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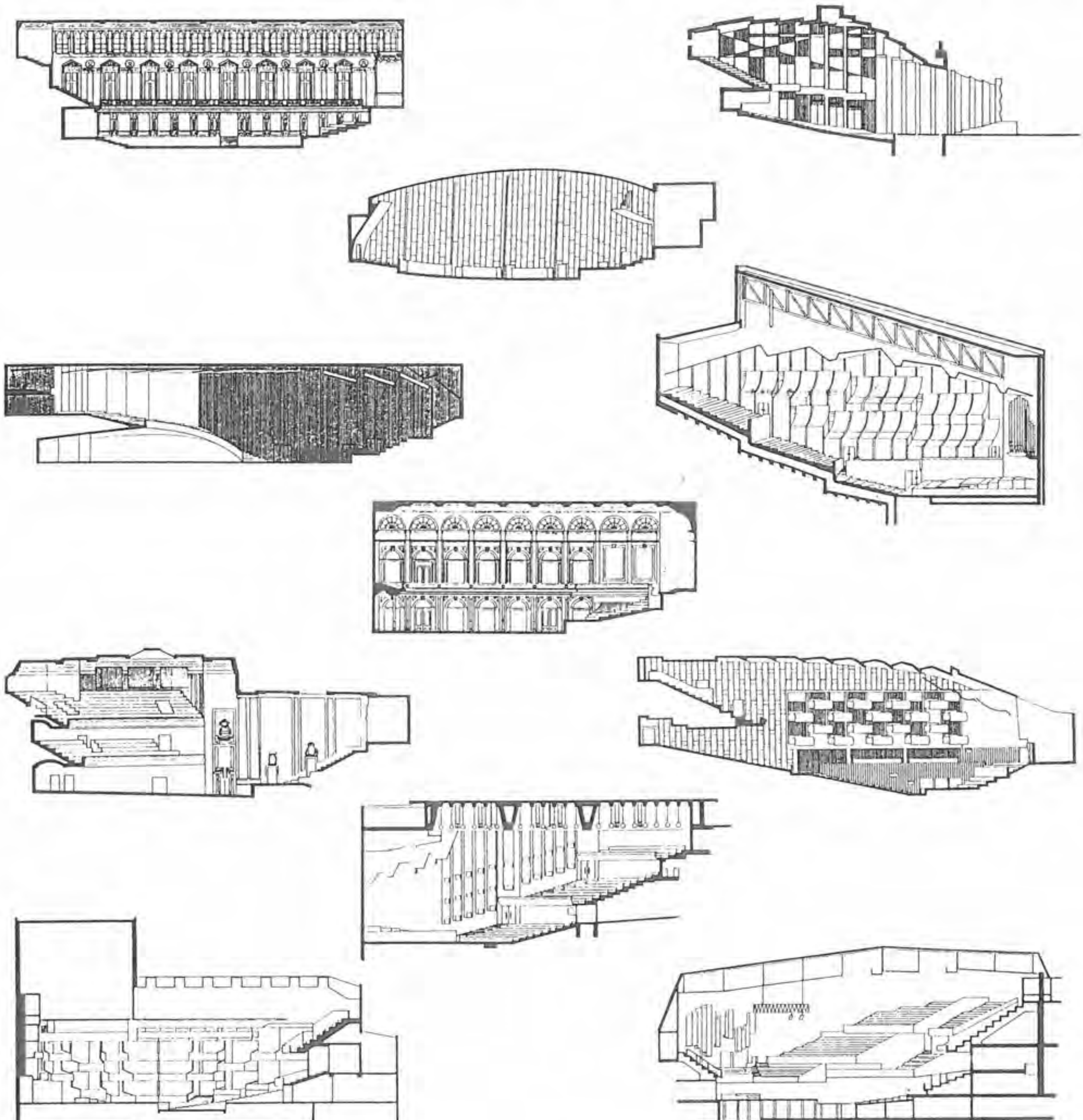
ACOUSTICAL SURVEY OF ELEVEN EUROPEAN CONCERT HALLS

- a basis for discussion of halls in Denmark



by A. C. Gade

THE ACOUSTICS LABORATORY

TECHNICAL UNIVERSITY OF DENMARK

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ACOUSTICAL SURVEY OF ELEVEN EUROPEAN CONCERT HALLS

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To all who enrich life
by their playing

Preface

In 1984 a report was published containing detailed room acoustic measurements in 21 Danish auditoria [1]. It soon became clear that the results of that survey needed to be seen in an international perspective; but this could only be done if the measurements were extended to cover a number of foreign, well estimated halls - a costly enterprise beyond our possibilities as a mainly state financed laboratory. However, with the author receiving the Rockwool Price in 1986 it became possible to finance this international extension of the survey.

In line with the goals of our previous research, it would be desirable to include foreign halls of different designs and shapes (- shapes which are often quite different from the Danish halls), and to be able to analyze these differences with statistical significance. This lead to the number of halls included in this new series of measurements being about twice as many as originally planned (- with a proportional effect on the date of publication for this report).

The new data were collected mainly during two measurement tours, one in the United Kingdom in the autumn of 1986 (following the Danish Radio Symphony Orchestra on a concert tour) and one in 1987 to three countries in continental Europe. When the last hall in Göteborg, Sweden, had been visited in August 1988, 15 foreign halls had been added to our collection of data.

In the present report the results from the 11 most interesting of these halls are presented together with drawings and other information in the same form as in the previous Danish Report, and comparisons between the Danish and the foreign halls are made. Main results from the statistical analyses on the extended set of data concerning acoustical and geometrical relationships are also included.

With the extension of the investigation going beyond the Danish borders, it was felt natural to write the report in English.

This report is intended for everybody interested in the acoustics of concert halls. The layman may wish to skip the formulae, but can get an introduction to technical and subjective evaluation of concert halls by reading Chapter one. The architect may wish to study the drawings of old and new designs in Chapter two. Chapter three provides the acoustician with practical design tools while Chapter four should be of interest to everybody who care about the acoustic conditions for symphonic performances in Denmark.

I would like to express my gratitude to the Rockwool Foundation for its generous funding, without which this work would never have been possible. The hall managements and staffs deserve warm thanks for allowing us access to their halls and for assistance during our visits. Also the willingness of architects and acoustical consultants to provide information and drawings is thankfully acknowledged. The 1986 tour would not have been possible without the kind and interested cooperation of the management and members of the Danish Radio Symphony Orchestra, which even participated in subjective experiments during the tour. (The results of these experiments will soon be published in Acustica [2]). Warm thanks goes to my foreign research colleagues John Bradley and Mike Barron for many helpful discussions on measurement techniques and for sharing with me their own experiences and results. (John Bradley joined the 1987 tour to make a parallel series of measurements using a different technique.) Several members of the staff at the Acoustics Laboratory have contributed to various phases of this project: Jørgen Rasmussen has been an invaluable assistant and travelling companion, Jens Holger Rindel has provided much help and support during the whole project and especially during the 1987 tour, and Graham Naylor has assisted in smoothing the english text. I would like to thank The Acoustics Laboratory for allowing use of its equipment, staff man hours and for printing the report. Finally I am deeply grateful to Vivi, Ulrik, Uffe, and Johan for their patience and for taking over my normal home duties while numerous overtime hours were spent on this project.

Virum, October 1989
Anders Christian Gade

Summary

An acoustical survey of eleven concert halls in Europe has been carried out, with a dual purpose:

1): to establish a frame of reference for evaluation of halls covered by a previous Danish survey, and

2): to extend the range of validity and adjust the relationships between acoustics and design found in the previous survey.

Besides presentation of each hall including drawings, acoustical data etc. (as in the previous publication of the Danish survey), the data from the two surveys are analyzed together.

It is found that volume and the classical room acoustic parameter: reverberation time are the main factors governing most aspects of the acoustics as measured also by the newer and more sophisticated parameters. However, geometrical factors can also have a major influence on the acoustics, especially on aspects like clarity, spaciousness and the conditions for the musicians on the orchestra platform.

Among the Danish halls, only Odense Koncerthus possess acoustic properties which can bear comparison with the conditions measured in famous, classical concert halls like Musikverein or Concertgebouw. Even compared with the more modern foreign halls, reverberation time is too low and volume too small in most of the Danish halls.

Resumé

Der er foretaget en rumakustisk undersøgelse af de akustiske forhold i 11 europæiske koncertsale med det dobbelte formål at:

1) opstille en referenceramme for vurdering af danske sale omfattet af en tidligere undersøgelse, og

2) at få justeret og udviddet gyldighedsområdet for de sammenhænge mellem akustik og design, som blev opstillet i denne tidligere undersøgelse.

Udover præsentation af salene med blandt andet tegninger og akustiske data (som i den tidligere publikation fra den danske undersøgelse), er de nye data analyseret sammen med de danske.

Analyserne viser, at volumen og den klassiske rumakustiske parameter: efterklangstiden er de væsentligste faktorer til styring af en sals akustik - som den måles af de nyere og mere raffinerede parametre. Geometriske faktorer kan dog også have en væsentlig indflydelse, specielt på aspekter som klarhed og rumvirkning samt på forholdene for musikerne på orkesterpodiet.

Bortset fra Odense Koncerthus er der ingen af de danske sale, der tåler sammenligning med berømte, klassiske sale som Musikverein og Concertgebouw. Selv i forhold til de nyere udenlandske sale er efterklangstiden for lav og volumenet for lille i de fleste danske sale.

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List of symbols

Symbol	Unit	Meaning	Page
BA		Barbican Concert Hall, London	44
BR(L)	dB	Bass ratio based on L	21
BR(RT)	-	Bass ratio based on RT	21
C	dB	Clarity	19
CA		St. Davids Hall, Cardiff	36
CG		Concertgebouw, Amsterdam	64
CS		Clarity measured 1m from the source	23
dr		Danish Radio Concert hall, Copenhagen	73
ED		Usher Hall, Edinburgh	40
EDT	sec.	Early Decay Time	18
EDTF	-	EDT frequency balance on the platform	21
EDTP	sec.	EDT measured on the orchestra platform	21
EEL	dB	Early Ensemble Level	22
E(t1,t2)	-	Impulse response energy within t1 - t2	15
fc		Falkoner Centret, large hall, Copenhagen	73
FH		Royal Festival Hall, London	48
FS		Grosses Festspielhauss, Salzburg	28
GK		Göteborgs Koncerthus, Göteborg	68
GM		Gasteig Philharmonie, München	56
h(t)	-	Impulse response time function	15
L	dB	Level	19
LEF	-	Lateral Energy Fraction	20
LS		Liederhalle, Stuttgart	60
mo		Århus Musikhus, Århus	73
ms		Musikhuset, Sønderborg	73
MW		Musikvereinsaal, Wien	32
NO		Derngate, Northampton	52
of		Odd Fellow Palæet, large hall, Copenhagen	73
oh		Ålborg Hallen, Ålborg	73
ok		Odense Koncerthus, Carl Nielsen Hall	73
<PAR>	-	Room acoustic parameter (general symbol)	75
$\langle PAR \rangle_{exp}$	-	Expected value (diffuse field theory)	18
$\langle PAR \rangle_{dif}$	-	Measured deviation from expected value	75
Px		Microphone pos. No. x on orch. platform	24

r	-	Correlation coefficient	78
R(t)	-	Reverberation decay time curve	17
RT	sec.	Reverberation Time	17
RT_m	sec.	RT at mid frequencies (500 + 1000 Hz)	24
Rx		Microphone pos. No. x in audience area	24
s(t)	-	Sweep signal time function	96
sa		Sct. Annæ hall, Copenhagen	73
ST	dB	Support	21
ST1	dB	Support, 100 ms integration limit	22
ST2	dB	Support, 200 ms integration limit	22
STD	-	Standard deviation	26
Sx		Source position No. x	24
ti		Tivoli Concert hall, Copenhagen	73
T_i	ms	Time interval	17
TS	ms	Centre time	17
V	m^3	Volume	20
$\delta(t)$	-	Dirac delta function	96

I. INTRODUCTION

1.1. Background

In the field of subjective room acoustics, intense research activity in the sixties and seventies has resulted in a high degree of consensus regarding 1) what aspects are important in listeners' perception of room acoustic quality, and 2) how these aspects can be measured objectively by means of room acoustic parameters. Thus, a set of new objective parameters has been found, which are subjectively more relevant than the classical Reverberation Time, RT. However, these newer parameters are much more difficult to predict, unless expensive scale - or computer models are applied. The main reason for this is that they are more sensitive to changes in the early reflection sequence, and thus are highly dependent on the choice of measurement position and on the geometrical shaping of the room. The commonly used practice of looking at delay times of single reflections is not sufficient for estimating these newer measures and for guiding architects on the choice of room shape; we need to know how - and how much - the design may or should be changed before significant changes in the objective parameters appear. Obviously, this knowledge is essential for participation in the early discussions of choice of shape for a new hall.

On this background it not surprising that in this decade a number of measurement surveys of existing halls e.g. [1;3;4;5] have been carried out, which from different angles have approached the problem of unveiling the behaviour of the newer parameters in different hall designs.

In one of these surveys, based on measurements in 21 Danish halls [1], the main purpose was to obtain an evaluation of the room acoustic properties of Danish halls used for symphonic concerts. Besides, derivation of certain relationships between the room acoustical parameters and geometrical factors of hall design was possible by subjecting the large amount of data to statistical analysis. However, the results were rather vague for two reasons:

1) a frame of reference for judgements of what should be regarded good or bad was missing, since internationally well known and well reputated halls had not been measured by the same technique (- and we are still lacking knowledge and standards telling how these more advanced room acoustic measurements should be carried out in order for results to be comparable),

2) the variation in geometry and size of Danish halls is fairly limited, which did put certain limits on the relationships being revealed.

In other words an extension of the survey to a number of important, foreign halls was an obvious need, which the present report is trying to meet. More precisely, the purposes have been the following:

a) to establish a frame of reference for evaluation of the Danish halls,

b) to extend the range of validity and adjust the relationships found in the previous Danish survey to larger and more complex halls than those most common in Denmark.

1.2. The halls investigated

To meet the purposes listed above, the foreign halls to be investigated were selected using one or both of the following criteria :

a) The halls should be widely known for their room acoustic merits, and preferably be well described in acoustics literature

b) With respect to sizes and shape, the foreign halls should supplement and extend the range of variety of the data already collected from the Danish halls.

Combining these criteria with certain practical considerations resulted in the following list of halls being included in the survey:

Austria:	Grosses Festspielhauss, Salzburg	(**FS**)
	Musikvereinsaal, Wien	(**MW**)
Great Britain:	St. Davids Hall, Cardiff	(**CA**)
	Usher Hall, Edinburgh	(**ED**)
	Barbican Concert Hall, London	(**BA**)
	Royal Festival Hall, London	(**FH**)
	Derngate, Northampton	(**NO**)
West Germany:	Gasteig Philharmonie, München	(**GM**)
	Liederhalle, Stuttgart	(**LS**)
The Nederlands:	Concertgebouw, Amsterdam	(**CG**)
Sweden:	Göteborgs Koncerthus, Göteborg	(**GK**)

All the halls except **NO** are designed and used mainly for performance of classical music.*

The number of audience seats in these eleven halls vary between about 1300 and 3000, while the ranges of volume and reverberation time (empty) are approximately 12,000 - 30,000 cubic metres and 1.6 - 3.0 sec. respectively. For a brief comparison with the Danish halls, the rounded averages of these figures for the present survey of the foreign halls and the previous survey of the Danish halls respectively have been listed below:

Average for :	11 foreign halls	21 Danish halls
No. of seats :	2000	900
Volume :	18,000 m^3	9,000 m^3
RT (empty) :	2.1 sec.	1.9 sec.

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* **NO** was included as an example of a multi purpose hall intended to be flexible enough to provide uncompromised acoustic conditions also for symphonic concerts.

Concerning the RT values it should be added that the values in the occupied state will be more different than indicated above, due to the seats in the Danish halls generally being less absorptive than the seats in the foreign halls.

Also concerning gross shape, the 11 foreign halls were more varied than the - mostly rectangular - Danish halls:

Shape:		Number of halls:
fan	:	6
rectangular	:	3
arena	:	1
horse shoe	:	1

Further information about the geometrical proporties of the halls was collected as in the previous Danish survey and can be found in the following chapters.

1.3. The room acoustic parameters

The objective parameters measured have been listed in Table 1.1 along with the subjective qualities which each one intends to describe. Besides the well established parameters related to listener conditions, the table also contains suggested measures for describing the conditions for musicians on the platform. The set of platform parameters in Table 1.1 is slightly different from the set emphasized in the Danish survey [1]. This is due to the developments in our research in that field since 1984.

All parameters were evaluated on the basis of impulse response measurements. The definitions and further details about each of the parameters are given below. In the formulae $E(t_1,t_2)$ denote the energy within the time limits t_1 to t_2 of the impulse response: $h(t)$, counted from the time of arrival of the direct sound:

$$E(t_1,t_2) = \int_{t_1}^{t_2} h^2(t)\, dt \,. \qquad (1.1)$$

Room acoustic par.	Symbol	Associated subj. aspect	Ref.
Reverberation Time	RT	(standard/reverberance)	[6]
Early Decay Time	EDT	reverberance/clarity	[7]
Centre time	TS	"	[8]
Clarity	C	clarity	[9]
Level/Strength	L	relative level	[1;10]
Lat. Energy Frac.	LEF	spatial impression	[11]
RT bass ratio	BR(RT)	tonal colour	[12]
L " "	BR(L)	" "	[1]
EDT on Platform	EDTP	reverberance for music.	[2]
Clarity at 1 metre	CS	"	"
Support-100ms	ST1	ease of ensemble	"
Support-200ms	ST2	support	"

TABLE 1.1 Room acoustic parameters measured in the eleven halls.

Details about the measurement technique used can be found in section 1.4, Appendix A, and in the previous Danish report [1].

The data presented in the following chapters relate to position averaged values of the parameters only; but a few remarks about the general trends in variation with position have been included in the following presentation of the parameters. The variations with position in the halls investigated can be studied by looking at the detailed data listed in Appendix B.

For most of the parameters, a formula can be derived for expected value based on RT and classical diffuse field theory, assuming exponential decay. These formulas have also been listed below. (Empirical modifications to these formulas and predictions based on geometrical relationships have been suggested in sections 3.4 and 3.5).

Recommendable parameter values for fully occupied halls have been discussed in the references listed in Table 1.1). This question has not been further elaborated on in the present report because the measurement data are related to the empty hall conditions, and because many comparisons between the Danish and the foreign halls can be done on the basis of the "empty" data alone. However, RT values for the occupied condition found in literature have been quoted in Chapter 2 and compared in section 4.2.

1.3.1. Audience parameters

Reverberation Time , RT

According to Schroeder [13], the reverberation decay R(t) can be calculated from the impulse response, as :

$$R(t) = 10*\log\frac{E(t,\infty)}{E(0,\infty)} \text{ (dB)} \qquad (1.2)$$

Due to the limited recording time for the impulse response and unavoidable background noise, it is more applicable to use the following approximations:

$$E(t,\infty) = E(t,t+T_i) \quad \text{and} \quad E(0,\infty) = E(0,0+T_i) \qquad (1.3)$$

in formula (1.2). The fixed size of the integration interval T_i can be chosen as short as 1/5*RT without any serious error in the estimation of the energy (< 1 dB). Because of the smooth nature of the Schroeder curve (and limited computing power in the old DEC PDP/8 used), RT was not calculated by fitting a regression line to the curve; but derived simply as:

$$RT = 3 * (t_{-5} - t_{-25}), \qquad (1.4)$$

with t_x being the time corresponding to the x dB point on the R(t) curve. The value obtained is related to a decay range of 60 dB by multiplication with the factor 3. It should be noted, that according to the ISO standard [6] the evaluation interval should be -5 to -35 dB; but in order to avoid the noise problems often associated with the Schroeder method, the higher limit of -25 dB is now widely used.

Early Decay Time , EDT

EDT [7] is a newer measure of reverberation time, taking into account the subjective importance of the early part of the reverberation process by only looking at the slope of the R(t) curve during the first 10 dB interval of the decay. In our implementation, EDT is calculated as:

$$EDT = 6 * t_{-10} \tag{1.5}$$

with t_{-10} being defined as explained for RT in (1.4). The factor six ensures that the decay time is related to a 60 dB decay like the original RT definition. This means, that the two measures can be easily compared, which is of interest partly because according to diffuse field theory (and disregarding the direct sound component) the expected value of EDT is equal to RT. A high EDT value indicates much reverberance/low clarity and vice versa. The seat to seat variation of EDT is somewhat larger than for RT (EDT values near the platform are generally lower than the seat average); but the position averaged value in the audience area is generally within +/- 0.2 sec. from RT [1,Chapter 3]. EDT was also measured on the orchestra platform as described in section 1.3.2.

Centre Time , TS

TS [8] is the time counted in milli-seconds corresponding to the point of gravity of the squared impulse response:

$$TS = 1000 * \int_0^{\infty} h^2(t) * t \, dt \Big/ \int_0^{\infty} h^2(t) \, dt \tag{1.6}$$

i.e. the centre of gravity of the impulse response energy. (Instead of ∞, the upper limit for integration is normally set to 1 sec.) A low value means that most of the energy arrives early - whereby it adds to the clarity of the sound -, while a high value means that it arrives long after the direct sound - and so provides reverberance. TS is very highly correlated with EDT [1,App.E], and therefore it seldom contains any new information compared with EDT. Still it has been included here because of its wide use. The expected value is simply:

$$TS_{exp} = RT/0.0138 \text{ (ms)}. \tag{1.7}$$

Clarity , C

C [9] is defined as the ratio in dB between the energy of the impulse response before 80 ms (i.e. the direct sound plus early reflections) and the energy of the later part after 80 ms (i.e. the reverberation):

$$C = 10*\log \frac{E(0,80\ \text{ms})}{E(80,1000\ \text{ms})}\ \text{dB}. \qquad (1.8)$$

A high value of C means much early energy and high subjective clarity, while a low value indicates an unclear or muddy sound. Generally, C is not as highly correlated with EDT as t_s, and the value of C is much more dependent on position than is the case with EDT. In seats near the platform, C is normally higher than the value averaged over all positions (corresponding to the lower EDT values in these seats as mentioned above). In areas with low ceiling hight over the chairs (on and below balconies), C is generally higher too because of a low level of the late sound at such seats. The expected value based on the assumptions of a diffuse field with exponential decay is given by:

$$C_{exp} = 10*\log(\exp(1.104/RT)-1)\ \text{dB} \qquad (1.9)$$

Level/Strength , L

L [1;10] is defined as the ratio in dB between the total impulse response energy and the energy of the direct sound as measured 10 metres from the source. However, since a one metre distance is more convenient for measurement of the direct sound, L is often determined as:

$$L = 10*\log \frac{E(0,1000\ \text{ms})}{E(0)_{1m}} + 20\ \text{dB}\ . \qquad (1.10)$$

L can also be measured by means of a calibrated, stationary sound source, as the difference between the level at a seat position when the source is placed on the stage, and the level at 10 m distance when the source is placed under free field conditions [3]. Thus, L can be used for measurement of the sound distribution in the hall. L describes the influence of the room on the percieved level. Besides, it is an open question, whether it would not be more appropriate to use the frequency variation of L rather than of RT (or EDT) to measure the influence of the hall on timbre or tone colour. Anyway, the frequency curves of the two measures often differ from each other as seen in Chapter 2, although this is not to be expected according to the classical, diffuse field theory. Concerning the variation within the hall, L decreases monotonically with distance from the source [1;3;5], which is another indication of the sound field in concert halls not being diffuse. The expected value is given by:

$$L_{exp} = 10*\log(RT/V) + 45 \text{ dB} , \qquad (1.11)$$

when RT is given in seconds and the volume V in cubic metres. L_{exp} is always a couple of dB higher than the position average of the measured values [1;3].

Lateral Energy Fraction , LEF

LEF [11] is the ratio between the energy of early reflections arriving from lateral directions and the energy of direct sound plus early reflections from all directions:

$$\text{LEF} = \frac{E_8(5,80 \text{ ms})}{E(0,80 \text{ ms})} \qquad (1.12)$$

The subscript "8" indicates that the lateral energy is captured by a figure of eight microprone, the axis of which should be placed horizontal and perpendicular to the direction of the direct sound propagation (i.e. "through the ears"). The normal omnidirectional microphone, used to record the energy in the denominator, should be placed as close as possible to the figure of eight capsule (often in the same housing). The two microphones need to be calibrated for equal sensitivity measured in the most sensitive directions of the figure of eight capsule.

LEF is a measure of the percieved spaciousness, i.e. the degree to which the listener has a sense of being enveloped by the sound. High values indicate a high degree of spaciousness/ envelopment and vice versa. Like the concept of timbre, spaciousness is a very complicated phenomenon, which is still subject to intense investigations [14;15]. Among other things, it seems to be dependent on level as well as on LEF. The expected value of LEF is of little interest, since it is supposed to be constant in a diffuse field.

Bass ratio , BR(RT) & BR(L)

Besides describing tonal colour by drawing curves of RT and L per octave band, a single number parameter related to the relative strength of the bass sound has been suggested by Beranek [12]:

$$BR(RT) = \frac{RT(125Hz)+RT(250Hz)}{RT(500Hz)+RT(1kHz)} \; , \qquad (1.13)$$

In line with the discussion above concerning the possible relevance of looking at the frequency variation of L, a bass ratio based on L has also been formed as:

$$BR(L) = [L(125Hz)+L(250Hz)-L(500Hz)-L(1kHz)]/2 \qquad (1.14)$$

In both cases high values indicate strong bass sound and vice versa.

1.3.2. Platform parameters

Early Decay Time , EDTP

In order to distinguish EDT measurements on the platform from measurements in the audience area, the platform measurement have been denoted EDTP. There are good reasons to keep this distinction, since EDTP is generally about 30% lower than EDT. EDTP may be used to describe musicians' sense of reverberance.*

Support , ST1 & ST2

ST [2] describes the ratio in dB between the early reflection energy sent back to the platform and the energy of the direct sound. This ratio is measured with a microphone placed only one metre from the source. ST has been calculated with an upper limit

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* Besides, the ratio between EDTP values at middle low and middle high frequencies :

$$EDTF = \frac{EDTP(250Hz)+EDTP(500Hz)}{EDTP(1kHz)+EDTP(2kHz)} \; , \qquad (1.15)$$

correlates with their judgements of timbre [2].

for integration of early reflections of both 100 and 200 ms, denoted ST1 and ST2 respectively:

$$ST1 = 10*\log\frac{E(20,100ms)}{E(0,10ms)}, \qquad (1.16)$$

$$ST2 = 10*\log\frac{E(20,200ms)}{E(0,10ms)}, \qquad (1.17)$$

ST1 or (ST_{early}) is suggested for measurement of musicians' possibility to hear each other on the orchestra platform [2].*

ST2 has been found to correlate well with musicians' general judgement on acoustic quality and the feeling of support, i.e. the degree to which the reflections from the room assist the sound created by the musician's own instrument. (Without much change in the measured values, the integration limit in ST2 may be extended to ∞ (one second), in which case it is called ST_{total}.)

As one would guess, ST1 and ST2 are generally highly correlated, and for both parameters, high values indicate good conditions with much reflected sound - and vice versa. (Also the subjective judgements of ease of ensemble playing and support are normally highly correlated.) The values of both parameters tend to increase as one moves further back and closer to the rear wall on the platform.

The expected values of ST1 and ST2 according to diffuse field theory are given by:

$$ST1_{exp} = 10*\log(\frac{RT}{V}*[\exp(-0.276/RT)-\exp(-1.38)]) + 25 \text{ dB} \qquad (1.18)$$

and:

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* For this purpose, another parameter: EEL was used in the previous survey. However, later work has indicated EEL to be of limited value for practical measurements. Still, values of EEL as defined in [1;16] can be found for each hall in appendix B.

$$ST2_{exp} = 10*\log(\frac{RT}{V}*[\exp(-0.276/RT)-\exp(-2.76)]) + 25 \text{ dB} \quad (1.19)$$

respectively.

Clarity at one metre , CS

Like ST1 and ST2, Clarity was also measured on the platform at a distance of one meter from the source, in which case it has been denoted CS [2]. CS can be used as a measure of the reverberation level (although with inverted sign). This use of the clarity measure is possible because of the direct sound dominating the 0 - 80 ms interval at such a short distance from the source:

$$CS = 10 * \log \frac{E(0,80ms)}{E(80ms,\infty)} = - 10 * \log \frac{E(80ms,\infty)}{E(0,80ms)}$$

$$\approx - 10 * \log \frac{E(80ms,\infty)}{E(dir)}. \quad (1.20)$$

Like EDTP, CS has been found to correlate with musicians' impression of reverberance [2]. Because of the inverted sign, low CS values correspond to high levels of the late energy - giving a strong feeling of reverberance. (The level of the late energy on the platform may also be measured directly using the ST_{late} parameter as suggested in [2]. However, generally CS $\approx$ - ST_{late}.) The expected value of CS according to diffuse field theory is :

$$CS_{exp} = 10*\log(\frac{RT}{V}*\exp(-1.104/RT)) + 25 \text{ dB}. \quad (1.21)$$

Besides these parameters, RT, TS, and C as defined in section 1.3.1 were also measured on the platform. The values obtained have been listed in Appendix B.

1.4. Measurement conditions

All parameters were evaluated per octave from impulse responses produced by deconvolving recordings of 1/1 octave tone sweep signals. These had been emitted in the halls by an ikosahedron shaped loudspeaker consisting of 20 full range units. The procedures and equipment used has been further described in [1] and in Appendix A.

1.4.1. Frequency ranges

The frequency range for the audience measurements covered the six 1/1 octaves from 125 Hz to 4000 Hz except for LEF (125 - 1000 Hz).* In the case of the platform measurements, the range was 250 to 2000 Hz. Most of the values listed in Chapter 2 and analysed in Chapters 3 and 4 have been frequency averaged over the four octave bands from 250 to 2000 Hz. Exceptions are LEF averaged from 125 - 1000 Hz and the RT value at mid frequencies, called RT_m, which covers the range 500 to 1000 Hz. In addition, BR(RT) and BR(L) have been listed as defined above.

1.4.2. Measurement positions

The general outline of the measurement positions on the platform and in the audience area are shown in Figure 1.1. ST1, ST2, and CS were measured by a microphone one metre from the source positions marked 'Sx': S1 (typical soloist position), S2 (middle of right side strings between violas and celli) and S3 (far left in second row of winds). For each source position, EDTP (plus EEL, C, TS, and RT listed in Appendix B) were measured at the 'Px' position with corresponding number: P1 (normal position of solo oboist), P2 (middle of left side strings between primo and second violins), and P3 (far right in second row of winds). The distance S2 - P2 was always very close to 8 metres, and the distance S3 - P3 close to 6 metres. The acoustic centres of all transducers on the platform were one metre above the floor.

Depending on the lay out of the seating, five to seven 'Rx' microphone positions were chosen as shown in Figure 1.1. The exact positions used in each hall appear from the drawings in Chapter 2. The height of the microphone was about 70 cm above the seat (i.e. about 1.2 metres above the floor).

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* In some of the UK halls, the RT and L values at 4000 Hz are missing because of noise problems during the measurements.

In all cases the halls were empty during the measurements. The platforms were equipped with chairs and music stands. However, close to the transducers these obstacles were often moved slightly in order to avoid too strong reflections from them and in order to ensure a free sight line between corresponding Sx and Px positions.

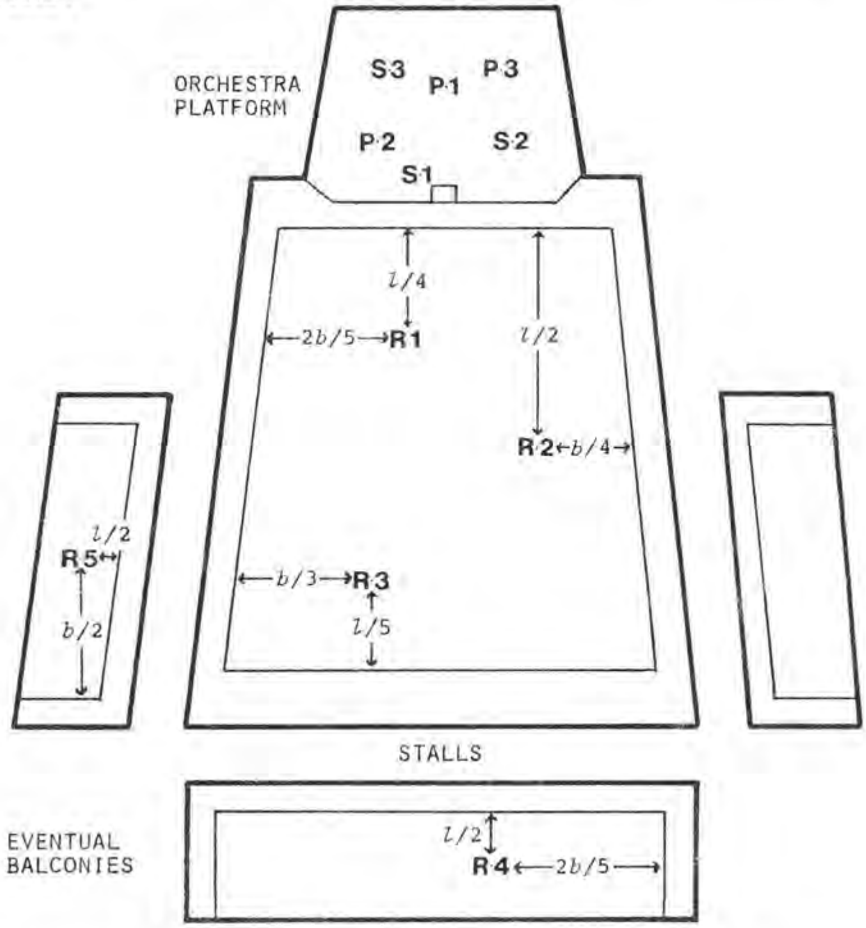


Fig. 1.1 General outline of measurement positions in the halls.

1.5. Measurement accuracy

Unfortunately very few investigations on the reproducibility and accuracy of room acoustic parameter measurements have been made. The worst problems occur with the energy fraction parameters (i.e. all exept RT, EDT and TS), in which the short integration intervals mean, that generally the statistical/random variance for these measures is very large compared with the variance between halls and seats, unless averaging over octave bands (and source positions) is performed [17]. The random variance manifests itself as large variations in the measured values for even small changes in position. For audience parameters, reproducibility of measurements in the same hall including changes of 30 cm in the position of the microphone have been found to be as listed in Table 1.2 [18]. For comparison, the standard deviation (STD) over seat positions in this particular hall are also listed. The values listed are averages per octave band, since the values changed only little with frequency (- the tendency being STD at 125 Hz being a factor two larger than at 4 kHz at the most). Assuming that these results - reflecting the

Parameter	RT	EDT	C	L	LEF
Unit	sec.	sec.	dB	dB	-
STD, random	0.05	0.12	0.8	0.7	0.05
STD,position	0.07	0.27	2.3	1.9	0.06

TABLE 1.2 Comparison of standard deviations, STD pr. octave band associated with random errors and STD associated with different seat positions. Based on measurements in one hall; from [18].

experiences in one hall - are general, it can be seen, that it does not make sense at all to quote RT and LEF values per position, and that position differences need to be about two times the random STD values listed (divided by the square root of the number of averaged octave bands) in order to be significant at a 95% level.

One may also use the information in Table 1.2 to estimate how large the difference should be between the position averaged values of a particular parameter in two halls in order for that difference to be statistically significant. Assuming that the variation between positions is purely random (which is a very pessimistic guess, since the lay out of measurement positions was the same in all halls as shown in Figure 1.1), the STD of the mean based on 10 source/microphone positions times four 1/1 octaves equals STD,position/$\surd$(10*4). Thus, two halls are surely different (at a 95% level) with respect to a particular parameter, if their position averaged values differ more than about 1/3 times the STD,position listed in Table 1.1.

II. ELEVEN EUROPEAN CONCERT HALLS

In the following, data for the eleven halls are presented in alphabetical order according to country and city. For reasons of clarity, only one position- and frequency averaged value of each room acoustic parameter has been listed for each hall. However, a graphical presentation of RT and L versus frequency (averaged over positions) is also shown. The values per position and per octave band can be found in Appendix B, while tables of averaged values of acoustical and architectural data appear in Appendix C.

It should again be emphazised, that all measurements were carried out in the unoccupied halls. For most of the halls RT values for the occupied condition have been published, and these are also listed in this chapter and used for comparisons in section 4.2.

Besides the room acoustic data, the descriptions include: percentage of use for different purposes, brief information about surface materials and furnishing, references to where more detailed descriptions can be found, basic geometrical data, and drawings (plans and a longitudinal section). The drawings are scale 1:400 - within the accuracy of the various stages of reproduction. The measurement positions are marked on the drawings, which also indicate the riser setting and platform size (often variable) during the measurements.

All measurements were carried out between October 1986 and September 1988, and the various information on properties and use of the halls is related to the state of things then.

2.1. Grosses Festspielhaus, Salzburg (**FS**)

Inaugurated 1960. Architect: C. Holzmeister.
Acoustic consultants: H. Kielholz, G. A. Schwaiger.
Major modifications: 1979 (new orchestra shell).

Percentage of use for :
Symphonic concerts : 70 % (about 120 per year)
Drama and Opera : 30 %

Surface materials:
Ceiling: painted plaster on reeds. Walls: plaster on reeds covered with a thin layer of wood. In front of the concave sections of the side walls convex wooden panels of about 40 mm thickness are mounted, forming cavities behind which lighting and PA loudspeakers are hidden. These panels cover about half of the area of the concave wall sections. In the platform area the walls are moveable and made of wood of 40 mm thickness. Rear walls above the balcony consist of wooden panels and some glass areas; below the balcony the rear wall is dominated by boxes with curtains. Floor: Linoleum on wood with carpet on main aisles. Platform: partly recessed into the stagehouse and separated from this by an orchestra shell. In the shell, convex panels are mounted on the walls as described above, however, here these panels are made of 10 mm plywood. Platform floor: linoleum on wood over air space with moveable risers of 22 mm wood. Chairs: fixed, wooden folding chairs with upholstered seat and thinly upholstered backrest.

References: [12;19]

Geometrical Data:

Volume : 15,500 m^3

Platform area : 260 m^2

Seating area : 1050 m^2

Number of seats: 2168 (1289 on main floor, 762 on balcony, 71 in boxes below balconies, 46 in side wall boxes).

Acoustical data:

RT_m : 2.2 sec.

RT_m occup. : 1.5 sec. [12] (measured with old orchestra shell; see [19])

Audience area:

EDT : 2.15 sec.

L : 2.3 dB

t_s : 155 msec.

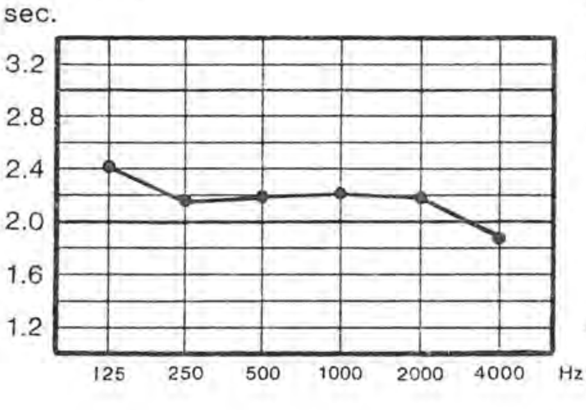
LEF : 0.11

C : -1.6 dB

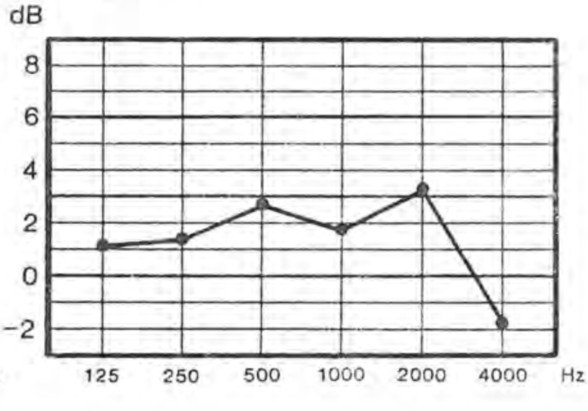
BR(RT): 1.04

BR(L): -1.0 dB

RT(f) :



L(f) :



Platform area:

EDTP : 1.6 sec.

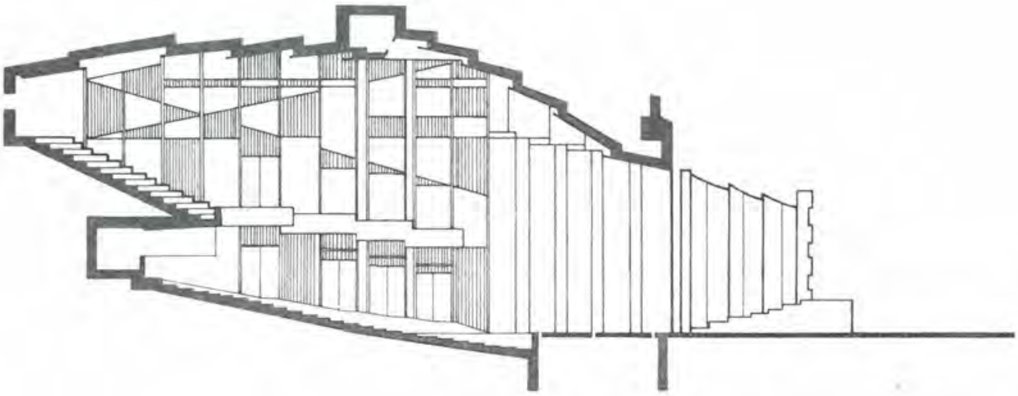
ST1 : -15.8 dB

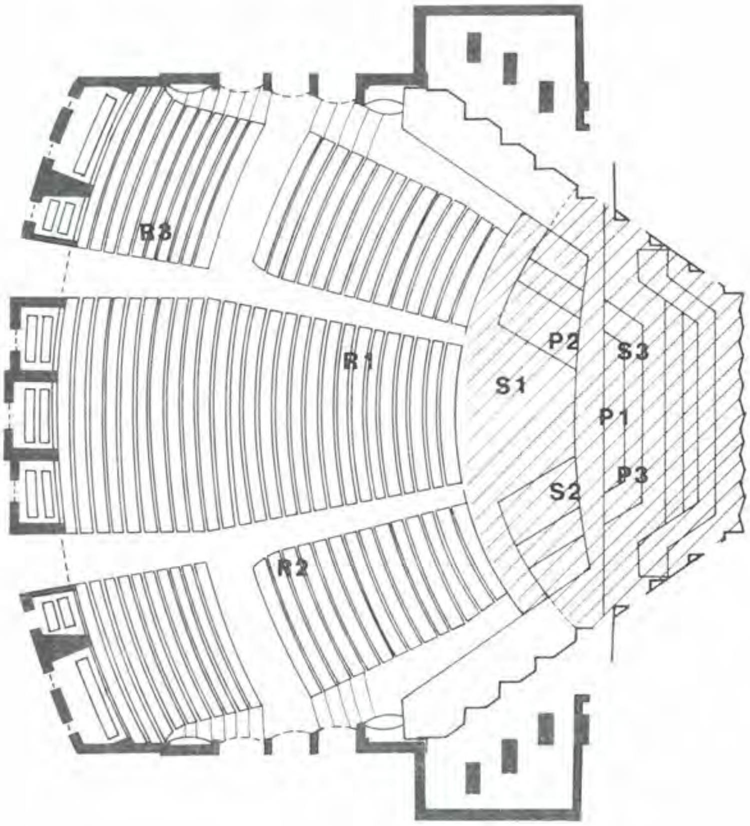
CS : 16.3 dB

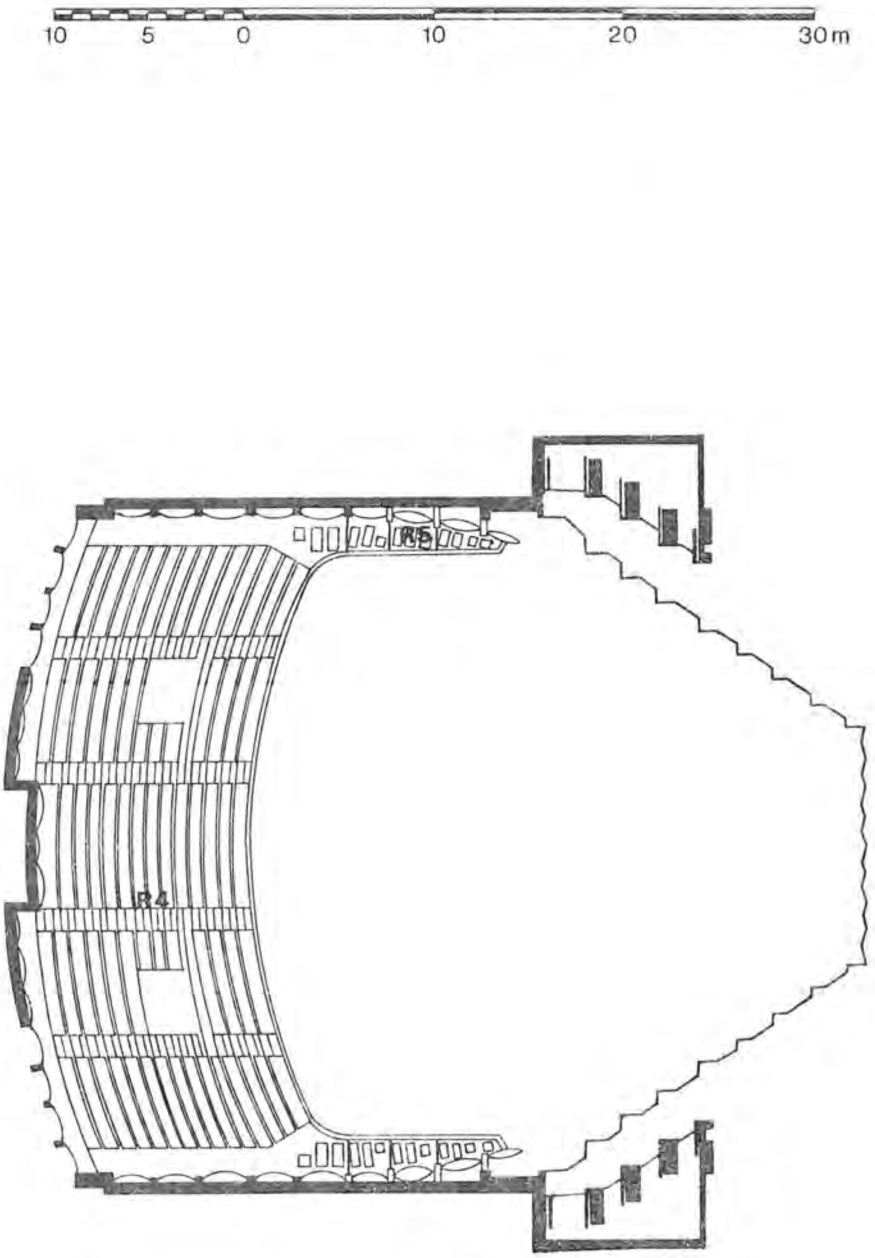
ST2 : -14.1 dB

Remarks on measurement conditions:

The measurements were carried out on 28. September 1987.



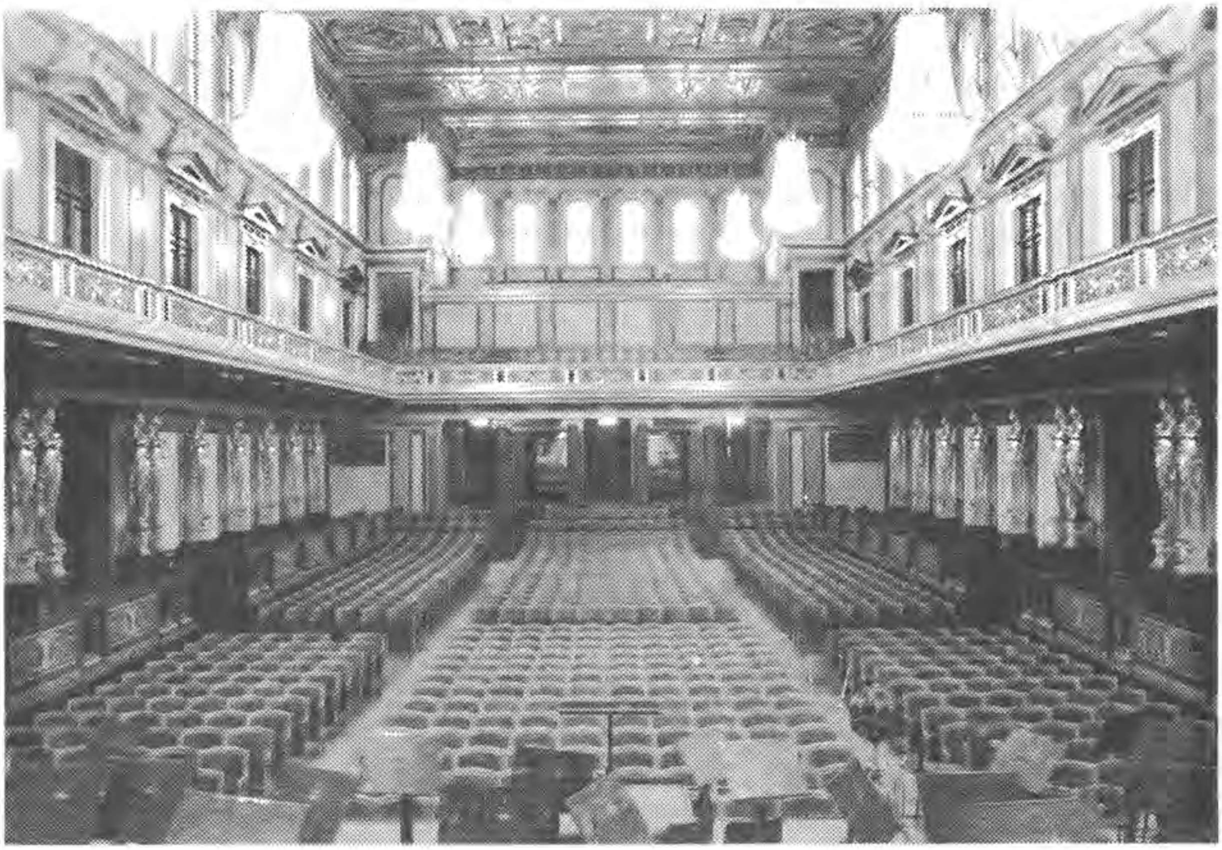

R3
R1
R2
S1
S2
S3
P1
P2
P3


10
5
0
10
20
30m
R5
R4

2.2. Musikverein, Wien (MW)

Inaugurated 1870. Architect: Teophilus Hansen.

Percentage of use for :
Symphonic concerts : 75 % (about 300 per year)
Recitals and chamber music : 25 %



Surface materials:
Ceiling: gilded and painted plaster on wood. Walls: plaster on brick, heavy wooden doors (except for glass doors below the rear balcony), and extensive window areas near the ceiling. Some areas of wood panelling around the platform. Balcony fronts are plaster on wood. The side loge fronts are covered with draperies. Floor: Linoleum on wood with carpet on main aisles. Platform floor: wood over air space with steep, fixed risers. Chairs: fixed, wooden folding chairs with upholstered seats. No upholstery on rear balcony chairs (except for the first row). On side balconies and in side loges the chairs are separate with thinly upholstered seat and backrest.

References: [12;19]

Geometrical Data:

Volume : 15,000 m^3

Platform area : 125 m^2

Seating area : 620 m^2

Number of seats: 1600 (672 on main floor, 232 in side loges, 118 on platform, 249 on side balconies, 209 on 1. rear balcony, 120 on 2. rear balcony)

Acoustical data:

RT_m : 3.2 sec.

RT_m occup. : 2.1 sec. [12]

Audience area:

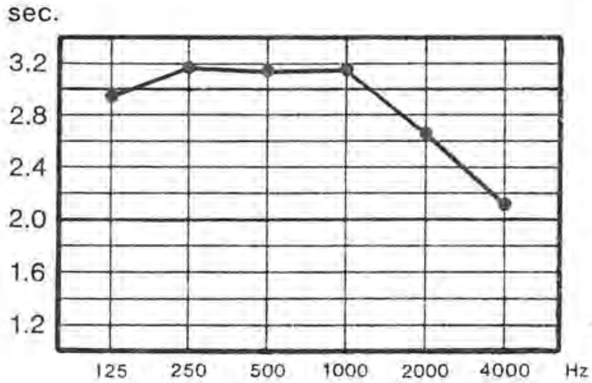
EDT : 3.16 sec. L : 6.5 dB

t_s : 225 msec. LEF : 0.16

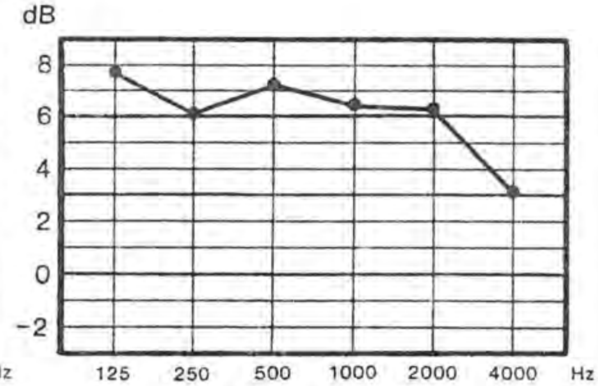
C : -5.1 dB

BR(RT): 0.97 BR(L): 0.1 dB

RT(f) :



L(f) :



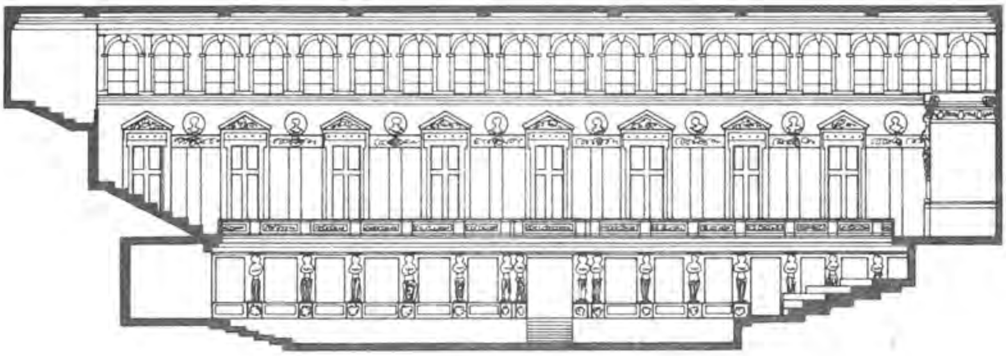
Platform area:

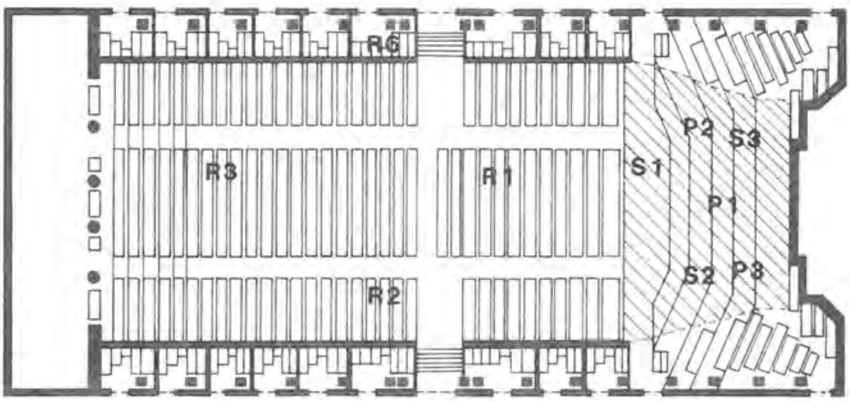
EDTP : 2.0 sec. ST1 : -13.0 dB

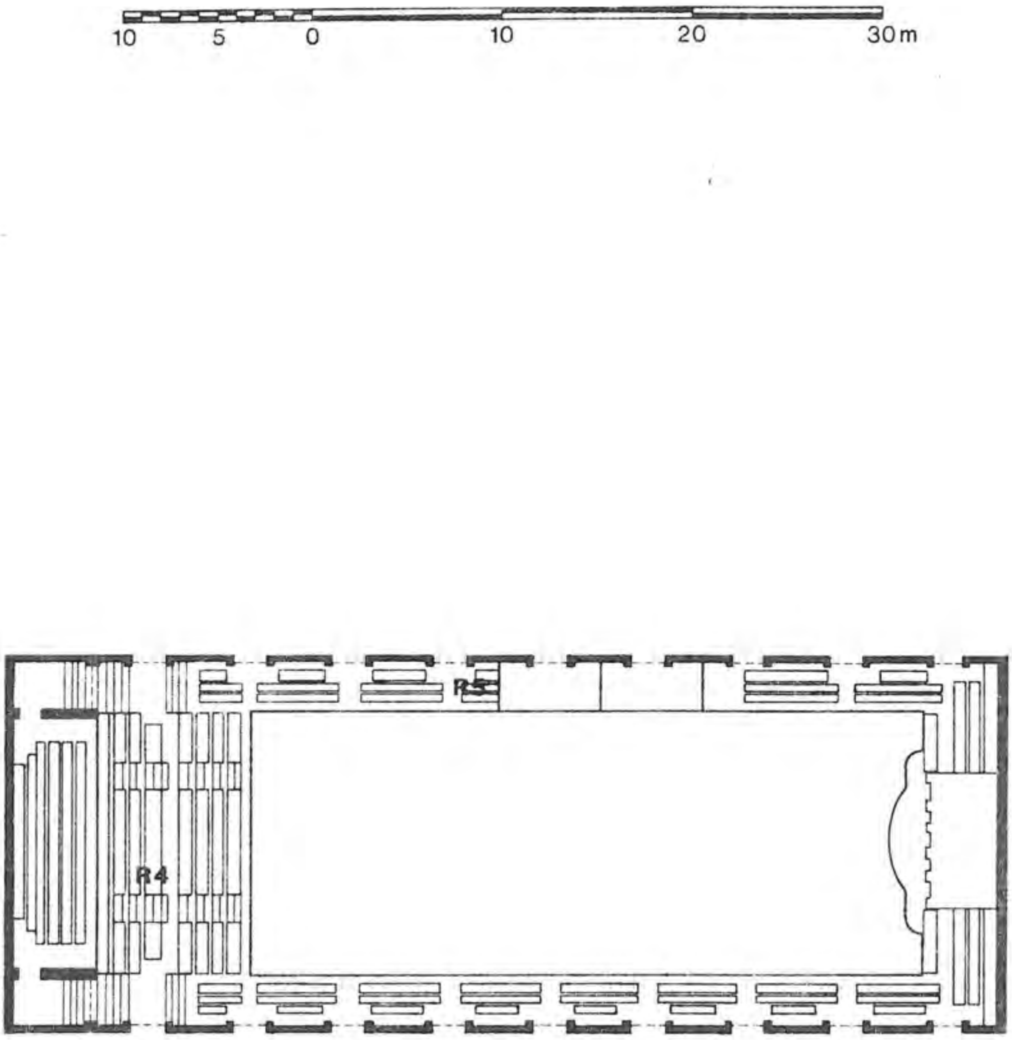
CS : 13.7 dB ST2 : -11.8 dB

Remarks on measurement conditions:

The measurements were carried out on 2. October 1987.



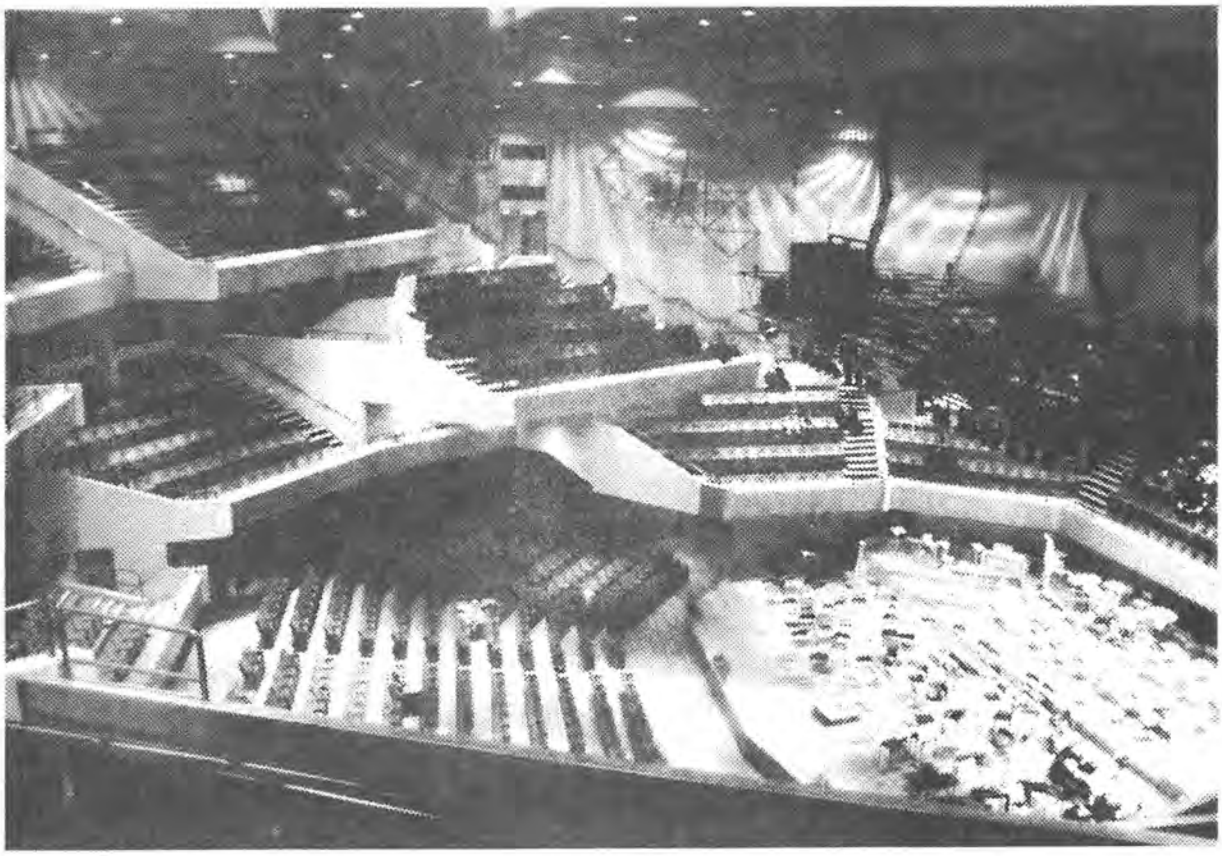

R6
P2 S3
R3
R1
S1
P1
S2 P3
R2


10 5 0 10 20 30m
R5
R4

2.3. St. Davids Hall, Cardiff (**CA**)

Inaugurated 1982. Architect: J. Seymour Harris partnership.
Acoustic consultant: Sandy Brown Associates.

Percentage of use for :
Symphonic concerts : 17% (about 50 per year)
Recitals and chamber music : 13 %
Pop, jazz, Rock concerts : 15 %
Miscellaneous : 55 %



Surface materials:
Ceiling: Concrete with suspended acoustically transparent wood fibre grid below, which visually covers lighting bridges and ventilation ducts. Walls: painted concrete. Rear walls behind the audience, the walls around the platform, and the balcony fronts are of wood with air space behind. Floor: Parquet on concrete with carpet on some access areas. Platform floor: 22 mm parquet on 22 mm plywood over air space. The whole platform is divided into 10 individually controllable hydraulic lift areas, to allow for a flexible platform size with risers or a flat stage with an orchestra pit in front. A large metal grid carrying stage lighting, loudspeakers and some minor reflecting areas is suspended at adjustable height over the platform. Chairs: Fixed, wooden folding chairs fully upholstered except for the rear of the backrests, which are of plywood. On the balconies, these plywood boards are extended about 20 cm above the upholstered back rests forming a reflecting surface at ear height.

References: [20;21;22]

Geometrical Data:

Volume : 22,000 m^3

Platform area : 176 - 270 m^2

Seating area : 1070 m^2

Number of seats: 1952 (1771 with fully extended platform; 612 (431) on main floor, 1340 in balconies, of which 270 are placed behind the platform)

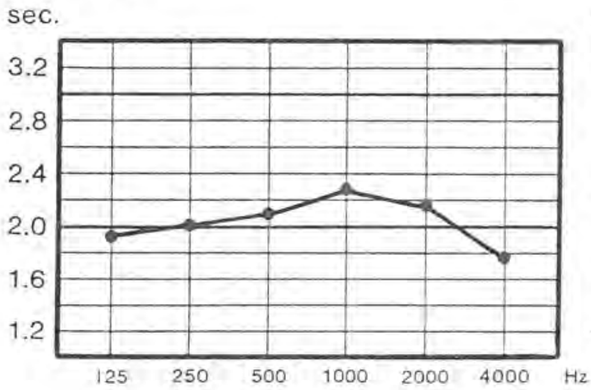
Acoustical data:

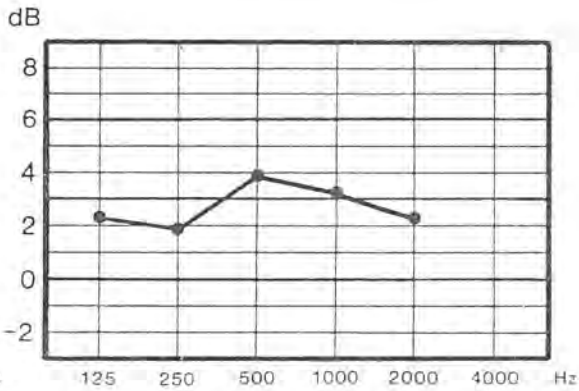
RT_m : 2.2 sec.

RT_m occup. : 1.9 sec. [20]

Audience area:

EDT :	2.04 sec.	L :	2.9 dB
t_s :	143 msec.	LEF :	0.18
C :	-1.2 dB		
BR(RT):	0.90	BR(L):	-1.5 dB
RT(f) :		L(f) :	



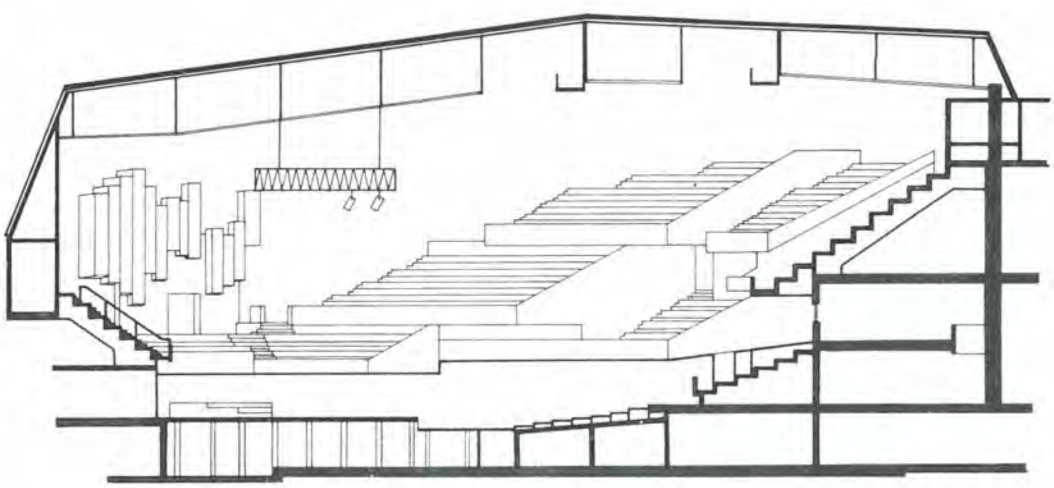


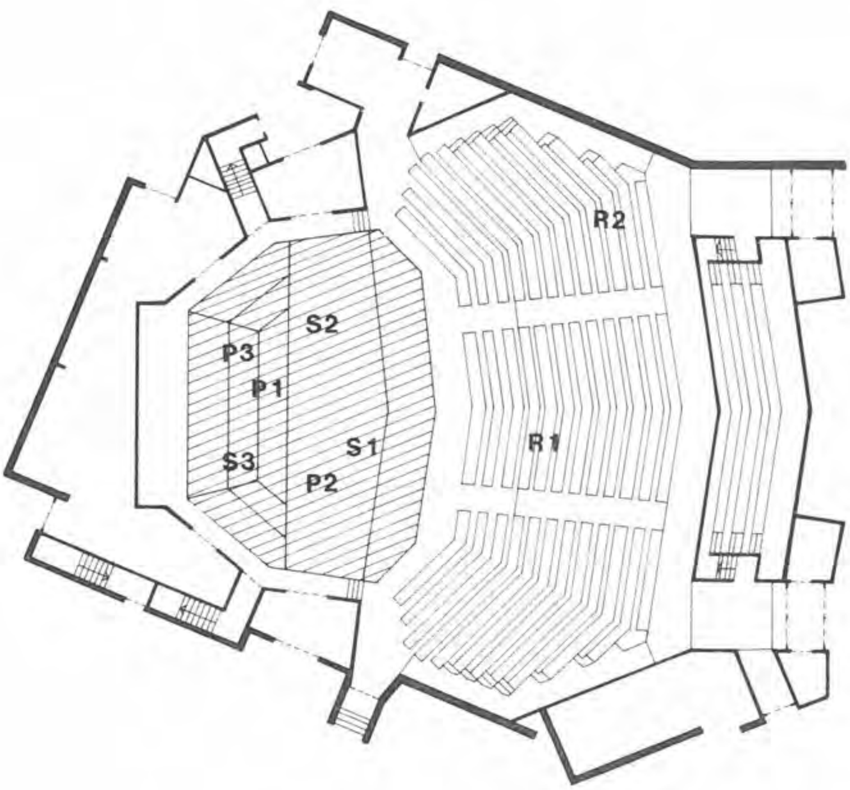
Platform area:

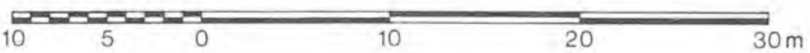
EDTP :	1.5 sec.	ST1 :	-16.6 dB
CS :	15.6 dB	ST2 :	-14.3 dB

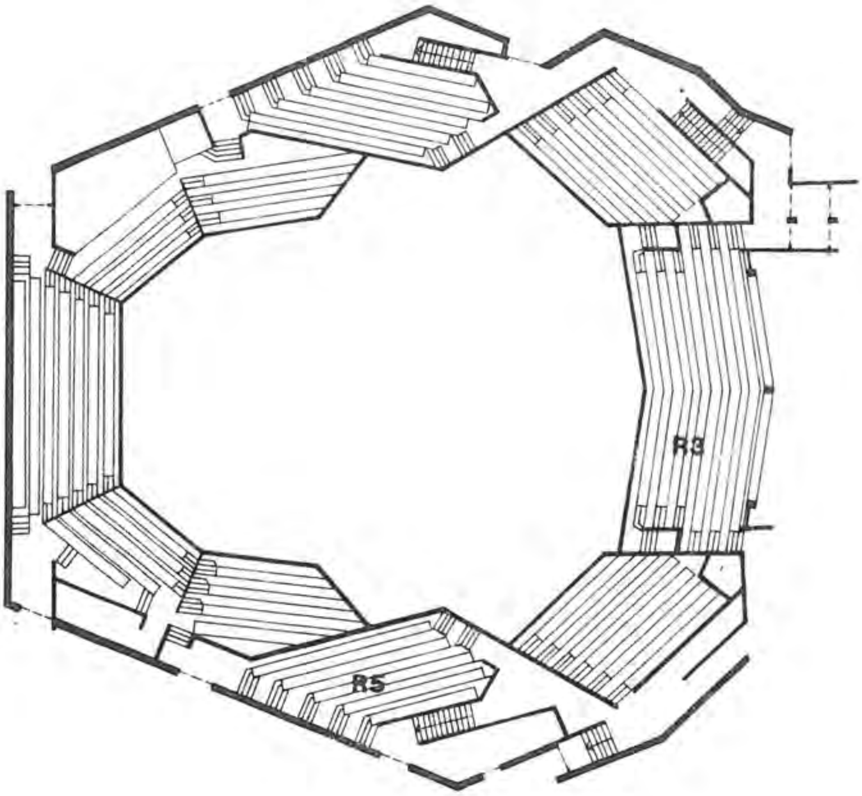
Remarks on measurement conditions:

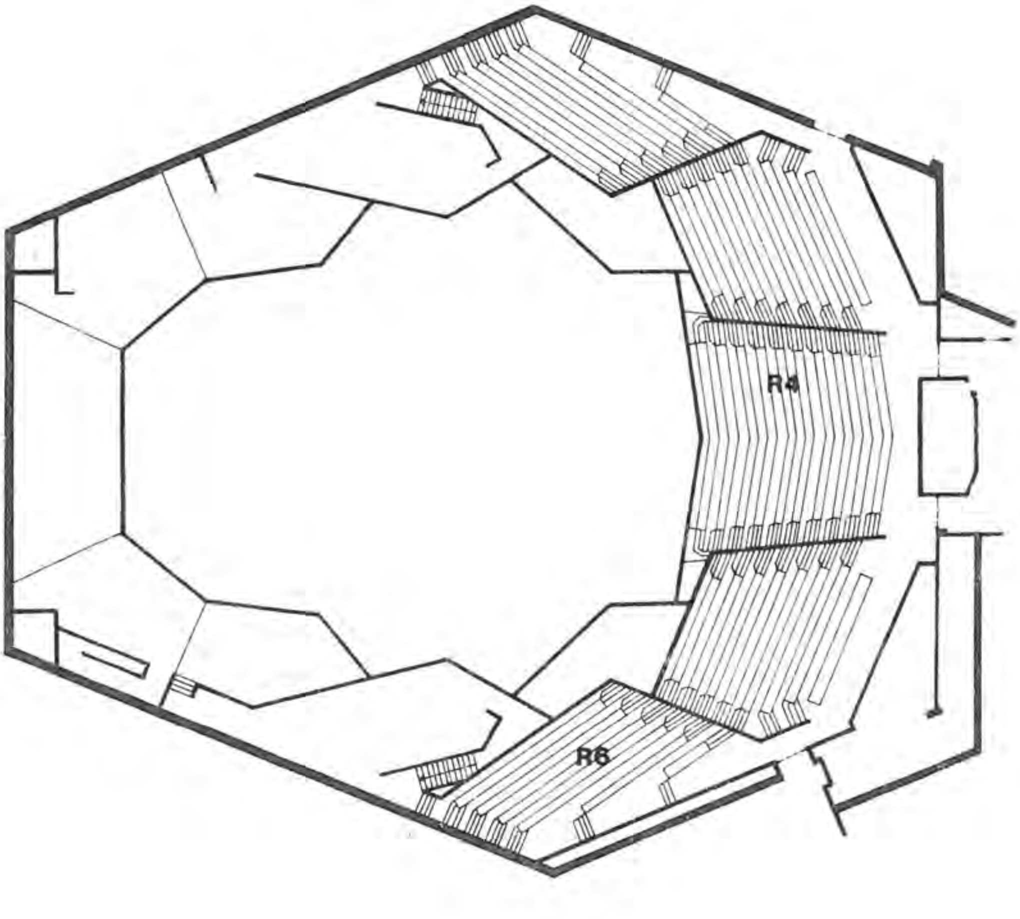
The lifts were set to form a platform area of 224 m^2 resulting in the number of audience seats being 1896.
The measurements were carried out on 1. December 1986.




R2
S2
P3
P1
R1
S1
S3
P2


10
5
0
10
20
30m

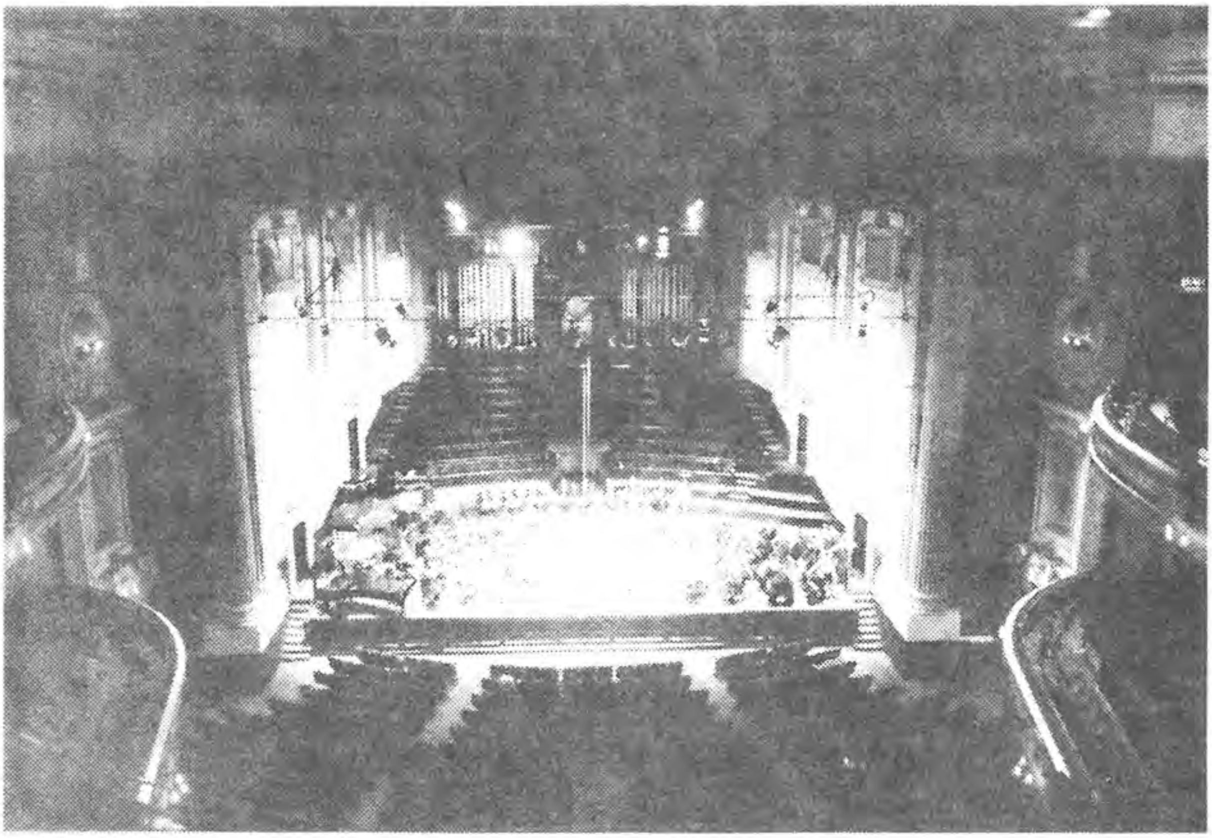

R3
R5


R4
R6

2.4. Usher Hall, Edinburgh (**ED**)

Inaugurated 1914. Architect: Stockdale Harrison and Sons,
and H.H. Thomson.

Percentage of use for :
Symphonic concerts : 80% (about 55 per year)
Recitals and chamber music : 10 %
Pop, jazz, Rock concerts : 5 %
Drama and Opera : 2 %
Miscellenious : 3 %



Surface materials:
Ceiling: plaster on wood with high relief ornamentation. Walls: Plaster on wood with air space behind. On the upper side walls, some window areas are covered with curtains. Floor: wood over airspace with carpets on aisles except for the first balcony, in which the whole floor is carpeted. Platform floor: wood over airspace with fixed wooden risers. Chairs: Fixed folding chairs with upholstered seat, back-, and armrests. Hard wooden folding chairs in the second balcony and hard fixed benches in the choir area behind the orchestra.

References: [12;22;23;24]

Geometrical Data:

Volume : 16,000 m^3

Platform area : 130 m^2

Seating area : 1100 m^2

Number of seats: 2548 (990 on main floor, 428 on first balcony, 797 on second balcony, 333 choir seats behind the orchestra

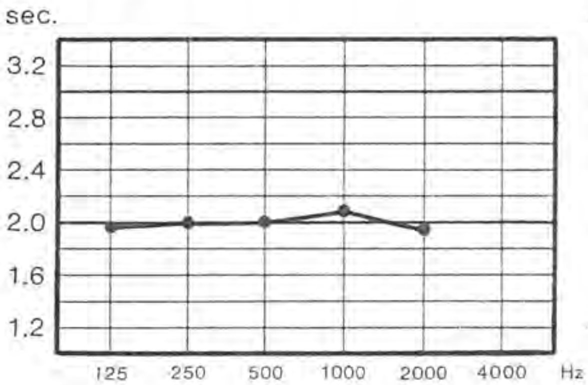
Acoustical data:

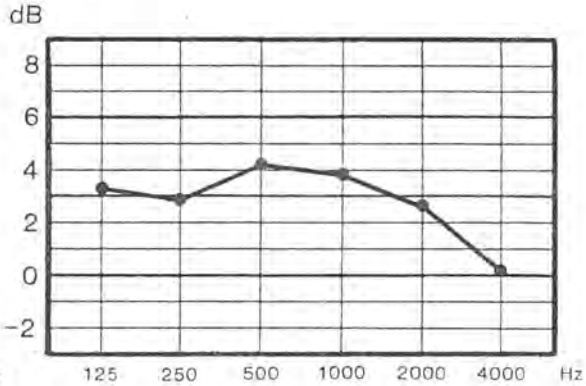
RT_m : 2.1 sec. *

RT_m occup. : 1.8 sec. (500 Hz), [24]

Audience area:

EDT :	2.13 sec.	L :	3.4 dB
t_s :	156 msec.	LEF :	0.23
C :	-1.7 dB		
BR(RT):	0.97 *	BR(L):	-0.9 dB
RT(f) * :		L(f) :	



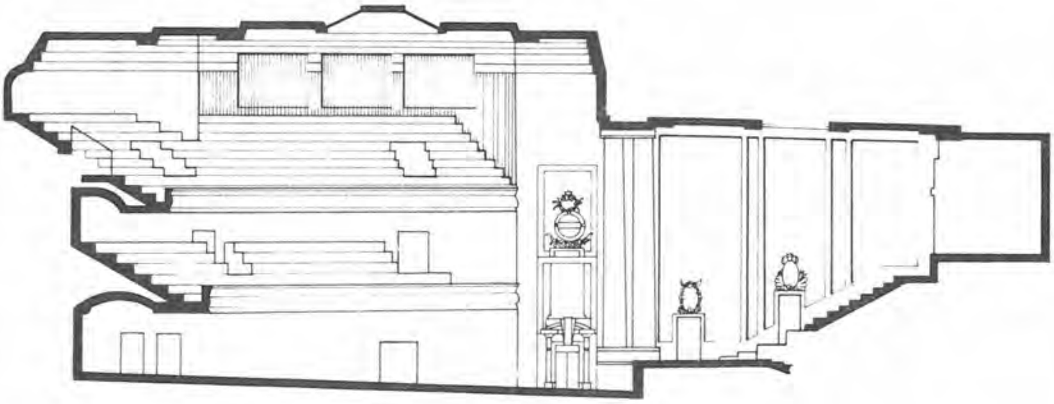


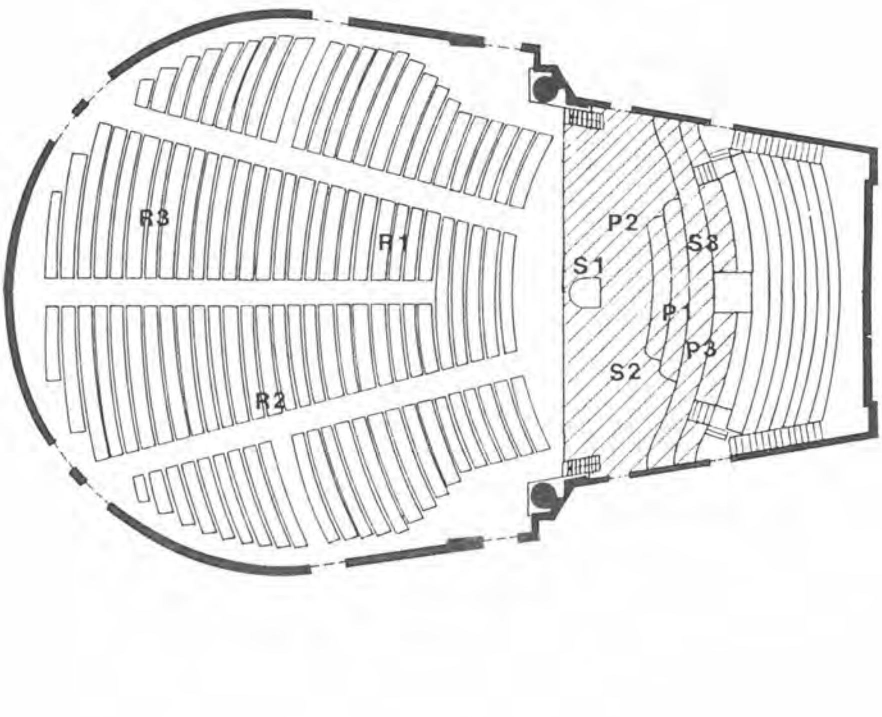
Platform area:

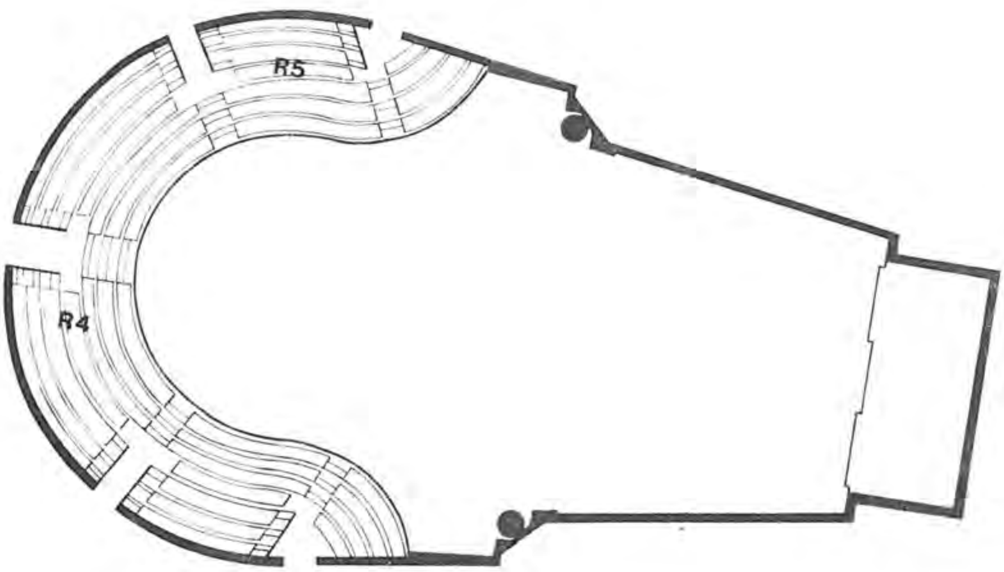
EDTP :	1.5 sec.	ST1 :	-16.3 dB
CS :	12.9 dB	ST2 :	-13.6 dB

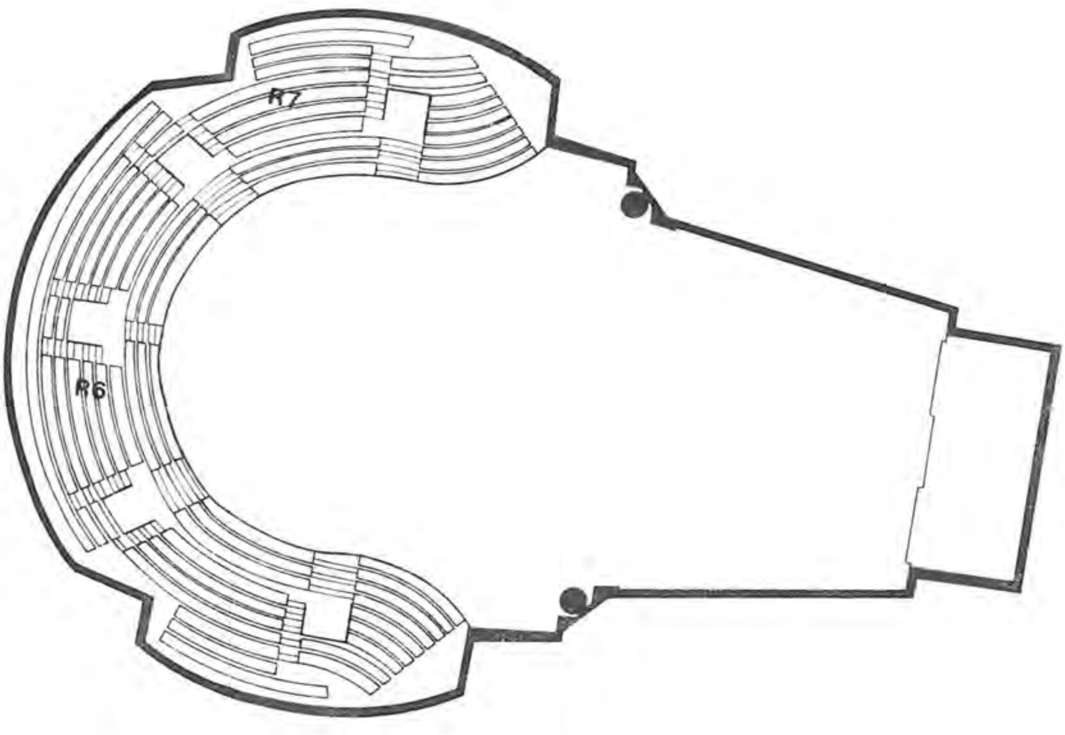
Remarks on measurement conditions:

The measurements were carried out on 26. November 1986.
* RT values from Barron [22].




R3
R1
R2
P2
S3
S1
P1
P3
S2
10 5 0 10 20 30m

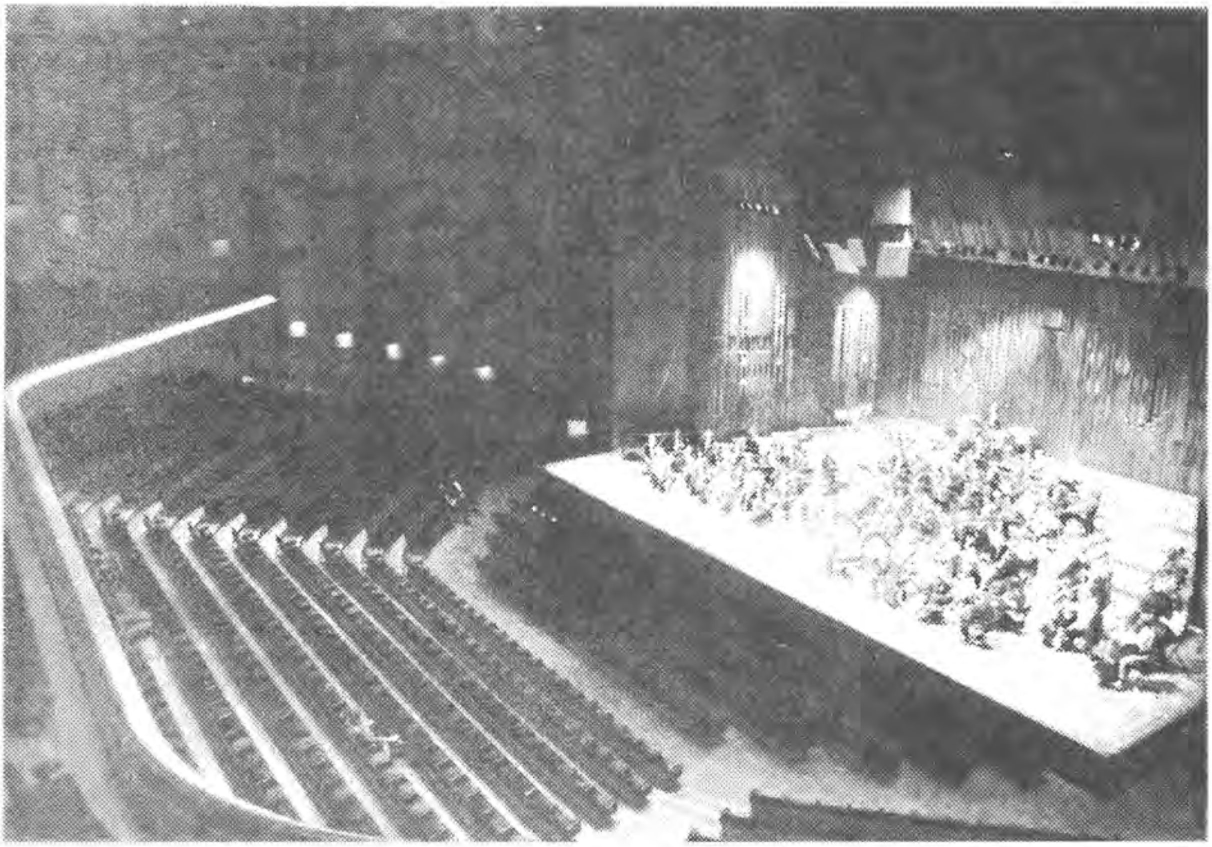

R5
R4


R7
R6

2.5. Barbican Concert Hall, London (**BA**)

Inaugurated 1982. Architect: Chamberlin, Powell & Bon.
Acoustic consultant: Hugh Creighton and Arup Acoustics.

Percentage of use for :
Symphonic concerts : 60% (about 200 per year)
Recitals and chamber music : 10 %
Pop, jazz, Rock concerts : 10 %
Miscellaneous : 20 %



Surface materials:
Ceiling: Concrete with exposed concrete beams and ventilation ducts. Walls: Wood panels in front of concrete. On major side wall areas this panelling has been given a zig zag shape. Floor: parquet on hard surface. Platform floor: 22 mm parquet on 22 mm plywood and gypsum over airspace. The platform is equipped with a hydraulic riser system adjustable in eight individual sections and supplemented with loose wooden riser elements. Pivoting steel supports are hidden behind the platform front for mounting of a 2.2 m extension of the platform. In the orchestra shell large areas of the wall panelling have slots opening into the air space behind. A wooden canopy is suspended over the platform. Chairs: Fixed, wooden chairs with upholstered seat and backrest.

References: [22]

Geometrical Data:

Volume : 17,750 m^3

Platform area : 156 - 200 m^2

Seating area : 1050 m^2

Number of seats: 2026 (1955 with extended platform; 936 (865) on main floor, 767 on first balcony, 323 on second balcony)

Acoustical data:

RT_m : 2.0 sec.

RT_m occup. : 1.7 sec. [25]

Audience area:

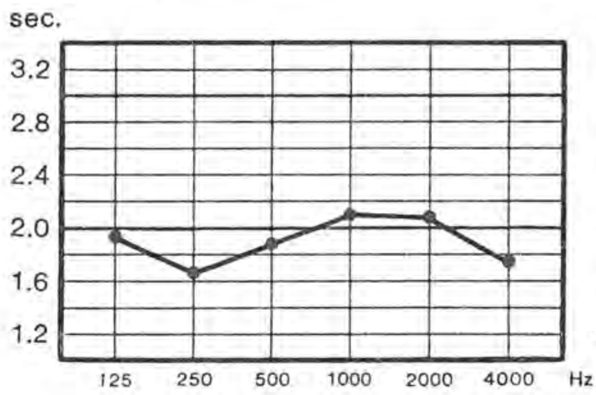
EDT : 1.91 sec. L : 2.9 dB

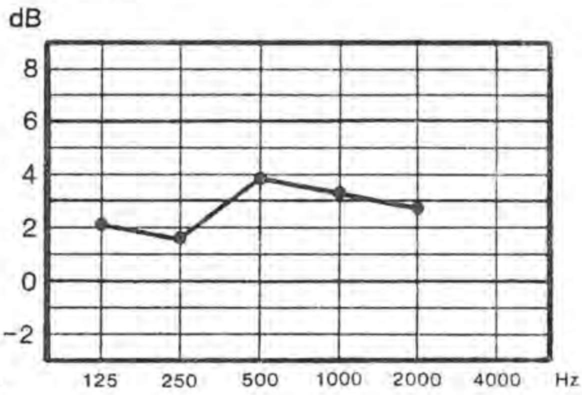
t_s : 141 msec. LEF : 0.17

C : -1.6 dB

BR(RT): 0.90 BR(L): -1.7 dB

RT(f) : L(f) :





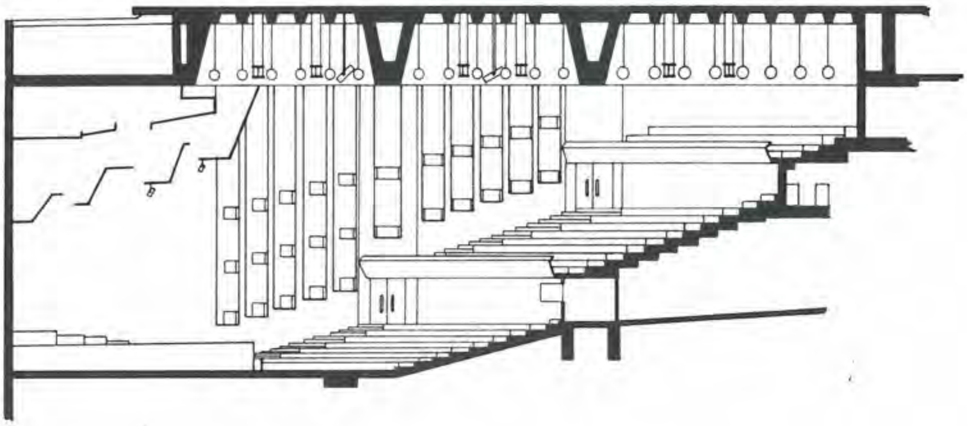
Platform area:

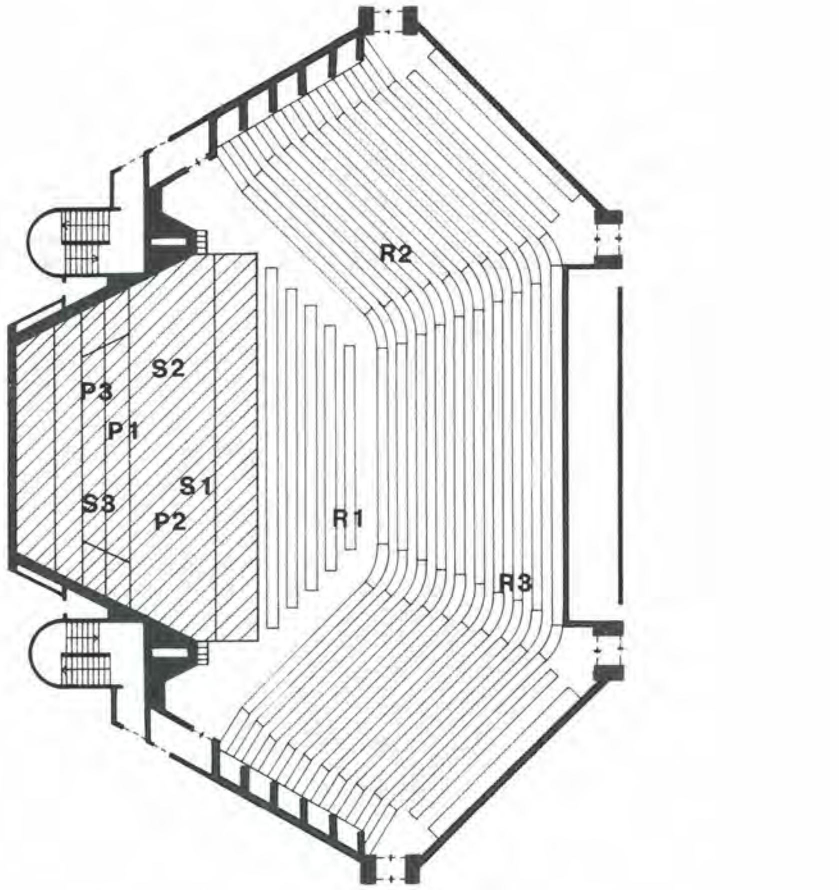
EDTP : 1.3 sec. ST1 : -13.2 dB

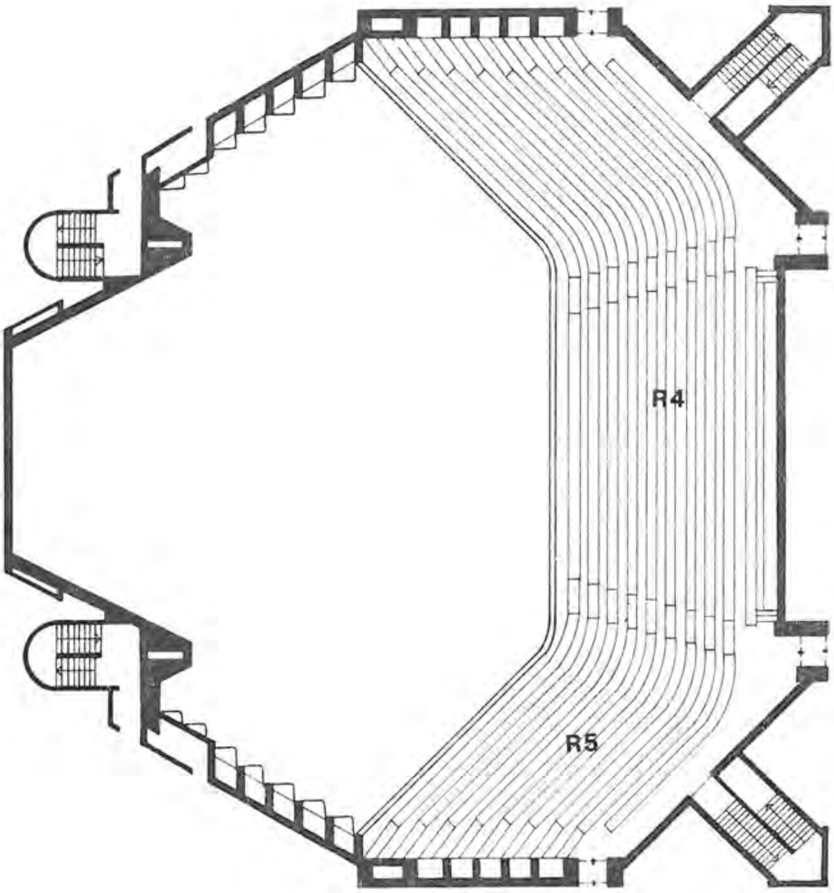
CS : 15.1 dB ST2 : -12.0 dB

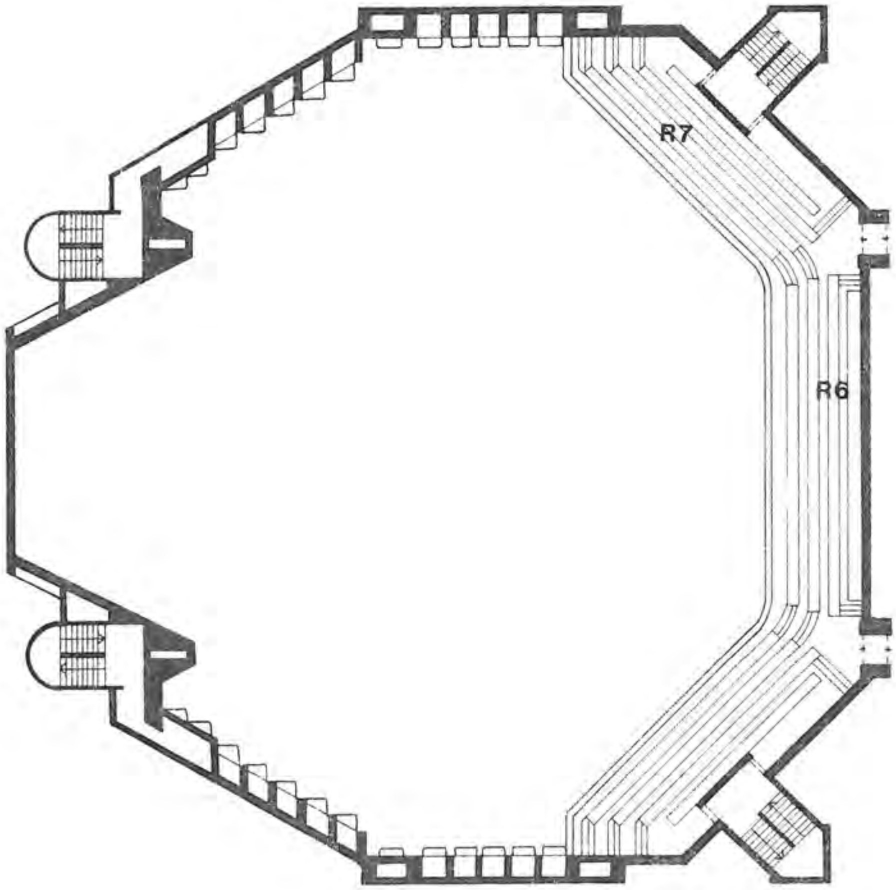
Remarks on measurement conditions:

The platform was extended to 200 m^2
The measurements were carried out on 3. December 1986.




R2
S2
P3
P1
S1
S3
P2
R1
R3
10
5
0
10
20
30m

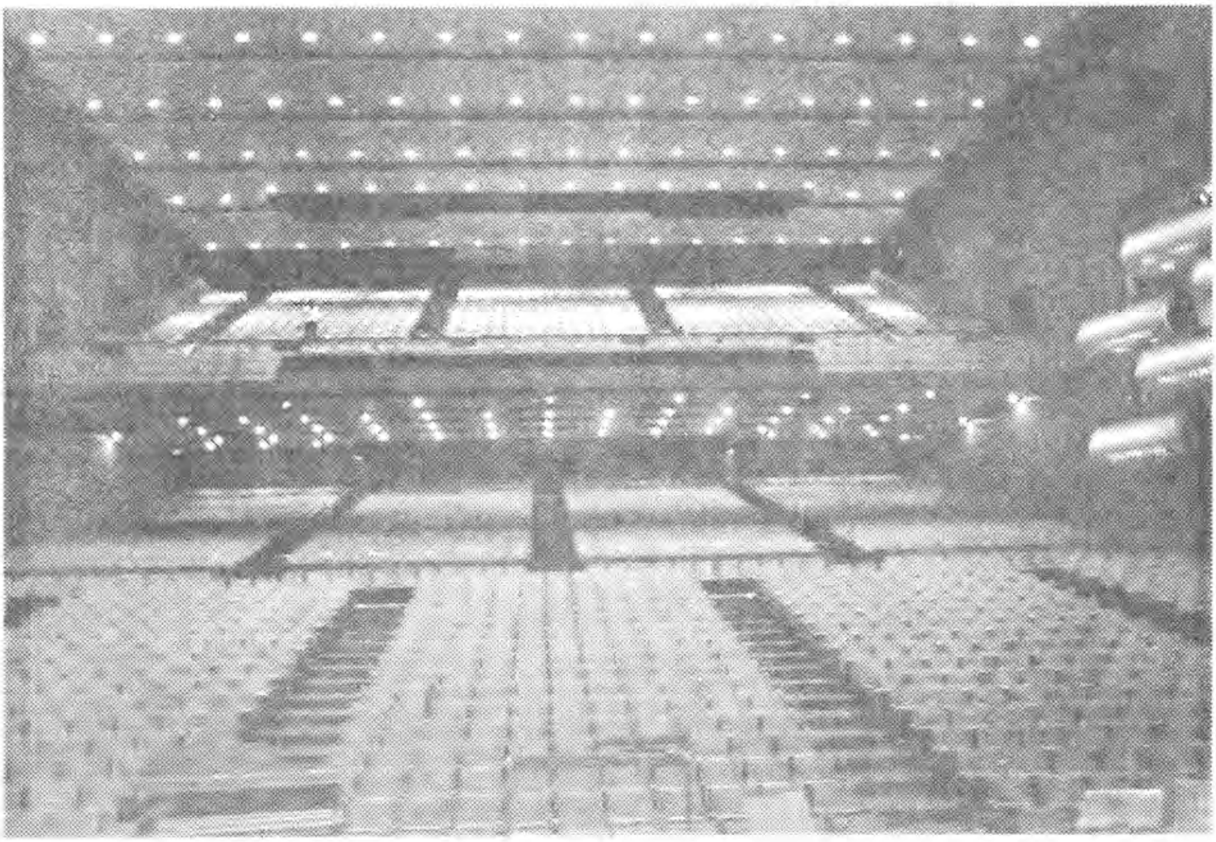

R4
R5


R7
R6

2.6. Royal Festival Hall, London (FH)

Inaugurated 1951. Architect: R.H. Matthew, J.L. Martin.
Acoustic consultant: H. Bagenal and The Building Research Station
Major modifications: Assisted resonance installed 1964 - 1969.

Percentage of use for :
Symphonic concerts : 55 % (about 200 per year)
Recitals and chamber music : 15 %
Pop, jazz, Rock concerts : 10 %
Miscellaneous : 20 %



Surface materials:
Ceiling: Suspended panels of 10 - 20 mm fibrous plaster covered by a 30 - 40 mm layer of vermiculite plaster. Walls: Main areas are 10 mm plywood with airspace behind. In front of the side wall terraces at floor level, the walls are made of slit panels in front of air space filled with mineral wool. The rear walls and the recessed wall sections behind the seats in side wall terraces and side wall boxes are made of leather cusions stuffed with glass wool in front of 10 cm airspace filled with mineral wool. Floor: Cork tiles on concrete. Platform floor: wood over airspace except for the rear part, which is wood on concrete. The risers are hydraulic except for the last step which is fixed. The choir balcony front is of wood serving as a reflector for the orchestra, and a wooden canopy is suspended over the platform. Chairs: folding chairs with upholstery on seat and backrest fronts. The seats are perforated underneath.

References: [12;26;27]. On the assisted resonance: [28;29].

Geometrical Data:

Volume : 21,950 m^3

Platform area : 173 m^2

Seating area : 1480 m^2

Number of seats: 2901 (1721 on main floor and rear terrace, 616 on rear balcony, 308 on side terraces and side balconies, 256 choir seats behind the orchestra.)

Acoustical data:

RT_m : 1.6 sec.

RT_m occup. : 1.5 sec. [26]

Audience area:

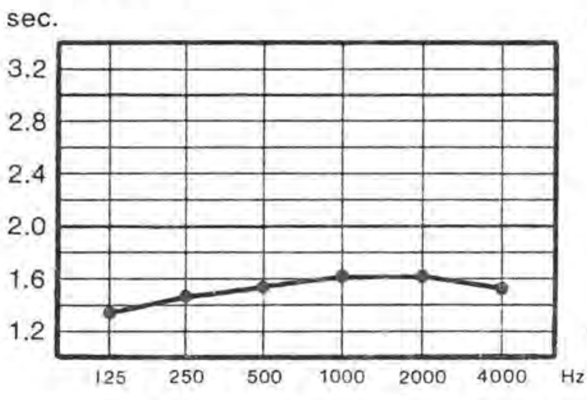
EDT : 1.38 sec. L : 1.6 dB

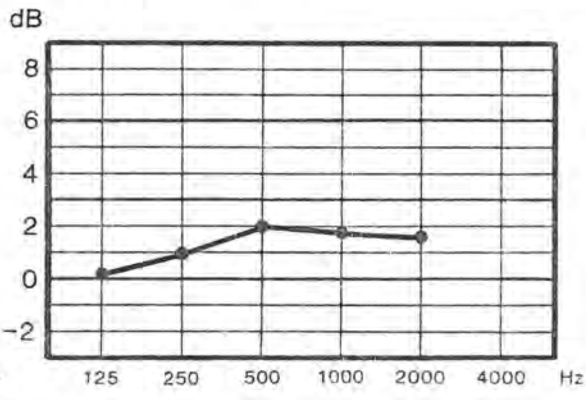
t_s : 104 msec. LEF : 0.24

C : 0.7 dB

BR(RT): 0.90 BR(L): -1.3 dB

RT(f) : L(f) :





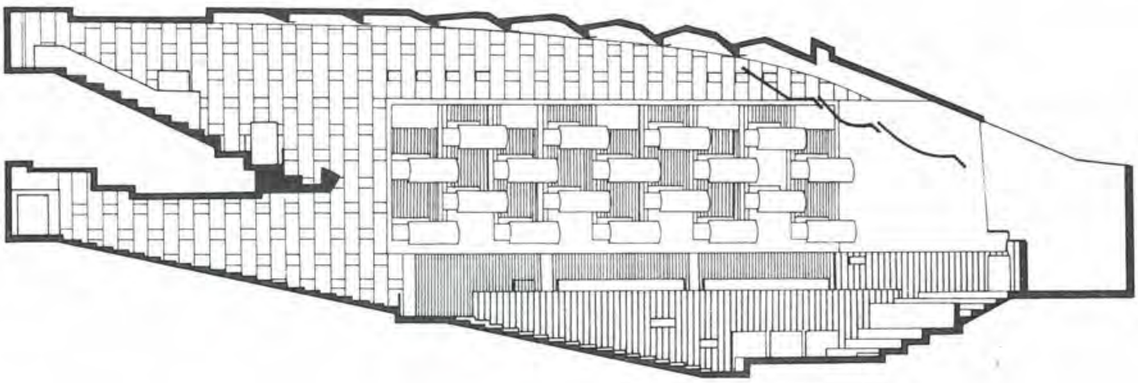
Platform area:

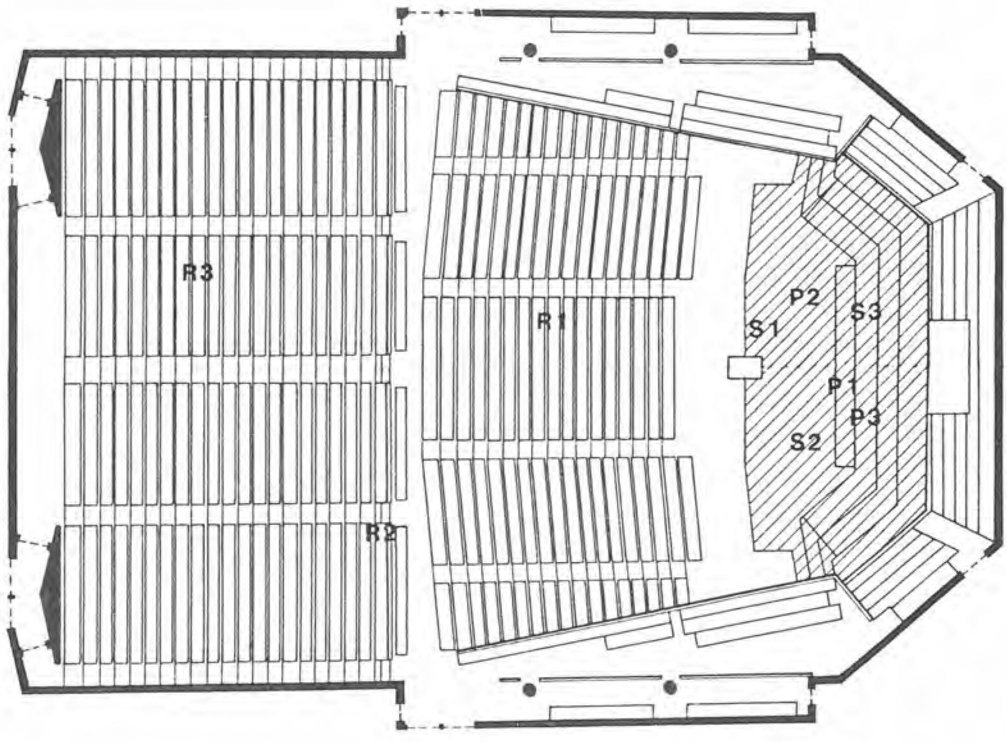
EDTP : 1.0 sec. ST1 : -16.0 dB

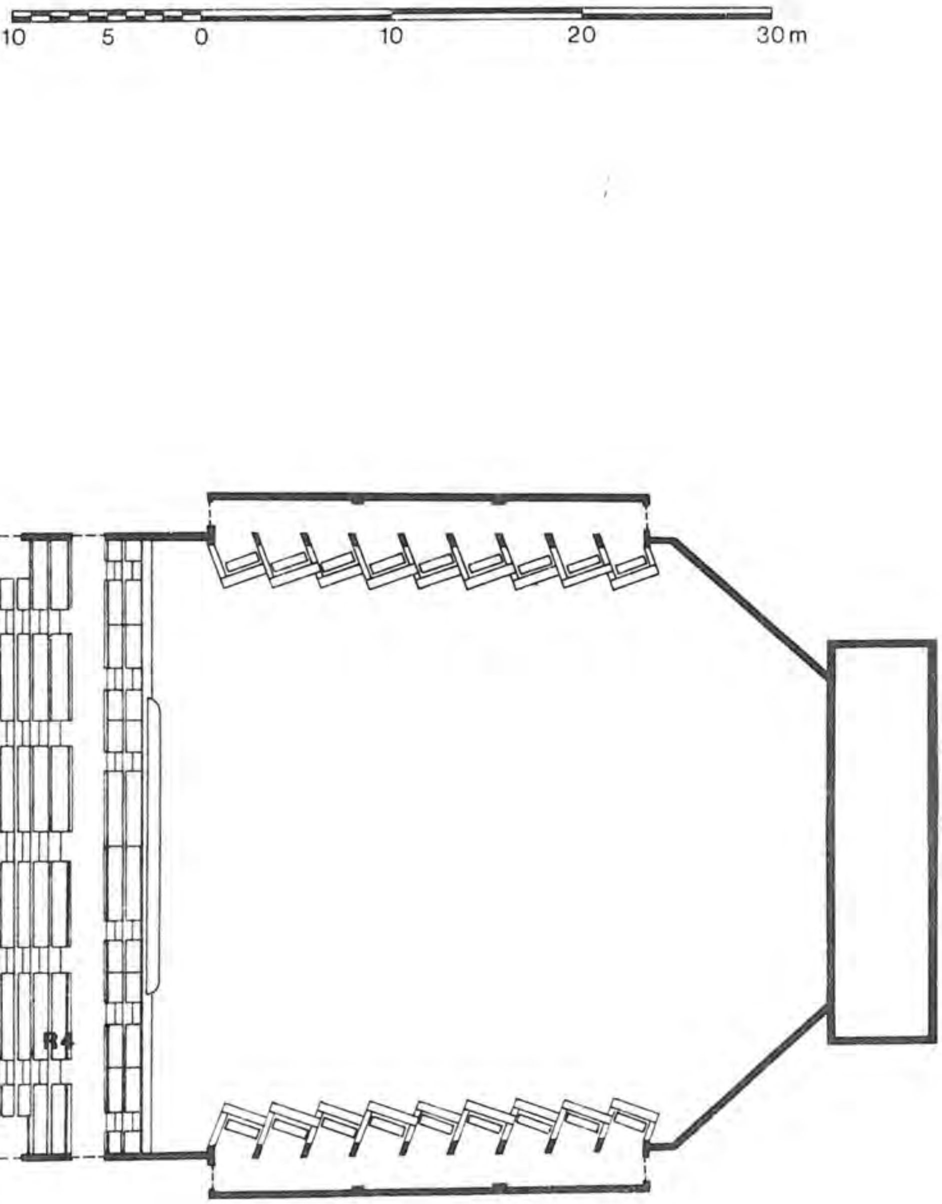
CS : 16.3 dB ST2 : -14.8 dB

Remarks on measurement conditions:

The measurements were carried out on 4. December 1986. The assisted resonance system was turned off.



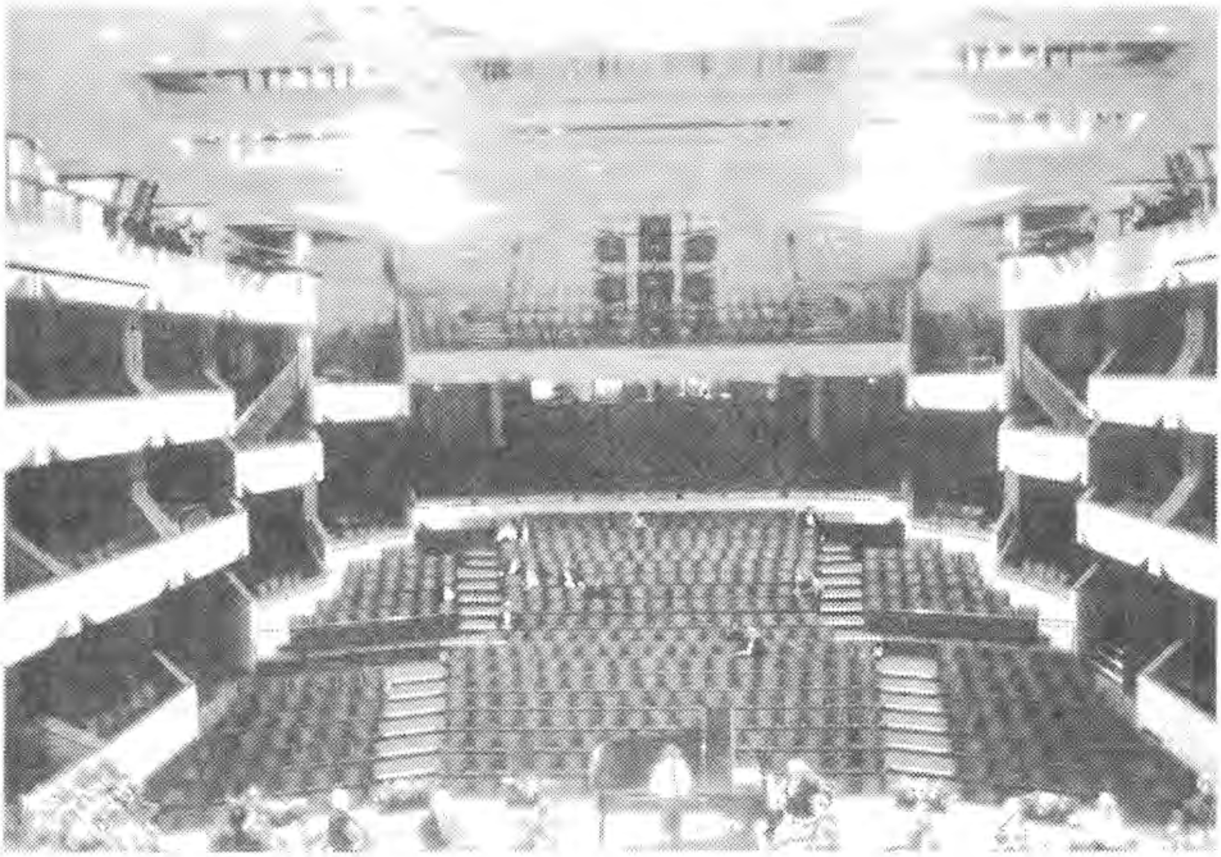

R3
R1
R2
P2
S3
S1
P1
P3
S2


10 5 0 10 20 30 m
R5
R4

2.7. Derngate, Northampton (NO)

Inaugurated 1983. Architects: Renton Howard Wood Levin Partnership. Acoustic consultant: Artec Consultants Inc.

Percentage of use for :
Symphonic concerts : 12 % (about 31 per year)
Recitals and chamber music : 3 %
Pop, jazz, Rock concerts : 29 %
Drama, opera and ballet : 39 %
Meetings, exhibitions, sports etc. : 17 %



Surface materials:
Ceiling: Concrete with suspended catwalks covered with hard panelling. The fly tower over the platform is closed off by mobile ceiling panels for concerts. Walls: Painted concrete. Seating box towers of chipboard on steel frames are placed along both side walls. Most of these towers can be moved around on air cushions. Curtains can be lowered to cover the hard side walls behind the boxes. Floor: Linoleum on concrete in the rear half of the main floor and on rear balconies. The front half of the main floor consists of two large lift sections for adjustable floor height (including forming of a pit) and transport of the large chair sections to storage space in the basement. The floor on the chair sections are of linoleum on thick plywood. In the side wall boxes, the floor is also plywood but covered with thin carpeting. Platform floor: Linoleum on plywood over narrow air space. The movable riser elements have plywood surface and their height is adjustable. Chairs: Folding chairs with upholstered seat and backrest. The back sides of seats and backrests are hard.

References: [20;30;31]

Geometrical Data:

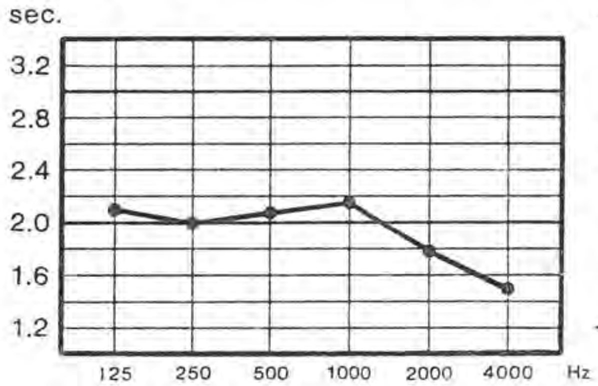
Volume	:	13,500 m^3
Platform area	:	210 m^2
Seating area	:	700 m^2
Number of seats: (in concert mode)		1398 (483 on main floor, 435 on rear balconies, 78 on elevated choir balconies behind the platform, 402 in side wall boxes) A telescopic choir bleacher with 90 extra seats can be pulled out from below the balcony behind the platform.

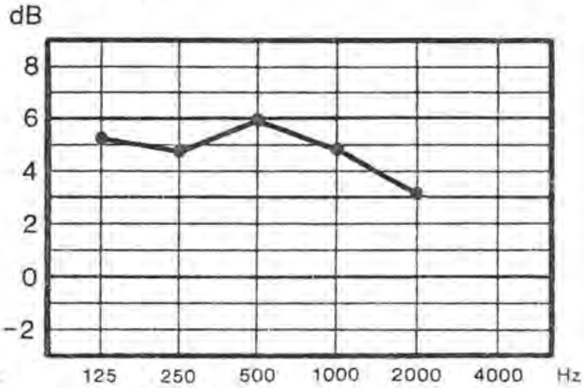
Acoustical data:

RT_m	:	2.1 sec.
RT_m occup.	:	1.8 sec. (estimated by the author; no measured data exist.)

Audience area:

EDT	:	2.25 sec.	L	:	4.7 dB
t_s	:	147 msec.	LEF	:	0.24
C	:	-1.7 dB			
BR(RT)	:	0.97	BR(L)	:	-0.4 dB
RT(f)	:		L(f)	:	

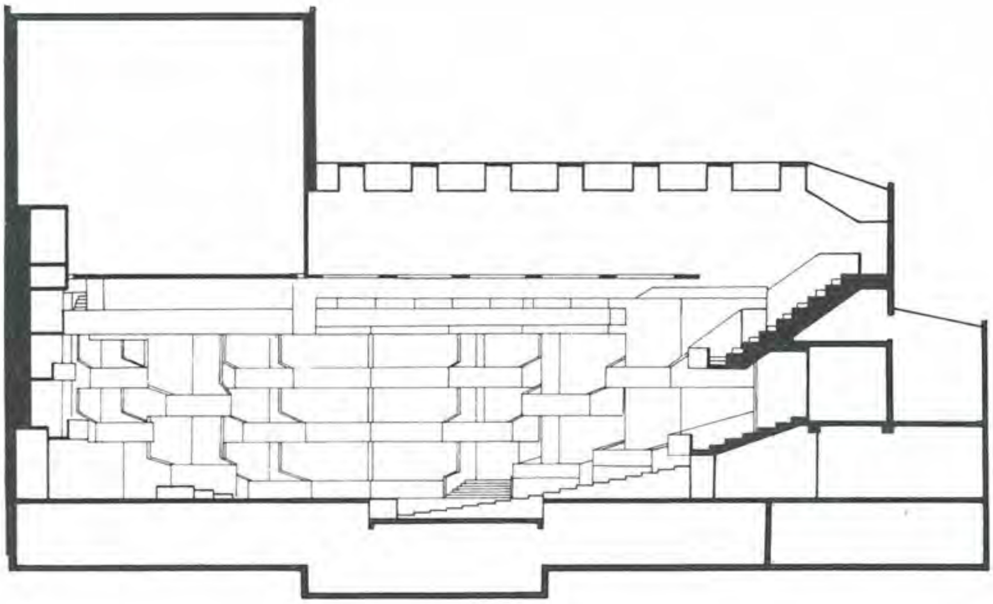


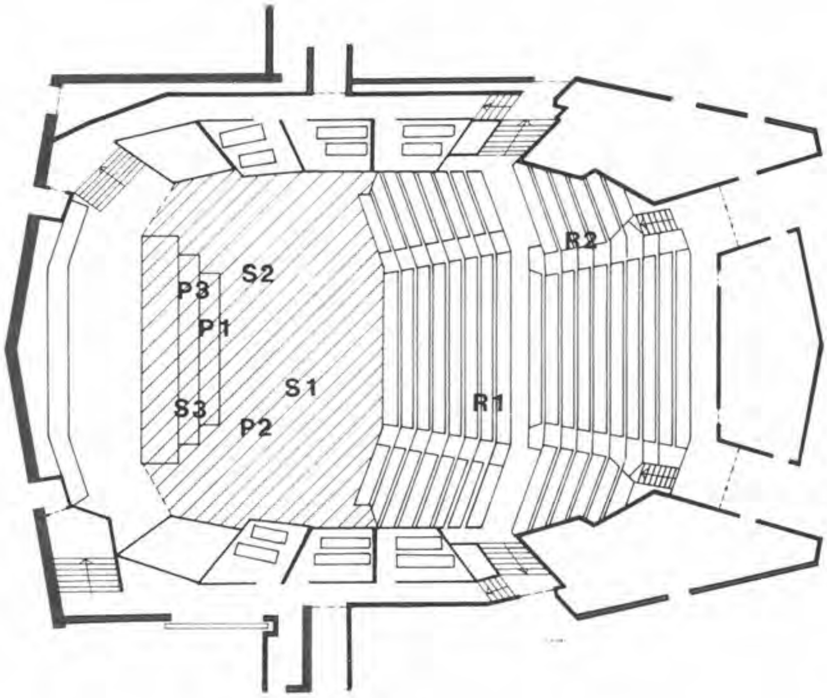


Platform area:

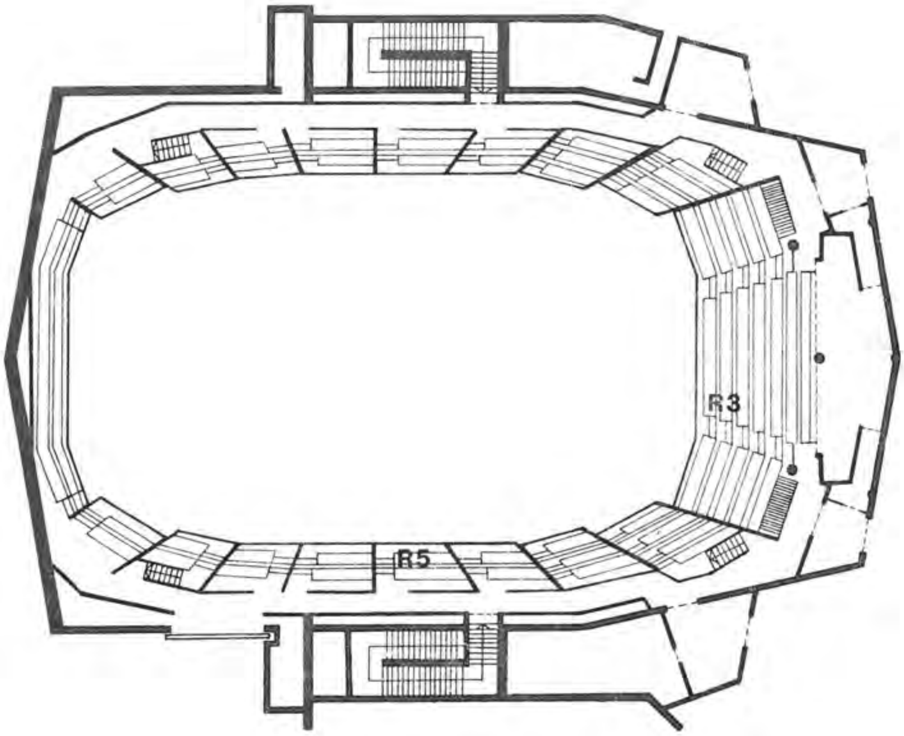
EDTP	:	1.6 sec.	ST1	:	-14.6 dB
CS	:	12.6 dB	ST2	:	-12.3 dB

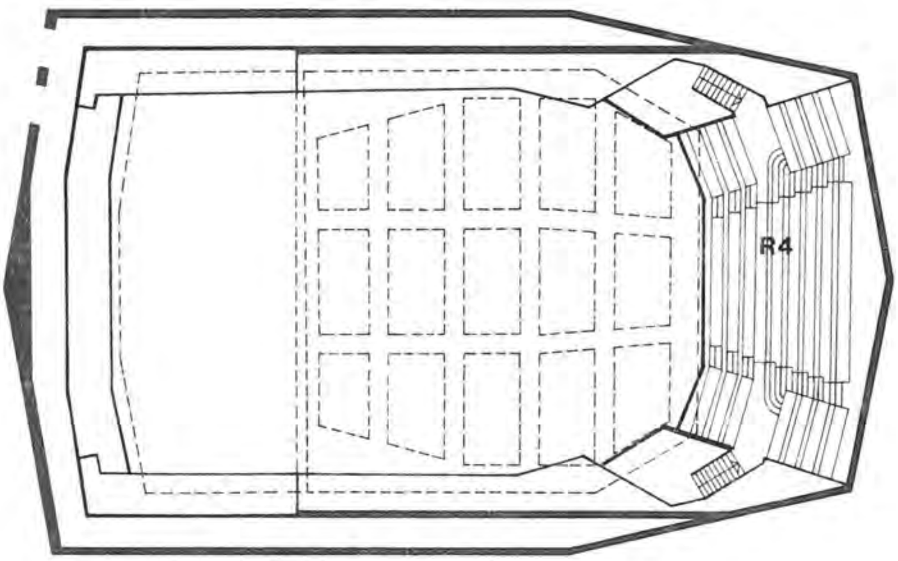
Remarks on measurement conditions:
The choir seats on the platform and the side wall curtains were removed. The measurements were carried out on 30. November 1986.




S2
P3
P1
S1
S3
P2
R1
R2

10
5
0
10
20
30 m


R3
R5


R4

2.8. Gasteig Philharmonie, München (**GM**)

Inaugurated 1985. Architects: Raue, Rollenhagen, Lindemann & Grossmann BDA.
Acoustic consultant: Müller BBM.

Percentage of use for :
Symphonic concerts : 85% (about 180 per year)
Pop, jazz, Rock concerts : 5 %
Drama and Opera concerts : 5 %
Miscellaneous : 5 %

Surface materials:
Ceiling: suspended convex and concave elements of 60 mm wood. Walls: 38 mm veneered wood fibre board in front of concrete. Large convex, wooden reflectors on major side wall areas. Floor: parquet on concrete. Platform floor of 44 mm wood over airspace with a very flexible hydraulic riser system supplemented with loose wooden riser elements. Chairs: Fixed, wooden folding chairs with 8 cm upholstery on seat and backrest. The seats are perforated underneath. The rear side of the backrests are of plywood, the hight of which is extended about ten cm in the rearmost reating areas.

References: [32;33;34]

Geometrical Data:

Volume : 30,000 m^3

Platform area : 300 m^2, (including 50 m^2 mainly for choir)

Seating area : 1500 m^2

Number of seats: 2387

Acoustical data:

RT_m : 2.0 sec.

RT_m occup. : 2.1 sec. [34]

Audience area:

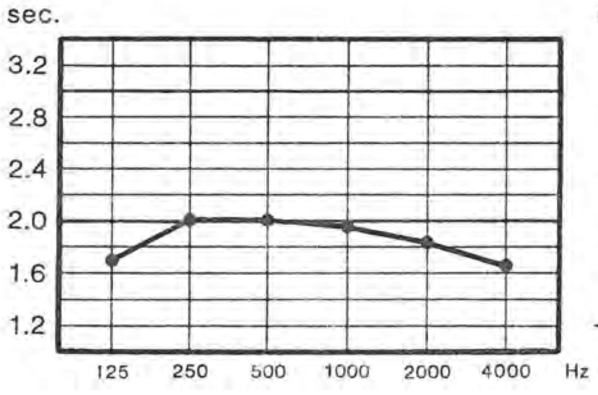
EDT : 1.91 sec. L : 3.6 dB

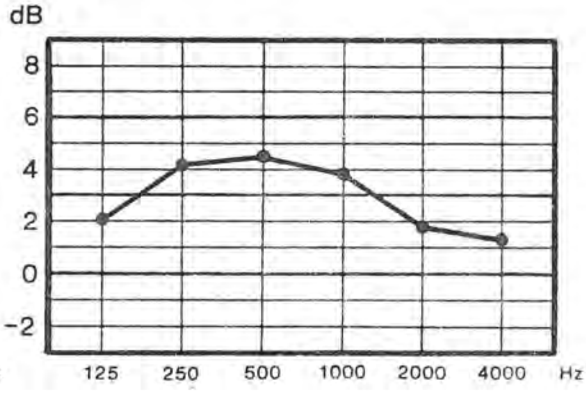
t_s : 139 msec. LEF : 0.20

C : -1.0 dB

BR(RT): 0.93 BR(L): -1.1 dB

RT(f) : L(f) :





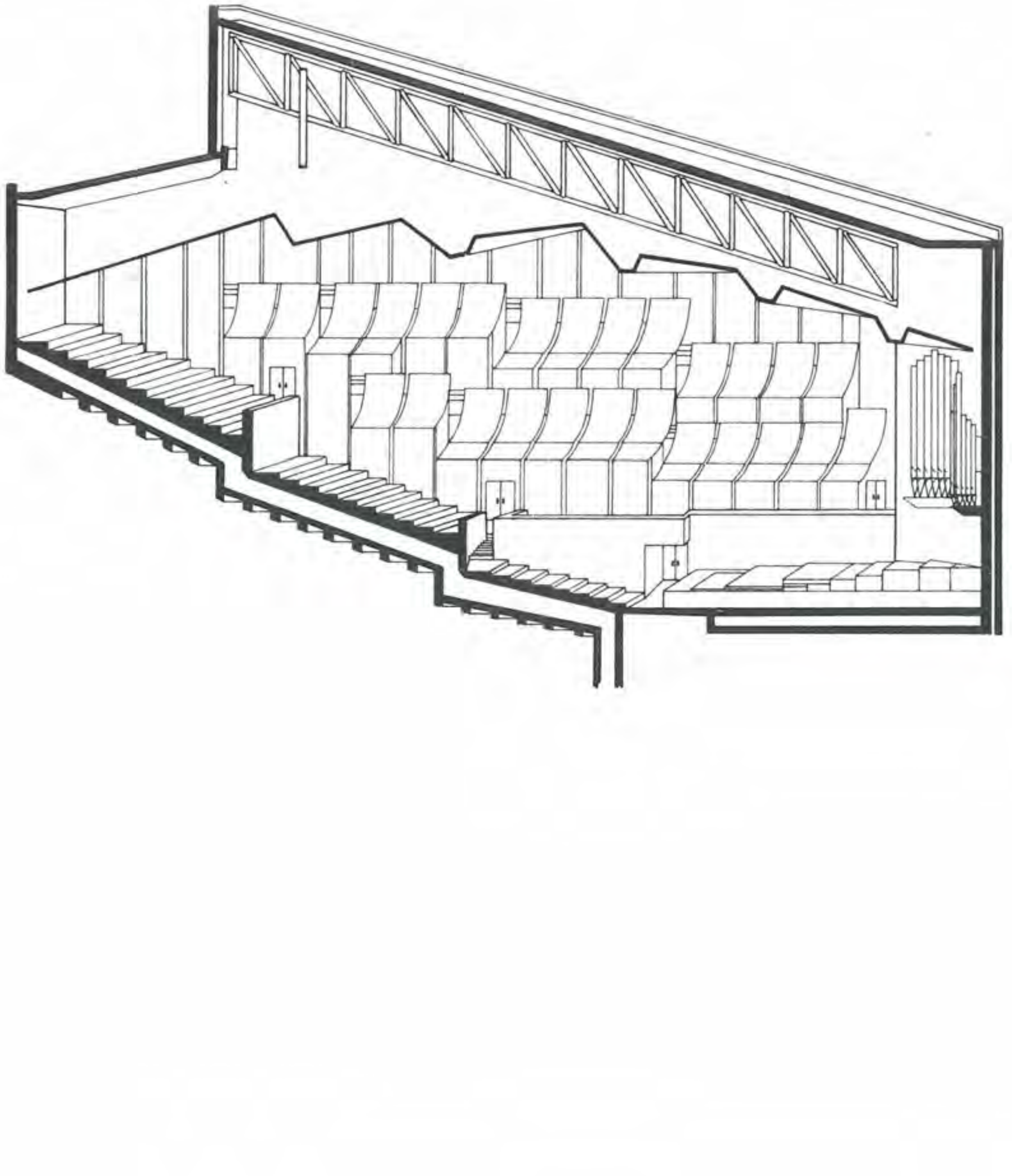
Platform area:

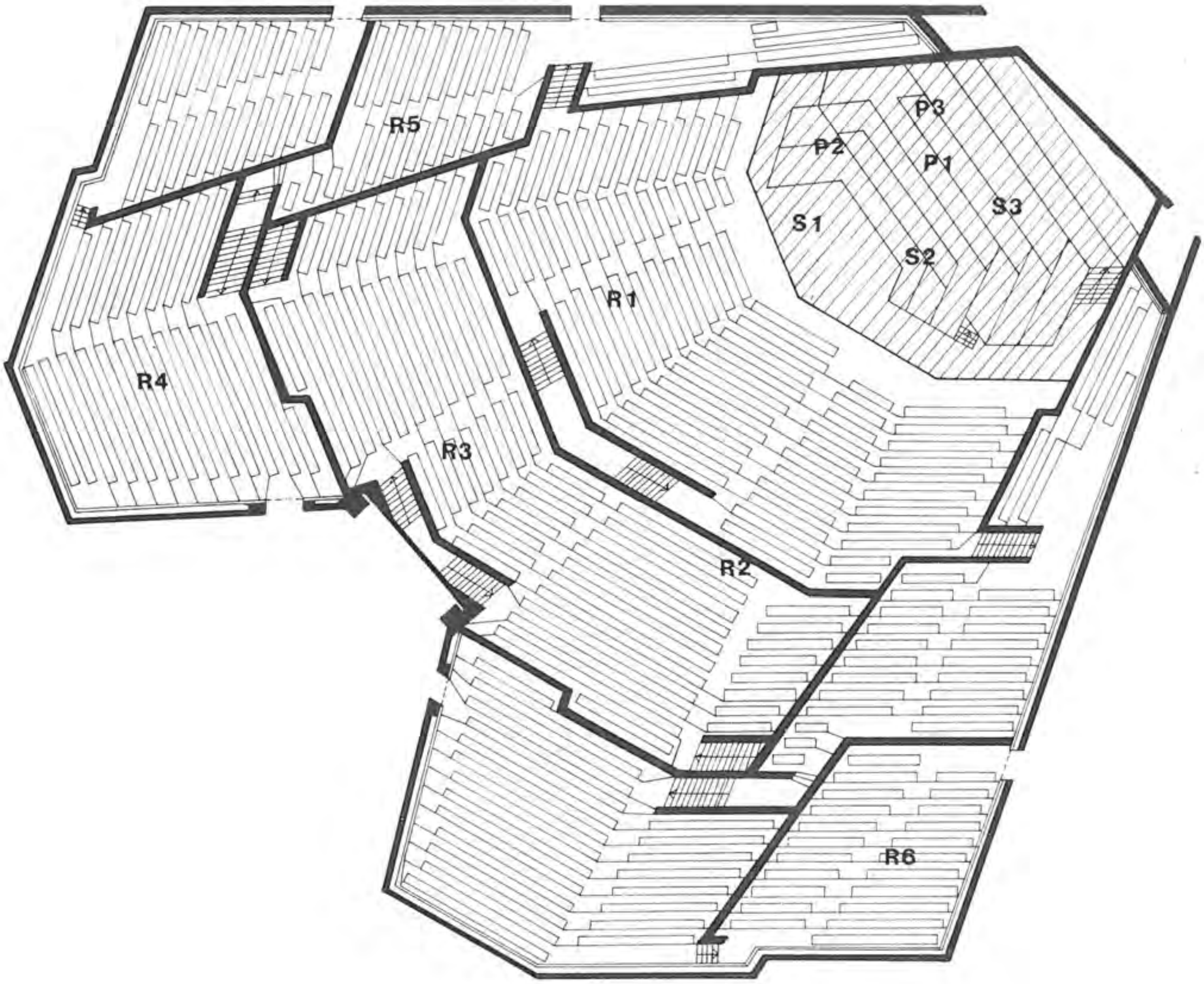
EDTP : 1.5 sec. ST1 : -18.0 dB

CS : 18.0 dB ST2 : -16.8 dB

Remarks on measurement conditions:

The measurements were carried out on 1. October 1987.

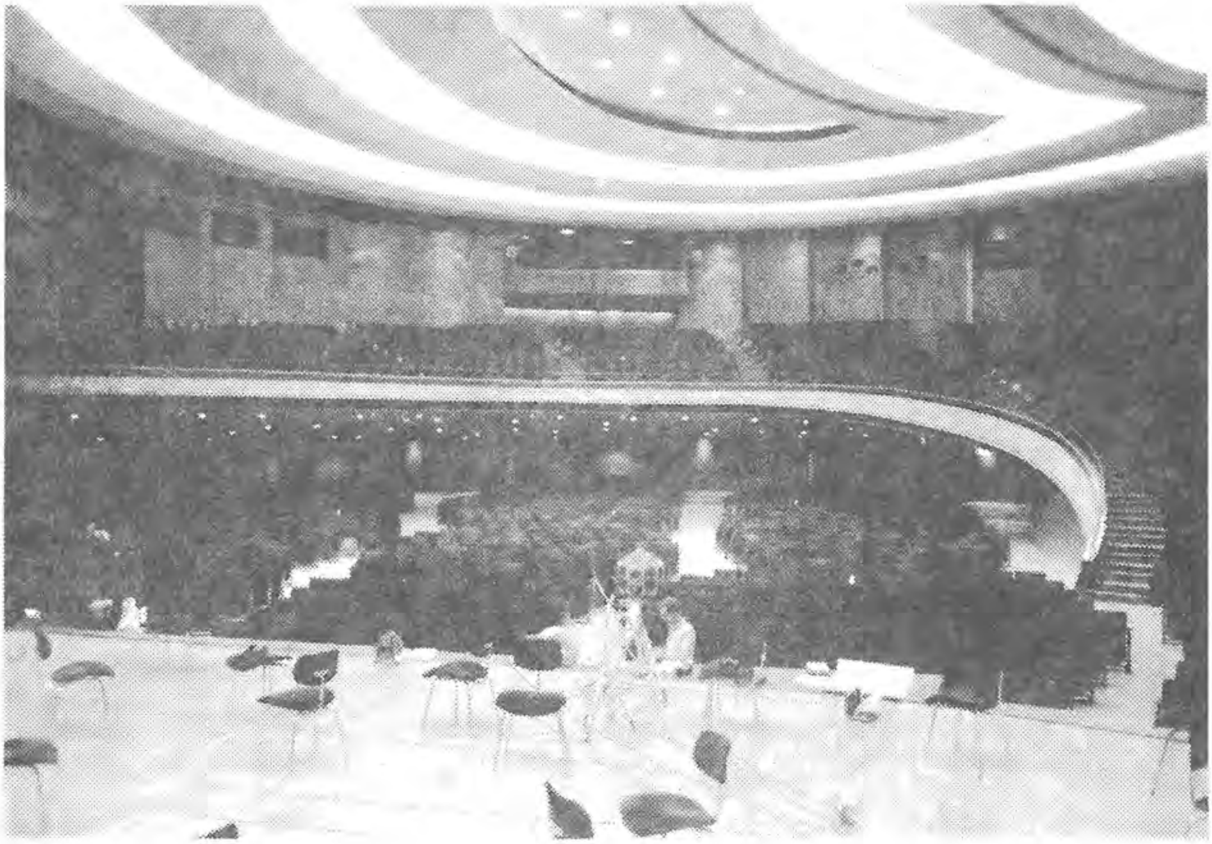

10 5 0 10 20 30m


P3
P2
P1
S1
S3
S2
R5
R1
R4
R3
R2
R6

2.9. Liederhalle, Stuttgart (LS)

Inaugurated 1956. Architects: A. Abel, R. Gutbrod.
Acoustic consultants: L. Cremer, L. Keidel, H.A. Müller.

Percentage of use for :
Symphonic concerts : 60% (about 100 per year)
Recitals and chamber music : 15 %
Pop, jazz, Rock concerts : 15 %
Drama and Opera : 5 %
Misscellaneous : 5 %



Surface materials:
Ceiling: plaster on metal lath in the central part, and plane and slotted fiberboard near the walls (acting as membrane and resonator panel absorbers). The ceiling is made irregular by large strips of suspended plaster board. Walls: One large convex side wall of concrete with low relief surface. Other wall areas are of plywood of varying thickness in front of air spaces of varying depths. Floor: parquet on main floor; linoleum on balcony. Platform floor of wood over airspace with hydraulic riser system. The walls and ceiling in the platform area are of 22 mm plywood. The choir balcony can be closed of by a wooden sliding wall. Diffusing reflectors extend to over the first rows of seats. Chairs: Wooden folding chairs with upholstered seat and backrest. The seats on the main floor are grouped in movable sections, while they are fixed on the balcony.

References: [12;35]

Geometrical Data:

Volume : 15,000 m^3

Platform area : 178 m^2 (plus choir area 70 m^2)

Seating area : 1150 m^2

Number of seats: 1994 (1169 on main floor, 803 on balcony and 22 in side wall boxes)

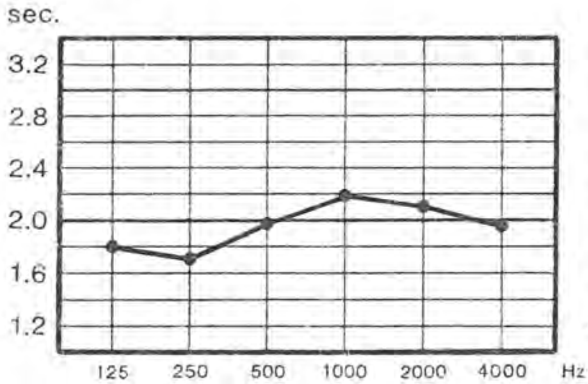
Acoustical data:

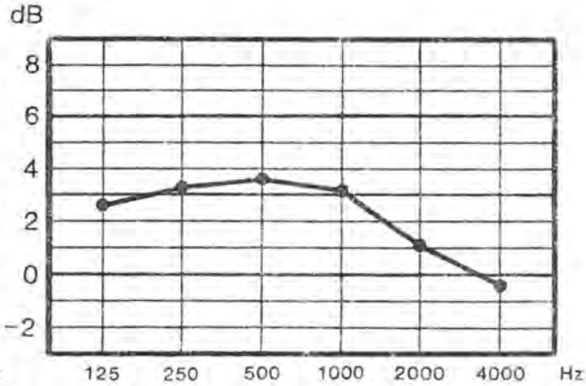
RT_m : 2.1 sec.

RT_m occup. : 1.6 sec. [35](including a choir of 250)

<u>Audience area:</u>

EDT :	2.03 sec.	L :	2.8 dB
t_s :	149 msec.	LEF :	0.15
C :	-1.7 dB		
BR(RT):	0.84	BR(L):	-0.4 dB
RT(f) :		L(f) :	



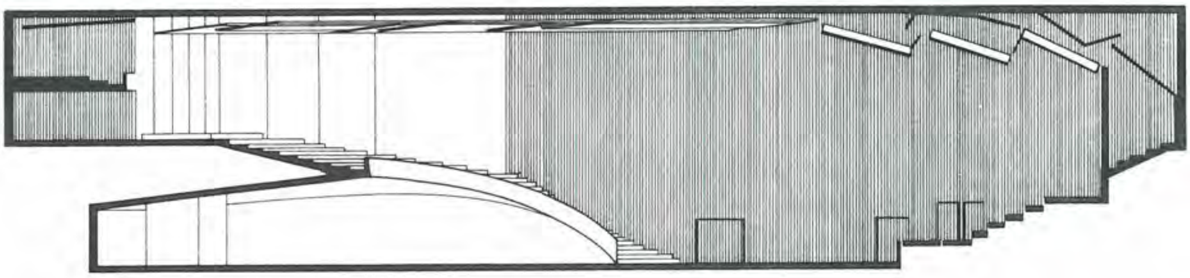


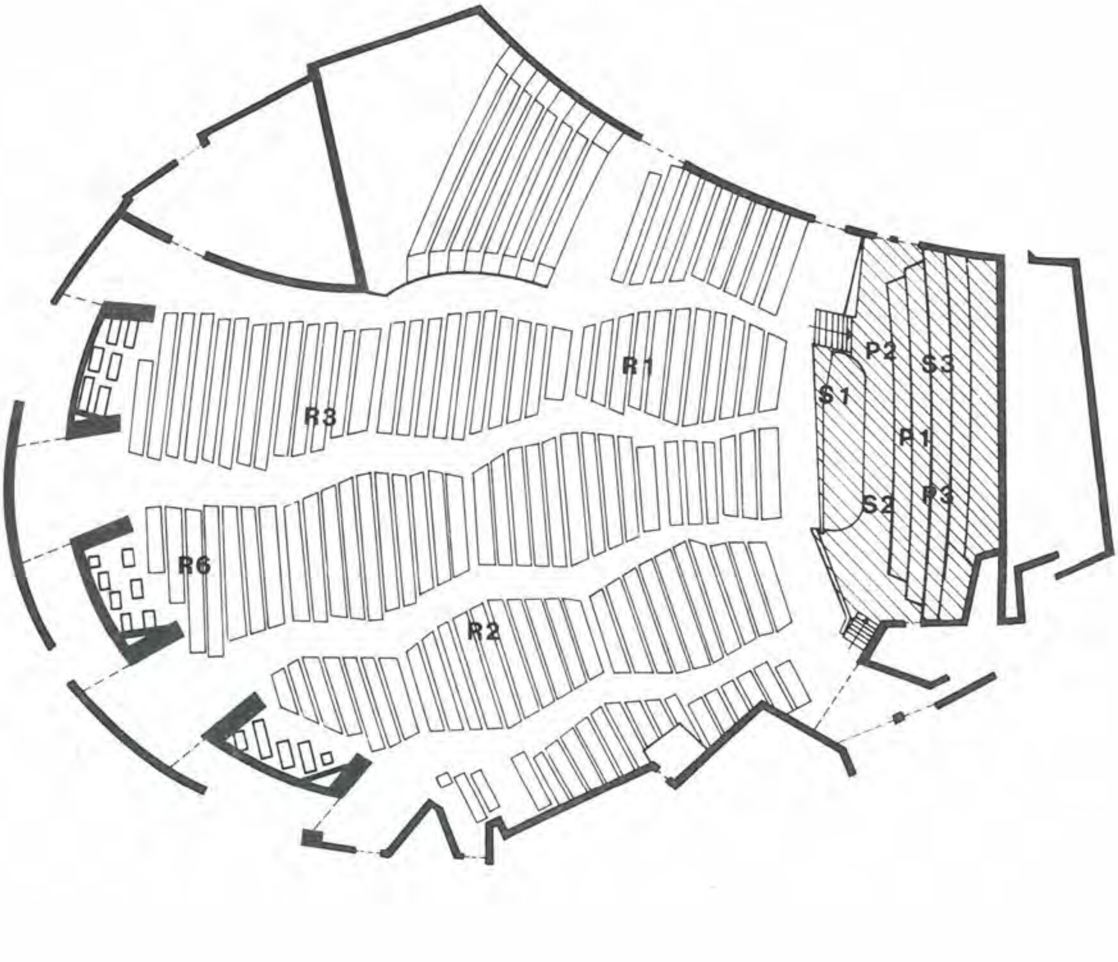
<u>Platform area:</u>

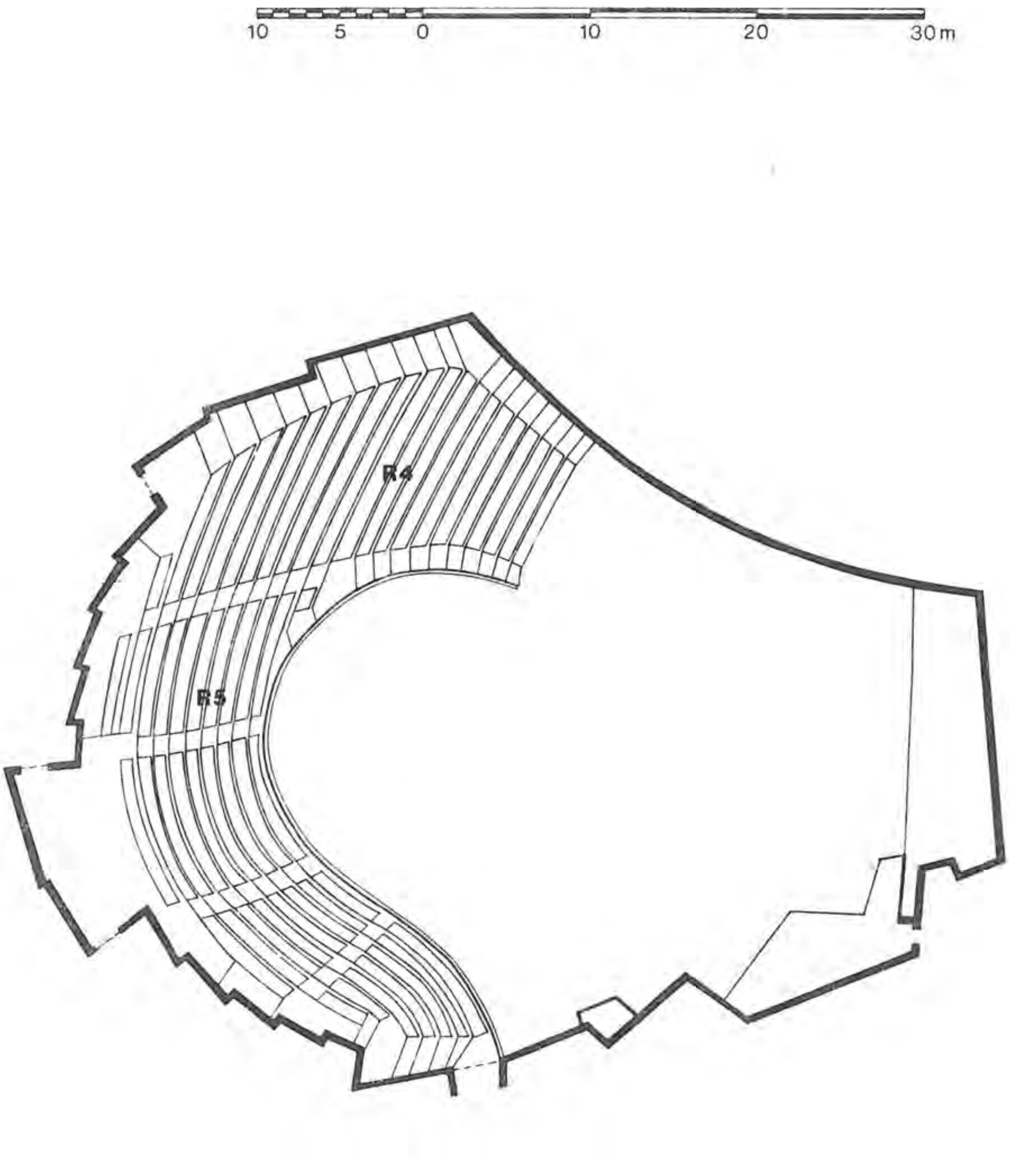
EDTP :	1.3 sec.	ST1 :	-14.5 dB
CS :	14.5 dB	ST2 :	-12.6 dB

Remarks on measurement conditions:

The choir balcony was closed off by a sliding wall. The measurements were carried out on 26. September 1987.



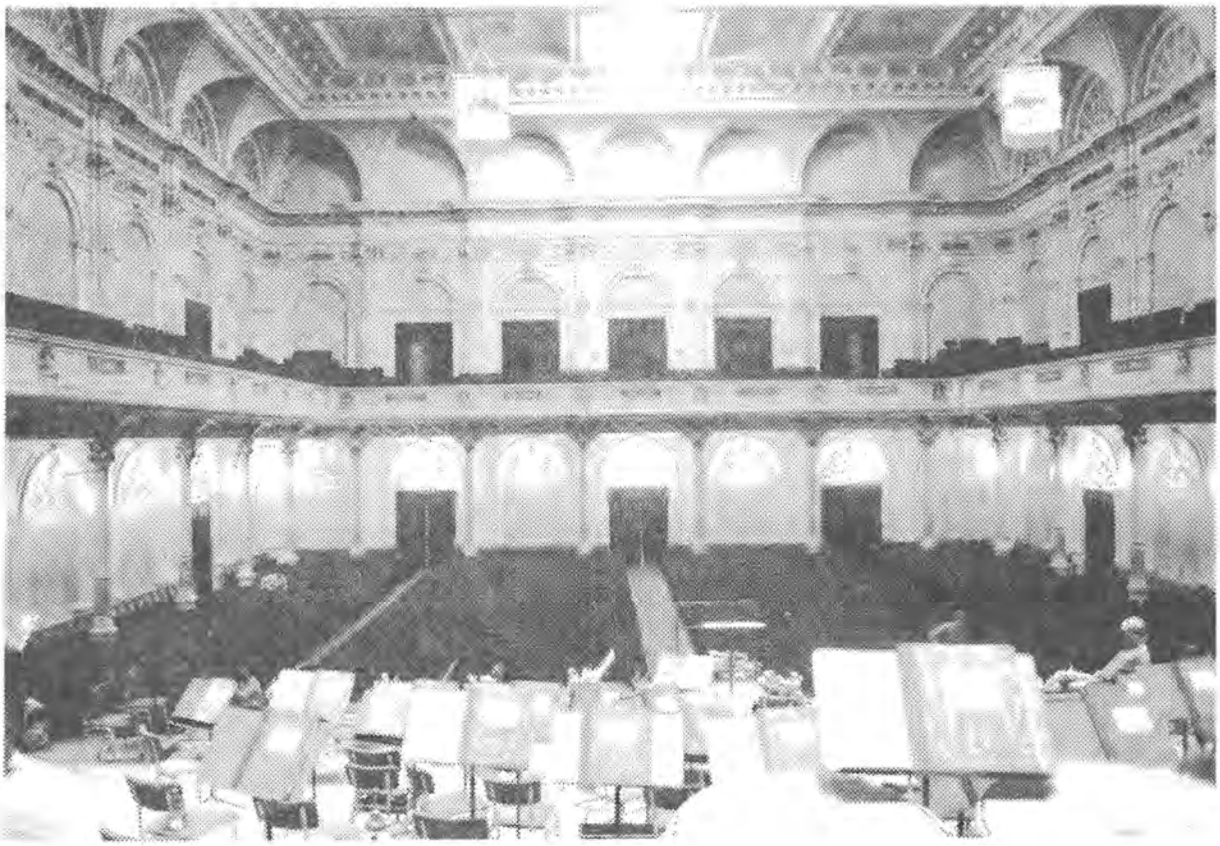

R1
R3
R6
R2
P2
S3
S1
P1
S2
P3


10
5
0
10
20
30 m
R4
R5

2.10. Concertgebouw, Amsterdam (**CG**)

Inaugurated 1888. Architect: Dolf van Gendt.
Major modifications: (the foundation was renovated 1986-88)

Percentage of use for :
Symphonic concerts : 75% (about 215 per year)
Recitals and chamber music : 14 %
Pop, jazz, Rock concerts : 3 %
Misscellaneous : 8 %



Surface materials:
Ceiling: coffered, of 40 mm plaster on reeds. Walls: plaster on bricks at floor level, and plaster on reeds above the balcony. Door areas are covered with velvet draperies. Floor: Wood over 70 mm airspace filled with sand. The balcony floor and the aisles on the main floor are carpeted. Platform floor of wood over airspace with steep, fixed risers. Chairs: Fixed, wooden folding chairs with upholstery on seat and backrest.

References: [12]

Geometrical Data:

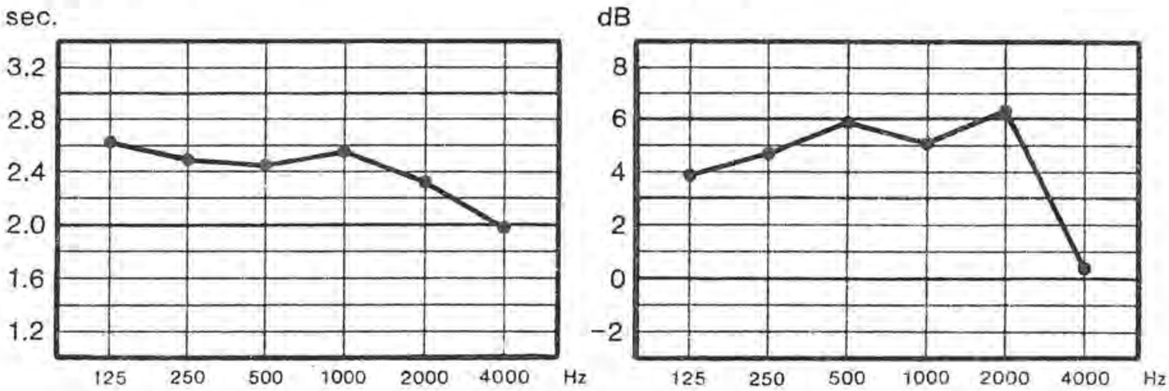
Volume	:	18,700 m^3
Platform area	:	150 m^2
Seating area	:	900 m^2
Number of seats:		2040 (1308 on main floor, 420 on rear and side balconies, 312 behind the orchestra). 147 extra chairs can be placed on the platform.

Acoustical data:

RT_m	:	2.5 sec.
RT_m occup.	:	2.0 sec. [12]

Audience area:

EDT	:	2.64 sec.	L	:	5.5 dB
t_s	:	196 msec.	LEF	:	0.16
C	:	-4.4 dB			
BR(RT):		1.02	BR(L):		-1.2 dB
RT(f) :			L(f) :		

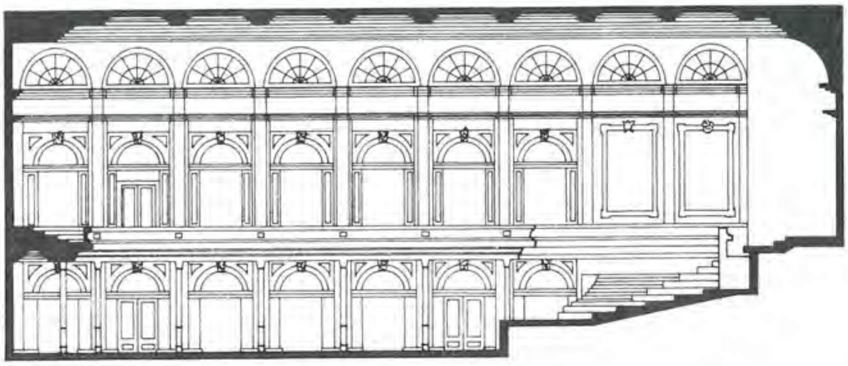


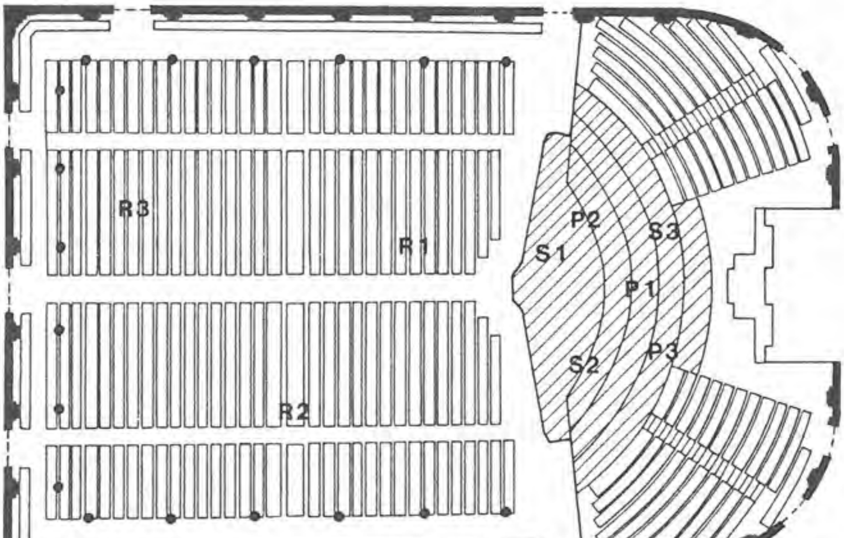
Platform area:

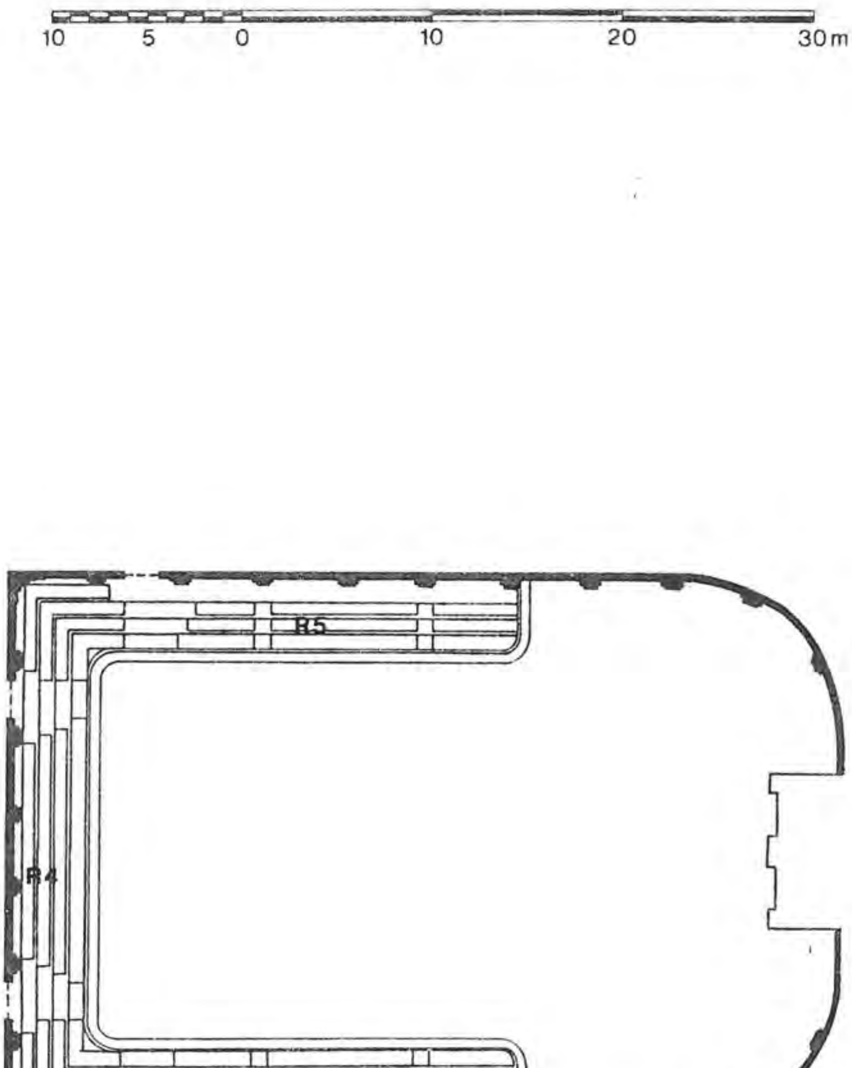
EDTP	:	2.0 sec.	ST1	:	-18.3 dB
CS	:	14.4 dB	ST2	:	-15.3 dB

Remarks on measurement conditions:

The measurements were carried out on 24. September 1987.



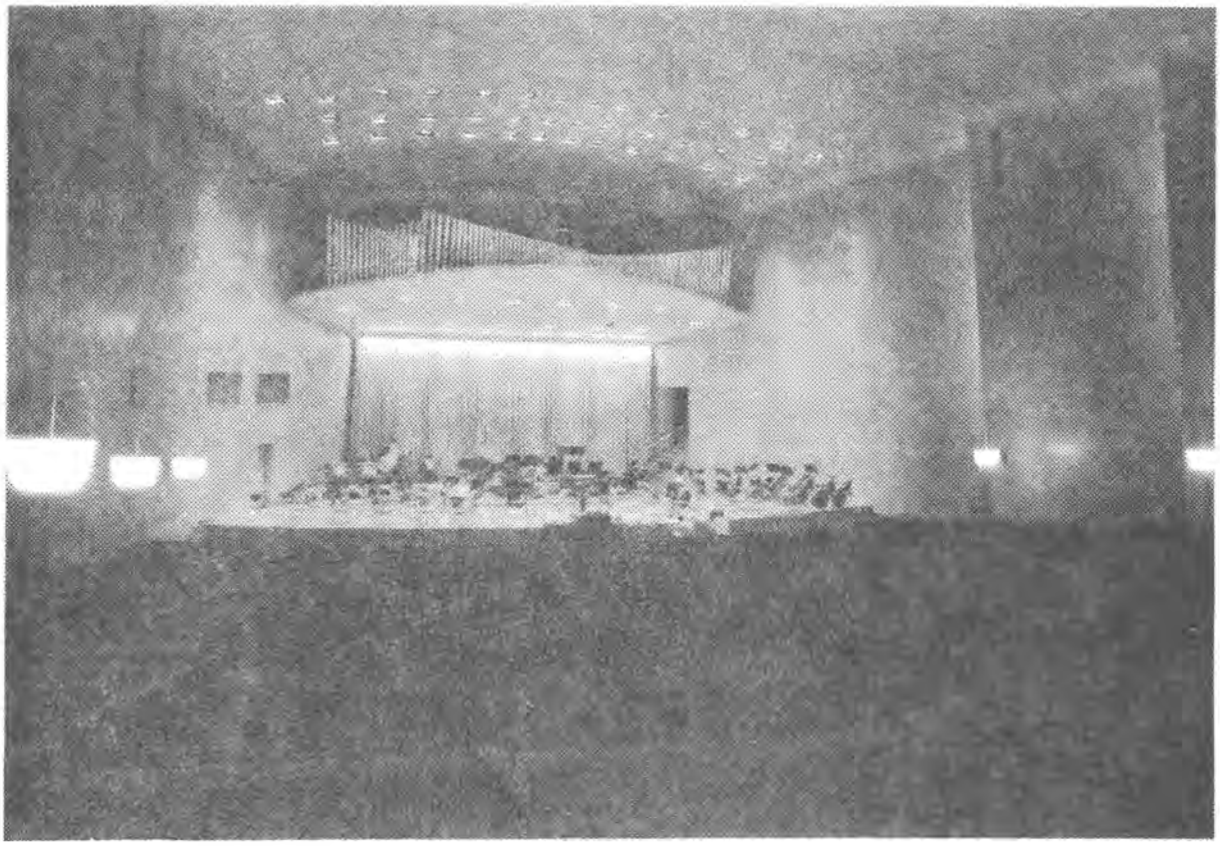

R3
R1
R2
S1
P2
S3
P1
S2
P3


10 5 0 10 20 30m
R5
R4

2.11. Göteborgs Koncerthus (GK)

Inaugurated 1935. Architect: Niels Einar Eriksson.
Acoustic consultant: H. Kreüger.
Major modifications: 1984-85. The platform and the ceiling reflector were extended, and the first two seat rows removed.
Acoustic consultant: Akustikon AB

Percentage of use for :
Symphonic concerts : 80 % (about 70 per year)
Recitals and chamber music : 5 %
Pop, jazz, Rock concerts : 10 %
Misscellaneous : 5 %



Surface materials:
Ceiling and walls: 20 mm lacquered wood panels rigedly fastened to the concrete structure behind. The backwall is slanted downwards. Some sound absorbing material is placed in the niches in the saw tooth shaped side walls. The wall behind the platform is covered by a drapery. Floor: linoleum on concrete. Platform floor of wood over airspace with movable riser elements of wood. A large slightly convex reflector of 20 mm plywood is suspended over the platform. Chairs: Fixed, wooden fully upholstered folding chairs.

References: [12;36]

Geometrical Data:

Volume : 11,900 m^3

Platform area : 180 m^2

Seating area : 650 m^2

Number of seats: 1286 (876 on main floor, 272 on elevated rear section, 138 in side loges.)

Acoustical data:

RT_m : 1.7 sec.

RT_m occup. : 1.7 sec. [12]

Audience area:

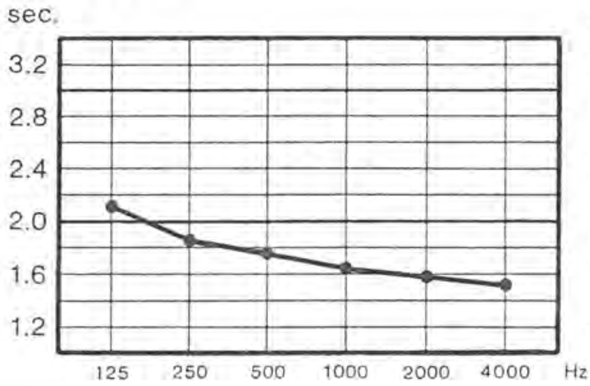
EDT : 1.70 sec. L : 4.7 dB

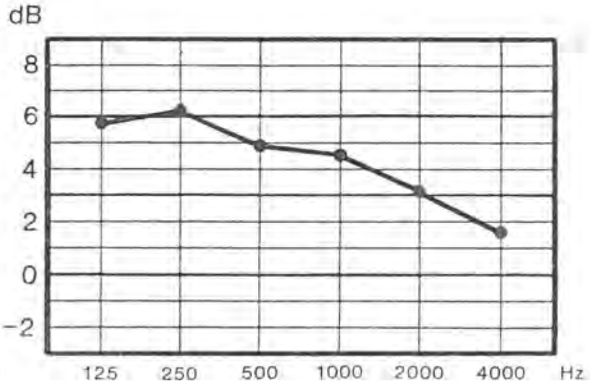
t_s : 127 msec. LEF : 0.09

C : 0.0 dB

BR(RT): 1.17 BR(L): 1.3 dB

RT(f) : L(f) :





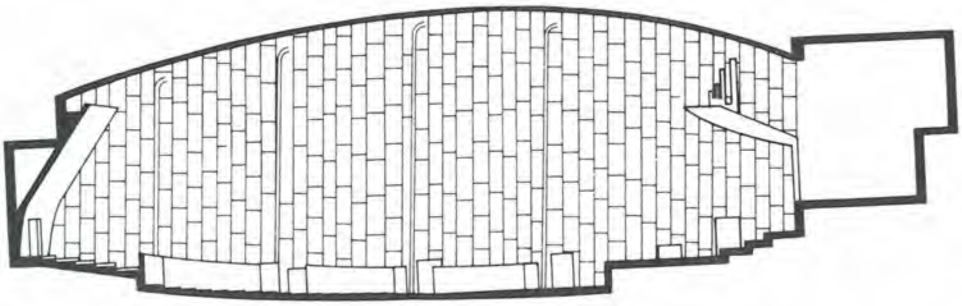
Platform area:

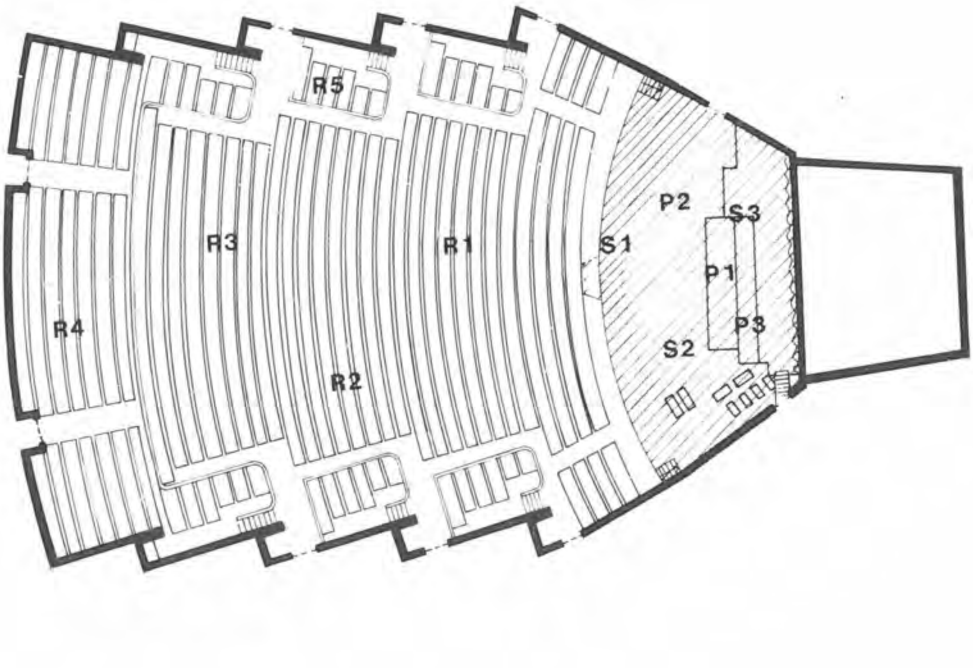
EDTP : 1.6 sec. ST1 : -14.3 dB

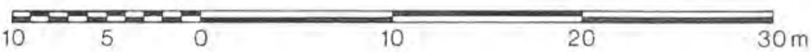
CS : 16.0 dB ST2 : -13.5 dB

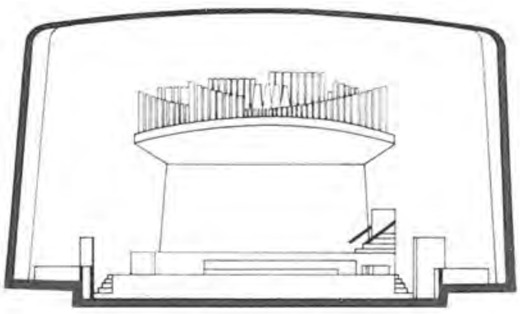
Remarks on measurement conditions:

The measurements were carried out on 2. September 1988.




R5
P2
S3
R3
R1
S1
P1
R4
P3
S2
R2


10 5 0 10 20 30m



III. GENERAL RELATIONS BETWEEN ACOUSTICS AND DESIGN.

3.1. Introduction

This chapter deals with the results of analyzing the combined set of data from this and the previous Danish Survey [1] by statistical methods. The aims of the analyses have been to unveil some of the mutual connections among the room acoustic parameters and their dependencies on architectural design variables. The Danish survey covered 21 halls, i.e. the conclusions are based on measurements in 32 halls in total.

In this and in the following chaper, only frequency and position averaged values will be discussed, since the design aspects dealt with are related to the overall features of the halls.

A weak point in any attempt to establish relationships between the acoustic data and architectural variables by means of statistical methods is the difficulties in describing the design properties by means of numeric data. For instance, the shape of a room can only be described by forming ratios between the main dimensions and supplementing this information with volume and angles between walls, and in many odd shaped halls even the main dimensions can only be determined as rough estimates. Besides, the acoustic conditions may depend on a very complicated interplay of different architectural variables. Therefore one should only expect the most dominant relationships to be revealed by the analyses below. The geometric data used in the analyses were derived from the drawings in Chapter 2 and appear in Appendix C.

In this and the following chapter, all the Danish halls are represented by data points in the figures; but for reasons of clarity only the 9 most important (with respect to number of symphonic concerts per year or size) will have a label attached to their data points. In order to distinguish the Danish from the foreign halls, the two letter code labels identifying Danish halls are written in small letters while capital letters have been used for the foreign halls. The nine Danish halls which can be immediately identified in the plots are:

Danish Radio Concert hall, Copenhagen	(**dr**)
Falkoner Centret, Copenhagen, large hall	(**fc**)
Odd Fellow Palæet, Copenhagen, large hall	(**of**)
Sct. Annæ hall, Copenhagen	(**sa**)
Tivoli Concert hall, Copenhagen	(**ti**)
Odense Koncerthus, Carl Nielsen Hall	(**ok**)
Musikhuset, Sønderborg	(**ms**)
Ålborg Hallen, Ålborg	(**oh**)
Århus Musikhus, Århus	(**mo**)

The data points representing the other 12 Danish halls can be identified by comparing the figures in this chapter with the data values for all the Danish halls listed in Appendix C.*

3.2. The objective parameters' mutual connections

Before discussing connections between the many parameters and the design, it is helpful to investigate how the objective parameters themselves are interrelated, since a high mutual correlation between two parameters means, that to a large extent they will be related to the design in the same way.

3.2.1. The 'raw' parameters

An overview of the mutual correlations between the various objective parameters is easily obtained by factor analysis. In Figure 3.1 are shown the so called factor weights of each objective parameter along the first two factors in a three dimensional, rotated factor space, which explains 90 % of the total variance in the data. Each objective parameter appears as a point in the picture, with coordinates equal to the correlation coefficients between that parameter and factor 1 and factor 2

---

* NB: Due to a change in the calibration procedure between the two surveys, a +0.4 dB correction was added to the Danish L data from [1] before the comparisons made in this report; see also Appendix A.

respectively. (The factors themselves have been generated as mutually independent dimensions, which each account for as large an amount of the total variance as possible.) Thus, all parameters with a high numeric value of the coordinate along one axis (i.e. high weight in one dimension) are highly mutually correlated but not related to those parameters which have only a

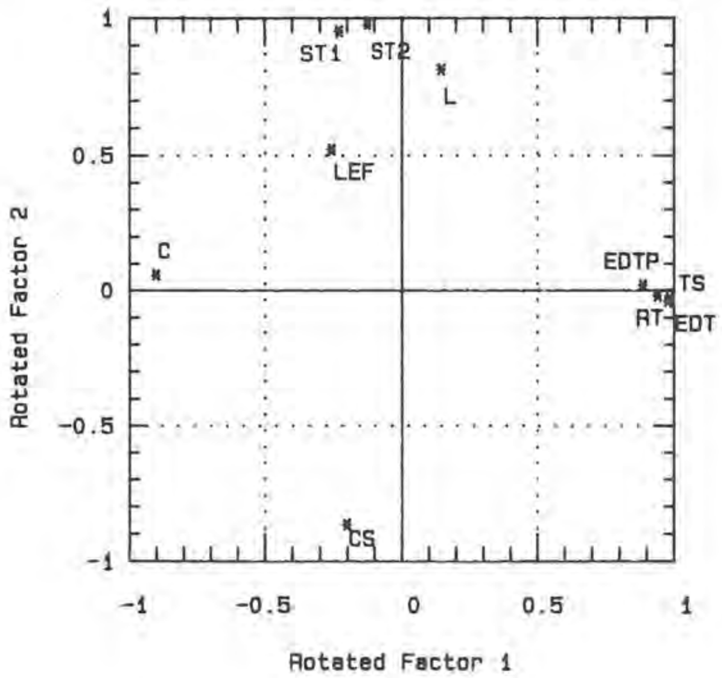


Fig. 3.1: The placing of the objective parameters in the first two dimensions of a three dimensional factor space.

high weight on another dimension. It is clearly seen, that the reverberance/-clarity measures RT, EDT, EDTP (= EDT measured on the orchestra platform), TS and C are all highly mutually correlated and comprise the first dimension, whereas the level measure L, plus all platform parameters apart from EDTP, are also highly interrelated and form the second dimension. The only parameter which does not come out with a high correlation along any of the first two dimensions is seen to be LEF. This is because LEF was the main contributor to the third dimension (on which its weight was 0.82). Therefore, when frequency and position averaged, the ten parameters only describe roughly three different factors of the acoustics in concert halls. In other words, the number of parameters could be reduced to three - had it not been for our general interest in more detailed information such as differences between positions including the conditions on the platform.

Concerning the audience parameters, it is interesting to see, that the three factors also correspond to three subjectively different aspects: reverberance/clarity, level and spaciousness. Thus, it is necessary to use (at least) one objective parameter per subjective aspect to be investigated.

3.2.2. The diffuse field deviations.

As described in section 1.3, most of the objective parameters have an expected value according to classical diffuse field theory. By forming the difference between the measured value and the expected value, called $\langle PAR\rangle_{dif}$:

$$\langle PAR\rangle_{dif} = \langle PAR\rangle - \langle PAR\rangle_{exp}, \qquad (22)$$

one gets an expression for that part of the parameter variance, which is not accounted for by its relationship with reverberation time, but which must be related to other design factors, i.e. the hall geometry and the distribution of absorption materials.

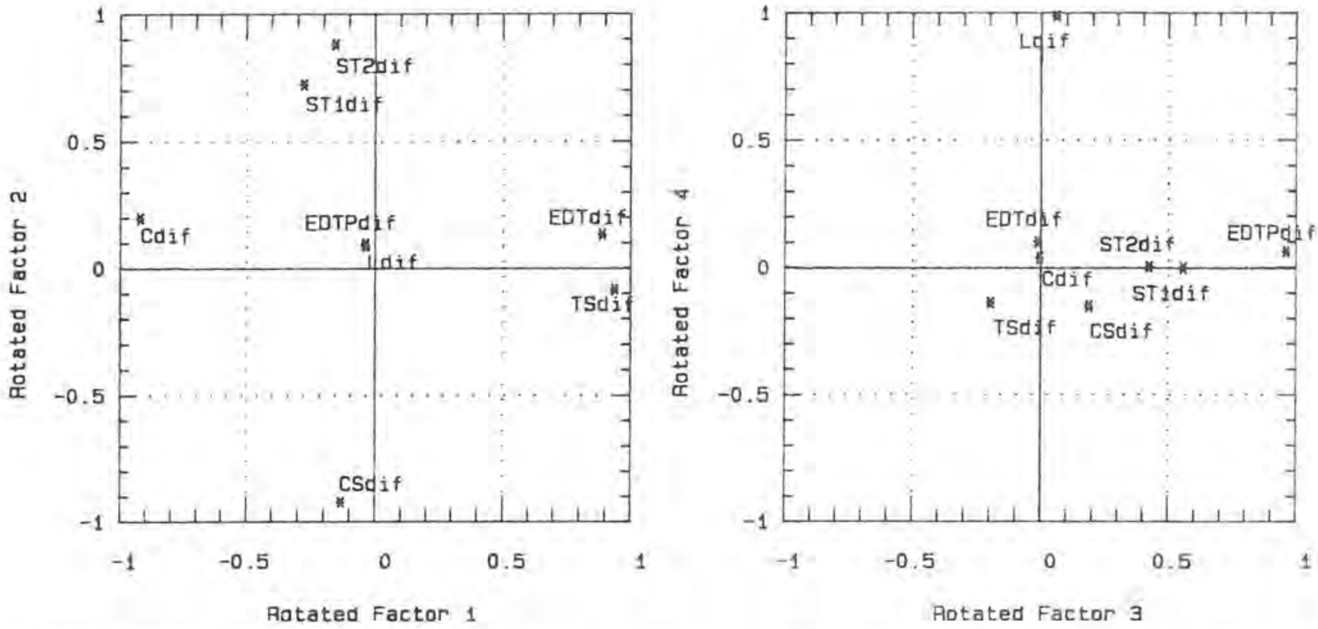


Fig. 3.2: The placing of the parameter residuals (deviations from their predictions according to diffuse field theory) in a four dimensional factor space.

Subjecting these parameter residuals to factor analysis resulted in the factor spaces shown in Figure 3.2. In this case four dimensions are nessecary in order to account for at least 90 % of the variance. It is seen that factors one and two are formed by reverberance/clarity parameters in the audience area and level measures in the platform area respectively, while EDTP measured on the platform dominates factor three and L comprises factor four. This must imply that - apart from the common influence of reverberation time - these four groups of parameters are to a large extent influenced independently by different (geometrical) design factors. In particular, it should be possible to change the platform conditions without changing the audience conditions or vice versa.

3.3. Relations with predicted values

The correlations between the measured values of the objective parameters and the expected values calculated according to the formulae in section 1.3 indicate to what degree these parameters are determined by RT and volume (or total absorption area). The correlation coefficients are illustrated in Figure 3.3. With all

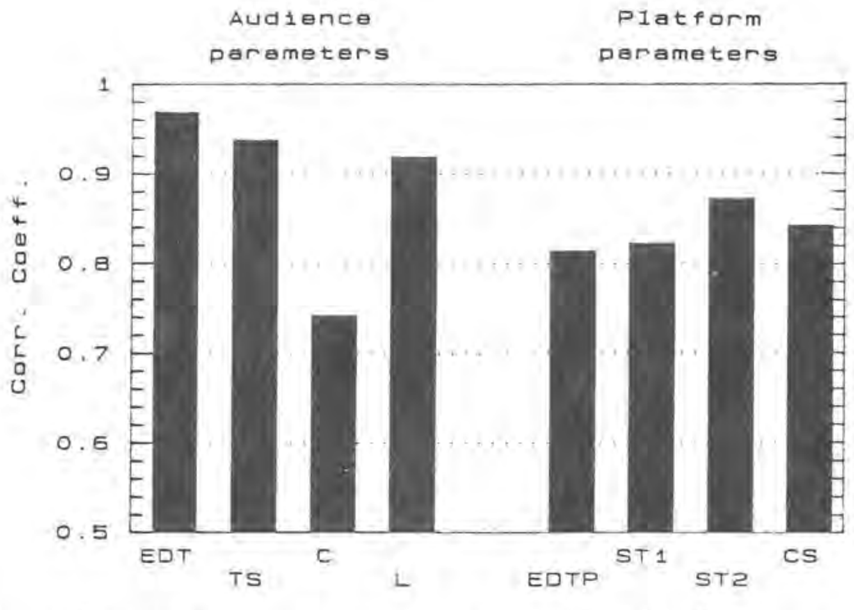


Fig. 3.3: Numeric values of correlation coefficients between room acoustic parameters and their diffuse field predictions. Audience measures are placed to the left and platform measures to the right.

coefficients being higher than 0.7, all eight parameters of relevance are significantly related to their respective RT predictions. The reason for the lower value of the correlation in the case of C compared to EDT and TS is not surprising, since C is more strongly influenced by the early reflection energy than are the two other parameters, and the behaviour of the early reflections is less likely to obey the assumption of randomness than is the later reverberation energy. This is probably also the reason why the correlation is lower for ST1 than for ST2.

3.4. Revised predictions for audience parameters

A high correlation between a parameter $\langle PAR \rangle$ and its $\langle PAR \rangle_{exp}$ based on diffuse field theory does not always imply, that $\langle PAR \rangle_{exp}$ itself is the best predictor of that parameter, only that a linear relationship exsists. However, by means of regression analysis, an empirical equation describing this (linear) relationship can be derived, and this equation can then be used as an improved prediction formula for the behaviour of the parameter in concert halls. Since the expected value is based on RT, which by definition is a property of the room as a whole, the revised predictions should also only be used to describe the expected value corresponding to the value of the parameter obtained after averaging over several positions throughout the hall. In cases where the correlation with $\langle PAR \rangle_{exp}$ is low or without meaning (as in the case of LEF), it is also possible to look for the influence of geometrical variables.

3.4.1. Reverberance/clarity parameters

Among the reverberance/clarity parameters, the highest correlation is found for EDT, whose expected value is simply RT. The linear regression fit was found to be:

$$EDT = -0.2 + 1.1*RT, \qquad (3.1)$$

i.e. almost EDT = RT. The high correlation means, that there is no room for significant influence of other factors determining the variation in EDT. (Actually, the model in equation (3.1) accounts for 94 % of the total variance in the measured data.) For TS, the situation is the same with the regression model:

$$TS = 8 + 0.95*TS_{exp} \; ; \; TS_{exp} = RT/0.0138 \text{ [ms.]} \quad (3.2)$$

accounting for 88 % of the variance.

Concerning C, the regression line is given by:

$$C = -0.4 + 0.9*C_{exp} \; ; \; C_{exp} = 10*\log(\exp(1.104/RT)-1) \quad (3.3)$$

This means, that for $C_{exp} > -4$ dB, C is on average slightly lower than expected by C_{exp} alone. However, in the case of C, the correlation between measured and expected values is fairly low: r = 0.74 (see Figure 3.3 above), and the regression model corresponding to formula (3.3) also explains only 55 % of the variance. Consequently, also other factors than RT have a considerable influence on C. A few of these emerged from the correlations between C_{dif} and the geometrical variables. C_{dif} (= $C - C_{exp}$) was found to be significantly correlated with hall

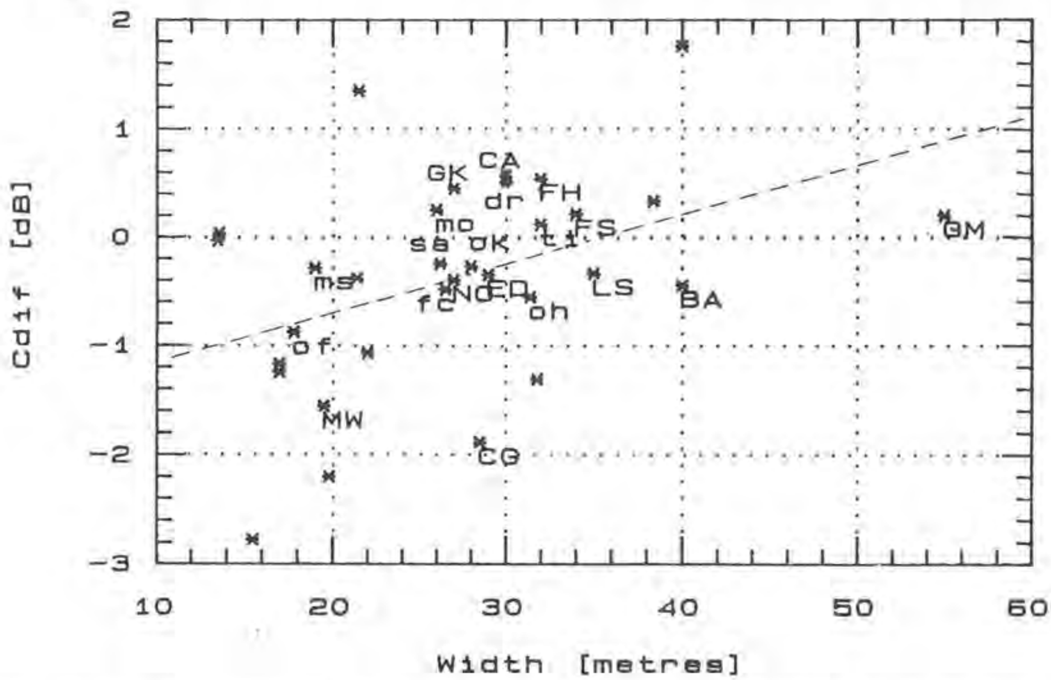


Fig. 3.4: Corresponding values of the difference between measured and expected clarity: C_{dif} and hall width in 32 concert halls. The regression line is drawn dashed.

width as well as the angle between the side walls. In both cases, however, the correlation coefficients were modest and positive (r = 0.42 and 0.40 respectively), which means that in wide or fan shaped halls, there is a certain tendency of C being higher than in narrow or rectangular halls. The relationship between C_{dif} and hall width is illustrated in Figure 3.4. The large scatter means, that the relationship is rather weak, and with the width accounting for only 18 % of this residual variance, it is hardly justified to incorporate this variable into the regression model (3.3).

3.4.2. The level parameter

Concerning L, the correlation with L_{exp} was high: r = 0.92, with the regression fit :

$$L = -1.3 + 0.9*L_{exp} \; ; \; L_{exp} = 10*\log(RT/V) + 45 \quad [dB] \quad (3.4)$$

explaining 84 % of the total variance. This means that in the range covered by our data, the measured values will normally be

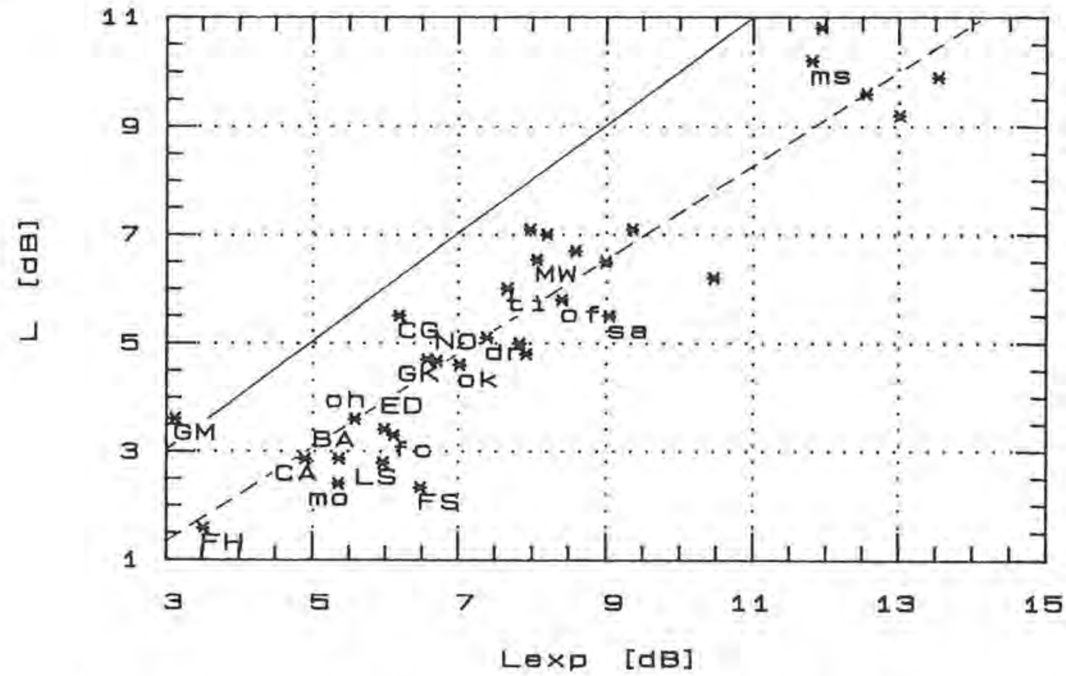


Fig. 3.5: Corresponding values of L and Lexp for 32 halls. A solid line is drawn corresponding to $L = L_{exp}$, and the regressionn line given by equation (3.4) has been drawn dashed.

between 2 and 3 dB lower than expected from diffuse field theory alone. The spread of the data points around the regression line in Figure 3.5 is limited, indicating that L can be predicted with a rather high degree of accuracy from (3.4) without further consideration of geometric properties of the hall.

3.4.3. Lateral Energy Fraction

LEF does not have a meaningful connection to diffuse field theory but shows a highly significant relationship with hall width. Based on the data from all 32 halls the correlation is: r = - 0.66 (explaining 42 % of the variance). However, if the analysis is restricted to 16 rectangular halls, r increases to -0.82, and the regression model becomes:

$$\text{LEF} = 0.47 - 0.0085 * \text{Width}, \qquad (3.5)$$

which accounts for 63 % of the LEF variance among these 16 halls. This line is shown in Figure 3.6 along with the data points for all 32 halls.

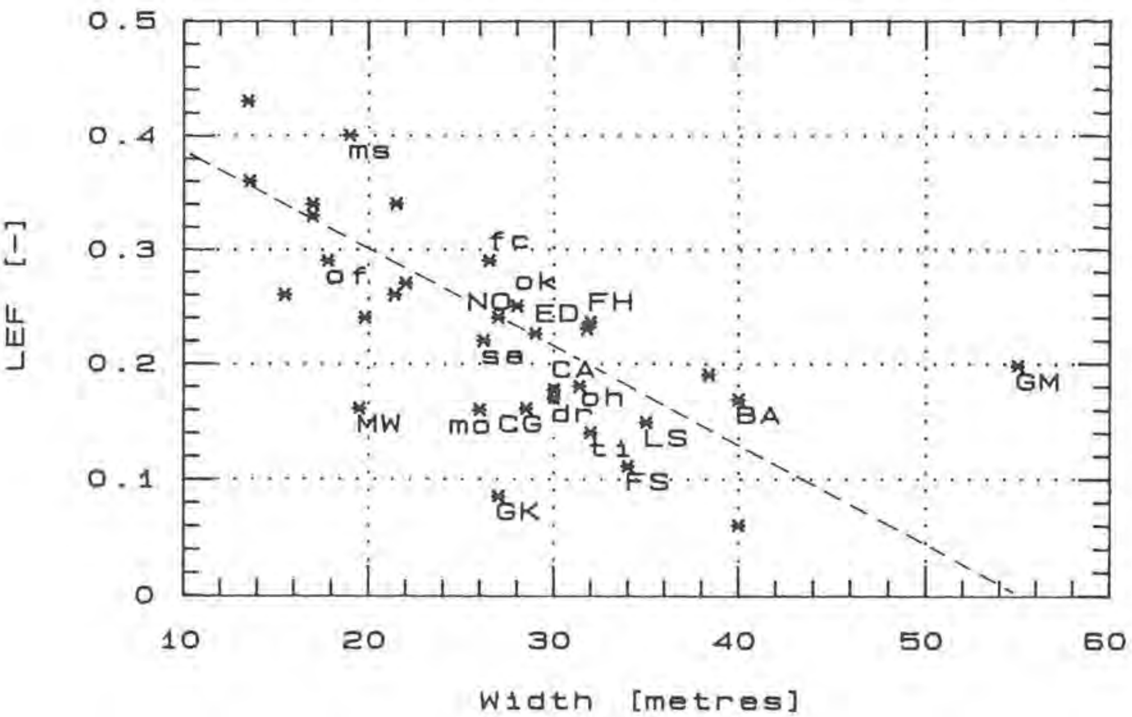


Fig. 3.6: Corresponding values of LEF and mean width for 32 halls. The dashed line corresponds to the regression formula in equation (3.5).

3.5. Revised predictions for Platform parameters

With the platform parameters being concerned with the conditions in a normally relatively small part of the hall, comparison of the diffuse field expected values (which are naturally related to the conditions averaged over the whole volume of the hall as discussed in section 3.4) and the measured values becomes less relevant than in the case of the audience parameters. As seen in Figure 3.1 the correlations were also slightly lower for the platform parameters in the right side of the figure than for the audience parameters to the left. Therefore, concerning the connections to the geometrical data, the correlations with the platform parameters directly will be discussed rather than the $\langle PAR \rangle_{dif}$ correlations.

3.5.1. EDT measured on the platform

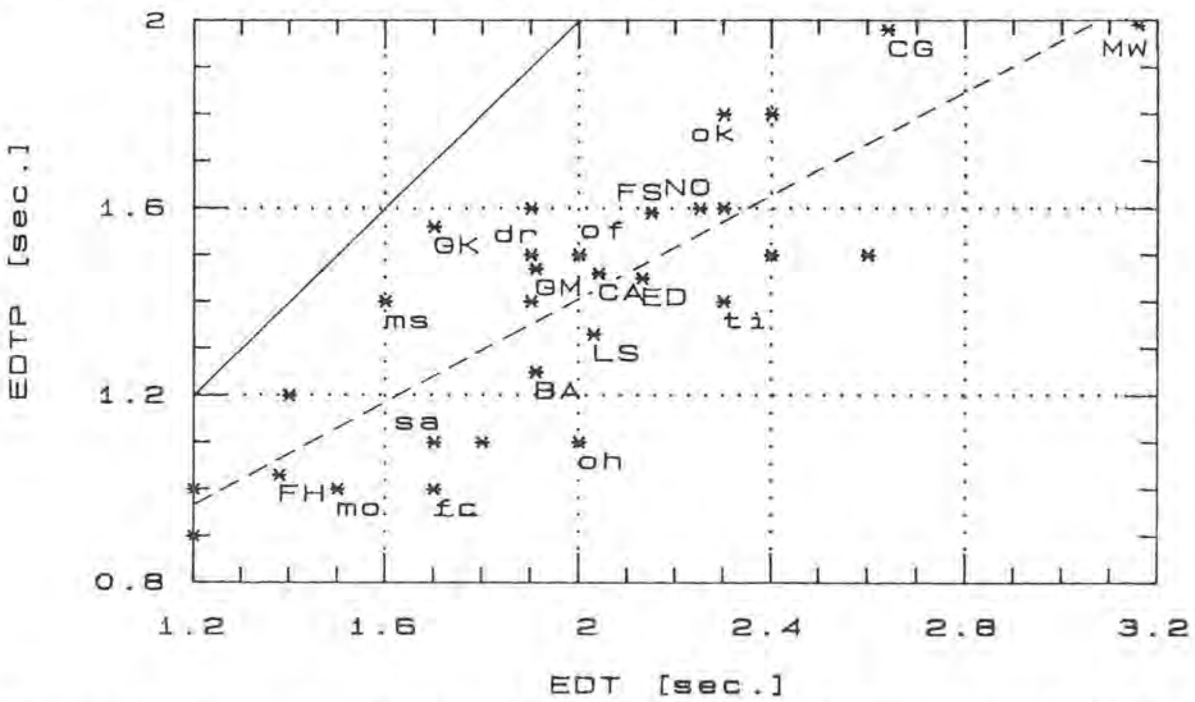


Fig. 3.7: Corresponding values of EDTP and EDT for 32 halls. A solid line is drawn corresponding to EDTP = EDT, and the regression line given by equation (3.6) has been drawn dashed.

In line with the discussion above, it seems more relevant to compare EDTP with EDT than with RT. Therefore corresponding values of EDT and EDTP are shown in Figure 3.7. The correlation between the two measures is high: $r = 0.83$, and the regression model describing the relationship is given by:

$$EDTP = 0.3 + 0.56*EDT. \qquad (3.6)$$

Thus, EDTP will generally be about two thirds the value measured in the audience area.

3.5.2. The support parameters

As illustrated in Figure 3.3, both ST1 and ST2 are strongly related to their respective predictions according to diffuse field theory. The regression formulae are:

$$ST1 = -1.9 + 0.72*ST1_{exp} \qquad (3.7)$$

and:

$$ST2 = -1.6 + 0.73*ST2_{exp} \qquad (3.8)$$

in which $ST1_{exp}$ and $ST2_{exp}$ are given by the formulae (1.18) and (1.19) respectively. With the expected values of ST1 and ST2 being in the range -10 to -20 dB, equations (3.7) and (3.8) indicate, that ST1 and ST2 will generally be less negative i.e. higher than expected. This result is contrary to the situation for the level L in the audience, which was found to be lower than expected (Figure 3.5); but it is not surprising considering the influence of the often strong reflections from surfaces in the vicinity of the platform. With the slope coefficients being different from one, the ST1 and ST2 deviations are seen to be dependent on the expected values. Thus, ST1 is on average about 4 dB higher than expected when $ST1_{exp}$ equals -20 dB, but only about 1 dB higher for $ST1_{exp}$ equal to -10 dB.

Among the platform parameters, ST1 is the one which is most sensitive to changes in the early reflection sequence, since it only considers these and not the reverberant energy at all. Therefore, it is not surprising either, that ST1 also turned out to be the one having the highest correlation with the variables describing the platform geometry. In line with the logarithmic nature of sound attenuation with distance as well as of stationary level versus volume, the highest correlations were found after logarithmic transformation of the geometric variables. The geometric variables having the highest correlations with ST1 are the ceiling height and the volume of the platform area (equal to mean hight to the ceiling from the platform floor X mean distance between side walls in the platform area X the distance from the platform front to the back wall behind the musicians). In both cases the correlation coefficient is r = -0.76. The negative sign means, that ST1 decreases as the ceiling hight or the volume in the platform area increases - as one would expect. The regression formula describing the platform volume relationship was found to be:

$$\text{ST1} = 12 - 7.65*\log(\text{Platform Volume}) \qquad (3.9)$$

i.e. not far from a "-10*log" -relationship, which would correspond to an ordinary 3 dB decrease per doubling of the volume. A strong relationship between ST1 and platform volume has also been found by others [37;38]. The model in equation (3.9) explains 59 % of the total variance. In Figure 3.8 are shown the corresponding values of ST1 and Platform volume. The platform

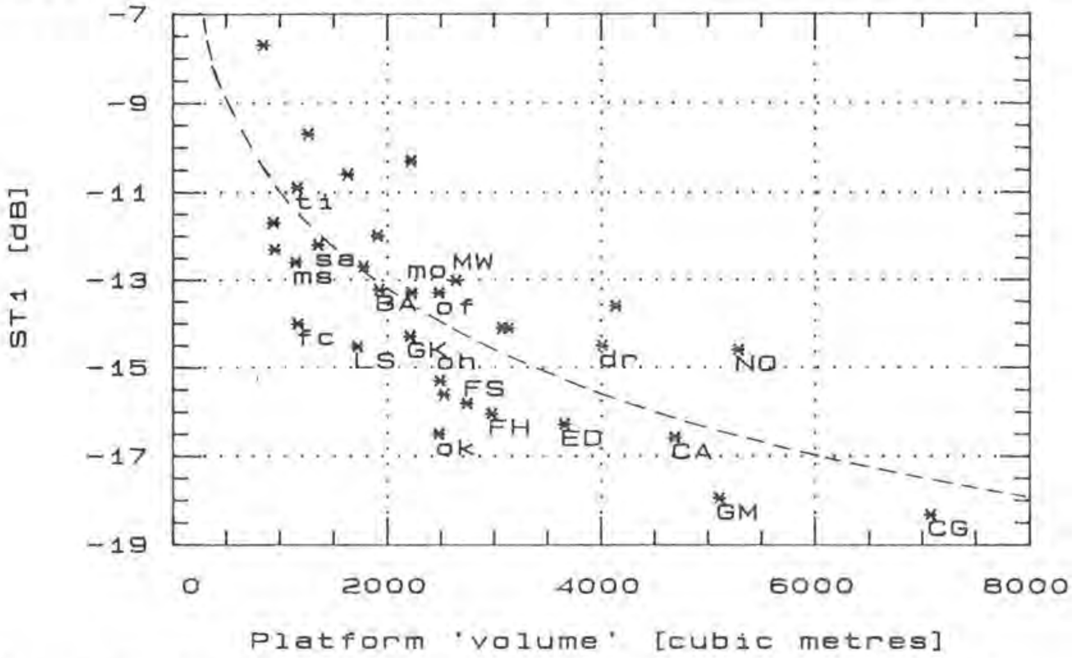


Fig. 3.8: Corresponding values of ST1 and 'platform volume' (explained in the text) for 32 halls. The logarithmic relationship is illustrated by the dashed curve given by equation (3.9).

volume is shown on a linear scale whereby the regression model appears as an exponential curve. According to experience from a number of subjective experiments [2], ST1 values between -11 and -13 dB correspond to satisfactory ensemble conditions. From Figure 3.8 it is seen, that ST1 values within this range are likely to be achieved, if the platform volume is chosen to be between 1500 and 3000 cubic metres.

3.5.3. The level of reverberant sound

The strong linear relationship between the measured and expected values of CS as seen in Figure 3.3 was found to obey the following regression formula:

$$CS = 3.8 + 0.69 * CS_{exp} \qquad (3.10)$$

in which CS_{exp} is given by formula (1.21). This relationship accounts for 71 % of the variance in the measured CS values. Remembering the fact that CS describes the level of the reverberant energy with inverted sign (see formula 1.20), it can be seen that if CS_{exp} is higher than about 12 dB, CS is lower than expected, i.e. also the reverberant energy on the platform is higher than predicted by diffuse field theory. Again, this is contrary to the behaviour of L in the audience area.

3.6. Discussion

To a large extent, classical diffuse field theory and RT explains the behaviour of the newer room acoustic parameters. Nevertheless, it is found that the predictions can be refined by applying empirical, linear transformations to the diffuse field expected values. In cases where correlations with the diffuse field predictions are low or without meaning, it has been possible to establish prediction models describing the influence of geometrical variables.

By including the foreign, larger halls into our body of data, the prediction models have been made more general, since the international halls generally represent a more varied architecture and more geometric degrees of freedom than most often found in the smaller, Danish halls. On the other hand, with the models being more general, it is not surprising that the correlations between acoustical and architectural properties has decreased somewhat compared to what was found in the analyses of the Danish data alone [1]. However, the larger set of data makes it possible to select groups of halls with more simple geometrical variations for further study, and thus it was possible to get a more clear idea about the influence of width on LEF.

Many possible geometrical factors other than the few found here must exist. Hints about some of these can probably be found by comparing the drawings of the halls in Chapter 2 and in [1] with the placing of their data relative to each other in the figures in this and in the following chapter.

IV. COMPARISONS OF SPECIFIC DANISH AND FOREIGN HALLS

4.1. Introduction

In this chapter, acoustic differences between the investigated halls will be discussed with emphasis on the differences between the foreign and the Danish halls.

As shown in section 3.2, acoustic conditions in concert halls are multidimensional in nature, which means that two halls can be equal with respect to one acoustic aspect while other aspects may be very different. Therefore, it has been chosen to illustrate the acoustic differences between the halls by means of two dimensional plots of corresponding values of independent (or not too closely related) parameters. This also makes it possible to see how much one acoustic parameter can differ between halls which are comparable with respect to another parameter.

Again it should be emphasized, that all data presented (except those in section 4.2) were measured in the empty halls, and that all the parameters will change somewhat when the halls are occupied. Unlike RT, the change in the other, more specific parameters is difficult to predict (- although one could be tempted to lean to the RT relationships discussed in Chapters 1 and 3 or to the theories in [4]). Therefore one should not make too close comparisons from the plots in sections 4.3 and 4.4.

4.2. Basic differences (when occupied)

Since most of the acoustic parameters are related to RT and/or Volume through the diffuse field predictions, a sensible first approach to describing the acoustic differences is to plot RT versus V for the 32 halls, as shown in Figure 4.1. In order to make the comparisons as relevant as possible, the RT data for the condition with audience have been used.

Most of the foreign halls (capitalized labels) are found to the right in Figure 4.1 indicating the volume of the foreign halls generally being larger than in the Danish halls (small letter labels or no labels). This basic difference between the two

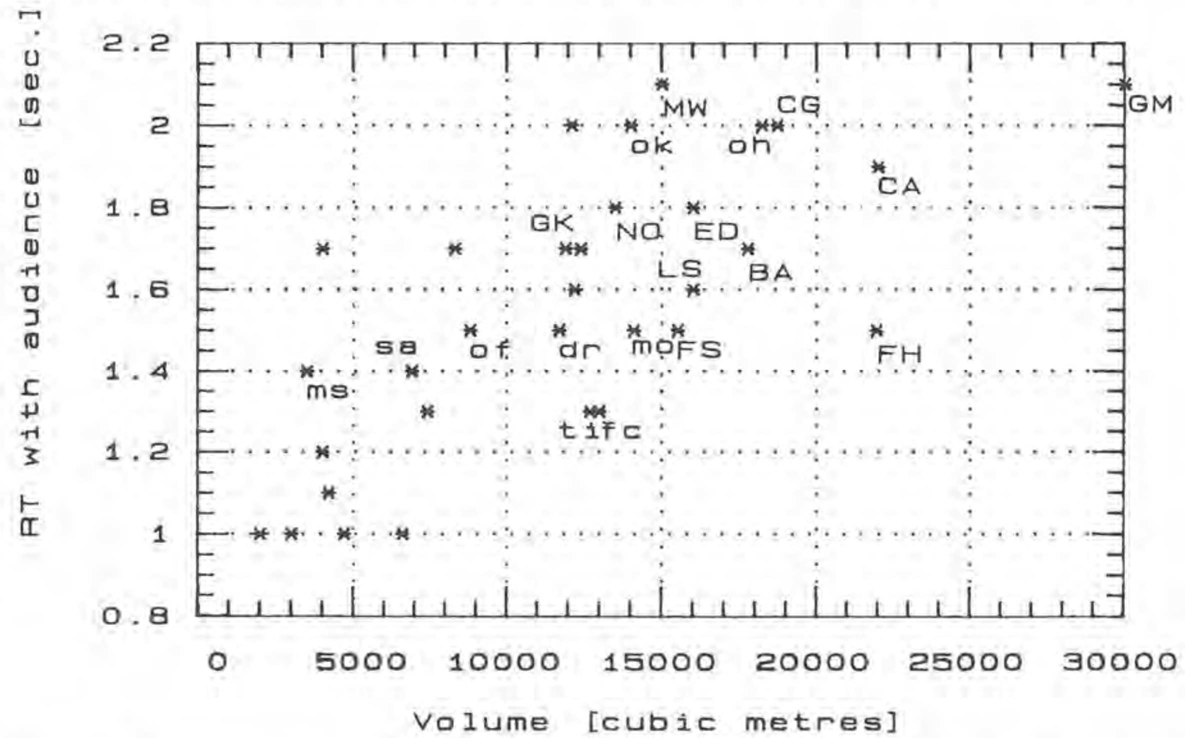


Fig. 4.1: Reverberation Time with audience (from literature) versus volume for 32 halls.

groups is not surprising since also small regional halls were included in the Danish sample, while the foreign 'references' are all large concert halls. In general, the larger, 'proper' concert halls are seen to have volumes of at least 15,000 m3 and RT values above 1.6 sec.

Among the labelled Danish halls, only **ok** and **oh** have RT values above 1.6 seconds. **of**, **dr** and **mo** have RT values equal to **FS** and **FH**, but with full audience, **FS**, **FH**, and even **LS** are claimed to be too dry for symphonic music [12]. (In **FH** an assisted resonance system has been installed in an attempt to reduce this problem.) Obviously, both **fc** and **ti** have too low RT values.

It is seen that **ms**, **sa**, **of** (and a large number of unlabeled, Danish halls) are all much smaller than the foreign halls. **of** has a volume which is only about 60% that of **MW**, which is its closest relative in shape. **GK** is the smallest of the foreign halls, but it has a good international reputation. Its volume is comparable with **dr**, **ti** and **fc**, but its RT is considerably higher. Besides, **GK** features a substantial increase in RT at low frequencies, which is not found in any of these three Danish halls (- but fortunately in the smaller **of**; see Appendix C).

Disregarding **FH** with its unusually low RT, and **GM** with its extreme volume, a certain relationship is seen between size and RT values, which is due to the audience covered floor being the main absorption area.* Therefore, a basic rule for obtaining a desired RT is to choose the Volume per seat sufficiently high. In a concert hall 8 to 12 m^3 per seat is necessary **. The plot of RT versus Volume per seat in Figure 4.2 gives a clear indication of which halls apply to this rule. In most foreign halls with a

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* This relationship would have been less pronounced if RT values from the empty condition had been used, because of the larger variation in absorption of empty chairs. In most of the smaller Danish halls, the chairs are less upholstered and absorptive than the chairs in the foreign halls.

** - depending on the <u>area</u> per seat as discussed extensively in [12,App.1]. Area per seat data for all 32 halls are listed in Appendix C.

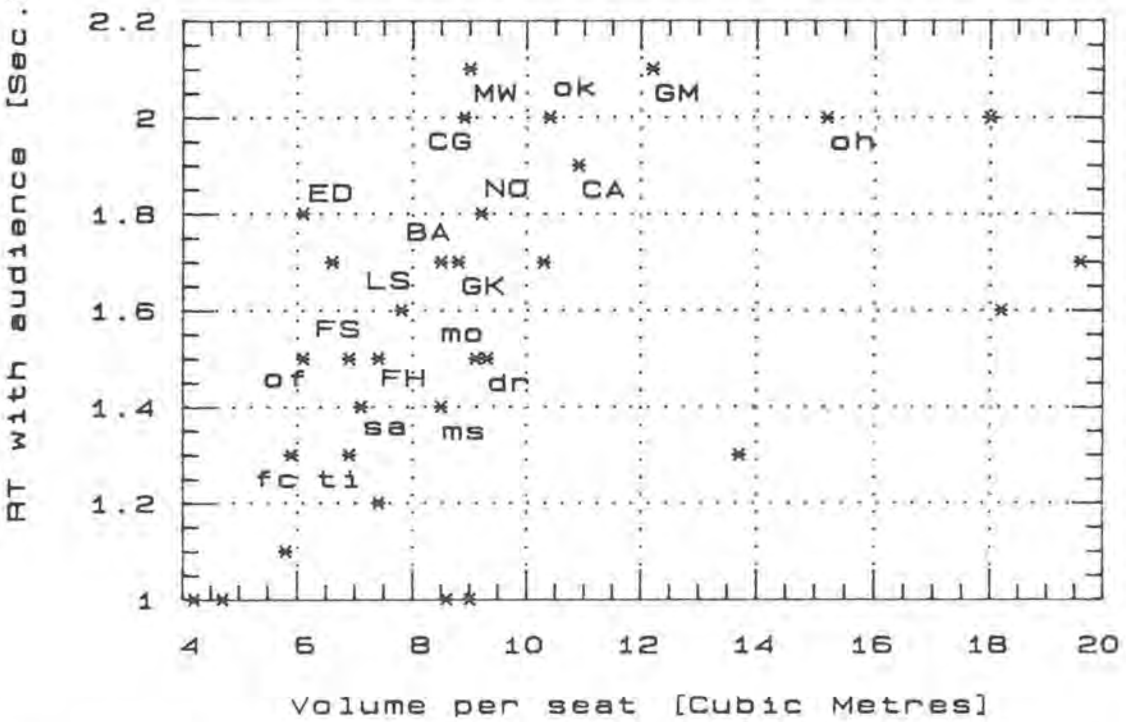

Fig. 4.2: Reverberation Time with audience (from literature) versus volume per seat for 32 halls.

sufficiently high RT, the volume per seat ratio is within the range specified. It is also seen that in most Danish halls this ratio is either to small or too large. The halls with very high ratios are mainly sports halls in which it has been necessary to add absorption - beyond that provided by the (relatively small) audience - in order to control reverberance in the excessive volume. However, hereby also the dynamics and lustre of the sound is lost. Although not really a sports hall, **oh** is seen to belong to this group. This leaves **ok** the only Danish hall in which both RT and volume are favorably chosen. **ok** is found very close to **MW** and **CG** in Figure 4.2.

4.3. Audience conditions

In order to illuminate the differences between the halls concerning the more specific acoustic aspects of relevance to audiences or musicians, we need to return to the data measured in the empty halls. Regarding the audience, L versus EDT and LEF versus C have been shown in Figures 4.3 and 4.4 respectively.

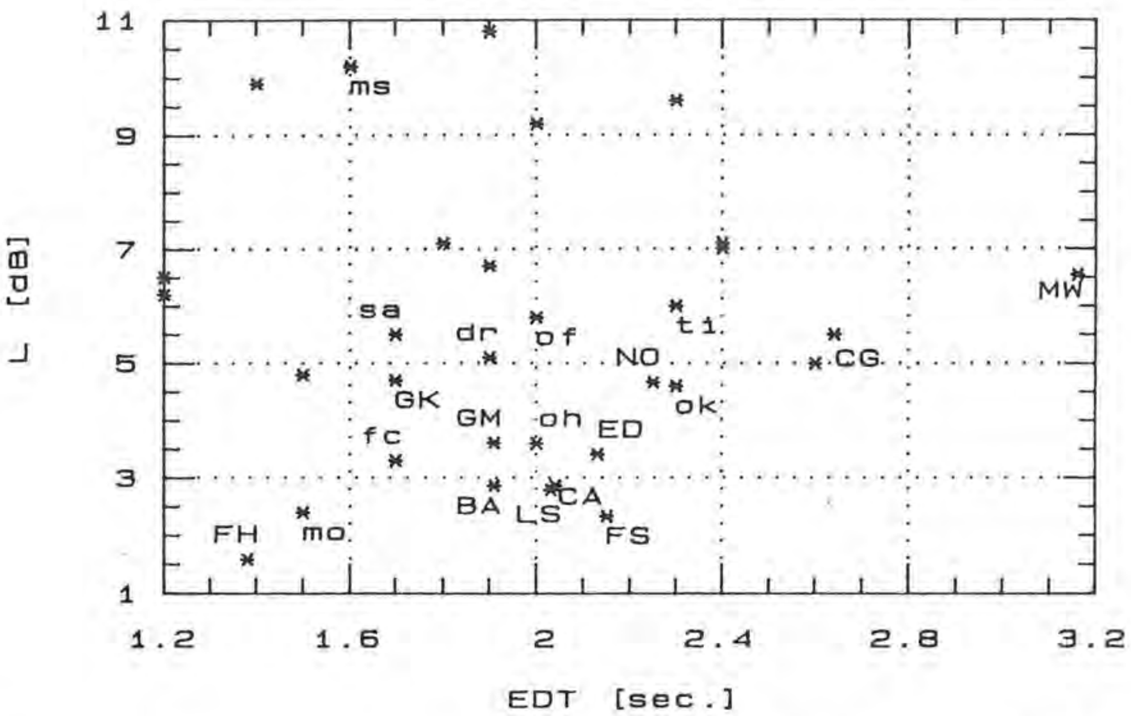

Fig. 4.3: Corresponding values of L and EDT measured in 32 empty halls.

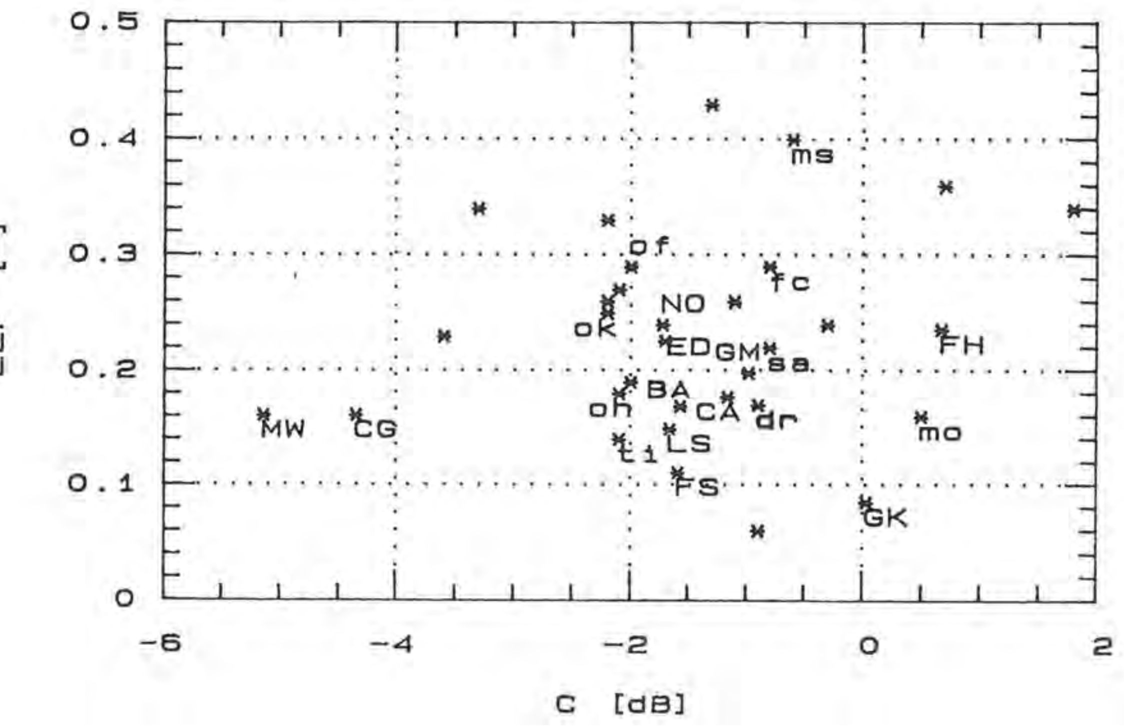

Fig. 4.4: Corresponding values of LEF and C measured in 32 empty halls.

EDT is remarkably high and correspondingly C is very low in the classical shoebox halls: **MW** and **CG**, which are normally considered to be the room acoustic references for symphonic music. **ok** is seen to be the Danish hall which comes closest to these classical halls (since in **ti** EDT will be markedly reduced with audience); The differences in C and EDT between **ok** and **CG** or **MW** will probably be somewhat reduced when the halls are occupied, because the chairs in **ok** are more absorptive than in **CG** and **MW**. Other Danish halls like **dr**, **of**, **oh** are found among the large lump of foreign halls with EDT values around 2 sec; i.e. apart from the classical halls **CG** and **MW** there is no great distinction between the Danish and Foreign halls concerning EDT, and the same is true concerning C.

On average, C is only 0.4 dB higher and EDT is 0.2 sec lower in the Danish halls than in the foreign halls; but that difference is likely to increase somewhat when the halls are occupied.

Concerning L, however, the value is on average 2.7 dB higher in the 21 Danish halls than in the eleven foreign halls; i.e. the amount of sound energy is nearly double in Danish halls. Of course this is simply a consequence of the differences in volume as explained in section 3.4.2. Among the foreign halls, the highest L was found in **MW**, in which L is unusually high compared with the volume (because of the very high RT value). L in this hall is comparable to **sa**, **dr**, **of**, and **ti**, which on the other hand do not possess its high RT. In **ok**, L is nearly 2 dB lower than in **MW**; but **ok** is comparable with **CG** in this respect, while **oh**, which was comparable with **ok**, **MW**, and **CG** on an RT basis (Figure 4.1), is another 1 dB lower and closer to other, even larger halls like **GM** and **CA**.

With the strong dependency of LEF on width (see Figure 3.6) it is no wonder that in general LEF is higher in the smaller Danish halls than in the foreign halls. **ms**, **of**, **fc**, and **ok** all have LEF values which are at least as high (and favorable) as any of the foreign halls. **ti**, **dr**, and **mo** are less impressive in this respect. Concerning the foreign halls, it is surprising to find a rather low value of LEF in **MW**. The value is lower than expected from the width relationship in Figure 3.6, and also low compared with the general opinions about the sound in **MW** being very spacious and enveloping. The reason for the low LEF may be the draperies on the side loge fronts combined with the attenuation at grazing incidence of the side wall reflections. In that case, the subjective impression of spaciousness must then be related to the high level [11] and/or to the rich reverberation [15] (see Figure 4.3). The low value of LEF compared to the width in **GK** could be related to the wide angle between the stepped side wall sections and the strong reflections from the smooth, slightly concave ceiling.

4.4. Platform conditions

The differences between the platform conditions in the various halls can be studied in Figure 4.5.

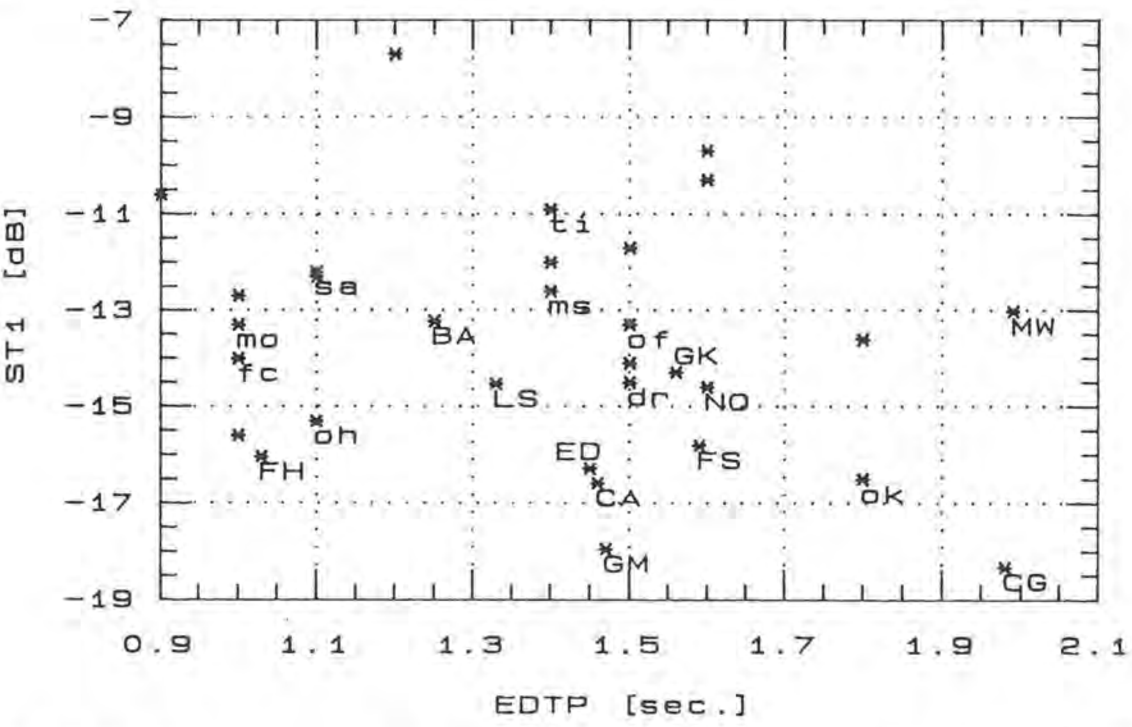

Fig. 4.5: Corresponding values of ST1 and EDTP measured in 32 empty halls.

In Figure 4.5, all labeled Danish halls except **ok** are found to have EDTP values around or below 1.5 sec., while the values in most of the larger, foreign halls are around 1.5 sec. or higher.

Thus, within the large group of halls having EDTP values around 1.5 sec., we find **of** and **dr** being comparable with **ED**, **CA**, **GM**, and **GK**. **ok**, however, is again found to be close to the classical halls **MW** and **CG**, while it is surprising to find **oh** so far to the left. In general, very large EDTP differences are seen to be possible between halls with similar ST1 values. Thus, there is 1 sec. of difference between **MW** and **mo**.

The values of ST1 are generally higher in Danish halls than in the larger, foreign ones. With its low ST1 value, **ok** is again closer to several foreign halls rather than to other Danish halls like **ti** or **mo**. Measured on the ST1 scale, the two classical halls **MW** and **CG** are now found to be very different, - for reasons which are obvious when looking at the geometrical relationship in Figure 3.8.

4.5. Discussion

Due to the many different aspects which need to be considered when comparison of the acoustics of concert halls is attempted, the description of the differences between Danish and foreign halls above is by no means exhaustive. Rather, it should be regarded as a guide for the reader who wants to compare the acoustics of halls of her/his own interest from the figures presented.

It is a combination of properties which characterize the acoustics of a hall and all of these need to be considered in order to decide whether two halls are similar or not. With respect to a single, specific aspect, the foreign halls do not form one homogeneous group. The classical halls **MW** and **CG** are different from any of the other halls with respect to reverberation, level and clarity, but also mutually different regarding the conditions on the orchestra platform. No hall in Denmark is like **MW** or **CG**; but when occupied **ok** comes close regarding reverberation time (and presumably also in clarity and level). **ti**, **dr**, **of**, and **oh*** are in certain acoustical aspects comparable with some newer, major foreign halls like **CA**, **BA** or **LS**. However, simply due to the obvious differences in size or in volume per seat, the majority of Danish halls are acoustically far from the eleven foreign halls. Some consequences of the general differences are discussed below.

On average, C is 0.4 dB higher and EDT is 0.2 sec. lower in the selection of Danish halls compared to the foreign halls. High clarity is often regarded as an advantage; but due to the high correlation between C and EDT this clarity is obtained at the expense of EDT, i.e. of the reverberance and fullness of the sound. Besides, high clarity means that any detail in the performance is exposed to the audience, which puts strong demands on the quality of the playing; demands which can be particularly difficult to meet by the less experienced regional orchestras, which are generally performing in the smaller "high clarity" halls.

On average L is as much as 2.7 dB higher in the 21 Danish halls than in the eleven foreign halls. One might think, that this higher level in small regional halls matches the normally smaller size of local orchestras; but this is only true for the string sections. The winds can not be reduced in number, since most often each wind instrument has its own part in the symphonic score. Therefore a reduced size orchestra in a small hall often leads to wrong orchestral balance - a tendency which is also emphasized by the fact that the development of more powerful wind instruments is still going on, while the standards for string instruments were established about two hundred years ago.

In the Danish halls LEF is on average 50 % higher than in the foreign halls, which is a natural and not unfavorable property of smaller halls.

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* **oh** is being renovated 1989; but not with the purpose of becoming a better concert hall, since RT will be reduced.

Generally, the performers will benefit from ST1 on average being 2.8 dB higher in Danish halls; but as mentioned above for audiences, also the musicians will miss the fullness of the sound in the more reverberant, foreign halls.

Finally, it should again be emphasized, that most of the comparisons above have been based on position averaged data from measurements in the empty halls. The conditions change somewhat when the audience arrives, depending on the absorption properties of the empty chairs. Besides, the variation between two positions is often as large as the differences between two halls [1;4;17]. Therefore, the results above will not match any experience the readers might have from personal listening at selected seats in the halls reviewed in this survey.

V. CONCLUSIONS

Volume and the classical reverberation time are the main factors governing most aspects of the room acoustic conditions as measured by the more modern room acoustic parameters. However, geometrical factors can also have a major influence, especially on acoustic aspects like Clarity, Spaciousness and the conditions for the musicians on the orchestra platform. Besides, the geometry can be used to control many of these aspects independently from each other, and of course the geometry will determine how the conditions vary with position.

The empirical prediction models listed should be suitable for use in the early stages of auditorium design, since they are based on simple RT calculations and rough geometrical considerations. It is also hoped that this study from real halls will be a valuable supplement to further investigations on geometrical relationships by means of scale or computer models.

Major, foreign concert halls have volumes of at least 15,000 m^3, equal to around 10 m^3 per seat, and RT values above 1.6 sec when occupied. Very few Danish halls meet these standards either because they are too small and RT is too low, or - in a few cases

- because the volume is too large compared to the number of seats. Famous, well liked halls like **MW**, **CG**, and **GK** in particular have high RT values compared to volume. These halls are also different from most Danish halls by having been designed and by being used nearly exclusively for performances of classical music. On this background it is not surprising, that among the halls in Denmark only one (**ok**) is comparable with these classical, dedicated concert halls.

Concerning the smaller ones among the Danish halls, the changes in acoustics determined by the smaller size are not always in a direction which is favorable for the artistic quality of symphonic performances in smaller musical communities.

It is my hope that this documentation on the differences between Danish and foreign halls will stimulate the discussion of proper acoustic conditions for the symphonic music scene in Denmark.

APPENDICES

A Notes on measurement setup and procedures.

All room acoustic parameters were measured from registrations of impulse responses h(t), which were obtained by emitting 1/1 octave sweep signals in the halls and processing the recorded sweep-responses by a computer in the laboratory. This method (which should not be confused with "time delay spectrometry") is based on the property of signals of the form $s(t) = \cos(\pi r t^2)$, that:

$$s(t) \cdot s(-t) = \delta(t). \qquad (A.1)$$

In (A.1) $\delta(t)$ is the Dirac delta function and "$\cdot$" denotes convolution while (-t) indicates that the time axis has been inverted. The duration as well as the spectrum of the signal s(t) are infinite, but by proper choice of "r", which determines the sweep rate in the cos-function above, and by multiplying s(t) with a matching window function w(t), one can design sweep signals: $s'(t) = w(t) * s(t)$ having a 1/1 octave (or any other) bandwidth and a suitable duration. If $\delta'(t)$ denotes the octave filtered version of $\delta(t)$, one gets for the impulse response limited to the same frequency range:

$$h'(t) = h(t) \cdot \delta'(t) = h(t) \cdot s'(t) \cdot s'(-t). \qquad (A.2)$$

With s'(t) emitted by a loudspeaker in the hall, and the sweep response $h(t) \cdot s'(t)$ being recorded on tape, the second convolution with s'(-t) acts as a compression in time of the superimposed sweeps in the recorded signal and at the same time as a 1/1 octave band pass filter. By using this technique the energy emitted in the hall can be increased by a factor comparable to the ratio between the durations of s'(t) and $\delta'(t)$ (roughly equal to 25 in our application) without increased demands on loudspeaker power. This means, that the measurements become less sensitive to background noise in the halls and to signal/noise ratio limitations in the recording equipment.

Compensations for linear distortion in the measurement equipment were attempted by analog equalizations and various calculation corrections per 1/1 octave band. Phase corrections were not attempted and would anyway have been in vain above the 1 kHz octave, where the loudspeaker used was no longer purely omnidirectional.

The loudspeaker consisted of 20 full range units distributed on an ikosahedron about 50 cm in diameter. The computer-generated 1/1 octave sweeps with centre frequencies from 125 to 4000 Hz were pre-recorded on one channel of a four channel FM tape recorder, while the three other channels were used for recording the responses picked up by two microphones:

> one B&K 1/2 inch microphone 4134 placed one metre from the centre of the sound source (for ST and L-reference measurements),

and

> one microphone containing an omnidirectional as well as a figure of eight capsule for recordings in the "P" and "R" positions in Figure 1.1 (This microphone was a Neumann SM2 in the British halls and an AKG C34 in the other halls).

Further details about the equipment, measurement procedures and frequency dependent corrections are described in the report covering the Danish survey [1]. However, one difference regarding the calibration of the L reference should be noticed. When the "free field" direct sound level one metre from the source is to be estimated in the hall, it is necessary to compensate for the influence of the reflection from the hard platform floor (one metre below the transducers). This reflection could not be separated from the direct sound in the 1/1 octave impulse response recordings (except in the 4 kHz recording). In the Danish survey, this compensation was done by adding theoretically calculated corrections to the direct sound levels measured per 1/1 octave band. However, in the foreign halls, the corrections were based on measurement of L in a reverberation chamber in the laboratory using the same height of the transducers over the floor as in the halls. The corrections were then found as the differences between the measured L values and the expected values from formula (1.11) assuming a proper diffuse field in the chamber (volume = 315 m^3 and RT between 4.5 and 2.5 seconds). While the theoretical corrections for the six octaves from 125 Hz to 4000 Hz were:

-4.0 dB +1.7 dB -0.2 dB +0.6 dB +0.4 dB 0.0 dB,

the reverberation chamber method suggested:

0.0 dB +2.5 dB +1.1 dB +0.5 dB 0.0 dB 0.0 dB.

Before comparing the L(f) curves from this report with those in [1], one should therefore add the differences:

125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz
+4.0 dB	+0.8 dB	+1.3 dB	-0.1 dB	-0.4 dB	0.0 dB

to the Danish L values. Since most of the discussions on L in this report are based on the values averaged over the 250 Hz - 2 kHz octaves, +0.4 dB were added to the Danish, frequency avaraged L data from [1] before performing the joint analyses and plotting of figures for Chapters 3 and 4 and before listing of the values in Appendix C. Correspondingly, the BR(L) values for the Danish halls were raised +1.8 dB before being listed in Appendix C.

B Acoustical data per position and 1/1 octave band.

The acoustical data are presented without the units. However, the units presented in the list of symbols p. 10 apply.

Grosses Festspielhauss, Salzburg (**FS**)

Platform parameters

	Px						Sx		
	Freq	RT	EDT	TS	C	EEL	CS	ST1	ST2
S1-P1/S1	250	2.1	1.4	87	3.7	-14.8	16.8	-20.0	-16.4
	500	2.0	1.9	128	1.1	-16.3	16.2	-16.4	-14.8
	1000	1.8	1.3	82	3.6	-12.4	17.1	-18.2	-15.9
	2000	1.7	1.4	85	3.0	-13.4	13.4	-21.1	-17.5
S2-P2/S2	250	2.1	1.8	107	2.0	-18.9	18.4	-16.8	-15.4
	500	1.8	1.6	97	1.8	-13.7	15.7	-13.8	-12.5
	1000	1.9	1.7	109	1.3	-15.5	17.0	-14.8	-13.5
	2000	1.7	1.6	113	0.7	-16.1	14.4	-14.8	-13.3
S3-P3/S3	250	1.6	1.6	87	4.1	-12.7	16.7	-12.6	-11.5
	500	1.8	1.7	121	1.1	-14.9	16.8	-12.9	-12.1
	1000	1.9	1.5	82	4.0	-13.1	17.9	-14.2	-13.4
	2000	1.6	1.6	96	2.1	-14.4	15.1	-14.1	-13.5

Audience parameters (FS)

S1-

Receiver	Freq	RT	EDT	TS	C	L	LEF
R1	125	2.5	1.9	150	-5.0	3.9	0.14
	250	2.0	2.1	170	-5.3	3.7	0.06
	500	2.3	1.9	126	0.2	5.1	0.05
	1000	2.1	1.9	121	0.3	4.9	0.08
	2000	2.1	2.2	159	-2.9	5.0	
	4000	1.8	1.8	121	0.1	-0.1	
R2	125	2.3	2.1	218	-10.9	1.8	0.06
	250	2.2	2.1	168	-6.3	3.0	0.03
	500	2.2	2.2	145	-0.4	3.6	0.04
	1000	2.1	2.2	144	-0.7	2.8	0.05
	2000	2.2	2.4	194	-4.8	3.4	
	4000	2.0	2.1	161	-2.5	-2.4	
R3	125	2.4	2.5	235	-8.6	0.8	0.04
	250	2.0	2.1	160	-2.2	2.9	0.14
	500	2.1	2.3	163	-2.4	3.6	0.07
	1000	2.1	1.7	137	-0.8	3.2	0.07
	2000	2.2	2.1	154	-2.6	4.2	
	4000	1.8	2.0	156	-3.3	-2.8	
R4	125	2.4	2.4	216	-8.5	-0.7	0.18
	250	2.3	2.5	177	-3.5	0.9	0.16
	500	2.2	2.2	165	-3.1	1.2	0.15
	1000	2.3	2.3	180	-5.6	0.2	0.09
	2000	2.3	2.2	157	-2.9	2.8	
	4000	1.9	1.9	148	-3.1	2.4	
R5	125	2.4	2.4	194	-6.7	1.7	0.22
	250	2.1	2.4	178	-1.6	1.8	0.22
	500	2.2	2.1	142	0.8	3.0	0.27
	1000	2.3	2.2	150	0.3	1.9	0.14
	2000	2.1	2.3	158	-0.5	3.9	
	4000	1.9	1.9	129	0.4	-1.9	
R6	125	2.4	1.5	142	-1.4	1.3	0.09
	250	2.1	2.3	166	-2.7	0.6	0.18
	500	2.2	1.9	120	1.9	2.4	0.08
	1000	2.3	2.2	144	-0.3	0.4	0.05
	2000	2.1	1.8	125	0.9	3.6	
	4000	1.9	1.4	104	2.0	0.3	

S3-

Receiver	Freq	RT	EDT	TS	C	L	LEF
R1	125	2.4	2.8	174	-1.9	3.0	0.11
	250	2.3	2.6	166	-2.0	1.4	0.10
	500	2.1	2.1	156	-0.7	3.0	0.08
	1000	2.2	2.0	146	-0.1	2.7	0.10
	2000	2.1	2.3	172	-2.2	3.3	
	4000	1.8	1.8	109	1.8	-1.1	
R2	125	2.0	2.4	193	-2.3	1.4	0.08
	250	2.0	2.2	160	-0.9	2.4	0.11
	500	2.2	2.2	156	-1.2	2.9	0.15
	1000	2.2	2.1	154	-2.1	2.0	0.14
	2000	2.1	2.1	156	-1.8	3.8	
	4000	1.9	2.0	146	-1.4	-2.9	
R3	125	2.5	2.8	206	-5.8	1.5	0.16
	250	2.2	1.8	160	-3.7	1.6	0.13
	500	2.1	1.9	140	-0.9	2.9	0.03
	1000	2.2	1.9	142	-1.5	1.9	0.05
	2000	2.2	2.2	162	-3.0	3.4	
	4000	1.9	1.7	130	-0.8	-2.4	
R4	125	2.3	2.5	175	-2.9	-0.5	0.06
	250	2.2	1.9	143	-2.8	0.4	0.25
	500	2.2	2.1	148	-2.7	1.5	0.19
	1000	2.3	2.3	156	-1.3	-0.5	0.03
	2000	2.3	1.8	132	-0.6	2.7	
	4000	2.0	1.6	113	0.8	-3.5	
R5	125	2.9	2.2	208	-5.5	0.2	0.07
	250	2.1	2.4	190	-2.8	1.1	0.05
	500	2.2	2.5	175	-1.2	1.3	0.11
	1000	2.1	2.3	158	-0.3	1.1	0.06
	2000	2.1	2.9	220	-4.6	1.0	
	4000	1.9	2.3	162	-1.7	-4.3	
R6	125	2.4	1.8	148	-0.7	-0.5	0.12
	250	2.4	2.7	189	-2.6	-2.1	0.28
	500	2.3	1.7	109	3.2	2.2	0.10
	1000	2.3	1.8	110	2.3	1.1	0.12
	2000	2.3	1.8	117	1.6	2.8	
	4000	1.8	1.2	89	4.1	-2.0	

Musikvereinsaal, Wien (**MW**)

Platform parameters

	Px					Sx			
	Freq	RT	EDT	TS	C	EEL	CS	ST1	ST2
S1-P1/S1	250	3.2	2.2	161	-1.4	-17.6	15.0	-15.9	-13.7
	500	2.9	2.1	136	0.0	-13.2	13.6	-12.7	-11.4
	1000	2.7	1.9	124	0.7	-12.1	13.8	-14.5	-12.4
	2000	2.6	2.1	139	-0.6	-14.6	12.4	-14.5	-13.3
S2-P2/S2	250	3.0	2.1	146	-0.5	-15.2	15.4	-12.1	-11.0
	500	3.1	2.5	166	-0.8	-17.1	13.6	-14.5	-12.4
	1000	3.0	2.3	141	0.6	-14.9	14.7	-13.6	-12.6
	2000	2.6	1.8	125	0.7	-14.8	10.8	-11.1	-10.3
S3-P3/S3	250	3.1	1.8	88	4.1	-12.2	16.0	-14.1	-13.3
	500	2.8	1.6	88	3.6	-9.8	14.7	-10.8	-10.0
	1000	3.0	1.8	114	2.0	-12.1	13.4	-10.2	-9.4
	2000	2.5	1.7	95	3.4	-11.2	10.6	-12.2	-11.3

Audience parameters (MW)

S1-								S3-						
Freq	RT	EDT	TS	C	L	LEF		Freq	RT	EDT	TS	C	L	LEF
125	3.0	1.8	144	0.4	11.0	0.15		125	3.0	3.0	216	-3.2	6.7	0.09
250	3.4	2.8	168	-0.9	7.5	0.15		250	3.0	2.8	193	-3.3	12.6	0.35
500	3.2	3.0	180	-0.5	8.9	0.19	R1	500	3.1	2.7	175	-1.6	8.8	0.26
1000	3.1	2.5	155	-1.1	8.9	0.18		1000	3.0	2.9	198	-2.3	7.1	0.26
2000	2.4	2.1	136	-0.2	9.2			2000	2.7	2.4	161	-1.7	7.8	
4000	2.2	1.6	120	0.4	5.7			4000	2.1	1.8	128	-0.4	4.6	
125	2.4	2.0	208	-4.6	9.6	0.07		125	2.7	1.5	154	-2.8	10.1	0.02
250	3.0	3.2	241	-6.8	6.4	0.14		250	3.1	2.8	227	-6.6	6.3	0.13
500	3.1	3.1	220	-5.0	8.2	0.09	R2	500	3.2	3.0	214	-4.7	7.1	0.19
1000	3.1	2.8	201	-3.9	7.2	0.13		1000	3.3	3.1	217	-4.3	6.6	0.18
2000	2.6	2.7	197	-3.5	6.7			2000	2.7	2.8	201	-4.0	6.2	
4000	2.1	1.7	123	0.0	4.9			4000	2.1	2.1	155	-2.4	3.0	
125	3.1	3.7	283	-10.2	6.7	0.13		125	3.0	3.5	223	-4.2	6.7	0.06
250	3.2	3.7	255	-6.5	4.7	0.10		250	3.3	3.5	257	-6.4	3.7	0.10
500	3.2	3.4	266	-7.8	5.7	0.26	R3	500	3.3	3.7	255	-6.4	5.1	0.20
1000	3.3	3.6	261	-5.8	5.5	0.16		1000	3.3	3.4	235	-4.9	5.2	0.14
2000	2.7	3.0	217	-4.6	5.5			2000	2.7	2.6	197	-3.6	5.6	
4000	2.2	2.2	160	-1.5	2.4			4000	2.1	2.1	157	-2.0	2.1	
125	3.0	3.7	247	-13.2	8.5	0.14		125	3.0	2.8	222	-5.8	7.2	0.06
250	3.3	3.9	277	-8.2	5.8	0.22		250	3.1	3.1	231	-6.1	6.4	0.08
500	3.1	3.4	250	-7.2	8.1	0.16	R4	500	3.2	3.4	231	-3.7	7.5	0.15
1000	3.2	3.6	262	-6.6	6.2	0.10		1000	3.1	3.1	219	-4.0	6.8	0.10
2000	2.8	3.0	211	-4.1	6.4			2000	2.7	2.8	205	-3.7	6.4	
4000	2.2	2.4	174	-3.0	2.5			4000	2.1	2.2	166	-2.4	2.2	
125	3.0	3.4	261	-6.7	6.9	0.09		125	3.1	3.3	245	-5.2	5.5	0.11
250	3.3	3.9	280	-11.2	5.5	0.21		250	3.3	3.8	276	-10.6	4.8	0.23
500	3.0	3.4	250	-7.0	8.0	0.25	R5	500	3.3	3.7	281	-8.5	6.2	0.30
1000	3.2	3.7	280	-8.7	6.1	0.24		1000	3.1	3.1	235	-4.6	6.3	0.17
2000	2.7	3.2	233	-6.1	5.8			2000	2.7	3.1	229	-5.5	5.5	
4000	2.2	2.3	175	-3.4	2.7			4000	2.1	2.5	187	-4.1	1.8	
125	2.9	3.9	202	-3.2	7.2	0.14		125	3.2	2.6	183	-1.5	7.1	0.09
250	3.1	3.5	248	-6.8	5.7	0.15		250	3.0	3.4	240	-5.3	4.3	0.15
500	3.0	3.6	255	-6.4	7.0	0.20	R6	500	3.1	3.3	244	-6.6	6.4	0.18
1000	3.2	3.3	223	-4.4	6.0	0.20		1000	3.1	3.1	224	-5.5	5.7	0.30
2000	2.7	2.7	198	-4.2	5.8			2000	2.7	2.8	215	-5.3	4.7	
4000	2.1	2.1	162	-3.1	2.9			4000	2.1	2.0	142	-1.3	2.5	

St. Davids Hall, Cardiff (CA)

Platform parameters

	Px					Sx			
	Freq	RT	EDT	TS	C	EEL	CS	ST1	ST2
S1-P1/S1	250	1.8	1.2	72	5.0	-13.7	17.3	-21.1	-17.0
	500	2.0	1.5	98	1.5	-15.6	16.1	-16.8	-14.0
	1000	2.1	1.3	71	4.3	-13.1	15.8	-17.8	-14.4
	2000	2.1	1.9	123	0.6	-17.5	11.7	-17.0	-14.3
S2-P2/S2	250	1.8	1.0	56	6.0	-12.8	16.7	-15.8	-14.3
	500	2.1	1.4	107	1.3	-16.5	15.7	-14.8	-13.1
	1000	2.2	1.7	105	2.2	-16.1	16.8	-16.4	-14.6
	2000	2.0	1.8	126	0.1	-18.5	13.1	-16.0	-14.7
S3-P3/S3	250	2.0	1.5	76	3.7	-13.8	18.3	-19.7	-16.7
	500	1.9	1.5	112	0.1	-16.2	16.1	-18.6	-15.0
	1000	2.2	1.4	71	4.5	-12.7	17.0	-14.2	-13.3
	2000	2.0	1.3	63	5.5	-11.8	13.0	-10.8	-10.2

Audience parameters (CA)

S1-								S3-						
Freq	RT	EDT	TS	C	L	LEF		Freq	RT	EDT	TS	C	L	LEF
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125	1.9	1.4	104	1.0	7.0	0.04		125	2.1	1.8	120	-0.8	3.5	0.07
250	2.0	1.9	149	-3.3	3.8	0.06		250	2.0	1.9	144	-2.9	3.4	0.08
500	2.1	1.7	111	0.8	6.7	0.09	R1	500	2.0	1.9	129	-0.2	5.0	0.25
1000	2.1	1.8	116	0.0	6.2	0.07		1000	2.3	1.9	136	-1.0	3.8	0.32
2000	2.1	1.8	129	-0.8	4.7			2000	2.1	2.0	141	-0.9	2.1	
4000	1.6	1.7	127	-2.1				4000	1.7	1.4	92	2.4		
125	1.9	2.1	132	0.6	3.4	0.41		125	2.0	1.9	128	0.6	2.0	0.30
250	2.0	2.3	164	-2.7	2.2	0.41		250	2.0	2.0	150	-2.0	2.7	0.51
500	2.1	2.1	149	-2.6	3.9	0.41	R2	500	2.1	2.2	154	-1.4	3.4	0.22
1000	2.2	1.9	143	-0.5	3.9	0.29		1000	2.3	2.1	142	-0.3	3.0	0.30
2000	2.2	2.1	151	-2.0	2.8			2000	2.2	2.1	158	-2.9	2.1	
4000	1.7	1.8	138	-2.2				4000	1.6	1.6	122	0.1		
125	1.9	2.0	168	-5.6	2.2	0.10		125	1.9	2.2	175	-4.4	0.8	0.18
250	2.2	2.0	141	-1.6	1.3	0.05		250	2.2	2.1	139	-0.6	0.8	0.06
500	2.1	2.0	131	0.0	4.1	0.13	R3	500	2.1	2.0	122	1.0	3.4	0.10
1000	2.2	1.9	133	-0.2	3.6	0.13		1000	2.3	1.8	116	0.7	3.5	0.12
2000	2.3	2.1	159	-2.6	1.9			2000	2.2	2.0	145	-1.5	1.9	
4000	1.7	1.6	127	-0.9				4000	1.7	1.6	122	-0.3		
125	1.7	1.7	146	-3.2	2.2	0.04		125	1.6	1.5	150	-1.7	1.4	0.19
250	2.0	2.5	177	-5.3	0.8	0.26		250	2.1	1.9	128	0.6	1.6	0.09
500	2.1	2.1	153	-1.[illegible]	[illegible].1	0.10	R4	500	2.1	1.9	143	-0.5	2.5	0.10
1000	2.6	2.2	141	0.1	2.2	0.08		1000	2.3	2.1	134	0.3	2.5	0.07
2000	2.2	2.1	130	0.3	1.8			2000	2.1	1.9	130	-0.2	2.0	
4000	1.8	1.7	113	0.7				4000	1.9	1.7	114	1.1		
125	2.0	2.1	163	-5.6	3.4	0.12		125	2.2	2.2	163	-1.4	2.0	0.19
250	2.1	1.9	138	-1.3	2.8	0.08		250	1.9	2.4	173	-3.3	2.2	0.24
500	2.0	2.0	136	-0.2	4.8	0.13	R5	500	2.2	1.9	141	-0.8	4.6	0.14
1000	2.3	2.2	150	-1.9	3.5	0.13		1000	2.2	2.0	139	-0.5	4.0	0.12
2000	2.2	1.8	107	1.5	4.0			2000	2.1	2.0	121	0.6	2.4	
4000	1.8	1.6	106	1.3				4000	1.8	1.4	91	2.3		
125	2.0	2.1	165	-3.0	0.7	0.16		125	1.8	2.1	188	-4.2	-0.5	0.17
250	2.0	1.9	139	-0.8	1.5	0.25		250	2.0	2.4	173	-2.8	-0.1	0.46
500	2.2	2.0	147	-2.2	3.1	0.21	R6	500	2.2	2.3	168	-3.1	2.4	0.16
1000	2.4	2.3	173	-2.7	1.2	0.19		1000	2.3	2.1	166	-2.8	1.7	0.13
2000	2.2	2.1	149	-1.1	1.3			2000	2.2	2.1	143	-0.9	1.4	
4000	2.0	2.1	152	-2.1				4000	2.0	1.9	147	-1.2		

Usher Hall, Edinburgh (**ED**)

Platform parameters

	Px					Sx			
	Freq	RT	EDT	TS	C	EEL	CS	ST1	ST2
S1-P1/S1	250	1.8	1.6	89	3.1	-15.1	13.5	-16.0	-12.9
	500	1.9	1.6	101	0.5	-13.9	13.3	-16.1	-13.2
	1000	1.9	1.3	78	3.1	-11.9	13.0	-17.4	-14.2
	2000	1.9	1.6	117	0.4	-12.5	7.7	-13.0	-10.9
S2-P2/S2	250	1.6	1.4	92	2.5	-14.4	15.6	-21.6	-16.9
	500	1.7	1.5	110	0.4	-15.2	13.9	-15.1	-12.8
	1000	2.0	1.6	113	0.4	-15.7	13.8	-16.5	-13.5
	2000	1.9	1.7	125	-1.0	-16.3	10.7	-16.7	-14.7
S3-P3/S3	250	1.7	1.0	65	5.6	-12.4	14.9	-17.0	-14.2
	500	1.8	1.3	88	1.9	-12.0	12.2	-13.1	-11.6
	1000	2.0	1.2	72	4.3	-10.9	15.1	-16.3	-14.3
	2000	1.9	1.6	106	0.7	-13.7	10.6	-16.6	-14.3

Audience parameters (ED)

S1-

Receiver	Freq	EDT	TS	C	L	LEF
R1	125	1.3	104	1.2	6.8	0.05
	250	1.9	122	-0.2	5.7	0.05
	500	2.0	124	0.2	6.5	0.06
	1000	2.0	122	0.9	7.2	0.05
	2000	2.1	142	-0.9	5.8	
	4000		143	-1.9	2.4	
R2	125	2.2	167	-2.3	4.2	0.27
	250	2.5	195	-6.5	2.7	0.44
	500	2.2	174	-2.9	4.4	0.15
	1000	2.3	173	-2.3	4.6	0.22
	2000	2.5	192	-4.4	3.4	
	4000	1.7	127	-0.3	0.9	
R3	125	2.3	153	-1.9	1.4	0.08
	250	1.7	135	-1.4	3.4	0.38
	500	1.9	144	-0.7	3.2	0.40
	1000	2.0	146	-1.1	2.9	0.49
	2000	2.3	172	-3.2	1.3	
	4000	1.4	109	1.2	0.0	
R4	125	1.6	116	0.4	4.5	0.31
	250	1.5	118	0.9	3.4	0.16
	500	1.6	117	2.1	5.3	0.12
	1000	2.1	152	-0.9	3.2	0.17
	2000	2.1	159	-0.5	2.2	
	4000	1.8		-1.0	-1.5	
R5	125	1.8	175	-9.3	3.9	0.32
	250	2.4	180	-3.6	0.9	0.31
	500	2.4	166	-1.6	2.5	0.23
	1000	2.3	157	-1.8	2.2	0.22
	2000	2.3	175	-3.8	0.9	
	4000			-3.2	-0.5	
R6	125	1.8	131	0.7	4.1	0.23
	250	2.2	148	-2.1	3.9	0.13
	500	1.9	149	-1.7	5.1	0.17
	1000	2.5	185	-3.3	3.5	0.14
	2000	2.0	143	-0.4	4.2	
	4000	1.6	119	0.5	0.4	
R7	125	2.3	170	-2.5	2.8	0.49
	250	2.6	205	-5.8	2.2	0.44
	500	2.3	168	-2.2	4.0	0.31
	1000	2.4	173	-2.2	3.5	0.23
	2000	2.3	191	-4.5	2.5	
	4000			-3.1	0.4	

S3-

Receiver	Freq	EDT	TS	C	L	LEF
R1	125	2.2	179	-2.8	3.5	0.42
	250	2.0	165	-4.9	4.1	0.18
	500	1.9	146	-1.0	5.9	0.14
	1000	2.0	146	-1.5	6.2	0.15
	2000	2.1	156	-1.5	5.1	
	4000	1.8	141	-1.3	2.0	
R2	125	2.0	162	-2.5	1.9	0.18
	250	2.5	185	-4.8	2.6	0.23
	500	2.2	162	-2.3	4.2	0.14
	1000	2.3	162	-2.3	4.4	0.12
	2000	2.4	171	-3.0	3.2	
	4000	1.9	168	-2.8	-0.6	
R3	125	1.9	144	-0.4	1.0	0.15
	250	2.4	182	-4.1	0.5	0.20
	500	2.2	171	-2.7	1.7	0.30
	1000	2.4	161	-1.2	2.8	0.23
	2000	2.2	162	-1.1	1.9	
	4000			-2.6	-0.5	
R4	125	1.7	106	1.0	2.9	0.26
	250	1.5	110	1.7	3.0	0.11
	500	1.6	107	2.5	4.2	0.18
	1000	2.0	131	0.5	2.8	0.15
	2000	2.3	168	-0.7	1.4	
	4000	1.5	121	2.4	-1.2	
R5	125	1.2	102	2.4	3.5	0.17
	250	2.2	163	-1.9	0.2	0.24
	500	2.1	152	-1.8	2.6	0.35
	1000	2.0	136	0.1	2.2	0.20
	2000	2.1	148	-0.4	2.3	
	4000			-0.7	-1.2	
R6	125	2.0	151	-1.9	3.3	0.17
	250	2.0	139	-1.9	3.7	0.31
	500	1.7	120	0.5	5.3	0.22
	1000	2.0	141	0.0	4.1	0.07
	2000	2.1	147	-1.3	3.4	
	4000			-0.6	0.9	
R7	125	2.1	161	-0.8	2.8	0.27
	250	2.7	200	-5.0	4.2	0.39
	500	2.0	144	-0.5	4.4	0.30
	1000	2.1	156	-1.4	4.3	0.18
	2000	2.0	151	-1.2	-0.1	
	4000			-1.7	1.1	

Barbican Concert Hall, London (BA)

Platform parameters

	Px						Sx		
	Freq	RT	EDT	TS	C	EEL	CS	ST1	ST2
S1-P1/S1	250	1.5	1.0	66	5.2		16.8	-14.8	-13.6
	500	1.8	1.4	84	3.1	-13.0	15.1	-14.1	-12.4
	1000	1.9	1.2	68	4.9	-11.4	15.8	-14.9	-13.4
	2000	1.9	1.5	90	2.7	-13.9	11.9	-14.8	-13.6
S2-P2/S2	250	1.4	0.9	66	4.0		15.3	-15.3	-13.0
	500	1.8	1.5	100	2.5	-14.8	17.1	-12.9	-12.0
	1000	2.0	1.8	126	0.3	-16.8	15.6	-13.5	-12.2
	2000	2.0	1.7	117	1.1	-16.7	11.4	-14.8	-13.0
S3-P3/S3	250	1.4	1.0	68	3.6		16.2	-11.7	-10.9
	500	1.7	0.9	66	6.6	-11.0	15.9	-11.7	-10.9
	1000	1.9	1.2	65	5.7	-11.4	16.6	-12.1	-11.4
	2000	1.8	0.9	50	6.7	-10.1	13.1	-8.0	-7.6

Audience parameters (BA)

S1-

Pos.	Freq	RT	EDT	TS	C	L	LEF
R1	125	1.9	1.3	116	-0.2	6.6	0.06
	250	1.5	1.6	96	1.1	6.4	0.05
	500	1.8	1.6	119	-1.2	7.8	0.06
	1000	1.9	1.5	91	1.7	7.4	0.05
	2000	2.0	2.0	143	-1.4	5.2	
	4000	1.6	1.8	137	-1.9		
R2	125	1.9	2.1	154	-2.7	2.5	0.24
	250	1.7	1.7	127	-1.7	4.1	0.36
	500	1.7	1.6	137	-1.0	5.2	0.09
	1000	2.0	1.9	131	-0.5	5.3	0.09
	2000	2.2	2.2	171	-3.7	3.6	
	4000	1.6	1.8	129	-0.9		
R3	125	2.0	1.6	134	-2.1	4.3	0.10
	250	1.7	1.6	112	0.1	3.7	0.17
	500	1.9	1.7	126	-0.5	6.3	0.28
	1000	2.0	1.9	133	-0.4	5.4	0.14
	2000	2.0	2.2	174	-3.7	3.5	
	4000	1.7	1.8	129	-1.2		
R4	125	1.9	1.9	167	-6.5	1.2	0.20
	250	1.6	1.9	145	-2.9	1.2	0.15
	500	1.9	2.1	159	-3.3	3.1	0.32
	1000	2.2	2.2	160	-2.5	2.8	0.16
	2000	2.1	2.1	155	-3.3	2.6	
	4000	1.9	2.0	169	-5.0		
R5	125	1.9	1.5	141	-3.9	2.9	0.29
	250	1.7	1.7	140	-3.3	1.2	0.38
	500	1.9	1.9	142	-2.2	3.9	0.21
	1000	2.2	2.3	166	-2.8	2.6	0.15
	2000	2.0	2.2	160	-2.7	2.7	
	4000	1.7	1.8	124	-0.4		
R6	125	1.9	1.6	153	-2.7	0.3	0.13
	250	1.8	2.1	164	-3.3	-3.4	0.37
	500	1.9	2.2	155	-1.8	1.1	0.15
	1000	2.4	2.1	169	-4.5	1.1	0.14
	2000	2.1	2.1	151	-2.0	1.5	
	4000	1.7	1.8	140	-1.9		
R7	125	2.2	2.2	151	-2.0	-0.4	0.22
	250	1.7	2.1	166	-6.1	-1.8	0.22
	500	2.1	1.9	142	-2.2	1.8	0.25
	1000	2.2	2.1	157	-3.1	1.3	0.12
	2000	2.1	1.9	138	-1.1	2.1	
	4000	1.7	1.6	124	0.1		

S3-

Pos.	Freq	RT	EDT	TS	C	L	LEF
R1	125	2.0	2.3	142	-0.8	3.2	0.06
	250	1.5	1.9	134	-0.9	3.9	0.09
	500	1.8	1.7	114	1.8	4.4	0.08
	1000	2.0	1.9	137	-1.4	3.1	0.12
	2000	2.0	2.2	158	-2.1	3.8	
	4000	1.8	1.9	150	-2.6		
R2	125	2.0	2.1	140	-2.8	2.3	0.23
	250	1.7	1.7	107	1.8	3.5	0.16
	500	1.9	1.7	128	-1.1	5.8	0.14
	1000	2.0	1.9	133	-0.3	4.8	0.14
	2000	2.1	2.3	172	-3.0	2.9	
	4000	1.8	1.8	134	-0.5		
R3	125	2.1	1.8	131	-0.6	3.1	0.15
	250	1.4	1.6	117	1.6	4.0	0.17
	500	1.7	1.8	137	-0.9	5.9	0.17
	1000	1.9	1.6	108	2.5	6.0	0.16
	2000	2.1	2.1	152	-1.3	3.2	
	4000	1.8	1.6	117	1.0		
R4	125	1.9	2.2	167	-3.1	0.2	0.15
	250	1.5	1.6	131	0.1	1.7	0.07
	500	1.8	1.9	145	-1.5	3.6	0.23
	1000	2.1	1.9	137	-1.4	3.0	0.19
	2000	2.1	1.9	147	-2.0	2.6	
	4000	1.6	1.8	138	-2.2		
R5	125	1.7	2.0	165	-3.6	0.9	0.17
	250	1.9	1.9	141	-1.7	0.3	0.07
	500	2.0	1.9	148	-2.1	2.9	0.10
	1000	2.1	2.2	160	-2.2	1.8	0.17
	2000	2.1	2.0	142	-0.6	2.2	
	4000	1.7	1.8	137	-1.2		
R6	125	1.9	1.7	122	-1.3	1.9	0.11
	250	1.7	1.5	113	-0.5	0.0	0.21
	500	1.9	1.9	134	-0.6	1.6	0.19
	1000	2.1	1.9	150	-3.1	1.2	0.04
	2000	2.1	1.9	152	-2.7	1.0	
	4000	1.8	1.9	145	-1.7		
R7	125	1.8	1.4	114	-0.4	0.9	0.30
	250	1.9	1.8	141	-2.8	-2.2	0.25
	500	2.0	1.9	144	-1.4	0.3	0.28
	1000	2.3	2.2	157	-2.4	0.3	0.11
	2000	2.1	1.9	140	-1.4	1.1	
	4000	1.7	1.9	146	-1.9		

Royal Festival Hall, London (**FH**)

Platform parameters

	Px						Sx		
	Freq	RT	EDT	TS	C	EEL	CS	ST1	ST2
S1-P1/S1	250	1.4	0.7	42	8.1		16.7	-17.6	-15.8
	500	1.4	1.0	57	6.4	-13.7	17.3	-14.8	-13.5
	1000	1.5	0.7	39	7.3	-11.4	17.3	-14.4	-13.1
	2000	1.6	1.0	55	5.9	-13.7	13.0	-15.6	-14.3
S2-P2/S2	250	1.3	0.9	56	5.4		18.5	-17.4	-16.1
	500	1.5	1.2	72	4.8	-15.6	11.9	-18.1	-16.4
	1000	1.5	1.3	67	4.8	-15.5	11.8	-13.6	-12.7
	2000	1.5	1.1	55	5.5	-15.0	14.7	-16.0	-14.9
S3-P3/S3	250	1.3	0.8	40	7.6		20.2	-18.0	-16.7
	500	1.5	1.3	68	4.6	-12.5	18.1	-13.2	-12.4
	1000	1.6	1.1	47	6.6	-13.5	19.2	-17.0	-15.9
	2000	1.6	1.3	63	4.8	-15.6	17.4	-16.8	-15.9

Audience parameters (FH)

S1-								S3-						
Freq	RT	EDT	TS	C	L	LEF		Freq	RT	EDT	TS	C	L	LEF
125	1.1	1.0	70	3.9	7.9	0.06		125	1.2	0.9	74	3.1	5.5	0.09
250	1.5	1.2	80	2.3	5.5	0.05		250	1.4	1.2	90	2.0	4.3	0.10
500	1.4	1.3	80	2.6	5.9	0.06	R1	500	1.4	1.3	96	0.5	5.1	0.19
1000	1.6	1.2	76	3.3	5.3	0.16		1000	1.6	1.2	81	2.2	4.5	0.10
2000	1.5	1.3	98	1.7	5.1			2000	1.6	1.4	108	-0.5	3.6	
4000	1.4	1.5	116	-0.6				4000	1.6	1.2	87	2.1		
125	1.2	1.2	125	-4.3	1.6	0.34		125	1.2	1.1	114	-2.2	0.2	0.21
250	1.5	1.6	126	-1.7	0.8	0.31		250	1.5	1.7	134	-1.3	-0.2	0.43
500	1.7	1.6	116	-0.2	1.3	0.37	R2	500	1.5	1.4	97	1.9	2.3	0.39
1000	1.7	1.5	112	0.5	1.8	0.23		1000	1.6	1.6	105	2.0	1.9	0.17
2000	1.6	1.7	138	-1.9	0.9			2000	1.6	1.6	119	-0.4	1.4	
4000	1.6	1.6	133	-1.8				4000	1.6	1.5	121	0.1		
125	1.5	1.3	129	-3.2	-4.9	0.35		125	1.7	1.1	105	0.8	-4.6	0.23
250	1.5	1.6	115	0.8	-0.7	0.18		250	1.4	1.5	134	-2.8	-2.5	0.58
500	1.5	1.5	120	-0.4	-0.8	0.14	R3	500	1.7	1.3	100	1.0	-0.9	0.20
1000	1.6	1.3	100	0.8	-0.1	0.13		1000	1.5	1.0	78	3.6	0.2	0.05
2000	1.7	1.2	95	1.3	0.3			2000	1.7	1.2	80	3.5	-0.2	
4000	1.7	1.4	115	0.0				4000	1.6	1.2	93	2.5		
125	1.2	1.1	95	1.4	1.9	0.04		125	1.4	0.9	86	3.2	0.5	0.08
250	1.5	1.1	105	-0.9	2.3	0.70		250	1.5	1.7	132	-1.5	-0.3	0.46
500	1.5	1.3	112	-1.3	2.0	0.47	R4	500	1.6	1.3	100	1.4	2.2	0.32
1000	1.5	1.3	106	-0.1	2.1	0.24		1000	1.7	1.4	98	1.9	1.3	0.18
2000	1.6	1.6	118	-0.3	0.9			2000	1.6	1.5	105	1.1	1.8	
4000	1.5	1.5	121	-0.4				4000	1.5	1.3	101	1.1		
125	1.4	1.4	125	-3.6	-2.4	0.13		125	1.6	1.5	121	-2.4	-3.9	0.40
250	1.4	1.3	112	-0.9	-0.9	0.43		250	1.5	1.2	86	2.9	1.3	0.15
500	1.7	1.4	122	-2.7	1.0	0.24	R5	500	1.4	1.3	95	1.2	1.8	0.27
1000	1.6	1.7	127	-1.1	-0.7	0.15		1000	1.7	1.0	82	3.3	1.6	0.04
2000	1.6	1.4	101	0.9	0.8			2000	1.7	1.3	98	2.2	1.3	
4000	1.4	1.2	93	2.4				4000	1.4	1.3	115	-0.3		

Derngate, Northampton (NO)

Platform parameters

	Px					Sx			
	Freq	RT	EDT	TS	C	EEL	CS	ST1	ST2
S1-P1/S1	250	1.9	1.8	115	1.0	-16.5	14.2	-15.1	-13.3
	500	2.0	1.7	104	2.1	-12.6	12.9	-16.6	-13.1
	1000	2.1	1.8	106	2.1	-14.2	13.2	-18.2	-14.3
	2000	1.7	1.6	109	0.8	-15.5	7.9	-16.7	-14.1
S2-P2/S2	250	1.8	1.6	100	1.6	-14.8	15.8	-18.4	-15.1
	500	1.6	1.5	119	-0.4	-15.5	12.0	-13.1	-10.4
	1000	2.1	1.7	114	1.3	-15.2	14.0	-14.9	-12.9
	2000	1.6	1.7	126	-0.6	-15.5	9.1	-9.7	-8.4
S3-P3/S3	250	1.9	1.4	77	3.7	-11.9	16.0	-16.6	-14.7
	500	2.0	1.8	123	0.6	-14.3	12.6	-10.9	-9.8
	1000	2.0	1.4	83	3.6	-12.6	14.2	-13.6	-11.9
	2000	1.6	1.2	80	2.9	-10.9	8.9	-11.4	-10.0

Audience parameters (NO)

	S1-							S3-						
	Freq	RT	EDT	TS	C	L	LEF	Freq	RT	EDT	TS	C	L	LEF
R1	125	2.1	2.0	131	-0.5	7.7	0.08	125	2.1	1.6	134	0.0	6.8	0.15
	250	1.8	2.0	149	-2.5	6.4	0.14	250	2.1	2.0	154	-2.7	5.9	0.22
	500	2.1	2.1	155	-2.5	7.3	0.23	500	2.2	2.1	163	-2.3	6.4	0.12
	1000	2.0	11.8	127	-0.2	6.9	0.19	1000		2.1	154	-1.8	5.8	0.10
	2000	1.7	1.7	117	-0.4	5.1		2000		1.9	156	-2.3	4.0	
	4000	1.5	1.3	99	1.2			4000		1.4	111	1.1		
R2	125	1.7	1.6	120	0.3	7.1	0.20	125	2.8	1.9	158	-2.1	5.3	0.15
	250	1.9	1.9	168	-4.5	4.5	0.28	250		2.0	156	-3.0	4.8	0.30
	500	2.0	2.1	159	-2.6	6.9	0.15	500	2.2	2.2	165	-2.5	5.2	0.25
	1000	2.2	2.0	137	-1.1	5.7	0.19	1000		2.2	160	-1.8	4.8	0.26
	2000	1.8	1.7	137	-2.1	3.5		2000		1.9	160	-1.6	2.9	
	4000		1.4	106	1.0			4000		1.7	174	-0.7		
R3	125	2.0	2.6	175	-3.2	4.0	0.22	125	2.4	2.2	173	-2.6	3.2	0.07
	250	2.0	2.2	158	-3.5	4.4	0.24	250	1.9	2.2	202	-7.6	3.1	0.79
	500	2.0	2.4	172	-3.0	4.5	0.22	500	2.1	2.3	165	-2.6	4.3	0.24
	1000	2.2	2.2	148	-1.9	3.9	0.15	1000	2.2	2.2	152	-1.4	3.4	0.21
	2000	1.9	1.9	136	-1.4	1.4		2000	1.9	1.8	132	-1.3	1.3	
	4000		1.6	125	-0.8			4000		1.5	141	0.4		
R4	125	2.3	1.9	170	-4.3	2.6	0.51	125	1.9	1.3	137	-6.3	4.9	0.33
	250	2.0	1.8	134	-0.1	4.6	0.25	250	1.9	1.7	132	-0.6	3.8	0.38
	500	2.1	2.1	148	-2.3	5.5	0.25	500	2.1	2.1	144	-1.0	5.5	0.11
	1000	2.2	2.1	137	-0.4	4.5	0.16	1000	2.2	2.2	156	-1.6	3.1	0.11
	2000	1.8	1.6	109	0.7	3.2		2000	1.8	1.8	140	-1.6	1.5	
	4000		1.3	98	1.9			4000		1.5	115	0.1		
R5	125	1.8	1.8	112	0.9	7.8	0.21	125	1.9	2.5	205	-5.1	3.7	0.74
	250	2.2	2.4	162	-0.6	4.6	0.35	250	2.2	1.8	125	0.0	5.8	0.16
	500	2.1	1.7	109	1.5	7.5	0.25	500	1.9	2.1	156	-1.5	6.4	0.18
	1000	2.2	1.9	141	-1.6	5.5	0.24	1000	2.1	2.0	150	-2.1	4.8	0.22
	2000	1.7	1.7	105	1.1	4.9		2000	1.7	1.9	141	-2.1	3.3	
	4000	1.5	1.4	95	1.6			4000	1.5	1.6	122	-1.4		

Gasteig Philharmonie, München (GM)

Platform parameters

		Px					Sx		
	Freq	RT	EDT	TS	C	EEL	CS	ST1	ST2
S1-P1/S1	250	2.2	1.3	76	4.0	-15.9	18.7	-17.9	-16.5
	500	2.3	1.8	119	1.8	-19.2	17.2	-17.4	-15.8
	1000	2.1	1.6	90	4.2	-17.2	18.2	-19.1	-17.4
	2000	2.3	1.7	95	3.6	-17.0	14.3	-18.0	-16.8
S2-P2/S2	250	2.0	1.5	72	5.4	-16.0	18.8	-19.3	-17.4
	500	2.3	2.1	123	2.0	-18.1	17.5	-19.5	-17.6
	1000	2.1	1.8	100	3.0	-18.2	20.0	-20.2	-18.9
	2000	2.3	1.7	102	3.9	-17.7	14.7	-18.3	-17.5
S3-P3/S3	250	1.7	0.5	42	9.2	-10.6	18.5	-17.0	-16.0
	500	2.1	1.5	84	4.5	-16.5	20.8	-15.0	-14.6
	1000	2.1	1.0	66	6.3	-15.1	20.6	-17.7	-17.0
	2000	2.1	1.1	[illegible]	6.1	-14.9	16.9	-16.0	-15.6

Audience parameters (GM)

S1-

	Freq	RT	EDT	TS	C	L	LEF
R1	125	1.6	1.1	103	-0.3	7.1	0.04
	250	2.0	2.1	133	-0.1	6.3	0.08
	500	1.9	2.1	130	0.2	6.0	0.06
	1000	2.1	1.4	75	4.0	6.8	0.03
	2000	1.8	1.8	128	-1.5	3.6	
	4000	1.6	1.5	113	-0.7	2.7	
R2	125	1.9	1.4	101	1.5	2.9	0.18
	250	2.0	2.3	170	-3.7	4.9	0.11
	500	2.0	2.4	177	-2.2	4.5	0.19
	1000	1.8	1.9	131	-0.9	4.2	0.19
	2000	1.8	2.0	152	-2.9	2.2	
	4000	1.7	1.9	144	-2.6	0.6	
R3	125	1.6	1.5	135	-2.2	3.7	0.08
	250	2.0	1.7	154	-3.7	5.2	0.10
	500	2.0	1.7	120	1.2	6.2	0.22
	1000	1.8	1.5	99	2.8	5.4	0.10
	2000	1.8	1.5	110	1.8	3.4	
	4000	1.6	1.1	89	3.4	2.6	
R4	125	1.9	1.7	147	-4.8	0.6	0.12
	250	2.1	2.1	168	-4.9	3.8	0.35
	500	1.9	2.2	174	-2.9	4.4	0.28
	1000	2.0	1.8	147	-3.6	3.5	0.39
	2000	1.8	1.7	122	-0.4	3.0	
	4000	1.6	1.6	130	-1.9	1.2	
R5	125	1.6	1.4	121	-1.2	4.7	0.18
	250	2.2	2.2	142	1.0	4.2	0.25
	500	2.1	1.8	122	1.7	5.3	0.28
	1000	2.1	1.4	95	4.4	5.1	0.14
	2000	1.8	1.7	116	1.2	2.7	
	4000	1.5	1.3	88	3.9	2.7	
R6	125	1.8	2.0	172	-3.0	-0.6	0.23
	250	1.8	2.0	166	-5.8	1.9	0.61
	500	2.1	1.9	136	-0.7	3.8	0.11
	1000	2.0	1.4	108	2.9	3.9	0.20
	2000	1.8	1.6	116	0.8	1.5	
	4000	1.6	1.4	104	1.6	0.0	

S3-

	Freq	RT	EDT	TS	C	L	LEF
R1	125	1.7	1.6	133	-0.3	3.8	0.07
	250	1.9	1.9	162	-2.3	5.7	0.09
	500	2.1	2.2	150	-1.1	4.7	0.07
	1000	2.0	2.1	142	-1.6	3.8	0.13
	2000	1.9	2.1	153	-2.6	1.6	
	4000	1.8	1.6	102	1.7	2.6	
R2	125	1.3	1.6	145	-2.1	3.1	0.24
	250	2.1	2.0	160	-3.4	5.3	0.49
	500	2.1	2.2	166	-3.9	4.2	0.20
	1000	2.0	2.1	147	-1.1	3.3	0.15
	2000	1.9	2.1	156	-1.8	1.0	
	4000	1.7	1.9	128	-0.4	0.0	
R3	125	1.7	1.8	155	-6.1	-1.1	0.70
	250	2.1	1.8	118	1.2	4.5	0.03
	500	1.9	1.8	126	-0.2	5.1	0.09
	1000	1.8	1.9	118	0.7	3.2	0.09
	2000	1.9	2.1	151	-2.5	0.4	
	4000	1.7	1.7	123	-0.5	5.6	
R4	125	2.0	1.4	140	-5.2	0.8	0.18
	250	1.9	1.6	139	-3.7	4.1	0.14
	500	2.0	1.9	150	-4.0	4.8	0.14
	1000	1.9	1.9	138	-1.5	3.2	0.10
	2000	1.9	1.7	124	-0.1	2.6	
	4000	1.6	1.6	125	-0.7	1.3	
R5	125	1.6	1.7	156	-5.7	1.8	0.43
	250	2.0	2.3	173	1.5	2.6	0.17
	500	1.9	2.4	178	-3.6	2.6	0.21
	1000	2.0	2.2	164	-3.1	1.7	0.28
	2000	1.8	2.2	160	-3.0	0.2	
	4000	1.8	1.9	143	-2.3	-1.4	
R6	125	1.7	2.1	[illegible]	-2.5	-2.6	0.32
	250	2.0	1.8	136	-1.3	1.7	0.30
	500	2.1	1.9	131	0.0	2.7	0.25
	1000	2.0	1.7	111	1.0	2.4	0.12
	2000	1.9	1.7	115	1.5	0.1	
	4000	1.8	1.6	118	0.4	-1.6	

Liederhalle, Stuttgart (LS)

Platform parameters

	Px					Sx			
	Freq	RT	EDT	TS	C	EEL	CS	ST1	ST2
S1-P1/S1	250	1.7	1.1	69	4.6	-13.4	14.7	-17.3	-13.9
	500	1.8	1.4	87	2.1	-6.6	13.9	-7.4	-5.9
	1000	2.0	1.2	67	5.0	-11.3	15.4	-16.0	-14.2
	2000	2.0	1.7	110	0.6	-13.7	10.9	-15.7	-13.9
S2-P2/S2	250	1.5	1.0	64	6.1	-13.6	15.5	-16.1	-13.9
	500	1.9	1.7	117	1.7	-16.8	13.9	-15.6	-13.2
	1000	2.1	1.8	119	0.7	-15.8	14.9	-15.0	-13.1
	2000	2.0	1.7	115	-0.2	-16.4	13.0	-15.7	-14.3
S3-P3/S3	250	1.5	0.9	68	5.1	-14.3	16.9	-12.1	-11.1
	500	1.8	1.4	90	2.6	-13.2	15.3	-12.5	-11.3
	1000	1.9	1.2	75	4.8	-11.4	14.7	-14.9	-12.9
	2000	2.0	0.9	51	6.1	-7.5	14.6	-16.0	-13.8

Audience parameters (**LS**)

	S1-							S3-						
	Freq	RT	EDT	TS	C	L	LEF	Freq	RT	EDT	TS	C	L	LEF
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	125	1.9	1.7	111	2.6	5.2	0.14	125	2.0	2.2	134	0.3	4.0	0.05
	250	1.7	1.8	134	-1.5	5.1	0.06	250	1.9	2.1	137	0.6	2.7	0.05
R1	500	2.0	1.8	124	1.4	6.8	0.07	500	2.0	2.4	168	-1.4	4.8	0.07
	1000	2.1	1.9	123	1.6	6.6	0.13	1000	2.1	2.2	150	-0.2	4.7	0.08
	2000	2.0	2.3	166	-1.7	3.2		2000	2.1	2.3	182	-3.7	1.8	
	4000	1.9	1.9	138	0.0	1.7		4000	1.9	1.9	129	0.3	1.2	
	125	1.9	1.5	129	-3.1	2.0	0.08	125	2.3	2.6	183	-2.5	-1.6	0.06
	250	1.7	1.5	125	-0.6	4.6	0.06	250	1.6	1.6	113	1.9	4.0	0.04
R2	500	2.0	2.4	182	-5.1	3.1	0.21	500	2.1	2.5	180	-4.8	2.8	0.17
	1000	2.3	2.3	173	-4.0	3.2	0.09	1000	2.2	2.6	185	-4.0	2.1	0.13
	2000	2.1	2.4	186	-4.9	1.0		2000	2.1	2.3	174	-3.1	0.8	
	4000	2.0	2.0	151	-3.4	0.0		4000	2.0	2.0	148	-2.7	-1.3	
	125	1.5	1.6	159	-9.5	3.9	0.67	125	1.9	1.7	169	-6.3	1.2	0.41
	250	1.7	1.7	148	-2.8	2.6	0.25	250	1.7	1.8	134	-1.1	5.8	0.26
R3	500	2.0	1.9	162	-4.9	4.2	0.18	500	1.9	2.3	171	-1.9	1.8	0.29
	1000	2.2	2.4	176	-4.3	2.4	0.18	1000	2.2	2.3	166	-1.9	2.3	0.29
	2000	2.1	2.2	160	-2.6	1.2		2000	2.2	2.0	137	-0.1	1.2	
	4000	1.9	1.8	132	-1.2	-0.3		4000	2.1	1.6	116	0.7	-0.4	
	125	2.0	1.2	103	1.3	3.9	0.04	125	1.6	1.6	129	-1.5	4.9	0.13
	250	1.6	1.8	133	-1.6	3.8	0.21	250	1.8	1.2	106	0.6	3.7	0.12
R4	500	2.0	2.0	133	-0.7	4.8	0.12	500	2.0	2.2	151	-1.2	3.9	0.31
	1000	2.2	2.0	142	-0.8	3.8	0.23	1000	2.2	2.1	142	-1.6	3.7	0.18
	2000	2.1	2.1	145	-1.0	2.2		2000	2.1	2.1	143	-0.6	1.5	
	4000	1.9	1.7	123	0.0	0.3		4000	1.9	1.6	118	0.6	0.5	
	125	1.5	1.6	149	-5.1	2.3	0.10	125	1.7	1.7	131	-2.4	1.8	0.30
	250	1.8	1.9	136	-0.9	2.1	0.14	250	1.6	1.0	92	2.0	4.1	0.06
R5	500	2.0	2.0	150	-2.3	3.9	0.11	500	1.9	2.0	142	-1.9	3.6	0.27
	1000	2.2	2.1	158	-3.1	3.2	0.05	1000	2.2	2.0	140	-1.6	3.1	0.06
	2000	2.0	2.1	157	-2.3	1.5		2000	2.1	1.7	112	1.1	2.7	
	4000	2.0	1.8	140	-2.2	-0.6		4000	1.9	1.4	103	1.4	0.1	
	125	1.6	1.3	137	-4.6	2.4	0.09	125	1.7	1.1	116	-1.8	1.6	0.09
	250	1.7	1.9	147	-2.2	0.8	0.08	250	1.8	1.5	110	1.3	0.8	0.06
R6	500	2.0	1.9	158	-2.6	1.5	0.11	500	1.9	1.7	125	0.3	2.4	0.12
	1000	2.2	2.2	170	-2.6	0.9	0.11	1000	2.2	2.4	160	-1.6	0.9	0.05
	2000	2.2	2.5	191	-5.0	-2.0		2000	2.2	2.2	163	-2.2	-1.9	
	4000	2.0	1.8	132	-0.3	-2.9		4000	2.0	1.8	128	0.3	-3.1	

Concertgebouw, Amsterdam (**CG**)

Platform parameters

	Px					| Sx			
	Freq	RT	EDT	TS	C	EEL	CS	ST1	ST2
S1-P1/S1	250	2.5	2.2	135	-1.6	-17.	15.1	-22.5	-16.3
	500	2.2	2.4	150	-1.1	-15.	14.7	-19.3	-15.0
	1000	2.5	2.1	141	-1.2	-16.	14.6	-17.5	-14.8
	2000	2.3	2.1	142	-1.4	-16.	10.8	-17.0	-14.6
S2-P2/S2	250	2.2	2.0	114	1.4	-14.	17.8	-20.9	-18.2
	500	2.6	2.2	161	-1.8	-17.	13.9	-18.4	-14.1
	1000	2.4	1.8	109	1.1	-13.	14.2	-17.5	-14.1
	2000	2.3	1.4	74	4.3	-11.	12.5	-17.6	-15.7
S3-P3/S3	250	2.1	1.5	98	0.8	-14.	16.4	-16.1	-14.1
	500	2.1	1.8	121	-0.6	-14.	14.9	-17.1	-14.5
	1000	2.5	2.1	145	-1.2	-17.	15.9	-17.1	-15.4
	2000	2.5	2.1	145	-1.2	-20.	10.1	-18.8	-17.3

Audience parameters (CG)

S1-

Position	Freq	RT	EDT	TS	C	L	LEF
R1	125	2.5	2.3	167	-2.9	2.4	0.47
	250	2.2	1.9	121	1.2	8.5	0.06
	500	2.4	2.0	130	0.4	9.4	0.08
	1000	2.6	2.1	127	0.5	8.3	0.14
	2000	2.2	1.8	106	2.0	10.3	
	4000	1.9	1.1	67	4.2	5.7	
R2	125	2.4	2.3	206	-5.8	5.7	0.17
	250	2.3	2.8	202	-6.9	6.0	0.15
	500	2.4	3.0	226	-6.9	5.8	0.30
	1000	2.5	2.9	209	-4.3	5.4	0.15
	2000	2.3	2.6	199	-5.2	6.8	
	4000	2.0	2.1	165	-4.0	0.9	
R3	125	2.7	2.8	214	-6.3	4.9	0.14
	250	2.7	2.9	217	-5.3	4.2	0.15
	500	2.4	2.7	210	-5.7	5.8	0.26
	1000	2.6	2.8	218	-5.3	4.4	0.29
	2000	2.3	2.5	190	-3.8	5.9	
	4000	2.0	2.1	159	-2.3	-0.2	
R4	125	2.4	2.4	189	-4.9	7.1	0.06
	250	2.7	2.4	203	-6.0	4.4	0.19
	500	2.3	2.8	215	-6.2	5.2	0.17
	1000	2.7	2.9	212	-4.9	4.2	0.18
	2000	2.4	2.5	183	-2.7	5.5	
	4000	2.0	2.2	162	-2.4	1.8	
R5	125	2.7	2.7	227	-4.9	4.0	0.19
	250	2.5	3.0	211	-3.6	4.4	0.06
	500	2.6	2.7	192	-2.8	6.1	0.09
	1000	2.5	2.8	200	-2.6	5.3	0.08
	2000	2.4	2.6	198	-5.8	6.1	
	4000	1.9	2.2	164	-3.5	0.0	

S3-

Position	Freq	RT	EDT	TS	C	L	LEF
R1	125	2.9	3.0	201	-3.4	3.8	0.08
	250	2.5	2.5	204	-6.2	4.9	0.07
	500	2.5	2.8	222	-6.8	6.4	0.07
	1000	2.6	2.9	216	-6.2	5.2	0.16
	2000	2.4	2.5	197	-5.5	6.4	
	4000	1.9	2.1	164	-3.2	0.3	
R2	125	2.8	2.9	227	-8.1	3.5	0.22
	250	2.3	3.0	212	-5.3	4.4	0.06
	500	2.5	2.6	213	-5.8	5.4	0.31
	1000	2.5	2.9	213	-5.5	4.4	0.39
	2000	2.3	2.6	204	-5.7	5.6	
	4000	2.0	2.1	162	-3.0	-0.7	
R3	125	2.8	3.8	296	-8.9	1.5	0.28
	250	2.5	2.9	220	-5.8	3.2	0.08
	500	2.4	2.6	195	-3.9	5.3	0.12
	1000	2.5	2.7	201	-4.9	4.7	0.14
	2000	2.3	2.5	196	-4.8	5.2	
	4000	1.9	2.0	155	-2.3	-1.2	
R4	125	2.3	3.2	231	-7.0	2.4	0.20
	250	2.6	2.4	189	-3.9	3.6	0.15
	500	2.5	2.4	192	-4.5	4.4	0.16
	1000	2.5	2.8	200	-3.7	4.2	0.11
	2000	2.3	2.5	176	-2.2	5.5	
	4000	2.0	2.1	154	-2.3	-1.8	
R5	125	2.8	2.8	251	-6.9	3.5	0.14
	250	2.6	2.7	209	-6.0	3.6	0.13
	500	2.5	2.8	215	-5.3	4.9	0.08
	1000	2.6	3.0	215	-3.3	4.6	0.12
	2000	2.4	2.6	193	-4.7	6.0	
	4000	2.2	2.1	165	-3.4	-0.9	

Göteborgs Koncerthus, Göteborg (GK)

Platform parameters

	Px					Sx			
	Freq	RT	EDT	TS	C	EEL	CS	ST1	ST2
S1-P1/S1	250	2.0	1.7	78	4.1	-13.4	16.1	-14.0	-13.1
	500	1.8	1.5	94	4.1	-13.0	15.9	-13.9	-12.8
	1000	1.6	1.5	84	3.6	-13.8	17.3	-17.1	-15.7
	2000	1.7	1.5	76	4.8	-12.7	13.2	-16.2	-15.0
S2-P2/S2	250	1.9	1.4	86	3.7	-12.8	16.9	-14.4	-13.9
	500	1.4	1.6	125	0.0	-14.0	16.9	-15.9	-14.8
	1000	1.5	1.7	114	0.5	-15.2	17.0	-15.0	-14.2
	2000	1.5	1.7	104	1.7	-13.5	12.8	-16.1	-15.0
S3-P3/S3	250	1.5	1.5	88	3.7	-11.3	19.1	-12.7	-12.4
	500	1.6	1.6	83	3.8	-11.3	17.6	-14.4	-13.8
	1000	1.5	1.4	63	5.2	-10.6	17.4	-13.4	-12.8
	2000	1.3	1.6	100	2.2	-10.3	11.3	-8.4	-8.0

Audience parameters (**GK**)

S1-

	Freq	RT	EDT	TS	C	L	LEF
	125	2.2	3.0	183	-2.7	7.9	0.25
	250	1.8	2.0	147	-1.0	7.3	0.05
R1	500	1.8	2.0	130	1.0	5.6	0.05
	1000	1.5	1.6	102	2.1	6.6	0.04
	2000	1.5	1.2	91	3.1	-1.2	
	4000	1.4	1.4	100	2.3	-3.8	
	125	1.9	1.5	213	-9.4	9.6	0.02
	250	1.8	2.1	190	-6.0	5.1	0.04
R2	500	1.6	2.0	167	-3.5	4.7	0.13
	1000	1.7	1.7	135	-2.1	5.1	0.13
	2000	1.6	1.8	141	-2.0	3.6	
	4000	1.5	1.7	129	-1.4	2.8	
	125	2.5	3.2	235	-9.6	4.8	0.11
	250	1.9	2.2	169	-4.7	4.9	0.05
R3	500	1.8	1.9	140	-1.8	4.3	0.07
	1000	1.7	1.9	125	0.1	4.6	0.07
	2000	1.6	1.8	122	0.7	3.7	
	4000	1.5	1.7	121	0.1	2.1	
	125	2.1	1.8	126	-2.0	6.0	0.13
	250	1.9	1.3	105	0.4	7.9	0.14
R4	500	1.9	1.4	102	2.0	6.6	0.08
	1000	1.7	1.5	110	-1.2	5.6	0.20
	2000	1.6	1.5	115	-0.8	4.1	
	4000	1.5	1.4	106	0.1	2.6	
	125	2.4	2.6	196	-5.1	3.0	0.06
	250	2.0	2.3	154	-0.4	4.6	0.06
R5	500	1.8	2.1	149	-0.5	4.2	0.11
	1000	1.7	1.9	132	-0.1	4.2	0.09
	2000	1.6	2.0	150	-1.3	2.2	
	4000	1.6	1.8	133	-0.8	1.0	

S3-

	Freq	RT	EDT	TS	C	L	LEF
	125	1.9	1.4	145	-1.3	3.5	0.12
	250	2.0	1.7	112	2.8	6.3	0.05
R1	500	1.6	2.0	141	-1.1	4.4	0.06
	1000	1.6	1.9	152	-2.4	2.7	0.21
	2000	1.6	1.9	131	-0.3	3.0	
	4000	1.6	1.9	137	-1.6	0.9	
	125	2.0	1.6	182	-4.4	6.7	0.04
	250	1.8	2.0	146	-2.1	5.7	0.08
R2	500	1.6	1.9	147	-3.1	4.7	0.06
	1000	1.6	1.9	132	-0.6	4.0	0.06
	2000	1.6	1.8	125	-0.7	3.6	
	4000	1.5	1.6	115	0.1	2.0	
	125	2.2	1.0	121	-0.8	6.7	0.04
	250	1.7	1.6	122	-3.5	7.2	0.05
R3	500	1.8	1.6	124	-0.9	4.2	0.06
	1000	1.7	1.7	108	1.1	4.4	0.11
	2000	1.6	1.6	109	1.9	3.7	
	4000	1.6	1.4	109	1.1	1.8	
	125	1.9	1.8	96	4.5	5.5	0.08
	250	1.8	0.8	82	5.0	8.5	0.05
R4	500	1.7	1.1	83	5.5	6.6	0.07
	1000	1.7	1.4	97	3.3	4.5	0.10
	2000	1.5	1.0	97	6.3	6.0	
	4000	1.4	0.6	69	7.0	4.6	
	125	2.1	2.0	129	-0.5	4.1	0.07
	250	1.9	1.7	125	0.3	4.9	0.04
R5	500	1.8	0.9	123	1.8	3.4	0.08
	1000	1.6	1.6	114	1.6	3.7	0.10
	2000	1.6	1.7	111	2.1	2.6	
	4000	1.6	1.4	95	3.9	1.9	

C Averaged acoustical and physical data for 32 halls.

In the tables below each row of data belongs to one hall, which is identified by a two letter symbol in the leftmost column. Besides the set of symbols with which the reader is already familiar from the previous chapters, the following are used to identify 12 more Danish halls:

bh	:	Baltorp Hallen, Ballerup
es	:	Assembly hall, Esbjerg Highschool
ha	:	Theatre, Hotel "Harmonien", Haderslev
kh	:	Assembly hall, Kulsvierskolen, Hillerød
ho	:	Holstebro Hallen
hg	:	Assembly hall, Holte Highschool
ka	:	Kalundborg Hallen
kk	:	Congress Hall, Kolding
jr	:	Assembly hall, Restaurant "Jylland", Randers
vu	:	Assembly hall, Vordingborg education centre
so	:	Symfonien, Aalborg
ou	:	Assembly hall, Aarhus university

The acoustical data are presented without the units. However, the units presented in the list of symbols p. 10 apply.

The acoustical data are averaged over octave bands as described in section 1.4.1 and over the source and relevant receiver positions described in section 1.4.2.

	MT	RT	EDT	TS	C	L	LEF	BRRT	BRL	EDTP	EEL	ST1	ST2	CS
BA	1.99	1.93	1.91	141	-1.6	2.9	0.17	0.90	-1.7	1.25	-13.2	-13.2	-12.0	15.1
CA	2.20	2.15	2.04	143	-1.2	2.9	0.18	0.90	-1.5	1.46	-15.3	-16.6	-14.3	15.6
CG	2.51	2.46	2.64	196	-4.4	5.5	0.16	1.02	-1.2	1.98	-15.5	-18.3	-15.3	14.2
ED	2.05	2.01	2.13	156	-1.7	3.4	0.23	0.97	-0.9	1.45	-13.6	-16.3	-13.6	12.9
FH	1.58	1.56	1.38	104	0.7	1.6	0.24	0.90	-1.3	1.03	-14.0	-16.0	-14.8	16.3
FS	2.20	2.18	2.15	155	-1.6	2.3	0.11	1.04	-1.0	1.59	-14.4	-15.8	-14.2	16.3
GK	1.71	1.71	1.70	127	0.0	4.7	0.09	1.17	1.3	1.56	-12.7	-14.3	-13.5	16.0
GM	1.98	1.95	1.91	139	-1.0	3.6	0.20	0.93	-1.1	1.47	-17.1	-18.0	-16.8	18.0
LS	2.09	2.00	2.03	149	-1.7	2.8	0.15	0.84	-0.4	1.33	-12.5	-14.5	-12.6	14.5
MW	3.16	3.04	3.16	226	-5.1	6.5	0.16	0.97	0.1	1.99	-13.3	-13.0	-11.8	13.7
NO	2.11	2.00	2.25	147	-1.7	4.7	0.24	0.97	-0.4	1.60	-14.0	-14.6	-12.3	12.6
bh	2.10	1.90	1.90	146	-2.1	6.7	0.27	0.90	1.6	1.40	-12.1	-12.0	-10.6	12.1
es	2.10	1.98	1.90	141	-1.3	10.8	0.43	0.73	-0.3	1.60	-11.4	-10.3	-8.5	10.4
ha	1.40	1.43	1.40	104	0.7	9.9	0.36	1.18	1.4	1.20	-9.0	-7.7	-6.1	9.4
kh	1.80	1.80	1.80	151	-1.1	7.1	0.26	0.83	1.9	1.10	-10.2	-12.3	-10.9	13.2
ho	2.80	2.40	2.40	162	-2.0	7.1	0.19	0.73	0.8	1.50	-11.2	-14.1	-12.3	13.6
hg	2.40	2.28	2.30	174	-3.3	9.6	0.34	1.00	4.2	1.60	-10.5	-9.7	-7.8	9.1
ka	1.50	1.48	1.20	92	1.8	6.2	0.34	0.83	2.0	0.90	-10.1	-10.6	-9.7	13.5
kk	2.80	2.55	2.40	161	-0.9	7.0	0.06	0.89	1.5	1.80	-13.2	-13.6	-12.6	14.7
dr	2.10	2.03	1.90	137	-0.9	5.1	0.17	0.83	0.9	1.50	-14.1	-14.5	-13.0	13.9
fc	1.80	1.68	1.70	127	-0.8	3.3	0.29	0.89	0.1	1.00	-11.0	-14.0	-12.6	15.6
of	1.80	1.93	2.00	151	-2.0	5.8	0.29	1.19	3.0	1.50	-13.6	-13.3	-10.9	11.5
sa	1.80	1.75	1.70	127	-0.8	5.5	0.22	1.06	0.5	1.10	-11.9	-12.2	-10.9	14.5
ti	2.40	2.35	2.30	162	-2.1	6.0	0.14	0.92	0.3	1.40	-10.6	-10.9	-10.1	13.4
ck	2.30	2.23	2.30	163	-2.2	4.6	0.25	1.04	0.4	1.80	-14.4	-16.5	-13.5	13.8
jr	2.10	1.90	2.00	153	-2.2	9.2	0.33	0.71	2.7	1.50	-13.0	-11.7	-10.0	11.4
ms	1.70	1.68	1.60	122	-0.6	10.2	0.40	0.97	2.6	1.40	-11.0	-12.6	-10.6	12.1
vu	2.60	2.38	2.60	187	-3.6	5.0	0.23	0.73	1.0	1.50	-13.7	-14.1	-12.3	13.3
so	1.20	1.18	1.20	101	-0.3	6.5	0.24	1.17	1.6	1.00	-12.8	-12.7	-11.6	14.9
oh	2.20	2.08	2.00	152	-2.1	3.6	0.18	0.84	1.5	1.10	-12.5	-15.3	-14.1	16.7
mo	1.60	1.53	1.50	109	0.5	2.4	0.16	0.97	-1.7	1.00	-11.4	-13.3	-12.3	15.0
ou	1.50	1.45	1.50	121	-2.2	4.8	0.26	0.93	4.8	1.00	-11.6	-15.6	-14.2	16.6

Expected values according to diffuse field theory

Hall	RT	Cexp	TSex	Lexp	ST1exp	ST2exp	CSexp
BA	1.93	-1.1	140	5.4	-18.9	-16.7	17.1
CA	2.15	-1.7	156	4.9	-19.6	-17.3	17.3
CG	2.46	-2.5	178	6.2	-18.7	-16.3	15.8
ED	2.01	-1.4	146	6.0	-18.3	-16.1	16.4
FH	1.56	0.1	113	3.5	-20.2	-18.2	19.6
FS	2.18	-1.8	158	6.5	-18.1	-15.7	15.7
GK	1.71	-0.4	124	6.6	-17.4	-15.3	16.2
GM	1.95	-1.2	141	3.1	-21.1	-18.9	19.3
LS	2.00	-1.3	145	6.0	-18.4	-16.1	16.4
MW	3.04	-3.6	220	8.1	-17.5	-14.9	13.5
NO	2.00	-1.3	145	6.7	-17.6	-15.4	15.7
bh	1.90	-1.0	138	8.6	-15.6	-13.4	13.9
es	1.98	-1.3	143	11.9	-12.4	-10.1	10.5
ha	1.43	0.7	104	13.5	-10.0	-8.1	9.8
kh	1.80	-0.7	130	9.4	-14.7	-12.6	13.3
ho	2.40	-2.3	174	8.0	-16.9	-14.4	14.0
hg	2.28	-2.1	165	12.6	-12.1	-9.7	9.5
ka	1.48	0.4	107	10.5	-13.1	-11.2	12.8
kk	2.55	-2.7	185	8.2	-16.8	-14.3	13.7
dr	2.03	-1.4	147	7.4	-17.0	-14.7	15.0
fc	1.68	-0.3	122	6.1	-17.8	-15.7	16.7
of	1.93	-1.1	140	8.4	-15.8	-13.6	14.1
sa	1.75	-0.6	127	9.0	-14.9	-12.8	13.7
ti	2.35	-2.2	170	7.7	-17.1	-14.7	14.4
ok	2.23	-1.9	162	7.0	-17.6	-15.2	15.1
jr	1.90	-1.0	138	13.0	-11.2	-9.0	9.5
ms	1.68	-0.3	122	11.8	-12.1	-10.0	11.0
vu	2.38	-2.3	172	7.8	-17.0	-14.6	14.2
so	1.18	1.9	86	9.0	-14.2	-12.6	15.1
oh	2.08	-1.5	151	5.6	-18.8	-16.6	16.7
mo	1.53	0.2	111	5.4	-18.3	-16.4	17.8
ou	1.45	0.6	105	7.9	-15.6	-13.8	15.4

Measured deviations from diffuse field predictions

Hal	EDTdif	Cdif	TSdif	Ldif	EDTPdi	ST1dif	ST2dif	CSdif
BA	-0.02	-0.4	1	-2.5	0.68	5.7	4.7	-2.1
CA	-0.11	0.6	-13	-2.0	0.69	3.0	3.0	-1.7
CG	0.18	-1.9	18	-0.7	0.48	0.4	1.0	-1.5
ED	0.12	-0.3	10	-2.6	0.56	2.0	2.5	-3.5
FH	-0.18	0.5	-9	-1.9	0.53	4.2	3.4	-3.2
FS	-0.03	0.2	-3	-4.2	0.59	2.3	1.5	0.6
GK	-0.01	0.5	3	-1.9	0.15	3.1	1.8	-0.3
GM	-0.04	0.2	-3	0.5	0.48	3.2	2.1	-1.3
LS	0.03	-0.3	4	-3.2	0.67	3.9	3.5	-1.9
MW	0.12	-1.6	5	-1.5	1.05	4.5	3.1	0.2
NO	0.25	-0.4	2	-2.0	0.40	3.0	3.1	-3.1
bh	0.00	-1.1	8	-1.9	0.50	3.6	2.8	-1.8
es	-0.08	0.0	-2	-1.1	0.38	2.1	1.6	-0.1
ha	-0.03	0.0	0	-3.6	0.23	2.3	2.0	-0.4
kh	0.00	-0.4	5	-2.3	0.70	2.4	1.7	-0.1
ho	0.00	0.3	-12	-0.9	0.90	2.8	2.1	-0.4
hg	0.02	-1.2	9	-3.0	0.68	2.4	1.9	-0.4
ka	-0.28	1.4	-15	-4.3	0.58	2.5	1.5	0.7
kk	-0.15	1.8	-24	-1.2	0.75	3.2	1.7	1.0
dr	-0.13	0.5	-10	-2.3	0.53	2.5	1.7	-1.1
fo	0.02	-0.5	5	-2.8	0.68	3.8	3.1	-1.1
of	0.07	-0.9	11	-2.6	0.43	2.5	2.7	-2.6
sa	-0.05	-0.2	0	-3.5	0.65	2.7	1.9	0.8
ti	-0.05	0.1	-8	-1.7	0.95	6.2	4.6	-1.0
ok	0.07	-0.3	1	-2.4	0.43	1.1	1.7	-1.3
jr	0.10	-1.2	15	-3.8	0.40	-0.5	-1.0	1.9
ms	-0.08	-0.3	0	-1.6	0.28	-0.5	-0.6	1.1
vu	0.22	-1.3	15	-2.8	0.88	2.9	2.3	-0.9
so	0.02	-2.2	15	-2.5	0.18	1.5	1.0	-0.2
oh	-0.08	-0.6	1	-2.0	0.98	3.5	2.5	0.0
mo	-0.03	0.3	-2	-3.0	0.53	5.0	4.1	-2.8
ou	0.05	-2.8	16	-3.1	0.45	0.0	-0.4	1.2

Geometrical data

Hall	BA	CA	CG	ED	FH	FS	GK	GM	LS	MW	NO	bh	es	ha	kh	ho
Volume [m^3]	17750	22000	18700	16000	21950	15500	11900	30000	16000	15000	13500	8300	4000	2000	6600	12100
AUDIENCE AREA																
Number of seats	2026	1952	2040	2548	2901	2168	1286	2387	1994	1600	1398	500	470	355	700	600
Volume per seat incl. 70 musicians [m^3]	8.5	10.9	8.9	6.1	7.4	6.9	8.8	12.2	7.8	9.0	9.2	19.6	7.4	4.7	8.6	18.0
Distance between seat rows [cm] (on balconies)	101	90	80	80-95	80	80 (72)	75	95-100	100	75 (67)	90	106	85	89	92	90
seat width [cm]	53	58	55	55	55	51-55	55	55-67	58	51	55	59	52	59	52	54
Netto area per seat [m^2]	0.54	0.52	0.44	0.48	0.44	0.42(0.38)	0.47	0.60	0.58	0.38(0.35)	0.50	0.59	0.44	0.53	0.48	0.49
Netto area of seating [m^2]	1050	1070	900	1100	1480	1050	650	1500	1150	620	700	300	210	190	340	290
Distance from platform front to rearmost seat [m]	33	30	26	35	39	29	32	42	36	40	26	21	14	20	29	20
Mean width between side walls [m]	40.0	30.0	28.5	39.0	32.0	34.0	27.0	55.0	35.0	19.5	27.0	22.0	13.5	13.6	21.4	38.4
Mean ceiling height [m]	15.0	18.0	17.5	18.5	15.0	14.0	14.5	15.0	12.6	17.5	16.0	8.4	10.5	5.0	7.1	10.0
Angle between side walls [degrees]	60	47	0	30	10	30	28	72	50	0	0	0	0	0	0	0
Floor slope angle [degrees]	15	20	0	15	20	15	3	20	5	5	15	0	0	13	0	0

Hall	hg	ka	kk	dr	fo	of	sa	ti	ok	jr	ms	vu	so	oh	mo	ou
Volume [m^3]	4000	4200	12200	11700	13000	8800	6900	12700	14000	3000	3500	13400	4700	18200	14100	7400
AUDIENCE AREA																
Number of seats	607	650	600	1093	2127	1373	900	1780	1272	650	340	1130	453	1125	1477	470
Volume per seat incl. 70 musicians [m^3]	6.6	5.8	18.2	9.3	5.9	6.1	7.1	6.9	10.4	4.2	8.5	10.3	9.0	15.2	9.1	15.7
Distance between seat rows [cm] (on balconies)	92	90	100	85	80	75	80	83	90	100	82	90	91	79	94	62
seat width [cm]	52	51	50	55	54	50	56	58	55	47	60	53	59	54	53	62
Netto area per seat [m^2]	0.48	0.46	0.50	0.47	0.43	0.38	0.45	0.43	0.49	0.47	0.49	0.48	0.54	0.42	0.55	0.56
Netto area of seating [m^2]	320	300	300	550	920	510	420	760	620	300	170	540	243	470	810	260
Distance from platform front to rearmost seat [m]	25	18	20	21	35	23	27	35	31	17	14	32	21	30	33	16
Mean width between side walls [m]	17.0	21.5	40.0	30.0	26.5	17.8	26.2	32.0	28.0	17.0	19.0	31.8	19.8	31.4	36.0	15.5
Mean ceiling height [m]	6.5	7.4	8.5	15.0	11.0	13.5	9.0	13.5	13.0	7.5	8.0	8.9	8.0	13.5	14.0	17.5
Angle between side walls [degrees]	0	0	0	40	0	0	0	38	0	20	-29	0	0	0	54	-44
Floor slope angle [degrees]	0	0	0	20	8	0	4	6	9	0	5	0	11	[illegible]	20	0

Hall	BH	CA	CG	ED	FH	FS	GK	GM	LS	MU	NO	bh	es	ha	kh	ho	hg	ka	kk	dr	fo	of	sa	ti	ok	jr	ms	vu	so	oh	mo	ou
Height * width [m^2]	600.0	540.0	498.8	536.5	480.0	476.0	391.5	825.0	441.0	341.3	432.0	184.8	141.8	68.0	151.9	384.0	110.5	159.1	340.0	450.0	291.5	240.3	235.8	432.0	364.0	127.5	152.0	283.0	158.4	423.9	364.0	271.3
Ratio: Width/height	2.667	1.667	1.629	1.568	2.133	2.429	1.862	3.667	2.778	1.114	1.688	2.619	1.286	2.720	3.014	3.840	2.615	2.905	4.706	2.000	2.409	1.319	2.911	2.370	2.154	2.267	2.375	3.573	2.475	2.326	1.857	0.986
Ratio: Distance/ (height*width) [1/m]	0.055	0.056	0.052	0.065	0.081	0.061	0.082	0.051	0.082	0.117	0.060	0.112	0.101	0.294	0.188	0.052	0.226	0.110	0.059	0.047	0.120	0.096	0.115	0.081	0.085	0.133	0.092	0.113	0.130	0.071	0.091	0.059

PLATFORM AREA

Hall	BH	CA	CG	ED	FH	FS	GK	GM	LS	MU	NO	bh	es	ha	kh	ho	hg	ka	kk	dr	fo	of	sa	ti	ok	jr	ms	vu	so	oh	mo	ou
Platform area [m^2]	200	225	150	130	170	260	180	300	180	130	210	147	166	90	59	128	130	120	170	210	99	190	130	195	178	95	170	100	200	150	243	75
Distance from plt. front to rear wall [m]	12.5	13.0	16.0	16.0	11.0	14.0	11.0	17.0	10.0	9.0	17.0	11.5	15.6	12.3	7.0	8.0	11.5	10.6	11.0	12.7	6.9	15.5	9.6	12.0	9.9	9.5	10.0	13.0	10.5	8.8	15.4	10.0
Mean width between side walls [m]	17.0	20.0	28.5	19.0	22.5	23.0	20.0	20.0	19.0	19.5	27.0	22.0	13.5	13.6	21.4	38.4	17.0	21.5	50.0	21.0	21.0	14.5	19.2	16.0	18.5	14.0	19.0	31.6	19.8	24.5	18.0	14.0
Mean ceiling height [m]	9.0	18.0	15.5	12.0	12.0	8.5	10.0	15.0	9.0	15.0	11.5	7.5	10.5	5.0	6.3	10.0	6.4	7.1	7.5	15.0	8.0	11.0	7.3	6.0	13.5	7.0	6.0	7.6	8.5	11.5	8.0	18.0
Angle between side walls [degrees]	60	60	0	18	30	70	70	60	12	0	0	0	0	0	0	0	0	0	0	40	0	0	0	36	28	20	29	0	0	60	33	44
Distance * width [m^2]	212.5	260.0	456.0	304.0	247.5	322.0	220.0	340.0	190.0	175.5	459.0	253.0	210.6	167.3	149.8	307.2	195.5	227.9	550.0	266.7	144.9	224.8	184.3	192.0	183.2	133.0	190.0	410.8	207.9	215.6	277.2	140.0
Platform "volume" [m^3] (see Cpt.3)	1912.5	4680.0	7068.0	3648.0	2970.0	2737.0	2200.0	5100.0	1710.0	2632.5	5278.5	1897.5	2211.3	836.4	943.7	3072.0	1251.2	1618.1	4125.0	4000.5	1159.2	2472.3	1345.5	1152.0	2472.5	931.0	1140.0	3122.1	1767.2	2479.4	2217.6	2520.0
Height of platform over main floor [cm]	91	71	150	135	80	90	105	60	125	71	97	72	67	85	72	42	0	0	0	75	54	110	79	90	80	0	22	123	55	85	80	0

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The Acoustics Laboratory
Technical University of Denmark
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(11 pages)

P.22, equation (1.18):

$$ST1_{exp} = 10*\log(\frac{RT}{V}*[\exp(-0.276/RT)-\exp(-1.38)]) + 25 \text{ dB}$$

should read:

$$ST1_{exp} = 10*\log(\frac{RT}{V}*[\exp(-0.276/RT)-\exp(-1.38/RT)]) + 25 \text{ dB}$$

P.23, equation (1.19):

$$ST2_{exp} = 10*\log(\frac{RT}{V}*[\exp(-0.276/RT)-\exp(-2.76)]) + 25 \text{ dB}$$

should read:

$$ST2_{exp} = 10*\log(\frac{RT}{V}*[\exp(-0.276/RT)-\exp(-2.76/RT)]) + 25 \text{ dB}$$

P.23, equation (1.21):

$$CS_{exp} = 10*\log(\frac{RT}{V}*\exp(-1.104/RT)) + 25 \text{ dB.}$$

should read:

$$CS_{exp} = -[10*\log(\frac{RT}{V}*\exp(-1.104/RT)) + 25] \text{ dB.}$$

P.29 & P 57:

The measured (unoccupied) acoustic data for the audience area in Festspielhaus (**FS**) and Gasteig Philharmonie (**GM**) have been interchanged throughout the report. New versions of p. 29 and p. 57 as well as of the pages 100 and 114 in Appendix B and of pages 122 to 124 in Appendix C are therefore supplied, and all places in text, figures and tables, where this has had any influence are mentioned in the following.*

P.68, line 6:

should read: Acoustic Consultant: Ingemansson Akustik.

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* This error has had practically no influence on the analyses described in Cpt. 3. However, more detailed analyses based on the corrected data plus data from three more halls are currently (August 1990) being prepared for publication in the Journal of the Acoustical Society of America.

P.78, Fig. 3.4:

The data labels 'FS' and 'GM' should be interchanged.

P.79, equation (3.4):

$L = -1.3 + 0.9*L_{exp}$ should read: $L = -1.5 + 0.9*L_{exp}$

P.79, line 15:

'84 %' should be changed into '89%'.

P.79, Fig. 3.5:

The coordinates of the 'FS' data point should be changed to:
(Lexp,L) = (6.0 dB,3.6 dB)
The coordinates of the 'GM' data point should be changed to:
(Lexp,L) = (3.6 dB,2.3 dB)

P.80, line 10:

'r = - 0.66 (explaining 42 % of the variance)'
should be changed into:
'r = - 0.73 (explaining 54 % of the variance)'

P. 80, Fig. 3.6:

The coordinates of the 'FS' data point should be changed to:
(Width,LEF) = (34 metres,0.20)
The coordinates of the 'GM' data point should be changed to:
(Width,LEF) = (55 metres,0.11)

P. 81, Fig. 3.7:

The coordinates of the 'FS' data point should be changed to:
(EDT,EDTP) = (1.9 sec.,1.6 sec.)
The coordinates of the 'GM' data point should be changed to:
(EDT,EDTP) = (2.15 sec.,1.5 sec.)

P.82, equation (3.6):

$EDTP = 0.3 + 0.56*EDT$ should read: $EDTP = 0.3 + 0.55*EDT$

P.82, equation (3.7):

$ST1 = -1.9 + 0.72*ST1_{exp}$ should read: $ST1 = -1.8 + 0.72*ST1_{exp}$

P.84, equation (3.10):
$CS = 3.8 + 0.69*CS_{exp}$ should read: $CS = 3.7 + 0.69*CS_{exp}$

P.89, Fig. 4.3 and Fig. 4.4:
In both figures the data labels 'FS' and 'GM' should be interchanged.

P.100, 114, 122 - 124, (data tables):
Five new pages are supplied.

P.126:
The height of the platform in MW (row 10, 1.st column) should be changed from 71 cm to 100 cm.

P. 127, Ref.[2]:
Acustica 70 (2) 1990, (page yet unknown).
should be changed into:
Acustica 69 1989, p. 249.

P.128, Ref.[16]:
Acustica 70 (1) 1989, (page yet unknown).
should be changed into:
Acustica 69 1989, p. 193.

Geometrical Data:

Volume : 15,500 m^3

Platform area : 260 m^2

Seating area : 1050 m^2

Number of seats: 2168 (1289 on main floor, 762 on balcony, 71 in boxes below balconies, 46 in side wall boxes).

Acoustical data:

RT_m : 2.0 sec.

RT_m occup. : 1.5 sec. [12] (measured with old orchestra shell; see [19])

Audience area:

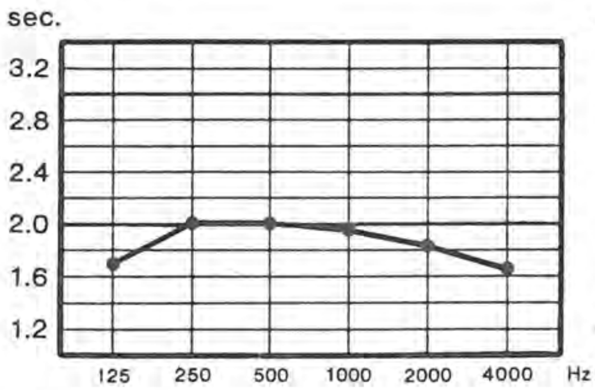
EDT : 1.91 sec. L : 3.6 dB

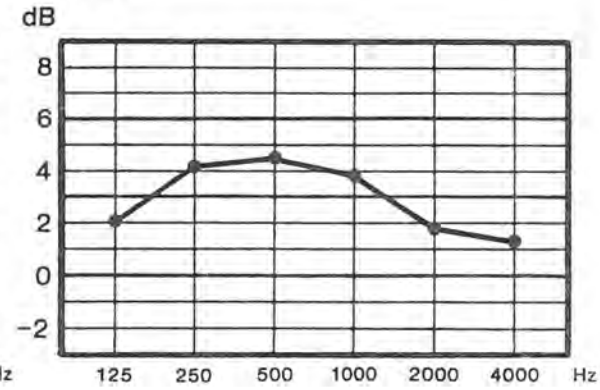
t_s : 139 msec. LEF : 0.20

C : -1.0 dB

BR(RT): 0.93 BR(L): -1.1 dB

RT(f) : L(f) :





Platform area:

EDTP : 1.6 sec. ST1 : -15.8 dB

CS : 16.3 dB ST2 : -14.1 dB

Remarks on measurement conditions:

The measurements were carried out on 28. September 1987.

Audience parameters (**FS**)

	S1-							S3-						
	Freq	RT	EDT	TS	C	L	LEF	Freq	RT	EDT	TS	C	L	LEF
R1	125	1.6	1.1	103	-0.3	7.1	0.04	125	1.7	1.6	133	-0.3	3.8	0.07
	250	2.0	2.1	133	-0.1	6.3	0.08	250	1.9	1.9	162	-2.3	5.7	0.09
	500	1.9	2.1	130	0.2	6.0	0.06	500	2.1	2.2	150	-1.1	4.7	0.07
	1000	2.1	1.4	75	4.0	6.8	0.03	1000	2.0	2.1	142	-1.6	3.8	0.13
	2000	1.8	1.8	128	-1.5	3.6		2000	1.9	2.1	153	-2.6	1.6	
	4000	1.6	1.5	113	-0.7	2.7		4000	1.8	1.6	102	1.7	2.6	
R2	125	1.9	1.4	101	1.5	2.9	0.18	125	1.3	1.6	145	-2.1	3.1	0.24
	250	2.0	2.3	170	-3.7	4.9	0.11	250	2.1	2.0	160	-3.4	5.3	0.49
	500	2.0	2.4	177	-2.2	4.5	0.19	500	2.1	2.2	166	-3.9	4.2	0.20
	1000	1.8	1.9	131	-0.9	4.2	0.19	1000	2.0	2.1	147	-1.1	3.3	0.15
	2000	1.8	2.0	152	-2.9	2.2		2000	1.9	2.1	156	-1.8	1.0	
	4000	1.7	1.9	144	-2.6	0.6		4000	1.7	1.9	128	-0.4	0.0	
R3	125	1.6	1.5	135	-2.2	3.7	0.08	125	1.7	1.8	155	-6.1	-1.1	0.70
	250	2.0	1.7	154	-3.7	5.2	0.10	250	2.1	1.8	118	1.2	4.5	0.03
	500	2.0	1.7	120	1.2	6.2	0.22	500	1.9	1.8	126	-0.2	5.1	0.09
	1000	1.8	1.5	99	2.8	5.4	0.10	1000	1.8	1.9	118	0.7	3.2	0.09
	2000	1.8	1.5	110	1.8	3.4		2000	1.9	2.1	151	-2.5	0.4	
	4000	1.6	1.1	89	3.4	2.6		4000	1.7	1.7	123	-0.5	5.6	
R4	125	1.9	1.7	147	-4.8	0.6	0.12	125	2.0	1.4	140	-5.2	0.8	0.18
	250	2.1	2.1	168	-4.9	3.8	0.35	250	1.9	1.6	139	-3.7	4.1	0.14
	500	1.9	2.2	174	-2.9	4.4	0.28	500	2.0	1.9	150	-4.0	4.8	0.14
	1000	2.0	1.8	147	-3.6	3.5	0.39	1000	1.9	1.9	138	-1.5	3.2	0.10
	2000	1.8	1.7	122	-0.4	3.0		2000	1.9	1.7	124	-0.1	2.6	
	4000	1.6	1.6	130	-1.9	1.2		4000	1.6	1.6	125	-0.7	1.3	
R5	125	1.6	1.4	121	-1.2	4.7	0.18	125	1.6	1.7	156	-5.7	1.8	0.43
	250	2.2	2.2	142	1.0	4.2	0.25	250	2.0	2.3	173	1.5	2.6	0.17
	500	2.1	1.8	122	1.7	5.3	0.28	500	1.9	2.4	178	-3.6	2.6	0.21
	1000	2.1	1.4	95	4.4	5.1	0.14	1000	2.0	2.2	164	-3.1	1.7	0.28
	2000	1.8	1.7	116	1.2	2.7		2000	1.8	2.2	160	-3.0	0.2	
	4000	1.5	1.3	88	3.9	2.7		4000	1.8	1.9	143	-2.3	-1.4	
R6	125	1.8	2.0	172	-3.0	-0.6	0.23	125	1.7	2.1	162	-2.5	-2.6	0.32
	250	1.8	2.0	166	-5.8	1.9	0.61	250	2.0	1.8	136	-1.3	1.7	0.30
	500	2.1	1.9	136	-0.7	3.8	0.11	500	2.1	1.9	131	0.0	2.7	0.25
	1000	2.0	1.4	108	2.3	3.9	0.20	1000	2.0	1.7	111	1.0	2.4	0.12
	2000	1.8	1.6	116	0.8	1.5		2000	1.9	1.7	115	1.5	0.1	
	4000	1.6	1.4	104	1.6	0.0		4000	1.8	1.6	118	0.4	-1.6	

Audience parameters (GM)

	S1-							S3-						
	Freq	RT	EDT	TS	C	L	LEF	Freq	RT	EDT	TS	C	L	LEF
	125	2.5	1.9	150	-5.0	3.9	0.14	125	2.4	2.8	174	-1.9	3.0	0.11
	250	2.0	2.1	170	-5.3	3.7	0.06	250	2.3	2.6	166	-2.0	1.4	0.10
R1	500	2.3	1.9	126	0.2	5.1	0.05	500	2.1	2.1	156	-0.7	3.0	0.08
	1000	2.1	1.9	121	0.3	4.9	0.08	1000	2.2	2.0	146	-0.1	2.7	0.10
	2000	2.1	2.2	159	-2.9	5.0		2000	2.1	2.3	172	-2.2	3.3	
	4000	1.8	1.8	121	0.1	-0.1		4000	1.8	1.8	109	1.8	-1.1	
	125	2.3	2.1	218	-10.9	1.8	0.06	125	2.0	2.4	193	-2.3	1.4	0.08
	250	2.2	2.1	168	-6.3	3.0	0.03	250	2.0	2.2	160	-0.9	2.4	0.11
R2	500	2.2	2.2	145	-0.4	3.6	0.04	500	2.2	2.2	156	-1.2	2.9	0.15
	1000	2.1	2.2	144	-0.7	2.8	0.05	1000	2.2	2.1	154	-2.1	2.0	0.14
	2000	2.2	2.4	194	-4.8	3.4		2000	2.1	2.1	156	-1.8	3.8	
	4000	2.0	2.1	161	-2.5	-2.4		4000	1.9	2.0	146	-1.4	-2.9	
	125	2.4	2.5	235	-8.6	0.8	0.04	125	2.5	2.8	206	-5.8	1.5	0.16
	250	2.0	2.1	160	-2.2	2.9	0.14	250	2.2	1.8	160	-3.7	1.6	0.13
R3	500	2.1	2.3	163	-2.4	3.6	0.07	500	2.1	1.9	140	-0.9	2.9	0.03
	1000	2.1	1.7	137	-0.8	3.2	0.07	1000	2.2	1.9	142	-1.5	1.9	0.05
	2000	2.2	2.1	154	-2.6	4.2		2000	2.2	2.2	162	-3.0	3.4	
	4000	1.8	2.0	156	-3.3	-2.8		4000	1.9	1.7	130	-0.8	-2.4	
	125	2.4	2.4	216	-8.5	-0.7	0.18	125	2.3	2.5	175	-2.9	-0.5	0.06
	250	2.3	2.5	177	-3.5	0.9	0.16	250	2.2	1.9	143	-2.8	0.4	0.25
R4	500	2.2	2.2	165	-3.1	1.2	0.15	500	2.2	2.1	148	-2.7	1.5	0.19
	1000	2.3	2.3	180	-5.6	0.2	0.09	1000	2.3	2.3	156	-1.3	-0.5	0.03
	2000	2.3	2.2	157	-2.9	2.8		2000	2.3	1.8	132	-0.6	2.7	
	4000	1.9	1.9	148	-3.1	2.4		4000	2.0	1.6	113	0.8	-3.5	
	125	2.4	2.4	194	-6.7	1.7	0.22	125	2.9	2.2	208	-5.5	0.2	0.07
	250	2.1	2.4	178	-1.6	1.8	0.22	250	2.1	2.4	190	-2.8	1.1	0.05
R5	500	2.2	2.1	142	0.8	3.0	0.27	500	2.2	2.5	175	-1.2	1.3	0.11
	1000	2.3	2.2	150	0.3	1.9	0.14	1000	2.1	2.3	158	-0.3	1.1	0.06
	2000	2.1	2.3	158	-0.5	3.9		2000	2.1	2.9	220	-4.6	1.0	
	4000	1.9	1.9	129	0.4	-1.9		4000	1.9	2.3	162	-1.7	-4.3	
	125	2.4	1.5	142	-1.4	1.3	0.09	125	2.4	1.8	148	-0.7	-0.5	0.12
	250	2.1	2.3	166	-2.7	0.6	0.18	250	2.4	2.7	189	-2.6	-2.1	0.28
R6	500	2.2	1.9	120	1.9	2.4	0.08	500	2.3	1.7	109	3.2	2.2	0.10
	1000	2.3	2.2	144	-0.3	0.4	0.05	1000	2.3	1.3	110	2.3	1.1	0.12
	2000	2.1	1.8	125	0.9	3.6		2000	2.3	1.8	117	1.6	2.8	
	4000	1.9	1.4	104	2.0	0.3		4000	1.8	1.2	89	4.1	-2.0	

	MT	RT	EDT	TS	C	L	LEF	BRRT	BRL	EDTP	EEL	ST1	ST2	CS
BA	1.99	1.93	1.91	141	-1.6	2.9	0.17	0.90	-1.7	1.25	-13.2	-13.2	-12.0	15.1
CA	2.20	2.15	2.04	143	-1.2	2.9	0.18	0.90	-1.5	1.46	-15.3	-16.6	-14.3	15.6
CI	2.51	2.46	2.64	196	-4.4	5.5	0.16	1.02	-1.2	1.98	-15.5	-18.3	-15.3	14.2
ED	2.05	2.01	2.13	156	-1.7	3.4	0.23	0.97	-0.9	1.45	-13.6	-16.3	-13.6	12.9
FH	1.58	1.56	1.38	104	0.7	1.6	0.24	0.90	-1.3	1.03	-14.0	-16.0	-14.8	16.3
FS	1.98	1.95	1.91	139	-1.0	3.6	0.20	0.93	-1.1	1.59	-14.4	-15.8	-14.2	16.3
GK	1.71	1.71	1.70	127	0.0	4.7	0.09	1.17	1.3	1.56	-12.7	-14.3	-13.5	16.0
GM	2.20	2.18	2.15	155	-1.6	2.3	0.11	1.04	-1.0	1.47	-17.1	-18.0	-16.8	18.0
LS	2.09	2.00	2.03	149	-1.7	2.5	0.15	0.84	-0.4	1.33	-12.5	-14.5	-12.6	14.5
MW	3.16	3.04	3.14	226	-5.1	6.5	0.16	0.97	0.1	1.99	-13.3	-13.0	-11.8	13.7
NO	2.11	2.00	2.25	147	-1.7	4.7	0.24	0.97	-0.4	1.60	-14.0	-14.6	-12.3	13.6
bh	2.10	1.90	1.90	146	-2.1	6.7	0.27	0.90	1.6	1.40	-12.1	-12.0	-10.6	12.1
cs	2.10	1.98	1.90	141	-1.3	10.8	0.43	0.73	-0.3	1.60	-11.4	-10.3	-8.5	10.4
ha	1.40	1.43	1.40	104	0.7	9.9	0.36	1.16	1.4	1.20	-9.0	-7.7	-6.1	9.4
kh	1.60	1.60	1.80	15[illegible]	1.1	7.1	0.26	0.83	1.9	1.10	-10.2	-12.3	-10.9	12.2
ho	2.80	2.40	2.40	162	-2.0	7.1	0.19	0.73	0.8	1.50	-11.2	-14.1	-12.[illegible]	13.6
hg	2.40	2.26	2.30	174	-3.3	9.6	0.34	1.00	4.2	1.60	-10.5	-9.7	-7.8	9.1
ka	1.50	1.48	1.20	92	1.8	6.2	0.34	0.83	2.0	0.90	-10.1	-10.6	-9.7	13.5
kk	2.80	2.55	2.40	161	-0.5	7.0	0.06	0.89	1.5	1.80	-13.2	-13.6	-13.6	14.7
dr	2.10	2.03	1.90	137	-0.9	5.1	0.17	0.83	0.9	1.50	-14.1	-14.5	-13.0	13.9
fc	1.80	1.68	1.70	127	-0.8	3.3	0.29	0.89	0.1	1.00	-11.0	-14.0	-12.6	15.6
of	1.60	1.93	2.00	151	-2.0	5.8	0.29	1.19	3.0	1.50	-13.6	-13.3	-10.9	11.5
sa	1.90	1.75	1.70	127	-0.8	5.5	0.22	1.06	0.5	1.10	-11.9	-12.2	-10.9	14.5
ti	2.40	2.35	2.30	162	-2.1	6.0	0.14	0.92	0.3	1.40	-10.6	-10.9	-10.1	13.4
-v	2.30	2.23	2.30	163	-2.2	4.6	0.25	1.04	0.4	1.80	-14.4	-16.5	-13.5	13.8
ur	2.10	1.90	2.00	153	-2.2	9.2	0.33	0.71	2.7	1.50	-13.0	-11.7	-10.0	11.4
ms	1.70	1.68	1.60	122	-0.6	10.2	0.40	0.97	2.6	1.40	-11.0	-12.6	-10.6	12.1
vu	2.60	2.38	2.60	187	-3.6	5.0	0.23	0.73	1.0	1.50	-13.7	-14.1	-12.3	13.3
so	1.20	1.18	1.20	101	-0.3	6.5	0.24	1.17	1.6	1.00	-12.8	-12.7	-11.6	14.9
oh	2.20	2.08	2.00	152	-2.1	3.6	0.18	0.84	1.5	1.10	-12.5	-15.3	-14.1	16.7
mo	1.60	1.53	1.50	109	0.5	2.4	0.16	0.97	-1.7	1.00	-11.4	-13.3	-12.3	15.0
ou	1.50	1.45	1.50	121	-2.2	4.8	0.26	0.93	4.8	1.00	-11.6	-15.6	-14.2	16.6

Expected values according to diffuse field theory

Hall	RT	Cexp	TSex	Lexp	ST1exp	ST2exp	CSexp
BA	1.93	-1.1	140	5.4	-18.9	-16.7	17.1
CA	2.15	-1.7	156	4.9	-19.6	-17.3	17.3
CG	2.46	-2.5	178	6.2	-18.7	-16.3	15.8
ED	2.01	-1.4	146	6.0	-18.3	-16.1	16.4
FH	1.56	0.1	113	3.5	-20.2	-18.2	19.6
FS	1.95	-1.2	141	6.0	-18.3	-16.1	16.5
GK	1.71	-0.4	124	6.6	-17.4	-15.3	16.2
GM	2.18	-1.8	158	3.6	-20.9	-18.6	18.6
LS	2.00	-1.3	145	6.0	-18.4	-16.1	16.4
MW	3.04	-3.6	220	8.1	-17.5	-14.9	13.5
NO	2.00	-1.3	145	6.7	-17.6	-15.4	15.7
bh	1.90	-1.0	138	8.6	-15.6	-13.4	13.9
es	1.98	-1.3	143	11.9	-12.4	-10.1	10.5
ha	1.43	0.7	104	13.5	-10.0	-8.1	9.8
kh	1.80	-0.7	130	9.4	-14.7	-12.6	13.3
ho	2.40	-2.3	174	8.0	-16.9	-14.4	14.0
hg	2.28	-2.1	165	12.6	-12.1	-9.7	9.5
ka	1.48	0.4	107	10.5	-13.1	-11.2	12.8
kk	2.55	-2.7	185	8.2	-16.8	-14.3	13.7
dr	2.03	-1.4	147	7.4	-17.0	-14.7	15.0
fc	1.68	-0.3	122	6.1	-17.8	-15.7	16.7
of	1.93	-1.1	140	8.4	-15.8	-13.6	14.1
sa	1.75	-0.6	127	9.0	-14.9	-12.8	13.7
ti	2.35	-2.2	170	7.7	-17.1	-14.7	14.4
ok	2.23	-1.9	162	7.0	-17.6	-15.2	15.1
jr	1.90	-1.0	138	13.0	-11.2	-9.0	9.5
ms	1.68	-0.3	122	11.8	-12.1	-10.0	11.0
vu	2.38	-2.3	172	7.8	-17.0	-14.6	14.2
so	1.18	1.9	86	9.0	-14.2	-12.6	15.1
oh	2.08	-1.5	151	5.6	-18.8	-16.6	16.7
mo	1.53	0.2	111	5.4	-18.3	-16.4	17.8
ou	1.45	0.6	105	7.9	-15.6	-13.8	15.4

Measured deviations from diffuse field predictions

Hal	EDTdif	Cdif	TSdif	Ldif	EDTPdif	ST1dif	ST2dif	CSdif
BA	-0.02	-0.4	1	-2.5	-0.68	5.7	4.7	-2.1
CA	-0.11	0.6	-13	-2.0	-0.69	3.0	3.0	-1.7
CG	0.18	-1.9	18	-0.7	-0.48	0.4	1.0	-1.5
ED	0.12	-0.3	10	-2.6	-0.56	2.0	2.5	-3.5
FH	-0.18	0.5	-9	-1.9	-0.53	4.2	3.4	-3.2
FS	-0.04	0.2	-3	-2.4	-0.39	2.5	1.9	-0.2
GK	-0.01	0.5	3	-1.9	-0.15	3.1	1.8	-0.3
GM	-0.03	0.2	-3	-1.3	-0.73	3.0	1.9	-0.6
LS	0.03	-0.3	4	-3.2	-0.67	3.9	3.5	-1.3
MW	0.12	-1.6	5	-1.5	-1.05	4.5	3.1	0.2
NO	0.25	-0.4	2	-2.0	-0.40	3.0	3.1	-3.1
bh	0.00	-1.1	8	-1.9	-0.50	3.6	2.8	-1.8
es	-0.08	0.0	-2	-1.1	-0.38	2.1	1.6	-0.1
na	-0.03	0.0	0	-3.6	-0.23	2.3	2.0	-0.4
kh	0.00	-0.4	5	-2.3	-0.70	2.4	1.7	-0.1
ho	0.00	0.3	-12	-0.9	-0.90	2.8	2.1	-0.4
hg	0.02	-1.2	9	-3.0	-0.68	2.4	1.9	-0.4
ka	-0.28	1.4	-15	-4.3	-0.58	2.5	1.5	0.7
kk	-0.15	1.8	-24	-1.2	-0.75	3.2	1.7	1.0
dr	-0.13	0.5	-10	-2.3	-0.53	2.5	1.7	-1.1
fc	0.02	-0.5	5	-2.8	-0.68	3.3	3.1	-1.1
of	0.07	-0.9	11	-2.6	-0.43	2.5	2.7	-2.6
sa	-0.05	-0.2	0	-3.5	-0.65	2.7	1.9	0.8
ti	-0.05	0.1	-8	-1.7	-0.95	6.2	4.6	-1.0
ok	0.07	-0.3	1	-2.4	-0.43	1.1	1.7	-1.3
jr	0.10	-1.2	15	-3.8	-0.40	-0.5	-1.0	1.9
ms	-0.08	-0.3	0	-1.6	-0.28	-0.5	-0.6	1.1
u	0.22	-1.3	15	-2.8	-0.88	2.9	2.3	-0.9
so	0.02	-2.2	15	-2.5	-0.18	1.5	1.0	-0.2
oh	-0.08	-0.6	1	-2.0	-0.98	3.5	2.5	0.0
mo	-0.03	0.3	-2	-3.0	-0.53	5.0	4.1	-2.8
ou	0.05	-2.3	16	-3.1	-0.45	0.0	-0.4	1.2

Geometrical Data:

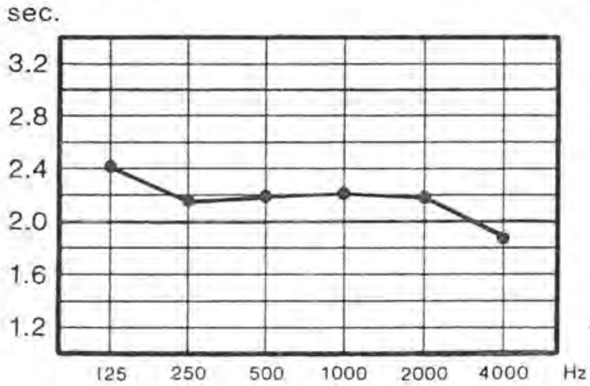
Volume	:	30,000 m^3
Platform area	:	300 m^2, (including 50 m^2 mainly for choir)
Seating area	:	1500 m^2
Number of seats:		2387

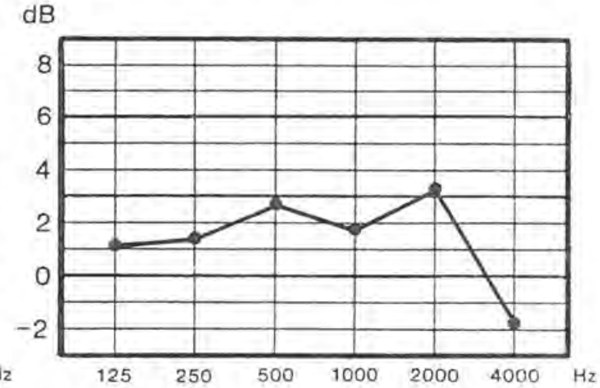
Acoustical data:

RT_m	:	2.2 sec.
RT_m occup.	:	2.1 sec. [34]

Audience area:

EDT	:	2.15 sec.	L	:	2.3 dB
t_s	:	155 msec.	LEF	:	0.11
C	:	-1.6 dB			
BR(RT):		1.04	BR(L):		-1.0 dB
RT(f) :			L(f) :		





Platform area:

EDTP	:	1.5 sec.	ST1	:	-18.0 dB
CS	:	18.0 dB	ST2	:	-16.8 dB

Remarks on measurement conditions:

The measurements were carried out on 1. October 1987.