

# The influence of suspended ceilings on the impact sound insulation of wooden-beamed ceilings in a Wilhelminian style house

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**Abstract.** The refurbishment of Wilhelminian style houses, driven by the densification of the living space, is increasingly leading to problems in the field of sound insulation. The high-quality refurbishment of the outer shell of the existing buildings significantly reduces the basic noise level in living rooms. The focus of the project and the work shown is to improve the impact sound insulation of wooden beamed ceilings in Wilhelminian style houses without adding floor height. This ceiling systems show significant differences in its basic constructions compared to the modern wood-beamed ceilings (beam dimensions, spans width, etc.). The work shown examines different suspended ceilings constructions on a wood-beamed ceiling in a Wilhelminian style house. The conclusions are based on the measurement of the impact sound level in different construction phases according to ÖNORM EN ISO 16283-2:2018. An unknown influence are openings, in large numbers, in the suspended ceiling. These are often caused by the installation of lighting or by ventilation systems. The results show that depending on the resulting cross-sectional area of the holes, a reduction in the impact sound insulation is recognizable and should be considered in the planning process.

## 1. Introduction

The sustainable refurbishment and upgrading of Wilhelminian style houses increasingly require, in addition to the thermal measures, sound-technical upgrades. The installation of new high-insulating windows significantly increases the sound insulation of the building envelope. This requires minimizing in-house sound transmission, especially the improvement of the impact sound insulation. In the case of a complete refurbishment of the building, the floor structure is usually removed down to the raw ceiling. Then all installation lines such as electricity, heating, water and sewage are mounted on the raw ceiling. In some cases, line crossings lead to large filling heights. The cables must be covered with a bulk of heavy splinter. Sewage pipes are therefore often soaked into the wall or lowered under the ceiling formwork. A sound insulation made of 3cm mineral fibre is laid on the split filling. Above this, a 5 to 7cm thick screed is inserted, which is decoupled from the walls by means of insulation strips. As a covering, a glued wooden parquet is usually used. To further improve the impact sound protection, a suspended ceiling is installed on the ceiling underside. These acoustic measures are based on experience and a trial and error process. Valid data for the forecast of building acoustic performance of refurbished Wilhelminian style house ceilings are barely available.

## 2. Approach

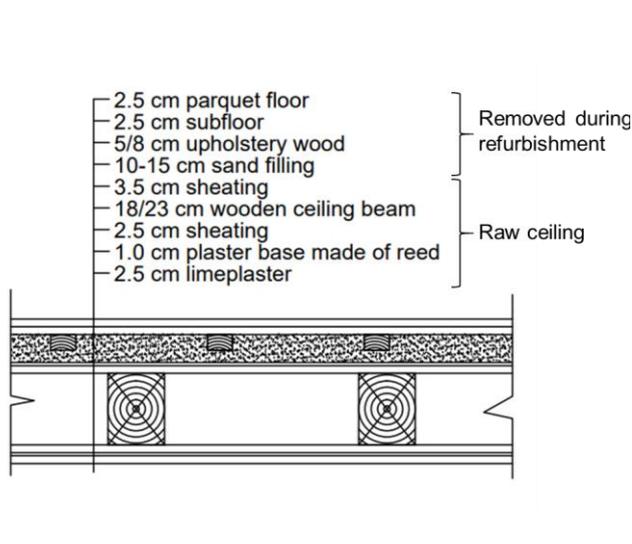
The literature already knows some guide values for the acoustic renovation of wood-beamed ceilings. [1,2,3,4]. However, the wooden ceilings shown in the examinations differ in significant details from typical Wilhelminian style house ceilings examined in this study. Also, the influence of openings in ceilings to the building acoustic upgrades is not known. In order to determine the influence of the openings in suspended ceilings for the installation of electrical installations on the reduction of the impact sound level, different configurations of suspended- and raw ceilings were investigated. These suspended ceilings, which differ from the building acoustic quality, were provided with different numbers of holes in order to quantify this influence depending on the entire open cross-section of the openings. The following sections describe the different properties of the raw- and suspended ceilings and the used measurement techniques to measure the impact sound levels on the building site. The measurements were carried as an accompaniment process of two different projects in different phases of the ceiling refurbishment.

### 2.1. Test specimens

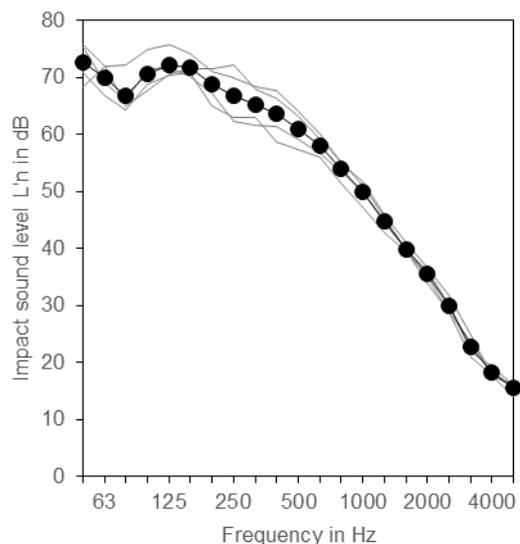
The ceilings examined consist of three components. Floating screed, wooden frame ceiling and suspended ceiling. The wooden frame ceiling is preserved in the refurbishment process and is upgraded due to several building physical and static requirements by means of floating screed and suspended ceiling. The following section describes the essential properties of those components.

#### 2.1.1. Raw ceilings

The wooden frame ceilings consist of wooden beams and boards. These ceilings are very typical in Wilhelminian style houses and don't vary significantly in their geometry or properties in one house. Figure 1 shows a schematic drawing of the typical Wilhelminian style wooden frame ceiling. Figure 2 shows the measured normalized impact sound level  $L'_{n}$  of the raw ceilings when the floor construction (Parquet, Subfloor, upholstery wood, sand filling) is removed. It can be seen that the five different measured ceilings have a very similar characteristic in their normalized impact sound level trend. The compared to modern wooden framed ceilings low impact sound level can be explained by the bigger wooden beam dimensions and the high weight of the plaster on the underside of the ceiling.



**Figure 1.** Schematic drawing of a typical Wilhelminian style wooden frame ceiling



**Figure 2.** Normalized impact sound levels of the raw ceilings. The line with the black dots shows the arithmetic average

### 2.1.2. Floating screeds

Table 1 shows the essential properties of the floating screeds. The cement screeds were all fully dried out and rested for three Weeks before measurement. The screeds are separated to the walls with insulation stripes to prevent structure borne noise transmission.

**Table 1.** Investigated floating Screed types

	Screed thickness in m	Screed Material	Resilient layer Type	Resilient layer thickness in m	Additional weighting
RC12_elgeb	0.05	Cement	Recycled polymers	0.012	Gravel (polymer binding)
RC12_zemgeb	0.05	Cement	Recycled polymers	0.012	Gravel (cement binding)
Sta5	0.05	Cement	Mineral wool	0.03	Gravel
Sta7	0.07	Cement	Mineral wool	0.03	Gravel

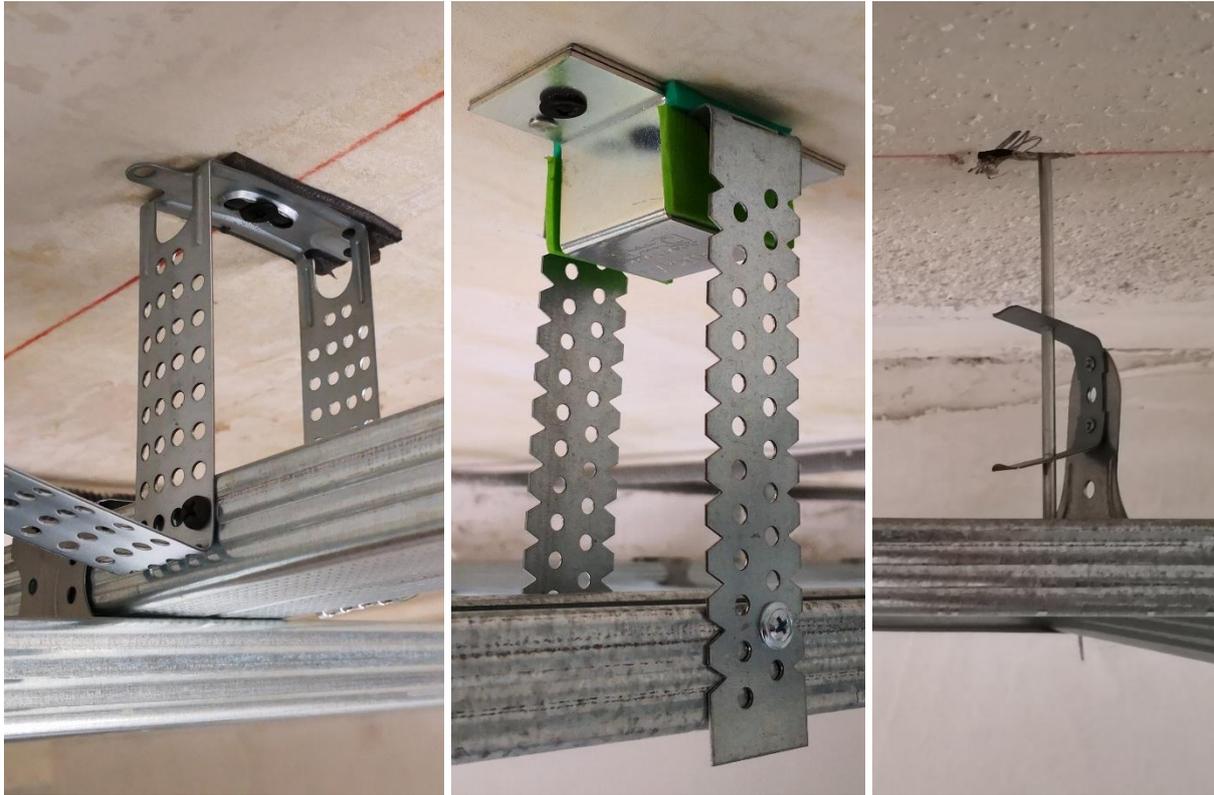
### 2.1.3. Suspended ceilings

Table 2 shows the essential properties of the investigated suspended ceilings. The panels were mounted to an aluminium supporting construction which is suspended from the wooden framed ceiling with different hangers. The border of the supporting construction was mounted to the flanking walls with a resilient layer between the structure and the wall. The gaps between the panels were filled with gypsum and the connection to the wall was filled with acrylic sealant to guarantee airtightness.

**Table 2.** Investigated suspended ceilings

	Suspension height in m	Hanger type	Air cavity damping material	Panel thickness in m	Panel density in kg/m <sup>3</sup>
DiA_GKP	0.12-0.15	Metal bracket	Mineral wool	0.0125	650
Syl_GKP	0.12-0.15	Metal bracket with foamed polymer	Mineral wool	0.0125	650
Syl_Duotech	0.12-0.15	Metal bracket with foamed polymer	Mineral wool	0.025	650
ÖsA_GKP	0.17-0.20	Metal rod	Mineral wool	0.0125	650

Figure 3 shows the different used Hangers for suspending the substructure from the wooden framed ceiling. The most popular hanger is the shown Metal bracket. The mounting space of the hangers vary with panel density and hanger type and is regulated by the Austrian standard ÖNORM B3415. The distance from one hanger to another one is between 0.75 - 0.90 m.



**Figure 3.** Hanger Types, (a) Metal bracket, (b) Metal bracket with foamed polymer, (c) Metal rod

## 2.2. Measurement Methods

The normalized impact sound levels  $L_n$  of the ceiling constructions were measured in accordance with ÖNORM EN ISO 16283-2 with a handheld sound analyzer of the type „Norsonic 140". The ceiling was excited by a tapping machine. The sound pressure levels  $L_i$  in the receiving rooms were measured with a 1/2" condenser microphone. Before the measurement, the measuring chain was calibrated with a calibrated test sound source of the type "Norsonic Type 1251". The spatial averaging of the sound pressure level was carried out by a sequential measurement of 4 measuring positions (averaging time 20s each) per excitation position. 4 different tapping machine positions were used.

$$L'_n = L_i - 10 \lg \frac{A}{A_0}$$

For the measurement of the reverberation time and the equivalent absorption area  $A_0$ , the air volume in the receiving room was excited by a sound pulse. The average value of the reverberation time was carried out over 3 decays at 3 different measuring positions. All measurements were made with terz filters in the frequency range from 50 Hz to 5000 Hz. The determination of the frequency-dependent reductions of the impact sound level  $\Delta L'_n$  by the suspended ceilings were carried out by calculation of the difference between the measured impact sound level of the raw ceiling  $L'_{no}$  and the the measured impact sound level of the same raw ceiling with mounted suspended ceiling  $L'_n$ .

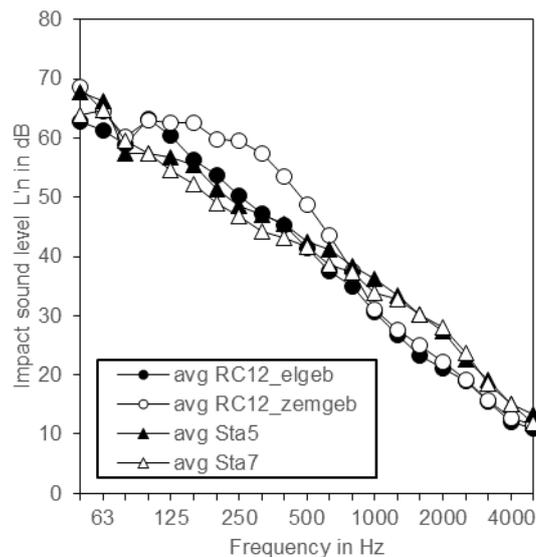
$$\Delta L'_n = L'_{no} - L'_n$$

### 3. Results

The results of the different building phases of the refurbishment process raw ceiling, applied screed and mounted suspended are presented by the measured impact sound levels in the following sections.

#### 3.1. Floating Screeds – Influence of grit binding and resilient layer material

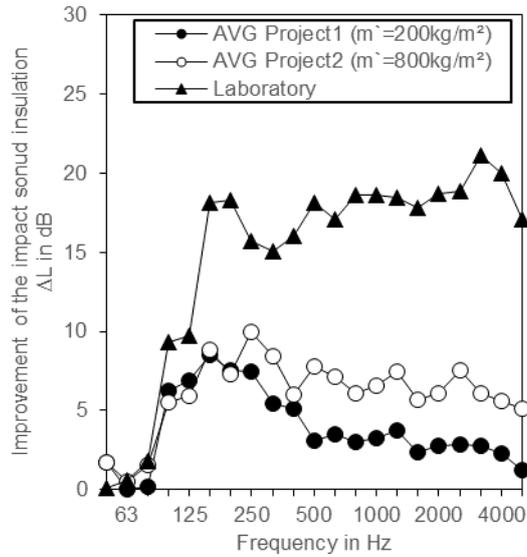
Different floating screeds were applied to the raw ceilings described in section 2.1.2. The measured frequency-dependent normalized impact sound levels of the floating screeds with wooden frame ceiling described in Table 1 are shown in Figure 4. It can be seen that the variants with recycled foamed polymers as resilient layer have a higher mass-spring-mass resonance (approx. 100Hz) than the variants with mineral wool (approx. 63Hz). This is due to the higher dynamic stiffness of the foamed polymer material. From 800Hz up to 5000Hz the higher internal losses in the recycled foamed polymer resilient layer reduces the normalized impact sound level up to 5dB. The elastic binding of the grit in the variant "RC12\_eleb" shows a significant improvement in the impact sound level in the range 100-500 Hz. Due to the higher internal losses and the reduced effect of the grit as a plate, improvements of up to 10dB can be achieved in individual terz bands. The difference of the slightly lower mass-spring-mass resonance, caused by the difference in thickness, of between the variants "Sta5" and "Sta7" are slightly recognizable in the 63Hz third band.



**Figure 4.** Comparison of measured frequency dependent impact sound levels of different wooden framed ceilings with floating screeds

#### 3.2. Suspended ceilings - Influence of flanking transmission

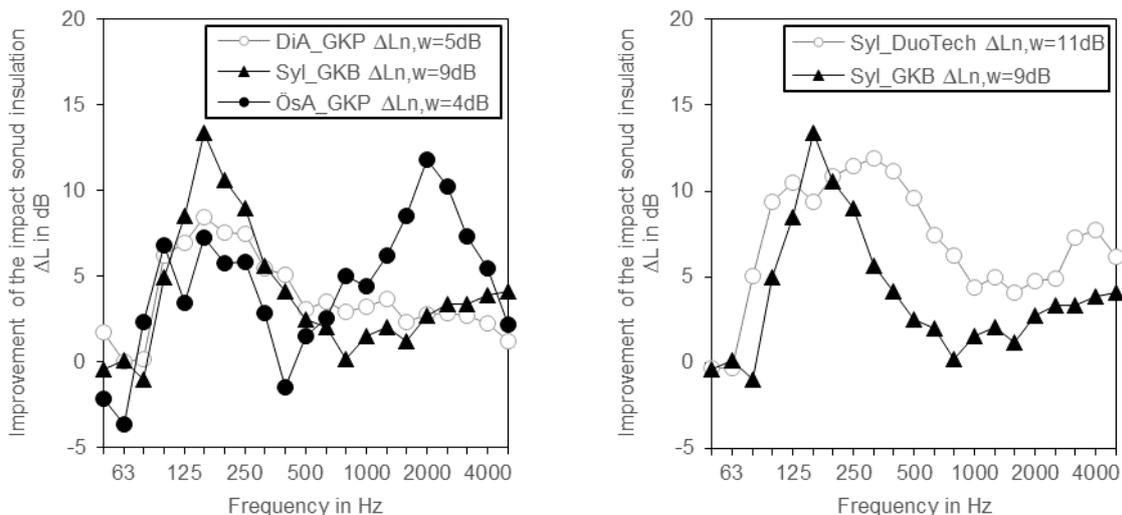
Figure 5 shows the improvement of the impact sound insulation of the same suspended ceilings with different flanking situations. It can be seen, that the improvement is highly influenced by the flanking transmission. Especially in the frequency range above 315Hz the improvement of the impact sound insulation differs with the area mass of the flanking walls. Due to the flanking transmission, an objective assessment of the frequency-dependent trends of the improvement of the impact sound insulation  $\Delta L_n$  is only between 50Hz and 315Hz possible. Above 315Hz, the impact sound level is significantly influenced by the flanking transmission. A comparison of the measurement data over 315Hz is only possible if the flank transmission can be neglected (laboratory situation, very heavy weight flanking walls).



**Figure 5.** Frequency depended improvement of the impact sound level of the suspended ceilings – Influence of the Area weight of the flanking walls on the flanking transmission

### 3.3. Suspended ceilings - Influence of hanger type and panel density

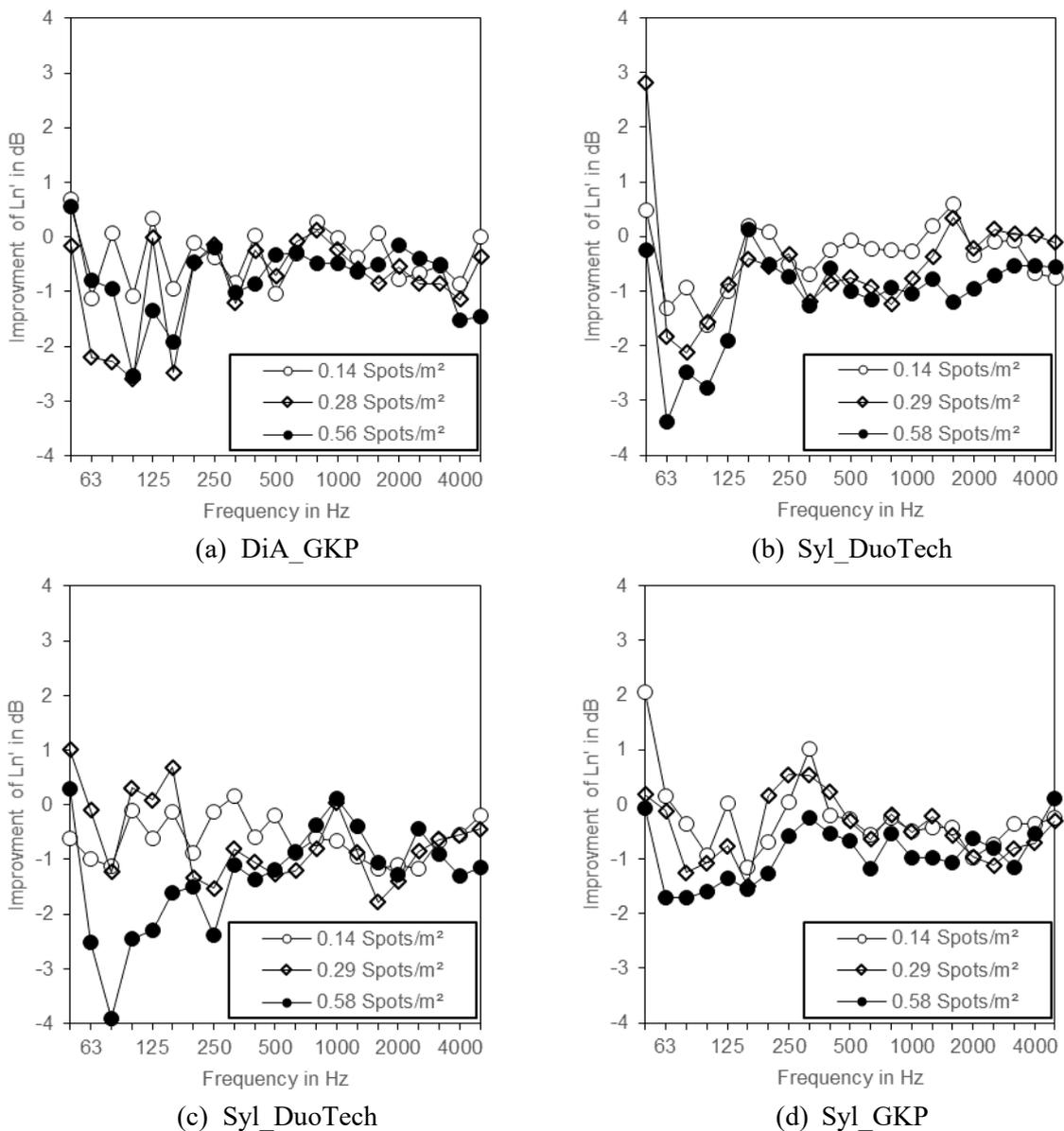
The investigated suspended ceiling differs in panel density and hanger Type. Figure 6 shows the influence of the hanger type. In Figure 6 it can be seen that the hanger with the lower stiffness causes a lower mass-spring-mass resonance frequency of the ceiling system (DiA\_GKP 80 Hz, Syl\_GKB 80 Hz, ÖsA\_GKP 63 Hz). Due to the higher damping in the suspension system of the variant Syl\_GKB, improvements of up to 6 dB compared to the other variants can be achieved. Due to the exclusive damping by the metal rod, the variant ÖsA\_GKB shows the deepest drop at its mass-spring-mass resonance frequency of the improvement of the impact sound insulation. The variant “ÖsA\_GKP” shows also a very significant dip of the improvement at 500 Hz. This may be caused in a resonance phenomenon in the suspension system. Figure 6 shows that raising the thickness of the panel from 12.5 mm to 25 mm reduces the mass spring mass resonance frequency from 80 Hz to 50 Hz. This results in a higher improvement of the impact sound insulation above 63 Hz up to 5 dB.



**Figure 6.** Frequency depended improvement of the impact sound level of the suspended ceilings – (left) Influence of the different Types of hangers, (right) –Influence of different panel thicknesses

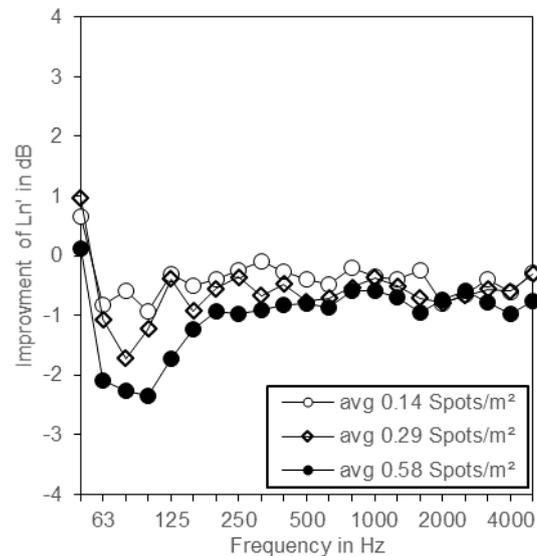
### 3.4. Influence of openings

The influence of openings on the improvement of the impact sound insulation is shown in Figure 7. In the reliably assessed frequency range between 50 and 315 Hz (see section 3.2), deteriorations can be observed depending on the number of openings of up to 4 dB per terzband. It can be seen that with better quality (b) and (c) ( $\Delta L_{n,w} = 9-11$  dB) and thus higher improvement of the impact sound insulation of the suspended ceiling, the influence is 1-3 dB higher than with suspended ceilings with worse quality (a) and (d) ( $\Delta L_{n,w} = 4-6$  dB). Especially in the low frequency range of 50-125 Hz, the measured deteriorations are to be considered as particularly critical for wooden framed ceilings, since these have a high impact sound level in this frequency range and the improvement of the impact sound insulation by the suspended ceiling is significantly reduced.



**Figure 7.** Difference in the normalized impact sound level between with and without openings – Influence of the number of openings per  $m^2$

The average over all suspended ceilings in Figure 8 shows the significant influence of the overall open Area in the suspended ceiling on the improvement of the impact sound level by the suspended ceiling.



**Figure 8.** Difference between the averaged normalized impact sound level of the different suspended ceilings with and without openings – Influence of the number of openings per m<sup>2</sup>

#### 4. Conclusion

The presented results show the influence of different parameters of floating screeds and suspended ceilings on the impact sound level of refurbished Wilhelminian style house ceiling systems. For floating screeds, it has been shown that low mass-spring-mass resonance frequency and high internal damping in the bulk material and resilient layer enable frequency-dependent improvements of up to 10dB. In the case of suspended ceilings, a low mass-spring-mass resonance is very important. This can be achieved by a low stiffness of the hanger system and a heavy planking. As a result, differences of up to 5dB can be achieved in the normalized single number rated impact sound level. It has been shown that the individual flanking situation on the construction site limits the effect of the measures to attenuate the direct transmission path on the reduction of the impact sound level especially above 315Hz. It could be shown that openings in suspended ceilings have a negative influence on the impact sound level of the investigated ceilings. Frequency-dependent deteriorations could be measured depending on the number of openings of up to 4dB between 50-250 Hz. This shows that in critical or particularly high requirements situations, these openings in suspended ceilings should be considered in the planning phase.

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