Developments in Variable Acoustics for Rehearsal Rooms in the new RCO-house (NL)

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ABSTRACT

In January 2019 the new home of the Royal Concertgebouw Orchestra (R.C.O.) in Amsterdam (NL) has been opened. It is realized by adapting a monumental school building in the vicinity of the famous Concertgebouw. Besides office spaces it houses 10 rehearsal studios for individual musicians and small groups, as well as a small hall of 800 m^3 for chamber music and group rehearsals. This hall had to have a rich sound for chamber music with strings and woodwinds, by means of enough volume, reverberation and evenness in the sound field. In order to adapt the loudness and reverberation for group rehearsals and especially brass instruments specific variable acoustics have been implemented in all rooms. Results show that a large variability of the reverberation time and strength has been achieved for a wide frequency range. Measured values in the rehearsal hall are T_{30}=0.6–1.6 s. (30 JND), G=11-17 dB (6 JND)) and in the rehearsal studio's T_{30}=0.2-0.3/0.4-0.5 s (5-8 JND) and G=18-21/20-24 dB (2-3 JND).

This paper focuses on the original search for a suitable home, especially with the acoustic requirement for the right volume for the hall. From there the goals, means, design and results will be described and discussed with emphasis on the variability with retrospect of other musical rehearsal rooms, literature and standards.

1. INTRODUCTION

This paper describes how the acoustic demands for a suitable chamber music and rehearsal hall for the new home of the Royal Concertgebouw Orchestra (RCO) were set and describes the necessary adaptations, compromises and final results related to the final smaller volume of the hall, with retrospect of literature and experience. Results of final room-acoustical measurements of the ensemble hall and several rehearsal studio's will be described and discussed.

2. ENSEMBLE HALL

2.1 Demands and Search for a Building

For more than a decade the Royal Concertgebouw Orchestra has been searching for an affordable building in the vicinity of The Concertgebouw Amsterdam, that could serve as their new home. It had to provide for sufficient office spaces for staff as well as several rehearsal rooms. Key demands originally were a chamber music hall suitable for 30 to 35 musicians (like for instance a small chamber orchestra or larger group rehearsal for the string sections) with 200 seats, and at least 10 individual rehearsal rooms for 1 to 4 musicians.

For a chamber orchestra of 30 musicians a sound power level when playing forte of $L_w(f)$=105 dB can be deduced [1][2]. To limit the sound pressure level at forte to a maximum range of 85-90 dB the required strength for the new chamber music hall should not exceed G=13 dB. With a reverberation time of 1.5-1.6 seconds that should be aimed for chamber music in occupied condition this leads to a minimal required room volume of 2,000 m^3 (200 m^2 floor, 10 m height), which is indicated by a red dot in the V-T graph of Rindel [2] (see figure 1).

This 2,000 m³ was already somewhat adapted to possibilities in the city centre of Amsterdam, where space is scarce and really expensive.

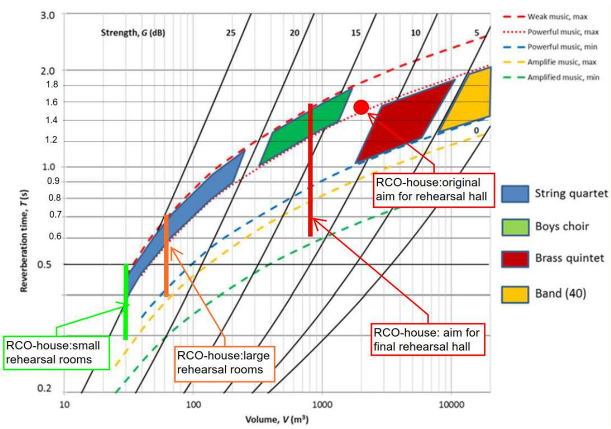


Figure 1. Limits of reverberation time in rehearsal rooms as function of volume [2] including values aimed for in RCO-house.

2.2 Final Building and Adapted Demands

So the room volume originally sought for the small ensemble hall was at least 2,000 m^3. In 2014 finally an old monumental school building in close vicinity of the Concertgebouw became a realistic option and was bought after consultation with Peutz as their acoustic consultant. The building had certain architectural qualities (architect Berlage) and could be easily adapted to almost all of the spatial demands for offices including rehearsal studio's that could be realized within a new extension behind the building, except for the large chamber music hall of

2,000 m^3. A spatial study was performed studying 11 different positions for the ensemble hall within the contours of the existing building and its structural limitations, and finally the variant with the largest possible volume was chosen. By tearing down several interior floors and structural walls applying necessary additional steel structures a maximum gross volume of 1,000 m^3 for the space required for the box-in-box of the ensemble hall could be realized, resulting in a net internal room volume of 800 m^3 (floor area of 100 m^2, internal height 8 m). The reconstruction and extension were undertaken during 2017-2018.

Figure 2. Facade view of renovated building for the RCO-house after completion

Because of the significant reduction of the room volume available for the new chamber music hall (800 m^3) compared with the goal originally aimed for (2,000 m^3) several adaptations in the design and use were inevitable due to acoustic laws and limitations [1][2]: In order to enlarge the dynamic range and to lower the loudness (and noise exposure) and reverberation for group rehearsals and especially brass instruments variable acoustics had to be implemented.

It was agreed upon to reduce the number of (removable) seats to 100 and to limit the number of musicians to 20-25 string instruments ($L_w(f)$=104 dB) or 6-8 brass players ($L_w(f)$=110 dB) for rehearsal situations. At the same time the hall still had to have a rich sound for chamber music with strings and woodwinds, by means of enough volume, reverberation and evenness in the sound field. To gain sufficient reverberance for strings a maximum reverberation time of 1.5-1.6 seconds was still aimed for, with a consequently strength G of 17 dB. On the other hand it can be deduced that in order to limit the forte sound levels with 6-8 brass players to 90 dB a reduction of the strength to G=11 dB is necessary. While maintaining the room volume, this can only be realized by a significant reduction of the reverberation time from 1,6 down to 0.6 s. which makes it necessary to apply an effective amount of 125-135 (m^2 open window) of variable absorption.

A large amount of this variable absorption had to be sufficiently effective for a wide frequency span (broad band absorption). With a wall surface of 300 m^2 this requires almost 50% of the walls to be applied with variable absorption, which is a serious acoustic challenge. Furthermore an additional requirement from an architectural point of view was that a significant amount of the variable absorption had to be almost invisible and should fully blend and be integrated with the wooden interior of the hall.

2.3 Design of Variable Absorption within the Hall

The variable absorption acoustics within the 800 m^3 hall consists of:

- 85 m^2 of retractable folded heavy acoustic curtains (170 m^2 fabric, folding factor 2) hanging in front of the glazed windows on both short ends of the hall. The acoustic curtains are divided in 8 parts and are electrically operated using 4 motors and can be stored in heavy wooden boxes (>35 kg/m^2) with an automatically closing lid in order to prevent residual absorption. A view of the interior with and without acoustic curtains is given in underlying figures:

Figure 3. Interior view of the Amsterdamzaal towards glazed facade with convex glazed windows during a rehearsal with 7 brass players and 1 timpani, with the hall in semi absorptive mode (no curtains, high side walls absorptive).

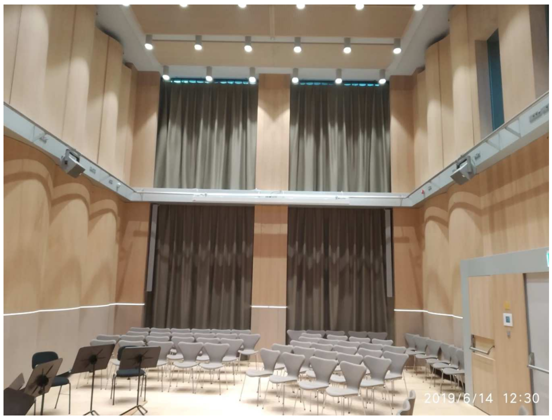


Figure 4. Interior view of Amsterdamzaal towards interior facade with acoustic curtains extracted in front of the glazed windows and with high side walls in reflective mode.

- 65 m^2 of sound absorbing panels consisting of 12 individually revolving, convex wooden panels in front of fixed absorption panels along the high side walls that are newly developed and integrate invisibly within the rooms' interior architecture. In their reflective setting a maximum amount of diffusion and reflection is generated for these high walls by alternating the structure of the wooden panels between a concave and a convex surface, see figure 5. The closed reflective front of the panels is significantly heavy (>25 kg/m^2) to limit the low frequent residual absorption as much as possible.

The fixed absorptive panels behind the revolving panel as well as the backside of the revolving panels themselves were designed to contain broad band absorption covered with perforated wooden panels (30% degree of perforation), in order to approach as much as possible a 100% full and broadband variation of absorption for these wall parts. The maximum amount of effective wall surface for variable absorption will in practice be limited by surface losses due to structural elements, panel edges, as is illustrated in figure 5.

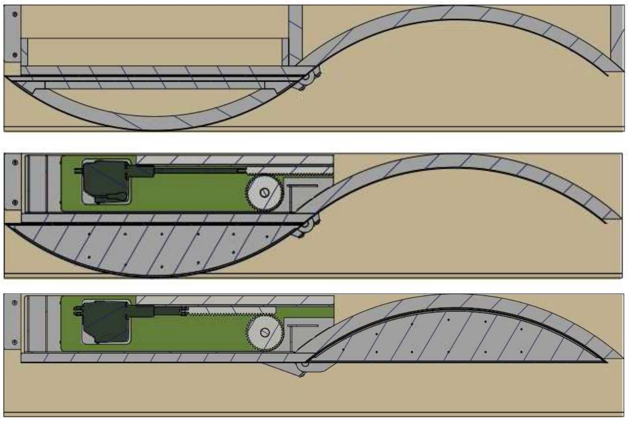


Figure 5. Schematic horizontal cross section and top view of variable absorptive elements along the high side walls with rotating panels in open and closed in condition.

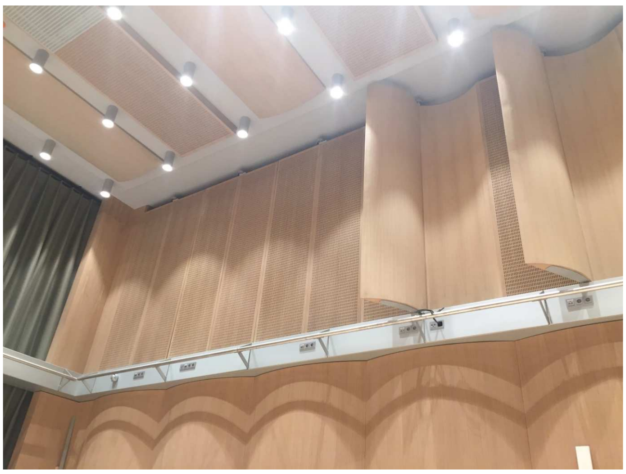


Figure 6. View of high side wall with 2 revolving convex panels changing from flat (left part, opened, absorptive) to convex/concave (closed, reflective).

All variable acoustic elements are electrically operated to ease their use. A view of a part of an interior side wall with the revolving panels in full operation is given in underlying figure.

A view of a part of the interior main entrance side wall in absorptive condition (revolving panels opened) is given in underlying figure.

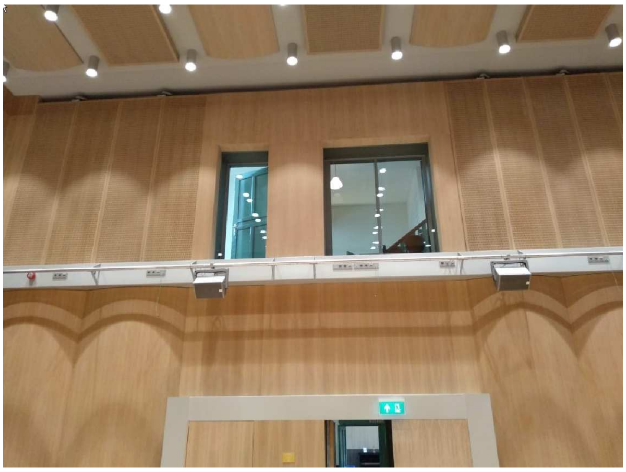


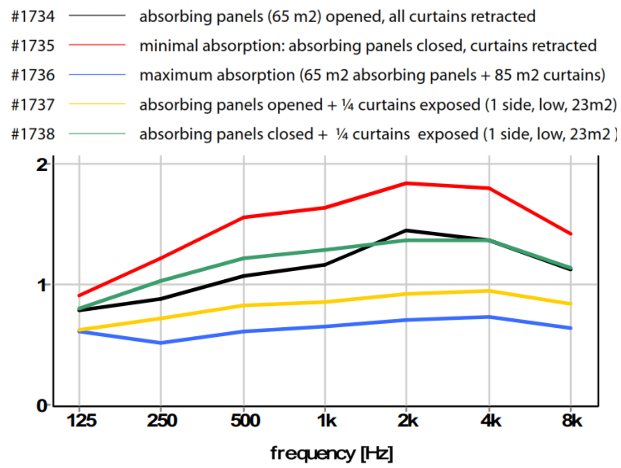
Figure 7. View of side wall with upper part in absorptive setting (flattened panels) and bottom part with fixed reflective concave diffusors.

In order to achieve a maximum of soft diffusion and evenness of the sound field almost all reflective parts of walls and ceiling have been designed as cylindrical convex shaped elements, as in shown in the photo above. In order to limit the maximum reverberation time a certain amount of fixed broad band absorptive elements (ca. 20 m^2) has been applied against the ceiling, alternated with diffuse convex cylindrical reflectors.

During the design-phase the acoustical design of the ensemble hall has been developed and supported using calculations with 3D acoustic modelling in Catt-Acoustics, in which the values used for the absorption and diffusion coefficients have been based on our experience. Due to time constraints during the execution phase there was no opportunity to perform acoustic laboratory tests on the sound absorption of the several wall- and ceiling elements like the variable absorptive (revolving) acoustic panels and the diffusive convex panels. The required build-up of all panels has been described precisely in the specifications and on drawings. However a check on their actual build up has not been performed before actual application on site, mainly because all panels were prefabricated in a decor workshop and have been installed subsequently on site.

2.4 Acoustic Results Ensemble Rehearsal Hall

2.4.1 Reverberation time



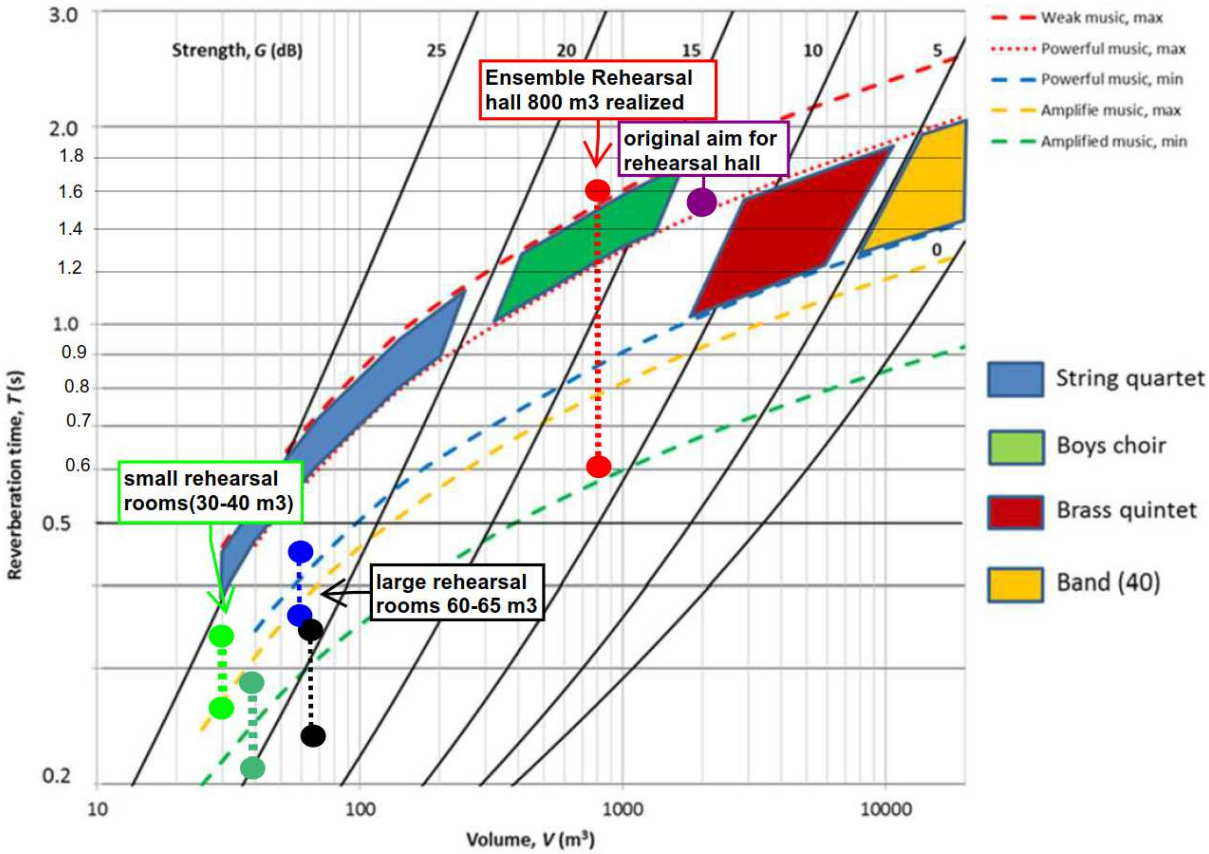
Rec.nr								
#1734	0,78	0,88	1,07	1,16	1,44	1,37	1,12	s
#1735	0,90	1,22	1,56	1,63	1,84	1,80	1,42	s
#1736	0,61	0,51	0,61	0,65	0,70	0,73	0,63	s
#1737	0,62	0,71	0,83	0,85	0,92	0,95	0,84	s
#1738	0,80	1,03	1,22	1,28	1,37	1,37	1,13	s

Figure 8. Measured T30 values for several octave bands (125 Hz – 8 kHz) in the ensemble rehearsal hall (Amsterdamzaal, V=800 m3) for 5 different settings of the variable absorptive elements.

A graphical spectral presentation of the resulting reverberation times (T30) measured within the rehearsal hall (without seats) for several settings of the variable absorptive elements, including a setting with minimal and maximum absorption is given in the left figure. From this measured data it can be concluded that in the ensemble rehearsal hall (Amsterdamzaal) of the RCO-House a lowest reverberation time $T30_{(500Hz-\ 1kHz)}$=0.6 s. is achieved which full fills the goal set. In the situation with minimal absorption the reverberation time increases up to 1,6 s., which fullfills the demands. The change in reverberation time is more than 150% and corresponds to a span of 30 JND for reverberation time, according to ISO 3382-1 [4] that states a JND of 5% for the reverberation time. Corresponding strength values are G=11 to 17 dB which means a span of 6 JND in strength, according to ISO 3382-1 [4] that states a JND of 1 dB for the strength.

The span of the variable acoustics as realized for the rehearsal hall (Amsterdamzaal) is indicated in the V-T-graph of Rindel [2] see underlying figure.

Figure 9. Limits of reverberation time in rehearsal rooms as function of volume [2] including span of values of variable acoustics realized in ensemble rehearsal hall (Amsterdamzaal) and rehearsal studio's of the new RCO-house in Amsterdam (NL).



An other conclusion from the measured data of the Amsterdamzaal was that for the low frequencies the increase of the reverberation time is rather limited and smaller than expected, and that the flat reverberation curve of 1,6 s. aimed for has not been achieved. Apparently a significant amount of residual low frequent absorption is still present in the reverberant setting. Some plausible explanations that could contribute to this effect are:

- Several of the cylindrical convex wall panels against the lower side walls still have a missing panel on the underside so the large cavity within these convex diffusors that is filled with mineral wool therefore has an open connection with the interior leading to unnecessary additional (low frequent) absorption (Helmholtz-effect);
- All the joints between the wall panels have open slits that are not sealed.
- There are several surface elements that have a lower mass compared with the mass requirement of 35 kg/m^2 as originally aimed for. For the revolving panels a more practical reduced mass requirement of 25 kg/m^2 was set. The wooden floor (20 kg/m^2 with an air space of 50 mm filled with mineral wool) has been designed as a low frequent resonating floor in order to contribute to the sound of certain string instruments (cello, double bass) but therefore also contributes in some extend to the low frequent absorption.

2.4.2 Strength and Clarity from Impulse Responses

From impulse response measurements performed in the ensemble rehearsal hall using an omnidirectional point source, it can be concluded that:

- For the reflective situation without seats the measured value for strength G=18 dB for listening positions at 8m from the source and further. This fullfills the aim set for a maximum strength of G=17 dB in a situation with seats.
- In the full absorptive situation the measured strength value is G=13 dB and for an intermediate half-absorptive situation measured strength value is G=15 dB, both measured at listening distances of 8m and further from the source. This full fills the goal set for the variable absorption to reduce the strength with at least 2 to 3 dB.
- Clarity values averaged over the listing positions are C_{80}=0 dB for the reflective situation, and C_{80}=+3 dB for the intermediate (half absorptive) situation. For the fully absorptive situation averaged clarity values are C_{80}=+7dB. All values full fill the demand set for clarity (C_{80}=0 to +5 dB).

2.4.3 Smoothness of Impulse Responses

In addition to the numerical objectives, it is always very important for music rooms that the reflection pattern is very uniform. The measurements in the Amsterdamzaal show a very nicely uniform impulse response for both the reflecting situation and the absorbing situation.

To illustrate this the two images below show a measured impulse response (1 kHz octave band) in the most reverberant situation and in the most absorbing situation.

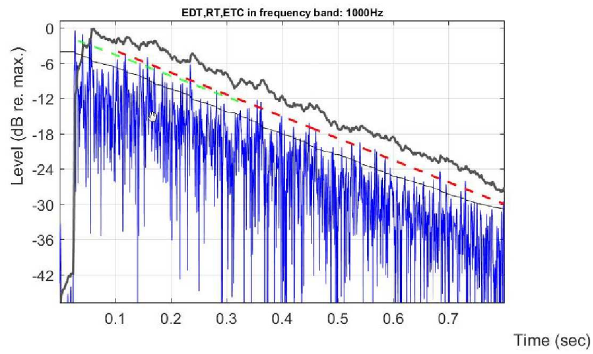


Figure 10. Measured impulse response (1 kHz octave band) for the most reverberant situation of the ensemble rehearsal hall (Amsterdamzaal).

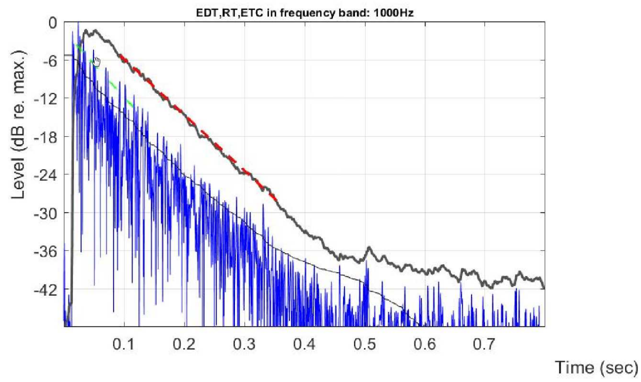


Figure 11. Measured impulse response (1 kHz octave band) for the most absorbing situation (without seats) of the ensemble rehearsal hall (Amsterdamzaal).

2.5 Concluding Remark

The acoustics of the Amsterdamzaal are very well received by the orchestra musicians and recording technicians as well. The Amsterdamzaal is so much in favour of the musicians that they also use the hall for recordings.

3. REHEARSAL STUDIO'S

3.1 Demands and Design of Variable Absorption

For the ten individual or small group rehearsal studio's variable acoustics have also been designed and implemented in order to adapt their acoustics to the number of musicians and to adapt the amount of wall reflections to the taste of the individual musician.

Seven rehearsal studios are semi-box-in-box rooms with three small ones with a volume of 30 m^3 for individual musicians with a maximum reverberation time aimed for of 0,4 s (G=26 dB). The four larger ones have a room volume of 60 m^3 and are meant for individual and small group rehearsals with a variable reverberation time aimed for between 0,5 and 0,8 s (G=23–25 dB). The variable absorption is design by using sliding reflective wooden panels (>20 kg/m^2) in front of 60 mm thick absorptive wall panels and meant to adapt the acoustics to the preference of each musician: with these panels the amount of sound reflections can be simply regulated: more reflections to hear oneself better or less reflections to reduce the loudness for ensemble or loud instruments. Underlying figures show a view within such a large 'small' rehearsal studio (1.50) for a situation with minimum absorption (sliding panels closed) and with maximum absorption (sliding panels aside from the absorptive wall panels).

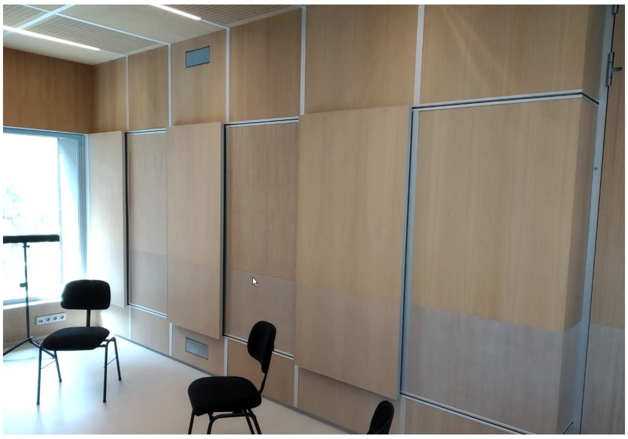


Figure 12. View of wall inside rehearsal room (1.50) in situation with minimal absorption (sliding reflective panels closed in front of wall absorption).

Figure 13. View of wall inside rehearsal room (3.50) in situation with maximum absorption (sliding reflective panels aside of the wall absorption).

Three of the rehearsal studios are completely sound insulated box-in-box rooms meant for individual brass rehearsals and have room volumes of 30, 40 and 60 m^3. Variable reverberation times aimed for are 0,3 to 0,5 s., with subsequent variable strength values aimed for of G=20–23 for the largest room up to G=24-26 dB for the smallest room. These rooms have also similar variable absorption using sliding reflective wooden panels in front of wall absorption to adapt the acoustics to the preference of each musician.

Underlying figures show a view of a long sidewall of such a large 'small' rehearsal studio (0.57) meant for brass players in a situation with minimum absorption (sliding panels closed) and with maximum absorption (sliding panels aside from the absorptive wall panels).

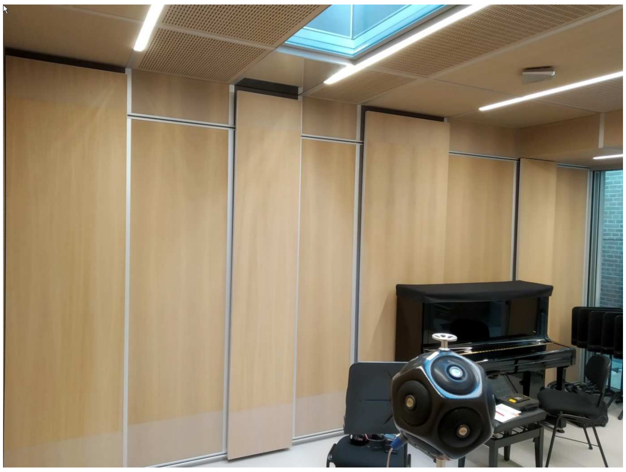


Figure 14. View of wall inside rehearsal room (0.57) for brass players in situation with minimal absorption (sliding reflective panels closed in front of wall absorption).

Figure 15. View of wall inside rehearsal room (0.57) for brass players in situation with maximum absorption (sliding reflective panels aside of the wall absorption grey surface)).

All rehearsal studios have sufficient diffusion by alternating between absorbent and reflective wooden panels in the walls as well as in the ceiling, and all have a minimal internal height of 2,8 m.

3.2 Acoustic Results Rehearsal Studio's

A graphical spectral presentation of the resulting reverberation times (T30) measured within 4 out of 10 different rehearsal studio's for the maximum settings of the variable acoustics (with minimal and maximum absorption) is given in the next four figures.

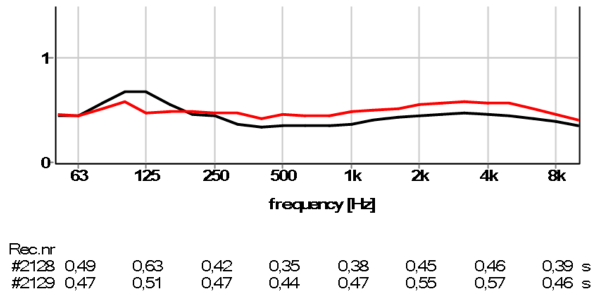


Figure 16. Measured T30 values in a large rehearsal room (no. 1.50, V=63 m3, 6 m2 of sliding wall panels)

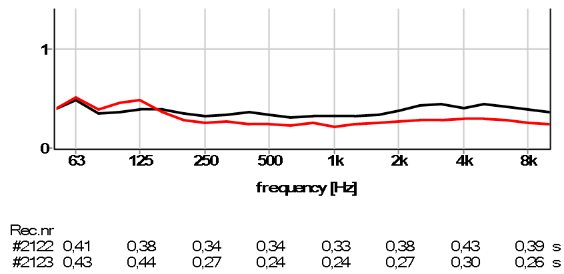


Figure 17. Measured T30 values in a large rehearsal room (no. 0.57, V=65 m3, 13 m2 of sliding wall panels)

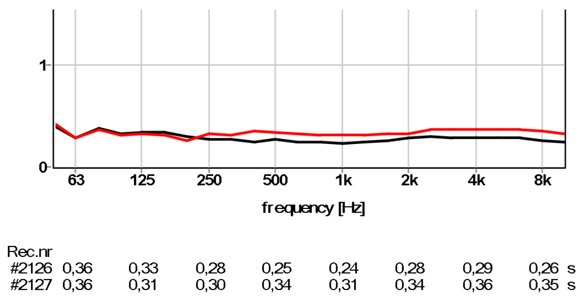


Figure 18. Measured T30 values in a small rehearsal room (no. 0.55, V=32 m3, 5 m2 of sliding wall panels)

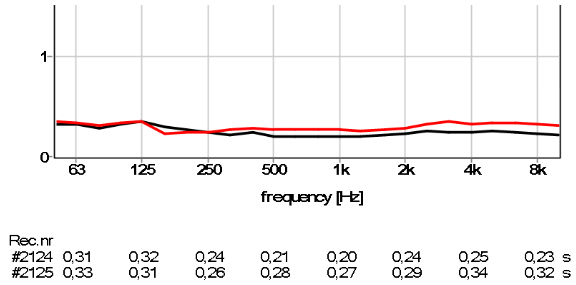


Figure 19. Measured T30 values in a small rehearsal room (no. 0.56, V=39 m3, 8 m2 of sliding wall panels)

The measured results of the reverberation time have been summarized in underlying table 1, together with the room volumes and the amount of variable absorptive elements.

Room no.	V (m^3)	variable surface (m^2)	T30 (s)	Change (%)	Span JND
Hall	800	150	0.63-1.6	153	30
1.50	63	6.3	0.37-0.46	25	5
0.57	65	12.9	0.24-0.34	40	8
0.55	32	5.3	0.25-0,33	33	6
0.56	39	7.7	0,21-0,28	34	7

Table 1. Reverberation times ($T30_{(500Hz-\ 1kHz)}$) measured in the Amsterdamhall and 4 rehearsal studio's and related span.

The measured results of the related strength values (G) have been summarized in underlying table 2, together with the room volumes and the amount of variable absorptive elements.

Room	V (m^3)	variable surface (m^2)	G-values (dB)	Change (dB)	Span JND
Hall	800	150	11 - 17	6	6
1.50	63	6.3	21 - 22	1	1
0.57	65	12.9	18 - 21	3	3
0.55	32	5.3	22 - 24	2	2
0.56	39	7.7	20 -22	2	2

Table 2. Strength values from measured reverberation times in the Amsterdamhall and 4 rehearsal studio's and related span.

From the measured data as described above it can be calculated that the change in reverberation time ($T30_{(500Hz-\ 1kHz)}$) as measured in the four rehearsal studio's is at least 25% for room no 1.50 corresponding to a span of 5 JND according to ISO 3382-1 [4] that states a JND of 5% for the reverberation time. The change in measured reverberation time increases for room no. 0.55 and 0.56 to 33% (span of 7 JND) up to 40% (span of 8

JND) for room number 0.57 that has the highest amount of variable wall panels (13 m^2).

Corresponding variable strength values range between G=18-21 dB for room no. 0.57 (span for strength 3 JND), up to G=20-22 dB for room no. 0.56 (span for strength 2 JND) and to G=21-22 dB for room no. 1.50 (span for strength 2 JND) all the way to G=22-24 dB for the smallest room no. 0.55 (span for strength 2 JND).

The span of the variable acoustics as realized for these four small rehearsal studio's has also been indicated in the previous V-T-graph of Rindel [2] in previous figure 9.

3.3 Remarks Regarding Results Rehearsal Studios

Several additional conclusions based on the results of the reverberation time measurements in the rehearsal studio's are:

- The reverberation curves are relative flat as aimed for;
- The average effective absorption coefficients of the variable absorption as applied can be deduced to be about 0.95 for the middle frequencies, reducing to values of 0.7 to 0.8 for the higher octave bands. This is probably due to the remaining openings (slits) around the perimeter of the sliding panels where no seals were applied.
- a variation of the reverberation at the middle and high frequencies in this small studio's is more relevant than low frequent variation, mainly because it allows to adapt the acoustics in these small rehearsal studio's to the preference of each individual musician: having mainly instruments with a high directivity these sliding wall panels enable a simple regulation of the amount of sound reflections: more reflections to hear oneself better or less reflections to reduce the loudness for ensemble or loud instruments.
- In figure 16 to 19 there appears to be a typical cross-over point at about 150-200 Hz. Below this frequency the effective amount of low frequent absorption in the room increases when the reflective panels are closed and slide before the (60 mm thick) fixed wall absorption. This is probably due to additional low frequent absorption because of the 1-2 cm wide openings around the reflective panel (Helmholtz-effect) that do not have seals, in combination with an additional resonator effect of the panel itself. Both contributions add up to a higher low frequent absorption compared to the low frequent absorption coefficient of the wall absorption itself. If more low frequent variation would be necessary application of flexible sealing around the sliding panels would probably be more effective compared to a further mass increase of the panels that are already 20 kg/m^2.
- Laboratory test on the effectiveness of the variable absorption of a complete wall fragment could have been a valuable tool to investigate such behaviour on beforehand before the actual build-up on site, but have not been performed due to time constraints.
- In all measured rehearsal rooms, the measured reverberation time is somewhat shorter than initially intended, which is favourable for limiting the loudness for the musicians which helps especially for professional musicians to limit their daily sound dose. The variation in reverberation time is also somewhat smaller than initially intended, which can be explained by the relatively smaller available wall surface area for variable absorption in the final stage compared with the design. Nevertheless, it may be expected that there are sufficient available wall surfaces, whereby the variable provision can be used to opt for a sound-supporting reflection or for the absence thereof.

3.4 Concluding Remarks

Feedback from the musicians of the RCO are up till now very, very positive. The occupancy of all the rehearsal rooms is much higher than expected upfront. The ensemble rehearsal hall (Amsterdamzaal) is so much in favour of the musicians that they also use the hall for sound recordings.

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