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Zulassung neuer Baustoffe, Bauteile und Bauarten
Forschung, Entwicklung, Demonstration und Beratung auf den Gebieten der Bauphysik

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# Integral Acoustic Systems for Thermally Active Concrete Building Components

# Abridged Report

The report comprises
7 pages of text
7 figures

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The author is responsible for the contents of the report.

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# 1 Project Objective

An increasing number of office and administrative buildings are equipped with thermally active floors. To cease to apply an acoustic suspended ceiling means to lose the most precious surface for room acoustic attenuation. The project was aimed developing sound absorbing systems for thermally active concrete floors which

- have an adequate sound absorption coefficient dependent on the use with simultaneous minimum thermal losses,
- have an even and planar surface to support present architectural trends,
- guarantee high economic efficiency with simple building site operation.

The solutions should allow an equally distributed sound absorption of the floor surface. This assures a basic attenuation of rooms with intensive communication as well as represents the condition for a flexible design of the acoustic separation of workstations by means of acoustical screens.

# 2 Procedure

An approach was alternatively aligned absorber strips and a sound-reflecting concrete floor. The change of acoustic impedances results in clearly higher absorption coefficients in comparison to the periodic structure with the same absorber surface. Thus, the proportion of thermally insulating absorbers can be kept at such a low degree so that the influence on cooling is negligible. Strips which are completely installed in the concrete floor allow an even surface.

A computed prognosis is important for the acoustic optimization of the strip geometry. Therefore, a theoretical modeling of the acoustic properties was developed. The computer model was checked by measuring the sound absorption coefficient of small-sized test specimens in the Kundt's tube.

Based on computation and measurement parameter variations principles and absorber materials were selected. Then, larger test specimens were investigated at random incidence in the reverberation room. The reduction of thermal transmittance was quantified for the most promising variables by FEM calculation.

# 3 Results

## 3.1 Theoretical Modeling

A computer model was developed and implemented as software to calculate sound absorption coefficients. The model is based on the scattering waves approach of Lord Rayleigh [1], where the basis is an infinitely extended area with the acoustic admittance $A_1$ in which absorber strips with width $L_2$ and admittance $A_2$ are completely installed. The structure is periodic with a period length $\Lambda_x$ (see Fig. 1).

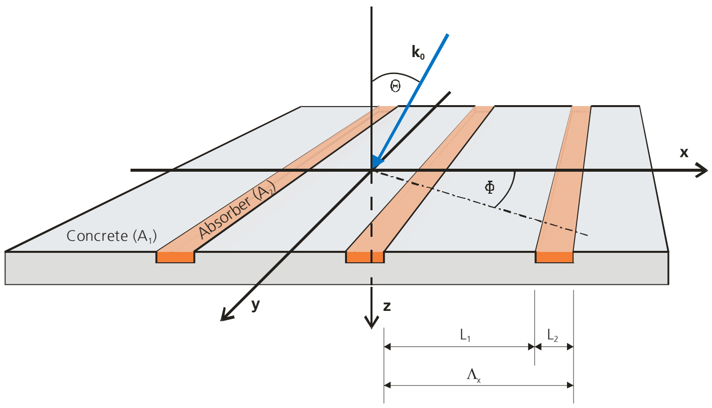



Fig. 1: concrete building component which is equipped with a few sound absorbing strips

The sound field scattered on the surface is composed by a sum of harmonic waves. If a sound wave impinges from a polar angle $\theta$ and an azimuth angle $\phi$, the sound field in front of the building component can be described as:

$$p(x,y,z) = e^{j(\alpha_0 x + \beta_0 y - \gamma_0 z)} + \sum_{m=-\infty}^{\infty} R_m e^{j(\alpha_m x + \beta_m y + \gamma_m z)}. \qquad (1)$$

whereby $\alpha_0$, $\beta_0$, $\gamma_0$ mean projections of the wave number $k_0$ on the Cartesian coordinates x, y, z. $R_m$ are the unknown (complex) amplitudes of the scattered sound waves and $\alpha_m$, $\beta_m$, $\gamma_m$ are their projected wave numbers. The time element is $e^{j\omega t}$.

The scattered wave number along the period (in x direction) can be described according to [2] as follows: $a_m = \alpha_0 + m \cdot 2\pi / \Lambda_x$. Wave numbers $\beta_m$ are equal to $\beta_0$ and the wave numbers $\gamma_m$ can be determined by the Helmholtz equation: $\gamma_m = \pm\sqrt{k_0^2 - \alpha_m^2 - \beta_0^2}$. Re($\gamma_m > 0$) results in propagating sound waves and Im($\gamma_m < 0$) in decreasing or evanescent sound waves towards to upper space of the reverberation room ($z < 0$) according to Fig. 1.

The amplitudes of scattered partial waves are calculated by an equation system as follows:

$$\sum_{n=-\infty}^{\infty} R_m \left(\omega\rho_0 \cdot a_{n-m} + \delta_{m,n}\gamma_m\right) = \omega\rho_0 \cdot a_n + \delta_{0,n}\gamma_0 . \qquad (2)$$

with

$$\delta_{m,n} = \begin{cases} 1 & : n = m \\ 0 & : n \neq m \end{cases} \quad \text{and} \quad \delta_{0,n} = \begin{cases} 1 & : n = 0 \\ 0 & : n \neq 0 \end{cases}. \tag{3}$$

The angle-dependent sound absorption coefficient of the striped component can now be calculated according to [3]:

$$\alpha_{\theta,\Phi} = 1 - \sum_{\mathrm{Re}(\gamma_m > 0)} \left| R_m \right|^2 \frac{\gamma_m}{\gamma_0}, \tag{4}$$

Thermal calculations were performed on the basis of the usual FEM program.

## 3.2 Development of sound absorbers

### 3.2.1 Acoustic effect

The result of computed parameter studies was the following properties of structures with periodic absorber strips:

- Geometries represent a clearly higher sound absorption coefficient as was to be expected from laminar media.
- The slimmer the period, the wider the sound absorption spectrum with the same absorber input.
- In contrast to non-periodic absorbers the absorption coefficient increases with an increasing polar angle θ. This is an advantage for the use in offices since the floor avoids reflections over long distances. Fig. 3 shows the angle-dependent absorption coefficient for an exemplary frequency where scattering waves are generated.

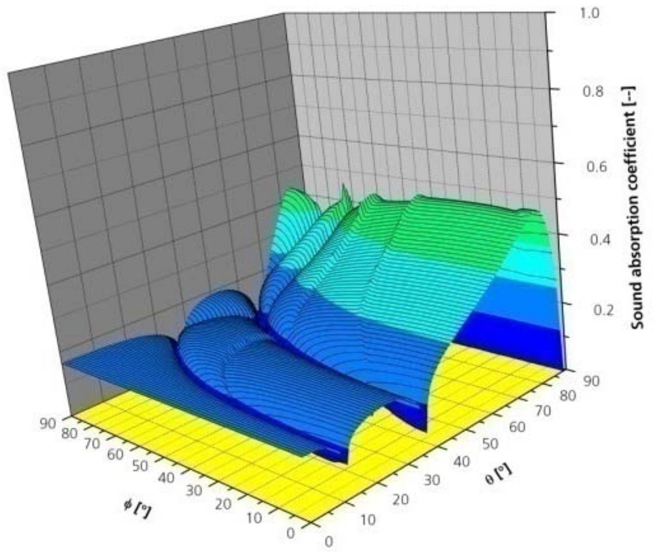



Fig. 2: Calculated sound absorption coefficient dependent on the angles of incidence according to the equations (2).
$L_1$ =0.8 m , $L_2$ = 0.2 m, $\Lambda_x$ =1.0 m,

$A_1 = 0$, $A_2 = 1$
$2\pi(\Lambda_x/\lambda_0) = 16$.

Three acoustic principles were investigated to find out whether they are appropriate for the structure of absorber strips: porous absorbers, micro-perforated absorbers MPA and slotted absorbers [4]. Fig. 3 shows the sound absorption coefficient at normal incidence for the structure with glass foam strips. Conformity of calculation and measurement in the Kundt's tube is sufficient for development purposes. The comparison with the absorption coefficient of a non-periodic structure with the same absorber surface area clearly demonstrates the advantages of the strip geometry.

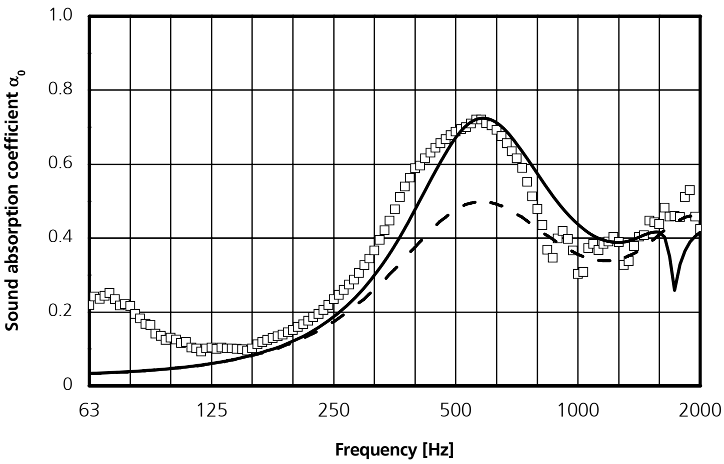



Fig. 3: measured (∀) and calculated (—) sound absorption coefficient at normal incidence of a test specimen made of glass foam strips and wooden beam (both 50 mm depth and width). The surface-averaged sound absorption coefficient (- -) serves as comparison.

Fig. 4 shows the sound absorption coefficient of a large-sized test specimen in the reverberation room

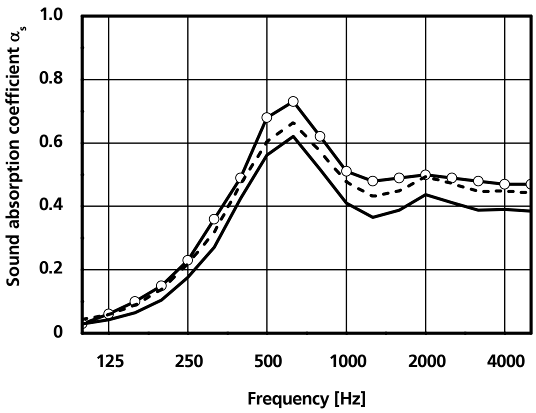



Fig. 4: measured sound absorption coefficient (–) at random incidence of a test specimen made of porous glass foam strip and wooden beam (both 50 mm

wide).
$L_2$ = 50 mm, $\Lambda_x$ = 250 mm. calculation (— or - -).

### 3.2.2 Thermal effect

The surface temperature of a thermally active floor is significant for thermal transmittance. Sections of the floor were modeled by a FEM program for calculation, whereby variations of the daily temperature curves of the room and coolant temperatures were known (Fig. 1). Efficiency $\eta$ shows the deterioration in comparison to an undisturbed concrete floor. The advantages of MPA by the heat transmission of the sheet can be clearly seen by means of the heat flow lines.

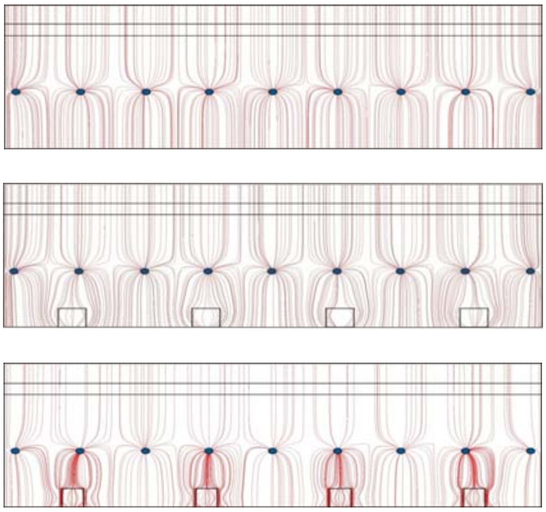
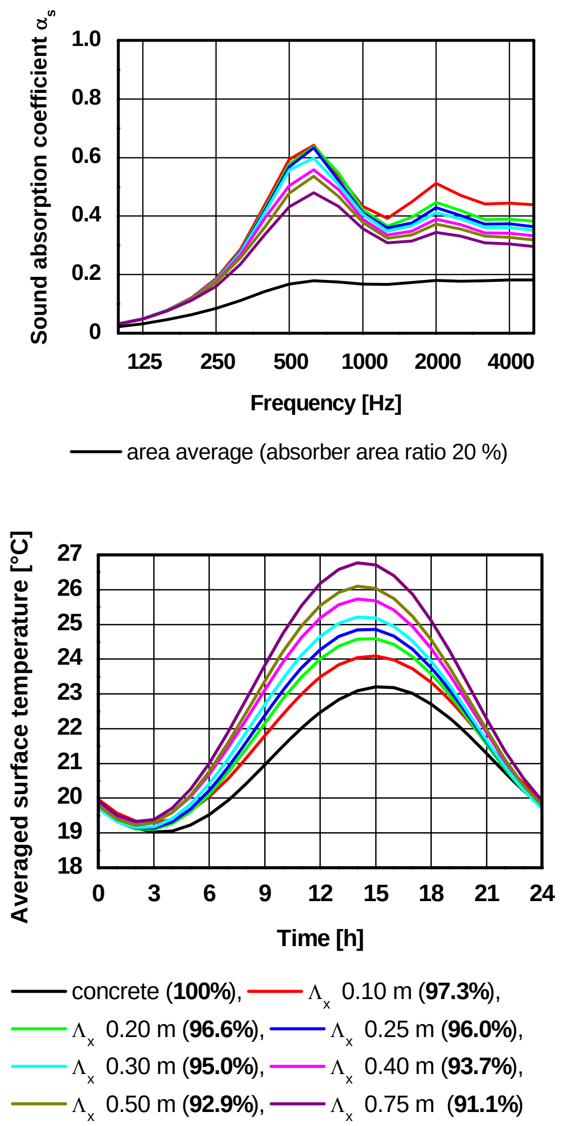


Fig. 5: Examples of calculated heat flows
top: undisturbed concrete floor, $\eta$ = 100%
center: porous glass foam strip , $\eta$ = 96% ($\Lambda_x$ = 250 mm, $L_2$ = 50 mm)
bottom: metal MPA, , $\eta$ = 99% ($\Lambda_x$ = 250 mm, $L_2$ = 50 mm)

The strip geometries were optimized with regard to acoustics and thermal insulation. Rig. 6 gives examples of the sound absorption coefficients and surface temperatures for floors with glass foam strips. The absorber area ratio is 20 % for all variations. The period length was varied. The sound absorption coefficient increases with smaller strips and the surface temperatures of the chilled ceiling drop.




Rig. 6: calculated sound absorption coefficient (top) and averaged surface temperature with thermal efficiency $\eta$ of a concrete building component with strips made of porous glass $L_2$ = 50 mm. $\Lambda_x$ = 250 mm, d = 50 mm, (20% absorber area ratio).

## 3.3 Investigations of test specimens

A first prototype implementation was successfully completed in the inHaus2 of the Fraunhofer Gesellschaft (Fig. 7) in the project duration.

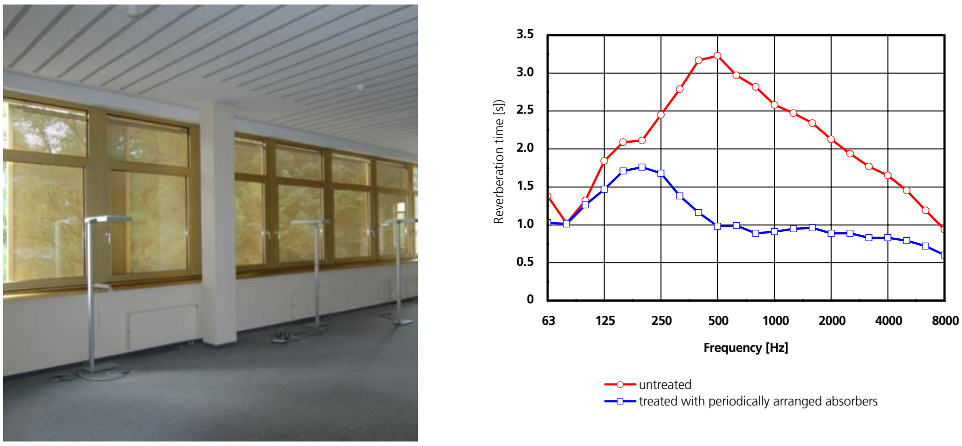



Fig. 7: absorber strips of porous glass installed in thermally active concrete floor in an office room designed for several persons [5] and measured reverberation times with and without absorber strips

A first functioning of the installations could be demonstrated in an office floor. Approaches were made concerning the cost-efficient installation in an in-situ concrete floor.

## References

[1] Lord Rayleigh, "On the Dynamical Theory of Gratings," Proc. R. Soc. London A 79 (532) 399 – 416 (1907)

[2] Brillouin L.: Wave Propagation in Periodic Structures, Dover Publications, 1953, 140

[3] Takahashi D.: Excess Sound Absorption due to Periodically Arranged Absorptive Materials, J. Acoust. Soc. Am. 86 (6), 2215 – 2222 (1989)

[4] Leistner, P.; Fuchs, H.V.: Schlitzförmige Schallabsorber. Bauphysik 23 (2001), 333-337

[5] http://www.inhaus-zentrum.de/site_de/index.php?node_id=2216