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Sound Decisions: Moving forward with Acoustics

20 years of micro-perforated (transparent) sound absorbers

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ABSTRACT

In 1975 the theory of microperforated sound absorbers was introduced by D.-Y. Maa. The first optically transparent sound absorbers have been applied in the late 1990s. In 2000 a nearly invisible micro-perforation was introduced to transparent sheets making these highly sound absorptive. Over the twenty years different set-ups made of micro-perforated layers, porous materials as well as plate resonators have been investigated.

In this contribution appliactions of various set-ups with micro-perforated stretched foils will be presented. Applications in different spaces will be shown. Day-light ceilings, mirror ceilings as well as absorbers in front of glass will be shown.

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 for example in (Maa, 2000 and 2001) and (Zha, 1998).

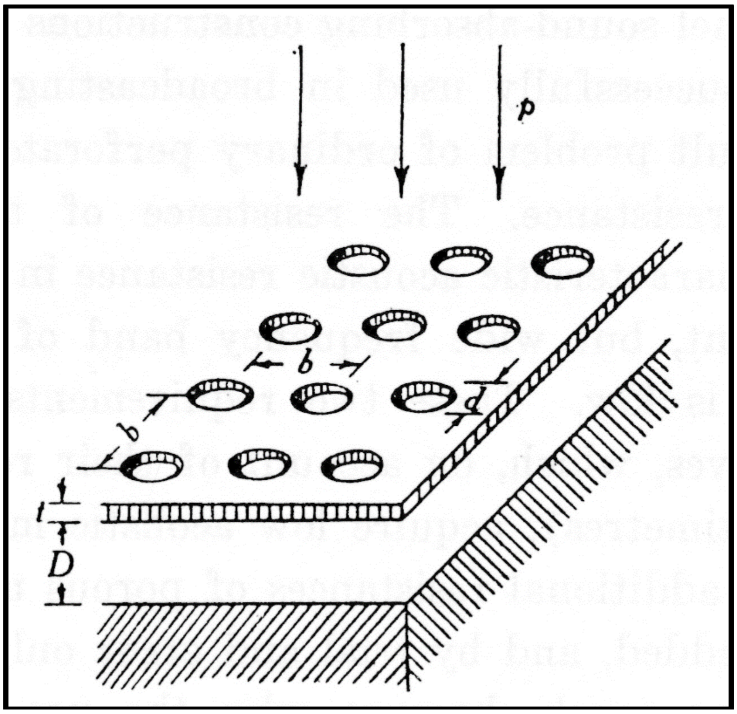
Stretched membrane ceilings were introduced in 1967. The stretched material consists of a special flexible sheet, which is mounted in-situ by clamping it to a frame construction. The sheet is heated before mounting, and the membrane acquires its final tension after cooling. Nearly any shape might be built by this technique.

Over the last 50 years this kind of stretched ceiling and wall covering has become a popular product in modern architecture and design. Until 20 years ago optical and other aspects of the product were of general interest. After first experiences with a micro-perforated polycarbonate foil (Zha, 1998) micro-perforation of the sheet used for the stretched ceiling was seen as an innovative feature. This acoustic property may open another range of applications for stretched ceilings. In November 1999, the first micro-perforation of a stretched ceiling were introduced and successfully been applied for room acoustic purposes.

The last part of this paper briefly deals with applications of micro-perforated stretched ceilings. Some examples of room acoustic projects will be described in which the micro-perforated stretched ceiling has been successfully applied to reduce reverberation while keeping attractive optical features of the room.

2 THEORTICAL BACKGROUND

The theory of the micro-perforated panel absorber as initially presented by Maa (Maa, 1975) is based on the classical treatment of sound propagation in short tubes. The derivation by Maa (Maa, 1975) first 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, see Figure 1 for principal set-up.



Source (Maa, 1975)
Figure 1: Sketch of micro-perforated panel absorber (MPA)

There are four defining geometrical parameters:

- d diameter of orifice,
- b spacing between orifices,
- t thickness of panel and
- D air cavity depth D between panel and backing wall.

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

The derivation by Maa first delivers an approximation for the specific acoustic impedance Z_{MPP} for a micro-perforated panel of thickness t as

$$Z_{MPP} = r + j\,\omega\,m \tag{1}$$

The corrected formulae for r and m are given as follows (Nocke, 2000)

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

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

Herein the parameter k is proportional to the ratio of the radius d/2 of the orifice 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 this system made of the micro-perforated panel and the air cavity 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 given by

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

With this the impedance $Z_{MPA}(\theta)$ the impedance of the micro-perforated panel absorber (MPA) can easily be calculated according to

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

With this impedance $Z_{MPA}(\theta)$ the absorption coefficient $\alpha(\theta)$ for a plane wave incident at a certain angle θ can be calculated according to

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

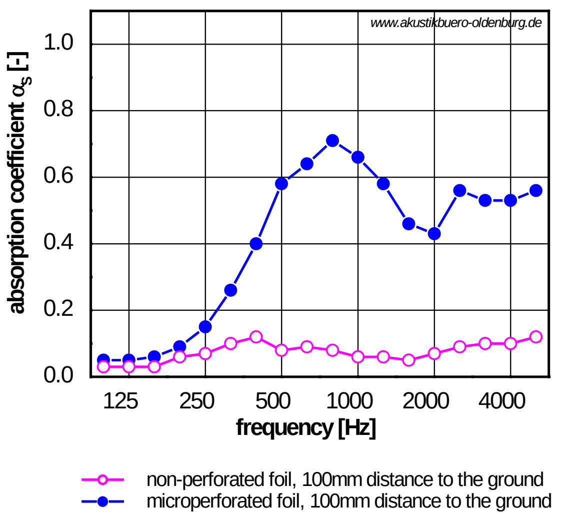
This equation for $\alpha(\theta)$ can now be used for the calculation of the so-called statistical or random incidence sound absorption coefficient according to the well-known Paris' formula

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

3 RESULTS FROM LABORATORY

In Figure 2 the frequency-dependent sound absorption coefficient according to (ISO 354, 2003) for the non-perforated and the micro-perforated stretched foil and a comparsion between a measurement and a theoretical prediction is depicted.

It can clearly be seen that the non-perforated foil shows hardly any sound absorption. The maximum value of 0.12 is reached at 400 Hz. The NRC-value according to ASTM C 423-01 (2001) is NRC = 0.05, the SAA-value is SAA = 0.07 for the non-perforated material. The micro-perforated stretched foil shows a maximum sound absorption of 0.69 at 800 Hz and 1000 Hz with a decrease towards low frequencies. At frequencies higher than 1000 Hz the sound absorption coefficient stays above 0.4. The NRC-value for the micro-perforated foil is NRC = 0.45 as well as the SAA-value, e.g. SAA = 0.45.



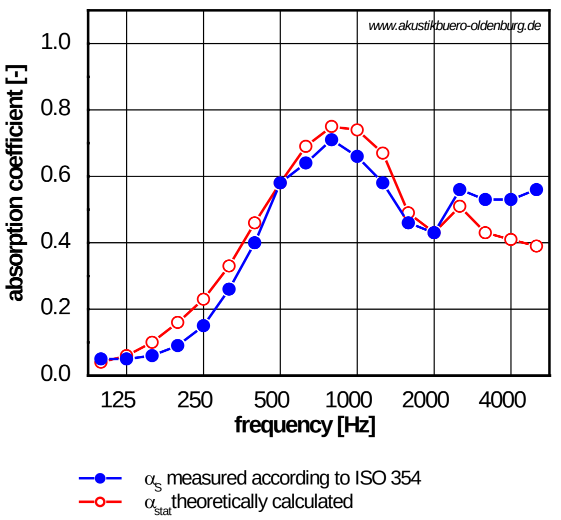


Figure 2: Measured result for sound absorption coefficient according to (ISO 354, 2003) for non-perforated and micro-foerated foil (left) and comparison between measurement and calculation.

4 APPLICATIONS WITH LIGHT AND SOUND ABSORPTION

Fig. 3 shows the first installations of micro-perforated acrylic glass (left) and polycarbonate foils (right). Both of them have not been stretched as the first installation of a stretched transparent sheet in Fig. 4.

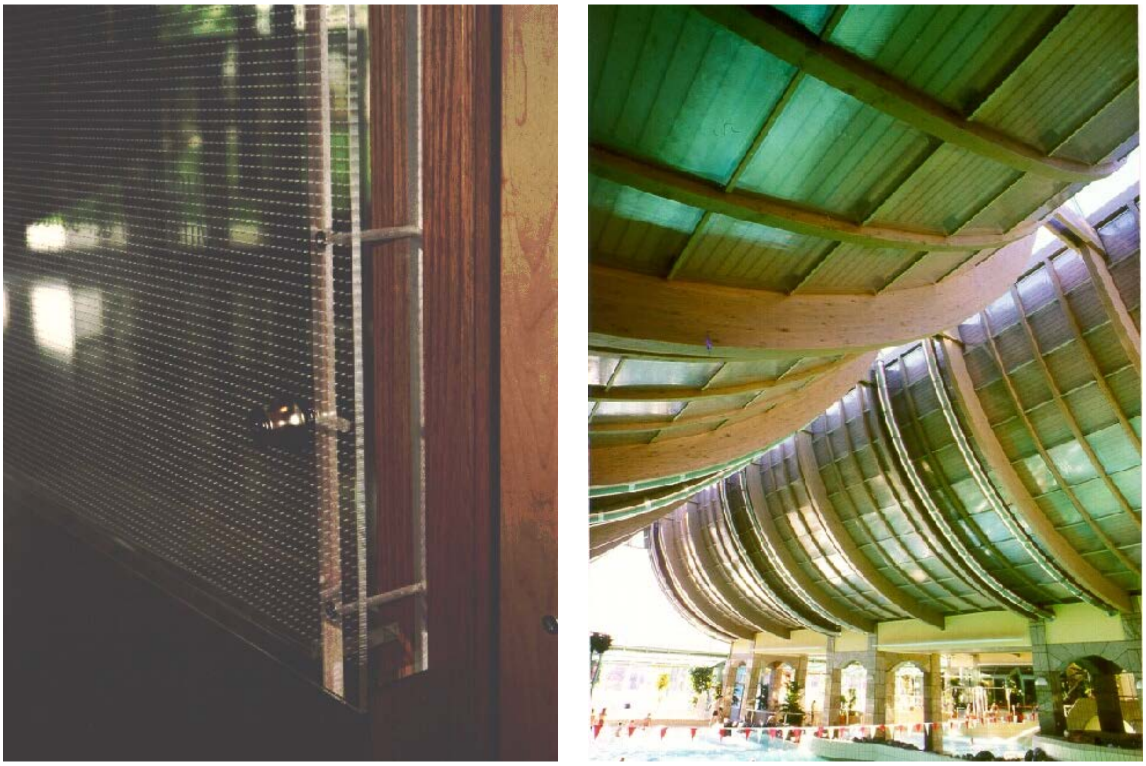


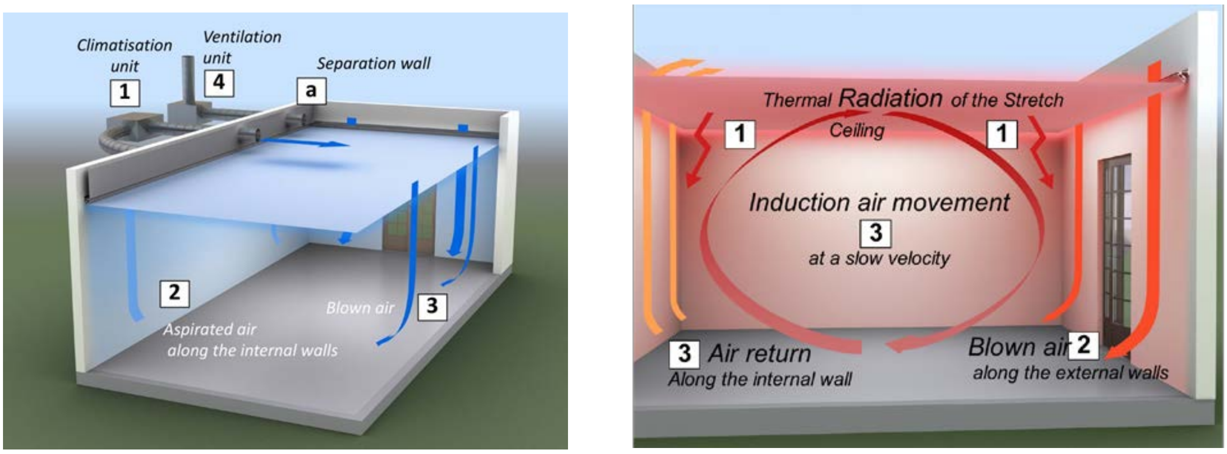
Figure 3: Application of micro-perforated panel absorber (MPA) as an acrylic glass panel (left) with overall thickness of 50 mm and polycarbonate foils on swimming pool at 130 mm, double layer set-up (right)..

Source (BARRISOL)
Figure 4: Micro-perforated stretched sheets in double layer frame construction.

Sound absorbing "daylight" ceilings can be achieved using combinations comprising an unperforated 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 unperforated translucent stretched sheet mounted some distance below them and a micro-perforated sheet below that. By varying the distance between the unperforated sheet and the lamps and between the two stretched sheets, the sound-absorption provided by the system can be customized.

Source (BARRISOL)
Figure 5: Details of installation process of day-light ceiling made of micro-perforated sheets.

Another new application is the combination of heating/cooling ceilings with daylight and micro-perforation for sound absorption. As illustrated in figure 6, the ceiling is designed in an open shape and can transfer air either by blowing or by suction between the plenum space and the rest of the room. Ambient air is taken in along the inner walls of the room, then channeled through a separating wall via a special ceiling unit. The ceiling becomes a huge diffuser, radiating heat or coolness across the entire surface. Using translucent sheets with micro-perforation adds other functions to the ceiling.



Source (BARRISOL, 2019)
Figure 6: Pincipal sketch of heating/cooling ceiling system (Barrisol® Clim®).

Fig. 7 shows a room with a heating/cooling system installed as presended in Fig. 6. A hard flooring as well as glass walls and large windows add only little absorption to the room. The only absorption in the room is from the acoustic ceiling. The graph on the right in Fig. 7 shows the measured reverberation time.

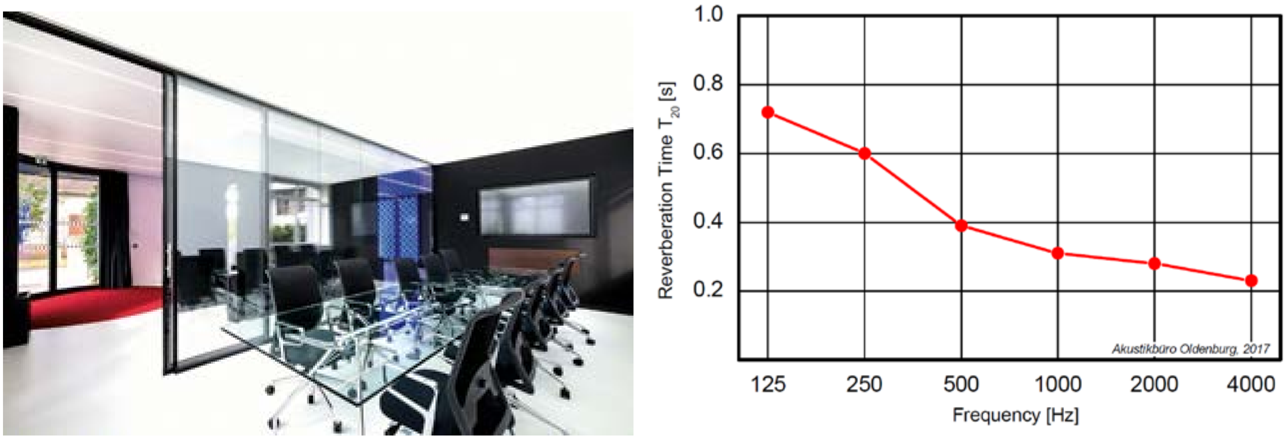


Figure 7: Room with heating/colling ceiling with lighting and sound absorption included.

Another application of micro-perforation is presented in Fig. 8 and 9. A high class restaurant in Strassbourg (France) was fitted with different sound absorbing set-ups. Printed textiles as well as freely suspended light frames can be seen in the glass wintergarden in Fig. 8.

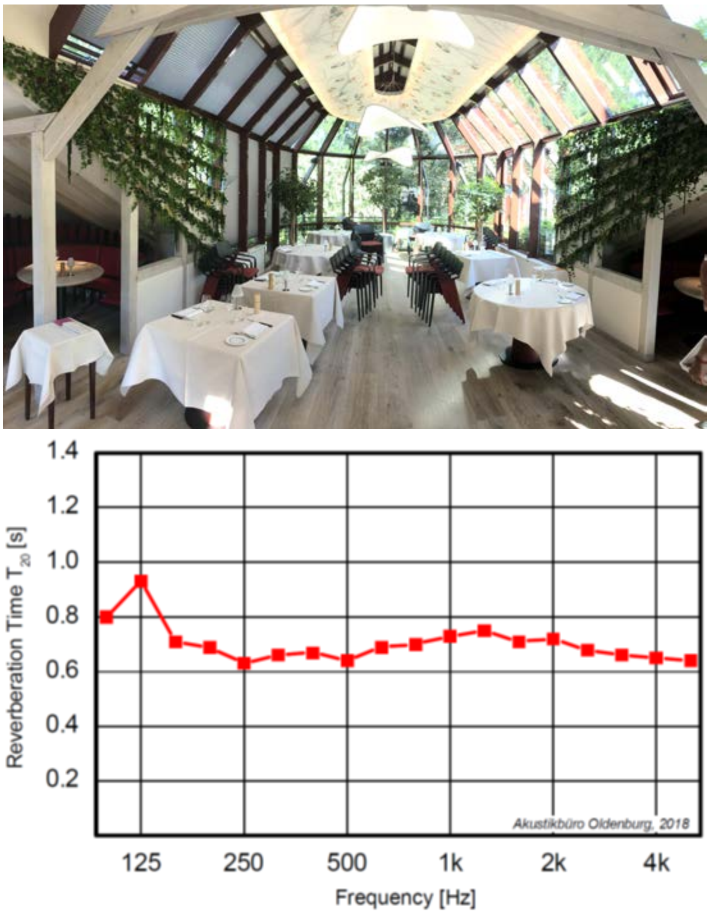
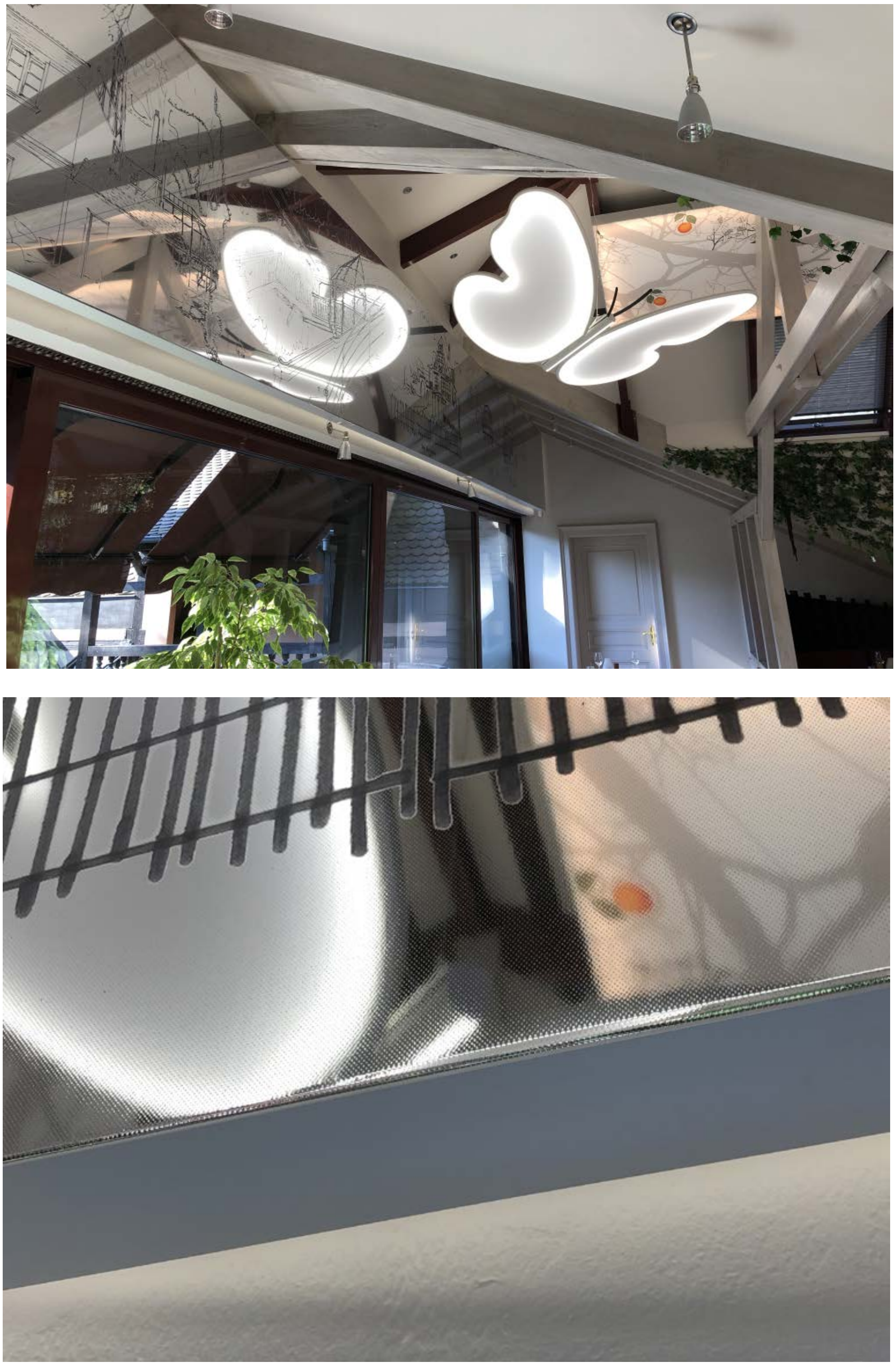


Figure 8: Photograph and measured reverberation time of room.

In Fig. 9 two more photographs are shown. In the upper picture a 6 m wide mirror with printing on the surface is shown. This mirror is made of a micro-perfrotated stretched sheet. The lower picture of Fig. 9 gives a closer impression of the sound absorbing mirror with an overall depth of 50 mm.



- Source (BARRISOL, 2019)

Figure 9: Figures should be centred with the caption positioned below the figure

5 CONCLUSIONS

The classical theory of micro-perforated sound absorbers according to D.-Y. Maa has been reported. Keeping all well-known and much appreciated properties of the stretched foil while adding new acoustic functionality by using micro-perforation offers new perspectives for the application and design of micro-perforated panel absorbers.

By suitable micro-perforation, stretched sheets can be given useful sound absorption characteristics for room acoustic purposes. Other properties of the film (moldability , installation arrangements, fire protection, etc.) 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, now also along with active thermal properties. So, one of the latest additions combines day-light and climatization into the range of micro-perforatet ceilings. Mirror sheets with or without printing give new design features.

ACKNOWLEDGEMENTS

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