Acoustics'08
Paris
June 29-July 4, 2008
www.acoustics08-paris.org

Sound insulation of traditional roof constructions considering energy efficiency requirements

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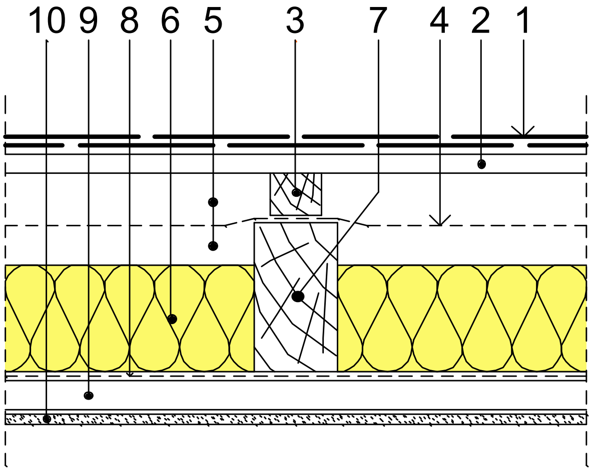
The efforts for energy efficiency result changes in building constructions, also in case of roof constructions. The most important constructional conclusion is the growth of the thickness of the heat insulating layer. Beside heat insulation, inner ventilation between the layers is the other important parameter, which has a great effect on sound insulation behaviour. In regular product information sheets, either in internet or in printed forms, the effect of this later parameter is often not present and this way these laboratory data do not show the reality.

For the purpose of modeling the reality, an installation method has been developed, which considers the effects of ventilation usually used in our climate conditions. This installation method has been realised and used in laboratory experiments. The results based on this installation method approach the reality better and reflect the acoustical importance of the certain constructional components.

1 Introduction

The theory that good heat insulation equals good sound insulation is basically incorrect but often appears in the practice of design and in the choice of construction. The correct approach is when the sound and heat insulating properties of building structures are considered without reference of each other.

The most used roof constructions in Hungary are light weighting constructions due to the price and the ease of implementation. The energy efficiency becomes ever important over the last years. The new energy directive EPDB (2002/91/EC) [1] (the Hungarian regulation has been introduced from 2006) gives the minimum requirements on the energy performance of new buildings which has constructional influence. The thickness of the heat insulating layer in roof constructions has grown from 10-12 to 20-25 cm. Beforehand the typical sizes of the rafters and other constructions allowed to build in one or even more ventilated air gaps, because the thickness of the heat insulation was less than the height of the rafters as shown in Figure 1.



,Fig.1 Horizontal section of former traditional roof constructions. 1: roof covering, 2: battens for roof tiles, 3: counter-batten, 4: vapour barrier foil, 5: ventilated air gap, 6: heat insulation, 7: rafter, 8: vapour barrier foil, 9: wooden framework, 10: gypsum board.

Just a few laboratory measurements were carried about the sound insulation of roof constructions, previous to the laboratory measurements a data acquisition was carried out to collect these data. The acoustical data in some product information sheets are not real, because some very important structural parameters for example ventilated air gap are not present. These data are not appropriate for further designing because they do not show the reality.

The examined structures were chosen with complex approach. The requirement for heat insulation, fire and vapour protection, and the economical and workmanship respects were regarded as well. The aim of the experiments was to determine the effect of the following structures on sound insulation: type and specific mass of roof covering, type and specific mass of gypsum boards in the inner side, ventilated air gap.

2 Laboratory measurements

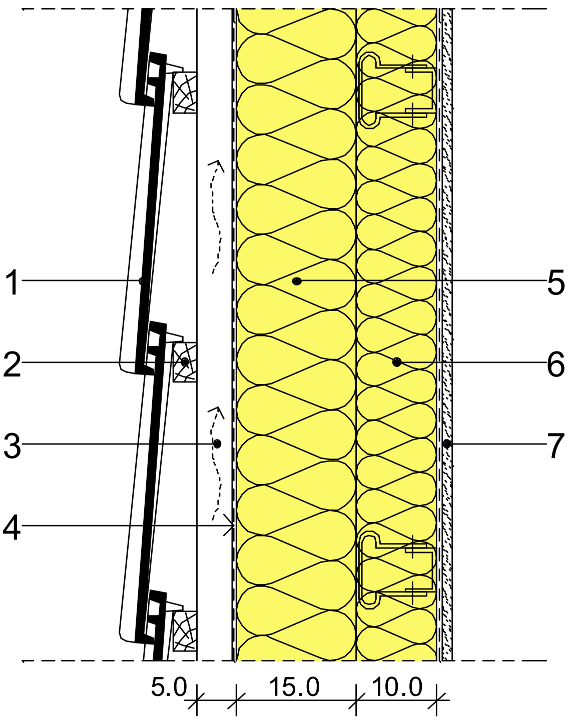
2.1 Building structures tested

Figure 2 shows the vertical section of the examined structures. The frame of the constructions was regular, the distance between the axis of rafters was approximately 80 cm. The roof covering was made of ceramic tiles. The constructions were built in almost vertically, in that position each roof tile must be fixed with bolts. Under the roof covering a ventilated air gap was installed with the height of 5 cm which is usual at our climate. Under the ventilated air gap a vapour permeable foil was formed. For heat insulation two glass wool layers were built in between and under the rafters with a thickness of 25 cm altogether (15 cm Ursa MTF glass wool between rafters and 10 cm Ursa Therwoo-Felt glass wool under the rafters with a vapour barrier foil in the inner side). The gypsum boards were mounted on UW studs that were fixed with resilient hangers. This solution assures more flexible connection than wooden framework. At the lower and upper side of the built in constructions a linear opening for ventilation was installed with the width of 2 cm.

The following constructional parameters were varied and thus 4 different constructions were examined:

- type of roof covering (overlapping: single or double, specific mass: 40 or 62 kg/m^2)
- type, thickness and number of layers of gypsum boards (type: fire resistant or normal, layers: 1 or 2, thickness: 12,5 or 15 mm, specific mass: from 9 to 20 kg/m^2)

The varied parameters of the different four constructions are listed up in Table 1.



,Fig.2 Vertical section of the examined structures. 1: ceramic roof covering (m”=40 or 62 kg/m^2; in the figure the type of overlapping is single), 2: battens for roof tiles, 3: ventilated air gap between counter-battens, 4: vapour permeable foil, 5: heat insulation between and under the rafters, with a vapour barrier foil in the inner side 7: gypsum board fixed with resilient hangers.

Parameters of roof constructions						
	Roof covering		Gypsum board			
nr.	over-lapping	m” (kg/m^2)	type	layers	thick-ness (mm)	m” (kg/m^2)
1	single	40	fire resistant	1	15	10
2	single	40	fire resistant	2	15	20
3	single	40	normal	1	12,5	9
4	double	62	normal	1	12,5	9

Table 1 Varied parameters of the examined four roof constructions

2.2 Measurement procedure

The measurements were carried out according to the standards ISO 140-3:1995 [2] and ISO 717-1:1996 [3].

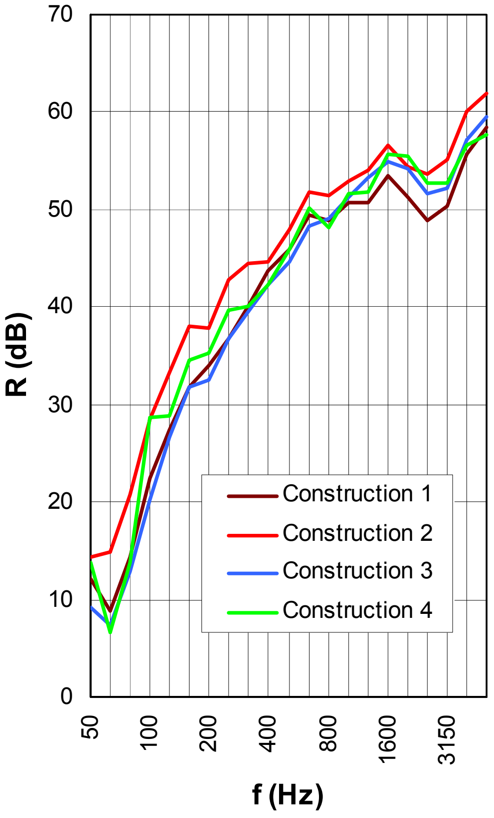
2.3 Results

The weighted sound reduction index and the spectrum adaptation term of the above specified constructions are listed up in Table 2.

The sound reduction index in 1/3 octave bands are shown in Table 2.

nr.	R_w (dB)	C_{tr} (dB)
1	47	-8
2	51	-6
3	47	-9
4	49	-7

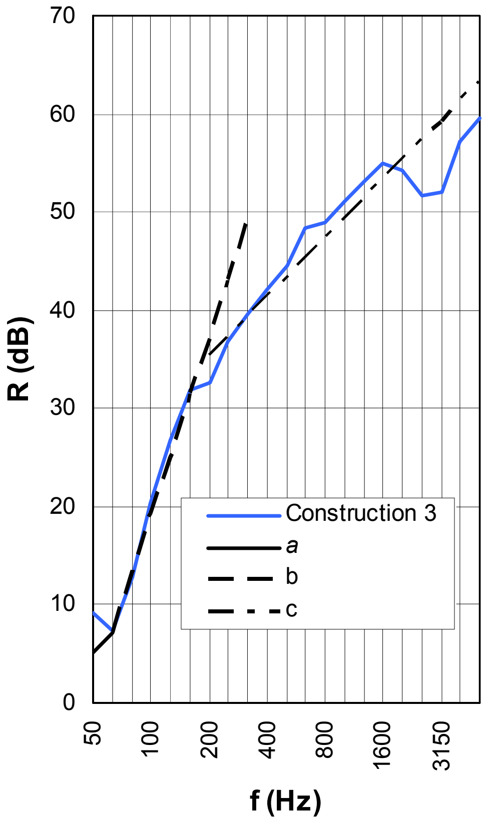
Table 2 Weighted sound reduction index and spectrum adaptation term of the measured roof constructions



,Fig.3 The sound reduction index in 1/3 octave bands of the measured roof constructions

For the analysis the structures can be considered as double-layered constructions. Their airborne sound insulation can be approximated using traditional theories being cited in [4]. For example Figure 4 shows the calculated and the measured sound reduction index of the examined

Construction 3. Under the resonance frequency the sound reduction is determined by the mass of the two layers. This section can be approximated with a curve of 6 dB/octave slope. In Figure 4 this section is marked with *a*. The resonance frequency was 62,8 Hz. Above the resonance frequency the sound reduction can be approximated with the sound insulation of the “ideal” two-layered structure. The second section can be approximated with a curve of 18 dB/octave slope. In Figure 4 this section is marked with *b*. The third section shows the properties of the “real” two-layered structure. This section can be approximated with a curve of 6 dB/octave slope up to about the coincidence frequency. This tendency is the result of several components: fixing of the layers and ventilated air gap, but the accurate physical content can not be determined from the results. In Figure 4 this third section is marked with *c*.

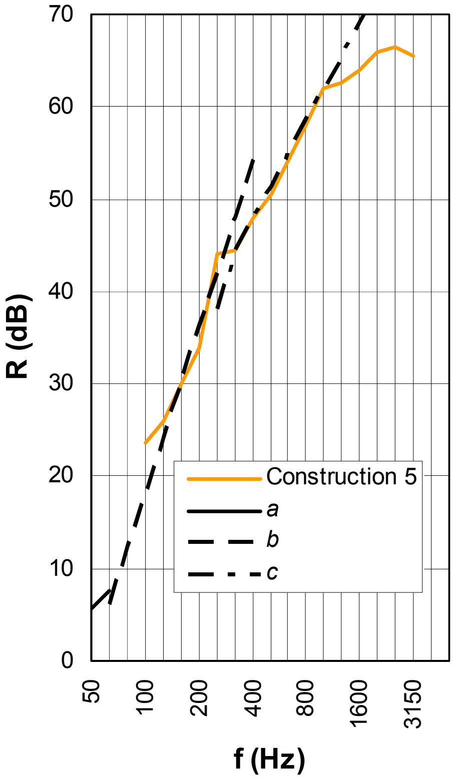


,Fig.4 Measured sound reduction index and the linear approximation of Construction 3

To understand better the characteristic sections of the air-borne sound insulation curve, another installation has been examined. This Construction 5 can be considered as typical structure and is similar to the examined Construction 3, but the ventilated air gap was not installed correctly. The structure is present in the data acquisition that was taken previous to the laboratory measurements and the details are found in [5]. The main parameters are the following:

- the inner covering is one layer of gypsum board that was installed on wooden framework;
- the heat insulating layer is 12 cm of glass wool between the rafters;
- the roof covering is made of concrete tiles which is very similar to ceramic tiles that was installed at the laboratory measurements;
- under the roof covering an air gap was installed, but the structure was not ventilated.

Figure 5 shows the measured sound reduction index and the linear approximation of Construction 5. The weighted sound reduction index was R_w=50 dB.



,Fig.5 Measured sound reduction index and linear approximation of Construction 5, R_w=50 dB

The linear approximation of the sound insulation was determined as of Construction 3. The resonance frequency was 68,9 Hz, and the sections *a* (under the resonance frequency) and *b* (above the resonance frequency) give good approximation to the measured sound insulation. The third section which is marked with *c* in Figure 5 can be approached up to about the coincidence frequency with a curve of approximately 10 dB/octave slope, which is substantially different from the previously presented structure’s.

3 Discussion

Sound insulation of roof constructions for the first approximation shows the characteristics of two-layered constructions, however above 200 Hz the effect of ventilated air gap appears. The results of the sound insulation of roof constructions can be approached with a linear approximation with three characteristic sections:

- under the resonance frequency: the sound reduction can be described by a linear with slope

6 dB/octave, which can be calculated from the mass of the two layers;

- over the resonance frequency: the sound reduction can be approached by the sound insulation of the “ideal” two layered structure, which can be described by a linear with slope 18 dB/octave;
- up to the coincidence frequency: the sound reduction could be determined with a linear, with slope between 6-10 dB/octave. The slope of the curve depends on the following constructional details:
    - *type of inner covering* (number of layers, type, specific mass, type and prevalence of fixing). Good results were reached with increased specific mass of the gypsum boards. Using two layers instead of one layer the sound insulation increased by 4 dB. The difference between the 1,25 and 1,5 cm thick boards was low.
    - *ventilated air gap* (rate and method of ventilation: along eaves and ridge or with ventilating tiles, foil under the ventilated layer). The construction without ventilated air gap gives better sound insulation. The extent of decline in sound reduction is determined with the effect of other constructional details altogether, for example type of roof covering and placement and type of foil which makes the construction air-tight.
    - *roof covering* (type: ceramic or concrete, specific mass, air-tightness, support). The type of roof covering in itself has a moderate influence on sound insulation. Using double overlapping instead of single increased the sound insulation with 2 dB. This layer is not air-tight, more or less fluxation through this layer is always present.

The results show that the sound insulation of roof constructions can not be examined without other building physical requirements, which is often neglected in acoustical measurements. The accurate effect of ventilated layer is determined by other constructional details altogether (type and air-tightness of roof covering, foil). The practice measuring the sound insulation of roof constructions without ventilated air gaps or with closed or sealed air gaps is not adequate tough these constructions give better results. These structures do not fulfill the requirements of vapour protection and therefore are not appropriate for further design.

To give results that can be used in designing process the measured constructions have to suit all building physical requirements.

Considering the results of the measurements the method of developing roof constructions with increased sound insulation can be reached by:

- using inner covering with increased specific mass;
- using more flexible fixing for inner covering which gives point-type connection;
- installing further layers under the roof covering which increases the specific mass of the construction.

4 In situ calculations

The compliance of roof constructions with acoustical requirements in a specific example is determined by many factors (function and geometrical data of the room, furnishing, external noise etc.). Calculations with living rooms of usual size and geometry give guidance toward the practical adaptability of above mentioned roof constructions. The calculation was carried out with the above detailed data according to the national standard MSZ 15601-2:2007. The further building constructions of the attic are usually used in practice (parapet wall: heat-insulating ceramic wall, roof window: usual sound insulation typically $R_w+C_{tr}\leq 32$ dB).

The results of the calculations show that the constructions above suit the requirements of sound insulation where the noise arising from the traffic is less than $L_{Aeq}\leq$ 60 dB. Where the external traffic noise is more than this (typically urban main roads with 2×2 lanes) the above constructions do not fulfill the requirements of sound insulation. The weak point is the roof window.

Acknowledgments

The experiments were financially supported by Ursa Salgótarjáni Üveggyapot zRt and Knauf Kft.

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