Silence at work - noise at home: a case study

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ABSTRACT

Plenty of normative handle too high noise impact at work, either in offices, factories or similar, in order to limit stress, increase productivity and for health protection. For private homes, structural acoustics becomes regulated, concerning air borne and tapping noise transmission plus noise from the outside. Private homes are not subject to limitation of noise, produced by residents in their own rooms. After a working day full of effort, you are looking forward to a home to recover. In many cases, however, self-produced noise inhibits to relax. There is a remarkable difference in the acoustical quality between “grandma’s living room” and a designed modern eat-in kitchen plus large living room. Sound reflecting surfaces, large windows, designed furniture and big volume result in a noisy home. In contrary to that, in a room full of curtains, carpets and thick upholstered sofas the acoustical comfort is higher. This case study shows both, a noisy home and a silent one. The acoustical effect of an invisible technical solution and an approach to reduce sound transmission through an open staircase for private homes are presented.

INTRODUCTION

Since decades, almost all around the world, normative and regulation handle protection against noise in buildings, many times through requirements, given by law. The main issue is protection of health, but also to separate different apartments in multi-storey buildings against unwanted sound transmission form adjacent apartments and, of course, to give a certain acoustical standard to buildings and work space. The related values are mainly to limit air borne sound transmission, impact noise, tapping noise, noise of technical equipment of buildings and traffic noise from the outside. This topic will not be considered here, as the mentioned disciplines are well controlled.

For offices, meeting rooms and similar auditoriums, recommendations concerning architectural acoustics of rooms are defined, completed by proposals for application and distribution of reflective and absorptive surfaces inside a room. The main values in question are reverberation time, background noise level and speech intelligibility. All requirements must be chosen and applied in reference to the desired purpose of buildings and its rooms in order to achieve the best-matching quality and functionality.

In contradiction, for private homes, there are no requirements, concerning acoustical conditions in your own living environment. All measures taken are voluntary for both, owner and architect. A typical situation will be described in the following.

REQUIREMENTS AND RECOMMENDATIONS

National standards, like the German DIN 4109 [1], define the maximum sound pressure level, caused by water and drainage installations or other technical installation inside buildings. For living rooms and bedrooms of apartments, or rooms in offices or schools, additionally for self-owned rooms and their ventilation, the maximum permitted value is $L_{A,F,max}$ = 30…35 dB(A), see table 9 and 10 of [1]. All other requirements, according to chapter 1 of DIN 4109 [1], are not applicable for noise insulation in your own living- or working area.

For self-produced sound and noise in private homes, precisely for living rooms, requirements do not exist; only optional recommendations are given. Especially the lately released DIN 18041 [2] excludes any requirement for self-owned rooms and apartments concerning acoustical criteria, like reverberation time. It remains within the owner’s responsibility to create a proper quality.

Unfortunately, there is no awareness for the advantage of acoustic treatment in your own apartment, which may result in adapted acoustic conditions. Neither the investor nor the architect respect on a regular basis these topics during planning and construction.

Hence, it is difficult to find an assessment of the best matching quality or any level to compare with. But, there is the withdrawn German Normative DIN 52219 [3], that gives an idea of reverberation time and absorption area, which might be considered as standard inside private rooms. Based upon an evaluation of many former on-site measurements the normative gives an advice, in order to measure the noise, emitted by water and drainage installations, with a shortened procedure. The equivalent sound absorption area A_{eq} can be estimated as follows:

$$A_{eq} \cong 0.8 \times S_{Ground} \qquad (1)$$

Therein are A_{eq} - equivalent sound absorption area in m² and S_{Ground} - ground surface in m² of a standard room of an apartment. With an assumed medium-sized room of S_{Ground} = 20 m² an absorption area of A_{eq} = 16 m² results. With a clear height of 2.5 m and a volume of V = 50 m³, Sabine’s formula gives a reverberation time of T = 0.5 s.

If you consider using the living room as a home cinema, there are - of course voluntary - recommendations on background noise and reverberation time, e.g. in the THX Design Manual [4], therein as follows: *Reverberation in theatres is always present, and must be controlled to be within reasonable limits to produce good articulation and consequent intelligibility throughout the hall. Too much reverberation smears together the syllables of speech, and sound effects and music are affected as well. Too little reverberation may make audible the effects of discrete reflections that are low in level. The optimum amount of reverberation varies with the volume of the theatre.*

If you regard your living room as a “theatre” or home cinema, with flat screen und multi-channel sound system, for rooms of 50 m² and a volume of about 100 m³ up to 150 m², in [4] a reverberation time between 0.25 s and 0.30 s is recommended to meet THX-standard. Longer reverberation time is in consequence not conducive for high quality reproduction of movies or music.

As consequence, it remains within the owners and architects responsibility and awareness, to treat private (living) rooms with noise reducing measures, in order to increase acoustical comfort in your private home.

TRANSFER TO UP TO DATE ARCHITECTURE

The actual situation of private homes shows no longer just small rooms, but such of 50 m² and more. It’s common, especially in one-family homes and semi-detached houses, to have eat-in kitchen and living room as on single volume, several times even directly connected to an open multi-level stair house. Thereof results a much greater volume than in homes, built decades ago. The combination with mainly sound reflective surfaces, e.g. wooden floors, stone floors, ceramic tiles, large windows, dry walls, rendered brick walls, the reduced equipment with low sound absorbing furniture and curtains, seats with leather upholstery and light gauze curtains, aggravates the acoustical situation. Private homes become noisier, in consequence the former assumption of quite a lot of sound absorption material in living rooms is more or less invalid here.

In case of an open stair house, sound transmission from the living room up into the bedrooms on first or second floor is not positively affected, if the living room is quite echoic and noisy. Unfortunately, people talk louder in a more reverberant room than in a more anechoic room, which occurs mainly during family parties or equivalent, which deteriorates the situation.

NOISY LIVING CONDITIONS

In Sto-internal case study [5] typical sound was measured in an open kitchen, connected to the living room, like having lunch with the family. In addition, the loudest machine was used, here for grinding nuts in a multifunctional kitchen mixer. The examined room shows a concrete ceiling, standard furniture, ceramic tiles on a ground surface of approx. 27 m² and a volume of about 65 m³. The measured mean value of reverberation time is T = 0.4 … 0.8 seconds, depending on frequency.

Figure 1 shows the acoustical condition in an open eat-in kitchen during lunch time with four persons, as graph sound pressure level $L_{A,F}$ / dB versus time. Maximum levels of up to $L_{A,F}$ = 85,5 dB(A) were found, induced by e.g. cluttering porcelain and laughing children. Standard conversation and radio playing causes between $L_{A,F}$ = 35…39 dB(A). The mean value of the shown period is $L_{A,eq}$ = 61,2 dB(A). With a background noise level of $L_{A,eq}$ = 26 dB(A) all sound incident is significantly louder.

In offices, an acoustical situation like this would not be accepted, as it is not suitable and far too loud for focussed office work. The conclusion is, that office work is more silent (due to acoustical treatment according to building regulations) than a modern standard private home.

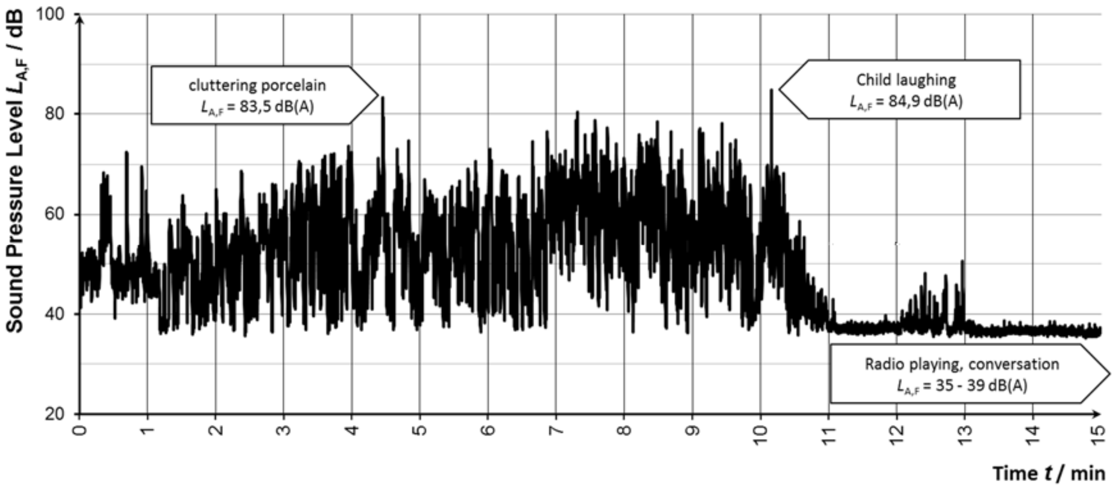

Figure 1: acoustical condition during lunch time, eat-in kitchen of 27 m² / 65 m³

Extremely noisy are kitchen machines, like a multi-purpose mixer, when e.g. grinding hazelnuts. A maximum sound level of $L_{A,F,max}$ = 103.5 dB(A) was detected, the grinding process remains at around $L_{A,F}$ = 83 dB(A), see figure 2. In work environment, you would be required to wear ear protection, when using this device. Any legal requirement concerning noise in offices would be exceeded.

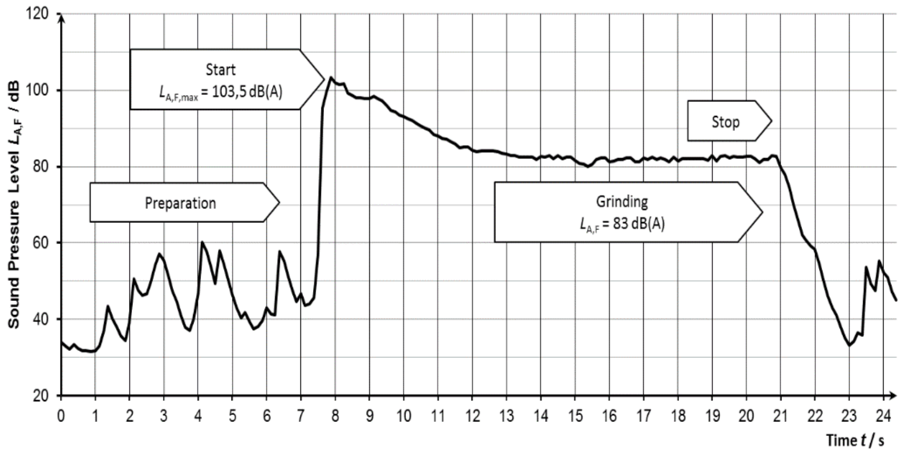

Figure 2: multi-purpose mixer, grinding hazelnuts, eat-in kitchen of 27 m² / 65 m³

But, as for sure, you will not grind hazelnuts every day, a more common kitchen tool was measured also. When preparing an Italian espresso, using an Italian fully automatic espresso machine, the measured values confirm, that it is a very noisy procedure to later enjoy a tasty coffee.

The maximum level, at the operators position, goes up to $L_{A,F,max}$ = 75.8 dB(A), the mean value of the entire process with around $L_{A,eq}$ = 55 dB(A) was detected, the grinding process remains at around $L_{A,eq}$ = 64 dB(A), see figure 3 for detailed results. 80 seconds of noise, just to enjoy a 50 ml espresso might become an acoustical challenge for all persons inside the room.

What happens, if you have a (birthday) party with the entire family, friends and relatives, who ask for coffee?

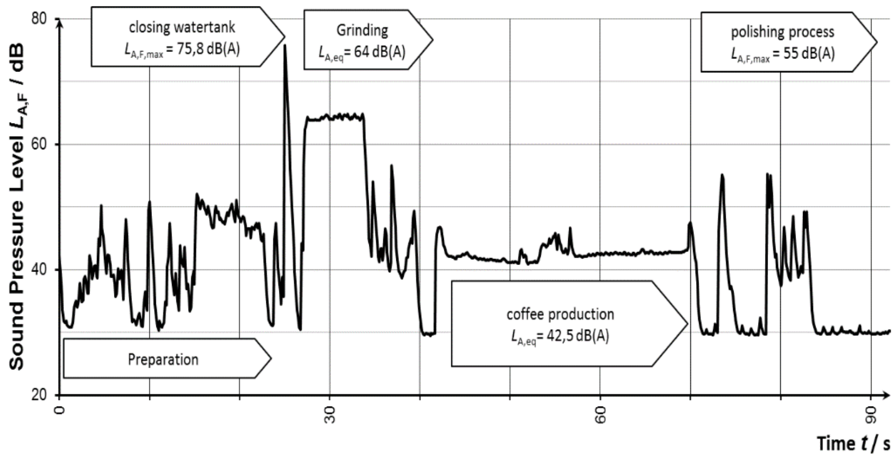

Figure 3: Preparing an Italian espresso, using an Italian fully automatic espresso machine

Summarizing, it can be confirmed, that the daily living in private rooms can become very noisy and disturbing, especially when compared to a more silent, well regulated office you are used to during work. Noise reducing measures would be more than welcome.

COMPARISON OF DIFFERENT LIVING ROOMS

Sto's case study, executed in March and April 2017 [6], deals also with the acoustics inside two mirror-inverted parts of a semi-detached house. The differences construction-wise between the living rooms on the ground floor of each house are an open eat-in kitchen (house no. 1) versus an enclosed kitchen (house no. 2).

The living room in house no. 1 shows a surface of about 50 m² with a volume of approx. 130 m³, including living room, eat-in kitchen and entry. The living room in house No. 2 offers approx. 41 m² and a smaller volume of 112 m³, due to the enclosed kitchen. Figure 4 shows the vertical section in principle.

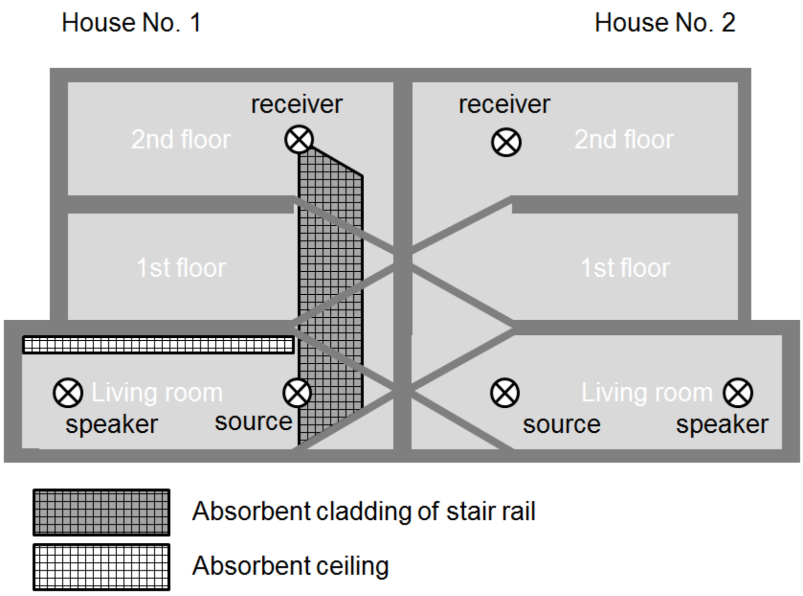

Figure 4: vertical section in principle of a semi-detached house; position of sound sources and microphones for measurement

Both living rooms were furnished almost in the same way, each with a five-seat sofa, dining table, wooden floor, light gauze curtains, a single carpet plus few decorative outfits, see figure 5.

Figure 5: view into living room no. 1, with open kitchen, entry, kitchen and stair house

TECHNICAL SOLUTION

To reduce noise, enlargement of sound absorption is the adequate measure. There are different types of absorbers and absorbing systems available on the market. Absorbent wall panels or suspended elements seem to be the easiest way, but they have an effect on the interior architecture.

Suspended ceilings need sufficient clear construction height and mostly have a technical appearance, e.g. with exposed grid system, that does not suit to a private living room and are in opposition to the architect's idea of open rooms with clear, white surfaces.

Invisible, jointless systems, as well as absorbing, are the silver bullet.

In the examined house no. 1, an invisible solution was applied (figure 5). The main difference between the living rooms in house 1 and house 2 cannot be seen, but heard - immediately when you enter. House 1 is equipped with a directly glued sound absorbing ceiling system (figure 6), seamlessly coated with a porous plaster, all-over the living room, plus eat-in kitchen and entry area, see figure 4 and 5 for details. Also the underside of the stair landings on first and second floor was clad with this system.

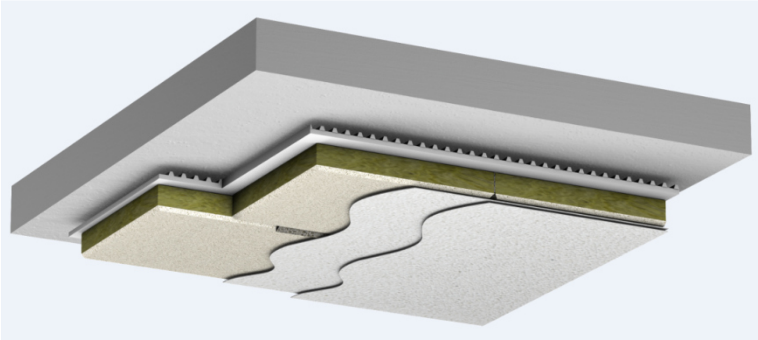

Figure 6: schematic view of 50 mm seamless absorbent ceiling system

In difference to freely suspended elements, this system performs with high absorption especially at low and mid frequencies, giving an advantage, when compared with standard canopies or similar. The gradient to higher frequencies is of no disadvantage, as the furnishing offers especially at frequencies high sound absorption, but not at medium and low frequencies.

The ceiling systems consist of an adhesive, a porous multi-layer board, filled joints, all-over coated with a levelling layer of porous plaster, completed by two layers of porous spray plaster. The acoustical performance is confirmed in the related third party test report [6] with $\alpha_w = 0.75$ acc. to EN ISO 354 [7] and EN ISO 11654 [8]. Figure 7 shows the test result in detail for a type A set up.
It seems obvious, to better install a ceiling system with highest sound absorption, Class A acc. to EN ISO 11654 [8]. But, this can seriously not be recommended, because with a 100 % sound absorbent ceiling, flutter echoes (multiple sound reflection between parallel surfaces, walls etc.) are intensified to an annoying level. Therefore, according to experience with many successful projects, the best trade of is a ceiling with $\alpha_w = 0.70 \ldots 0.80$.

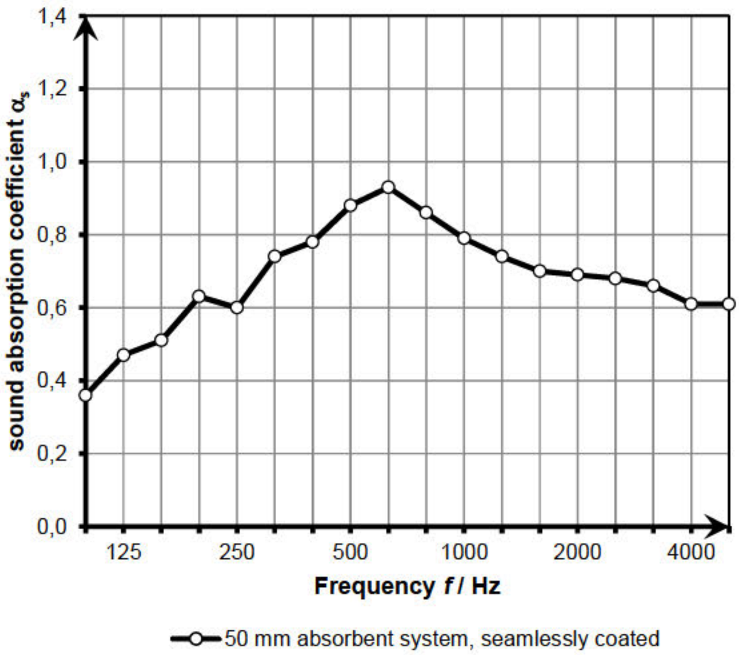

Figure 7: Sound absorption acc. EN ISO 354 for 50 mm directly glued ceiling system

In addition to the absorbent ceiling, the separating grid of the steel stair rail in house no. 1 was clad with a double layer of special, highly absorbent 8 mm PE-fibre board in grey, fixed all-over the separating steel construction from ground floor up to second floor, in order to create a “stair case silencer” (figure 8).

Figure 8: top view into stair house, steel stair rail clad with grey PE-fibre boards

MEASUREMENTS AND RESULTS

In order to compare the acoustical situation in both semi-detached houses, the measurements were as follows:

- back ground noise level in both living rooms
- reverberation time in both living rooms
- sound propagation in living rooms, from sound source to microphone, distance 5 m
- sound transmission from ground floor to stair house, 2nd floor

Background Noise Level

The background noise level in both living rooms was measured with $L_{A,F}$ = 25…27 dB(A). There is no difference between room with and without absorbent ceiling, as there is only sound incidence from the outside, radiated by façade and windows.

The first impression, namely that it is more silent in house No. 1 than in house No. 2, can be confirmed by measured reverberation time, see figure 9.

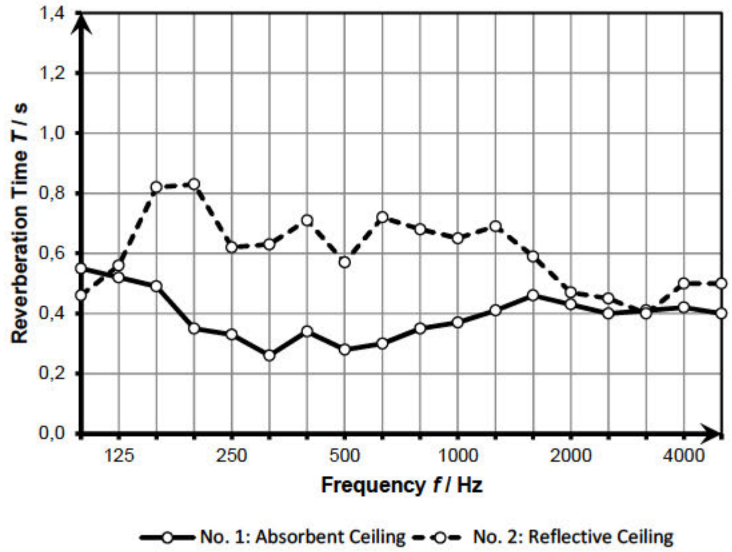

Figure 9: Reverberation Time *T* in living rooms house No. 1 and No. 2 absorbent versus reflective ceiling

Reverberation Time

In living room of house no. 1, the mean value of reverberation time is about 0.39 s, in difference to 0.6 seconds in living room of house no. 2. From 2,000 Hz and higher frequencies, there is no remarkable difference in reverberation time. This is caused mainly by high sound absorption of all furnishing, curtains and carpet. The additional absorption area of the absorbent ceiling system is of smaller effect, if the room is already acoustically damped.

By help of the absorbent ceiling, the relation between ground surface and absorption area A_{eq}/S_{Ground} could be enlarged by minimum 60 % up to more than double of the values than with only concrete ceiling. This could be calculated using Sabine's formula, respecting the room's volume and the measured reverberation times.

The theoretical noise reduction, caused by the absorbent ceiling as presented before, can be calculated to values of $\Delta L_{Absorption}$ = 3…4 dB. In theory, all emitted noise from sound sources of constant sound power (like coffee machine, dish washer etc.) will be reduced by this 3…4 dB in the diffuse sound field of the room. Of course, for the operator of a kitchen machine etc., this reduction is of no effect if standing close to it (near field). For any other person, staying rather far away of the sound source, this is a remarkable reduction.

It appears on first sight to be rather low value, but, fortunately, people adapt their sound power while speaking to the sensed acoustical situation they are in. With the people's unconscious behaviour, to behave and talk more silent in a more anechoic and thus less noisy environment, this leads to the higher comfort and greater chance to relax. Lazarus describes this effect in detail [9].

The first reaction and response of many guests, visiting hose no. 1, is, that they feel "something different" to all standard they have experienced in other buildings. The great advantage, confirmed by the owner, is, that his own family and their guests behave more silent, talk more silent, feel less stressed than in their neighbour's living room with reflective ceiling.

There is also reported a remarkable effect on the family-internal way of communication, over all less stressed and more silent. This living room performs with remarkable higher comfort, perfect to relax and to recover from work.

When using the TV-set with external loudspeakers, the condition in living room of house no.1, with reverberation time of 0.39 seconds and below, see figure 9, matches much better with e.g. THX-standard than in the room with only a concrete ceiling. The promised quality of high-class multimedia equipment can be utilised fully.

Sound Propagation

The gain of acoustical quality, caused by an absorbent ceiling, can be confirmed additionally, when regarding the sound propagation through the living room.
To verify this effect, there was measured in both the living rooms the sound pressure level in 5 m distance of a loudspeaker, calibrated to the near field sound power level, see figure 4 and 5 to see the position of the instruments. This procedure was chosen, because it is nearly impossible, to create and reproduce as sound source a typical noise and sound of people in daily life under both conditions (with and without absorbent ceiling). Figure 10 shows the difference of sound pressure level with absorbent ceiling minus that with concrete ceiling. The mean value of the gain is about ΔL = -5…-6 dB, the greatest value is about ΔL = -8 dB (difference between room 1 and 2). Note: The frequency dependency is not uniform or flat. This can be caused by multiple reflections between parallel walls and, of course, by the unusual comparison of results, found in different rooms.
Thereof a higher acoustical comfort results, supported by shorter reverberation times and the unconscious change in human behaviour - silent home, silent people in a more relaxing environment.

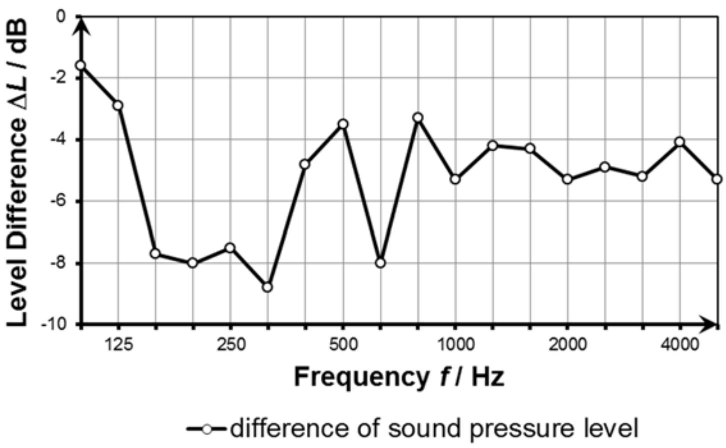

Figure 10: Sound pressure level difference between source and receiver, 5 m distance; living room 1 (absorbent ceiling) minus living room 2 (concrete ceiling)

Sound Transmission

Finally, the sound transmission out of the living room on ground floor via the open stair case up to the small corridor in front of the bedrooms on second floor was examined. Figure 8 shows the absorbent cladding of the stair rail. In house no. 2, there was the open metal grid along the stair rail without absorber panels, and no absorbent system underneath the stair landings.

For measurement, the sound source was positioned far of the stair in the living room. The source level was measured in the open entry of the stair case; the receiving level was measured on the open stair landing on second floor. Figure 11 shows the results. The overlap of both curves at f = 315 Hz can be ascribed to the format of the stair case. The clear dimension of the stair case corresponds to the wave length of sound wave.

The mean value of the gain, caused by the absorbent cladding, is about ΔL = 7 dB, maximum is about ΔL = 10 dB and more (difference between house 1 and 2). The positive effect of this simple measure is that an evening conversation in the living room is much less disturbing for e.g. children, sleeping upstairs in their bedroom - without any extra separating door!

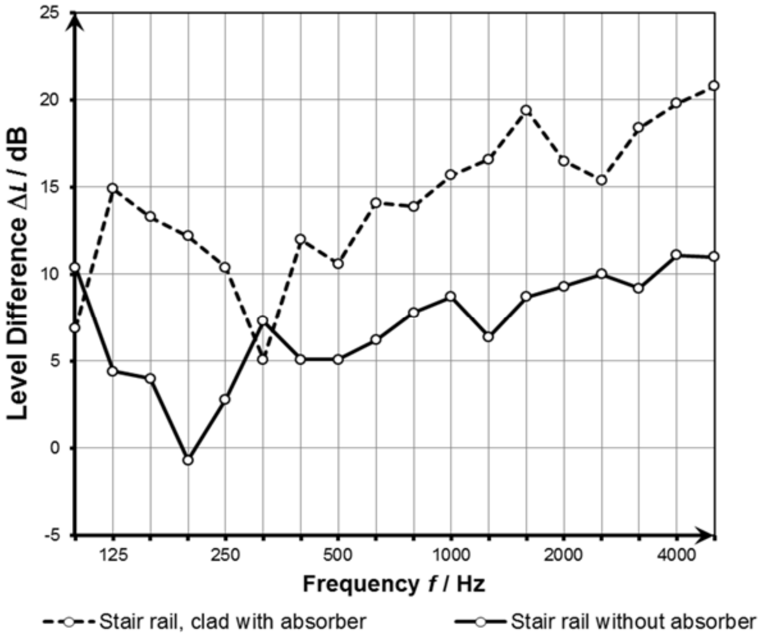

Figure 11: Sound pressure level difference - ground floor to first floor, via open stair case, with and without absorbent cladding of stair rail

CONCLUSION

Sound absorbing measures, such as seamlessly coated ceiling systems, reduce noise and shorten reverberation time in the equipped room. Large living rooms, combined with an open eat-in kitchen and entry, react positively on additional absorbers. There is additionally a remarkable reduction of communication noise, because people react unconsciously in talking silent in a less echoic room. The apparent quality of a private home can be improved to a different, much higher level.

Simple measures, like an absorbent cladding of open stair's stair rail increases the acoustical separation between noise living room on the ground floor and silent bed rooms on upper floors - without any separating door extra.

The market offers solutions, which are designed to fulfil even ambitious demands of both, owner and architect. The best solution is an invisible as well as sound absorbent ceiling, with no negative effect on the room's design. Additional absorbent wall panels would improve the acoustical situation.

Overall, a more silent private home helps to recover from work, to increase comfort and well-being and to gain quality of life at home.

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