Light, transparency and sound absorption

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Abstract

Optically transparent sound absorbers made out of micro-perforated structures were introduced 20 years ago. In between various applications and developments have been conducted. In this paper lighting sound absorbers or sound absorbing daylight ceilings as well as fully transparent absorbers in front of glass facades are discussed. Representative sound absorption data for different set-ups are presented. Metal, wood, polycarbonate plates and foils as well as other sheet materials have been micro-perforated. A short review of the applications of various different materials with transparent micro-perforated sound absorbers is given.

Originally published in ACOUSTICS 2016, Brisbane, Australia

1. Introduction

Micro-perforated panel absorbers (MPA) were first described by D.-Y. Maa in 1975 (Maa, 1975). Further developments of the theory and applications are presented in various other papers (Maa, 1983, 1984, 1985, 1987, 1988, 1997). The potential of MPA is shown in a publication (Maa, 1998) together with some possible applications. The calculation and measurement of MPA in so-called random incidence or diffuse sound fields has been investigated in two publications (Liu, 2000, Nocke, 2000). Other aspects and further investigations on micro-perforated structures are described in (Maa, 2000 and 2001) or (Zha, 1998).

Stretched membrane ceilings were introduced around forty years ago. The stretched ceiling consists of a special flexible sheet, which is mounted in-situ by clamping to a frame. The sheet is heated before mounting and the membrane acquires its final tension after cooling. Nearly any shape can be built by this method. Over the last 40 years this kind of ceiling and wall covering has become a popular product. Until 10 years ago optical and other aspects of the product were of general interest. However, after first experiences with a micro-perforated polycarbonate foil (Zha, 1998) micro-perforation of stretched ceilings, to increase sound absorption was seen as a useful and innovative approach. The ability to provide sound absorption opened another range of applications for such ceilings. In November 1999, the first micro-perforated stretched ceiling was introduced and applied for room acoustic purposes.

The last section of this paper shows some, room acoustic applications of micro-perforated stretched ceiling technology. Several examples are shown, where micro-perforated stretched ceilings and/or panel absorbers have been successfully used to reduce reverberation.

2. Theoretical background

The theory of the micro-perforated panel absorber as initially presented in (Maa, 1975) is based on the classical treatment of sound propagation in short tubes. The derivation by Maa (Maa, 1975) delivers an approximation for the specific acoustic impedance Z_{MPP} for a micro-perforated panel of thickness t with holes of diameter d spaced at a distance b apart in front of an air cavity with a depth D, (refer Figure 1).

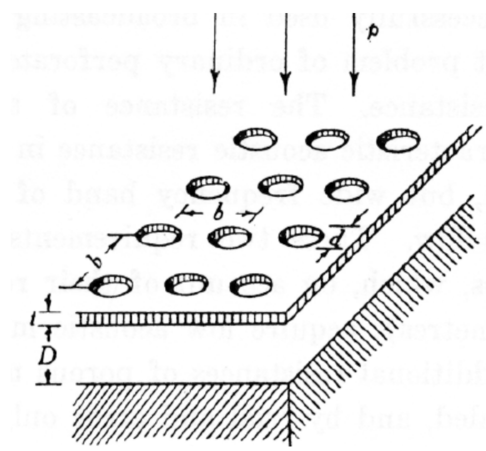


Figure 1: Micro-perforated panel absorber (MPA) according to (Maa, 1975) where d is the orifice diameter, b, the distance between orifices, t, panel thickness and D air cavity depth, between panel and backing wall.

From the angle-dependent impedance Z_{MPP} the sound absorption coefficient for normal and random incidence sound can be calculated using well-known principles (Maa, 1975), (Nocke, 2000).

The Maa's derivation gives an approximation for the specific acoustic impedance Z_{MPP} for a micro-perforated panel of thickness t as:

$$Z_{MPP} = r + j\omega\, m \qquad (1)$$

The corrected formulae for r and m are given below

(Nocke, 2000)

$$r = \frac{32\,\eta\,t}{p\,\rho\,c_0\,d^2}\left(\sqrt{1+\frac{k^2}{32}}+\sqrt{2}\,\frac{k\,d}{32t}\right) \tag{2}$$

$$\omega\,m = \frac{\omega\,t}{p\,c_0}\left(\frac{1}{\sqrt{9+k^2/2}}+0.85\,\frac{d}{t}\right) \tag{3}$$

Where the parameter k is proportional to the ratio of the orifice radius $d/2$ and the thickness of the viscous boundary layer in the orifice, see (Nocke, 2000) for all details and quantities.

A micro-perforated panel in front of an air cavity forms a resonant system. The impedance of the system can be calculated using the impedance $Z_{AIR}(\theta)$ of the air cavity of depth D at an angle θ to the normal of the surface:

$$Z_{AIR}(\theta) = -j\,\cot(\omega D/c_0 \cos\theta) \tag{4}$$

Using Z_{MPA} the impedance of the micro-perforated panel absorber (MPA) can be calculated as:

$$Z_{MPA}(\theta) = Z_{MPP}\cos\theta + Z_{AIR}(\theta) \tag{5}$$

From $Z_{MPA}(\theta)$ the absorption coefficient $\alpha(\theta)$ for a plane wave incident at an angle θ can be calculated:

$$\alpha(\theta) = \frac{4\,Re\{Z_{MPA}(\theta)\}}{[1+Re\{Z_{MPA}(\theta)\}]^2+[Im\{Z_{MPA}(\theta)\}]^2} \tag{6}$$

The so-called statistical or random incidence sound absorption coefficient can thus be calculated using the well-known Paris' formula:

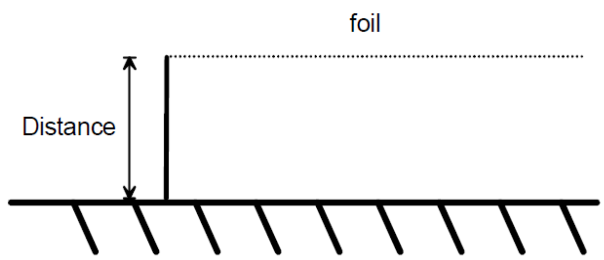
$$\alpha_{stat} = \int_{0^o}^{90^o} \alpha(\theta)\sin(2\theta)\,d\theta \tag{7}$$

3. Laboratory results

In this and following sections, sound absorption results for different arrangements of micro-perforated stretched sheet materials are presented. Firstly set-ups using only micro-perforated sheet will be investigated. Furthermore, combinations of un-perforated and micro-perforated stretched materials are shown that can be applied as light ceilings.

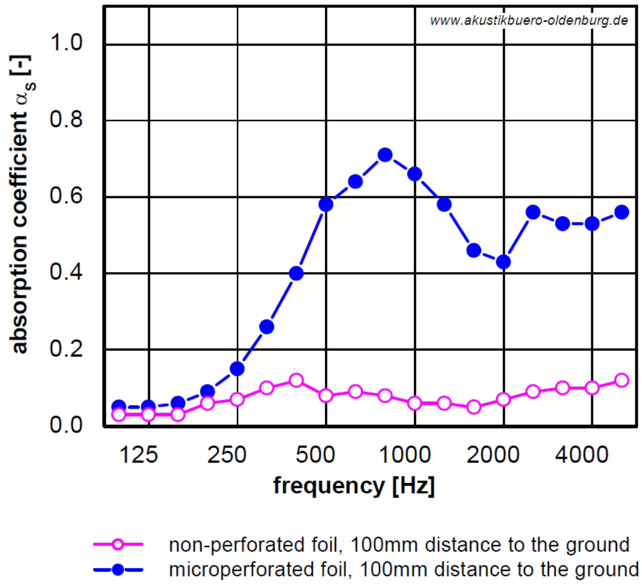
Figure 2 represents a sketch of a stretched ceiling as set-up for reverberation chamber measurements according to (Maa 1975). The foil is stretched on a frame spaced some distance from the backing wall or ceiling. Usually the wall or ceiling is acoustically hard. The distance between foil and backing can vary between a few centimetres to more than a metre. The sides are closed; the air volume has no connection to the outside.

Figure 2: Principal sketch of set-up of the stretched ceiling



/ foil.

Figure 3 shows ⅓ octave sound absorption coefficients measured according to (ISO 354, 2003) for a non-perforated and a micro-perforated stretched foil spaced 100 mm from the concrete floor of the test chamber. As may be noted the non-perforated foil provides little sound absorption. The coefficient of 0.12 occurs in the 400 Hz ⅓ octave band. The NRC-value according to ASTM C 423-01 (2001) is 0.05 whilst the SAA-value is 0.07. In contrast, the micro-perforated foil shows a maximum sound absorption coefficient of 0.69 at 800 Hz with the low frequency absorption approaching that of the non-



perforated foil.

Figure 3: Sound absorption coefficients according to (ISO 354, 2003) for non-perforated and micro-perforated foil.

For frequencies higher than 800 Hz the ⅓ octave sound absorption coefficients are everywhere higher than 0.4. The NRC-value for this example is NRC = 0.45 while the SAA-value is 0.45.

4. Applications with light and sound absorption

Sound absorbing "daylight" ceilings can be achieved using combinations comprising of an un-perforated stretched sheet and a micro-perforated sheet and/or two micro-perforated sheets. Lighting is installed behind the two layers. Fluorescent or LED lighting systems can be used.

Figure 4 shows one such sound-absorbing ceiling light. The system shown comprises of ceiling mounted LED elements, with an un-perforated translucent stretched sheet mounted some distance below them and a micro-perforated sheet below that. The system shown comprises of ceiling mounted LED elements, with an un-perforated translucent stretched sheet mounted some distance below them and a micro-perforated sheet below that. By varying

Figure 4: Typical stretched ceiling, sound absorbing lighting element.

Figure 5: Lighting system/sound absorbing ceiling in an office.

Figure 6: Sound absorptive, micro-perforated "daylight ceiling" modules.

the distance between the un-perforated sheet and the lamps and between the two stretched sheets, the sound-absorption provided by the system can be customized.

Figure 5 shows a light emitting and sound absorbent ceiling made of translucent micro-perforated sheets.

Figures 6 to 9, give examples of applications using transparent and translucent sound absorbers using mono and multi-layer micro-perforated sheets.

Figure 7: Backlit micro-perforated furniture.

Figure 10 provides sound absorption test results for some of the set-ups used in the various projects shown.

5. Conclusion

By suitable micro-perforation, stretched sheets can be given useful sound absorption characteristics for room acoustic purposes. Other properties of the film (moldability,

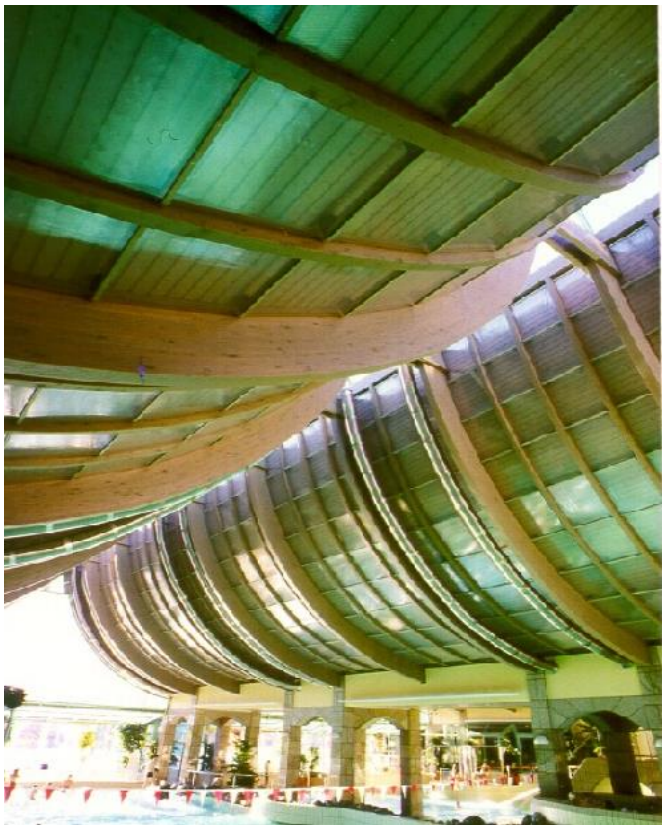


Figure 8: Sound absorptive, micro-perforated polycarbonate ceiling above a swimming pool.

installation arrangements, fire protection, and so forth) remain unchanged. The appeal from an architectural design perspective, is that even translucent and transparent films can be provided with micro-perforation and thus the ability to absorb sound. This creates new possibilities for brilliant acoustic ceilings.

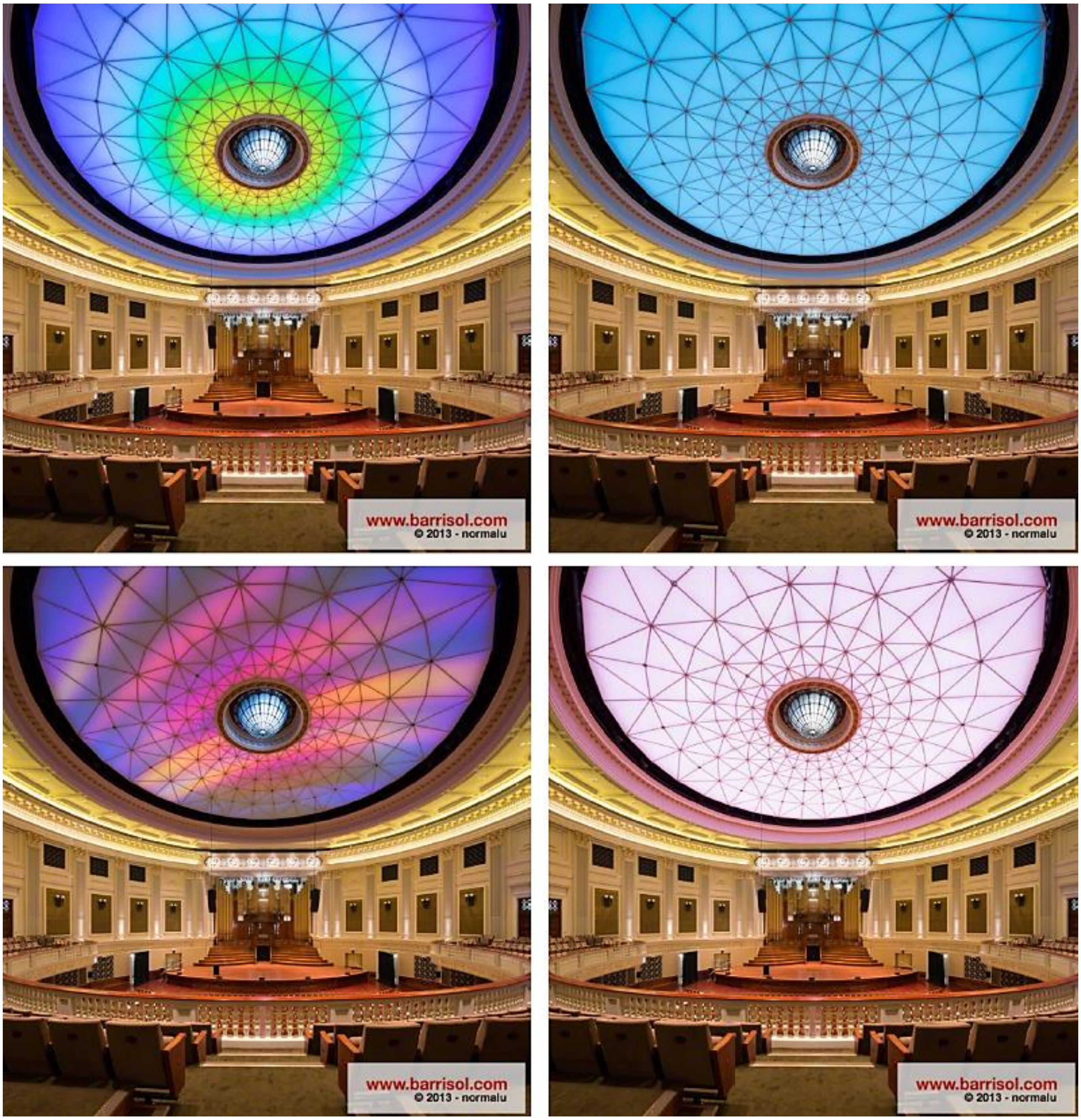


Figure 9: Translucent ceiling with changeable lighting, Brisbane City Hall

Acknowledgements

This work has kindly been supported by BARRISOL S.A.S, F–68680 Kembs, the manufacturer of BARRISOL® and micro-perforated BARRISOL® Acoustics® stretched ceiling.

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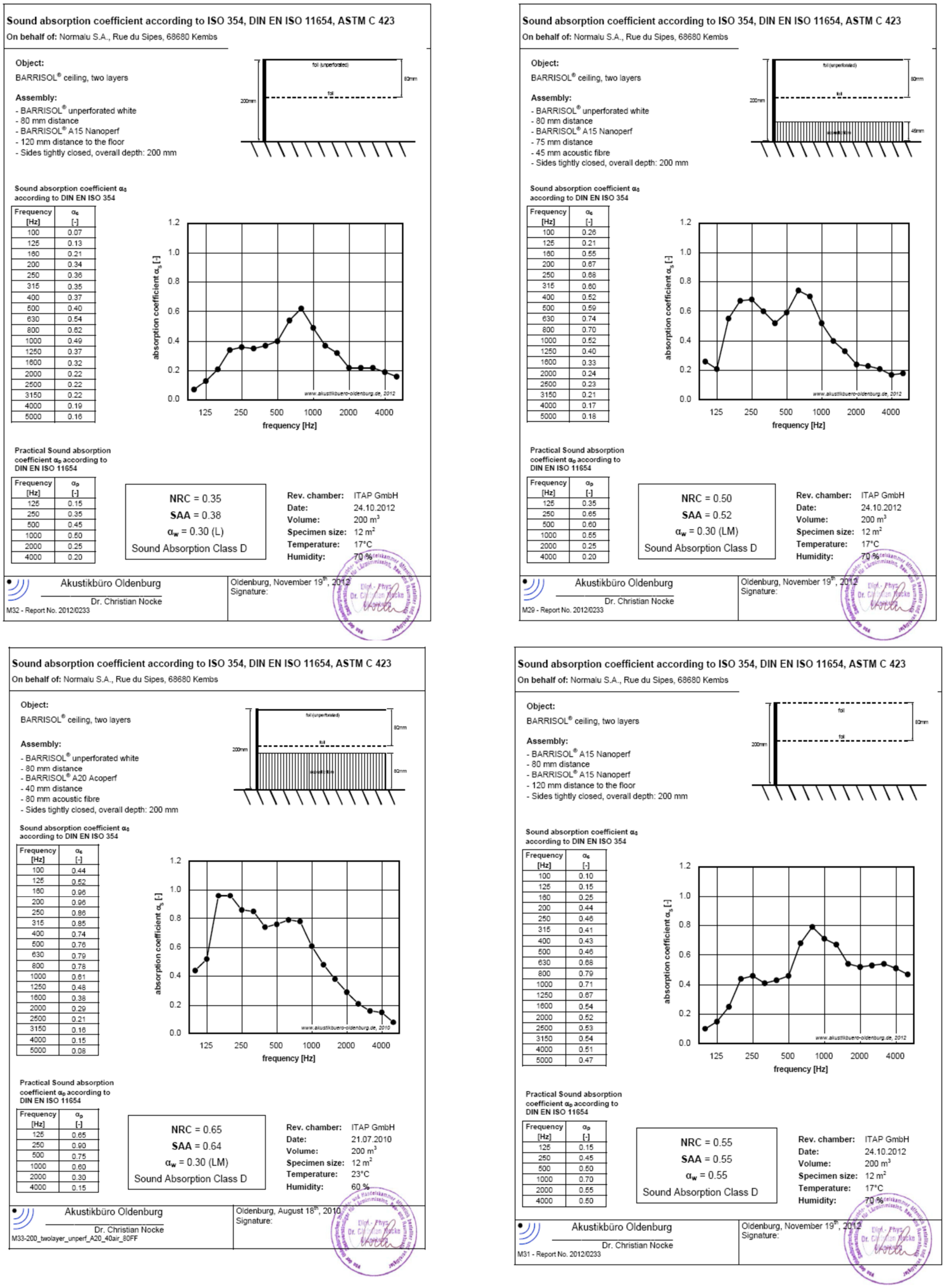

Sound absorption coefficient according to ISO 354, DIN EN ISO 11654, ASTM C 423
On behalf of: Normalu S.A., Rue du Sipes, 68680 Kembs

Object:
BARRISOL® ceiling, two layers

Assembly:
- BARRISOL® unperforated white
- 80 mm distance
- BARRISOL® A15 Nanoperf
- 120 mm distance to the floor
- Sides tightly closed, overall depth: 200 mm

Sound absorption coefficient α_s according to DIN EN ISO 354

Frequency [Hz]	α_s [-]
100	0.07
125	0.13
160	0.21
200	0.34
250	0.36
315	0.35
400	0.37
500	0.40
630	0.54
800	0.62
1000	0.49
1250	0.37
1600	0.32
2000	0.22
2500	0.22
3150	0.22
4000	0.19
5000	0.16

Practical Sound absorption coefficient α_p according to DIN EN ISO 11654

Frequency [Hz]	α_p [-]
125	0.15
250	0.35
500	0.45
1000	0.50
2000	0.25
4000	0.20

NRC = 0.35
SAA = 0.38
α_w = 0.30 (L)
Sound Absorption Class D

Rev. chamber: ITAP GmbH
Date: 24.10.2012
Volume: 200 m³
Specimen size: 12 m²
Temperature: 17°C
Humidity: 70 %

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Dr. Christian Nocke
M32 - Report No. 2012/0233
Oldenburg, November 19th, 2012
Signature:

Sound absorption coefficient according to ISO 354, DIN EN ISO 11654, ASTM C 423
On behalf of: Normalu S.A., Rue du Sipes, 68680 Kembs

Object:
BARRISOL® ceiling, two layers

Assembly:
- BARRISOL® unperforated white
- 80 mm distance
- BARRISOL® A15 Nanoperf
- 75 mm distance
- 45 mm acoustic fibre
- Sides tightly closed, overall depth: 200 mm

Sound absorption coefficient α_s according to DIN EN ISO 354

Frequency [Hz]	α_s [-]
100	0.26
125	0.21
160	0.55
200	0.67
250	0.68
315	0.60
400	0.52
500	0.59
630	0.74
800	0.70
1000	0.52
1250	0.40
1600	0.33
2000	0.24
2500	0.23
3150	0.21
4000	0.17
5000	0.18

Practical Sound absorption coefficient α_p according to DIN EN ISO 11654

Frequency [Hz]	α_p [-]
125	0.35
250	0.65
500	0.60
1000	0.55
2000	0.25
4000	0.20

NRC = 0.50
SAA = 0.52
α_w = 0.30 (LM)
Sound Absorption Class D

Rev. chamber: ITAP GmbH
Date: 24.10.2012
Volume: 200 m³
Specimen size: 12 m²
Temperature: 17°C
Humidity: 70 %

Akustikbüro Oldenburg
Dr. Christian Nocke
M29 - Report No. 2012/0233
Oldenburg, November 19th, 2012
Signature:

Sound absorption coefficient according to ISO 354, DIN EN ISO 11654, ASTM C 423
On behalf of: Normalu S.A., Rue du Sipes, 68680 Kembs

Object:
BARRISOL® ceiling, two layers

Assembly:
- BARRISOL® unperforated white
- 80 mm distance
- BARRISOL® A20 Acoperf
- 40 mm distance
- 80 mm acoustic fibre
- Sides tightly closed, overall depth: 200 mm

Sound absorption coefficient α_s according to DIN EN ISO 354

Frequency [Hz]	α_s [-]
100	0.44
125	0.52
160	0.96
200	0.96
250	0.86
315	0.85
400	0.74
500	0.76
630	0.79
800	0.78
1000	0.61
1250	0.48
1600	0.38
2000	0.29
2500	0.21
3150	0.16
4000	0.15
5000	0.08

Practical Sound absorption coefficient α_p according to DIN EN ISO 11654

Frequency [Hz]	α_p [-]
125	0.65
250	0.90
500	0.75
1000	0.60
2000	0.30
4000	0.15

NRC = 0.65
SAA = 0.64
α_w = 0.30 (LM)
Sound Absorption Class D

Rev. chamber: ITAP GmbH
Date: 21.07.2010
Volume: 200 m³
Specimen size: 12 m²
Temperature: 23°C
Humidity: 60 %

Akustikbüro Oldenburg
Dr. Christian Nocke
M33-200_twolayer_unperf_A20_40air_80FF
Oldenburg, August 18th, 2010
Signature:

Sound absorption coefficient according to ISO 354, DIN EN ISO 11654, ASTM C 423
On behalf of: Normalu S.A., Rue du Sipes, 68680 Kembs

Object:
BARRISOL® ceiling, two layers

Assembly:
- BARRISOL® A15 Nanoperf
- 80 mm distance
- BARRISOL® A15 Nanoperf
- 120 mm distance to the floor
- Sides tightly closed, overall depth: 200 mm

Sound absorption coefficient α_s according to DIN EN ISO 354

Frequency [Hz]	α_s [-]
100	0.10
125	0.15
160	0.25
200	0.44
250	0.46
315	0.41
400	0.43
500	0.46
630	0.68
800	0.79
1000	0.71
1250	0.67
1600	0.54
2000	0.52
2500	0.53
3150	0.54
4000	0.51
5000	0.47

Practical Sound absorption coefficient α_p according to DIN EN ISO 11654

Frequency [Hz]	α_p [-]
125	0.15
250	0.45
500	0.50
1000	0.70
2000	0.55
4000	0.50

NRC = 0.55
SAA = 0.55
α_w = 0.55
Sound Absorption Class D

Rev. chamber: ITAP GmbH
Date: 24.10.2012
Volume: 200 m³
Specimen size: 12 m²
Temperature: 17°C
Humidity: 70 %

Akustikbüro Oldenburg
Dr. Christian Nocke
M31 - Report No. 2012/0233
Oldenburg, November 19th, 2012
Signature:

Figure 10: Results from laboratory tests for different set-ups

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