



Stage Acoustics: Renovation of the concert hall de Doelen, Rotterdam and other stages

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ABSTRACT

When opened in 1966, the main concert hall in De Doelen, was fitted with six canopies above the stage platform, which were removed only six years later. During the design process of the renovation from 2007 to 2009, possibilities to re-introduce a stage canopy and influences of shape and materials are investigated. Objective acoustic parameters obtained by carrying out measurements in the hall are examined and compared to the results of several questionnaire rounds which gave an impression about the musicians' subjective judgement about the stage acoustics in De Doelen and two other halls. From comparison between subjective research and measurements it was concluded that increasing support (ST1) and Early Reflections Strength (G5-80) would be required to improve stage conditions. The Early Reflections Strength (G5-80) is not a standardized parameter but might be proposed for ensemble conditions. The influence of the proposed stage reflector is investigated in a 1:10 scale model and by calculations with a ray-tracing computer model. The renovation of De Doelen is completed in September 2009. This article gives an overview of the investigations and the final measured objective and subjective results of the stage acoustics in De Doelen. In spring 2010 a similar investigations on stage acoustics has taken place in the Maurice Ravel Auditorium Lyon, of which the results also are incorporated in the paper.

INTRODUCTION

The main hall of De Doelen, Rotterdam, the Netherlands, is a concert hall for classical music with a volume of about 27,000 m³ and a seating capacity of 2242. In 2009 the hall is renovated and as a part of the renovation design, research has been done on the stage acoustics [1].

When opened in 1966, the main concert hall in De Doelen, was fitted with six canopies above the stage platform [2,3], see figure 1. Their function was twofold:

- to provide a large part of the audience with early reflections;
- to create good ensemble conditions for the musicians on stage.

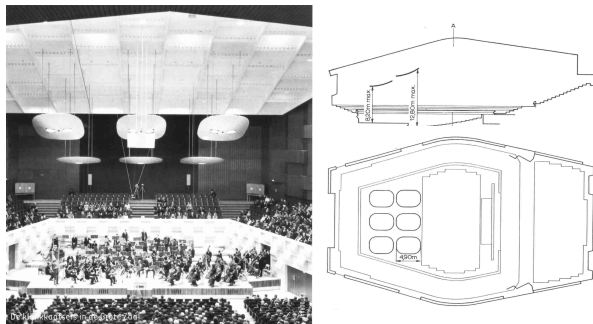


Figure 1. De Doelen 1966, photo, vertical and horizontal section

Despite good reviews after the opening, a few years later the canopies were removed, because they caused unwanted reflections at the recording microphone positions just below the canopy. Since then, a significant percentage of the orchestra was not completely satisfied with the acoustic conditions on stage. During the design process of the renovation, possibilities to re-introduce a stage canopy and influences of shape and materials are investigated. These investigations consisted of:

- reviewing the existing situation through measurements and questioning the musicians;
- scale and computer model research of possible canopies (and other possible improvements)

The renovation of De Doelen is completed in September 2009. In the renovated situation, measurements have been performed to evaluate the investigation results and compare them to the acoustical targets. Also the musicians have been given the chance to evaluate the stage acoustics through a new questionnaire.

REVIEW OF THE EXISTING SITUATION 2008

Questionnaire

In order to obtain a good overview of the opinions concerning the stage acoustics, the musicians of the Rotterdam Philharmonic Orchestra were asked to fill out four questionnaires. They were asked to give their opinion on their own playing conditions, the ensemble conditions, the stage and

hall acoustics in general in De Doelen as well as in De Singel in Antwerp.

The questionnaire was anonymous, but the musicians were asked to specify his or her instrument so the answers can be related to a position on stage. To compare the subjective opinions with acoustic parameters, the answers were given a score from minus 3 to plus 3 in the data processing. Figure 2 gives an example of the output

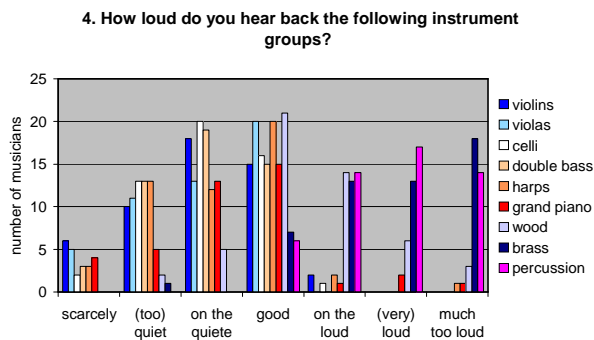


Figure 2. Example of the questionnaire output for ensemble conditions before renovation.

From the questionnaires the most important conclusion on loudness and intelligibility is that the musicians of the Rotterdam Philharmonic Orchestra judge that De Doelen Main hall has:

- low loudness en intelligibility at the front positions of the stage, especially for the strings;
- high loudness from the rear position of brass and percussion to the other instrument groups.

The stage of De Singel is judged to be louder than De Doelen.

Improvements of the acoustic of De Doelen stage are focussed on an increase of loudness and intelligibility of the strings and to reduce the shrill character of the hall and make it sound warmer.

Measurements

The goal of the measurements was to objectively describe the stage environment and, if possible, to correlate it to the subjective judgement of the musicians.

The measurements are performed according to ISO 3382 and in the unoccupied halls with orchestra furniture on stage. The stage risers were in the position equal to rehearsal and concert. The impulse responses between source and microphone were measured at the following locations:

- at a distance of 1 m in the middle of the instrument groups;
- from source location 1 (cello's) to the middle of the other instrument groups;
- from source location 2 (trumpets) to the middle of the other instrument groups;
- from source location 16 (leader) to the middle of the other instrument groups.

The middle positions of the instrument groups were chosen according to the orchestra formation of the concertoes on January 17th and 18th, which is the American arrangement.

If not mentioned otherwise, the presented results of the measurements are averaged over the octave bands 500 to 2000 Hz.

Comparison measurement results and musicians opinion

The loudness and intelligibility of the musical instrument depends above all things on the instrument itself, its loudness, its frequency range and its directivity. The stage and its surroundings won't change the individual character of the different instruments. But depending on the size and form of reflecting surfaces, the stage surroundings can add early first order reflections, which enhance the "natural" sound of the instruments.

It is noted that there is a significant individual variation in the response on the questionnaires. For that reason the responses are averaged. Nevertheless this average judgement will also have a limited accuracy. The number of measured situations (Doelen, Singel) is limited and therefore the spread in acoustical quality is rather low. These factors make that is difficult to find a significant relation between measured parameters and subjective quality.

Loudness and intelligibility of the musicians' own instruments

The opinion of the musicians on loudness and the intelligibility of their own instruments is compared to the measured values of these support values ST1 and ST2 [4], but also to speech intelligibility, direct-to-reverb, clarity (C_{80}) and definition (D_{50}). All these parameters are derived from the measured impulse response. Except for the support, no clear correlation was found between the parameters mentioned above and the musicians' judgement.

Generally it is considered that the support ST1 should be -12 to -15 dB and the ST2 -9 to -14 dB. (Which is not a statement that this is a sufficient condition, since influence of coloration or typical reflection patterns are not included).

It is noted that in the calculation of the ST1 only reflections after 20 ms are taken into account. This makes it a difficult parameter for musicians positioned at a distance less than 3,5 m to a wall. In De Doelen this is the case for percussion, brass and double bass.

For De Doelen, the musicians who judged the loudness of their own instrument as on the quiet side are the violins, the violas and the cellos (and the double bass). This correlates well to the measured ST values of -16 to -17 dB. The natural less loud instruments at the front of the stage receive the least early enhancing reflections from the stage surroundings.

In De Singel only a few musicians were not completely happy with the loudness or intelligibility of their instrument. This also corresponds quite well with the fact that all ST values are within the mentioned proposed range.

When the measured ST1's of the two stages are compared to the musicians opinions in one graph, a clear trend can be observed: a higher value for ST1 gives in general a higher score for loudness and intelligibility, See figure 3.

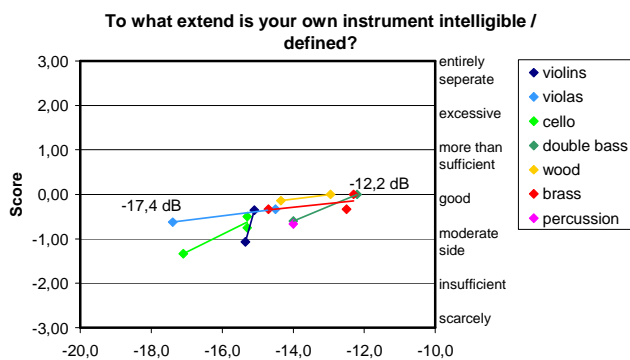


Figure 3. Overview comparison measured ST1 values in De Singel and De Doelen to the results of the Questionnaires.

Ensemble conditions on loudness and intelligibility

To evaluate ensemble conditions, the acoustic parameters AL_{cons} , Dir/Rev , C_{80} , D_{50} and $ST2$ are derived from the measured impulse responses and compared with the musicians' opinions on loudness and intelligibility. The $ST2$ is in this case not compared to the proposed value, but because of its time window, it might be a good parameter to evaluate the influence of the stage environment, especially when looking at possible improvements. Although one would expect a higher score on loudness or definition with a lower AL_{cons} or higher Dir/Rev , C_{80} , D_{50} and $ST2$, no clear relation was found. The main difference for ensemble conditions between De Doelen and De Singel is that almost 70% of the musicians judged the loudness and intelligibility of the violins as moderate (or worse) in De Doelen, to about 45% in De Singel. No clear correlation between the mentioned parameters and this judgement has been found though.

To describe the influence of the stage environment on the perceived loudness and intelligibility on stage, a parameter is required that is related to loudness, but not dependent on the distance between microphone and source. Otherwise the differences in distance at stage will dominate the resulting values which makes them incomparable. To describe the influence of the stage surroundings on intelligibility, only the early reflections are important (with no echoes or flutters present). Therefore the "strength" parameter G is used, but with a time window from 5 to 80 ms after direct sound, which excludes direct sound and takes into account reflections from surfaces up to a distance of roughly 14 m (from middle stage), which is of course arbitrary. It is referred to as Early Reflections Strength, G_{5-80} in dB.

$$G_{5-80} = 10 \log \frac{\int_5^{80} p^2(t) dt}{\int_5^{10} p_{10}^2(t) dt} [dB] \quad (1)$$

When the loudness of De Doelen stage was compared to De Singel, it appeared that the average G_{5-80} measured (at a source to microphone distance larger than 5m) in De Singel is 1,3 dB higher than in De Doelen, even with larger distances between the musicians. It also related quite well to the musicians' opinions. From the fact that at a certain value of Early Reflections Strength the judgement differs for different instrument groups, it seems that it will be hardly possible to define an optimum value for all instruments. It may be done

for individual instrument groups. But when asked "how loud do you hear a particular instrument group", a higher value relates quite well to a higher G_{5-80} , see figure 4.

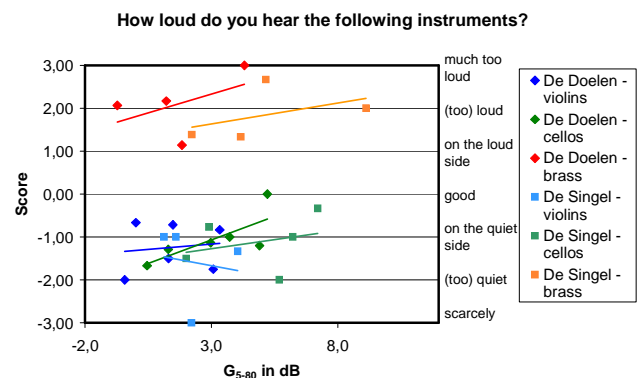


Figure 4. Comparison of G_{5-80} to the musician's opinion

The G_{5-80} ws therefore also used to evaluate the influence of the proposed alterations in De Doelen on the ensemble conditions, with the aspiration to enhance the G_{5-80} across stage.

INVESTIGATIONS DESIGN PROCESS

A stage reflector is proposed to improve the support at the front of the stage and the ensemble conditions. The stage reflector is positioned at a height of 10.5 m above the front of the stage and has slightly curved panels for diffusive reflections back to the stage. The reflector will be part of a suspended technical ceiling, the other parts of this technical ceiling will be acoustically transparent.

By means of a 1:10 scale model and a computer model (CATT-Acoustic) the influence of the proposed reflector as well as the influence of the original (1966) reflector is investigated. The original stage reflector consisted of six canopies and the front three were (according to pictures and drawings from then) quite tilted, and therefore primarily reflecting to the audience and as such not back to the stage (see also figure 1).

It is noted that besides the proposed reflector other reflectors have also been investigated. A smaller reflector gave to little improvement, especially at the edges of the stage. A larger reflector gave too much influence in the audience area and reduction of the reverberation time.

Scale model

Figure 6 gives a photo of the scale model from behind the investigated stage reflector. Figure 7 gives the measured impulse responses from B1 to M2 and from B2 to M1.

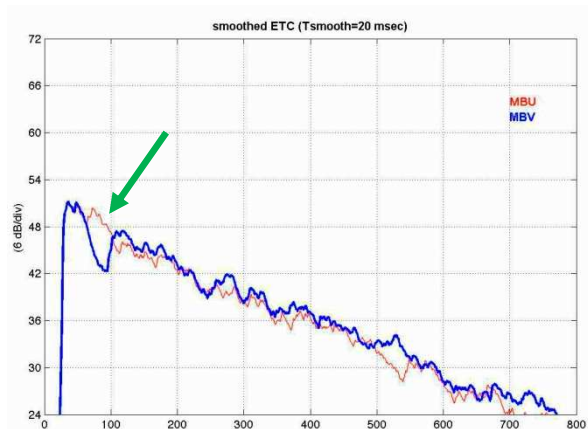


Figure 5. Scale model impulse responses with stage reflector (red) and without (blue), measured from B1 (cellos) to M2 (trumpets)

The stage reflector clearly fills the gap between the early reflections from the existing stage enclosure and the ceiling, which is marked by the green arrow. Within the own instrument groups (B1-M1 and B2-M2) the ST1 increases with 0.4 and 0.7 dB respectively at positions at the front of the stage. For a position more in the middle an increase was found of 1.7 dB.

Between the instrument groups, it can be concluded that for all positions the early reflections strength (G_{5-80}) increases with about 1.5 dB (averaged), see also figure 8, that also incorporates the measured influence of the original reflector.

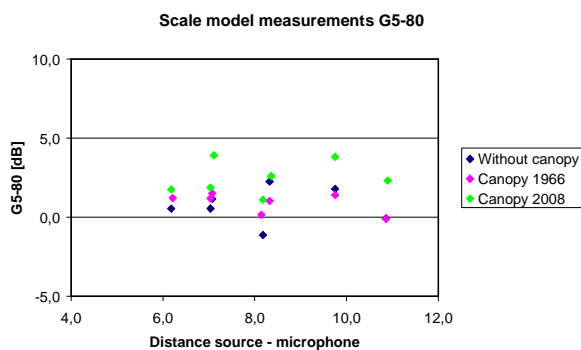


Figure 6. Measured G_{5-80} on stage in three scale model configurations: without canopy (blue), canopy 1966 (pink) and reflector as proposed (green)

Computer model

Most important objective of the computer model investigation was to determine the impact of the stage reflector on the reverberation time of the hall. With the proposed reflector the impact on the RT due to the reflector is minus 0.1 s, which will be compensated by other means (reduction of absorption of walls, ceiling, chairs). Just like in the scale model, the computer model calculations show that adding the stage reflector fills the gap between early reflections from the enclosure and the relative late reflections from the existing ceiling, resulting in an increase in ST1 and G_{5-80} of about 1 dB.

MEASUREMENTS AFTER RENOVATION



Figure 7. Overview of De Doelen after renovation

Just before the official opening of the hall, measurements were performed in the hall. The measured support ST1 at the front of the stage is enhanced from -17 dB before renovation to -15 dB after the renovation with canopy. The the early reflections strength (G_{5-80}) at the different positions is enhanced with 1 to 3 dB (averaged +1.5 dB), as can be seen from figure 8.

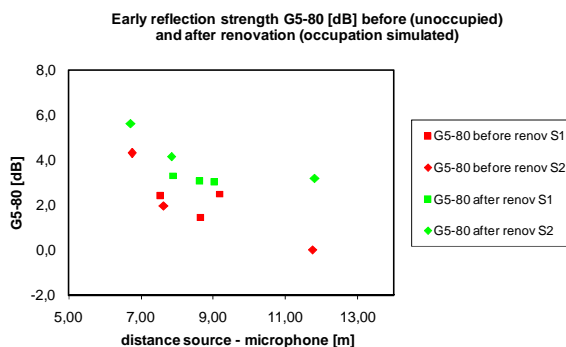


Figure 8. Measured G_{5-80} on stage in before renovation (2008, red), and after renovation (2009, green)

The musicians have expressed themselves as very positive towards the acoustic changes of the renovation. According to their opinion the ensemble conditions have improved significantly. Although the number of musicians that was enthusiastic about filling in another questionnaire was clearly less than before the renovation, the opinion on the ensemble conditions was much better, as can be seen from a comparison of figure 9 to figure 2.

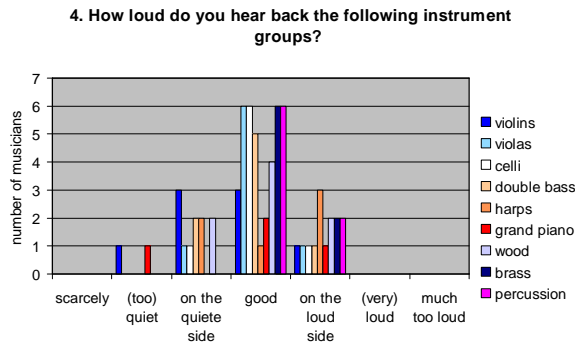


Figure 9. Example of the questionnaire output for ensemble conditions after renovation.

STAGE ACOUSTICS MAURICE RAVEL, LYON

For the Concert Hall Maurice Ravel in Lyon, Peutz was asked to investigate the stage acoustics and possible improvements. One of the questions for this investigation was to evaluate the negative opinion of the musicians on the stage acoustics.

The Maurice Ravel is quite a large concert hall, and especially very wide (59m), with a arena like public seating arrangement, see also figure 10. The stage is very large (425 m²) and although the ceiling above the stage is rather low (12 m) the measured impulse responses on stage show a significant gap between the direct sound and the important early reflections, see also figure 11.

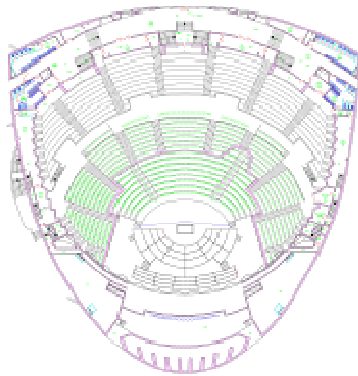


Figure 10. Plan of the Maurice Ravel Concert Hall, Lyon.

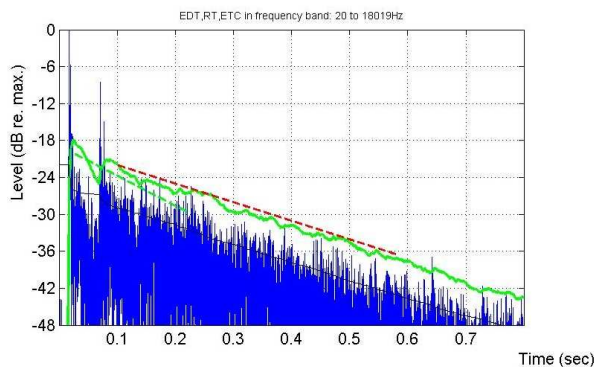


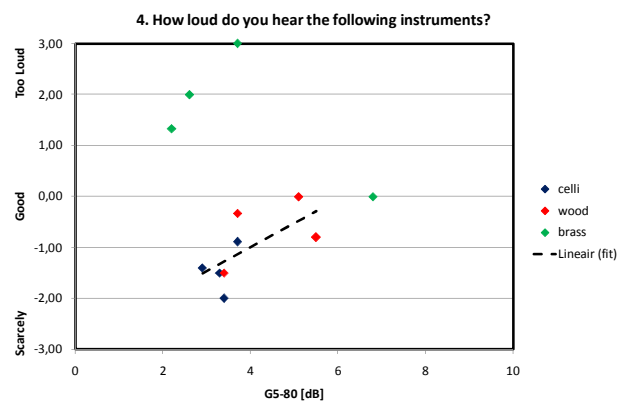
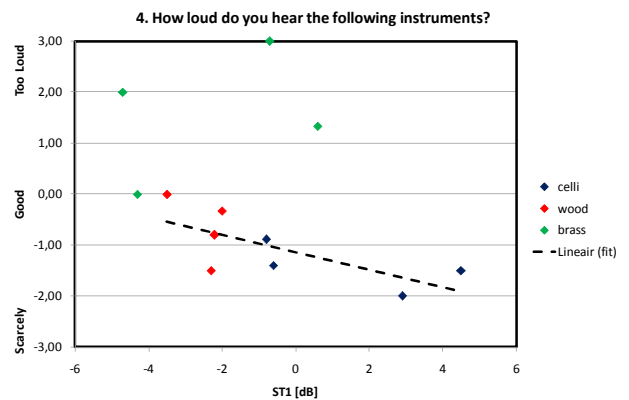
Figure 11. Measured (squared) Impulse Response Maurice Ravel on stage from B1 (cello) to M17 (conductor), with a significant gap between direct sound and “early” reflections

For this investigation measurements were performed in the unoccupied hall and listening sessions were held at several rehearsals. The measured support ST1 on stage is -15 to -17 dB.

The musicians of the de l’Orchestre National de Lyon, the main user and house-orchestra of the Maurice Ravel, have filled in the same questionnaire as the musicians of the Rotterdam Philharmonic Orchestra.

When comparing the musicians opinion on the ensemble conditions to the measurement results, also in this case only a correlation was found for the early reflections strength (G_{5-80}). Figures 11A and 11B give an example of the comparison of the musicians judgement and the ST1 and the G_{5-80} (it is noted that the ST1 is meant for the musician’s perception on the loudness of their own instrument and not for ensemble conditions, but it gives a good starting point to think about these matters).

In this case the musicians were asked how loud they can hear the other instrument groups. The answers are averaged over the musicians of a certain instrument group. The graphs show the musicians judgement versus the measured parameter derived from the impulse response between those instrument groups of source and receiver. As for the brass, a correlation is hard to find for both ST1 and G_{5-80} , it is simply (too) loud. For celli and woodwind, a linear fit can be made. The linear fit of the ST1 is initially the opposite of what is to be expected: a higher ST1 between instrument groups leads to a lower judged loudness. In case of the G_{5-80} the result is more in the line of expectations, as a higher G_{5-80} leads to a higher judged loudness



Figures 11A and B. Comparison between musicians judgement (y-axis) to the measured parameter (x-axis). Above: perceived loudness of celli and wood compared to ST1 (brass excluded from fitting), below: idem compared to G_{5-80}

DISCUSSION

On stage, the sound pressure level due to a certain source depends for a very large part on the distance between the source and the receiver, because these distances are mainly within the Hall Radius (or Critical distance). Every parameter measured on stage that includes the direct sound depends therefore for a significant part on the distance between source and receiver, which makes it very difficult to use it as a parameter for an acoustic description of the stage environment. If we want to have an acoustic parameter to describe the stage environment, it is to be preferred to exclude the direct sound.

Measurements on stage are usually performed without musicians on stage. This is certainly to be preferred from a measurement point of view: musicians make noise and the reproducibility will certainly decrease with a lively stage environment. The direct sound between a source (musical instrument) and receiver (musicians of other instruments) will partly be blocked by other musicians. The difference between the measurement situation and the situation judged by the musicians is for that matter quite different. Excluding the direct sound from the measured parameter will decrease this difference, at least partly.

The parameter used in this investigation, the G_{5-80} does exclude the direct sound, which might explain a certain correlation between the measured values and the musicians judgement. The range up to 80 ms is arbitrary though. In the case of De Doelen, the height of the stage reflector (10.5 m) certainly includes the measured ceiling reflections into the time window up to 80 ms. A lot of the second or third order reflections will also be incorporated. In the Maurice Ravel the ceiling height is at 12 m, which also will include the ceiling reflections to be within the 80 ms time window, although the first reflection with a distance of 12 m might be actually too far for supporting or improving the intelligibility on stage.

On the other hand it is known that small distances to an acoustically hard reflecting panel can result in a perceived coloration due to the comb filter effect. This negative aspect is not incorporated in a time window of 5-80 ms. Coloration or not, a reflecting panel at close distance will enhance the perceived level.

Up till now there is not a specified optimum value for the G_{5-80} . From the results a range of +3 to +6 dB seems to be a suitable target, the smaller the spread measured on one stage, the better. It is observed that a reflecting rear stage wall in combination with the public opening oblique stage side walls results in a larger G_{5-80} from back to the front than from front to back, and therefore enhances the instruments placed at the back of the stage. Except for the Vienna arrangement (in which the basses are on the back), this is usually the position of percussion and brass.

REFERENCES

- 1 M.R. Lautenbach, M.L.S. Vercammen, "Renovation of the Concert Hall De Doelen, Rotterdam, the Netherlands, Early Reflections Strength and Stage Acoustics" *Proceedings of the Institute of Acoustics Vol. 30. Pt.3.* (2008)
- 2 C.W. Kosten, "De Nagalmtijden van de Doelenzalen te Rotterdam", *NAG publicatie nr. 9* (1967) (in Dutch)
- 3 P.A. de Lange, "Aspecten van het akoestisch advies", *NAG publicatie nr. 9*, 1967 (in Dutch)
- 4 A.C. Gade, "Investigations of Musicians' Room Acoustic Conditions in Concert Halls. Part I and part II", *Acustica volume 69*, (1989)