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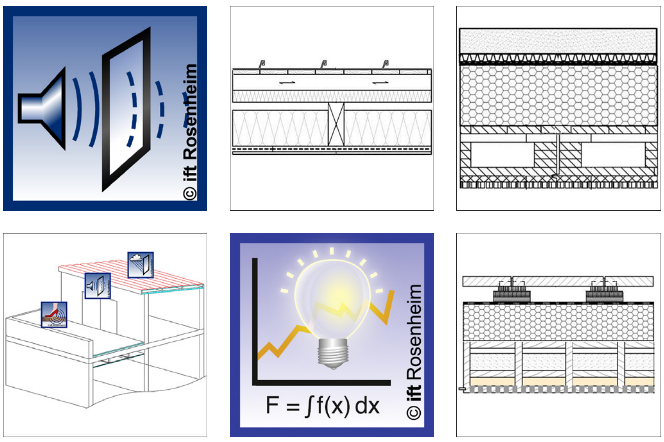
Short Report
July 2019

Sound insulation of flat roofs in timber constructions

Airborne and impact sound insulation of flat roofs and roof terraces



Short Report

Topic	**Sound insulation of flat roofs in timber construction - Air-borne and impact sound insulation of flat roofs and roof terraces**
Short title	Sound insulation of flat roofs in timber construction
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1 Motivation and Project Goal

In the planning of modern office and residential buildings, a flat roof or a slightly sloped roof for the attic storey is usually planned, especially in the area of multi-storey buildings. In order to meet the requirements of thermal insulation, statics, fire protection and sound insulation, these roof constructions must meet a whole range of criteria. Also in the area of sound insulation, the requirements vary depending on the design and use of the roof element as a pure roof element or as a walkable roof terrace.

A lack of planning data makes it difficult, especially for small and medium-sized companies, which include many timber construction companies, to enter the multi-storey timber construction market, which is not only advantageous from an ecological point of view. Beside the well-known points of the favourable CO_2 balance and the good thermal insulation of usual wood constructions, the building method is usually classified by the owner also optically and in relation to the living comfort positively. These positive aspects of timber construction should not be relativised by increased airborne and impact sound transmission through flat roofs, roof terraces and loggias.

Planning data, in particular for constructions in timber construction, which correspond to the building acoustic requirements, are only available to a very limited extent. Thus, only three constructions for light flat roofs were taken into account in the new DIN 4109. Suitable constructions for roof terraces and loggias, as well as constructions with solid wood elements are completely missing.

The objective of the project is therefore to provide planning documents for various construction variants of flat roofs and slightly sloped roofs, which in particular meet the requirements for sound insulation and other performance characteristics such as thermal and moisture insulation.

2 Procedure

In order to achieve the project objective, roof structures were first defined in close consultation with the project working group, which could meet the requirements for sound insulation and other performance characteristics such as thermal and moisture insulation.

The building acoustic examination of the specified superstructures resulted in pleasingly good values and planning data for the airborne and impact sound insulation, which are now available as a template for the revision of the component catalogue of DIN 4109-33 and have already found their way into various publications. In addition to the empirical investigations of the roof elements, the existing prognosis models were also compiled and further developed in order to be able to both predict unchecked construction variants and make statements about the expected rain noises of the roof structures.

On the basis of the measurement results for airborne and impact sound insulation, the influence of individual component layers could also be analysed. These include the decoupling of the roof terrace structure by construction bearings, the decoupling of the suspended ceiling by spring rails or hangers and the damping of the metal covering by bituminous separating layers.

In addition to decoupling, additional masses were investigated in the form of chippings in the element or gravel on the flat roof insulation. Weights were also applied below the roof terrace construction with plank flooring.

The results of these investigations are summarised in Section 3.

3 Results

The investigations were carried out on practical roof superstructures in order to be able to describe the influencing factors on the sound insulation of flat roofs and slightly sloped roofs and to provide planning documents for suitable constructions. In the following these constructive influences are listed and their influence on the sound insulation is shown.

3.1 Constructive influences

In order to investigate the constructive influences, first the most common roof constructions with their variants were recorded. Based on these constructions, a test matrix was created in close coordination with the project partners, which takes the following component variants into account:

- Roof types: Flat roofs, roof terraces, slightly inclined roofs
- Element types: beams/rafter elements, solid wood elements, ribbed or box elements
- Insulation: insulation on rafters, insulation between rafters
- Insulation type: EPS, PUR, wood fibre, vacuum panels
- Covering: waterproofing membrane, sheet metal roof, green roof, gravel roof, concrete plates, floorboards

Through comparative measurements, the improvement of the airborne and impact sound insulation for the various constructions could be determined. In the following these are shown for the basic construction and different roof constructions.

3.2 Roof constructions

Visible supporting structures can be realised with visible rafter roofs, roof elements made of solid wood elements (cross laminated timber, glulam, board stacking elements) or ribbed and box elements. These monocoque basic constructions require additional masses in the form of weighting in or on the element for high-quality acoustic designs. Alternatively, the air and impact sound insulation can be improved by a (decoupled) suspended ceiling. Construction and design variants are shown in Figure 1.

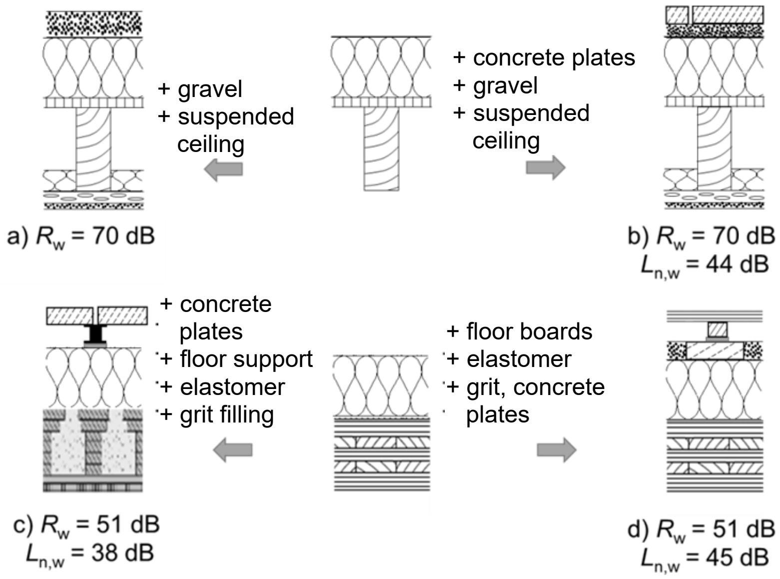


Figure 1 Flat roofs made of raftered or solid wood elements with different roofing materials. Constructions:
a) 50 mm gravel, suspended ceiling with spring rails, 12.5 mm GKF and 40 mm insulating material
b) 40 mm concrete plates, 30 mm gravel, suspended ceiling with spring rails, 12.5 mm GKF and 40 mm insulating material
c) 40 mm concrete plates, > 40 mm floor support, 12 mm elastomer bearing, grit filling in the element
d) 26 mm planks, 44 mm squared timber, 12 mm building store, 40 mm chippings and concrete plates (under elastomer bearing)

Solid wood elements are also used as acoustic elements. In order to check to what extent the acoustic perforation has an influence on the sound insulation of the roof element, a direct comparison was carried out with otherwise the same structure (see Figure 2). The results show a good agreement.

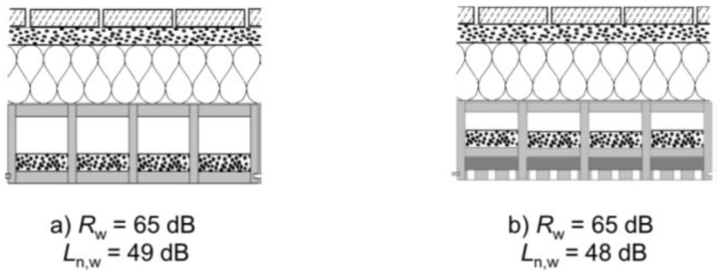


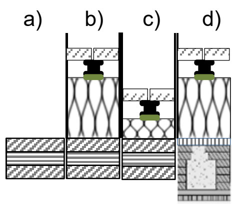
Figure 2 Flat roofs made of solid wood box elements, EPS on-roof insulation, roof sealing and concrete plates in the gravel bed:
a) Box element with 50 kg/m² grit filling
b) Acoustic element with 50 kg/m² grit filling

3.3 Insulation materials

Insulation materials between the rafters and in the suspended ceiling have a sound-absorbing effect by converting sound energy into heat energy through friction on and between the insulation fibres. This requires an open-cell structure of the insulation material which on the one hand allows the sound pressure wave to penetrate and on the other hand provides sufficient resistance. A good sound-absorbing effect is achieved with insulating materials whose length-related flow resistance r lies between 5 kPa s/m² and 50 kPa s/m². This can be achieved both with fibre insulating materials made from renewable raw materials and with conventional insulating materials. Closed-cell insulation boards (e.g. rigid foam boards) are not suitable.

In addition to their absorbing effect, pressure-loaded on-roof insulation also has the function of decoupling. In the case of pitched roofs, fibre insulation boards are often used for this purpose in roof constructions with sound insulation requirements. This is also possible for flat pitched roofs with sheet metal cladding. In the case of flat roofs, rigid foam insulation boards are usually used due to the higher load. Due to their high stiffness, low bulk density and lack of absorption, these initially behave unfavourably. As Figure 3 shows, the weighted sound insulation index R_w of the structure b) with 200 mm EPS on-roof insulation (R_w = 38 dB) hardly differs from the basic element (structure a) with R_w = 37 dB. The EPS on-roof insulation thus has no improving effect on the single value.

Even depending on the frequency, an improvement compared to the basic element can only be detected above 500 Hz. This is particularly evident here, as the concrete plates, mounted with installation joints on the stilted bearings, do not make any contribution to airborne sound. The same applies to the version with vacuum panels, which are often used for barrier-free exits to the roof terrace. A significant improvement can only be achieved by weighting the roof element, as was done in structure d) by filling the ribbed element with grit. The additional mass dampens the element and shifts the resonance of the insulation panels to lower frequencies (from 250 Hz to 125 Hz).



a) 140 mm cross laminated timber element, m' = 68 kg/m²

b) concrete plates on stilted bearings
200 mm EPS on-roof insulation
140 mm Cross laminated timber element

c) concrete plates on stilted bearings
58 mm Vacuum insulation slab
140 mm Cross laminated timber element

d) concrete plates on stilted bearings
200 mm EPS on-roof insulation
196 mm ribbed element with chippings, m' = 145 kg/m²

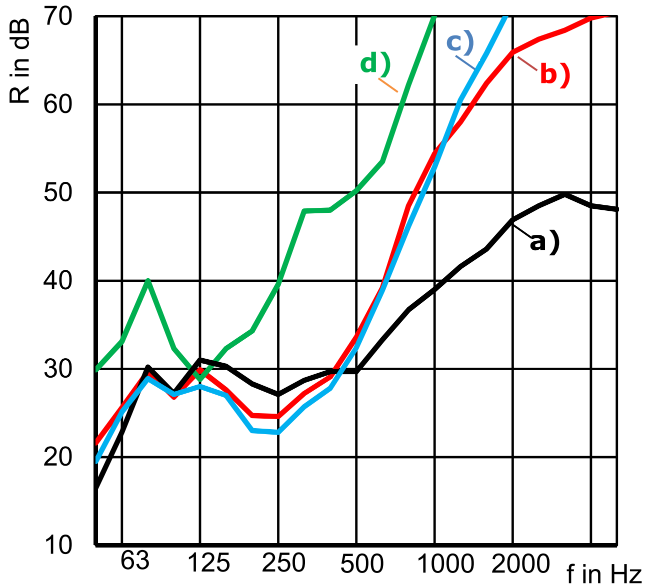


Figure 3 Influence of on-roof insulation on the sound insulation of flat-roof constructions. The construction above the insulation board (here: 40 mm concrete slabs, support bearings, construction bearings, roof sealing) is not decisive for the airborne sound transmission due to the joints between the concrete slabs.
a) Bare roof element, R_w = 37 dB
b) Roof element with 200 mm EPS and concrete plates on stilted bearings, R_w = 38 dB
c) Roof element with 58 mm vacuum panel and concrete plates on stilted bearings, R_w = 37 dB
d) Roof element with split weight in the element, 200 mm EPS and concrete plates on stilted bearings, R_w = 51 dB

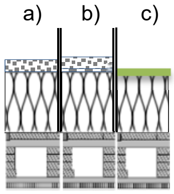
3.4 Waterproofing, roofing and walking surface

The construction above the insulation level is varied depending on the use. For flat roofs that cannot be walked on, gravel fills, extensive greening or roof sealing membranes are used. As expected, the use of roof waterproofing membranes without additional materials results in lower sound insulation values (see Figure 4c).

However, previous comparative measurements have also shown significantly lower sound insulation values for roof structures with extensive green roofs than for roof structures with gravel layers of the same area-related mass (see Figure 4a). The cause can be mentioned here as the influence of the drainage layer in combination with a protection fleece, which causes a reduction in sound insulation in the frequency range from 125 Hz to 2000 Hz.

Figure 5 shows a direct comparison for a roof terrace construction with and without a protection fleece. While in the impact sound passage the additional decoupling causes an improvement ($\Delta L = L_{n,\ \text{without fleece}} - L_{n,\ \text{with fleece}}$), for the airborne sound insulation the same deterioration ($\Delta R = R_{\text{with fleece}} - R_{\text{without fleece}}$) is apparent. Here there is still a need for investigation with regard to the building acoustic effects of the usual drainage, storage and protective layers.

a) b) c)



a) 50 mm gravel, roof sealing

b) 80 mm fill (green roof)
25 mm Drain plate
5 mm protection fleece
roof sealing

(c) roof waterproofing membrane

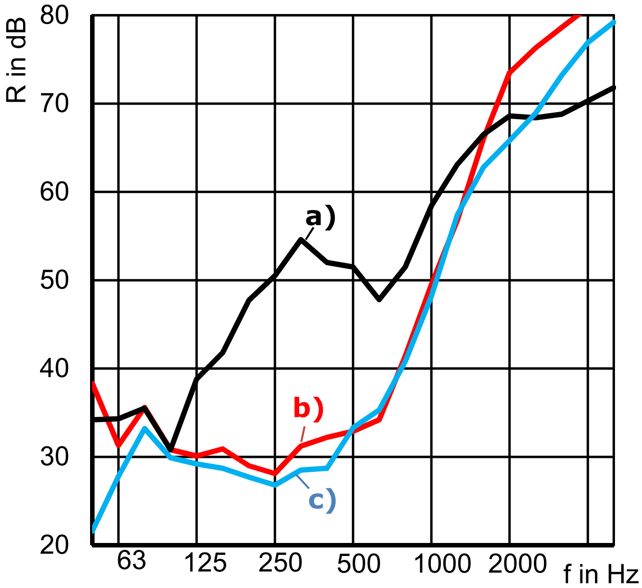
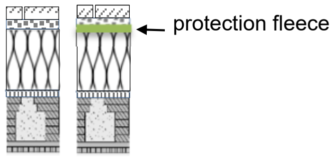
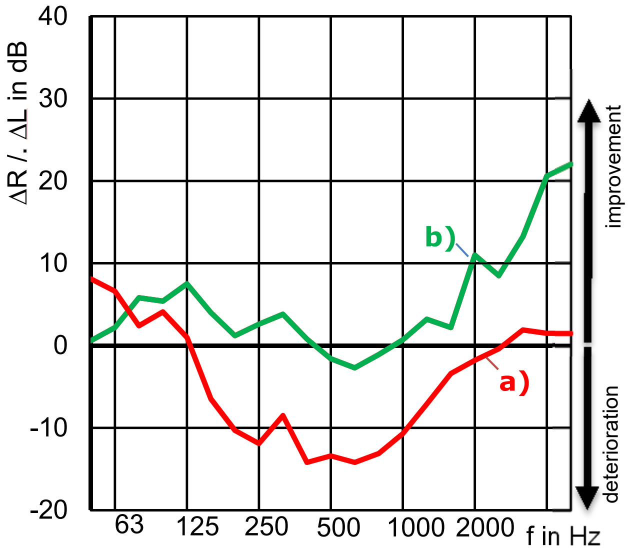


Figure 4 Comparison of the constructions: Gravel roof, green roof and simple waterproofing membrane on a cross laminated timber - box element with 200 mm EPS on-roof insulation
a) Gravel roof, R_w = 55 dB
b) Green roof, R_w = 39 dB
c) Roof waterproofing, R_w = 38 dB

Accessible roofs which are used as roof terraces can be constructed with concrete plates in a grit bed, plates on stilts or a wooden grid (floor boards on wooden beams). While the concrete plates in the grit bed are effective due to their surface-related mass, in the case of stilted bearings and wooden gratings an additional reduction in transmission can be achieved by means of decoupling measures (elastic storage on elastomer).

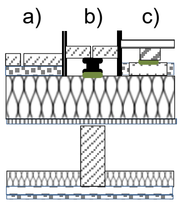
For this purpose, the decoupling material is designed by the manufacturer for a suitable eigenfrequency of the construction. Good decoupling is to be expected for eigenfrequencies f_0 = 20 to 30 Hz. In order to achieve the lowest possible deflection, the eigenfrequency of the tested structure was designed for f_0 < 60 Hz.

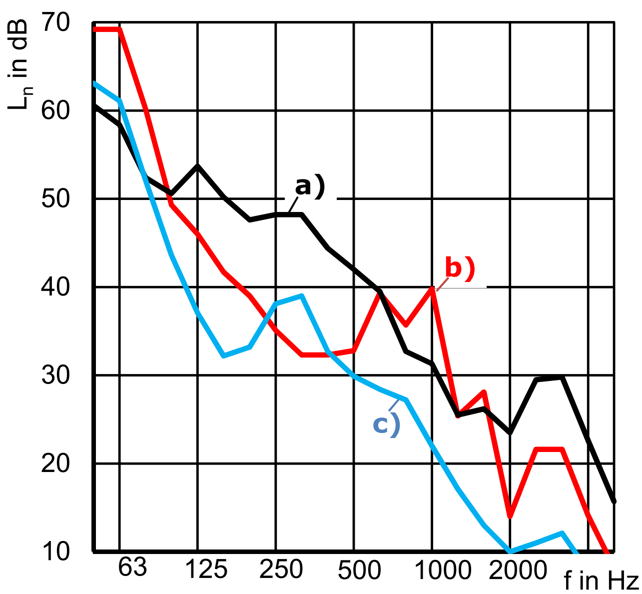




	concrete plates, grit
5mm	protection fleece
	roof sealing
200 mm	EPS on-roof insulation
196 mm	ribbed element with grit

Figure 5 Improvement of airborne and impact sound insulation by means of a protection fleece from the direct comparison measurement with and without a protection fleece
a) Difference airborne sound insulation ΔR with and without protection fleece
b) Impact sound reduction ΔL by the protection fleece





a)	40 mm	concrete plates
	30 mm	grit
b)	40 mm	concrete plates
	40 mm	stilted bearings
	12.5 mm	elastomer
(c)	26 mm	floor boards
	44 mm	slatted frame
	12.5 mm	elastomer layer
	40 mm	grit and concrete plates (under elastomer)

Figure 6 Standard impact sound level of different constructions on a rafter / beam element with suspended ceiling and 140 mm EPS on-roof insulation panels
a) Concrete plates in a grit bed, $L_{n,w}$ = 44 dB
b) concrete plates on stilted bearings, elastomer layer, $L_{n,w}$ = 38 dB
c) planks on slatted frame, elastomer layer, additional mass by grit, $L_{n,w}$ = 31 dB

4 Acknowledgment

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