Recent multi purpose hall designs in Denmark with physically variable acoustics

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Summary: Two recent Danish multi purpose hall designs are described, in which acoustic variability has been accomplished in different ways: through variable absorption and variable volume respectively. The different approaches were chosen in order to ensure that not only reverberation time (T) and so Clarity (C), but also the Strength parameter (G) could be varied in a favourable direction in view of the prescribed uses of the halls. In the case of the variable volume hall, the results indicate larger changes in clarity, C, and smaller changes in strength, G, than expected - most likely due to the moveable ceiling being sound transparent to some degree.

INTRODUCTION

During the last decade, we have seen many visionary ideas, plans and architect competitions for new performing arts facilities in Denmark - many of which were inspired by the fact that Copenhagen was appointed the Cultural capital of EU in 1996. Most prominent among these plans were the two competitions for a new national theatre and for a new large concert hall complex, both located in Copenhagen. While none of these will materialize in a foreseeable future, two other projects deserve mentioning, not only because they were actually realized, but also because of their different approach to the challenge of providing variable acoustics to serve multi purpose use. These two halls are:

1) the largest hall built in this decade in Denmark: Esbjerg Performing Arts Centre (Esbjerg Musikhus) inaugurated 1997, and

2) the only project realized in Copenhagen in this decade: the multi functional hall included in the extension of the Royal Library in Copenhagen, which will open later this year.

In Esbjerg, acoustic variability has been accomplished through variable volume, while in the Royal Library variable absorption has been provided. The different approaches were chosen in order to ensure that not only reverberation time (T) and so Clarity (C), but also the Strength parameter (G) could be varied in a favourable direction in view of the prescribed uses of the halls.

In the following, the design of these two halls along with acoustic data and predictions illustrating their acoustic variability will be described.

ESBJERG PERFORMING ARTS CENTRE

The hall in Esbjerg (on the west coast of Jutland) is rectangular and rather wide for its size, as the width (23 m) is almost equal to the length of the auditorium 25 m. Through a 20 m wide and 13 m high proscenium opening, the auditorium is connected to a huge stage house, which is equipped with a moveable orchestra shell for concerts. The hall seats about 1100 people, of which 240 are seated on a rear balcony, which can be closed off when moveable ceiling elements are lowered. The range for the average ceiling height is from about 9 to 14 metres. Roughly two thirds of the seat rows on the main floor are integrated with a rather steep telescopic riser system, whereby the flat floor can be used for conferences etc. For symphonic concerts, besides raising the ceiling elements, the intention was also to place seat rows on the flat floor (except for the last few rows, where the riser system would still be used). Therefore such concerts - which do not require sight lines as first priority - would also benefit from the extra volume otherwise occupied by the risers. By moving the ceiling elements and riser system, the volume can be changed between the limits indicated in Table 1. In all the cases listed in the table, the volume within the orchestra shell is fixed in order to illustrate the possible changes in the auditorium.

The hall's main uses are musicals, drama theatre, conferences and symphonic concerts, however, symphonic concerts are not frequent enough for the management to buy chairs to put on the flat floor exclusively for this activity. Therefore the riser system with its fixed chairs is used also for concerts.

In theory, the variable volume concept for acoustic flexibility has a great advantage in halls facilitating both symphonic music and drama theatre, because reducing the reverberation time is accompanied by an increase in strength, G. Thus speech becomes more clear as well as more loud, whereas when reduction of reverberation is achieved through adding absorption, the level is reduced as well.

Recently, measurements of reverberation time, T, clarity, C, and strength, G, were made with raised as well as lowered ceiling and the orchestra shell and the sloping seating in place.

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In the case of the multi functional hall for the Royal Library, the functions outlined in the brief were concerts with chamber music, symphony orchestra rehearsals, plus conferences and lectures with amplified speech and video-presentations with reproduction of sound including surround tracks.

Among these activities, those requiring a low reverberation time do not have any problem obtaining adequate loudness. On the contrary, for symphony orchestra rehearsals in a hall of this size, 4500 m^3, the problem is normally excessive loudness. Therefore there was no doubt that variable absorption was the right choice in this case.

The hall is part of the new 25,000 m^2 extension of the Royal Library in Copenhagen, which will open in the fall 1999. This hall is also rectangular in shape, the dimensions being about 28 m x 18 m x 9.5 m (L x W x H). The hall will have up to 600 seats of which about two thirds are to be permanently installed on a fixed, moderately sloping floor. The hall has no balconies.

The variable absorption is provided by means of 250 m^2 of absorbing panels sliding out from the recesses in the zig-zag shaped side walls plus 150 m^2 of heavy woolen curtains and banners that can cover about half of the end wall areas. By providing such a large area of variable absorption, we hope to achieve a range of variation which will be clearly audible and considered without compromises - natural prerequisites for variable acoustics to be used and be useful.

Since the seats and the curtains have not yet been installed, acoustic measurements in this hall were limited to reverberation time in the unfurnished room - however, both with and without the sliding sound absorbing panels exposed. From these data, values of T with chairs have been predicted using Beranek and Hidaka's recently published absorption data, Group 1; "heavily upholstered seats" (1). Also the effect of the curtains have been estimated, and subsequently prediction of G and C has been attempted using empirical formulas as described in the following section.

ACOUSTIC MEASUREMENT RESULTS AND PREDICTIONS

In the cases where measurements of C and G could not be made, values for these parameters were predicted using empirical models derived from statistical analysis of data from a large number of concert and multi purpose halls (2). Various models exist which include total absorption power (derived from measured T) as well as different geometrical variables. In this case, models were used, which include the geometrical factors which are changeable in the Esbjerg hall: ceiling height, H [m], and slope of the main floor, FS [degrees]:

$$C_{model} = -1.4 + 0.95\, C_{exp} + 0.47\, W/H + 0.031\, FS \quad [dB] \qquad (1)$$

$$G_{model} = -5.61 + 1.06\, G_{exp} + 0.17\, V/N + 0.04\, D \quad [dB] \qquad (2)$$

The remaining variables in these formulas are the expected values of C and G respectively according to Sabine diffuse field theory: $C_{exp} = 10\,LOG(e^{1.104/T} - 1)$ [dB] and $G_{exp} = 10\,LOG(T/V) + 45$ [dB], average hall width, W [m], volume, V [m^3], number of seats, N [-], and the distance from the stage front to the rearmost seat, D [m].

The results of measured and predicted values for each configuration of each hall are shown in Table 1. All data are averaged over the frequency range 250 - 2000 Hz and over all measured seats. (In Esbjerg only seats on the main floor which could be measured in both configurations were included in the averages.)

Table 1: Basic data and measured/predicted values of Clarity,C, and Strength, G, in two new acoustically variable multi purpose halls in Denmark. T-values in parentheses are extrapolated using available absorption data.

Esbjerg Performing Arts Centre (1997) Vol./seats: 13400 m^3/1091 - 8750 m^3/849			
Config	High ceil. Flat floor	High ceil. Slop. floor	Low ceil. Slop. floor
Tmeas..	(1.6 Sec.)	1.4 Sec.	1.3 Sec.
Cmeas.	-	1.0 dB	2.7 dB
Cmodel	-0.6 dB	0,5 dB	1.3 dB
Gmeas.	-	1.1 dB	1.7 dB
Gmodel	3.6 dB	3.3 dB	4.2 dB

Royal Library Multi purpose hall (1999) Volume 4500 m^3 ; 384 - 600 seats			
Config	480 seats No absorp.	480 seats Abs.panels	480 seats Pan.+Curt.
Tmeas.	(1,6 Sec.)	(1.2 Sec.)	(1.0 Sec.)
Cmeas.	-	-	-
Cmodel	-0.3 dB	1.2 dB	2.5 dB
Gmeas.	-	-	-
Gmodel	7.6 dB	6.4 dB	5.5 dB

As seen from the table, the values change in the expected directions, although in Esbjerg the measured and predicted changes are different. Changes in measured C are larger than and changes in G smaller than predicted by the statistical models. In accordance with the difference limens (3) for perception of changes in C (0.5 dB) and G (1.0 dB), the subjective experience of the changes in the hall was also mainly one of a change in clarity. It should be noted however, that both measured and perceived changes are likely to become larger than found here, when the orchestra shell is removed for theatre use.

In The Royal Library hall, the models predict somewhat larger changes than in Esbjerg.(In this case, the subjective changes were very pronounced, since with the chairs not yet installed, T changed from 2.7 to 1.8 seconds when the panels were moved.)

DISCUSSION

In the case of Esbjerg, it is worth noticing that besides showing little variation, the measured G values are also generally lower than expected. This might indicate, that the effective volume has been larger than calculated, most likely because the moveable ceiling - and the orchestra shell as well - had quite large open slits between its individual elements. On the other hand, apparently the low ceiling acted efficiently as a reflector, since C increased more than expected.

The fact that T did not change much with the change in ceiling height is no surprise since as the volume was reduced also the absorption area of the balcony seats were closed off of the hall volume and so the V/A ratio remained almost unchanged.

The observed behaviour of G in Esbjerg has a parallel in the E. J. Thomas Hall in Akron, Ohio, USA, which is probably the most famous example of a hall with variable volume. In this hall the moveable panel array ceiling is also fairly open, and measured G show the same tendencies of being low and not varying as mush as expected (4).

CONCLUSIONS

Whereas time will show, whether the variable absorption in the Royal Library Hall will work as intended - also with respect to variations in C and G - it is found that the not fully closed moveable ceiling in the Esbjerg performing arts hall behaves more like a suspended reflector (affecting clarity) than as a volume separator (affecting strength as well).

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