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Institutsleitung
Univ.-Prof. Dr.-Ing. Gerd Hauser
Univ.-Prof. Dr.-Ing. Klaus Sedlbauer

High Thermal Efficiency Acoustic Plaster Systems in Line with Market Requirements

Short Version of Report

The research report was financed by the Zukunft Bau research initiative of the Federal Institute for Research on Building, Urban Affairs and Spatial Development (BBSR).
(reference number: SF - 10.08.18.7-11.15 /
II 3-F20-10-1-007)
The author is responsible for the contents of the report.

The report comprises
8 pages of text
1 table
9 figure

Roman Wack
Stuttgart, July 29, 2013

Gruppenleiter	Bearbeiter
Dipl.-Ing (FH) M.Sc. H. Drotleff	Dipl.-Ing (FH) R. Wack

Fraunhofer-Institut für Bauphysik IBP
Nobelstraße 12 | 70569 Stuttgart
Telefon +49 711 970-00
Telefax +49 711 970-3395
www.ibp.fraunhofer.de

Standort Holzkirchen
Fraunhoferstr. 10 | 83626 Valley
Telefon +49 8024 643-0
Telefax +49 8024 643-366

Standort Kassel
Gottschalkstr. 28a | 34127 Kassel
Telefon +49 561 804-1870
Telefax +49 561 804-3187

1 Aim of the project

Multifunctional furnishings are increasingly applied for ceiling constructions in office and administrative building. In this project, various types with acoustic and thermal performance were investigated, the surface of which were uniformly designed by plasters without joints. Component activated ceilings with sound absorber strips [1] were investigated, see diagram in Figure 1, as well as acoustic chilled ceilings and acoustic ceilings without cooling performance.

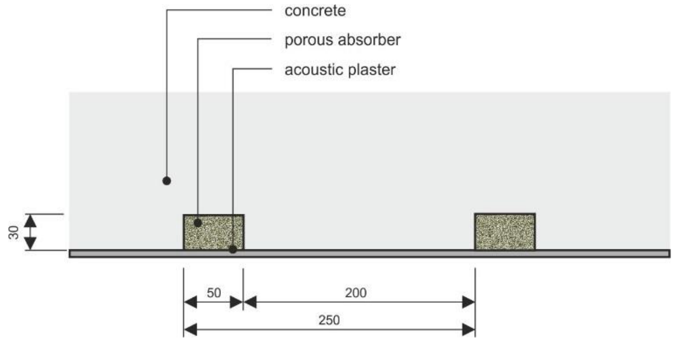

Figure 1:
Structure of a component activated ceiling with absorber strips.

Plaster systems should be developed for these system types allowing the adjustment to achieve sound absorption spectra as shown in Figure 2. On the other hand, however, thermal efficiency should not be deteriorated by more than 10 percent in comparison to an unplastered construction.

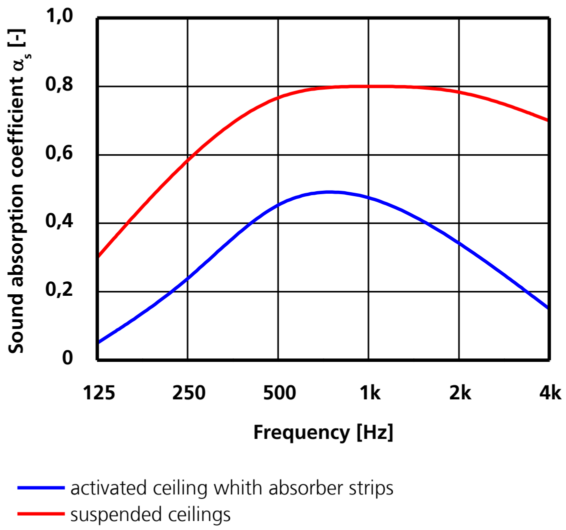

Figure 2:
Target sound absorption coefficients at diffuse incidence for the three system types.

2 Realization

The theoretical modeling of sound propagation in the plaster layer and the subsequent calculated parameter studies on the absorbing power of the plastered constructions were the focus of the acoustic part. First of all, a traditional model was used to model the plaster layers. The necessary input data were directly measured or indirectly determined by adjustment to the measured absorption coefficients.

In addition, a new method for the analysis and parametric synthesis of pore morphology was used. In this context, micro-tomographies of plaster samples were segmented so that the material share was achieved in a voxel grid. Afterwards, the integral geometric analysis supplied characteristic dimensions, e.g. particle size distributions of reconstructed granulates. A geometrical model of the material was generated on the basis of these parameters which can be simply varied. Then, flow and diffusion fields were simulated in the resulting pore volume from which the input data for the absorber model were gained.

Due to the established sound propagation in the plaster the absorbing power of the suspended ceilings was calculated by usual calculation models for layering. An already existing calculation model was expanded and implemented anew by additional all-over layers of plaster for the strip ceiling. Then, a calculated parameter variation supplied the optimal ranges of acoustically significant material characteristics adjusted to the respective system types.

The sound absorbing power of the plaster layers and constructions at normal incidence was measured by the Kundt's tube. The project partner Sto AG supplied samples of three different plaster systems. A substantial part of the measurements was necessary to select the base plate adequate for the investigation. Finally, the plasters were applied on a mineral fiber board. To be measured they were separated from it and investigated in front of air layers of various thickness in the back.

The thermal part was based on calculations by means of the finite element method. In this context, component related efficiencies were calculated by proportioning the mean surface temperatures of the plastered and unplastered components.

3 Results

3.1 Sound propagation in the plaster layer

The sound absorption coefficients of three different plaster systems were measured at normal incidence. Results are available for the separate plaster layers with rear air layers of four different thicknesses. Based on the measured air flow resistances the remaining input data for the model of the homogeneous flow absorber according to [2] were indirectly determined so that good compliance with the measured absorption coefficients was achieved as far as possible. Figure 3 shows an example of compliance for four distances to the wall. The comparison demonstrates good compliance for all plaster systems so that the absorber model can be principally assessed as being suitable.

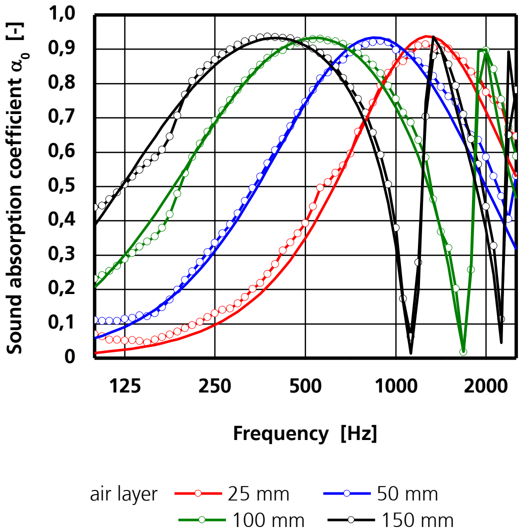

Figure 3:
Comparison of the measured (dotted) and calculated (continuous lines) sound absorption coefficients of a sample of plaster FH in front of various air layers.

In addition, another attempt was made to describe the sound propagation in the plaster system by a synthesis of the micro-structure. For this purpose, micro-tomographies were made of all plaster systems. However, only a reasonable segmentation of the grayscale pictures of plaster FH described in the following was possible, i.e. to achieve the separation of pore volume and material by methods of image processing. The structure of other plaster systems with several aggregates, which absorb x-rays in a very different way, brought about very noisy tomographies.

The skeleton geography was analyzed and the particle sizes and their distributions were reconstructed for plaster FH. Afterwards these particles were synthetized by means of the program GeoDict and assembled to the same compactness as the tomography. Figure 4 shows the morphology from a tomography and the synthesis in GeoDict. The acoustic conditions were simulated for the two geometries. The input data for the Johnson Allard model (Table 1) were achieved as a result.

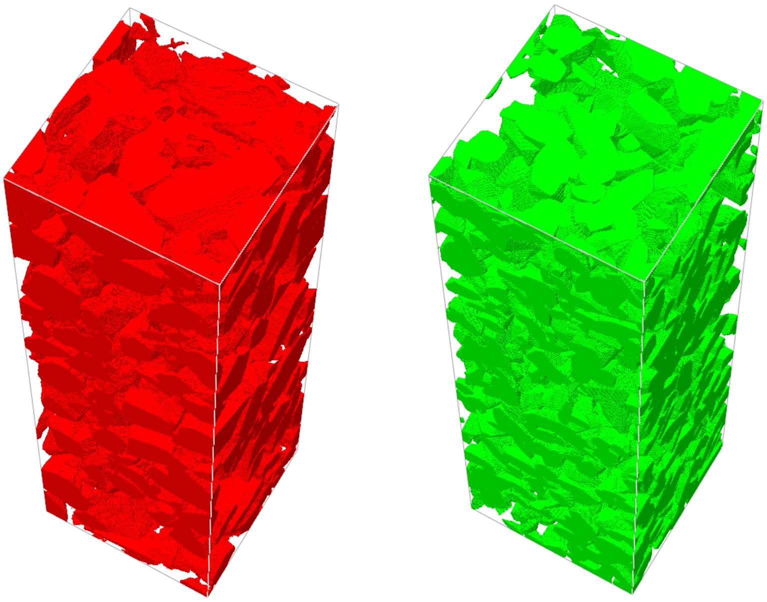

Figure 4:
Comparison of tomographed (left) and synthetized (right) skeleton morphology by the example of plaster system FH.

Sample		**Tomography**	**Synthesis**
Volume porosity	[—]	0,52	0,53
Tortuosity	[—]	1,9	1,6
Air flow resistance	[kPa s/m²]	87,1	86,0
Viscous characteristic length	[m]	$5{,}69 \cdot 10^{-5}$	$6{,}50 \cdot 10^{-5}$
Thermally characteristic length	[m]	$9{,}42 \cdot 10^{-5}$	$8{,}22 \cdot 10^{-5}$

Table 1:
Input data for the Johnson Allard model of plaster system FH calculated from pore geometry.

There is good compliance of the values of synthesis and tomography. Differences resulting in the absorption coefficient are within the range of the measurement accuracy of the Kundt's tube measurement, as can be seen in

Figure 5. However,

Figure 5 also shows that compliance with the measured absorption specters is dissatisfying. Thus, the method of the synthesis is basically useful. In combination with the available tomographies, however, a successful modeling was possible.

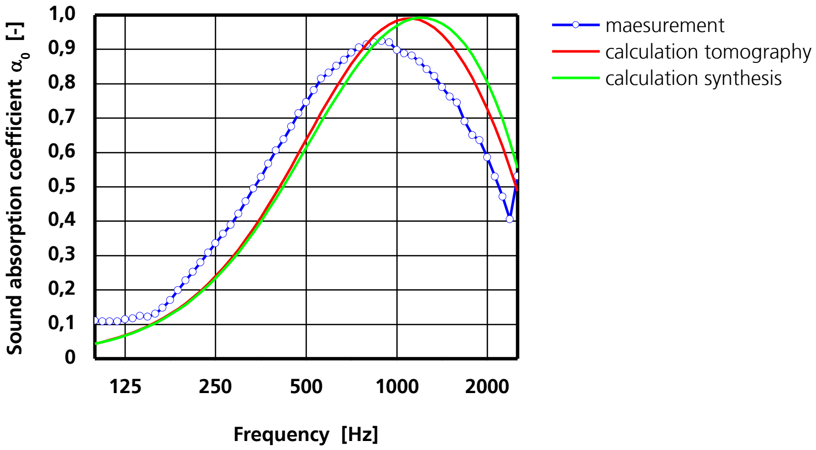

Figure 5:
Comparison of the sound absorption coefficients at normal incidence of plaster system FH at a 50 mm air distance.

3.2 Acoustic investigations of the system constructions

The absorption coefficients of several constructions for the system types were measured by small-sized samples. Figure 6 and 7 show the construction with absorber strips.

Figure 6:
Sample of wood-based material (Multiplex) and absorber strips made of open-cell glass foam with loosely added glass foam plate and plaster layer.

Very good compliance was achieved between measurement and calculation for the system constructions by modeling the plaster system as homogeneous flow absorber (Figure 7).

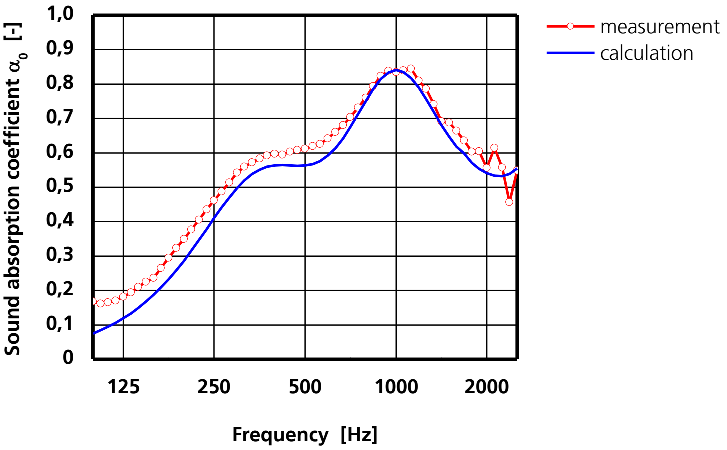

Figure 7:
Measured and calculated sound absorption coefficients at normal incidence of plaster system A3.4 BH on an all-over glass foam plate on a strip construction according to Figure 6 (glass foam strip width 67 mm, height 50 mm, period 200 mm).

This allowed calculative parameter variations resulting in the following essential statements for all constructions:

- Open volume porosity of more than 40 percent does not achieve any advantages worth mentioning.
- The total flow resistance of the plaster layer is decisive. A construction in layers with different flow resistances is not beneficial. This provides a great scope for arranging plaster layers according to constructional aspects.

The result for the system types is:

- Component activated strip ceiling:
  A plaster system with comparable acoustic properties as the absorber strip material itself is optimal. An acoustically transparent plaster is not necessary.
- Suspended ceiling:
  There is an essential potential for improvement at lower frequencies due to the plaster system.

3.3 Thermal investigations of the system constructions

Finite element calculations of the thermally activated strip ceiling show the effects of the layered ceiling and the thermal conductivity of the plaster layer on the cooling capacity. The example in Figure 8 shows the balancing effect of thicker plaster layers on temperature peaks within the range of the absorber strips. The deterioration due to the separate impact of thinner plaster layers is lower than one percent for usual layer thicknesses. The variation of thermal conductivity in Figure 9 shows that efficiency is very much reduced in case of high-level thermal insulation plaster layers.

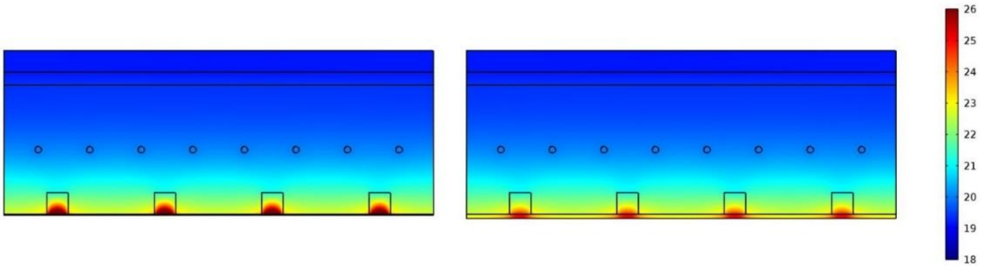

Figure 8:
Distributions of simulated component temperature given in degrees Celsius after 156 hours (at noon). Plaster system FH with halved thermal conductivity and 2.5 mm layer thickness (left) as well as with doubled thermal conductivity and 10 mm layer thickness (right).

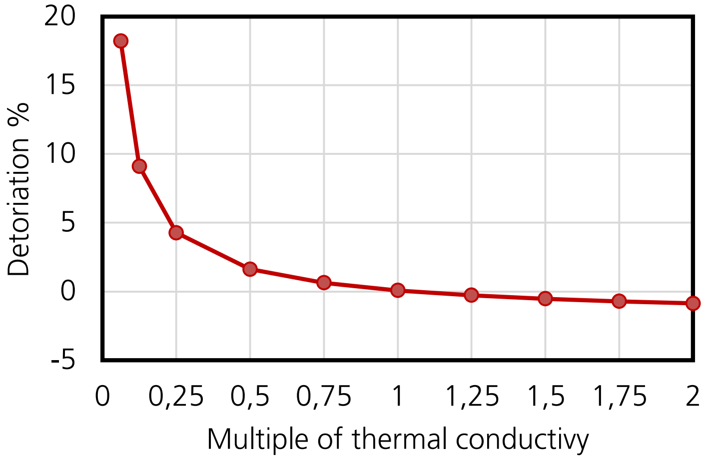

Figure 9:
Deterioration on a percentage basis in comparison with the unplastered strip ceiling with 5 mm thick plaster system of various thermal conductivity as a multiple of the value of plaster system FH (0.49 W/(m² K)).

3.4 Recommendations to select the plaster system

A porosity of approx. 40 percent should be adjusted for all plasters. Higher values do not have any acoustic benefit. The air flow resistance can be estimated in a first approximation by the particle sizes of the aggregate based on the assumption of bead granulate. The following recommendations were acquired for the individual system types:

Absorber strip ceiling:
It is recommended to reduce the plaster thickness to the constructional minimum and to increase particle sizes only in a way that processing, strength etc. permit. If only massive aggregates can be used, thermal performance should be within the range of the investigated plaster FH of 0.5 W/(m² K).

Suspended ceiling:
The optimal flow resistances of these system types are considerably higher than for system type 1. Therefore, they can only be achieved by massive aggregates with diameters clearly smaller than one millimeter. Thus, the exclusive application of massive aggregates is recommended for the thermally activated system type 2. Porous aggregates can also be used for system type 3. However, the investigation did not show any acoustic benefit.

[1] Fraunhofer-Institut für Bauphysik: Abschlussbericht: Integrale Akustiksysteme für thermisch aktive Betonbauteile - Akustik in Betondecken. Durchgeführt im Auftrag des Bundesamts für Bauwesen und Raumordnung im Rahmen der Forschungsinitiative „ZukunftBau", Z 6 – 10.08.18.7- 07.35/ II 2 – F20-07-41. Juni 2009.

[2] Mechel, F. P.: Schallabsorber, Bd.2, Innere Schallfelder, Strukturen. Stuttgart, Hirzel, 1995

[3] Johnson, D. L.; Koplik, J.; Dashen, R.: Theory of dynamic permeability and tortuosity in fluid-saturated porous media. J. Fluid Mechanics, 176 (1987), 379-402