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Rain Sound Insulation of Timber Roofs — Influence of Roof Cladding, PV Panels and Roof Windows

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Abstract

Laboratory measurements in accordance with EN ISO 10140-5:2021 are used to analyse the rain sound insulation of timber roof constructions with varying structural configurations. Rain induced sound intensity levels are examined for exposed-rafter roofs and timber frame roofs with aluminium sheet, zinc sheet, and two types of tile cladding (sliding tiles and beaver-tail tiles). The influence of additional underlays beneath the metal cladding — a bituminous membrane and a structured mat — is investigated. The effects of PV elements on tile- and aluminium-sheet-clad roofs are also examined, as is the influence of a roof window with and without a roller blind.

Keywords: Rain sound insulation, metal roof cladding, roof tiles, roof window, PV panels

1. Introduction

This paper presents a parameter study on the rain sound insulation of timber roof constructions, extending the investigations reported in [1,2]. Two objectives are pursued: first, to analyse the influence of structural variations on the airborne and rain sound insulation of the roofs; second, to record stimuli in the test stand for subsequent listening tests in the perception room of TGM. The listening tests aim to support the development of perceptually appropriate descriptors for describing and classifying rain sound insulation. All investigations were carried out within the research project "Schutz.aufs.Dach II".

2. Material and Methods

All measurements were carried out in the XL test stand of Akustik Center Austria [3]. The rain sound measurements followed EN ISO 10140-1:2021 Annex K [4] using “heavy rain” and the airborne sound measurements followed EN ISO 10140-2:2021 [5]. The source room volume was approximately 140 m³, the receiving room approximately 150 m³. Figure 1 shows a general description of the test stand in accordance with the standard and an interior view of the rain test stand at Akustik Center Austria. A detailed description of the test stand is given in [1,2]. Measurements were evaluated between 25 Hz and 5000 Hz to allow comparison of component behaviour also below 50 Hz.

For use in the listening tests, rain noise levels were additionally recorded using an Ambisonics measurement system with a reduced reverberation time in the receiving room.
Figure 2 shows the roof assemblies investigated. In addition to the exposed-rafter and timber frame roofs discussed below, warm roof constructions with cross-laminated timber (CLT) as the structural element were also investigated within the project.
The following component layers were varied in the present parameter study:

- Roof cladding (aluminium sheet, zinc sheet, Tile 1 and Tile 2, see Figure 3)
- Over rafter-insulation (mineral wool, 60 mm, 120 mm)
- Roof decking (with/without)
- Underlay beneath metal cladding (bituminous membrane, structured mat, see [2])

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For the warm roof-insulated and above rafter-insulated variants, counter battens were always fastened using dual-thread screws to minimise contact pressure on the insulation. As stated in [6,7], this significantly improves the airborne sound insulation of the roofs.

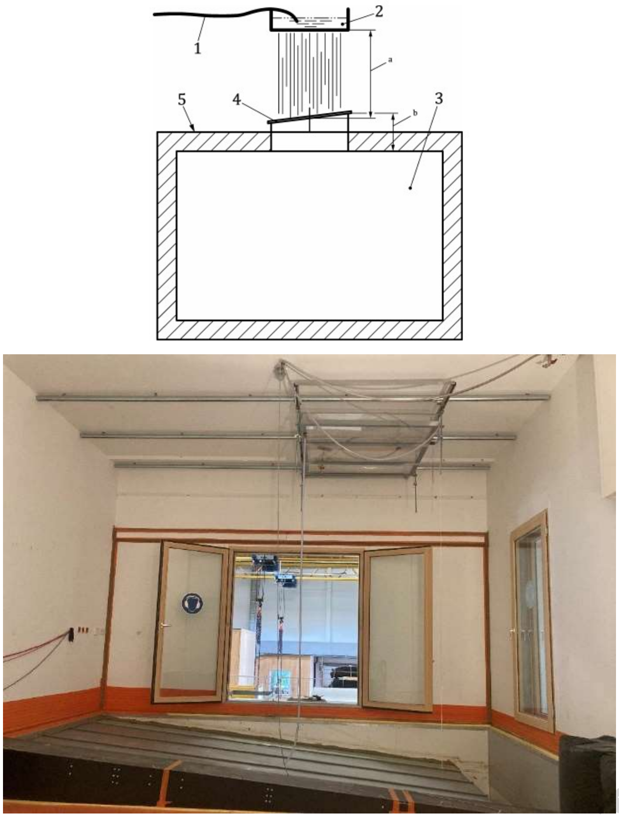

Figure 1: Top: Specification for the rain sound insulation test according to EN ISO 10140-5. 1.: Water supply system 2.: Tank with a perforated bottom 3.: Test Room 4.: Test specimen 5.: Water drainage; Bottom: Interior view of the rain test stand (sending room) at Akustik Center Austria

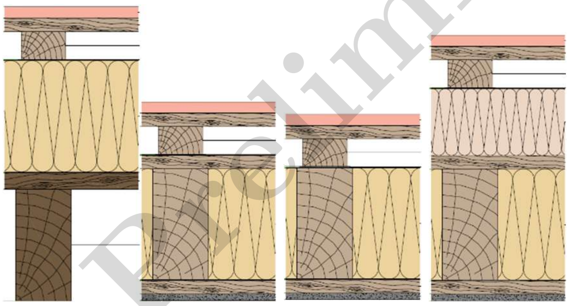

Figure 2: Roof assemblies investigated, from left to right: exposed-rafter roof with warm roof insulation, timber frame roofs with/without roof decking, timber frame roof with over rafter-insulation; specimen size (2.35 x 4.71) m²

Figure 3: Roof claddings investigated, from left to right: aluminium sheet, zinc sheet, tile 1 (sliding tile), tile 2 (beaver-tail tile)

In addition to the component layer variations, a timber frame roof with an integrated roof window and roller blind was investigated. To isolate the influence of the roof window frame, a variant with the frame area covered by soft insulation was also tested (Figure 4). In all roof window measurements, only the window itself was directly exposed to simulated rain; the tile cladding was not.

Figure 4: Roof window in the test stand — left: roller blind open; center: roller blind closed; right: frame area covered with soft insulation material

To investigate the influence of PV elements, the elements were mounted on the aluminium sheet and tile cladding, respectively, using appropriate substructures (Figure 5). Each PV element was supported on two rails.

The material properties of all components are listed in Table 1.

Figure 5: PV substructure — left: on aluminium sheet cladding; right: on tile cladding

Table 1: Component layers and material properties, listed from the underside of the roof upwards. MF: mineral fiber; e: center-to-center spacing; ρ: bulk density; m': surface mass; s': dynamic stiffness

Component layer	Properties
12,5 mm gypsum plasterboard (suspended ceiling)	m‘ = 9.1 kg/m²
(23 x 74) mm² sparse batten	e = 400 mm
(200 x 100) mm² rafter	e = 765 mm
200 mm MF between-rafter insulation	ρ = 21.3 kg/m³, s‘ = -- MN/m³
23 mm roof decking	m‘ = 10.7 kg/m²

200 mm MF warm roof insulation	ρ = 97 kg/m³, s‘ = 4 MN/m³
60 mm/120 mm MF above-rafter insulation	ρ = 67/93 kg/m³, s‘ = 9/4 MN/m³
(50 x 80) mm² counter batten	e = 765 mm
(30 x 50) mm² batten	e = 315 mm
2.9 mm bituminous membrane	m’ = 3.5 kg/m²
10 mm structured mat	m’ = 0.2 kg/m²
1 mm aluminium sheet	m’ = 2.1 kg/m²
1 mm zinc sheet	m’ = 5.7 kg/m²
Tile 1: sliding tile	m’ ~ 47 kg/m²
Tile 2: beaver-tail tile (double layered)	m’ ~ 63 kg/m²
(1220 x 1390) mm² roof window	Glass Makeup: 6.4 mm LSG / 12.7 mm Air / 3 mm Float
(1134 x 1724) mm² PV elements	m’ = 10.4 kg/m²

3. Results and Discussion

Rain sound intensity levels for all roof variants discussed above are presented below. In each figure, vertical dashed lines mark two frequency ranges: the rating range for the single-number rating L_{IA} (A-weighted sound intensity level, 100 Hz to 5000 Hz), and the very low frequency range from 25 Hz to 50 Hz, where measurement uncertainty may be increased. The latter range is highlighted in grey. L_{IA} values are given in the figure legends.

3.1 Overview of all measurements

Figure 6 shows the sound reduction indices (left) and rain-induced sound intensity levels (right) for all roof variants measured in the project. The selected variants cover a broad spectrum of frequency responses, providing a suitable range of stimuli for the subsequent listening tests.

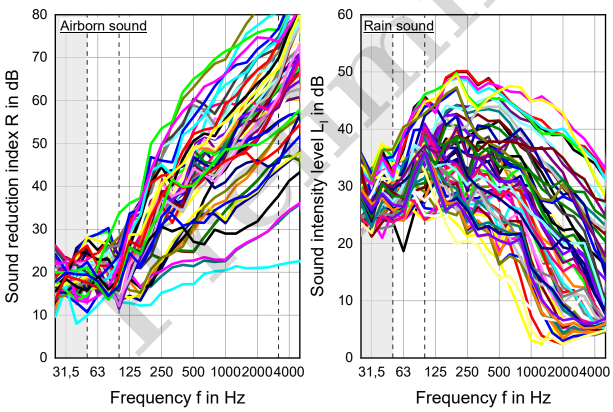

Figure 6: Sound reduction indices (left) and rain-induced sound intensity levels (right) for all roofs measured in the project. The broad spread in frequency response required for the listening tests is achieved.

3.2 Influence of roof cladding

3.2.1 Aluminium sheet vs. roof tiles

Figure 7 shows the difference between aluminium sheet and tile cladding. The left graph corresponds to an exposed-rafter roof, the right graph to a timber frame roof. Sound intensity levels differ substantially between aluminium sheet and tile cladding in both cases. Differences between the two tile types are considerably smaller, particularly for the exposed-rafter roof. In both roof types, Tile 2 — with its higher surface mass and presumably higher airtightness (cf. [8]) — yields slightly lower sound intensity levels. The timber frame roof shows lower sound intensity levels than the exposed-rafter roof. Elevated levels are observed at 160 Hz for the exposed-rafter roof and at 100 Hz for the timber frame roof. As also noted in [2], these peaks coincide with dips in the sound reduction index (data not shown).

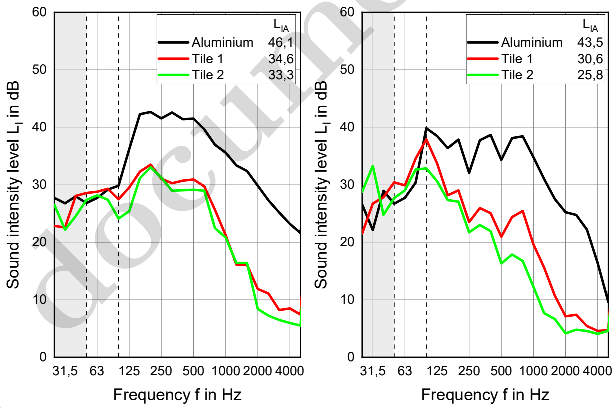

Figure 7: Influence of roof cladding — exposed-rafter roof (left), timber frame roof (right)

3.2.2 Aluminium sheet vs. zinc sheet without/with underlay

Figure 8 shows the influence of different metal claddings and underlays on an exposed-rafter roof with warm roof insulation. Adding a bituminous membrane directly beneath the aluminium sheet produces a pronounced reduction in sound intensity levels across the entire frequency range. The additional mass and damping of the bituminous membrane account for this effect. Zinc sheet cladding alone achieves slightly lower levels than aluminium sheet, owing to its greater mass and lower stiffness. Adding a structured mat beneath the zinc sheet increases levels slightly below 250 Hz but reduces them markedly above this frequency. This improvement is reflected in the L_{IA} value. In contrast, the investigations on a structured mat in [2] — tested on an exposed-rafter roof with EPS insulation and aluminium sheet — only yielded improvement above 1000 Hz. The more effective performance observed here for the zinc sheet variant suggests a favorable interaction between the structured mat and the zinc sheet. Adding a bituminous membrane beneath the structured mat produces a further level reduction across the full frequency range.

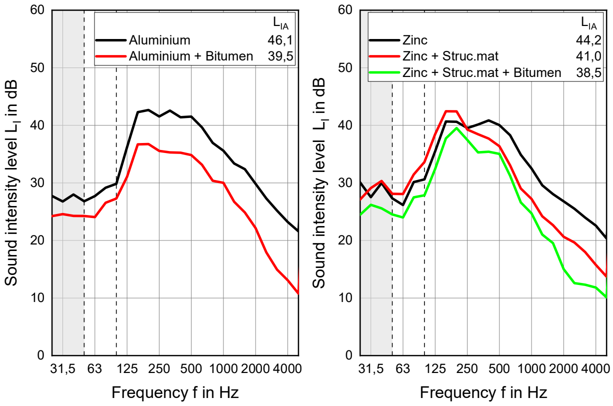

Figure 8.: Influence of metal roof claddings and underlays on an exposed-rafter roof with warm roof insulation made of mineral fiber — left: aluminium sheet without/with bituminous membrane; right: zinc sheet without/with structured mat and bituminous membrane

3.3 Influence of over rafter-insulation and roof decking

Figure 9 (left) shows the influence of over rafter-insulation on a timber frame roof with aluminium sheet cladding. Over rafter-insulation reduces the sound intensity level significantly from 125 Hz upwards. The thickness of the over rafter-insulation — 60 mm or 120 mm — has little effect on the result. This is also visible at the L_{IA} values in the legend. Structure-borne sound transmission through the soft over rafter-insulation layer is governed primarily by the fastening screws rather than the insulation material itself, which explains the insensitivity to thickness.

Figure 9 (right) shows the influence of the roof decking. Its removal increases sound intensity levels across the entire frequency range. The sound reduction index of the over-insulated roof, however, is barely affected by the presence or absence of decking (data not shown).

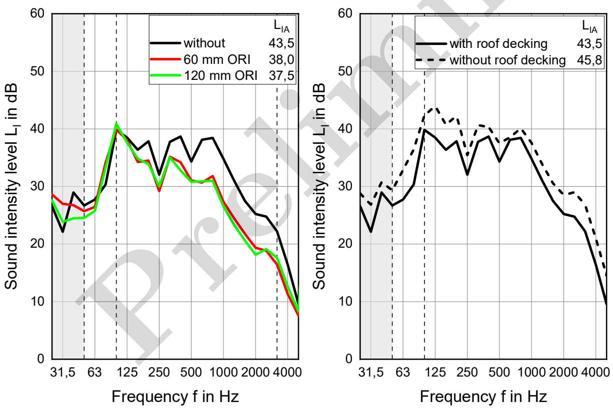

Figure 9: Timber frame roof with aluminium sheet cladding — left: influence of over rafter-insulation (ORI) made of mineral wool; right: influence of roof decking without over rafter-insulation

3.4 Influence of PV elements

Figure 10 shows the influence of PV elements on the rain sound insulation of a timber frame roof with aluminium sheet or tile cladding. For the aluminium-sheet-clad roof with bituminous membrane (left), PV elements increase the sound intensity level below 100 Hz. Above 100 Hz, the sound intensity levels are reduced. For the tile-clad roof (right), the low-frequency increase is considerably less pronounced, and only minor differences are observed above 100 Hz. The higher damping of the heavier tile cladding is considered responsible for this behavior.

The L_{IA} values in the legends show that the aluminium-sheet-clad roof with bituminous membrane and PV elements achieves a lower single-number rating than the tile-clad roof with PV elements. The pronounced low-frequency increase in the aluminium-sheet case is not captured by L_{IA}, as the rating range begins at 100 Hz.

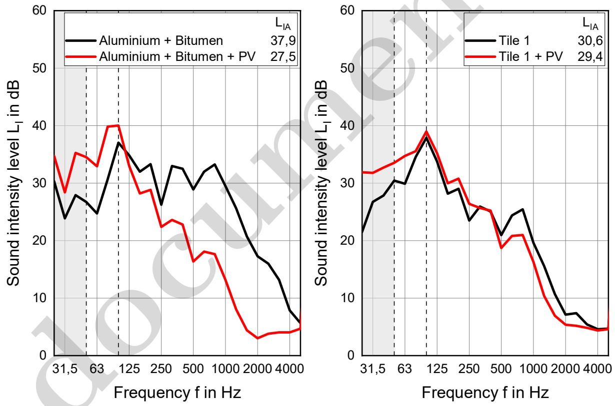

Figure 10: Influence of PV elements on a timber frame roof — left: aluminium sheet cladding plus bituminous membrane; right: tile cladding

3.5 Influence of a roof window

Figure 11 shows the influence of a roof window (RW) with and without a roller blind in a timber frame roof with tile cladding. The left graph compares the sound intensity levels of the undisturbed roof with those of the roof window — without and with the roller blind closed. The roof window produces substantially higher sound intensity levels than the undisturbed roof. Whether only the glazed area or also the frame was exposed to simulated rain had no measurable effect on the levels.

Closing the roller blind significantly reduces the sound intensity levels above 200 Hz. However, levels remain well above those of the undisturbed roof.

The right graph shows sound power levels calculated for a 24 m² roof comprising 20 m² of undisturbed roof area (timber frame roof with tile cladding) and 4 m² of roof window. Above 160 Hz, the total radiated sound power is almost entirely determined by the roof window. At lower frequencies, the contribution of the roof assembly remains marginally apparent.

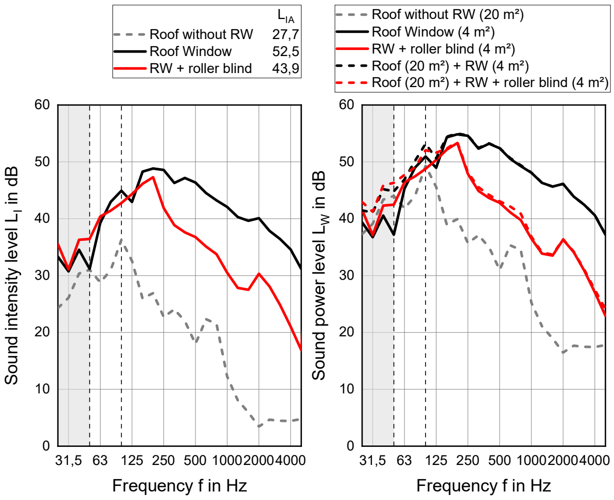

Figure 11: Influence of a roof window (RW) without and with closed roller blind on a timber frame roof with tile cladding — left: sound intensity levels; right: calculated sound power levels for 20 m² undisturbed roof area and 4 m² roof window

4. Conclusion

Rain sound measurements in accordance with EN ISO 10140-1:2021 Annex K [4] were carried out on a wide range of timber roof assemblies within the research project "Schutz.aufs.Dach II". The study investigated the influence of structural variants on rain sound insulation and recorded stimuli for subsequent listening tests. The key findings of the rain sound mesaurements are:

- the timber frame roof yields lower sound intensity levels than the exposed-rafter roof;
- aluminium sheet cladding yields higher sound intensity levels than tile cladding;
- differences in sound intensity level exist between the two tile types (sliding tile/ beaver-tail tile); the magnitude depends on the roof type;
- zinc sheet cladding yields lower sound intensity levels than aluminium sheet cladding;
- a bituminous membrane beneath the metal cladding substantially reduces sound intensity levels;
- a structured mat beneath zinc sheet cladding slightly increases sound intensity levels below 250 Hz and reduces them above;
- over rafter-insulation with mineral fiber significantly reduces sound intensity levels; insulation thickness has only a minor influence;
- the absence of roof decking (i.e. sarking membrane only) increases sound intensity levels across the entire frequency range;
- PV elements on an aluminium-sheet-clad, timber frame roof increase sound intensity levels below 100 Hz and reduce them above;
- PV elements on a tile-clad, timber frame roof slightly increase sound intensity levels at low frequencies; differences above 100 Hz are minor;
- a roof window produces substantially higher sound intensity levels than a timber frame roof with tile cladding;
- a roller blind reduces sound intensity levels of the roof window significantly above 200 Hz;
- for a roof combining 20 m² undisturbed area and 4 m² roof window, the radiated sound power above 160 Hz is almost entirely determined by the roof window.

Subsequent listening tests in the perception room of TGM will investigate the subjective perception of the sound intensity characteristics produced by the various structural configurations. Key objectives are the development of a perceptually appropriate descriptor and the classification of the rain sound insulation performance of roofs.

5. Acknowledgments

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