IN SITU ACOUSTIC EFFICIENCY OF VARIABLE BROADBAND ABSORPTION IN MUSIC REHEARSAL STUDIO'S AND MUSIC HALLS

M.P.M. Luykx MSc Peutz Consultants Netherlands

1 INTRODUCTION

In many music rehearsal studios and halls there is a need to adapt the room acoustics to the different types of use. Reasons for that are to reduce the loudness levels or improve intelligibility, or to adapt the amount of reverberance and acoustic feedback. One of the options to adapt the acoustics is the application of a changeable room volume for instance by using an orchestra shell on stage and/or a movable ceiling above the audience, as has been implemented by Peutz in several dedicated auditoria (Muziekgebouw at the IJ[1] (Amsterdam), Theatre “De Spiegel” [2,3] in Zwolle (NL). However, for most rehearsal studios and halls this option of a movable ceiling usually is not applicable and too costly. Variation of volume also inherently cannot influence the loudness of the room, whereas this is often required for rehearsal rooms with different types of use[4]. Application of variable absorption is another way to vary the room acoustics, and to adapt both the reverberation time and the loudness simultaneously. This was applied for instance in 2008 in the Conservatory of Amsterdam[5], where adaptable acoustics was applied using removable absorbing cushions with a specific layered build-ups in order to expand the broadband variation, especially towards the lower frequencies. Recently, in the context of plans for a new extension, in-situ measurements of the acoustic efficiency have been performed on these acoustic panels that have been used for 15 years in lesson rooms. Results hereof will be discussed in this paper.
When stringent visual requirements like invisibility and/or full integration within the architecture are set for the variable absorption, acoustic challenges are to maintain sufficient acoustic efficiency. Recent developments hereof were designed and implemented in the rehearsal rooms and studios for individual musicians and music ensembles in the new office building of the Royal Concertgebouw Orchestra (RCO), the “RCO House Amsterdam”[6], which opened in 2019. In addition to the previous paper[6] about this project, the results of in situ-measurements on the acoustic efficiency of the different types of variable absorption applied in this project will be given and discussed in the underlying paper.

2 CONSERVATORY OF AMSTERDAM

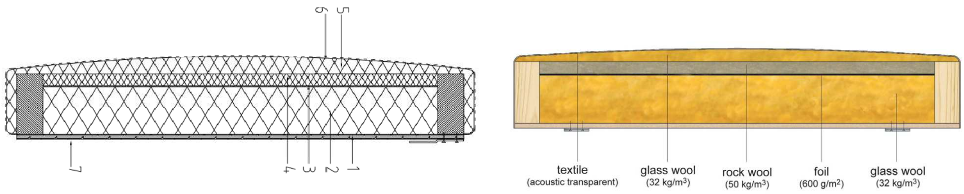
In 2021 plans were made for an additional location for the Conservatory in Amsterdam (NL). For that purpose, the adaptable acoustics that had been designed and applied in the lesson and study rooms of the main building[1], build in 2008, have been evaluated.

2.1 Design of broad band absorbers

The principle design of the removable acoustic cushions applied against the ceilings and walls of the lesson and study rooms in the Conservatory of Amsterdam is schematically given in figure 1 and 2. Their build-up was originally designed with the following elements, from back to front:

- closed back panel (1) (900x900x9 mm mdf) against a rectangular wooden frame (50x130 mm)
- inner filling (2) (100 mm glass wool 32 kg/m3)
- layer of closed foil (3) (600 g/m2)
- layer of rockwool (4) (40 mm, 50 kg/m3)
- top layer of glass wool (5) (40 mm, 32 kg/m3)
- visual layer of acoustically open textile (6) stretched around the panel over the edges.

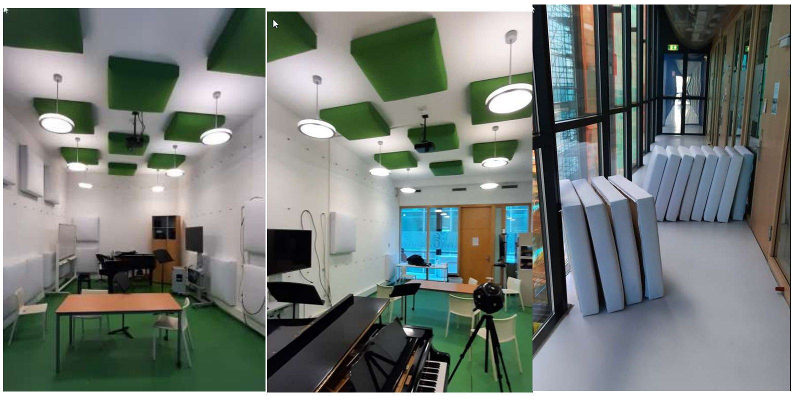
Figure 1: cross-section of absorbing cushion as designed with numbered elements



2.2 Recent measurements on acoustic efficiency

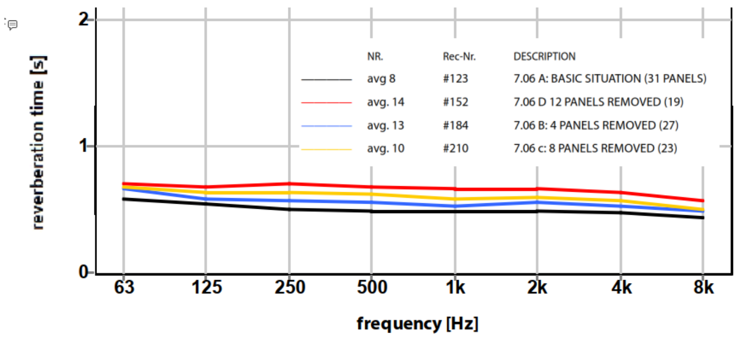
In 2021, measurements of the reverberation time have been performed when subsequently several acoustic panels were removed from the walls out of a lesson room. Figure 3 gives an impression of this lesson room before and after the removal of the panels. The average distance between adjacent wall cushions varies between 25 to 45 cm.

Figure 2: lesson room, sit A (31 panels) and D (19 panels), with 12 panels in the corridor.



The resulting reverberation times measured for the different settings of this lesson room are summarized in figure 4. It can be seen that with 12 wall panels a change of T_{mid}=0,49 to 0,6 s. can be achieved.

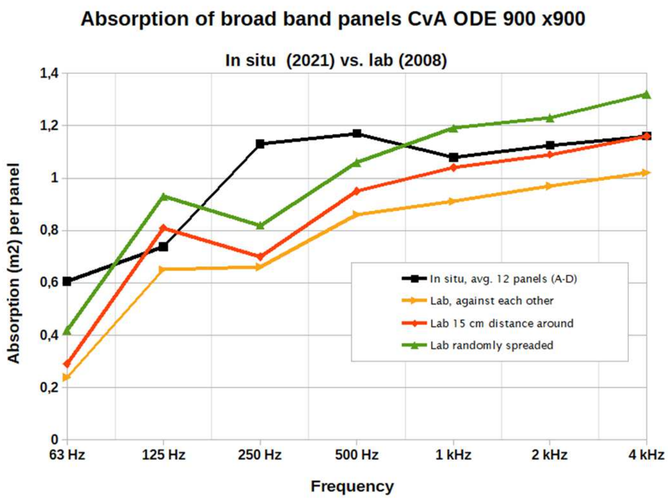
Figure 3: Measured T30 values in lesson room 07.06 with different amount of acoustic wall panels



Rec.nr									
#123	0,58	0,54	0,50	0,49	0,49	0,49	0,47	0,43	s
#152	0,70	0,67	0,70	0,68	0,66	0,66	0,64	0,57	s
#184	0,66	0,58	0,57	0,55	0,53	0,55	0,53	0,49	s
#210	0,68	0,64	0,63	0,62	0,58	0,59	0,57	0,50	s

From the measured reverberation times in this lesson room (V= 153 m3) for the situations with the largest difference in amount of wall panels (situation A to D:12 panels, total frontal surface ca. 9.8 m2) the effective in-situ absorption (in m2 open window) averaged for a single broad band panel can be calculated and has been spectrally octave band values (63 Hz to 4 kHz) summarized in figure 5, together with the results of earlier laboratory measurements on 12 new panels in different arrangements.

Figure 4: Absorption of a single broad band cushion in situ vs. laboratory



From the measurement results in figure 5 it can be concluded that:

- The in-situ sound absorption of the wall panels in the arrangement used is especially for mid-frequencies considerably higher than values measured in the laboratory on similar panels with an equal distance of 15 cm around. This might be due to an increased side effect due to higher distances between the panels for the in-situ arrangement in the lesson room compared with the laboratory arrangement.
- The averaged in-situ sound absorption of the wall panels for mid-frequencies (500 Hz-1kHz) is 1.12 m2 open window per panel of 0.81 m2 frontal surface (138%), and for low-frequencies (125-250 Hz) 0.93 m2 open window (115%).

2.3 Disassembly of a broad band absorbing panel

In order to examine the exact build-up and materials used for the broadband panels in the Conservatory of Amsterdam and to judge how the materials and build-up have sustained over the years and whether these could still last for future use, a single absorbing panel was disassembled in 2021 after almost 15 years of use. The next figures show several steps during the disassembly of the panel.

Figure 5 Front view and back view of cushions (with 2 holes in back panel for hanging of wall panels)

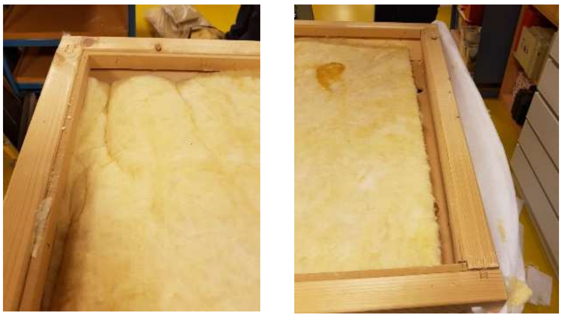
Figure 6 Side layers of (additional) fleece and textile finishing

Figure 7 Top side with textile finishing, additional fleece layer and top layer of glass wool (40 mm, 22 kg/m3)

Figure 8 Second mineral wool top layer of rockwool (25 mm, 45 kg/m3) and foil underneath

Figure 9: pvc-foil (650 g/m2) mounted from the back with staples, but clearly loosened from the (top) side.

Figure 10 Inner layer of glass wool (90 mm, 16 kg/m3), clearly shifted from top to bottom (due to gravity?).



The disassembly of this single broad band absorption cushion has given valuable insight into the exact composition and state of the materials used:

- The type of mineral wool layers applied had lower weight/densities than asked for. Nevertheless, the in-situ absorption values measured (see fig. 4) are still rather high.
- For vertically hanging wall cushions there appears a risk that the connections between the foil and the frame become loose if these are not secure enough, as can be seen in the photo where staples were applied. Also the inner glas wool layer can shift due to gravity over time if its position is not secured. Both aspects might have a negative influence on the low-frequent absorption. However, the measurement results show still rather high values.
- The 10 mm layer of fleece applied on the sides results in an additional side-effect on the in-situ absorption.
- The holes in the back of the wall panels seem not to have a drastic negative effect on the low frequent absorption, although it could be argued that these holes give an undesirable leak because the air volume behind the resonating foil should acoustically preferably be closed.

Future improvements could for instance be to apply a better fixation of the foil (airtight resonator) and a better fixation of the inner layer of mineral wool to prevent shifting and compression due to gravity, as well as a reduction of its total mass of which 85% is determined by the wooden structure and the backplate. Because the total weight of a single panel is 17.7 kg, this is nowadays considered as rather high by the users of the lesson and study rooms. Therefore, changes in panel arrangement are usually made only once a year by technicians, using scaffolding or a genie to reach the higher wall panels and/or to change the amount of ceiling panels.

3 RCO HOUSE AMSTERDAM

3.1 Variable absorption rehearsal hall

In order to obtain the variation of reverberation time (0.6-1.6 s) and loudness change (5-6 dB) aimed for in the 800 m3 rehearsal hall of the RCO-House in Amsterdam, a significant amount of variable absorption has been applied. In front of the glazed windows on both short ends of the hall 85 m2 of retractable folded heavy acoustic curtains (170 m2 fabric, mass 570 g/m2, Rs=1450 Ns/m3, folding factor 2) has been applied. These acoustic curtains are divided in 8 parts and are electrically operated using 4 motors and can be stored in heavy wooden boxes (>35 kg/m2) with an automatically closing lid in order to prevent residual absorption.
Along the long side walls 66 m2 of sound absorbing panels has been applied, 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. The closed reflective front of the panels is significantly heavy (>25 kg/m2) 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 this variable absorption will in practice be limited by surface losses due to structural elements, panel edges etc. Underlying figures show the interior of the rehearsal hall with and without acoustic curtains is engaged, as well with the high side wall panels in closed and open situation.

Figure 11 Interior view of rehearsal hall with acoustic curtains open (left) and closed (right)

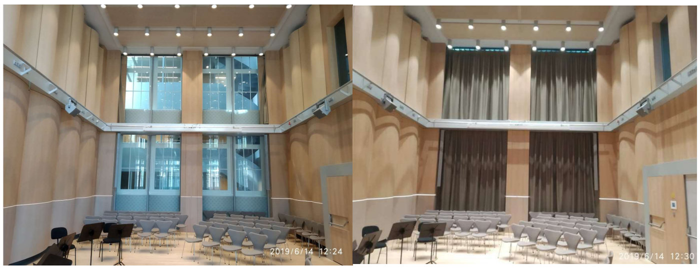
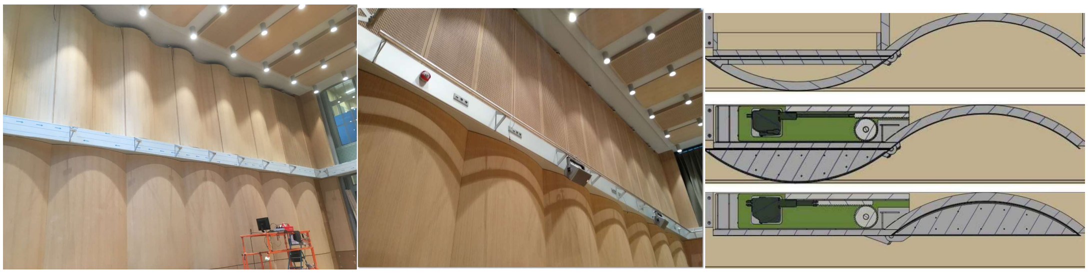
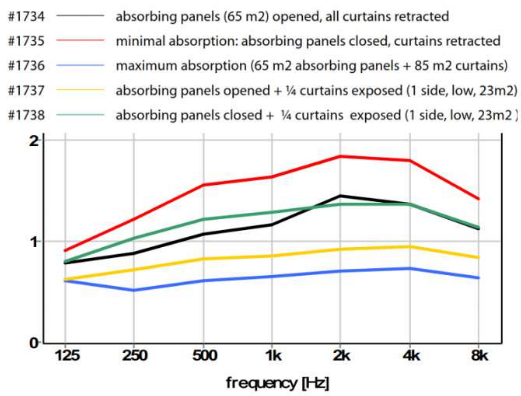


Figure 12 Rotating absorbing panels closed (left) and open (right), and cross section of panel (right)

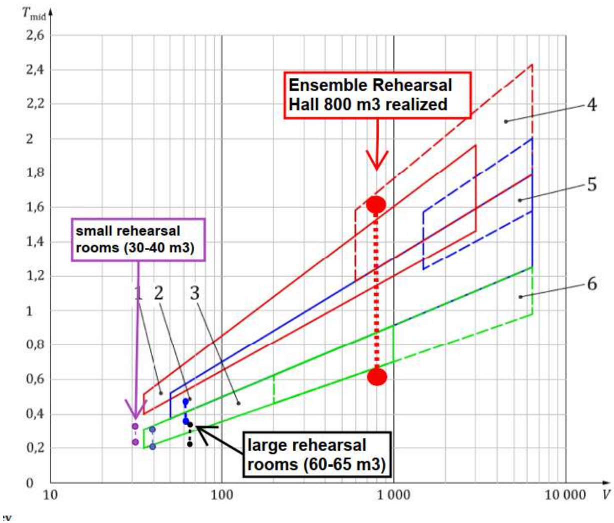


The resulting reverberation times (T30) measured within the rehearsal hall (without seats) for several settings of the variable absorptive elements, including a setting with minimal and maximum absorption is spectrally given in next figure (left) and T_{mid}-values are indicated in the right T-V plot from ISO 23591[4].

Figure 13 T30 values measured in the rehearsal hall (left) and Tmid values indicated in T-V graph from ISO 23591:2021[4]



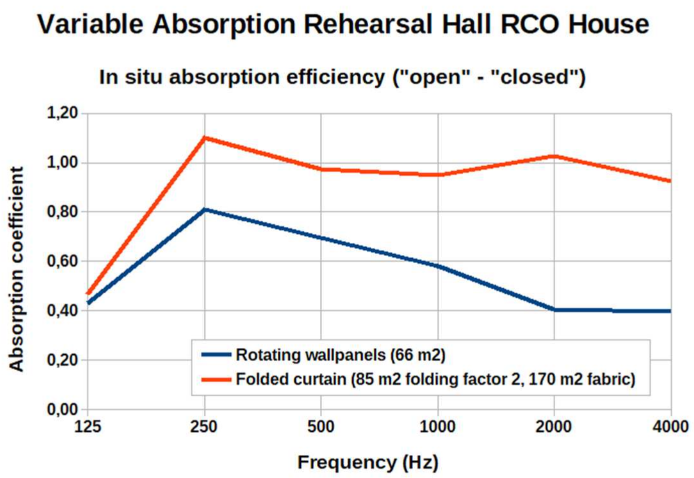
Rec.nr								
#1734	0,78	0,88	1,07	1,16	1,44	1,37	1,12	s
#1735	0,90	1,22	1,56	1,63	1,84	1,80	1,42	s
#1736	0,61	0,51	0,61	0,65	0,70	0,73	0,63	s
#1737	0,62	0,71	0,83	0,85	0,92	0,95	0,84	s
#1738	0,80	1,03	1,22	1,28	1,37	1,37	1,13	s



From this measured data in the rehearsal hall it can be concluded that 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 full fills the demands as well. 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[7] 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 that states a JND of 1 dB for the strength. The span of the variable acoustics as realized for the rehearsal hall is also indicated in the V-T-graph of ISO 23591:2021 see the right graph above.

Based on the measured reverberation times in the rehearsal hall (V= 800 m3) the effective in-situ absorption coefficient of the rotating wall panels and the acoustic curtains have been separately calculated and averaged over the different situations. These averaged values are spectrally (125 Hz to 4 kHz) summarized in figure 14.

Figure 14 In-situ absorption efficiency ("open" – "closed") of variable absorption measures in rehearsal hall.



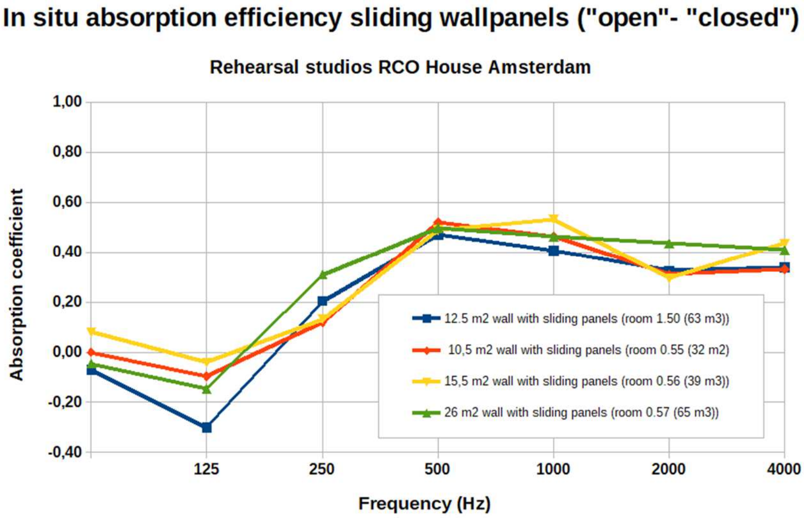
From figure 14 it can be concluded that the absorption efficiency (difference in absorption "open" – "closed" per m2 element) of the folded curtains measured in-situ is relatively high. Especially the low octave bands (125, 250 Hz) have significantly higher values (0.47, 1.10) than the laboratory values of the same folded curtain at 0.15 m void (0.15, 0.75). This is possibly due to the combination of a larger air gap behind the curtains as well as the retracted position of the curtains between the surrounding elements causing the air void behind the curtains to be almost fully 'closed' which increases low frequency absorption.
For the rotating perforated broad band absorbing panels, the absorption coefficient measured in-situ appears limited compared to the value of 1.0 aimed for application of broad band absorbing panels. This is possibly due to a combination of factors such as that a rather large part of the surface has not been perforated, that on several positions there were rigid parts (structure) behind the perforations, and that due to the curved shape of the rotating parts the effective thickness of the sound absorbing layers behind the perforations was limited and therefore probably no foil has been applied in between mineral wool layers for half of the absorbing surface. At least an acoustic laboratory test of the sound absorption of the rotating broad band absorption panels could have given more proof of this in advance, as well as a disassembly of a broad band panel, both of which have not been performed. However, due to the combination of elements still a significantly sufficiently high variation of reverberation times and loudness has been achieved in this rehearsal room.

3.2 Variable absorption rehearsal studio's

The variable absorption in the rehearsal studios of the RCO House is designed by using sliding reflective wooden panels (>20 kg/m2) in front of alternatingly absorbing (60 mm mineral wool with fabric) and reflective wall elements. These are used 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 of 65 m3 with almost 26 m2 of variable wall surface for a situation with minimum absorption (left: sliding panels closed) and with maximum absorption (sliding panels shifted aside and absorptive wall panels exposed (right)).

Figure 15 Two different settings of sliding wall panels in rehearsal studio (reflective (left) and absorptive (right)

Figure 16 In-situ absorption coefficient of wall with sliding panels in rehearsal studio's of RCO House



Based on the measured reverberation times in four out of 10 rehearsal studio's the effective in-situ absorption efficiency of the walls with sliding panels has been calculated. These values are spectrally (63 Hz - 4 kHz) summarized in figure 16. From this graph it can be concluded that for mid and high frequencies the absorption values reach the theoretical maximum value of 0.50 for such a flat wall. For the low frequencies, a limited absorption is reached, or even negative values for the 63 and 125 Hz octave band. This is because the absorbing parts were not designed as broadband absorbing elements and therefore the situation with 100% closed walls absorb more low frequent sound than in the absorptive setting with 50% closed walls.

4 REFERENCES

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