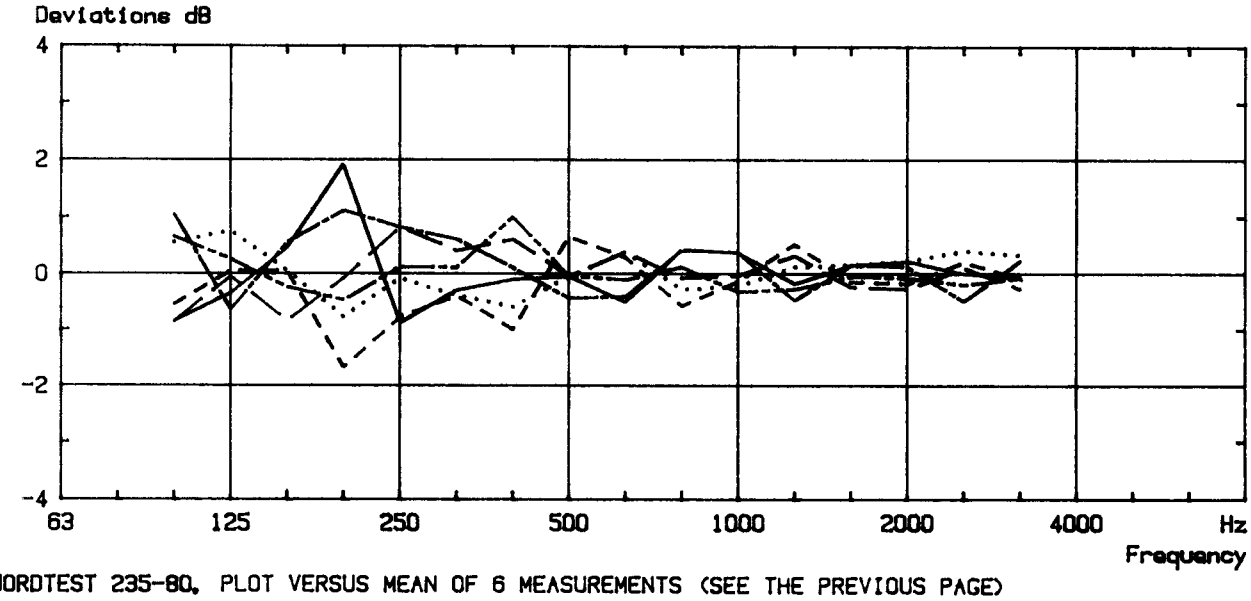
Measurement	2.2
Frequency Hz	dB
100	23.1
125	22.9
160	26.7
200	14.7
250	20.2
315	23.5
400	26.1
500	30.6
630	31.8
800	33.9
1000	35.5
1250	37.0
1600	38.9
2000	41.9
2500	42.9
3150	38.7
Rw	33.0
Δ_{max}	-8.3



NORDTEST 235-80
LABORATORY : AKUSTISK LABORATORIUM/ELAB
3. REPEATABILITY/REPRODUCIBILITY

——————— 3.1
. . . . . 3.2
– – – – – – – 3.3
— — — — 3.4
———·———·— 3.5
———··———·· 3.6

Measurement Frequency Hz	3.1 dB	3.2 dB	3.3 dB	3.4 dB	3.5 dB	3.6 dB	Mean dB
100	22.3	23.7	22.6	22.3	23.8	24.2	23.2
125	23.5	24.6	23.9	23.8	24.1	23.2	23.9
160	27.3	26.9	26.9	26.0	26.6	27.4	26.9
200	15.1	12.4	11.5	13.1	12.7	14.3	13.2
250	19.4	20.2	19.5	21.1	20.4	21.1	20.3
315	22.8	22.7	22.7	23.5	23.2	23.7	23.1
400	26.2	25.7	25.3	26.9	27.3	26.4	26.3
500	28.9	28.9	29.6	28.9	28.9	28.5	29.0
630	31.3	32.2	32.1	32.2	31.7	31.4	31.8
800	33.8	33.1	32.8	33.3	33.5	33.8	33.4
1000	36.1	35.5	35.6	35.7	35.4	36.1	35.7
1250	36.6	36.9	37.3	37.1	36.5	36.3	36.8
1600	39.0	39.0	38.7	38.6	38.8	39.0	38.9
2000	42.0	42.0	41.6	41.5	41.7	41.9	41.8
2500	42.8	43.2	43.0	42.9	42.6	42.3	42.8
3150	38.7	39.1	38.7	38.5	38.7	39.0	38.8
Rw	32.6	32.3	32.0	32.8	32.6	32.8	32.5
Δmax	-7.5	-9.9	-10.5	-9.7	-9.9	-8.5	



NORDTEST 235-80. PLOT VERSUS MEAN OF 6 MEASUREMENTS (SEE THE PREVIOUS PAGE)
LABORATORY : AKUSTISK LABORATORIUM/ELAB
3. REPEATABILITY/REPRODUCIBILITY

——————— 3.1
. . . . . 3.2
- - - - - - - 3.3
— — — — 3.4
——— — ——— 3.5
——— — — — 3.6

		Deviations from mean:					
Measurement Frequency	Mean	3.1	3.2	3.3	3.4	3.5	3.6
Hz	dB	dB	dB	dB	dB	dB	dB
100	23.2	-0.9	0.6	-0.6	-0.9	0.7	1.1
125	23.9	-0.4	0.8	0.1	-0.1	0.3	-0.7
160	26.9	0.5	0.1	0.1	-0.9	-0.3	0.6
200	13.2	1.9	-0.8	-1.7	-0.1	-0.5	1.1
250	20.3	-0.9	-0.1	-0.8	0.8	0.1	0.8
315	23.1	-0.3	-0.4	-0.4	0.4	0.1	0.6
400	26.3	-0.1	-0.6	-1.0	0.6	1.0	0.1
500	29.0	-0.1	-0.1	0.7	-0.1	-0.1	-0.5
630	31.8	-0.5	0.4	0.3	0.4	-0.1	-0.4
800	33.4	0.4	-0.3	-0.6	-0.1	0.1	0.4
1000	35.7	0.4	-0.2	-0.1	-0.0	-0.3	0.4
1250	36.8	-0.2	0.1	0.5	0.3	-0.3	-0.5
1600	38.9	0.2	0.2	-0.2	-0.3	-0.1	0.2
2000	41.8	0.2	0.2	-0.2	-0.3	-0.1	0.1
2500	42.8	0.0	0.4	0.2	0.1	-0.2	-0.5
3150	38.8	-0.1	0.3	-0.1	-0.3	-0.1	0.2
Rw	32.5	0.1	-0.2	-0.5	0.3	0.1	0.3

ELAB

Measurement Procedures in Series no. 4

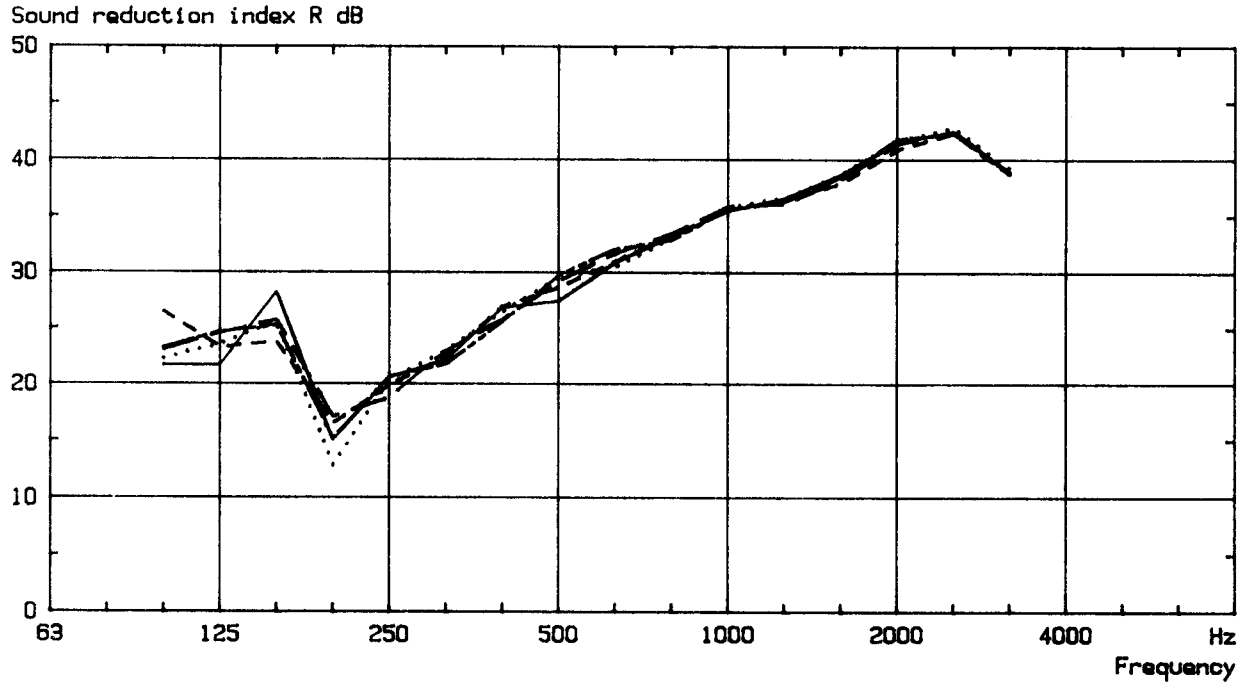
4.1 Only one loudspeakerposition in the source room.

4.2 One of the two loudspeakerpositions in the source room was changed.

4.3 A measurement in the opposite direction.

4.4 Diffusing elements were removed from the source room.

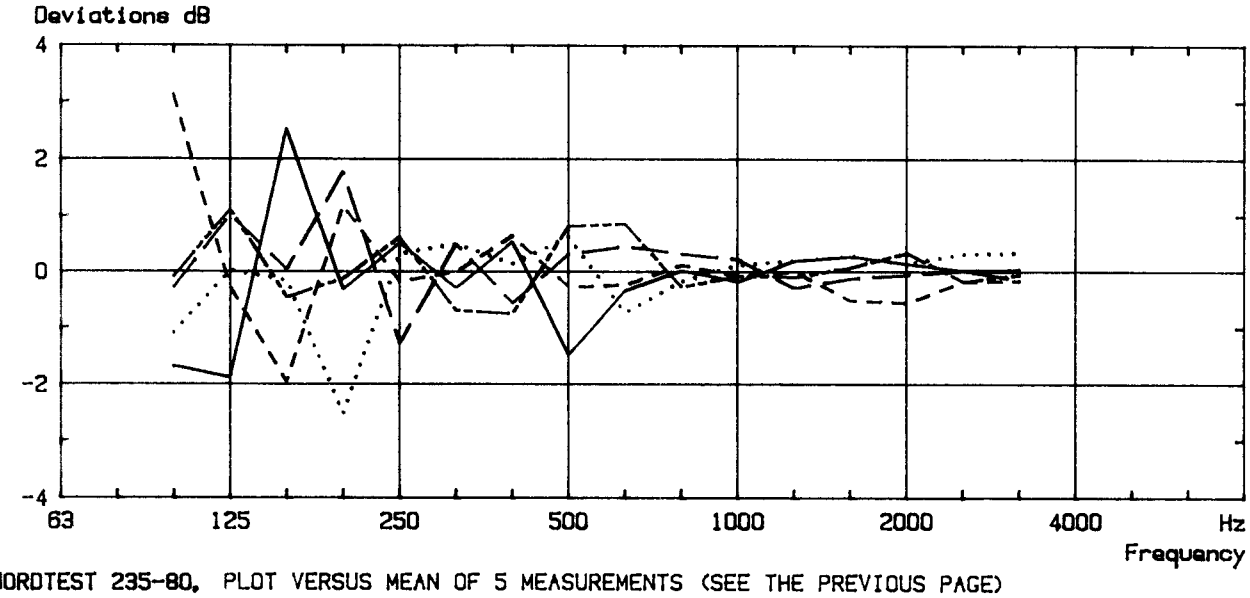
4.5 The reverberation time of the source room was changed.



NORDTEST 235-80
LABORATORY : AKUSTISK LABORATORIUM/ELAB
4. REPRODUCIBILITY WITHIN LABORATORIES

———— 4.1
..... 4.2
– – – – – – 4.3
— — — · 4.4
———— 4.5

Measurement Frequency	4.1	4.2	4.3	4.4	4.5	Mean
Hz	dB	dB	dB	dB	dB	dB
100	21.7	22.3	26.5	23.1	23.3	23.4
125	21.7	23.6	23.3	24.6	24.7	23.6
160	28.3	25.6	23.8	25.8	25.3	25.8
200	15.0	12.8	16.5	17.1	15.2	15.3
250	20.6	20.4	19.9	18.8	20.7	20.1
315	22.2	23.0	22.5	23.0	21.8	22.5
400	26.9	26.5	27.0	25.8	25.6	26.4
500	27.5	29.6	28.7	29.3	29.8	29.0
630	30.9	30.5	31.0	31.7	32.1	31.2
800	33.2	33.0	33.3	33.5	32.9	33.2
1000	35.5	35.8	35.6	35.9	35.6	35.7
1250	36.6	36.6	36.4	36.1	36.3	36.4
1600	38.7	38.7	37.9	38.3	38.5	38.4
2000	41.6	41.6	40.9	41.4	41.8	41.5
2500	42.5	42.8	42.3	42.5	42.3	42.5
3150	38.9	39.2	38.7	38.7	38.8	38.9
Rw	32.4	32.4	32.7	32.7	32.6	32.6
Δmax	-7.4	-9.6	-6.2	-6.9	-7.4	



NORDTEST 235-80. PLOT VERSUS MEAN OF 5 MEASUREMENTS (SEE THE PREVIOUS PAGE)
LABORATORY : AKUSTISK LABORATORIUM/ELAB
4. REPRODUCIBILITY WITHIN LABORATORIES

———— 4.1
. . . . . 4.2
– – – – – 4.3
— — — · 4.4
———— 4.5

		Deviations from mean:				
Measurement Frequency	Mean	4.1	4.2	4.3	4.4	4.5
Hz	dB	dB	dB	dB	dB	dB
100	23.4	-1.7	-1.1	3.1	-0.3	-0.1
125	23.6	-1.9	0.0	-0.3	1.0	1.1
160	25.8	2.5	-0.2	-2.0	0.0	-0.5
200	15.3	-0.3	-2.5	1.2	1.8	-0.1
250	20.1	0.5	0.3	-0.2	-1.3	0.6
315	22.5	-0.3	0.5	0.0	0.5	-0.7
400	26.4	0.5	0.1	0.6	-0.6	-0.8
500	29.0	-1.5	0.6	-0.3	0.3	0.8
630	31.2	-0.3	-0.7	-0.2	0.5	0.9
800	33.2	0.0	-0.2	0.1	0.3	-0.3
1000	35.7	-0.2	0.1	-0.1	0.2	-0.1
1250	36.4	0.2	0.2	0.0	-0.3	-0.1
1600	38.4	0.3	0.3	-0.5	-0.1	0.1
2000	41.5	0.1	0.1	-0.6	-0.1	0.3
2500	42.5	0.0	0.3	-0.2	0.0	-0.2
3150	38.9	0.0	0.3	-0.2	-0.2	-0.1
Rw	32.6	-0.2	-0.2	0.1	0.1	0.0

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Measuring arrangements for NORDTEST-projects 235-80 and 360-82.

1. MEASUREMENT ROOMS

The measurements were carried out in the transmission rooms designated "KLANGROM 2" (Reverberation room no. 2) and "Lydrom 4" (Transmission room no. 4) as shown in Figure 1 and Figure 2. The nominal dimensions of the test opening are, as indicated on Figure 2a, 1245 mm x 2245 mm. The volumes of the transmission rooms are 268 m^3 and 110 m^3, respectively.

The rooms are equipped with diffusing elements, free hanging panels made of plexiglas, 16 panels with a total area of 27 m^2 (one side) in "Klangrom 2" and 4 panels with a total area of 5 m^2 in "Lydrom 4". Both rooms have staircases made of steel plates which will also act as diffusing elements. Also, "Klangrom 2 " has a mounting platform freely suspended in the room. The total area of the platform is 14.5 m^2, but due to an "open" construction, an open grid plate, the effect on the diffusion is small.

Both rooms have randomly distributed patches of absorbent materials for adjustment of the reverberation time.

2. TEST OPENING

A test opening with dimensions 1.21 m x 1.21 m was constructed by filling the original opening on one side with elements made of concrete, thickness 140 mm, combined with a "resilient skin" construction, 22 mm chipboard and 200 mm mineral wool. Wooden plates are used on the other three sides for adjusting the dimensions.

The mounting of the glazing and the details of the test opening

as used in NORDTEST-project 235-80 are shown in Figure 3a and 3b.

Figure 3c shows the mounting conditions as used in NORDTEST-project 360-82, concerning measurement on glazings in a staggered test opening. The frames were fastened in the opening with wooden wedges as shown in Figure 3d.

3. MEASUREMENT PROCEDURE. INSTRUMENTATION

The measurements were carried out according to the requirements in ISO 140/III. In the normal measuring procedure, the instructions outlined in Annex B, "Example of a test procedure" was also followed, i.e. 2 loudspeaker positions and 6 microphone positions in each room were used. The loudspeaker positions are indicated in Figure 1, positions L_1, L_2 and L_3 in "Lydrom 4" and position K_1, K_2 and K_3 in "Klangrom 2". The positions with index 1 and 2 are on the floor, position marked 3 is at the ceiling. In the normal procedure, "Lydrom 4" is the sending room and loudspeaker positions L_1 and L_2 are used. For reverberation measurements in the receiving room, loudspeaker positions K_1 and K_3 are used.

Due to computer control, see below, the averaging time used in the sound pressure level measurement could be varied as a function of frequency, i.e. it is not fixed as suggested in ISO 140/III, Annex B. The averaging time is always adjusted to make the measurement uncertainty due to time averaging small compared with the uncertainty due to space averaging.

The measuring equipment used was: 4 loudspeakers, of laboratory design, with four tweeter elements and one bass element, volume 54 dm^3. 3 microphone channels for each room, each consisting of microphone B&K 4144 and microphone preamplifier B&K 2619. Microphone multiplexer, Norw. Elec. 824. Sound measuring system, Norw. Elec. 820 coupled to minicomputer HP-1000.

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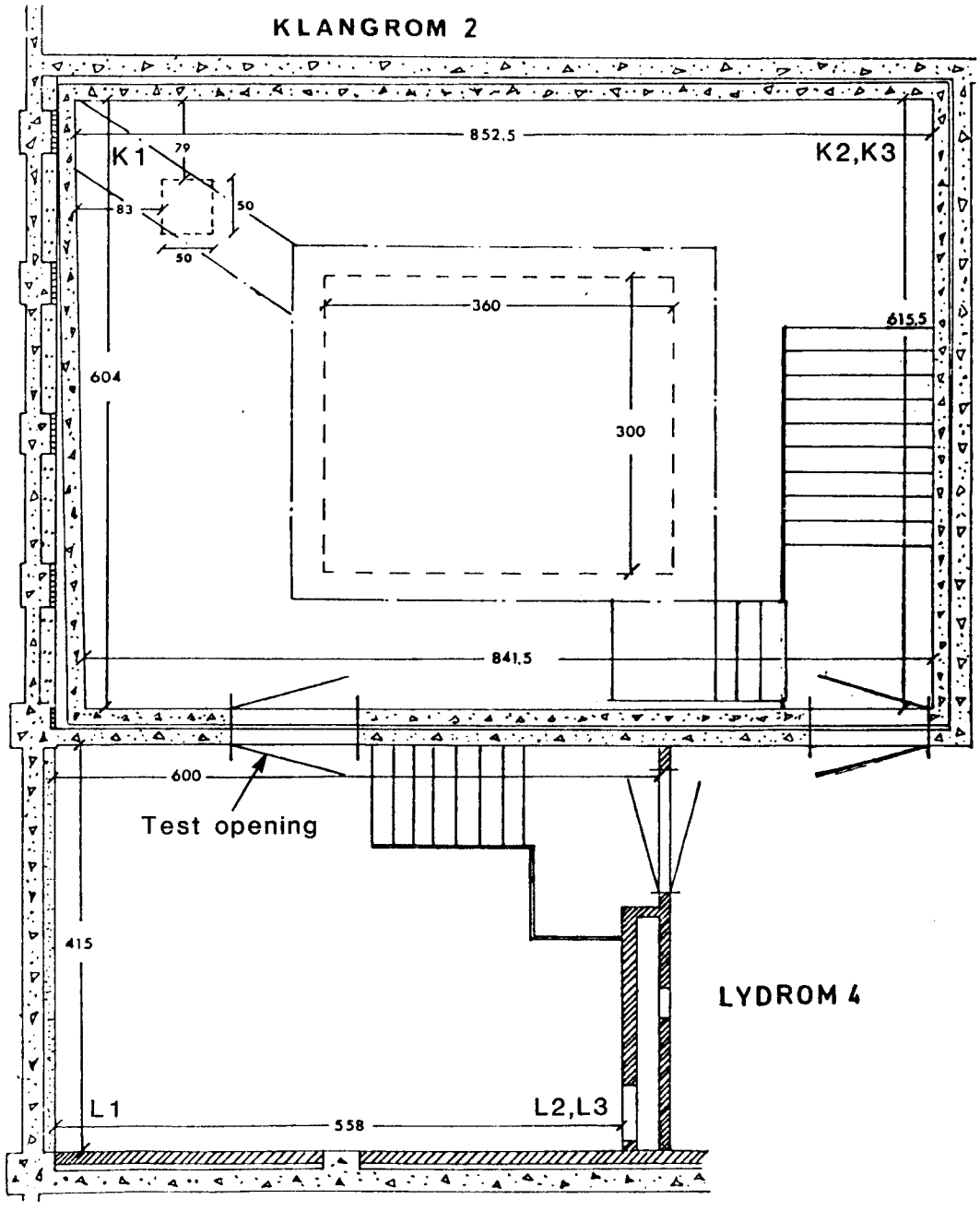
Fig. 1



Horizontal section

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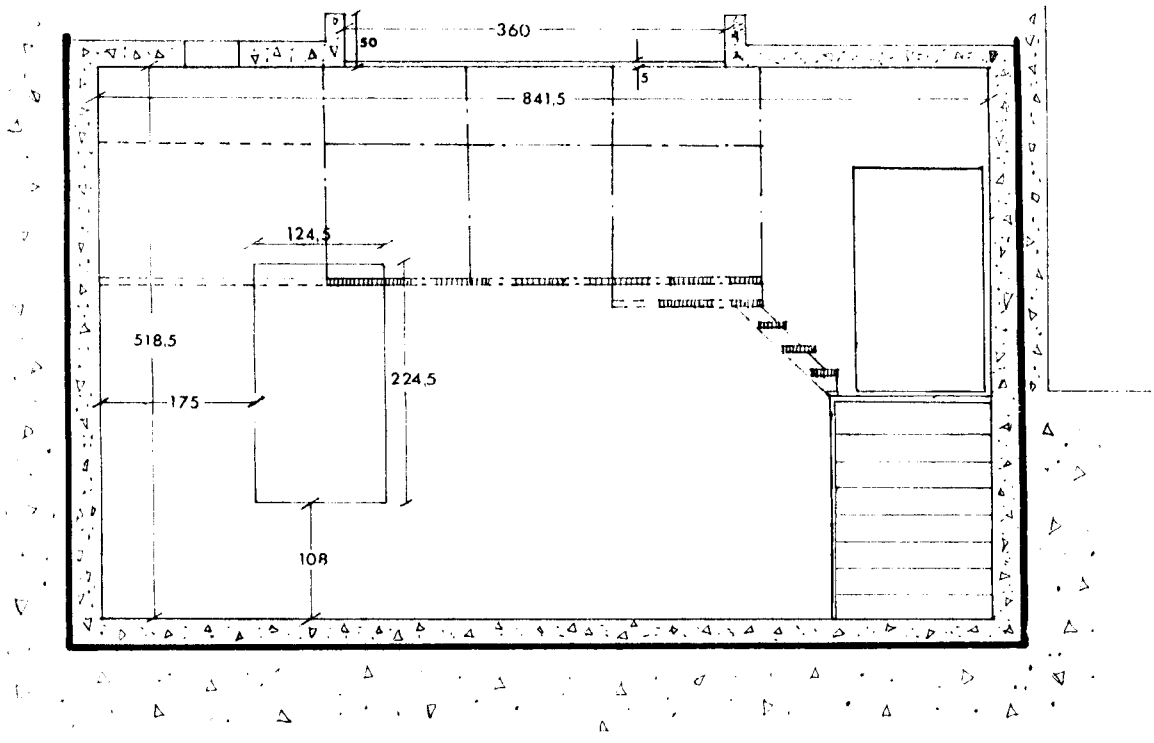
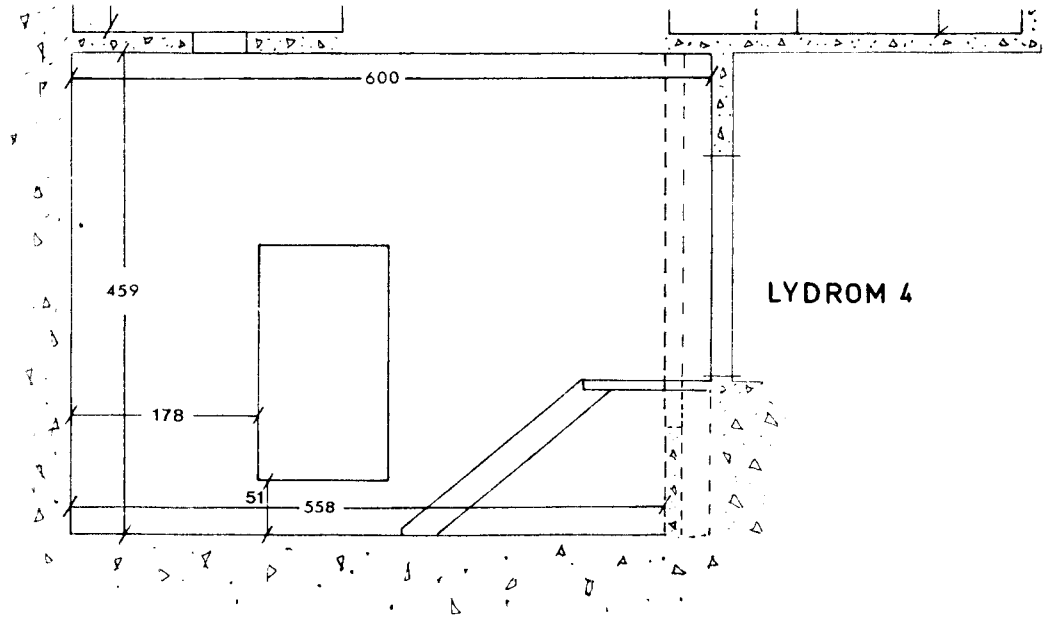
Fig.2 a, b

KLANGROM 2

a)



b)



Vertical section

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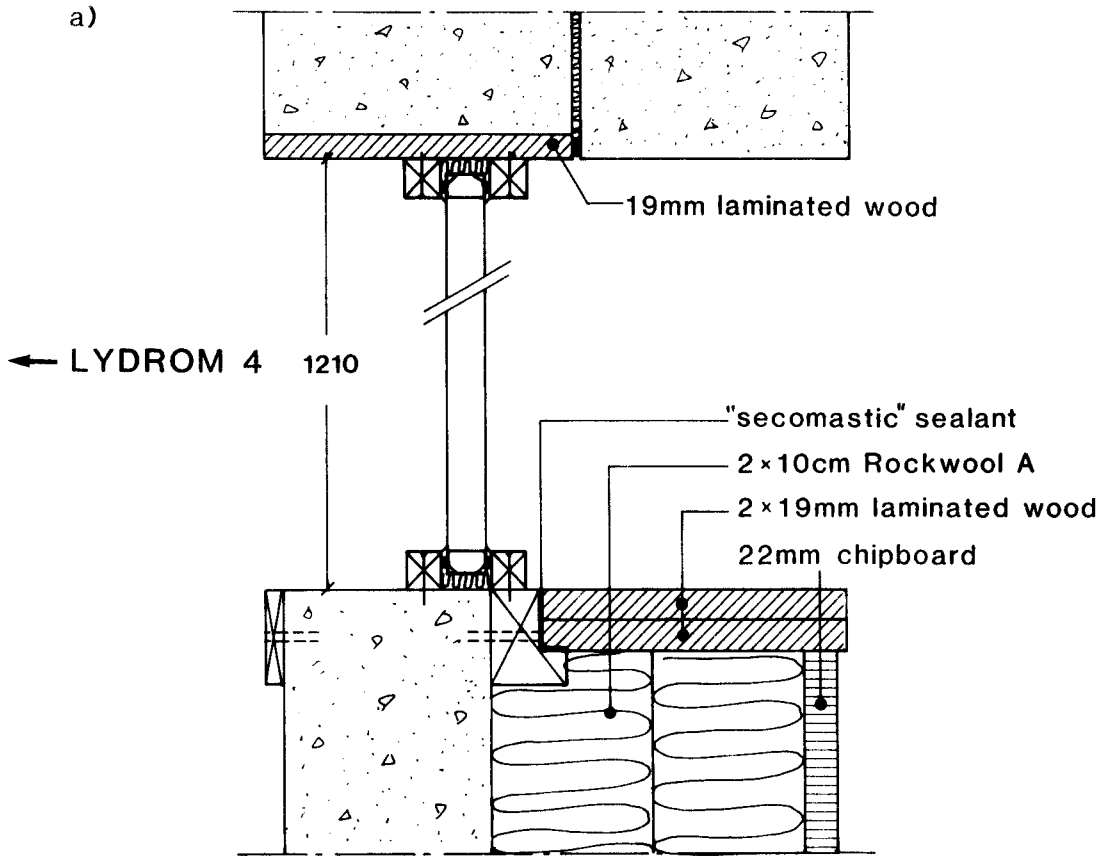
Fig.3 a, b

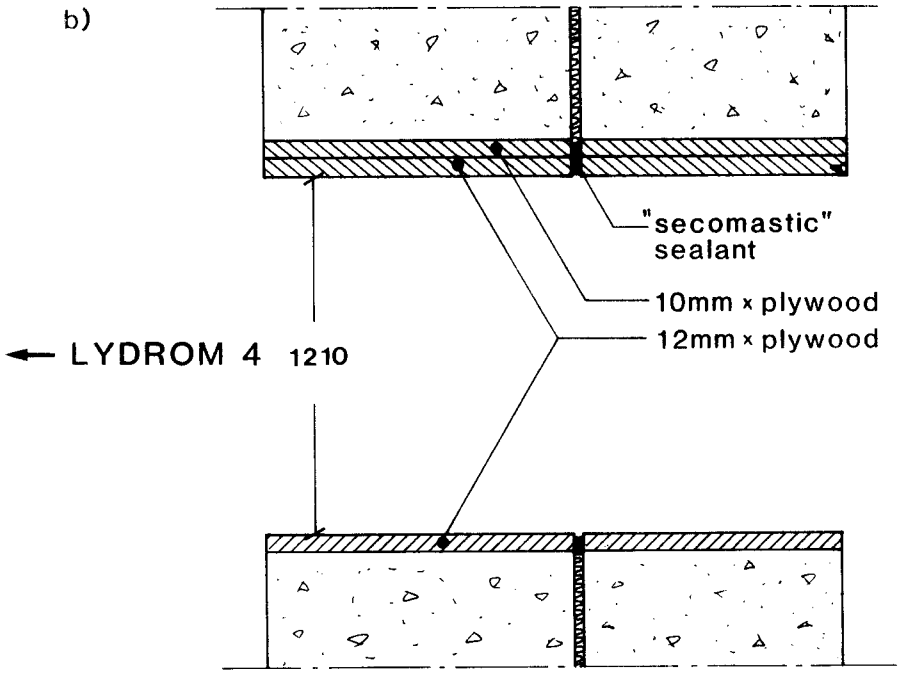
NT-project 235-80

a)



Vertical section

b)



Horizontal section

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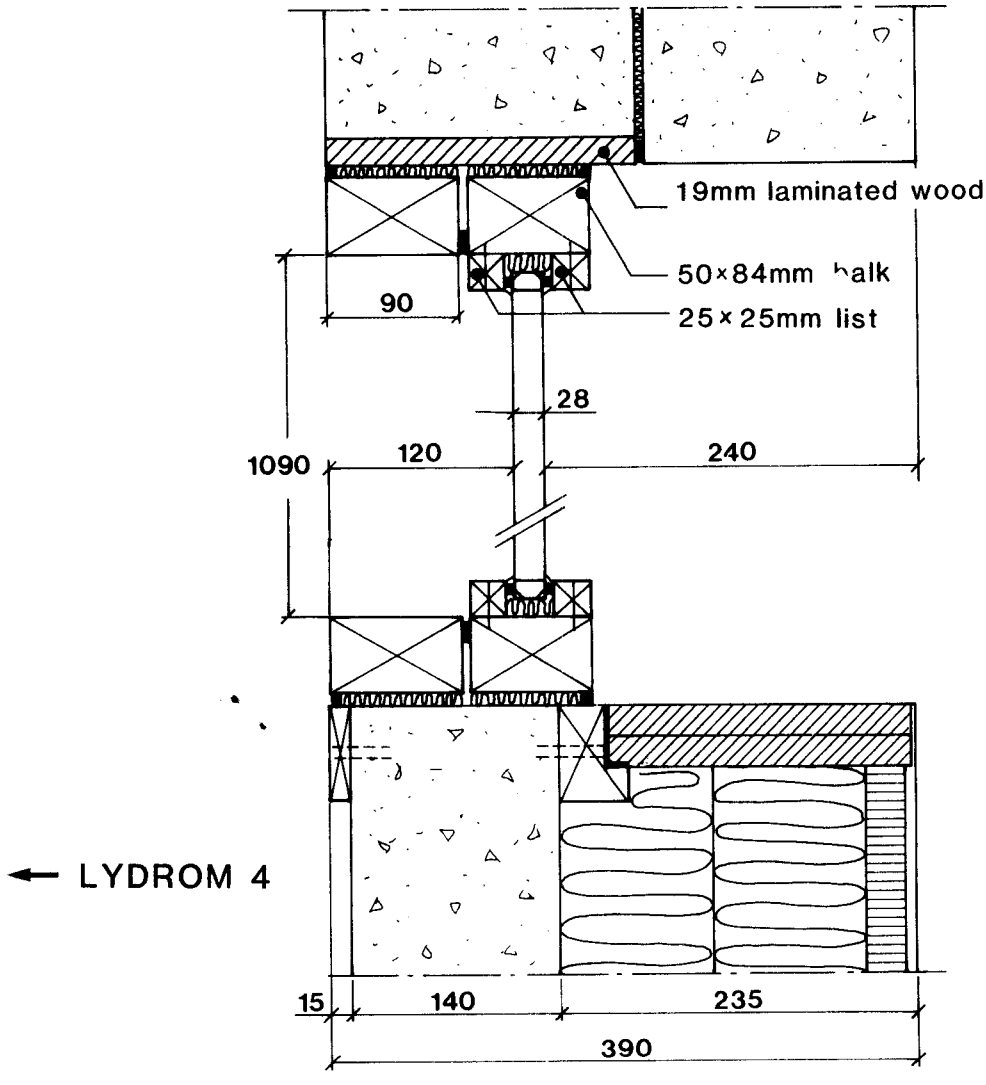
Fig.3 c, d

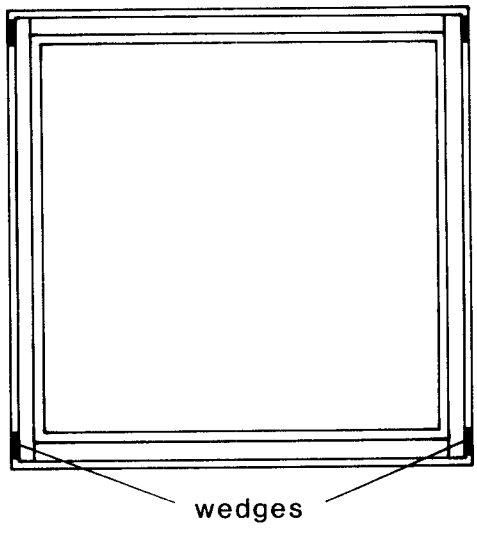
NT-project 360-82

c)



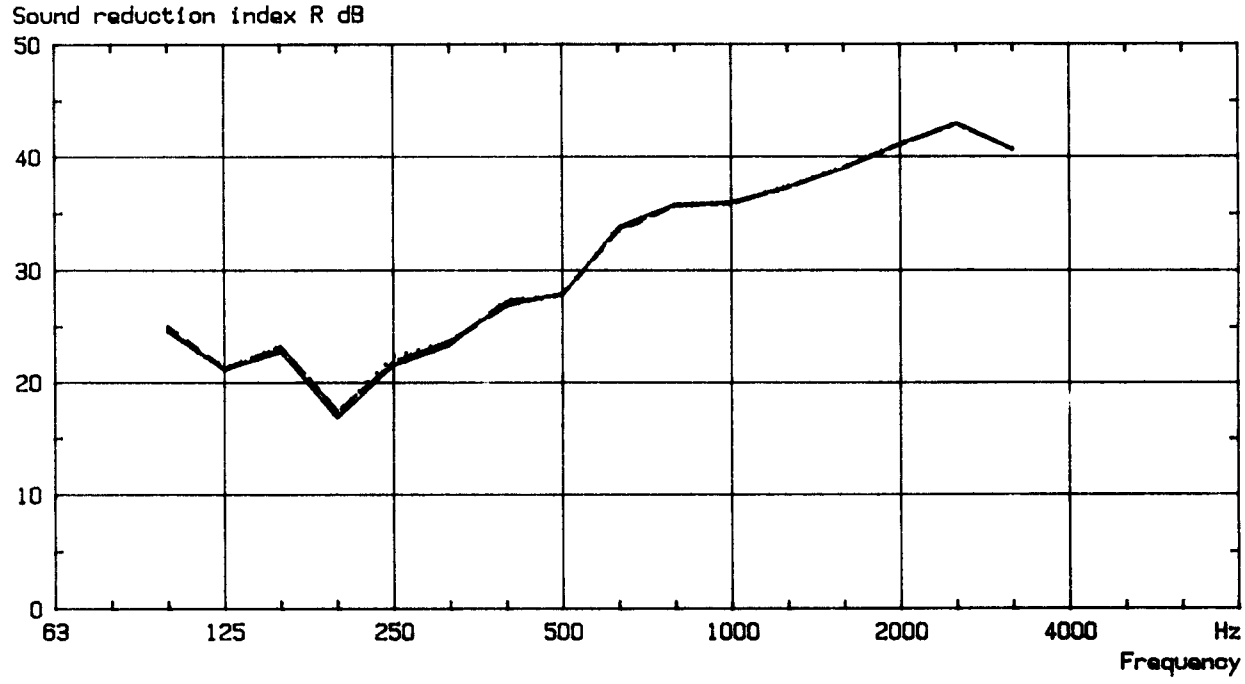
Vertical section

d)



APPENDIX E

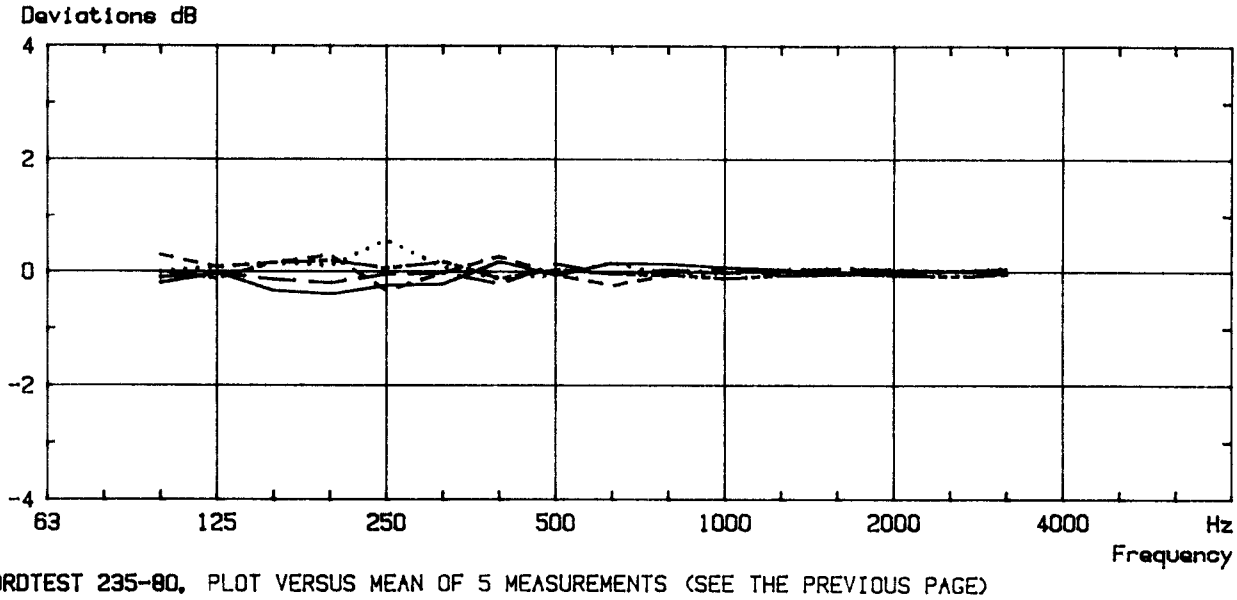
Results from Statens Provningsanstalt / SP



NORDTEST 235-80
LABORATORY : STATENS PROVNINGSANSTALT
1. INFLUENCE OF STOCHASTIC NOISE SIGNAL

——————— 1.1
. . . . . 1.2
– – – – – – – 1.3
— — — — 1.4
——·——·—— 1.5

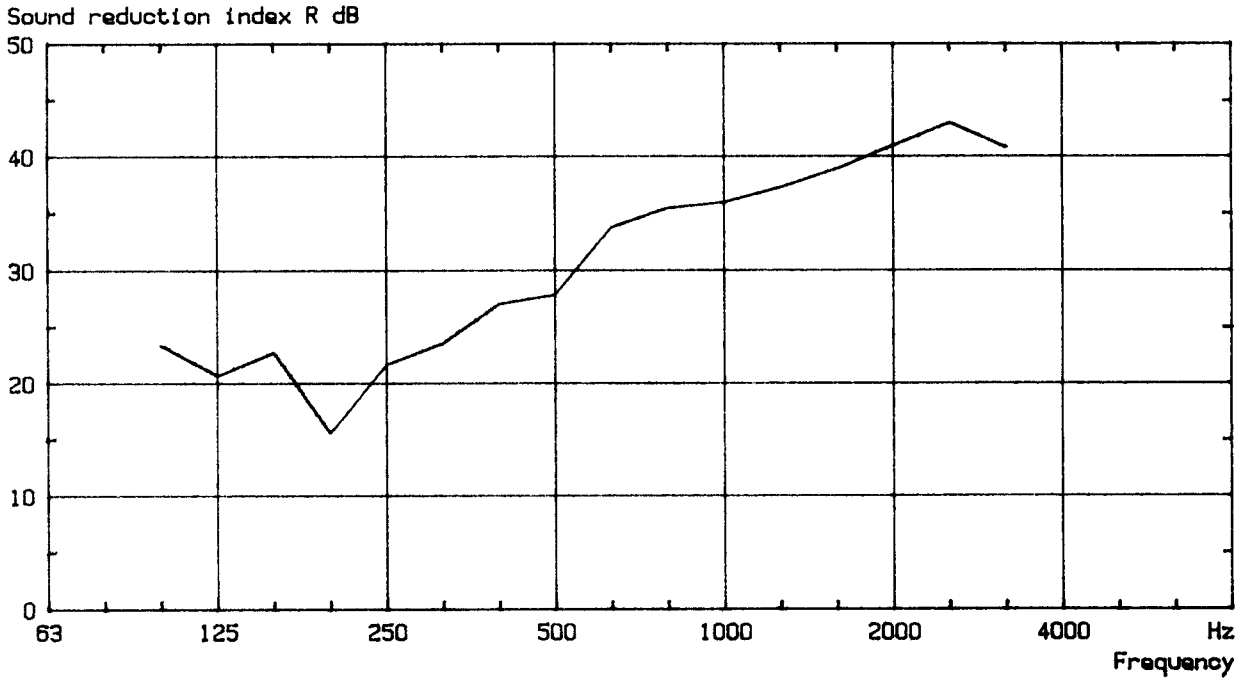
Measurement Frequency	1.1	1.2	1.3	1.4	1.5	Mean
Hz	dB	dB	dB	dB	dB	dB
100	24.6	24.8	25.1	24.7	24.8	24.8
125	21.2	21.3	21.3	21.2	21.1	21.2
160	22.8	23.3	23.3	23.0	23.3	23.1
200	16.8	17.3	17.5	17.0	17.4	17.2
250	21.6	22.4	21.5	21.8	21.9	21.8
315	23.4	23.7	23.6	23.6	23.8	23.6
400	27.3	27.0	27.4	26.9	27.0	27.1
500	27.8	27.8	27.8	28.0	27.9	27.9
630	33.9	33.9	33.5	33.7	33.7	33.7
800	35.9	35.7	35.7	35.8	35.7	35.8
1000	36.1	36.0	36.1	36.0	35.9	36.0
1250	37.4	37.4	37.3	37.4	37.3	37.4
1600	39.0	39.1	39.0	39.1	39.0	39.0
2000	41.2	41.2	41.1	41.2	41.1	41.2
2500	43.0	43.0	43.0	43.0	42.9	43.0
3150	40.7	40.7	40.6	40.6	40.6	40.6
Rw	33.7	33.9	33.8	33.7	33.8	33.8
Δ_{max}	-6.9	-6.6	-6.3	-6.8	-6.4	



NORDTEST 235-80, PLOT VERSUS MEAN OF 5 MEASUREMENTS (SEE THE PREVIOUS PAGE)
LABORATORY : STATENS PROVNINGSANSTALT
1. INFLUENCE OF STOCHASTIC NOISE SIGNAL

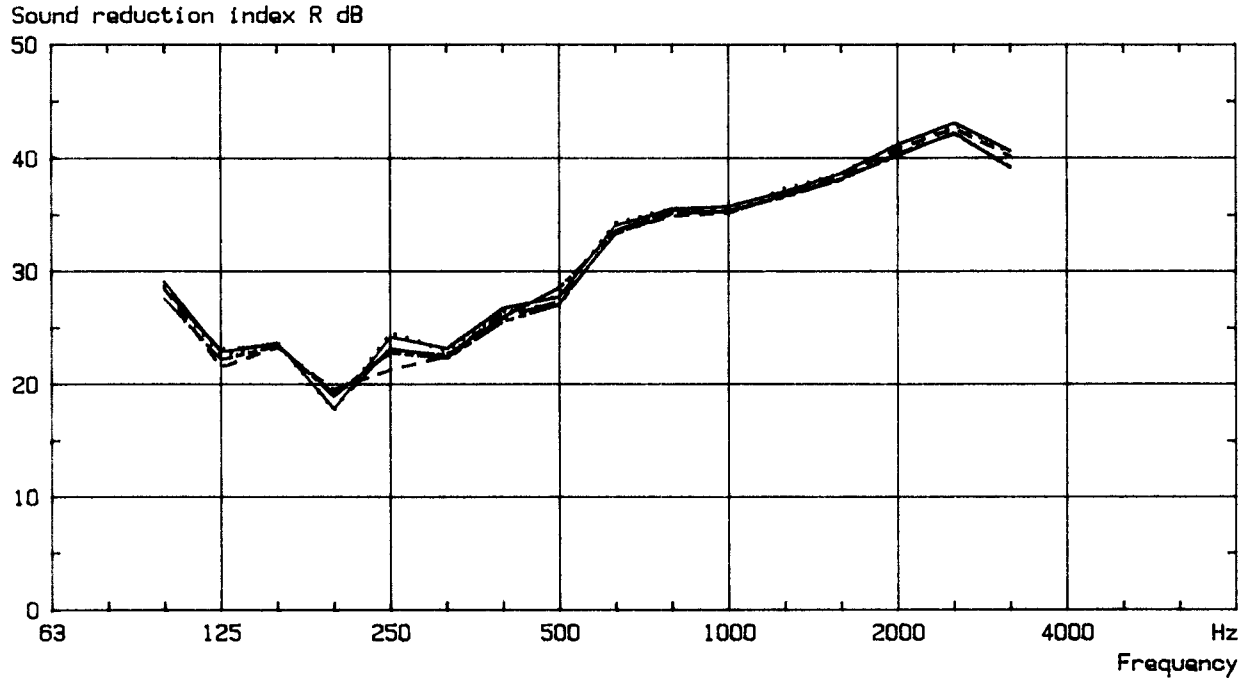
———— 1.1
. . . . . 1.2
- - - - - - 1.3
— — — · 1.4
———— 1.5

		Deviations from mean:				
Measurement Frequency	Mean	1.1	1.2	1.3	1.4	1.5
Hz	dB	dB	dB	dB	dB	dB
100	24.8	-0.2	0.0	0.3	-0.1	0.0
125	21.2	-0.0	0.1	0.1	-0.0	-0.1
160	23.1	-0.3	0.2	0.2	-0.1	0.2
200	17.2	-0.4	0.1	0.3	-0.2	0.2
250	21.8	-0.2	0.6	-0.3	-0.0	0.1
315	23.6	-0.2	0.1	-0.0	-0.0	0.2
400	27.1	0.2	-0.1	0.3	-0.2	-0.1
500	27.9	-0.1	-0.1	-0.1	0.1	0.0
630	33.7	0.2	0.2	-0.2	-0.0	-0.0
800	35.8	0.1	-0.1	-0.1	0.0	-0.1
1000	36.0	0.1	-0.0	0.1	-0.0	-0.1
1250	37.4	0.0	0.0	-0.1	0.0	-0.1
1600	39.0	-0.0	0.1	-0.0	0.1	-0.0
2000	41.2	0.0	0.0	-0.1	0.0	-0.1
2500	43.0	0.0	0.0	0.0	0.0	-0.1
3150	40.6	0.1	0.1	-0.0	-0.0	-0.0
Rw	33.8	-0.1	0.1	0.0	-0.1	0.0



NORDTEST 235-80
LABORATORY : STATENS PROVNINGSANSTALT
2. MOUNTING CONDITIONS

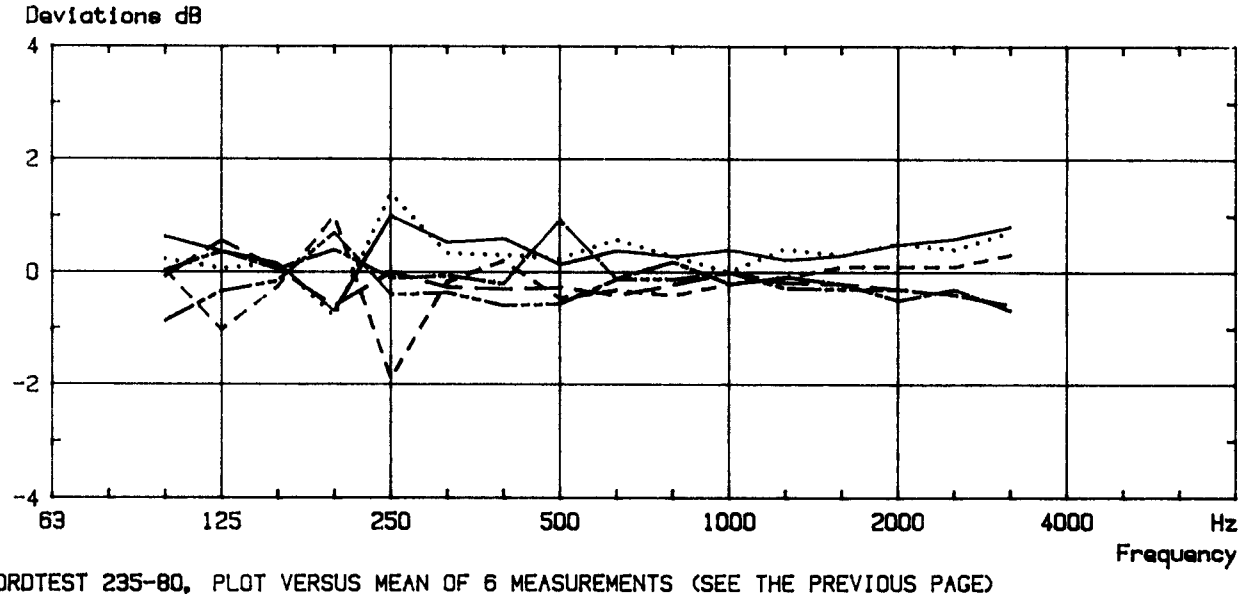
Measurement	3.2
Frequency	
Hz	dB
100	23.4
125	20.7
160	22.8
200	15.6
250	21.7
315	23.8
400	27.1
500	27.9
630	33.8
800	35.5
1000	36.0
1250	37.3
1600	38.9
2000	41.0
2500	43.0
3150	40.8
Rw	33.6
Δ_{max}	-8.0



NORDTEST 235-80
LABORATORY : STATENS PROVNINGSANSTALT
3. REPEATABILITY/REPRODUCIBILITY

——————— 3.1
. . . . . 3.2
– – – – – – – 3.3
— — — — · 3.5
———·——·——— 3.6
———·—·———·— 3.8

Measurement Frequency	3.1	3.2	3.3	3.5	3.6	3.8	Mean
Hz	dB	dB	dB	dB	dB	dB	dB
100	29.1	28.7	28.5	28.4	27.6	28.5	28.5
125	22.9	22.6	21.5	23.1	22.2	22.9	22.5
160	23.7	23.7	23.3	23.6	23.4	23.6	23.6
200	17.8	17.7	19.5	17.9	19.2	18.9	18.5
250	24.2	24.6	21.3	23.2	22.8	23.1	23.2
315	23.2	23.0	22.5	22.4	22.3	22.6	22.7
400	26.8	26.5	26.4	25.9	25.6	26.0	26.2
500	27.8	27.9	27.2	27.4	27.1	28.6	27.7
630	34.1	34.3	33.4	33.3	33.6	33.6	33.7
800	35.6	35.6	34.9	35.1	35.2	35.5	35.3
1000	35.8	35.4	35.2	35.4	35.4	35.2	35.4
1250	37.1	37.3	36.8	36.7	36.6	36.8	36.9
1600	38.7	38.7	38.5	38.2	38.1	38.2	38.4
2000	41.2	41.2	40.8	40.4	40.4	40.2	40.7
2500	43.1	42.9	42.6	42.1	42.1	42.2	42.5
3150	40.6	40.5	40.1	39.2	39.2	39.1	39.8
Rw	34.0	34.0	33.4	33.4	33.5	33.8	33.7
Δ_{max}	-6.8	-7.0	-6.9	-7.0	-7.2	-7.2	



NORDTEST 235-80. PLOT VERSUS MEAN OF 6 MEASUREMENTS (SEE THE PREVIOUS PAGE)
LABORATORY : STATENS PROVNINGSANSTALT
3. REPEATABILITY/REPRODUCIBILITY

——————— 3.1
. . . . . 3.2
- - - - - - - 3.3
—— —— —— · 3.5
———————— 3.6
———·———·—— 3.8

		Deviations from mean					
Measurement Frequency	Mean	3.1	3.2	3.3	3.5	3.6	3.8
Hz	dB	dB	dB	dB	dB	dB	dB
100	28.5	0.6	0.2	0.0	-0.1	-0.9	0.0
125	22.5	0.4	0.1	-1.0	0.6	-0.3	0.4
160	23.6	0.2	0.2	-0.3	0.1	-0.2	0.1
200	18.5	-0.7	-0.8	1.0	-0.6	0.7	0.4
250	23.2	1.0	1.4	-1.9	0.0	-0.4	-0.1
315	22.7	0.5	0.3	-0.2	-0.3	-0.4	-0.1
400	26.2	0.6	0.3	0.2	-0.3	-0.6	-0.2
500	27.7	0.1	0.2	-0.5	-0.3	-0.6	0.9
630	33.7	0.4	0.6	-0.3	-0.4	-0.1	-0.1
800	35.3	0.3	0.3	-0.4	-0.2	-0.1	0.2
1000	35.4	0.4	0.0	-0.2	0.0	0.0	-0.2
1250	36.9	0.2	0.4	-0.1	-0.2	-0.3	-0.1
1600	38.4	0.3	0.3	0.1	-0.2	-0.3	-0.2
2000	40.7	0.5	0.5	0.1	-0.3	-0.3	-0.5
2500	42.5	0.6	0.4	0.1	-0.4	-0.4	-0.3
3150	39.8	0.8	0.7	0.3	-0.6	-0.6	-0.7
Rw	33.7	0.3	0.3	-0.3	-0.3	-0.2	0.1

SP.

Measurement Procedures in Series no. 4

4.1 Measurement performed in accordance with the normal test procedure of our Laboratory. One loudspeaker position was used.

4.2 The same test procedure as in 4.1 but applied in the opposite measurement direction. Source and receiving room were shifted.

4.3 The measurement was performed in the same direction as in 4.1. The absorption of the receiving room was changed by adding some absorbents.

4.4 The additional absorbents were removed. New loudspeaker positions in both rooms.

4.5 Two loudspeaker positions in the source room.

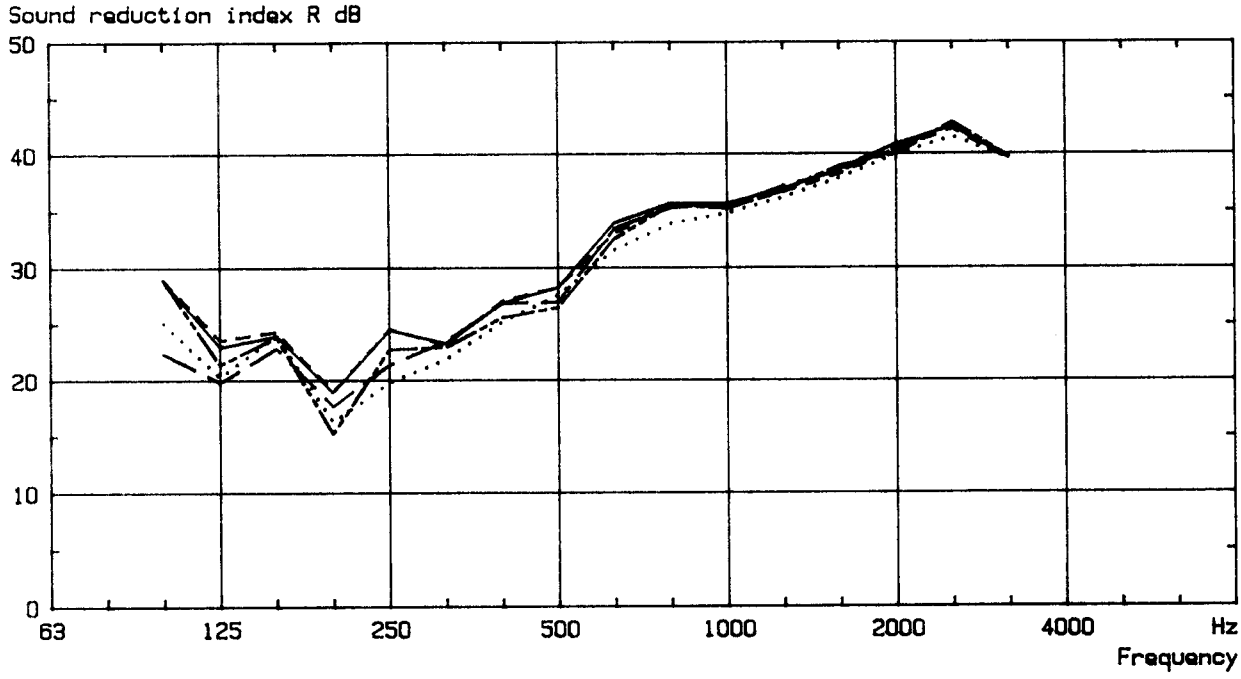
4.6 With the loudspeakers in their original positions. The configurations of the suspended plexiglas diffusers were changed in both rooms. The relative panel area was increased with 7.8 % and 6.7 % respectively.

4.7 The test rooms were restored to their normal conditions.

The measurement was made with an independent computer set-up. This test set-up is described in the reports of the Nordtest-projects 279-81 and 280-81. New loudspeaker was also used during the measurement.

4.8 Still another set-up was used to perform the measurement, Brüel & Kjaer Building Acoustics Analyzer type 4418.

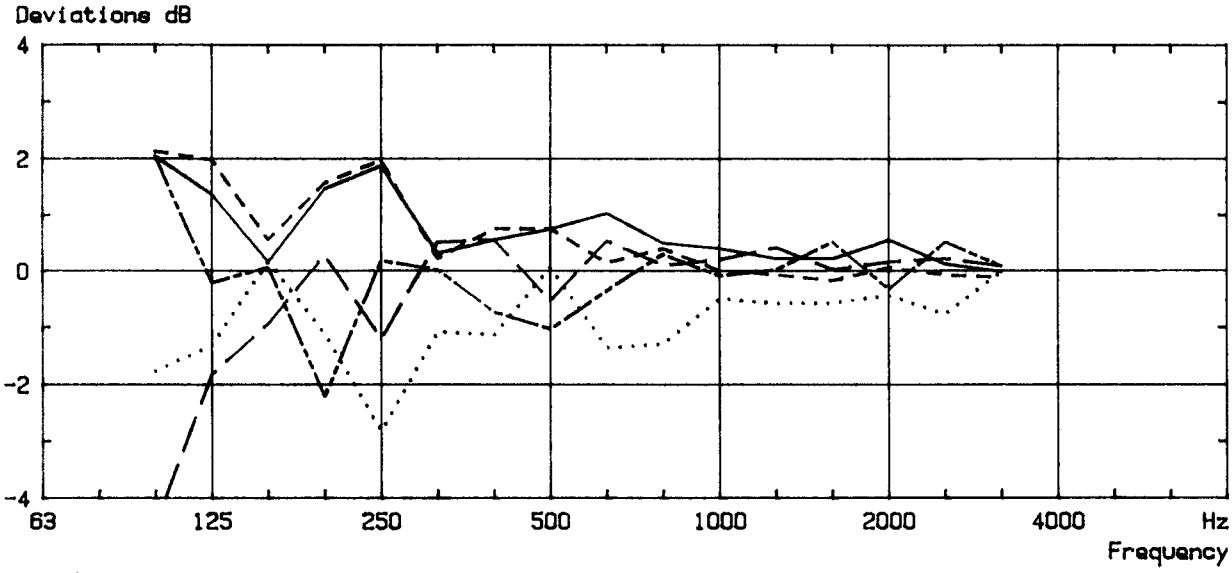
Note: In order to maintain the homogenity of the data material only 5 results, namely 4.1, 4.2, 4.3, 4.4 and 4.8 are included in the statistical analysis. The results from measurements no. 4.5, 4.6 and 4.7 are found in report no. 8231,906 from SP.



NORDTEST 235-80
LABORATORY : STATENS PROVNINGSANSTALT
4. REPRODUCIBILITY WITHIN LABORATORIES

———— 4.1
. . . . . 4.2
– – – – – – 4.3
— — — — 4.4
———— 4.8

Measurement Frequency Hz	4.1 dB	4.2 dB	4.3 dB	4.4 dB	4.8 dB	Mean dB
100	28.9	25.1	29.0	22.4	28.9	26.9
125	23.0	20.3	23.6	19.8	21.4	21.6
160	24.0	24.0	24.4	22.9	23.9	23.8
200	18.9	16.3	19.0	17.7	15.2	17.4
250	24.5	19.8	24.6	21.4	22.8	22.6
315	23.3	21.9	23.2	23.5	23.0	23.0
400	26.9	25.2	27.1	26.9	25.6	26.3
500	28.3	27.6	28.3	27.0	26.5	27.5
630	34.0	31.6	33.1	33.5	32.6	33.0
800	35.7	33.9	35.6	35.3	35.5	35.2
1000	35.7	34.8	35.3	35.5	35.2	35.3
1250	37.0	36.2	36.7	37.2	36.8	36.8
1600	38.7	37.9	38.3	38.5	39.0	38.5
2000	40.9	39.9	40.4	40.5	40.0	40.3
2500	42.4	41.5	42.2	42.5	42.8	42.3
3150	39.6	39.6	39.5	39.7	39.7	39.6
Rw	34.2	32.3	34.0	33.5	32.9	33.4
λ_{max}	-6.9	-6.4	-6.9	-6.5	-7.7	



NORDTEST 235-80. PLOT VERSUS MEAN OF 5 MEASUREMENTS (SEE THE PREVIOUS PAGE)
LABORATORY : STATENS PROVNINGSANSTALT
4. REPRODUCIBILITY WITHIN LABORATORIES

———— 4.1
. . . . . 4.2
– – – – – – 4.3
— — — — · 4.4
———·——·—— 4.8

		Deviations from mean:				
Measurement Frequency	Mean	4.1	4.2	4.3	4.4	4.8
Hz	dB	dB	dB	dB	dB	dB
100	26.9	2.0	-1.8	2.1	-4.5	2.0
125	21.6	1.4	-1.3	2.0	-1.8	-0.2
160	23.8	0.2	0.2	0.6	-0.9	0.1
200	17.4	1.5	-1.1	1.6	0.3	-2.2
250	22.6	1.9	-2.8	2.0	-1.2	0.2
315	23.0	0.3	-1.1	0.2	0.5	0.0
400	26.3	0.6	-1.1	0.8	0.6	-0.7
500	27.5	0.8	0.1	0.8	-0.5	-1.0
630	33.0	1.0	-1.4	0.1	0.5	-0.4
800	35.2	0.5	-1.3	0.4	0.1	0.3
1000	35.3	0.4	-0.5	0.0	0.2	-0.1
1250	36.8	0.2	-0.6	-0.1	0.4	0.0
1600	38.5	0.2	-0.6	-0.2	0.0	0.5
2000	40.3	0.6	-0.4	0.1	0.2	-0.3
2500	42.3	0.1	-0.8	-0.1	0.2	0.5
3150	39.6	-0.0	-0.0	-0.1	0.1	0.1
Rw	33.4	0.8	-1.1	0.6	0.1	-0.5

SP STATENS PROVNINGSANSTALT

APPENDIX

DETAILS OF MEASUREMENT PROCEDURE AND LABORATORY

Measurement rooms:

Sectional drawings of the transmission loss laboratory are presented in Figure 1. The source and receiving rooms are both provided with 5 hanging diffusers. The relative panel areas are 15.4% and 13.1% respectively.

Test opening:

Details of the test opening are presented in Figure 1 and 2.
N.B.,the test object in the photographs is not the same as investigated in this report.

Measurement procedure:

The test set-up is explained in Figure 3. The spatial and temporal averaging is achieved by using two rotating microphone booms (radius=1.12 m, revolution time=64 s, integration time=128 s).
No microphone position is closer to any room surface than 1 m:
The following instruments have been used.

Noise generator	Brüel & Kjaer	1405
Equalizer	Urei	539
Power amplifier	Accuphase	M-60
Loudspeaker	Philips	AD12100/HP
Microphone	Brüel & Kjaer	4144
Microphone preamplifier	Brüel & Kjaer	2619
Microphone power supply	Brüel & Kjaer	2801
Rotating microphone boom	Brüel & Kjaer	3923
Frequency analyzer	Brüel & Kjaer	2131
Sound level calibrator	Brüel & Kjaer	4230
Minicomputer	Digital Equipment	PDP/11-34

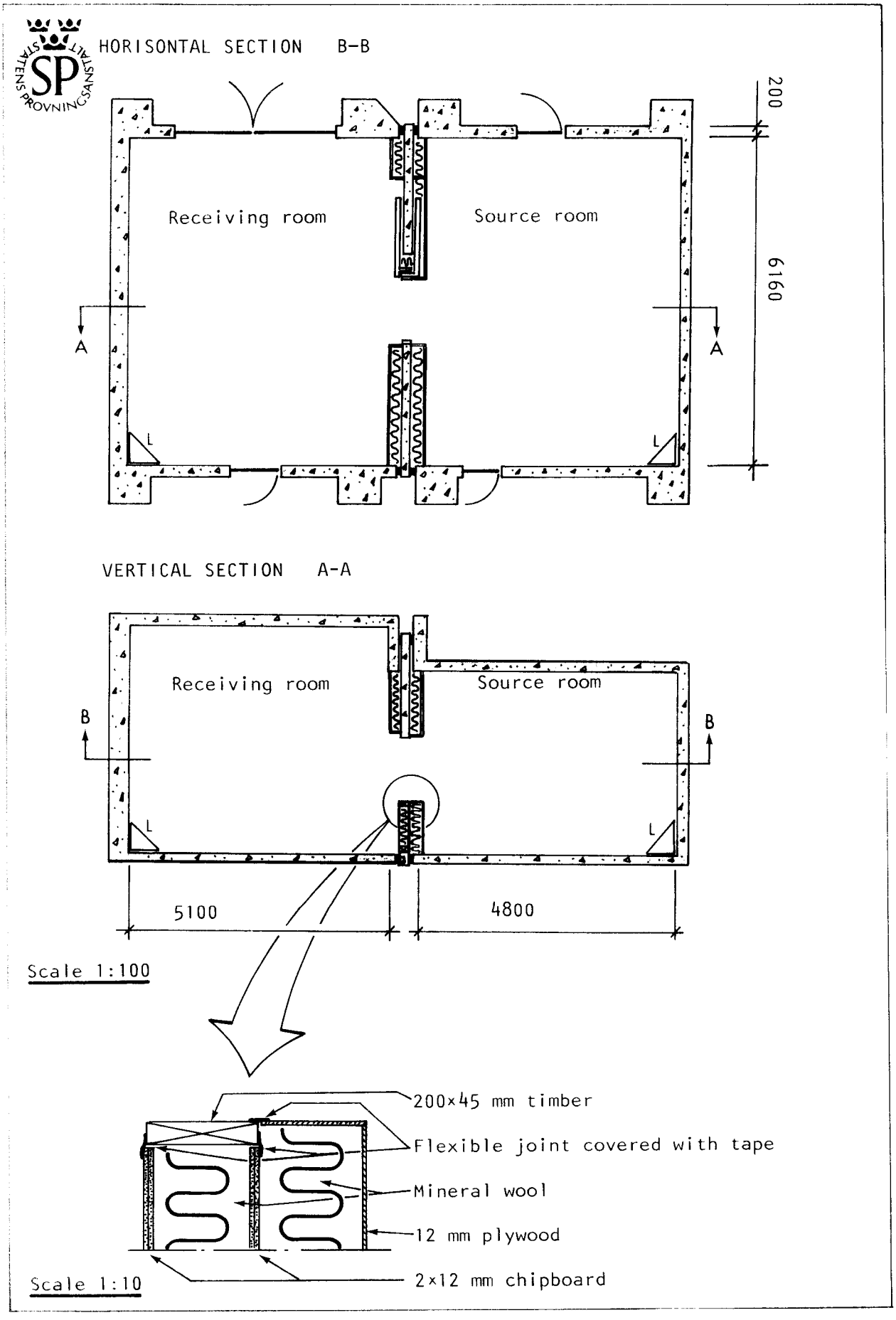
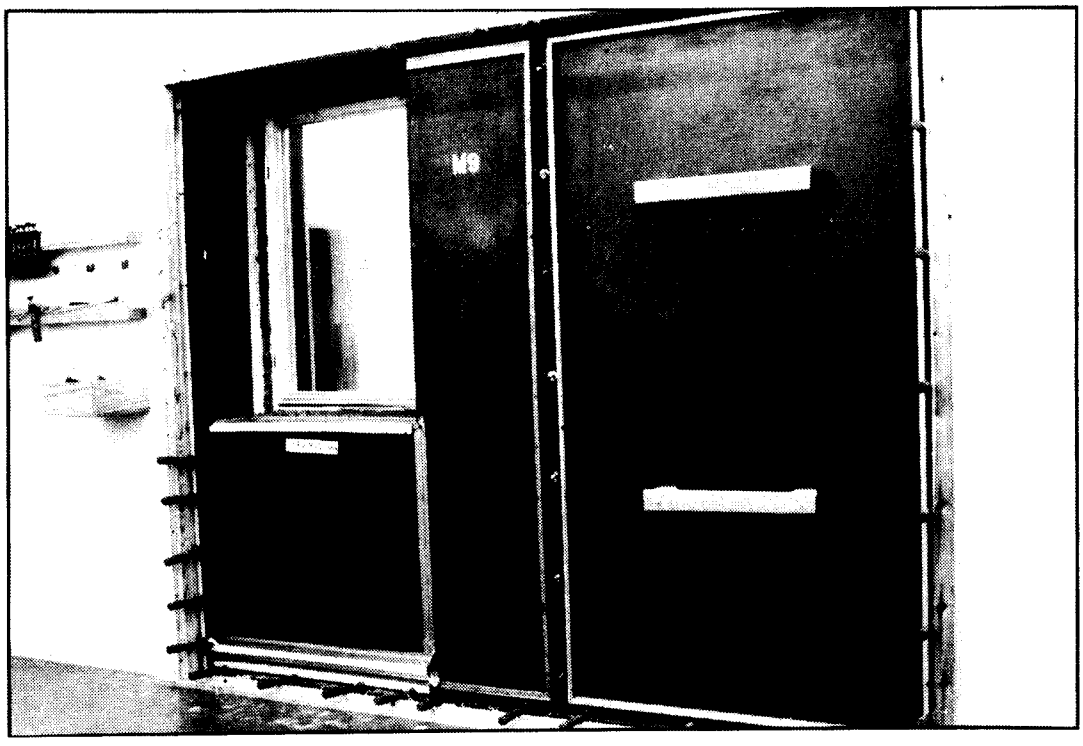
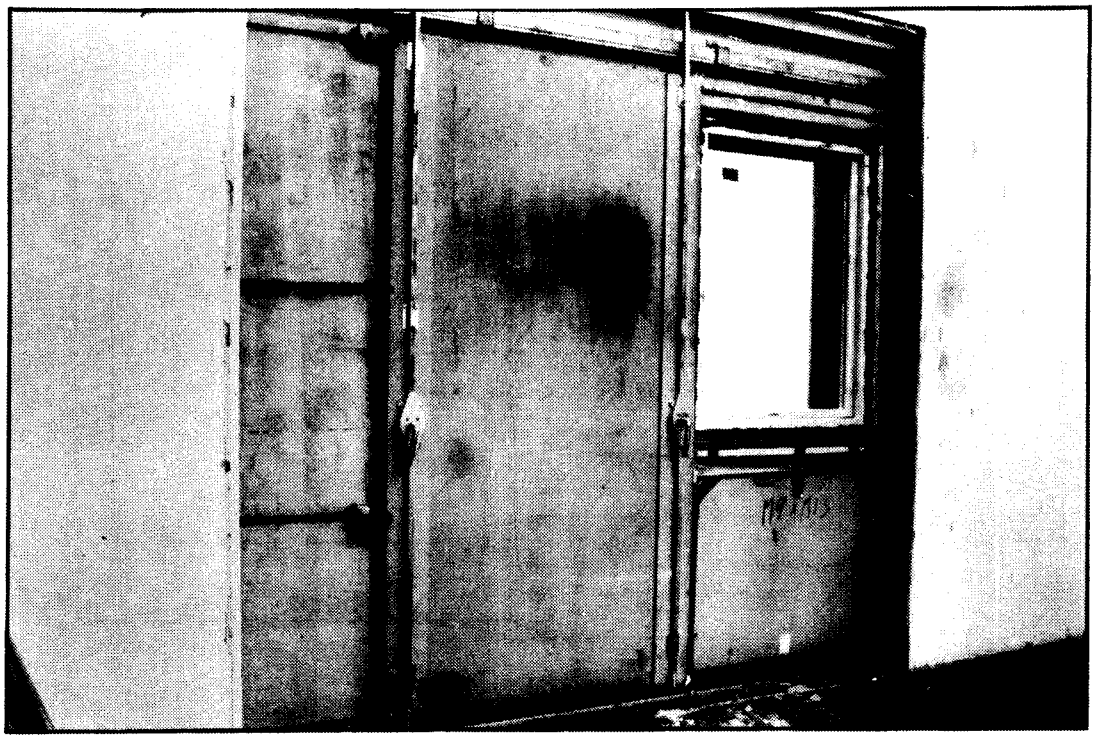


FIGURE 1 Drawings of the transmission loss laboratory.
L-normal loudspeaker positions



A



B

FIGURE 2 Photographs of the test opening for measurement of the transmission loss of Windows. The test object in the photos is not the same as tested in this report.

A- From the source room
B- From the receiving room

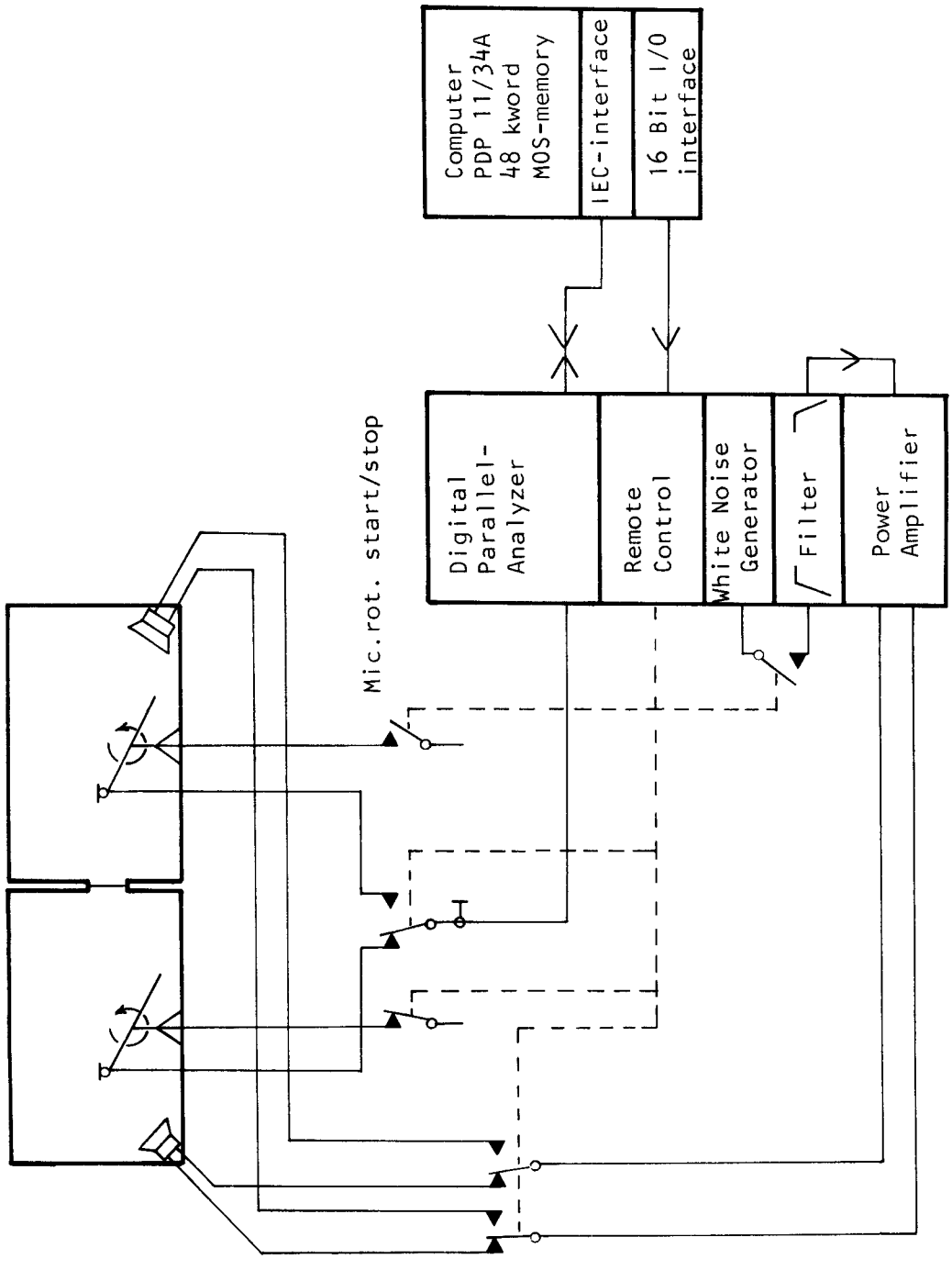
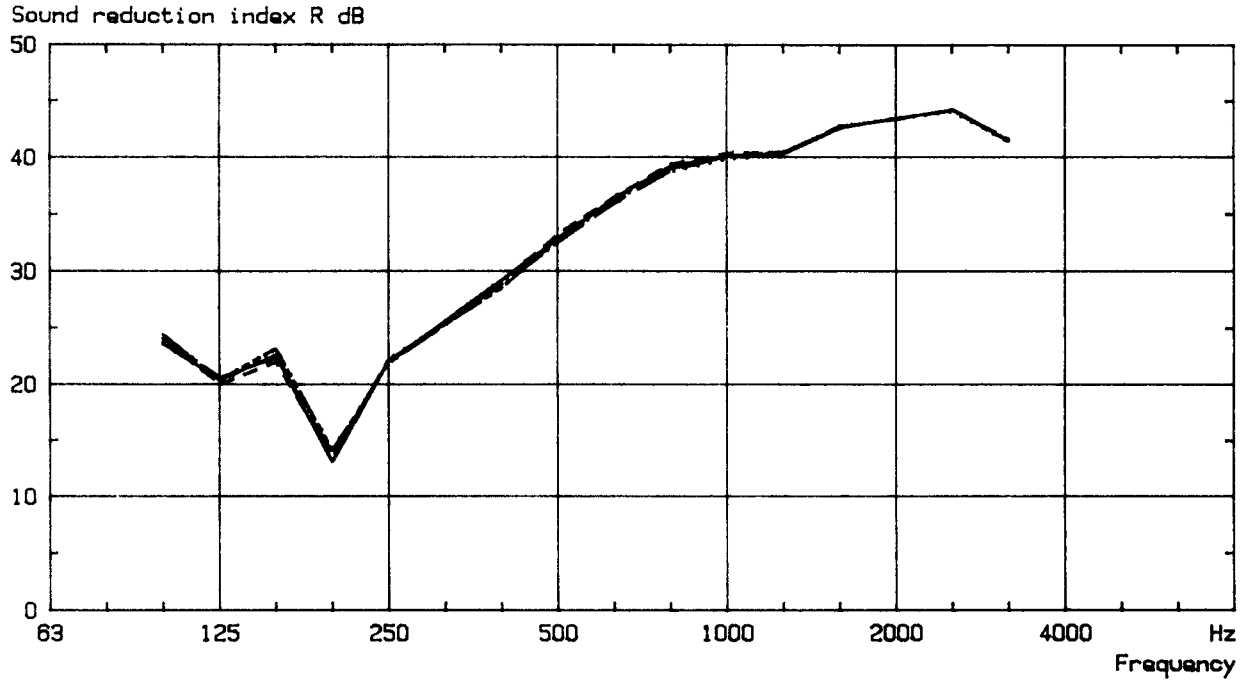


FIGURE 3 Measurement set-up for tests of the transmission loss of partitions

APPENDIX F

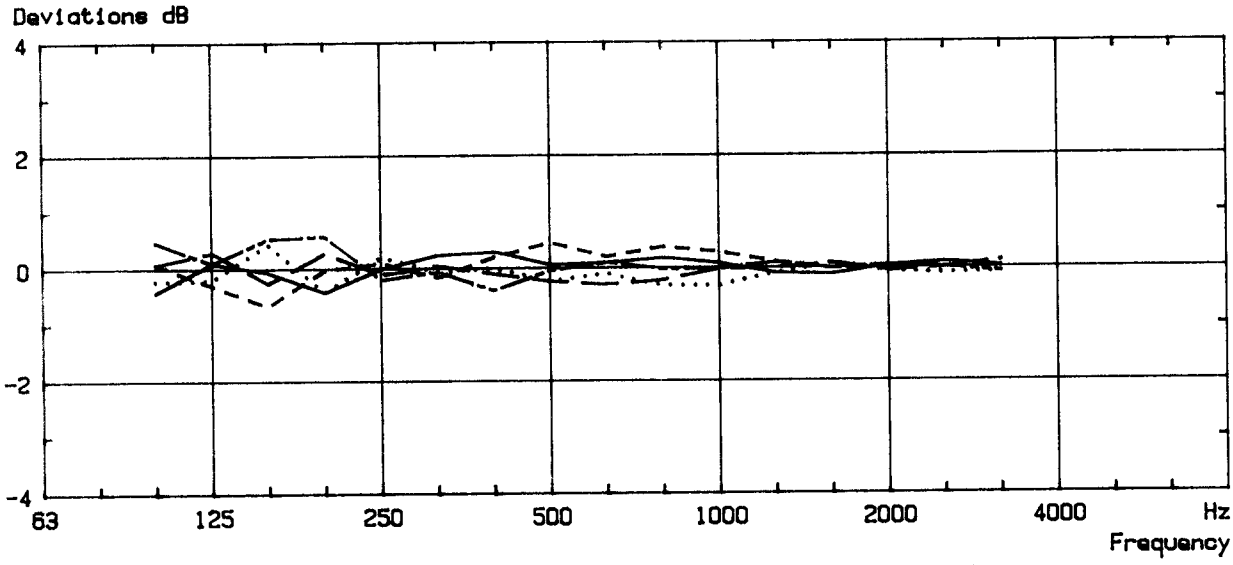
Results from Jydsk Teknologisk Institut / JTI



NORDTEST 235-80
LABORATORY : JYDSK TEKNOLOGISK INSTITUT
1. INFLUENCE OF STOCHASTIC NOISE SIGNAL

———— 1.1
. . . . . 1.2
– – – – – – 1.3
— — — · 1.4
———·—·— 1.5

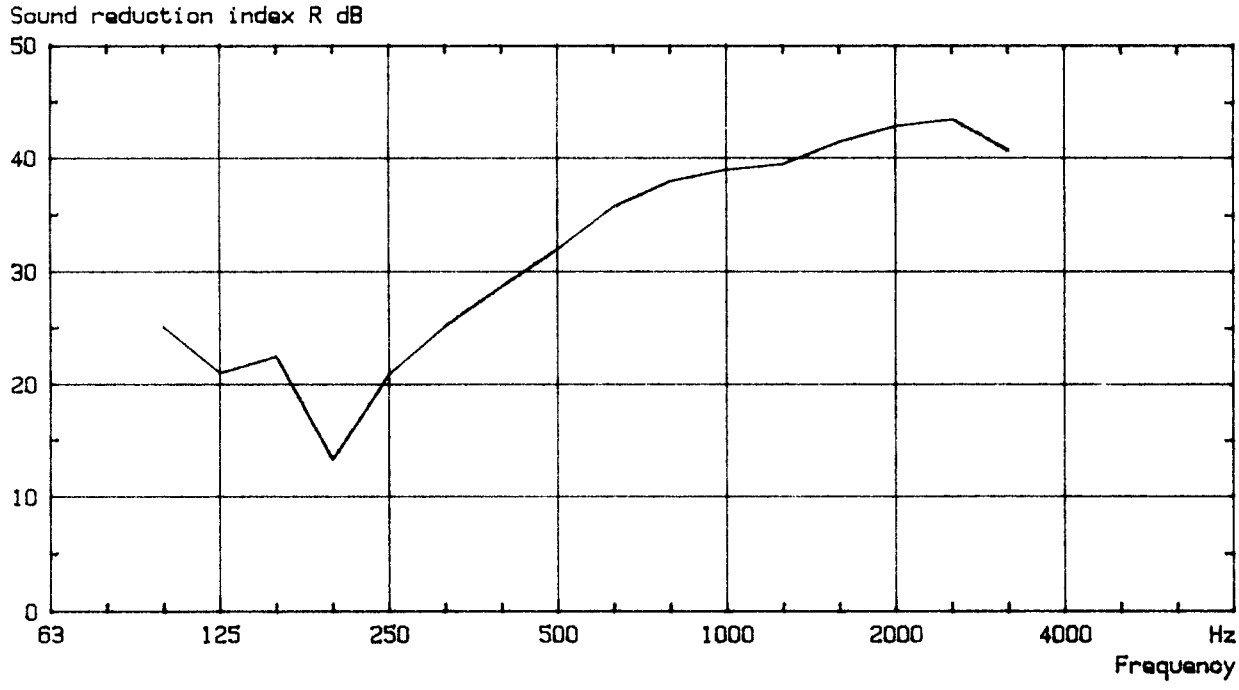
Measurement Frequency	1.1	1.2	1.3	1.4	1.5	Mean
Hz	dB	dB	dB	dB	dB	dB
100	23.6	23.8	24.1	24.1	24.5	24.0
125	20.4	20.1	20.0	20.6	20.4	20.3
160	22.6	23.1	22.0	22.4	23.2	22.7
200	13.1	13.1	13.5	13.8	14.1	13.5
250	22.1	22.3	22.2	22.0	21.9	22.1
315	25.6	25.3	25.2	25.4	25.3	25.4
400	29.2	28.9	29.1	28.8	28.5	28.9
500	32.8	32.5	33.2	32.5	32.7	32.7
630	36.4	36.2	36.5	36.0	36.4	36.3
800	39.2	38.7	39.4	38.8	39.0	39.0
1000	40.2	39.8	40.4	40.1	40.1	40.1
1250	40.3	40.3	40.5	40.4	40.5	40.4
1600	42.6	42.8	42.7	42.8	42.7	42.7
2000	43.5	43.4	43.5	43.4	43.5	43.5
2500	44.3	44.1	44.2	44.2	44.2	44.2
3150	41.5	41.4	41.6	41.5	41.4	41.5
Rw	35.3	35.2	35.3	35.2	35.3	35.3
Δ_{max}	-12.2	-12.1	-11.8	-11.4	-11.2	



NORDTEST 235-80. PLOT VERSUS MEAN OF 5 MEASUREMENTS (SEE THE PREVIOUS PAGE)
LABORATORY : JYDSK TEKNOLOGISK INSTITUT
1. INFLUENCE OF STOCHASTIC NOISE SIGNAL

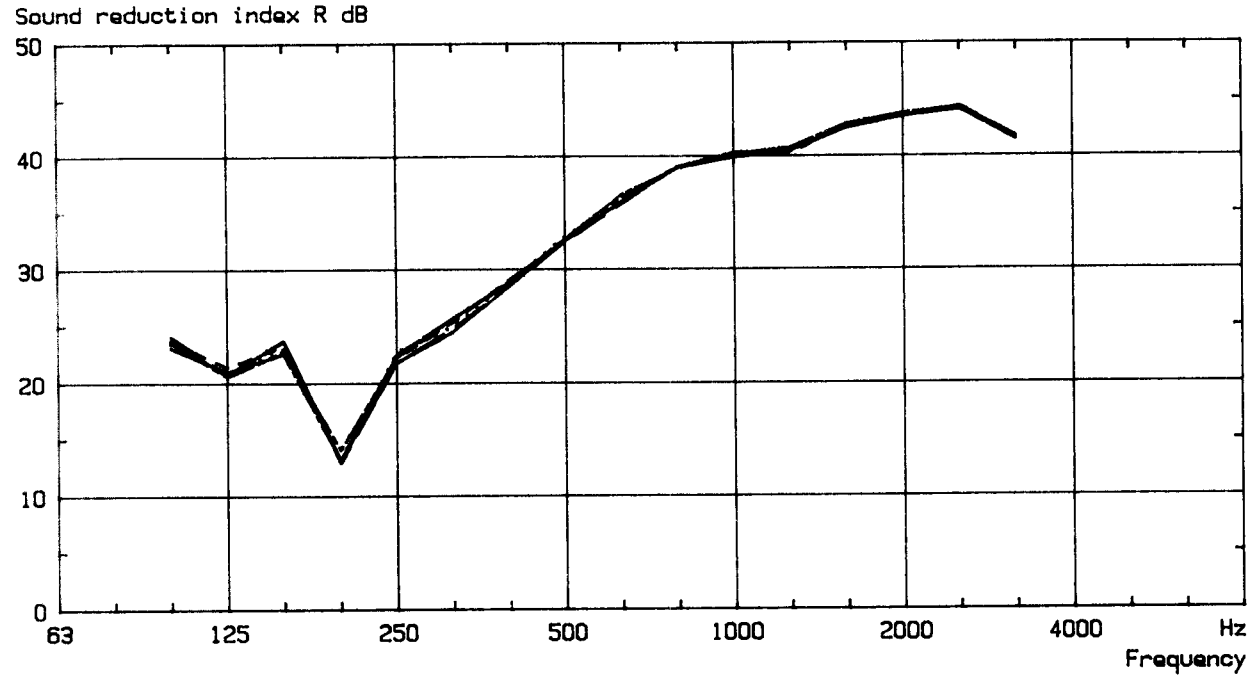
——————— 1.1
. . . . . 1.2
– – – – – – 1.3
— — — — · 1.4
———·—·—— 1.5

		Deviations from mean:				
Measurement Frequency Hz	Mean dB	1.1 dB	1.2 dB	1.3 dB	1.4 dB	1.5 dB
100	24.0	-0.4	-0.2	0.1	0.1	0.5
125	20.3	0.1	-0.2	-0.3	0.3	0.1
160	22.7	-0.1	0.4	-0.7	-0.3	0.5
200	13.5	-0.4	-0.4	-0.0	0.3	0.6
250	22.1	0.0	0.2	0.1	-0.1	-0.2
315	25.4	0.2	-0.1	-0.2	0.0	-0.1
400	28.9	0.3	0.0	0.2	-0.1	-0.4
500	32.7	0.1	-0.2	0.5	-0.2	-0.0
630	36.3	0.1	-0.1	0.2	-0.3	0.1
800	39.0	0.2	-0.3	0.4	-0.2	-0.0
1000	40.1	0.1	-0.3	0.3	-0.0	-0.0
1250	40.4	-0.1	-0.1	0.1	0.0	0.1
1600	42.7	-0.1	0.1	-0.0	0.1	-0.0
2000	43.5	0.0	-0.1	0.0	-0.1	0.0
2500	44.2	0.1	-0.1	0.0	0.0	0.0
3150	41.5	0.0	-0.1	0.1	0.0	-0.1
Rw	35.3	0.0	-0.1	0.0	-0.1	0.0



NORDTEST 235-80
LABORATORY : JYDSK TEKNOLOGISK INSTITUT
2. MOUNTING CONDITIONS

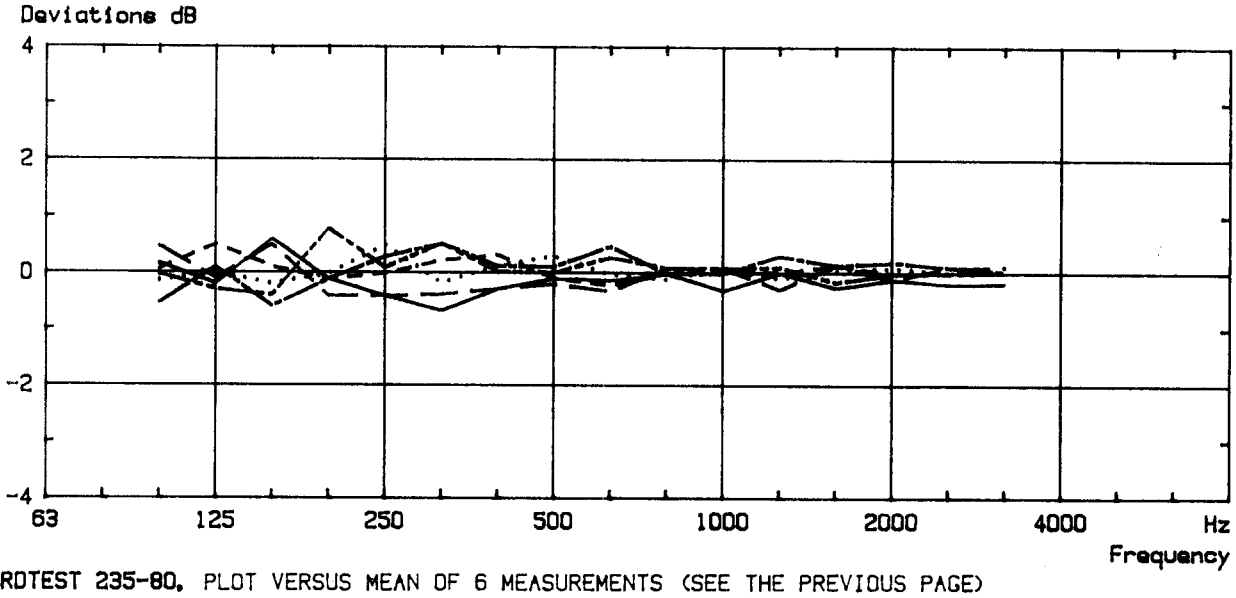
Measurement	4.2
Frequency Hz	dB
100	25.1
125	21.0
160	22.5
200	13.3
250	20.9
315	25.2
400	28.7
500	32.0
630	35.8
800	38.0
1000	39.0
1250	39.5
1600	41.5
2000	42.9
2500	43.5
3150	40.7
Rw	34.8
Δ_{max}	-11.5



NORDTEST 235-80
LABORATORY : JYDSK TEKNOLOGISK INSTITUT
3. REPEATABILITY/REPRODUCIBILITY

——————— 3.1
. . . . . 3.2
– – – – – – 3.3
— — — — 3.4
———————— 3.5
———·———·— 3.6

Measurement Frequency Hz	3.1 dB	3.2 dB	3.3 dB	3.4 dB	3.5 dB	3.6 dB	Mean dB
100	23.8	23.5	23.7	24.1	23.6	23.1	23.6
125	20.7	20.9	21.4	20.8	20.6	21.0	20.9
160	23.8	23.0	23.3	23.7	22.8	22.6	23.2
200	13.2	13.3	13.2	12.9	14.1	13.2	13.3
250	21.8	22.7	22.2	21.8	22.3	22.5	22.2
315	24.5	25.0	25.4	24.8	25.7	25.7	25.2
400	28.5	28.9	29.1	28.5	28.8	28.9	28.8
500	32.5	32.9	32.5	32.4	32.6	32.7	32.6
630	36.0	36.1	35.9	35.8	36.4	36.6	36.1
800	39.0	38.9	39.0	39.1	39.1	39.0	39.0
1000	39.9	40.3	40.3	40.3	40.3	40.2	40.2
1250	40.5	40.4	40.5	40.2	40.6	40.8	40.5
1600	42.5	42.8	42.9	42.9	42.6	42.9	42.8
2000	43.5	43.7	43.6	43.5	43.6	43.8	43.6
2500	44.1	44.3	44.3	44.4	44.3	44.4	44.3
3150	41.4	41.6	41.6	41.7	41.6	41.6	41.6
Rw	34.9	35.3	35.2	34.8	35.4	35.4	35.2
λ_{max}	-11.7	-12.0	-12.0	-11.9	-11.3	-12.2	



NORDTEST 235-80. PLOT VERSUS MEAN OF 6 MEASUREMENTS (SEE THE PREVIOUS PAGE)
LABORATORY : JYDSK TEKNOLOGISK INSTITUT
3. REPEATABILITY/REPRODUCIBILITY

——————— 3.1
. . . . . 3.2
- - - - - - - 3.3
— — — — 3.4
—·—·—·— 3.5
—··—··—·· 3.6

		Deviations from mean:					
Measurement Frequency	Mean	3.1	3.2	3.3	3.4	3.5	3.6
Hz	dB	dB	dB	dB	dB	dB	dB
100	23.6	0.2	-0.1	0.1	0.5	-0.0	-0.5
125	20.9	-0.2	0.0	0.5	-0.1	-0.3	0.1
160	23.2	0.6	-0.2	0.1	0.5	-0.4	-0.6
200	13.3	-0.1	-0.0	-0.1	-0.4	0.8	-0.1
250	22.2	-0.4	0.5	-0.0	-0.4	0.1	0.3
315	25.2	-0.7	-0.2	0.2	-0.4	0.5	0.5
400	28.8	-0.3	0.1	0.3	-0.3	0.0	0.1
500	32.6	-0.1	0.3	-0.1	-0.2	0.0	0.1
630	36.1	-0.1	-0.0	-0.2	-0.3	0.3	0.5
800	39.0	-0.0	-0.1	-0.0	0.1	0.1	-0.0
1000	40.2	-0.3	0.1	0.1	0.1	0.1	-0.0
1250	40.5	0.0	-0.1	0.0	-0.3	0.1	0.3
1600	42.8	-0.3	0.0	0.1	0.1	-0.2	0.1
2000	43.6	-0.1	0.1	-0.0	-0.1	-0.0	0.2
2500	44.3	-0.2	0.0	0.0	0.1	0.0	0.1
3150	41.6	-0.2	0.0	0.0	0.1	0.0	0.0
Rw	35.2	-0.3	0.1	0.0	-0.4	0.2	0.2

JTI

Measurement Procedures in Series no. 4

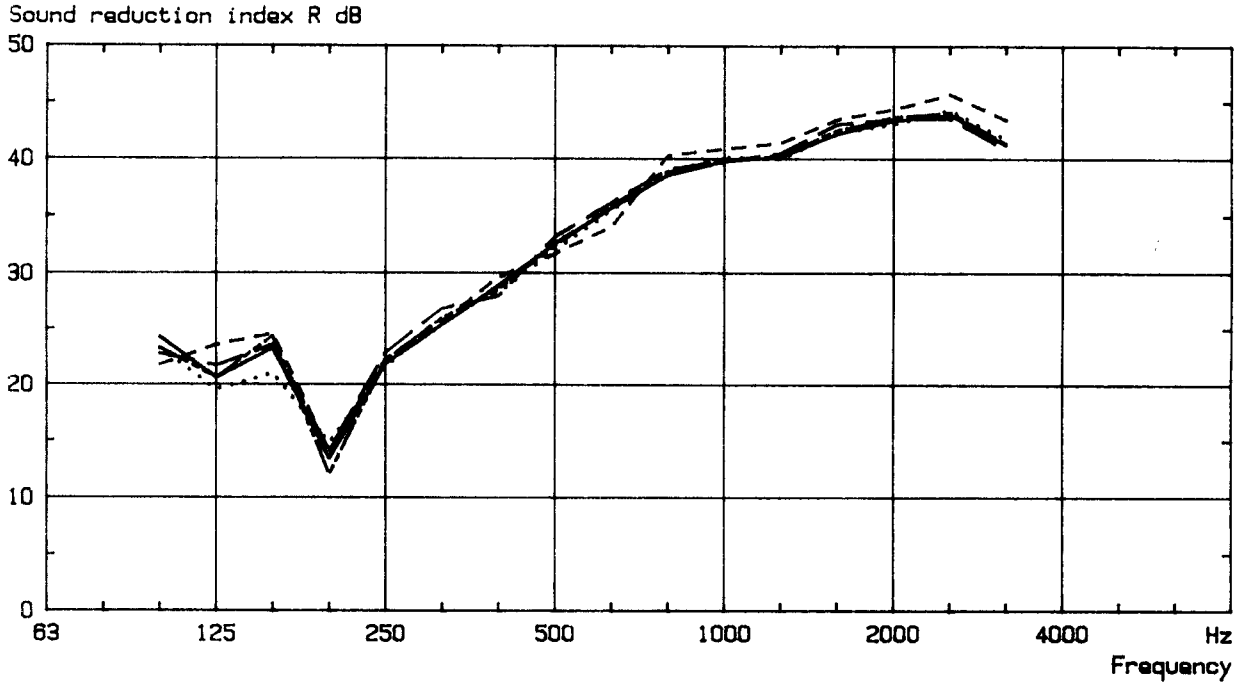
4.1 A measurement according to the normal test procedure.

4.2 A measurement with loudspeakers in positions different from normal positions.

4.3 A measurement in the opposite direction.

4.4 A measurement with the loudspeaker cabinets opened.

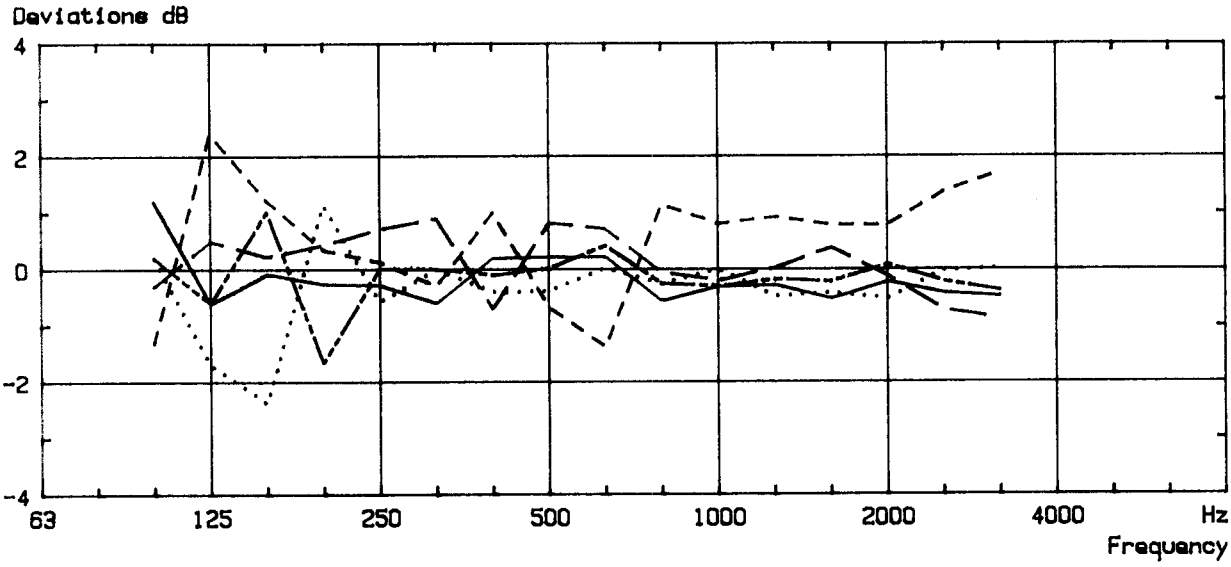
4.5 A measurement with the diffusers in the source room removed.



NORDTEST 235-80
LABORATORY : JYDSK TEKNOLOGISK INSTITUT
4. REPRODUCIBILITY WITHIN LABORATORIES

———— 4.1
. . . . . 4.2
– – – – – – 4.3
— — — — 4.4
———— 4.5

Measurement Frequency Hz	4.1 dB	4.2 dB	4.3 dB	4.4 dB	4.5 dB	Mean dB
100	24.3	23.3	21.8	22.8	23.3	23.1
125	20.6	19.5	23.6	21.7	20.6	21.2
160	23.3	21.0	24.6	23.6	24.4	23.4
200	13.4	14.8	14.0	14.1	12.0	13.7
250	21.9	21.6	22.3	22.9	22.2	22.2
315	25.4	26.0	25.7	26.9	26.0	26.0
400	28.9	28.3	29.7	28.0	28.6	28.7
500	32.6	32.0	31.7	33.2	32.4	32.4
630	35.7	35.5	34.1	36.2	35.9	35.5
800	38.6	38.9	40.3	39.1	38.9	39.2
1000	39.8	40.1	40.9	39.9	39.8	40.1
1250	40.2	40.0	41.4	40.5	40.3	40.5
1600	42.2	42.3	43.5	43.1	42.5	42.7
2000	43.4	43.1	44.4	43.5	43.7	43.6
2500	43.8	44.3	45.7	43.6	44.1	44.3
3150	41.2	41.7	43.4	40.8	41.3	41.7
Rw	35.1	35.0	35.0	35.7	35.0	35.2
Δ_{max}	-11.7	-10.2	-11.0	-11.6	-13.0	



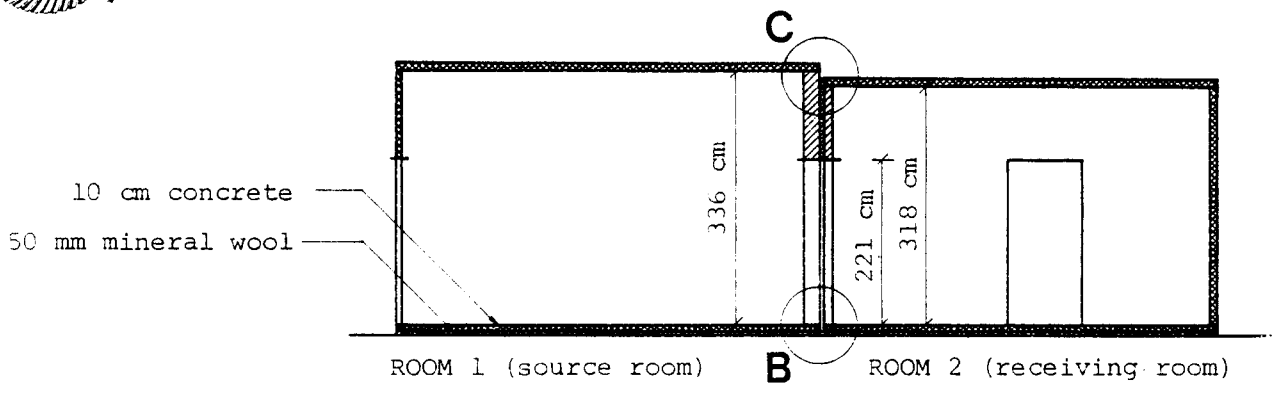
NORDTEST 235-80. PLOT VERSUS MEAN OF 5 MEASUREMENTS (SEE THE PREVIOUS PAGE)
LABORATORY : JYDSK TEKNOLOGISK INSTITUT
4. REPRODUCIBILITY WITHIN LABORATORIES

———— 4.1
. . . . . 4.2
– – – – – – 4.3
— — — — 4.4
———— 4.5

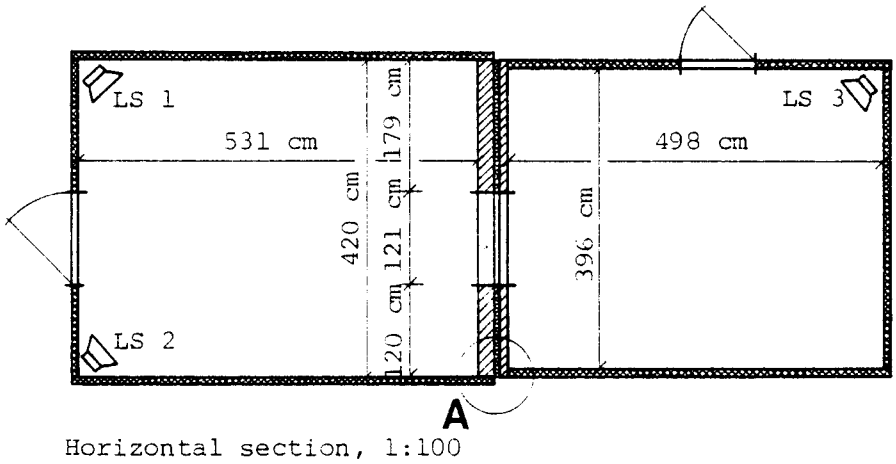
		Deviations from mean:				
Measurement Frequency	Mean	4.1	4.2	4.3	4.4	4.5
Hz	dB	dB	dB	dB	dB	dB
100	23.1	1.2	0.2	-1.3	-0.3	0.2
125	21.2	-0.6	-1.7	2.4	0.5	-0.6
160	23.4	-0.1	-2.4	1.2	0.2	1.0
200	13.7	-0.3	1.1	0.3	0.4	-1.7
250	22.2	-0.3	-0.6	0.1	0.7	0.0
315	26.0	-0.6	0.0	-0.3	0.9	0.0
400	28.7	0.2	-0.4	1.0	-0.7	-0.1
500	32.4	0.2	-0.4	-0.7	0.8	0.0
630	35.5	0.2	0.0	-1.4	0.7	0.4
800	39.2	-0.6	-0.3	1.1	-0.1	-0.3
1000	40.1	-0.3	0.0	0.8	-0.2	-0.3
1250	40.5	-0.3	-0.5	0.9	0.0	-0.2
1600	42.7	-0.5	-0.4	0.8	0.4	-0.2
2000	43.6	-0.2	-0.5	0.8	-0.1	0.1
2500	44.3	-0.4	-0.0	1.4	-0.7	-0.2
3150	41.7	-0.5	0.0	1.7	-0.9	-0.4
Rw	35.2	-0.1	-0.2	-0.2	0.5	-0.2

1. MEASUREMENT ROOMS

NT 235-80 - NT 360-82



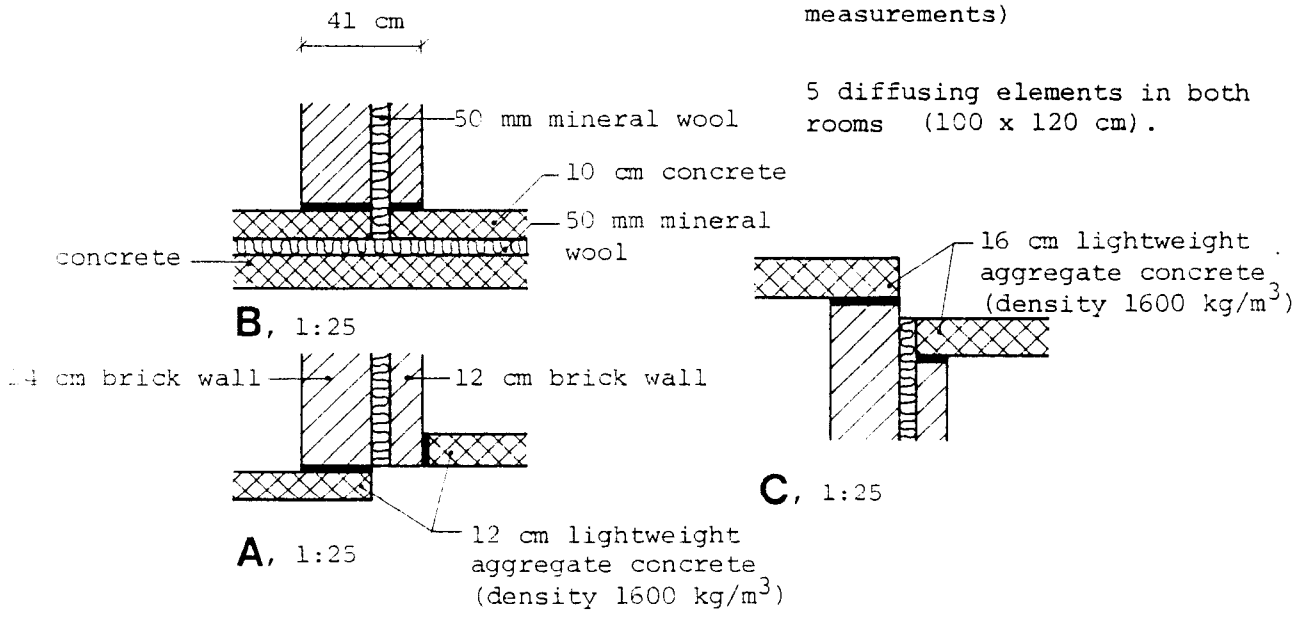
Vertical section, 1:100



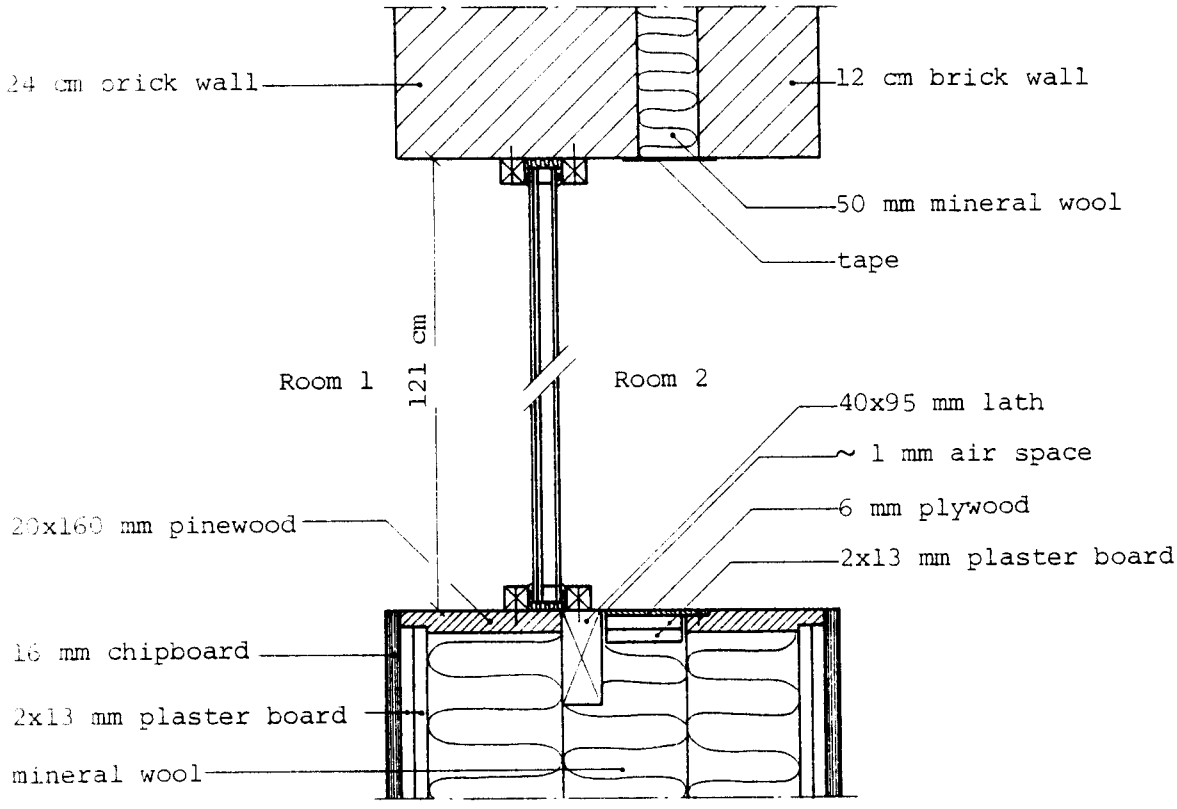
Horizontal section, 1:100

LS 1: positioned under the ceiling
LS 2: positioned on the floor
LS 3: positioned on the floor
(used for reverberation time measurements)

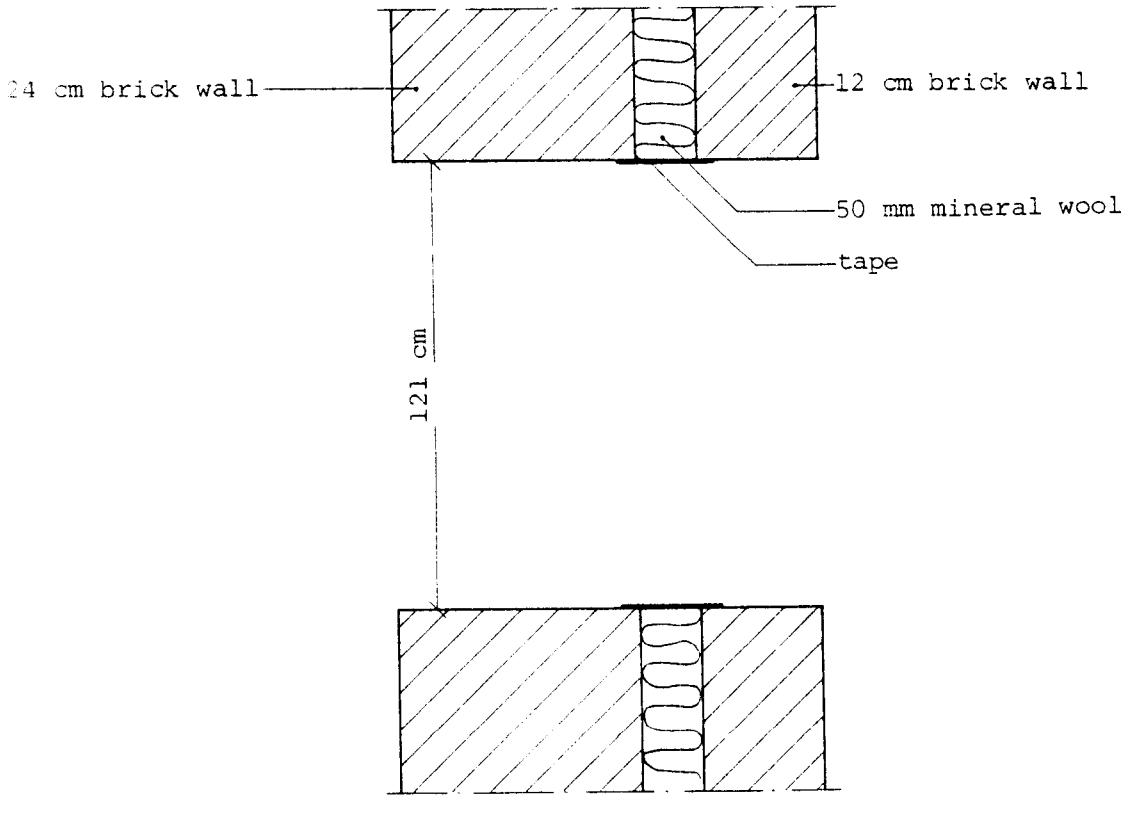
5 diffusing elements in both rooms (100 x 120 cm).



2. TEST OPENING (NT 235-80)

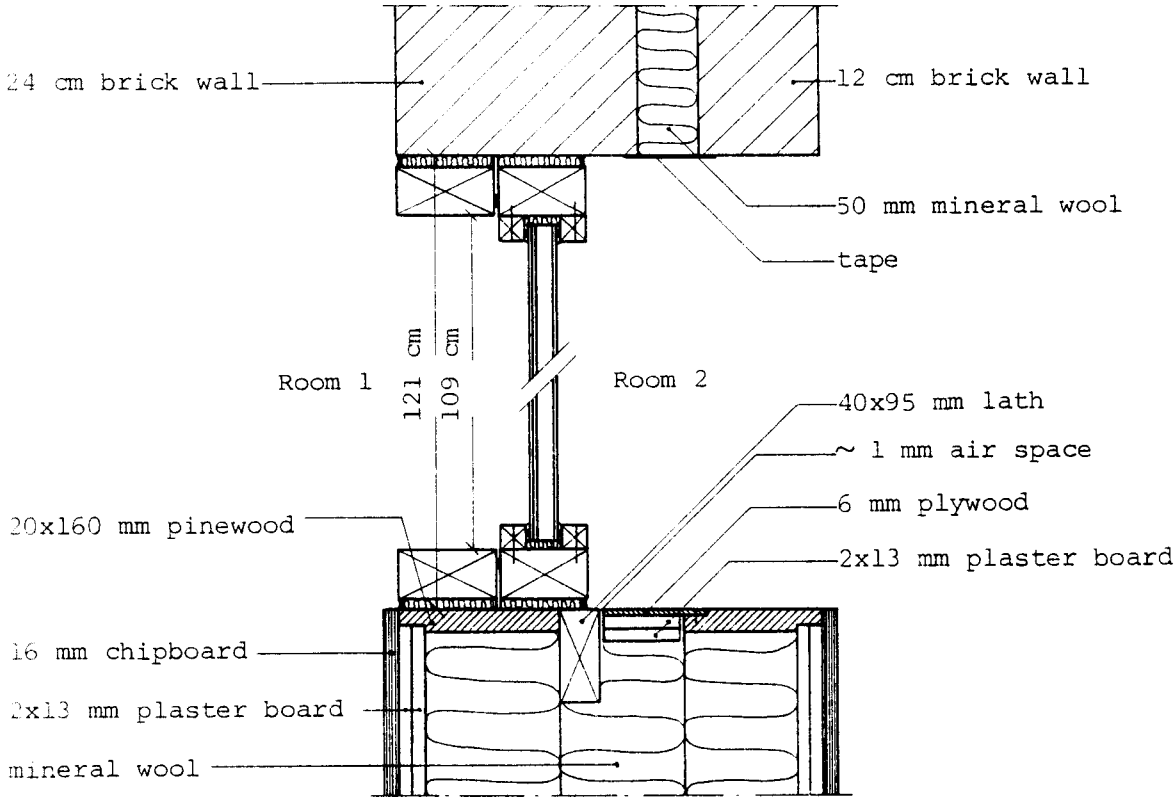


Vertical section, 1:7,5

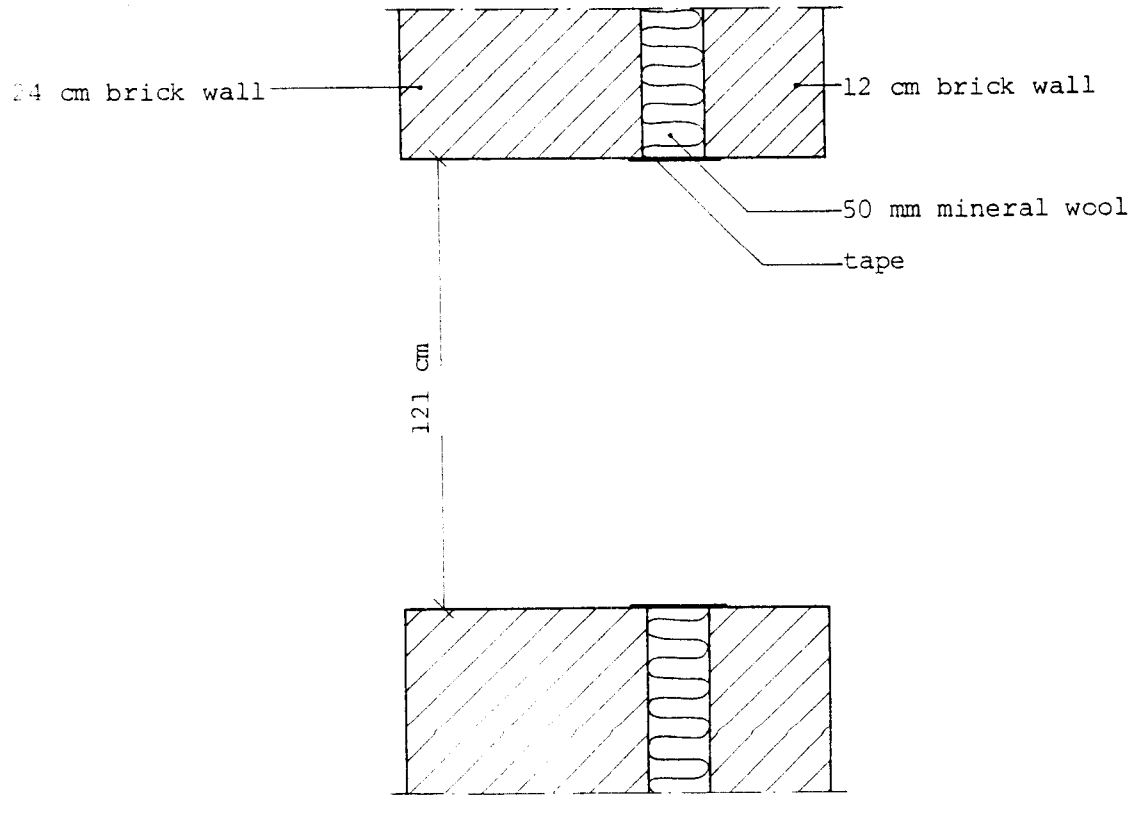


Horizontal section, 1:7,5

2. TEST OPENING (NT 360-82)



Vertical section, 1:7,5



Horizontal section, 1:7,5

3. MEASUREMENT PROCEDURE

(NT 235-80 - NT 360-82)

The measurements were carried out in 1/3 octave bands from 100 Hz to 3150 Hz using a parallel measuring system.

The sound signal consisted of pink noise and two loudspeaker positions were used for the sound pressure level measurements. Two rotating microphone systems with radius 110 cm were applied, and the integration time corresponding to each loudspeaker position was 32 sec. (equal to the time of one revolution of the rotating microphone systems).

The reverberation time was evaluated over a range of 30 dB using one excitation in each of 6 microphone positions equally spread around the microphone path. One loudspeaker position was used.

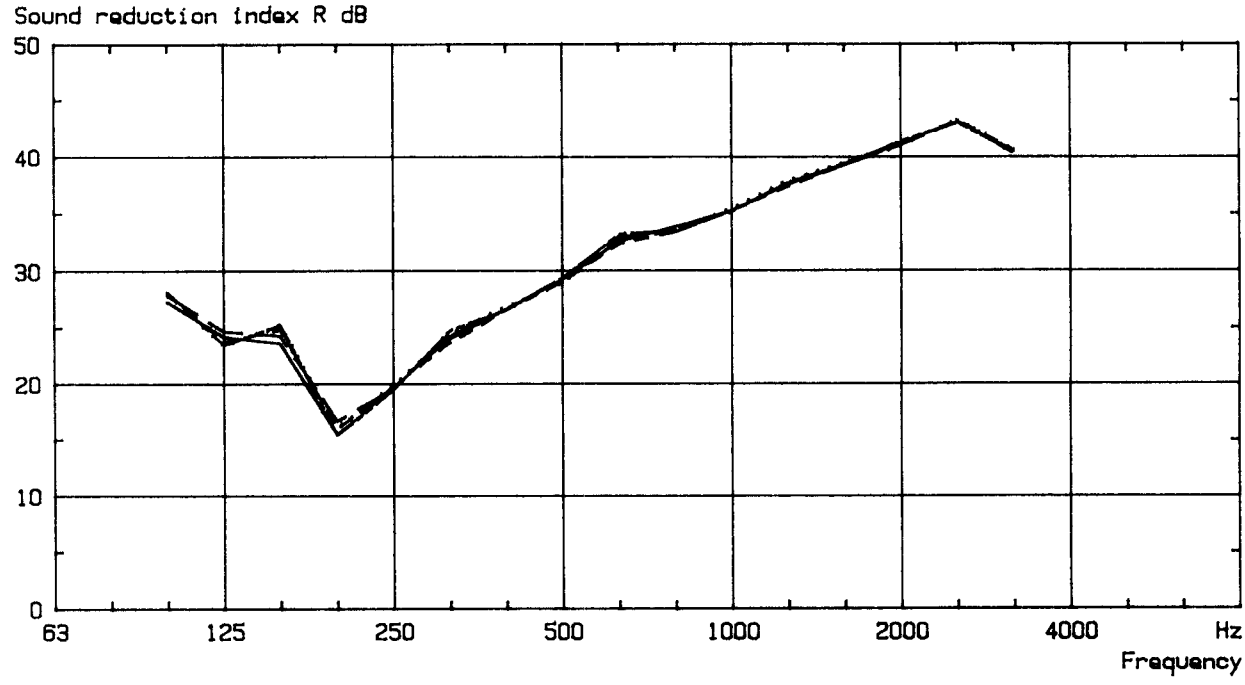
The sound reduction indexes have been corrected for sound transmission around the test specimen according to NT ACOU 013. No correction value exceeds 0.6 dB at 100 Hz and 0.1 dB at the rest of the 1/3 octave bands.

The following instruments were used for the measurements:

Digital Frequency Analyzer (1/3 octave)	Brüel & Kjær,	Type	2131
Microphone Power Supply	" " ,	"	2804
Power Amplifier	" " ,	"	2706
Noise Generator	" " ,	"	1405
Rotating Microphone System	" " ,	"	3923
1/2" Preamplifier	" " ,	"	2619
1/2" Condenser Microphone	" " ,	"	4166
Sound Level Calibrator	" " ,	"	4230
Calculator	Hewlett Packard,	"	9825 A
Graphics Printer	" " ,	"	2673 A
Loudspeaker Unit	Celestion ,	"	3055

APPENDIX G

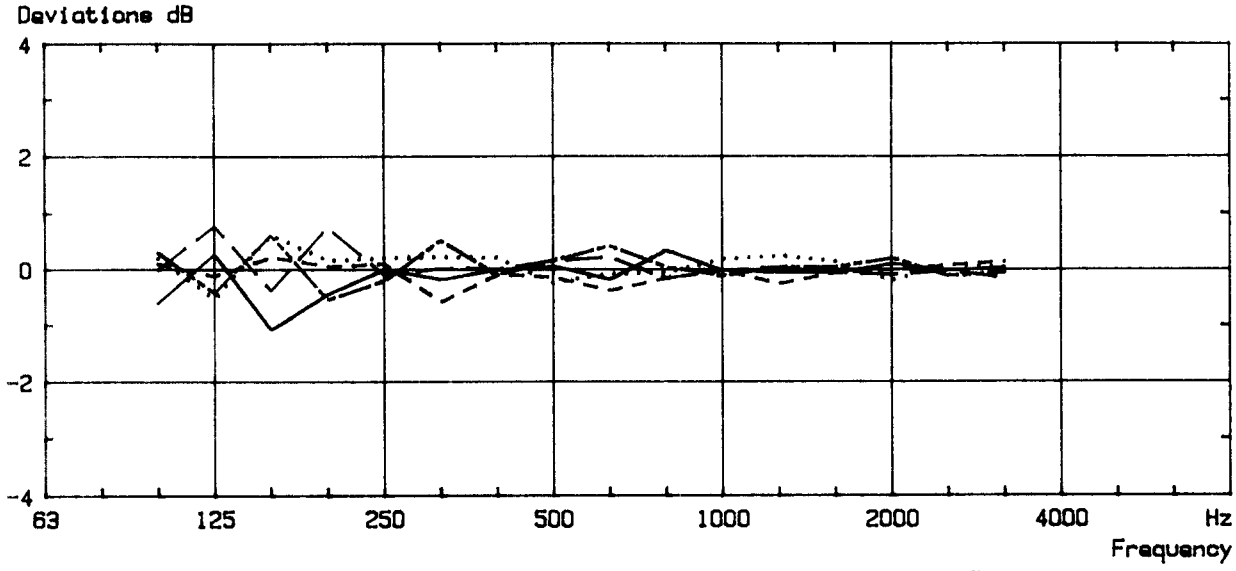
Results from Lydteknisk Institut / LI



NORDTEST 235-80
LABORATORY : LYDTEKNISK INSTITUT
1. INFLUENCE OF STOCHASTIC NOISE SIGNAL

——————— 1.1
. . . . . 1.2
– – – – – – – 1.3
— — — — · 1.4
———·——·— 1.5

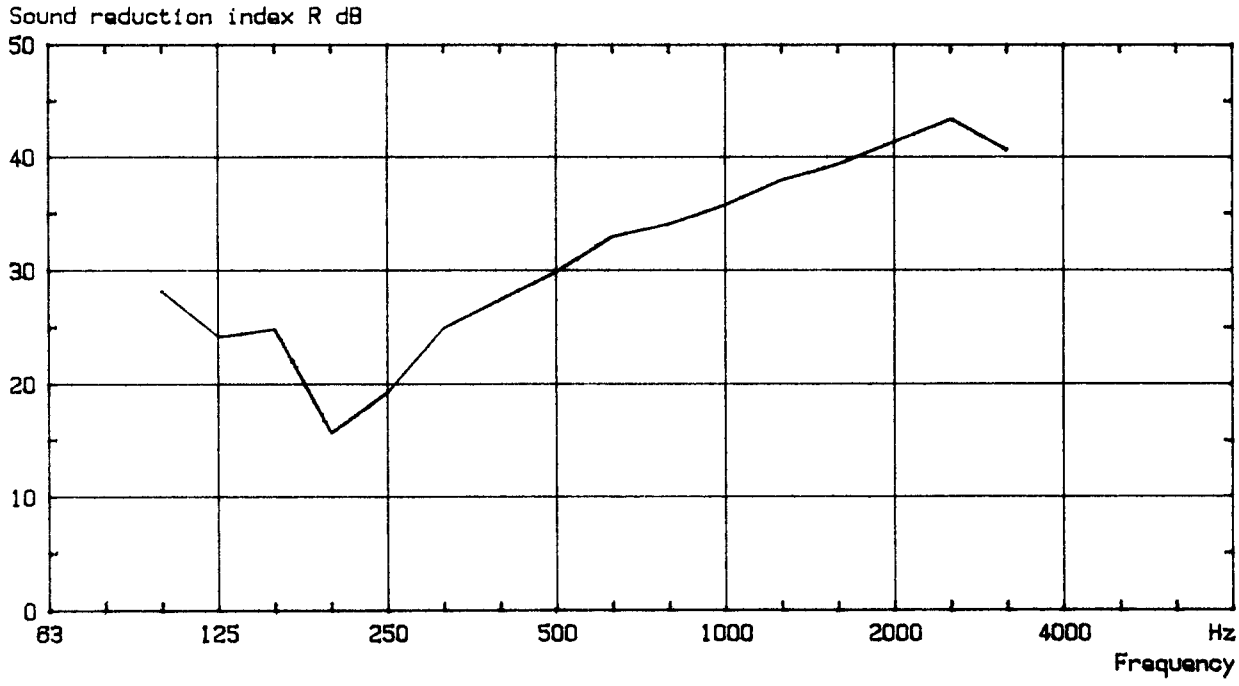
Measurement Frequency Hz	1.1 dB	1.2 dB	1.3 dB	1.4 dB	1.5 dB	Mean dB
100	27.3	28.1	28.0	27.9	28.2	27.9
125	24.2	23.4	23.8	24.7	23.5	23.9
160	23.6	25.3	24.9	24.3	25.3	24.7
200	15.5	16.1	16.0	16.7	15.4	15.9
250	19.7	19.9	19.8	19.6	19.5	19.7
315	24.1	24.5	23.7	24.3	24.8	24.3
400	26.7	26.9	26.6	26.7	26.6	26.7
500	29.3	29.0	29.1	29.4	29.4	29.2
630	32.6	32.7	32.4	33.0	33.2	32.8
800	33.9	33.5	33.4	33.4	33.6	33.6
1000	35.3	35.5	35.3	35.3	35.2	35.3
1250	37.6	37.9	37.4	37.7	37.7	37.7
1600	39.3	39.5	39.3	39.3	39.4	39.4
2000	41.3	41.0	41.2	41.1	41.4	41.2
2500	43.1	43.2	43.2	43.1	43.0	43.1
3150	40.5	40.5	40.6	40.3	40.4	40.5
Rw	33.1	33.2	33.0	33.3	33.2	33.2
Δ_{max}	-7.6	-7.1	-7.0	-6.7	-7.8	



NORDTEST 235-80. PLOT VERSUS MEAN OF 5 MEASUREMENTS (SEE THE PREVIOUS PAGE)
LABORATORY : LYDTEKNISK INSTITUT
1. INFLUENCE OF STOCHASTIC NOISE SIGNAL

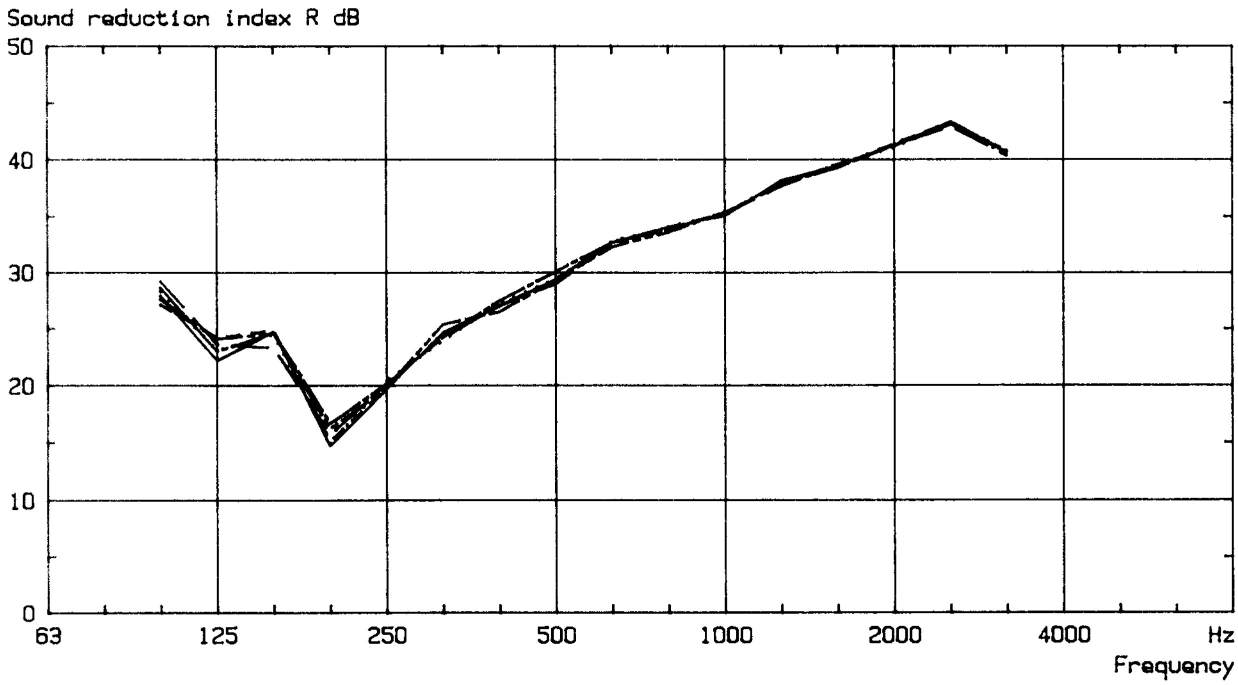
——————— 1.1
· · · · · · · · · · · · · 1.2
– – – – – – – – 1.3
— — — — · 1.4
———— - - - - - - 1.5

		Deviations from mean:				
Measurement Frequency	Mean	1.1	1.2	1.3	1.4	1.5
Hz	dB	dB	dB	dB	dB	dB
100	27.9	-0.6	0.2	0.1	0.0	0.3
125	23.9	0.3	-0.5	-0.1	0.8	-0.4
160	24.7	-1.1	0.6	0.2	-0.4	0.6
200	15.9	-0.4	0.2	0.1	0.8	-0.5
250	19.7	0.0	0.2	0.1	-0.1	-0.2
315	24.3	-0.2	0.2	-0.6	0.0	0.5
400	26.7	0.0	0.2	-0.1	0.0	-0.1
500	29.2	0.1	-0.2	-0.1	0.2	0.2
630	32.8	-0.2	-0.1	-0.4	0.2	0.4
800	33.6	0.3	-0.1	-0.2	-0.2	0.0
1000	35.3	-0.0	0.2	-0.0	-0.0	-0.1
1250	37.7	-0.1	0.2	-0.3	0.0	0.0
1600	39.4	-0.1	0.1	-0.1	-0.1	0.0
2000	41.2	0.1	-0.2	0.0	-0.1	0.2
2500	43.1	-0.0	0.1	0.1	-0.0	-0.1
3150	40.5	0.0	0.0	0.1	-0.2	-0.1
Rw	33.2	-0.1	0.0	-0.2	0.1	0.0



NORDTEST 235-80
LABORATORY : LYDTEKNISK INSTITUT
2. MOUNTING CONDITIONS

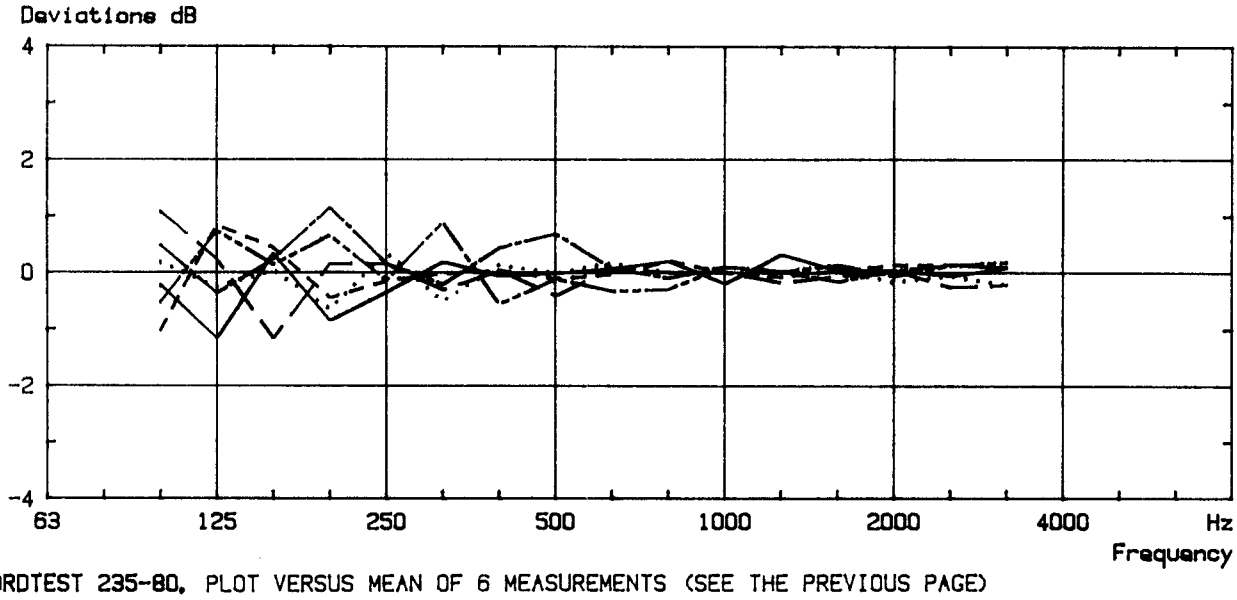
Measurement	5.2
Frequency Hz	dB
100	28.2
125	24.2
160	24.9
200	15.7
250	19.3
315	25.0
400	27.5
500	29.9
630	33.0
800	34.1
1000	35.8
1250	38.0
1600	39.4
2000	41.4
2500	43.4
3150	40.6
Rw	33.5
Δ_{max}	-7.8



NORDTEST 235-80
LABORATORY : LYDTEKNISK INSTITUT
3. REPEATABILITY/REPRODUCIBILITY

- 3.1
- 3.2
- 3.3
- 3.4
- 3.5
- 3.6

Measurement Frequency Hz	3.1 dB	3.2 dB	3.3 dB	3.4 dB	3.5 dB	3.6 dB	Mean dB
100	27.9	28.3	27.1	29.2	27.6	28.6	28.1
125	22.2	23.1	24.2	23.6	24.1	23.0	23.4
160	24.8	24.5	24.9	23.3	24.6	24.7	24.5
200	14.7	14.9	15.1	15.7	16.2	16.7	15.6
250	19.7	20.4	19.9	20.2	19.9	20.2	20.1
315	24.7	24.0	24.5	24.2	25.4	24.3	24.5
400	27.0	27.2	27.1	27.1	26.5	27.5	27.1
500	29.4	29.4	29.3	29.0	29.3	30.1	29.4
630	32.7	32.8	32.6	32.7	32.3	32.7	32.6
800	34.1	33.9	34.1	33.9	33.6	33.8	33.9
1000	35.1	35.3	35.3	35.3	35.4	35.4	35.3
1250	38.2	37.8	37.8	37.7	37.9	37.9	37.9
1600	39.5	39.5	39.5	39.4	39.6	39.3	39.5
2000	41.3	41.1	41.4	41.3	41.2	41.3	41.3
2500	43.1	43.1	43.3	42.9	43.3	43.3	43.2
3150	40.6	40.3	40.6	40.3	40.7	40.6	40.5
R_w	33.1	33.2	33.2	33.2	33.3	33.5	33.3
Δ_{max}	-8.4	-8.3	-8.1	-7.5	-7.1	-6.8	



NORDTEST 235-80. PLOT VERSUS MEAN OF 6 MEASUREMENTS (SEE THE PREVIOUS PAGE)
LABORATORY : LYDTEKNISK INSTITUT
3. REPEATABILITY/REPRODUCIBILITY

——————— 3.1
. . . . . 3.2
– – – – – – 3.3
— — — — 3.4
———— — — 3.5
———— — — 3.6

		Deviations from mean:					
Measurement	Mean	3.1	3.2	3.3	3.4	3.5	3.6
Frequency Hz	dB	dB	dB	dB	dB	dB	dB
100	28.1	-0.2	0.2	-1.0	1.1	-0.5	0.5
125	23.4	-1.2	-0.3	0.8	0.2	0.7	-0.4
160	24.5	0.3	0.0	0.4	-1.2	0.1	0.2
200	15.6	-0.9	-0.7	-0.5	0.2	0.7	1.2
250	20.1	-0.4	0.4	-0.2	0.2	-0.2	0.2
315	24.5	0.2	-0.5	-0.0	-0.3	0.9	-0.2
400	27.1	-0.1	0.1	0.0	0.0	-0.6	0.4
500	29.4	-0.0	-0.0	-0.1	-0.4	-0.1	0.7
630	32.6	0.1	0.2	-0.0	0.1	-0.3	0.1
800	33.9	0.2	0.0	0.2	0.0	-0.3	-0.1
1000	35.3	-0.2	0.0	0.0	0.0	0.1	0.1
1250	37.9	0.3	-0.1	-0.1	-0.2	0.0	0.0
1600	39.5	0.0	0.0	0.0	-0.1	0.1	-0.2
2000	41.3	0.0	-0.2	0.1	0.0	-0.1	0.0
2500	43.2	-0.1	-0.1	0.1	-0.3	0.1	0.1
3150	40.5	0.1	-0.2	0.1	-0.2	0.2	0.1
Rw	33.3	-0.2	-0.1	-0.1	-0.1	0.1	0.3

LI

Measurement Procedures in Series No. 4

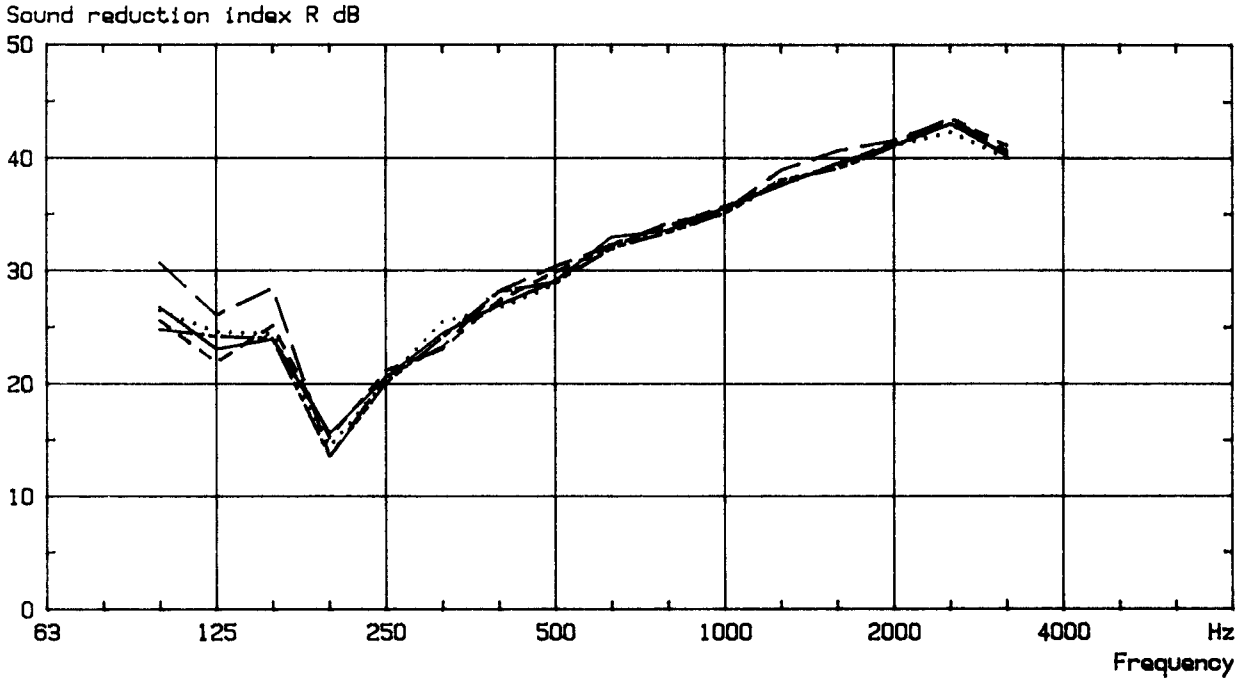
4.1 A measurement according to the normal test procedure, i.e. average of both directions.

4.2 A measurement being the average of two measurements in the same direction (room 004 source room).

4.3 A measurement being the average of two measurements in the same direction (room 003 source room, i.e. opposite to 4.2).

4.4 A measurement with the reverberation time in both rooms changed.

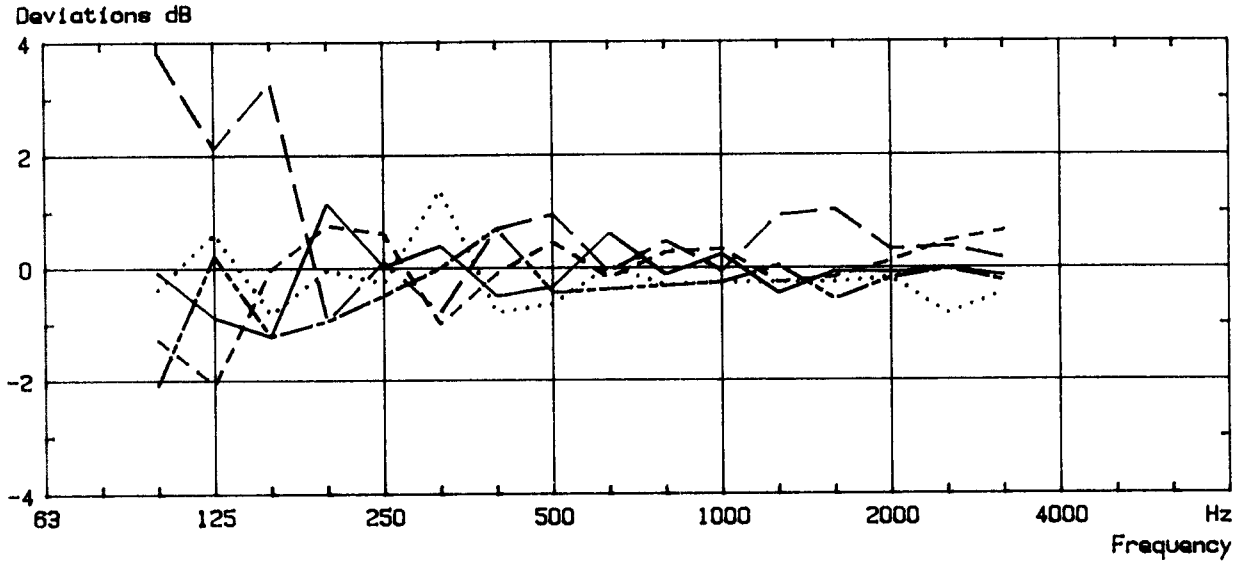
4.5 A measurement with loudspeakers in positions different from normal positions.



NORDTEST 235-80
LABORATORY : LYDTEKNISK INSTITUT
4. REPRODUCIBILITY WITHIN LABORATORIES

———— 4.1
. . . . . 4.2
– – – – – – 4.3
— — — · 4.4
———— 4.5

Measurement Frequency Hz	4.1 dB	4.2 dB	4.3 dB	4.4 dB	4.5 dB	Mean dB
100	26.8	26.5	25.6	30.7	24.8	26.9
125	23.1	24.6	21.9	26.1	24.2	24.0
160	24.0	24.4	25.2	28.5	24.0	25.2
200	15.6	14.4	15.2	13.5	13.5	14.4
250	20.6	20.3	21.2	20.7	20.1	20.6
315	24.5	25.5	23.1	23.3	24.1	24.1
400	27.0	26.7	27.4	28.2	28.2	27.5
500	29.1	28.8	29.9	30.4	29.0	29.4
630	33.0	32.4	32.2	32.3	32.0	32.4
800	33.6	33.4	34.0	34.2	33.4	33.7
1000	35.6	35.1	35.7	35.3	35.1	35.4
1250	37.6	37.8	37.8	39.0	38.1	38.1
1600	39.6	39.4	39.5	40.7	39.1	39.7
2000	41.2	41.1	41.4	41.6	41.1	41.3
2500	43.1	42.3	43.6	43.5	43.1	43.1
3150	40.3	40.0	41.1	40.6	40.2	40.4
Rw	33.3	33.0	33.3	33.2	32.9	33.1
Δ_{max}	-7.7	-8.6	-8.1	-9.7	-9.4	



NORDTEST 235-80, PLOT VERSUS MEAN OF 5 MEASUREMENTS (SEE THE PREVIOUS PAGE)
LABORATORY : LYDTEKNISK INSTITUT
4. REPRODUCIBILITY WITHIN LABORATORIES

———— 4.1
. . . . . 4.2
– – – – – 4.3
— — — · 4.4
———·—·— 4.5

		Deviations from mean:				
Measurement Frequency	Mean	4.1	4.2	4.3	4.4	4.5
Hz	dB	dB	dB	dB	dB	dB
100	26.9	-0.1	-0.4	-1.3	3.8	-2.1
125	24.0	-0.9	0.6	-2.1	2.1	0.2
160	25.2	-1.2	-0.8	-0.0	3.3	-1.2
200	14.4	1.2	-0.0	0.8	-0.9	-0.9
250	20.6	0.0	-0.3	0.6	0.1	-0.5
315	24.1	0.4	1.4	-1.0	-0.8	0.0
400	27.5	-0.5	-0.8	-0.1	0.7	0.7
500	29.4	-0.3	-0.6	0.5	1.0	-0.4
630	32.4	0.6	0.0	-0.2	-0.1	-0.4
800	33.7	-0.1	-0.3	0.3	0.5	-0.3
1000	35.4	0.2	-0.3	0.3	-0.1	-0.3
1250	38.1	-0.5	-0.3	-0.3	0.9	0.0
1600	39.7	-0.1	-0.3	-0.2	1.0	-0.6
2000	41.3	-0.1	-0.2	0.1	0.3	-0.2
2500	43.1	-0.0	-0.8	0.5	0.4	-0.0
3150	40.4	-0.1	-0.4	0.7	0.2	-0.2
Rw	33.1	0.2	-0.1	0.2	0.1	-0.2

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Description of Measurement Rooms, Test Opening and Measurement Procedure Used for the Nordtest-Projects NT 235-80 and 360-80

MEASUREMENT ROOMS

The measurements of sound reduction index are carried out in two reverberant rooms at the Technical University of Denmark. Sectional drawings of the transmission rooms - designated room 003 and room 004 - are found on Figures 1 and 2.

The rooms are made of concrete. Sound diffusing elements of concrete or damped steel plate are placed on two walls and at the ceiling. The volumes of the rooms are about 215 m^3 (room 003) and 230 m^3 (room 004).

TEST OPENING

A test opening with the dimensions 1,21 m × 1,21 m was used for the windows. The rooms are built for measurements of sound reduction index for walls. In the opening between the rooms there was built a wall with a high sound insulation (R_W = 67 dB), and a test opening for windows was left open, see Figure 3. The wall was a 35 cm thick double construction of 10 cm lightweight concrete elements (density 650 kg/m^3). The cavity in the wall was filled with mineral wool.

The test opening was constructed of the same type of elements as the wall. In the test opening there was surface-treated with filler, and the joint between the two parts of the wall was sealed with an elastic material. The test opening was placed 60 cm above the floor of the original opening between the rooms.

A sectional drawing of the flat test opening (NT 235-80) and the staggered test opening (NT 360-82) are shown on Figures 4 and 5, respectively.

MEASUREMENT PROCEDURE

The measurements of sound reduction index were carried out according to the method in ISO 140/3 and NT ACOU 013.

A building acoustics analyzer B&K 4418 and two rotating microphone booms were used at the measurements. The radii of the microphone paths were about 125 cm. The measurements were performed sequentially in 1/3 octave bands from 100 Hz to 3150 Hz. The noise signal was 1/3 octave band-limited pink noise.

At the sound pressure level measurements an averaging time of 16 sec. was used corresponding to one revolution of the rotating microphone.

The reverberation time in the receiving room was measured in 3 fixed positions, equally spaced along the microphone path (one excitation in each position). The evaluation range was 20 dB (5-25 dB below the steady state level).

The sound reduction index was measured in both directions without changing the microphone paths and the loudspeaker positions. The measurement results were determined as the mean values for the two measurement directions.

The following instruments were used for the measurements:

Instrument	Type
Building Acoustics Analyzer	B&K 4418
Measuring Microphones	B&K 4144
Microphone Preamplifiers	B&K 2619
Microphone Power Supplies	B&K 2804
Rotating Microphone Booms	B&K 3923
Sound Level Calibrator	B&K 4230

The measured sound pressure levels and reverberation times were transmitted from B&K 4418 to a computer HP 85 used for the calculations of the measurement results.

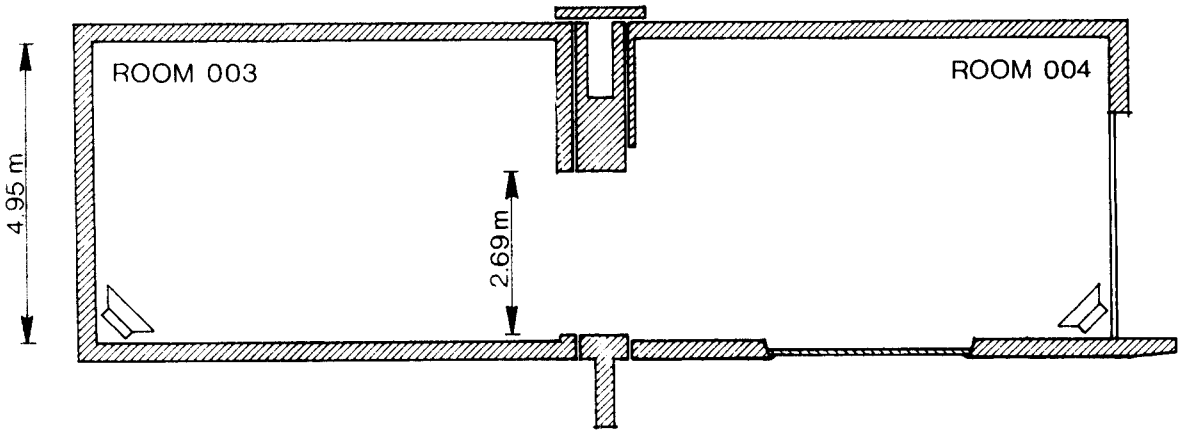


Figure 1 Measurement rooms.
Vertical section. Scale 1:125.

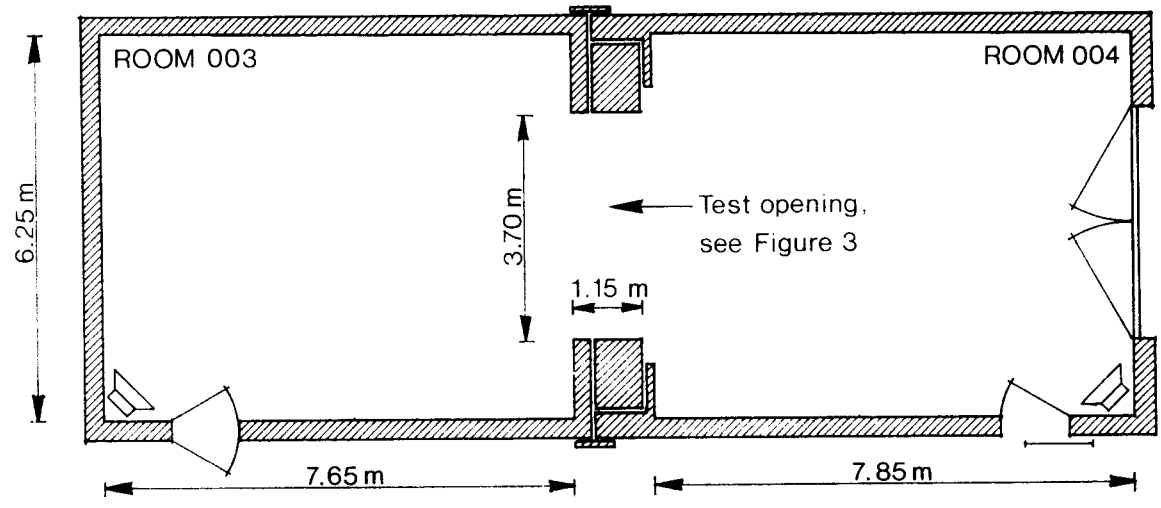


Figure 2 Measurement rooms.
Horizontal section. Scale 1:125.

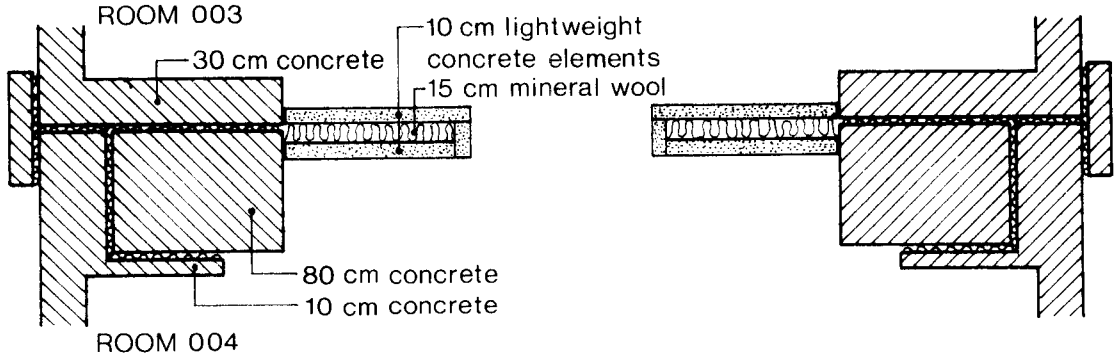


Figure 3 Test opening for windows.
Horizontal section. Scale 1:50.

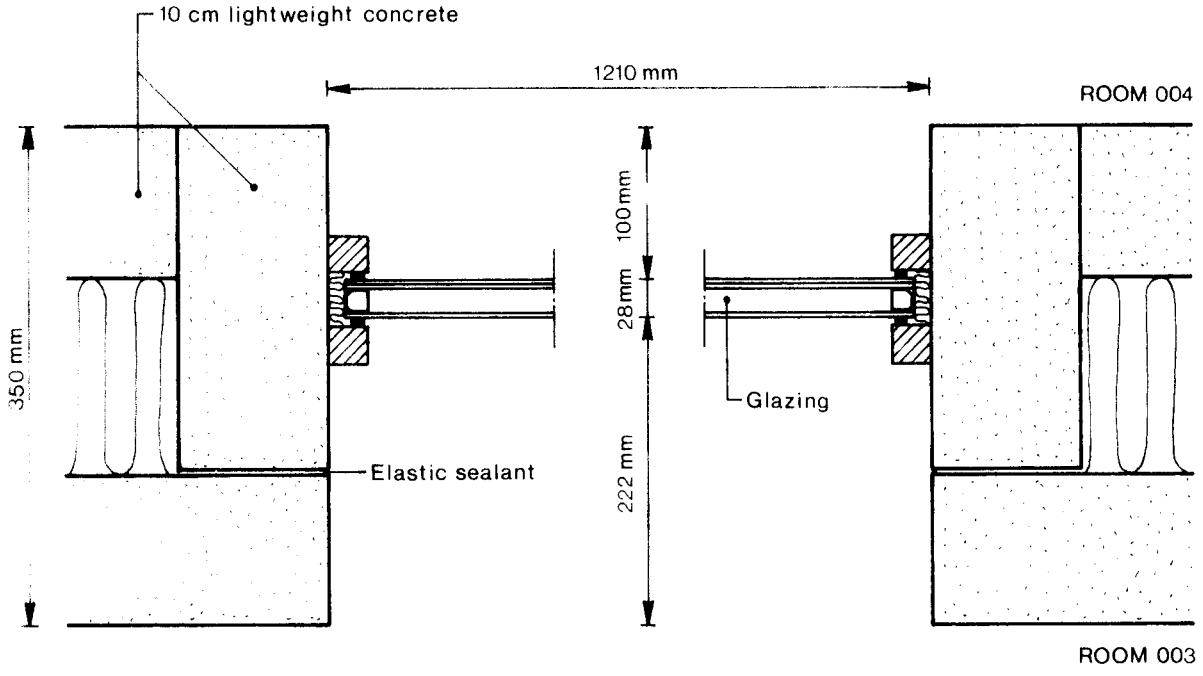


Figure 4 Glazing mounted in a flat test opening (NT 235-80). Horizontal and vertical section. Scale 1:5.

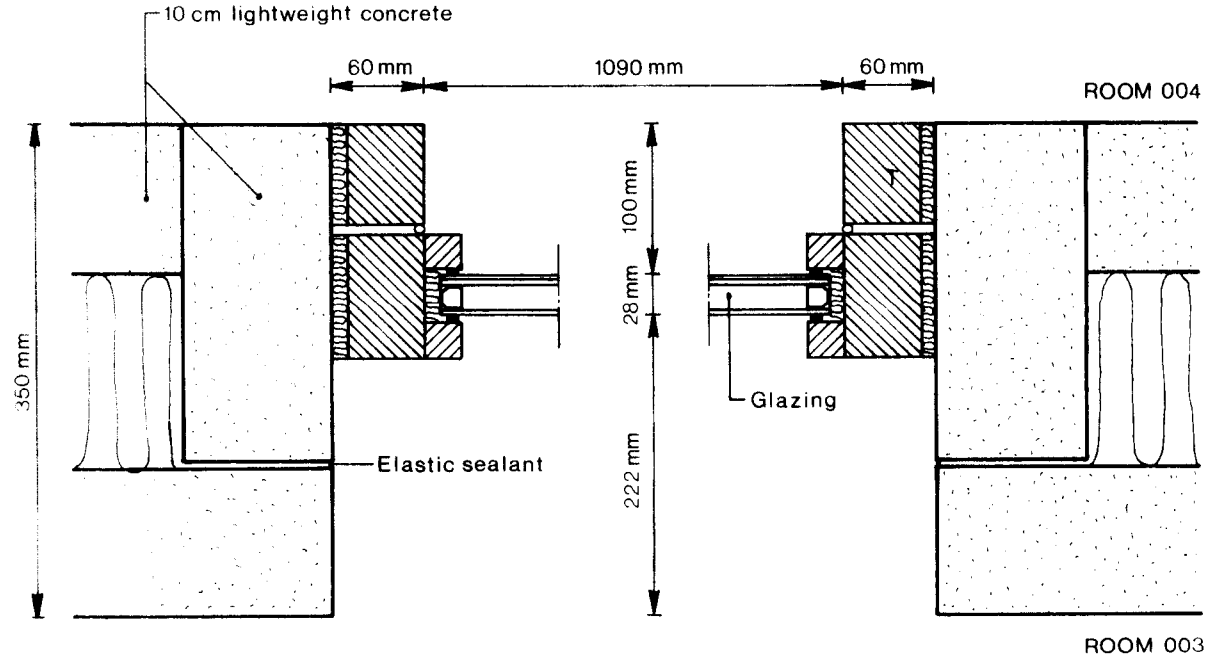
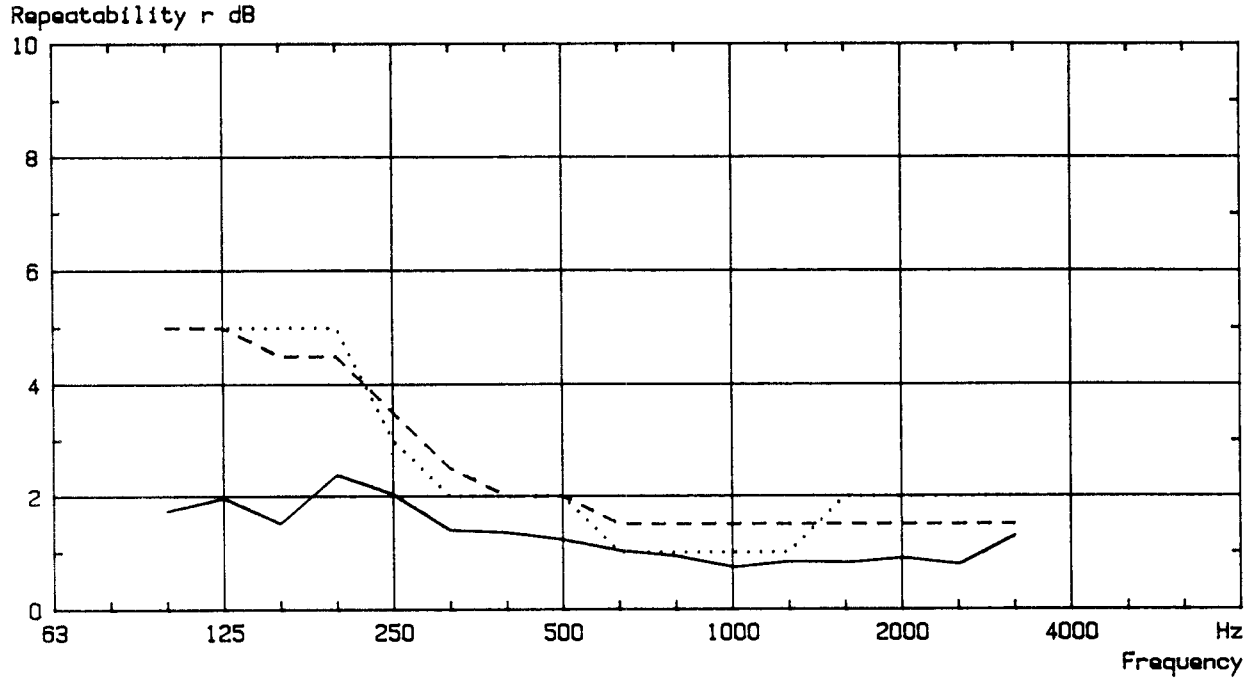


Figure 5 Glazing mounted in a staggered test opening (NT 360-82). Horizontal and vertical section. Scale 1:5.

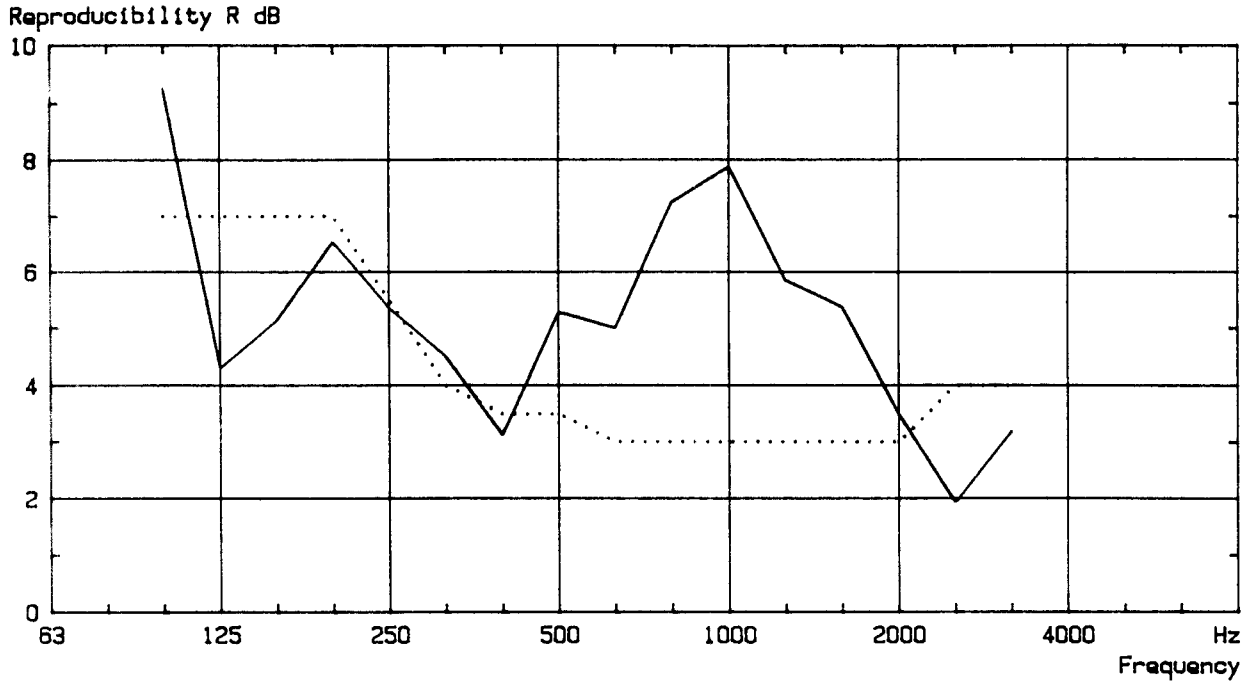
APPENDIX H

Tables of Repeatability and Reproducibility



1 CALCULATED REPEATABILITY r
2 REFERENCE CURVE FROM ISO 140/2-1978
3 PROPOSED REFERENCE CURVE ISO/TC 43/SC 2/WG 8 N34

Measurement Frequency Hz	1 dB	2 dB	3 dB
100	1.7	5.0	5.0
125	2.0	5.0	5.0
160	1.5	5.0	4.5
200	2.4	5.0	4.5
250	2.0	3.0	3.5
315	1.4	2.0	2.5
400	1.4	2.0	2.0
500	1.2	2.0	2.0
630	1.0	1.0	1.5
800	0.9	1.0	1.5
1000	0.7	1.0	1.5
1250	0.8	1.0	1.5
1600	0.8	2.0	1.5
2000	0.9	2.0	1.5
2500	0.8	2.0	1.5
3150	1.3	2.0	1.5



——— 1 CALCULATED REPRODUCIBILITY R
. . . . . 2 PROPOSED REFERENCE CURVE ISO/TC 43/SC 2/WG 8 N34

Measurement Frequency Hz	1 dB	2 dB
100	9.3	7.0
125	4.3	7.0
160	5.1	7.0
200	6.5	7.0
250	5.4	5.5
315	4.5	4.0
400	3.1	3.5
500	5.3	3.5
630	5.0	3.0
800	7.3	3.0
1000	7.9	3.0
1250	5.8	3.0
1600	5.4	3.0
2000	3.5	3.0
2500	1.9	4.0
3150	3.2	4.0