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EFFECTIVE ACOUSTIC ABSORPTION OF ETFE MEMBRANES AND CUSHIONS

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ABSTRACT

In this paper, we report on measurements of the acoustic absorption coefficient of ETFE membranes and cushions by two types of measurement approaches. The experimental results are compared with material simulations in ODEON® room acoustics ver.17. The absorption was determined via the assumption that the energy which passes through the foil can be considered as absorbed energy, and therefore can be measured in a transmission room facility based on an ISO 10140-2[1]. Also, the acoustic absorption was measured in a reverberant room, based on an ISO 354[2] test arrangement. Due to the high acoustic transparency of the membranes at low frequencies, the two approaches were adapted with the aim of minimizing measurement artifacts. The different results were compared and interpreted in view of getting insight into the physics of the absorption mechanisms and the reliability of the used measurement approaches.[1]

Keywords:*ETFE membrane, ETFE cushion, measurement, absorption coefficient*

1. INTRODUCTION

ETFE membranes and cushions are nowadays widely used as an alternative to glass panels. The properties of the material let architects and designers use it as large skylights and thus benefit from the natural light.
The acoustic absorption and transmission of ETFE structures have been the topic of some recent studies [3-7], while there is still an uncertainty on precision of the measurement methods due to the high acoustic transparency at low frequencies. This paper compares and analyzes different measurement methods to investigate the accuracy of the effective acoustic absorption of the ETFE membranes and cushions.

2. 2.APPROACHES

2.1 Measurement approaches

Measurements were carried out in a transmission room facility and in a reverberant chamber. The samples were provided by the Vector Foiltec company (Bremen, Germany). All samples were mounted in 1.36m by 1.53m aluminum frames.

2.1.1 Measurements in transmission room facility

In this setting, the sample was mounted in the opening between the sending and receiving room, which were respectively mimicking the indoor and outdoor environment on both sides of the ETFE cladding of a building (Fig. 1). By measuring the average energy that passes through the opening with and without sample(as the

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reference), and by assuming that a negligible fraction of the energy that has passed the sample into the receiving room is re-entering the sending room, it is possible to calculate the absorption coefficient.

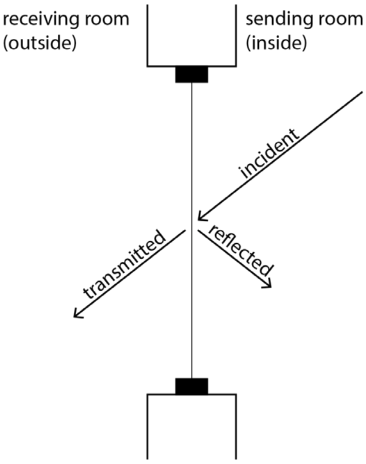

Figure 1. Test configuration in transmission room facility, in which all the transmitted energy to the receiving room is considered as absorbed.

Similarly to a ISO10140-2 test arrangement, the average SPL(dB) of 3 different source positions and 6 microphone positions(18 in total) in the sending room and the receiving room was determined.

The sound absorption coefficient(α) was calculated as follows:

$$\alpha = 10^{-(R/10)} \qquad (1)$$

where the R is sound reduction index.

Three approaches were used to determine R.

ISO 10140-2 defines the sound reduction index (R or SRI) as:

$$R_{ISO} = L_1 - L_2 + 10 \log S/A \qquad (2)$$

where L_1 and L_2(dB) are the energy average sound pressure level in the sending room and in the receiving room respectively, S(m^2) is the area of the free test opening in which the test element is installed, and A(m^2) is the equivalent sound absorption area in the receiving room.

ISO10140-2 has been developed to measure the sound insulation of materials that typically block a considerable amount of sound energy through the opening between two chambers. However, this method does not take into account that the transmission of an empty opening is smaller than zero for low frequencies, as a consequence of the wavelength being larger than the opening. Therefore, the calculated sound reduction index at low frequencies can be overestimated, and accordingly, the absorption coefficient is underestimated. Hence, two additional variants were used.

The first variant took into account the sound reduction index of the empty opening as follows:

$$R_{adapted} = R_{ISO} - R_{emptyopening} \qquad (3)$$

where $R_{emptyopening}$ is the sound reduction index of the empty opening without sample calculated by Eq. 2.

In the second "insertion loss" variant, the sound reduction index was calculated by simply subtracting the sound pressure level of the empty opening from the sound pressure level of the measurement when the sample is installed:

$$R_{IL} = L_1 - L_2 \qquad (4)$$

where L_1 and L_2(dB) are the average sound pressure level of the receiving room without sample and with sample respectively.

2.1.2 Measurements in the reverberation chamber

Absorption measurements in a reverberation chamber were carried out based on the ISO354 standard. However, due to the high transparency of the ETFE foils, the test arrangement was adapted. Two MDF boxes were constructed and filled with a thick 60cm layer of glass wool(Fig. 2). The frame holding the ETFE sample was mounted on top of the box, so that sound that was transmitted through the ETFE was absorbed by the glass wool and did not reflect back into the room. In this way, the inside of the boxes mimicked an outdoor environment like in the case of ETFE samples used in a building context.

Figure 2. Test arrangement in the reverberant room: two boxes filled with a 60cm thick layer of glass wool, on which an ETFE holding metal could be mounted.

Several tests were carried out with one box and two boxes (Fig. 3). In addition to the use of the boxes, the setup differed from ISO354 by the sample having a smaller surface than the minimum required one in the standard (10-12m^2).

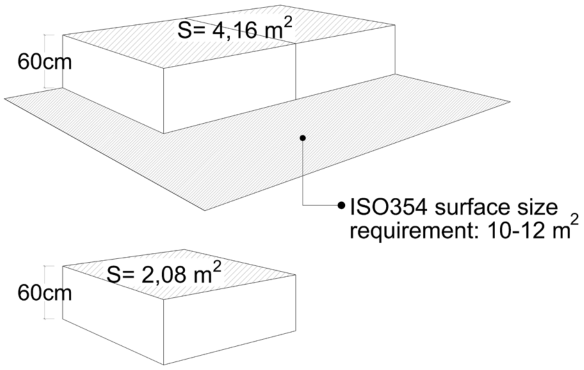

Figure 3. Sample tests surface area and minimum surface requirements according to ISO354 test arrangement- 1 box and 2 boxes test arrangement.

In each set of measurements, 8 microphone positions and 3 source positions were employed. The reverberation time (T_{20}) was measured by the sweep method using software REW® version 5.20.13 and a Roland Studio capture (12 channel) sound card.

The reverberation time of the empty boxes was allocated as the reference for the measurements. The top surface area (2.08m^2 for one box and 4.16m^2 for two boxes) was considered as effective absorptive surface.

The absorption coefficient values were calculated using Sabine's formula, taking into account the air absorption and without considering the edge effect:

$$\alpha_s = \{55.3V[(1/c_{sample}T_{20,sample}) - (1/c_{emptybox}T_{20,emptybox}) - 4V(m_{sample} - m_{emptybox})\}/S \qquad (3)$$

where V(m^3) is the volume of the room, c_{sample} and $c_{emptybox}$ (m/s) are the speed of the sound in the air during the measurement with the sample and during the measurement of the empty box, respectively. $T_{20,sample}$ and $T_{20,emptybox}$ are the average reverberation times of all 24 sets of the mic/sources position during the measurements, m_{sample} and $m_{emptybox}$ are the frequency and humidity dependent power attenuation coefficients based on ISO9613-1[8], and S(m^2) is the effective area of the sample.

As a validation of the effectiveness of the inside of the boxes acting as a not reflecting outdoor environment, Figure 4 shows the measured absorption coefficient of the two boxes filled with 60cm of glass wool. The absorption coefficient, which was calculated assuming the top surface as sample surface, is higher than 85% for frequencies from 250Hz and above, confirming the high broadband absorption of the glass wool layer and indicating that the use of the empty box reverberation time as a reference was an adequate choice.

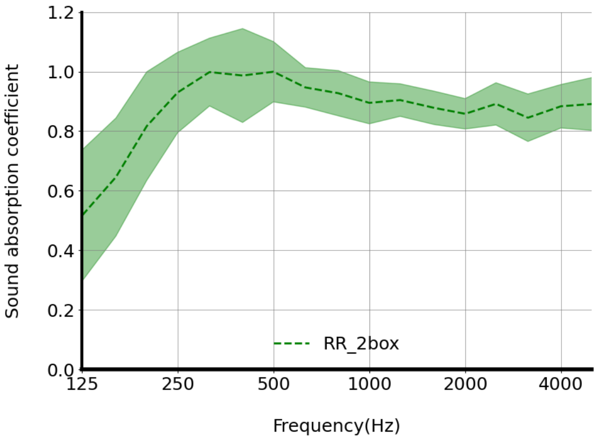

Figure 4. Absorption coefficient of the two boxes filled with 60cm of glass wool, using the configuration with empty boxes as a reference. The green shaded zone indicates the standard deviation on the values, obtained for the different microphone and source positions.

2.2 Simulation approach

Simulations were carried out by the material calculator of the Odeon room Acoustics Ver.17. Table 1 shows the assumed membrane properties.

Table 1. The applied membrane properties in Odeon room acoustics

Property	Value	Unit
Density	1700	kg/m^3
Young modulus	1.6	GPa
Poisson's ratio	0.35	-
Internal loss factor	0.005	-

2.3 Overview of used methods and investigated variants

In general, 3 methods and 6 variants were used in this study. For ease of understanding, in the following, for each method/variant, an abbreviation is used and the meanings of all abbreviations are listed in Table 2.

Table 2. Summary of applied methods, variants, and corresponding symbols

Environment	Method	Variant	Symbol
Transmission Room	ISO 10140-2	Original	TR-ISO
		Adapted	TR-A
		Insertion Loss	TR-IL
Reverberant Room	ISO 354	1 box	RR-1box
		2 boxes	RR-2box
ODEON® room ver 17	Material simulation	Infinite sample	MS-O

3. COMPARISON BETWEEN METHODS AND VARIANTS

3.1 Comparison between different transmission chamber schemes

Figure 5 shows the measured absorption coefficient of a 3-layer ETFE cushion with an air pressure of 200 Pa and a thickness of 250µm of each layer. The results show that there is a significant underestimation of the absorption coefficient value based on the ISO10140-2 sound reduction index, especially at low frequencies. As mentioned earlier, this is a consequence of this approach not taking into account the transmission loss of the opening as such, which is substantial at low frequencies, even for an empty opening. The two variants are more reliable, albeit with a large standard deviation of measurements across different microphone-loudspeaker position combinations.

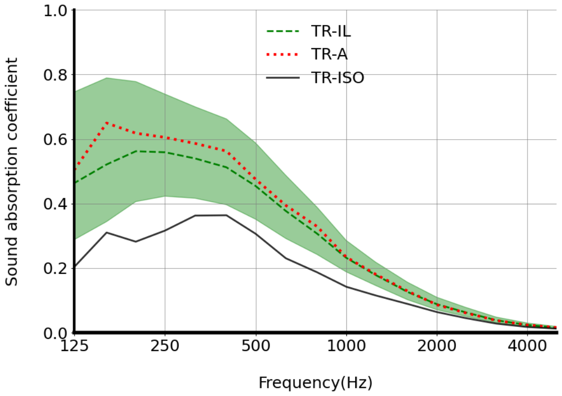

Figure 5. Comparison between ISO10140 original method and two variants. The green shaded zone indicates the standard deviation on the TR-IL values. Test sample: ETFE Cushion 200 Pa 250µm.

3.2 Comparison between different reverberant chamber variants

Figure 6 shows the results of the sound absorption coefficient of the ETFE membrane with a thickness of 250µm based on measurements in the reverberant room with one box and with two boxes (Fig. 3). The clear underestimation of the absorption obtained with the measurements with one box in the reverberant room, with negative values at high frequencies, indicates the smaller reliability of this configuration. This is expected, as the sample surface in that case is much smaller than the ISO354 prescribed value, and the effect of the sample absorption on the impulse response of the room is very small in comparison with the effect of the absorption of other surfaces and of attenuation in the air.

The dip in the absorption curve around 160Hz was found to be accompanied by dips in the reverberation time spectra in all configurations around 125-160Hz even in the empty room modes in that frequency[9].

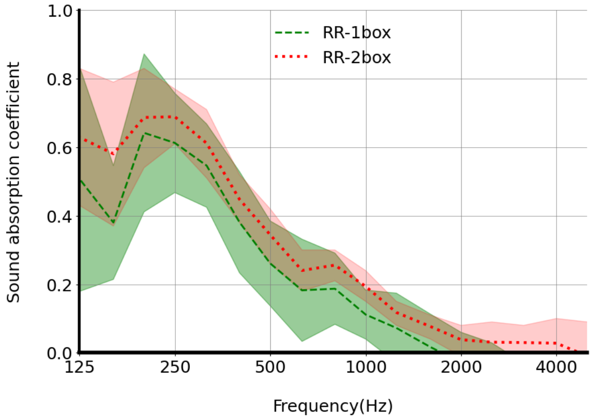

Figure 6. Comparison between absorption values obtained from one box and two boxes measurements in the reverberant chamber and the respective standard deviation on the values. Test sample: ETFE membrane 250µm.

3.3 Comparison between two types of experimental methods and simulations

Figure 7 shows a comparison between the results of measurements in the transmission rooms (variant 2-Insertion Loss) and in the reverberant room (two boxes) on a 250 µm ETFE membrane. There is a good agreement at frequencies above 800Hz. Between 250-630Hz the measurements done in the reverberant room yield lower values for the absorption, but the differences are still within experimental uncertainty.

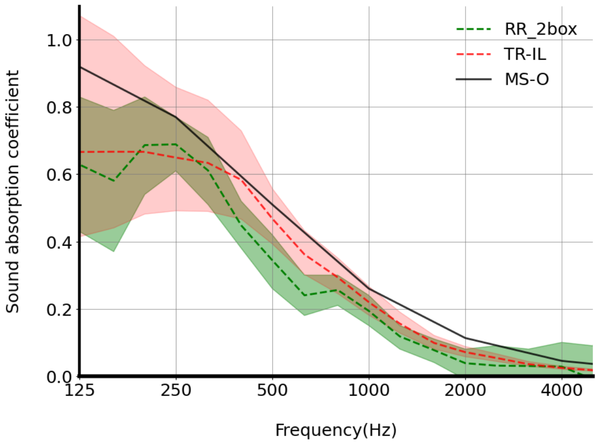

Figure 7. Comparison between two types of measurements: TR-IL and RR-2box and the material simulation- The green shaded zone indicates the standard deviation on the RR-2box values and the red shaded zone indicates the standard deviation on the TR-IL . Sample: ETFE membrane-250µm

In general, in spite of the differences between the two methods and the substantial error bars, using one method still would still make sense to get insight into relative changes of absorption spectra in the framework of parametric studies, even if the absolute spectrum is subject to method-related deviations.

Fig. 7 shows that there is also reasonable agreement between the results from the TR-IL method and the simulations (MS-O) at frequencies above 400Hz. Only at the lowest frequencies, the simulated absorption values exceed the measured ones, due to the former not taking into account the finite size of the sample.

4. CONCLUSION

In this paper, the acoustic absorption of an ETFE membrane and an ETFE cushion was experimentally determined by different variants of two laboratory settings that were aimed at coping with the large acoustic transparency of the samples. Differences between results were within experimental uncertainties or could be attributed to a limited sample size.

5. ACKNOWLEDGMENTS

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