

ROOM ACOUSTIC PARAMETERS MEASUREMENTS IN VARIABLE ACOUSTIC LABORATORY ARNI

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Abstract

The possibility to alter a room's acoustic conditions is useful for spaces requiring specific acoustics depending on diverse functions they serve. Such solutions are applied mostly in multipurpose auditoriums and concert halls, as well as in audio research facilities. The variable acoustics laboratory *Arni*, a facility within the Acoustics Lab of Aalto University in Espoo, is an example of a space where the wall absorption can be altered considerably with the help of specialized wall- and ceiling-mounted panels. The present work shows the results of measurements of over 5000 panel combinations in *Arni*, showcasing the change in values of the room acoustic parameters, such as reverberation time and clarity, in relation to the variation of the wall absorption.

1 INTRODUCTION

Variable acoustics, or active acoustics, systems are nowadays a common feature of multipurpose spaces that are expected to fulfill various requirements regarding their acoustic parameters. Such spaces are, for example, concert halls where different types of music are performed or buildings with combined congress and entertainment functions. Additionally, specialized acoustic laboratories equip their spaces with variable acoustic systems for research purposes. The research conducted utilizing varechoic rooms spans across many topics, and includes, among others, validation of reverberation time models [1], speech dereverberation [2, 3], microphone-array beamforming [4], and testing self-localisation memory in humans [5].

Many times the variable acoustic systems in the varechoic rooms allow for a great granularity of change in the acoustic conditions of the room [1, 3, 6]. Therefore, it is important to learn the possible configurations, their impact on the values of room acoustic parameters, as well as limitations.

This paper presents the measurement results from *Arni*, a variable acoustics laboratory built in the Acoustics Lab of Aalto University in Espoo during a renovation in 2019. The

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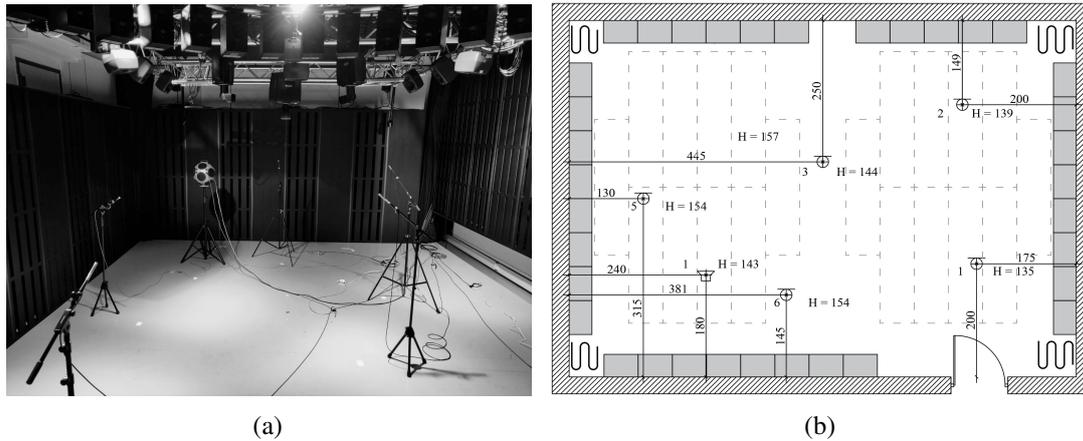


Figure 1: (a) View of *Arni* showcasing the measurement equipment. The panels on the walls are shown in both open and closed states. (b) Layout of *Arni* with the location of panels indicated.

analyzed parameters include reverberation time T_{20} , early decay time EDT , and two clarity measures, C_{50} and C_{80} . The way they are influenced by the change in absorption, its distribution, and atmospheric changes during the measurements is discussed.

2 MEASUREMENTS

2.1 Variable acoustics space

Arni is a shoebox-shaped room, with dimensions $8.9\text{ m} \times 6.3\text{ m} \times 3.6\text{ m}$ (length, width, and height, respectively). Its total sound absorption can be controlled by using the specialized panels that cover the room's four walls and the ceiling. Each panel is a rectangular cuboid, and its dimensions are $0.6\text{ m} \times 0.4\text{ m} \times 2.4\text{ m}$ (length, width, and height). They are made of painted metal sheets and filled with 25-cm-thick absorptive material. The rectangular slots cut out in the front surface of each panel can either be open, allowing the sound to reach the material inside, or closed, making the panel reflective. *Arni* is equipped with a total of 55 panels, including eight on three of the walls, 11 on the fourth wall, and 20 on the ceiling. The panels on three walls are placed directly on the floor, whilst those on the fourth wall are hanging 63 cm above the floor level due to the heating installations situated on that wall.

The room is also equipped with curtains which can further increase sound absorption when unfolded over the panels. During our measurements they were fully folded in the corners at all times. The concrete floor has been painted and is considered acoustically hard.

The view of *Arni* with the measurement equipment and panels is shown in Fig. 1(a), and the layout of the room showing the location of panels is presented in Fig. 1(b).

2.2 Measurement setup

The measurement equipment consisted of a 01dB LS01 omnidirectional loudspeaker used as a sound source, and five receivers: two G.R.A.S. 1/2-inch diffuse-field microphones of type 40AG, two G.R.A.S. 1/2-inch free-field microphones of type 46AF, and a Brüel & Kjær 1/2-inch diffuse-field microphone of type 4192. A G.R.A.S. power module of type 12AG served as the amplifier. All equipment were connected to a laptop via a MOTU UltraLite mk3 Audio Interface. The measurement signal was a 3-s long exponential sine sweep [7, 8]. Additionally, the atmospheric data was gathered during the measurement using a Testo 174H Mini data logger.

In total, 5342 of panel combinations were measured. This included the scenarios in which all panels are open, all panels are closed (one combination each), one panel is open, one panel is closed (55 combinations each), and 2 to 54 panels are closed (100 combinations each).

The whole experiment was conducted automatically, with a Python script controlling the opening and closing of panels, as well as playing and recording the signals. Thus, there were no people inside *Arni* at any point during the measurements.

3 RESULTS

The results showing the mean and standard deviation values of T_{20} , EDT , C_{50} , and C_{80} for each number of closed panels and six octave frequency bands, 250 Hz–8 kHz, are depicted in Figs. 2(a) and 2(b) and 2(c) and 2(d), respectively. The growing number of closed panel on horizontal axis is equivalent to a decrease of the total sound absorption.

3.1 Influence of absorption distribution on the parameters' values

Depending on which panels are open and closed during the measurements, the distribution of absorption between configurations with the same total absorption can change significantly. The results reveal how the absorption distribution alone can affect the parameter values, especially for 250–1000 Hz bands. The standard deviations in Figs. 2(a)–2(d) are big, over 0.1 s for T_{20} and over 0.2 s for EDT (when 50 or more panels are closed). For C_{50} , and C_{80} , the highest values of standard deviation are over 2 dB and over 3 dB, respectively, when the total absorption in the room is high.

3.2 Effect of panel's construction

The results show an interesting property of the variable acoustic panels: they are very efficient in absorbing low frequencies, acting almost as bass traps. Therefore, the difference in EDT and T_{20} values in the 250 Hz and 500 Hz bands is the biggest between combinations with 54 and 55 panels closed (one and zero panels open, respectively). This property of the panels, however, affects the clarity measures C_{50} and C_{80} only slightly, making the decrease in the values almost linear as the total absorption in the room declines.

The construction of the panels influences the high frequencies in an unusual way. The front of the panel in a closed state is predominantly reflective, with the values of absorption coefficient for 250 Hz–8 kHz octave bands $\alpha_{\text{closed}} =$

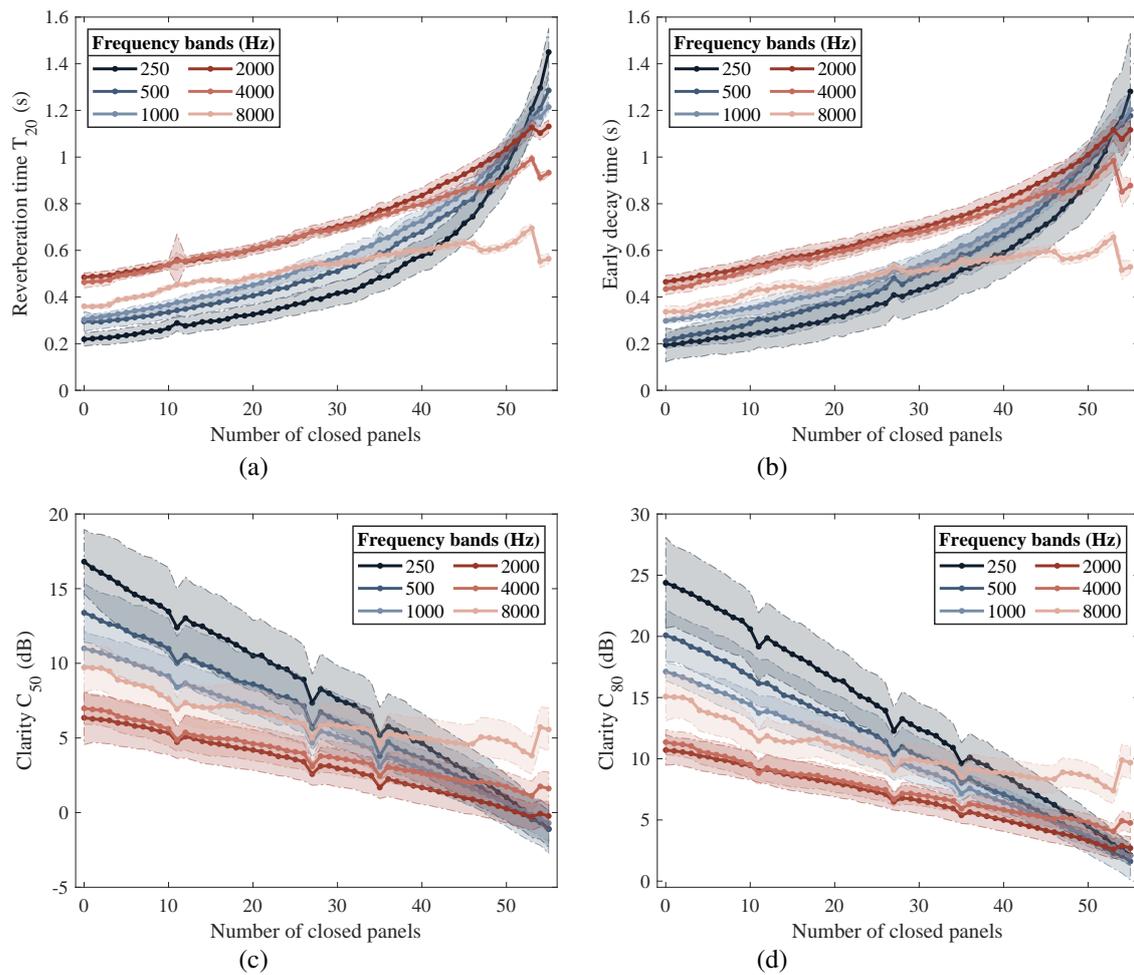


Figure 2: Measurement results of room acoustic parameters in *Arni*: (a) T_{20} , (b) EDT , (c) C_{50} , and (d) C_{80} . The mean (solid lines) and standard deviation (shaded areas) values were calculated from up to 100 combinations per each data point.

[0.09, 0.05, 0.05, 0.04, 0.02, 0.03] [9]. In the open state, part of the sound is absorbed by entering the panel through the slots, but a portion of it is also reflected off the remaining part of the frontal surface. This also shows in the values of the absorption coefficient for an open panel $\alpha_{\text{open}} = [0.86, 0.77, 0.66, 0.45, 0.38, 0.42]$ [9]. Therefore, the change of the acoustic parameter values with the reduction of absorption in the room is significantly less prominent for frequencies above 2 kHz than below it.

3.3 Impact of atmospheric conditions

Due to the number of measurements taken in *Arni*, the impulse responses were captured over the course of several days. During that time, the atmospheric conditions within the space, such as temperature, relative humidity, and atmospheric pressure, were changing.

The effect of those changes on the values of parameters in low frequencies (250 – 500 Hz) is negligible. It starts to be visible, however, already when the 1-kHz band is considered. The differences in the parameter values are not monotonic, displaying steep changes between adjacent absorption conditions (i.e., number of closed panels). The impact of

the atmospheric fluctuations is most notable for the highest frequency band, especially in the area of 53–55 panels closed. Intuitively, the EDT and T_{20} values should be the highest, and C_{50} and C_{80} the lowest, when all panels are closed. This is, however, not the case in our measurements.

This inconsistency is caused by the long breaks between individual measurements sessions. The experiments were not run overnights or during the weekends, which means that the atmospheric conditions could have changed dramatically during that time. Additionally, certain combinations, such as 54 and 55 panels closed, were captured in the beginning of the measurement session, whilst the combinations of 53 panels closed were measured at the end. This amounts to two weeks separating the results which are displayed next to each other in the figures. The differences in the measurement conditions result in a significant bias in the results.

4 CONCLUSION

The paper presents the variable acoustics space *Arni*, located at the premises of the Aalto Acoustic Lab. The study describes the measurements of over 5000 different panel combinations within the room and shows the results in terms of acoustic parameters related to reverberation (EDT and T_{20}) and clarity (C_{50} and C_{80}).

The results presented in the study show that the acoustic qualities of *Arni* are affected by the distribution of the sound absorption, the construction and properties of the variable acoustic panels, as well as the atmospheric conditions during the measurements. The conditions related to the absorption distribution have an impact on all parameters across all frequencies.

The characteristics of the panels impact high and low frequencies differently. Even one open panel is very effective in absorbing low-frequency sound. The fact that even with a panel in the open state a big part of the frontal plane is reflective makes the difference between acoustic parameter values between all-open and all-closed conditions small.

The changes in atmospheric conditions between measurements have a great impact on the values of all the analyzed parameters. Fluctuations in temperature, humidity, and pressure affect high frequencies the most, with their impact on the low frequency bands being negligible.

The present study shows that *Arni* allows for a flexible and easy change in its acoustical properties, enabling versatile and diverse research.

5 ACKNOWLEDGMENT

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