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Sound insulation properties of building elements, considering the frequency range below 100 Hz

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The constantly increasing standard of comfort in general and the rising number of apartment buildings in lightweight mode of construction directed the focus of research to the sound insulation properties of timber frame and massive wood element buildings. The complaints of the residents of terraced houses and multiple dwellings in lightweight buildings mainly concern noise events characterized by dominant low frequency. This problem regards airborne sound insulation as well as impact sound insulation. Based on empirical data the comparison of the sound insulation properties of the building elements investigated shows the specific problem of each category of construction mode in the frequency range below 100 Hz. The typical sound insulation characteristics regarding the low frequency range are discussed in the light of the current applied sound insulation requirements as well as in relation to the problem to comply with the resident's apperception of sound insulation quality.

1 Introduction

The intention of this paper is to discuss the problem that complaints about acoustic comfort of residents of lightweight buildings are in a higher frequency of occurrence compared to possible complaints of residents of traditional masonry houses although all the current requirement standards are met. There is evidence that the requirement regulations do not consider the crucial frequency range concerning the resident's experience of the acoustical comfort sufficiently so far, particularly if lightweight residential constructions are concerned. Due to this lack, there is no evidence of particular development effort of the industries to bring this topic to a current state-of-the-art.

2 Extended frequency range and low frequency problem

The frequency range in building acoustics is specified between 100 Hz and 5000 Hz. It is in common to communicate the sound insulation properties of building elements or between rooms with single values. The sound insulation of the building element itself (without flanking transmission) e.g. walls, doors or windows are characterized by the weighted sound reduction index R_w. The sound insulation in buildings between rooms is characterized by the weighted standardized sound level difference $D_{n,Tw}$. The single number quantities to characterizes the impact sound insulation properties are the weighted normalized and the weighted standardized impact sound level $L_{n,w}$ (the floor-element itself without flanking transmission) and $L_{nT,w}$ (between dwelling units). To obtain the standard single value, the rating-procedure follows according ISO 717 and considers the frequency range from 100 Hz to 3150 Hz. To get single values which are more precisely in characterization of the sound insulation considering particular sound spectra like the typical sound in dwellings or the typical sound spectrum of traffic noise according to ISO 717 the so called spectrum adaptation terms C and C_{tr} have to be calculated with the measured third octave band values and specified additionally. The spectrum adaptation term C_I is intended to modify $L_{n,w}$ or $L_{nT,w}$ to take into account the noise spectrum "foot steps on the floor". Optional according to ISO 717 it is possible to consider the frequency range down to 50 Hz. This low frequency range can be taken into account in the rating procedure to get single values if the spectrum adaptation terms $C_{50\text{-}3150}$ and $C_{tr50\text{-}3150}$ or $C_{I50\text{-}2500}$ are specified additionally like C, C_{tr} or C_I to the classical standard single value.

Up to now these spectrum adaptation terms neither C and C_{tr} nor $C_{50\text{-}3150}$ and $C_{tr50\text{-}3150}$ are considered by the standards which are regulating the requirements. Rassmusen [1] compared the airborne and impact sound insulation requirements of dwellings of 24 European countries and showed that most of these countries do not consider the C and C_{tr} value. Only in two countries $C_{50\text{-}3150}$ has to be taken into account. In Sweden it is obligatory and in Norway it is recommended.

Figure 1 shows the problem of the procedure to characterize the sound insulation of building elements or between dwellings only by the traditional single values R_w or $D_{nT,w}$.

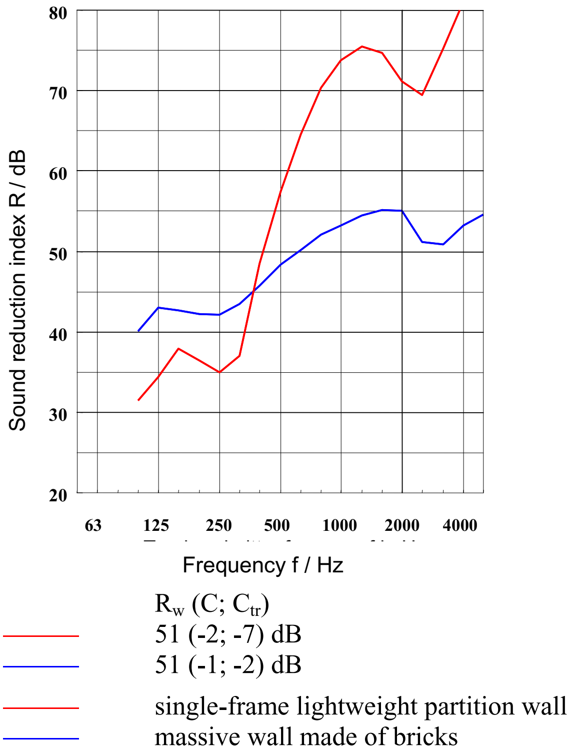


Fig 1. Airborne sound insulation of a wall made of hollow bricks and a light weight timber frame wall.

Due to the typical sound insulation properties of timber frame building elements and the traditional elements made of bricks or concrete the identical sound event can be perceived very different. Compared to massive construction elements the sound insulation of lightweight building elements is inferior in the low frequency range but superior in the upper frequency range. As it can be seen in Figure 1 even if only C and Ctr are specified additionally to the traditional single value the difference of the sound insulation quality to the particular sound spectra can be characterized much better. $R_w + C = 51 + (-2) = 49$ dB or $R_w + C_{tr} = 51 + (-7) = 44$ dB (lightweight building wall) compared to $R_w + C = 51 + (-1) = 50$ dB or $R_w + C_{tr} = 51 + (-2) = 49$ dB (massive wall). Regarding traffic noise, the difference in sound insulation is considerable.

The complaints of the residents of terraced houses and multiple dwellings in lightweight buildings mainly are focused to noise events characterized by dominant low frequency. Although the significance of the characterization of sound insulation quality has increased with C and C_{tr} some studies [2, 3] are suggesting that in many applications it is not satisfying enough. This is also a fact with impact sound insulation [4]. There is strong evidence that particularly in relation with lightweight building construction mode it is necessary to apply the spectrum adaptation terms $C_{50-3150}$ and $C_{tr50-3150}$ to get a more reliable correlation with the residents' perceived sound insulation quality.

Genuit [5] pointed out that the perception of low noise and the caused degree of annoyance considerably depends on the characteristics of the noise event. Tonal noise compared to broadband noise events cause immanently different effects of annoyance. One of these variables is the spectrum balance. Noise spectra with decreasing slopes up to the high frequency bands causing higher degrees of annoyance compared to noise events with less decreasing slopes [6]. Another important variable is the sound level fluctuation in relation to the magnitude of dominance of the low frequency noise [5, 7, 8]. There is evidence of a significant correlation between the irregularity of the noise level and annoyance [7].

Both, the balance of the sound spectrum as well as the low frequency sound level fluctuation particularly concerns the acoustical situation in buildings built of lightweight construction elements.

Due to the typical sound insulation characteristic of light weight building elements (rather poor in the low frequency range and attenuated to a much greater extent in the mid and high frequencies) the noise spectrum will be selectively attenuated, resulting in a spectrum dominated by low frequencies. The problem is increased by the dominant low-frequency content of the noise spectra which predominately occur [8, 9]. The level fluctuation with dominant low frequency noise is a topic considering impact sound insulation of timber frame ceilings and ceilings of massive wood elements particularly, too [8].

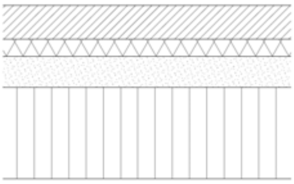
So far there is no generally accepted assessment tool, which would provide a reliable rating of the effect on humans' apperception of low frequency noise events. However, Mortensen [3] tries to show in his study that there seems a relationship between the degree of annoyance of the residents and the sound insulation ratings regarding the spectrum adaptation terms considering the frequency range down to 50 Hz.

As mentioned above so far most of the European countries do not consider the spectrum adaptation terms in their requirement regulations. This means that the critical frequency range significantly concerning the sound insulation in lightweight buildings predominantly is neglected. Because there are no requirements, which have to fulfilled obligatory, the problem is largely neglected by the lightweight building industries, too. Even if structural measures have to be implemented to improve sound insulation of building elements only the traditional characteristic values of the sound insulation are taken into account. In the light of the low frequency perception problem as discussed, this approach however often leads to counterproductive designs regarding the sound insulation quality in the low frequency range, as the following examples will show.

3 Examples of construction

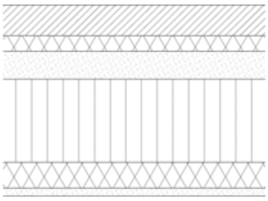
The sound insulation of the following constructions have been measured, according to ISO 140-3 in test stands for walls and test stands for floors that meet the requirements regarding ISO 140-1.

Figure 2 shows floor constructions, each consisting of massive wood elements with a floating floor. Both constructions are built according to the same principle but one has a suspended ceiling lining additionally. The suspended ceiling was mounted predominantly with the aim to improve the sound insulation properties of this construction. As expected without considering the spectrum adaptation term the improvement of the impact sound insulation seems considerable but if the value of the traditional normalized impact sound pressure level is "corrected" by adding $C_{I50-2500}$ it can be seen (cf. Fig. 3) that this kind of implementation leads just to an unacceptable improvement.



no suspended ceiling lining

60 mm	floor screed
30 mm	impact sound insulation slab
55 mm	pouring (polystyrene, cement mixture)
160 mm	massive wood element

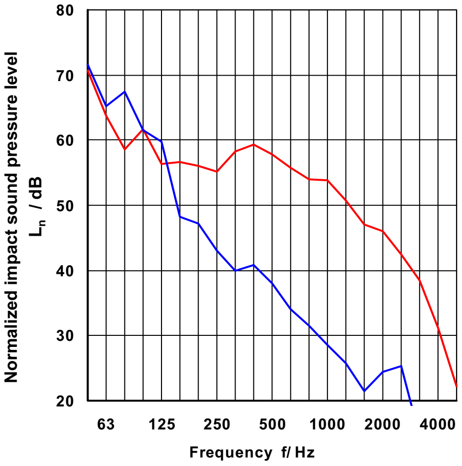


with suspended ceiling lining

60	mm	floor screed
30	mm	impact sound insulation slab
55	mm	pouring (polystyrene, cement mixture)
160	mm	massive wood element
50	mm	channels on spring clips, glass wool
1.25	mm	gypsum board

Fig. 2. Examples of wooden ceilings with floating floor with and without a suspended ceiling lining

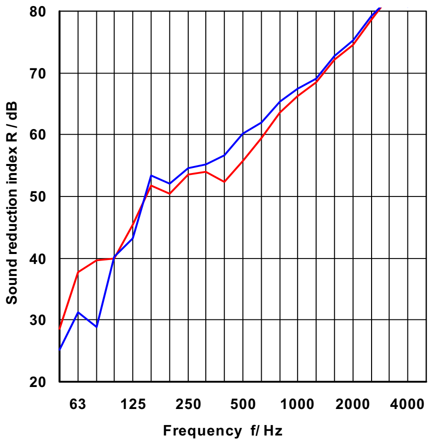
Analyzing the spectra it can be seen that from 100 Hz down to 50 Hz the acoustical effect caused by the suspended ceiling is decreasing the impact sound insulation in a significant degree regarding perceivable sound insulation quality. This effect can be characterized quite well by $L_{n,w} + C_{I50\text{-}2500}$ = 55 +3 = 58 dB (without suspended ceiling lining) compared to $L_{n,w} + C_{I50\text{-}2500}$ = 45 + 14 = 59 dB (with suspended ceiling lining). The same effect is observable if the airborne sound insulation properties of these constructions are analyzed (cf. Fig. 4). Similar to the single number characterization of the impact sound insulation the same is true regarding the airborne sound insulation $R_w + C_{50\text{-}3150}$ = 62 + (-3) = 59 dB or $R_w + C_{tr50\text{-}3150}$ = 62 + (-11) = 51 dB compared to $R_w + C_{50\text{-}3150}$ = 63 + (-6) = 57 dB or $R_w + C_{tr50\text{-}3150}$ = 63 + (-17) = 45 dB.



$L_{n,w}$ ($C_{I50\text{-}3150}$)
55 (3) dB
45 (14) dB

without suspended ceiling lining
with suspended ceiling lining

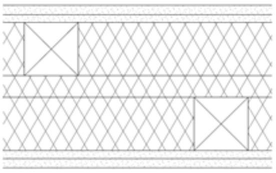
Fig 3. Impact sound insulation of the wooden ceiling with and without suspended ceiling lining.



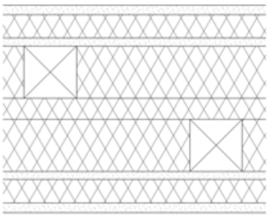
R_w ($C_{50\text{-}3150}$; $C_{tr50\text{-}3150}$)
62 (-3; -11) dB
63 (-6; -17) dB
without resilient wall lining
with resilient wall lining

Fig 4. Airborne sound insulation of the wooden floor with and without suspended ceiling lining.

Figure 5 shows a timber frame partition wall according to the double frame construction mode with double layer. The second double frame partition wall also shown in Figure 5 is consisting of a single layer of wooden board and additionally cladded with a resilient wall lining of gypsum board. The cavity of these claddings is filled with mineral wool.



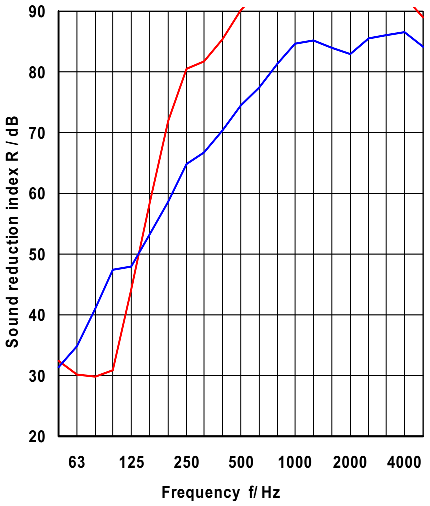
18 mm	gypsum board
15 mm	chipboard
100 mm	timber frame, mineral wool
40 mm	mineral wool
100 mm	timber frame, mineral wool
15 mm	chipboard
18 mm	gypsum board



18 mm	gypsum board
50 mm	channels on spring clips, mineral wool
15 mm	chipboard
100 mm	timber frame, mineral wool
40 mm	mineral wool
100 mm	timber frame, mineral wool
15 mm	chipboard
50 mm	channels on spring clips, mineral wool
18 mm	gypsum board

Fig. 5. Double wall with timber frame with and without resilient wall lining

In relationship with solid walls made of bricks or concrete it is state of the art to improve sound insulation with lining walls and it works quite well if it is dimensioned appropriately. But this technique can not be applied to lightweight partitions without a proper modification regarding the acoustical properties of this construction mode. This example shows that this kind of wall lining mounted to classical lightweight partition walls leads to a considerable decreasing of the sound reduction index in the frequency range from 100 Hz down to 50 Hz (cf. Fig. 6). This effect impressively can be seen if additionally to the classical single number quantity the spectrum adaptation terms are taken into account. $R_w + C_{50\text{-}3150}$ = 71 + (-14) = 57 dB or $R_w + C_{tr50\text{-}3150}$ = 71 + (-25) = 46 dB compared to $R_w + C_{50\text{-}3150}$ = 73 + (-8) = 65 dB or $R_w + C_{tr50\text{-}3150}$ = 73 + (-20) = 53 dB.



R_w ($C_{50\text{-}3150}$; $C_{tr50\text{-}3150}$)

71 (-14; -25) dB

73 (-8; -20) dB

with resilient wall lining

without resilient wall lining

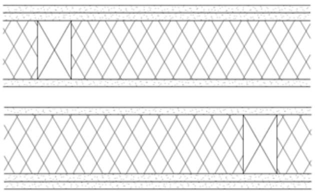
Fig. 6. Sound reduction index of the timber frame double wall with and without resilient wall lining

A possible approach

It can be demonstrated that lightweight constructions are not disadvantageous in general, considering the low frequency range. If the acoustical properties in this critical frequency range are regarded in the design and developmental process adequately, the sound insulation potential can be increased considerable.

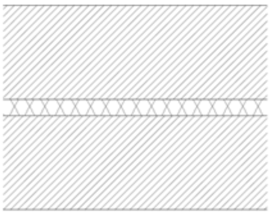
Figure 9 shows examples of partition walls usually applied as partition wall between dwellings or terraced houses.

In Figure 10 the sound insulation characteristics of the compared partitions are diagrammed. In comparison, the lightweight partition wall traditionally consisting of two double-walls separated by a narrow gap has the most disadvantage sound insulation behavior. The double partition made up of two walls of concrete separated by a gap filled with slabs of mineral wool with high density as expected has an advantageous characteristic in the frequency range from 100 Hz down to 50 Hz. The resonance frequency can be expected approximately around 20 Hz. The comparison of the sound insulation characteristics shows that the partition with double timber frame is very competitive to the traditional double concrete wall. If the layers are heavy enough and if according to the construction a multiple resonance system can be avoided the mass-air-mass resonance is approximately in the same range as it is with the double concrete partition wall.



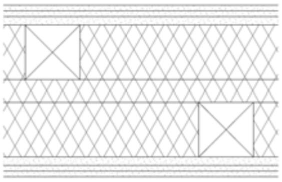
Traditional double wall with timber frame

12.5 mm	gypsum board
12.5 mm	gypsum board
95 mm	timber frame, mineral wool
12.5 mm	gypsum board
40 mm	gap
12.5 mm	gypsum board
95 mm	timber frame, mineral wool
12.5 mm	gypsum board
12.5 mm	gypsum board



Double wall of gravel concrete

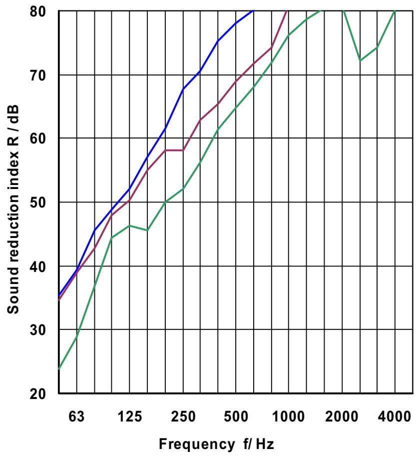
180 mm	gravel concrete
30 mm	mineral wool
180 mm	gravel concrete



Double timber frame partition

12.5 mm	gypsum board
12.5 mm	gypsum board
15 mm	chipboard
100 mm	timber frame, between mineral wool
40 mm	mineral wool
100 mm	timber frame, between mineral wool
15 mm	chipboard
12.5 mm	gypsum board
12.5 mm	gypsum board

Fig. 9. Examples of lightweight and masonry partition walls



R_w ($C_{50\text{-}3150}$; $C_{tr50\text{-}3150}$)

76 (-7; -19) dB

71 (-4;-15) dB

65 (-6; -19) dB

Double timber frame partition

Double wall of gravel concrete

Traditional double wall with timber frame

Fig. 10. Sound insulation index of the double partition wall constructions in lightweight and massive construction mode

Beside this quite easy practical realizable possibilities to improve sound insulation properties of light weight building components considerably demonstrated above are some other interesting promising attempts to optimize sound insulation in the low frequency range [10, 11]. They try to influence the primary structural resonance by aspects of the arrangement of the studs e.g. their distance to each other and their distance in relation to the given wall dimensions. As empirically demonstrated in [11] it seems that it is an effective approach to improve sound insulation in the critical frequency range below 100 Hz. In this respect they achieve an improvement in a degree which is competitive to the massive construction mode.

5 Conclusion

Sound insulation quality is a problem in general. However, the frequency of complaints about the acoustic comfort concern lightweight building dwellings in a more frequent extent than traditional masonry houses (cf. e. g. [2, 13]).

To meet the increasing demands on quality of sound insulation ([8, 12]) of lightweight residential constructions in particular it is necessary to extend the requirements down to 50 Hz (cf. [1, 8, 12]).

It is necessary to characterize lightweight constructions adequately in relation to the residents' apperception. However, the description of the apperception of low frequency dominated noise events is not yet solved sufficiently because the relationship of the variables is multifaceted (cf. [5, 6, 7, 8]). In this field of activity, further research has to be done. Not mentioned in this paper, but also further research has to be done in finding appropriate procedures to conduct sound insulation measurements correctly in the extended frequency range down to 50 Hz too. This problem is not yet sufficiently solved.

It should be investigated more closely whether or not it is an adequate approach to take the spectrum adaptation terms $C_{50\text{-}3150}$, $C_{tr50\text{-}3150}$ and $C_{I50\text{-}2500}$ as indices additionally to the traditional single values to characterize the building elements in consideration of their airborne and impact sound insulation qualities in relation to the residents' apperception. Adding the spectrum adaptation terms to the single value would ba a procedure according to recommendations of the standard ISO 717-1, -2. This would mean, no new guideline would have to be established.

In a first step, this approach could also be taken as one of the bases to support design and developmental work, which has in its focus the improvement of the sound insulation of lightweight residential constructions.

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