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Sound insulation of multi-storey houses

Summary of impact sound insulation

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Abstract

Problems connected with the sound insulation of wooden multi-storey buildings are even more severe than those connected with fire safety. Evidently a wooden house can be built so that modern requirements for both the airborne and the impact sound insulation are met with sufficient margins. However, low frequency impact sounds produced by walking may be audible or occupants may feel them as non audible vibrations.

There is still debate over what is the proper way to rate low frequencies and which of the rating methods is most appropriate. However, what is clear is that the ISO rating method is not sufficient where wooden floors are concerned because of the results may be subjectively wrong. On the other hand, this does not mean that the impact sounds should be rated with more than one method. Therefore existing methods shall be developed into one sole method (Fasold's method) covering all types of floors.

One of the main targets in the research project was to develop an impact sound insulation model of a multi-layered floor. An EXCEL-based system was developed with which it is possible to consider the effects of different structural parameters on the impact sound pressure levels. The comparison between measured and calculated impact sound pressure levels shows promising results. However, the model shall be surveyed and verified with a more extensive sample of floors.

It seems that walking on wooden floors causes low frequency "thumps", and that these floors are poorer, in this respect, than ordinary concrete floors. Measurements in laboratory and field were carried out with the floors carpeted and with and without the floating structure. The purpose of these tests was to study the effects of different floor sub-systems (e.g. different floating floor structures, different heights and spacings of the joists, different ceiling structures) on the impact sound insulation. The sound insulation properties of altogether 14 different wooden floors with some modifications to them were tested. There were not very many or so great differences between the floors concerning the airborne and the impact sound insulation. However, the wood-concrete composite slab behaves clearly better than the others. Additionally, a floor with a thicker and stiffer board on the top of the load-bearing sub-floor seems to function well.

PREFACE

As a part of a national research programme (Wood Programme) concerned with the topics of multi-storey wooden houses, a research project was started at VTT Building Technology in 1996 with the aim of examining the overall sound insulation performance of wooden houses and the relevance of the national requirements pertaining to them. It is hoped that the study will provide sound insulation guidelines for the design of wooden structures in the future. The research project is divided into three parts. The most laborious part, the experimental field and laboratory study of wooden floors, has already been published as a VTT Publications Report 345. Additionally, the part concerning the rating methods of impact sound has been published separately in *Journal of Sound and Vibration* and, finally, the part concerning the acoustical modelling of a wooden floor is not, so far, published. Here only a brief summary of all the separate parts of the research is presented.

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Espoo, November 1998

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1 Introduction

From a general point of view, the problems connected with the sound insulation of wooden multi-storey buildings may be regarded as even more severe than those connected with fire safety. In recent years the sound insulation of wooden constructions (here impact sound insulation) has been studied extensively, especially in the Scandinavian countries. Evidently a wooden house can be built so that modern requirements for both airborne and impact sound insulation are met with reasonable margins. However, low frequency impact sounds produced, for instance, by walking may be audible or occupants may feel them as non-audible vibrations. In a well-known American example [1] a wooden multi-storey house, intended to be luxurious, had severe impact sound insulation problems despite these having been detailed with utmost care and the house having met all local requirements. It was stated that low frequencies could not, after all, be taken adequately into account (when rating the impact sound insulation with the help of the standardised ISO method ISO 717 or a similar method used in the US).

There is still debate over what is the proper way to rate low frequencies and which of the rating methods is most appropriate (coherent with the subjective judgement made by inhabitants). On the other hand, measuring low frequency components at a site with the help of existing standardised methods is not necessarily unequivocal. However, what is clear is that the ISO rating method is not sufficient where wooden floors are concerned because the results may be subjectively wrong.

Below is a brief summary of the research project carried out by the Technical Research Centre of Finland (VTT) on acoustics in multi-storey wooden houses. The project comprised the following parts:

1. (Subjective) rating of floors
2. Acoustic modelling of a wooden floor construction
3. Measurements in laboratory and field.

Three main reports were published respectively:

- J. Parmanen. Comments and conclusions based on “Alternative reference curves for evaluation of the impact sound insulation between dwellings” [2],
- S. Uosukainen. Impact sound insulation of a wooden floor. Acoustic model of a wooden floor (in Finnish) [3],
- P. Sipari, R. Heinonen & J. Parmanen. Acoustic properties of wooden floor slabs [4].

Two further reports [5–6, both in Finnish] have also been published. The following describes mainly the contents of the three main reports. More space is devoted to the first part [2], since knowledge of how to implement proper systems for rating impact sounds seems somewhat exiguous. Furthermore, international discussion on this issue is limited [7] and studies of rating system principles are

simply not found in the literature. The bottom line is that there is little sense in developing a wooden floor for impact sound insulation as long as there is no consensus on rating method. Nor can wooden floors be rated with different methods giving different results for one floor type, as different ratings may lead to adverse constructional details for the same floor.

The acoustic model [3] developed for the impact sound insulation behaviour of a wooden floor is still incomplete and requires proper verification. This part of the research is described only briefly here in view of its complex mathematical and technical nature.

Numerous walking tests were made besides normal impact sound insulation measurements in both laboratory and field. In the laboratory tests the sound pressure levels produced by two male walkers were measured in the test room below. Similar measurements were also carried out at many sites (field measurements in finished buildings). With the help of these measurements differences between the sound spectrum of the standardised tapping machine and that produced by walking were compared and studied.

2 Rating of floors

2.1 General

Impact sound insulation is generally rated with the normalised and weighted impact sound pressure level $L_{n,w}$ defined in ISO 717 (rating standard). Use of this standard provides that the sound pressure levels are measured according to ISO 140 (measurement standard) using the standardised tapping machine as the impact source. These same measuring and rating methods have been used internationally, with some modifications, since the late of 1950s. In many countries special national features have been introduced, especially in the rating method. As far as we know, only Japan has used other impact sources such as heavy rubber balls or tyres, with not entirely positive results.

Particularly in Sweden, criticism has been raised against the use of $L_{n,w}$ for rating floors generally [8]. For wooden floors especially, a new suggested method [8] has been used in Sweden as a real standardised and verified rating method (as a result of the Nordic Wood projects). On the other hand, the suggested method [8] has been criticised [2] and, $L_{n,w}$ seems to act fairly well with more massive and hard surfaced floors or floors covered with not too soft a floor covering. Given that the majority of European multi-storey houses are built from mineral aggregate based materials, there has not been a need to create or introduce new methods for measuring or rating the impact sound insulation of wooden floors.

Different methods for rating the impact sound insulation are presented in reference [8] and the methods and principles for constructing rating methods are analysed in greater detail in reference [2]. In the following, the method by Fasold [9] and the method suggested by Bodlund [8] are surveyed, in addition to the reference curve method in the new ISO 717 and a special type of method used in France. The methods are compared as such and for a Swedish survey floor sample described and used in reference [8].

2.2 Principle of rating methods

Below it is assumed that the measurement method for impact sound insulation is that described in ISO 140, including the standardised tapping machine as the impact source. As is known, the idea of the tapping machine is that hammers hitting the floor generate sound in a room below. The sounds are called normalised impact sound pressure levels (if the measured sounds are “normalised” to a distinct room absorption). The measurement is normally performed in third-octave bands.

Following the above measurement the next step is to handle the third-octave band sound pressure levels to give a single number result. If the desired single number is $L_{n,w}$ for example, it must be calculated from a reference curve algorithm having a defined reference curve shape.

However, when using a reference curve algorithm some questions should be addressed, such as what actually happens when using such a procedure and what factors define the curve shape.

The first question can be answered by referring to Gösele's [10] idea, according to which the reference curve algorithm is equivalent to applying a frequency weighting to the measured normalised sound pressure levels. According to Gösele the frequency weighting terms are included in the reference curve as their negatives. Therefore, for example if one uses an A-weighting in a reference curve system, the weighting terms (the weighting curve) are reversed. Further, if one compares different weightings, this can be done directly by comparing the different weighting terms or curves or by comparing the reversed terms or curves in a reference curve algorithm representation (Figure 1).

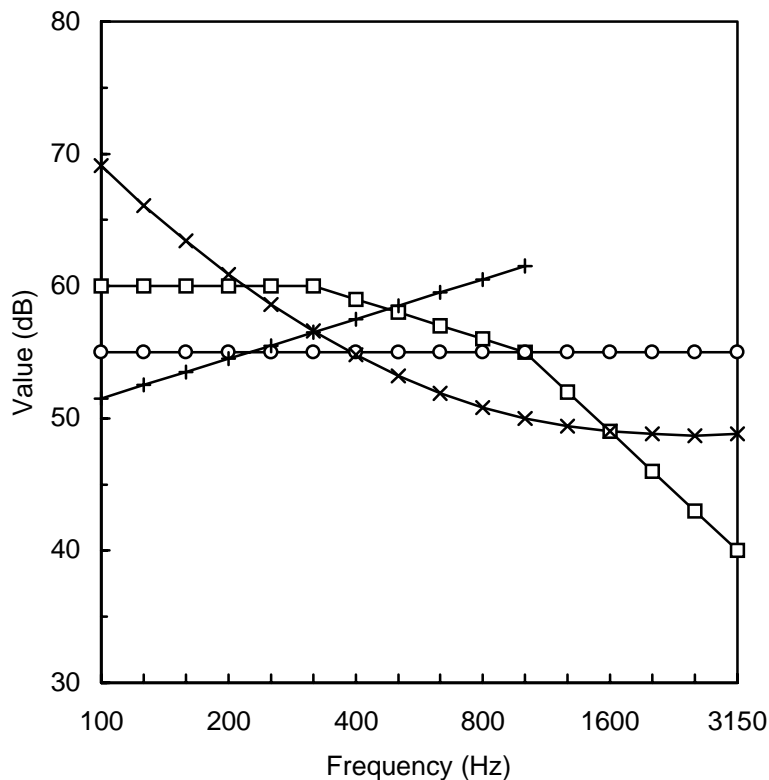


Figure 1. Weightings of the different rating methods: \square , ISO 717; \circ , Fasold [6]; \times , A-weighting (reversed A-weighting); $+$, Bodlund [8]).

The second question concerning the shape of the reference curve was originally considered by Fasold [8], who compared usual impact noises (e.g. walking etc) with the noise of the standard impact generator. Finally, the “mean disturbing dwelling impact noise” was defined as the differences in third-octave band levels between living sounds and impact sounds generated by the standardised tapping machine, and these differences were the first crucial factors defining the reference

curve shape. Additionally, a reference curve includes a weighting for the subjective perceived magnitude of the sound, for example an A-weighting (“acceptable noise” as applied by Fasold) and a mean absorption in receiving rooms. In the following the effect of the absorption on the reference curve shape is ignored. The limitations of the principles by Fasold of using the above differences on different floors and floor coverings are not discussed here.

From the above considerations it can be concluded that, in general, a reference curve method is a system for calculating a total weighted normalised sound pressure level. Secondly, one may conclude that the shape (weighting) of the reference curve consists of negatives of differences between living sounds and the sounds generated by the standardised tapping machine and the negatives of the chosen weighting for the subjective perceived magnitude of the sound. Thus, if one alters the shape of the reference curve, one has to show (or at least understand) that living sounds have changed since the 1950s, or alternatively that the subjective weighting for perceived magnitude of the sounds has changed. However, researchers have highly contradictory opinions of the magnitudes of factors defining the reference curve shape (Figure 1). In this respect, Fasold’s reference curve is the only one that is well defined.

2.3 Comparison of different methods

Figure 1 shows all the above mentioned methods, i.e. the frequency weightings in a reference curve application. As the figure shows, the traditional reference curve of the basic ISO 717 and the reversed A-weighting are quite different, pointing to the difference between ISO 717 and the method used in France (direct calculation of the total overall A-weighted level of normalised impact sound band pressure levels). The reference curve method of ISO 717 clearly restricts both low and high frequency band sound pressure levels more than does the A-weighting. On the other hand, if the A-weighting represented the correct weighting for the subjective perceived magnitude of the sound (as it should?), differences between living sounds and the impact sounds generated by the standardised tapping machine would not exist. This means that the standardised tapping machine would represent living sounds such as a human walker. However, this is not the case and it seems that the French method is somewhat recessive as a rating method.

The method by Bodlund [8] rates sounds at and below 1000 Hz, totally ignoring sound pressure levels at higher frequencies as these were generally absent in the floor survey sample he used in his study [8]. Neglecting all the higher frequencies gives a chaotic relation between this method and the traditional ISO 717 method (Figure 2). It has been concluded [2] that, if Bodlund’s method [8] were subjectively sufficient, $L_{n,w}$ would be wholly insufficient and *vice versa*. Despite this severe contradiction, Bodlund’s method was suggested as a general method applicable to all types of floors.

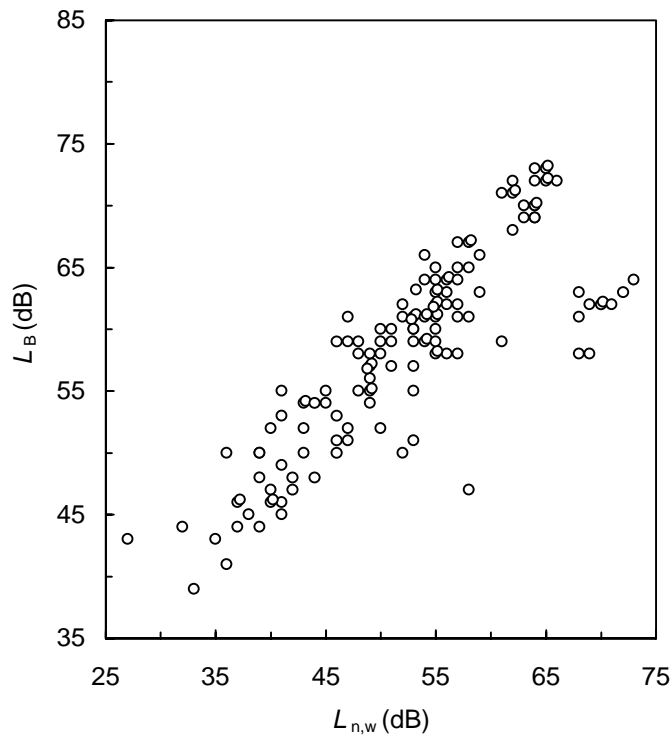


Figure 2. The relation between $L_{n,w}$ and Bodlund's impact sound pressure level L_B .

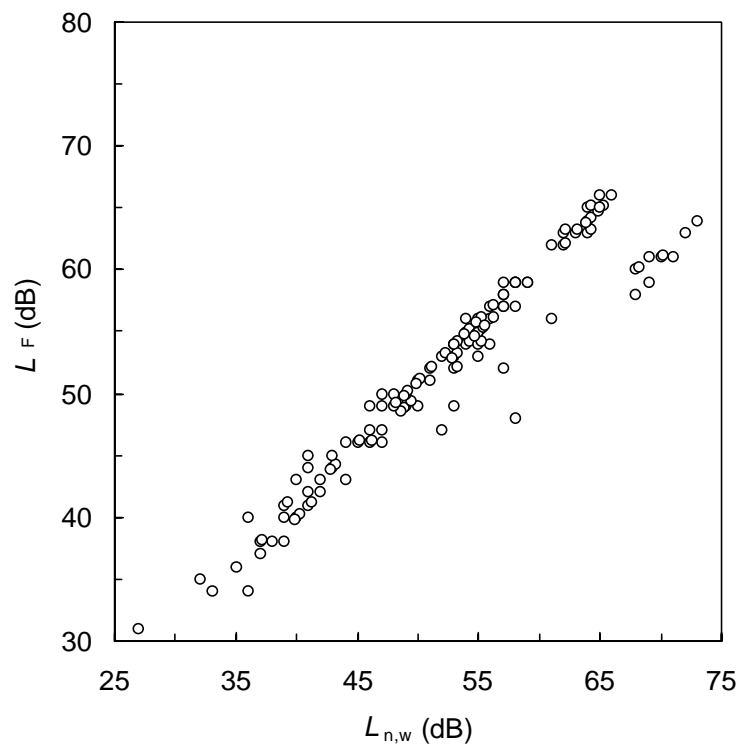


Figure 3. The relation between $L_{n,w}$ and Fasold's impact sound pressure level L_F .

Figure 3 shows a similar relation between Fasold's [9] measure and the traditional $L_{n,w}$ in ISO 717 to that with the method by Bodlund. Unlike the former method by Bodlund, Fasold's method also takes into account the higher frequencies but weights them less than the ISO 717 method. Figure 3 shows that if the ISO method were replaced by Fasold's method it would not lead to great and uncontrollable alterations in practice. In fact, Fasold's measure separates the sample floor material principally into three systematic categories: In the first and major category, Fasold's measure generates the same order of performance of the floors as $L_{n,w}$. In the second category, hard massive floors (with hard floor covering) generally have a smaller Fasold's measure than $L_{n,w}$. The third category comprises floors, such as wooden floors, having strong low-frequency components when excited with the standardised tapping machine. Fasold's method has been regarded [2] as a hypothetical example of a real perfect method, without major contradictions if compared with the traditional ISO 717 method. Therefore, it is recommended that Fasold's method be developed as the sole method for rating all types of floors.

3 Modelling

One of the main targets in the research project was to develop an acoustical model for the impact sound insulation of a multi-layered floor. The model developed is based on power transfer equations. These basic equations have been collected from the literature [9–12] and have been modified for the purposes of modelling. The principle of the model is shown in Figure 4. An EXCEL-based version currently exists with which it is possible to consider the effects of different parameters on the impact sound pressure level induced by a tapping machine. The model will be surveyed more carefully and verified with a more extensive sample of floors in the near future. Figure 5 shows a comparison between measured and calculated impact sound pressure levels.

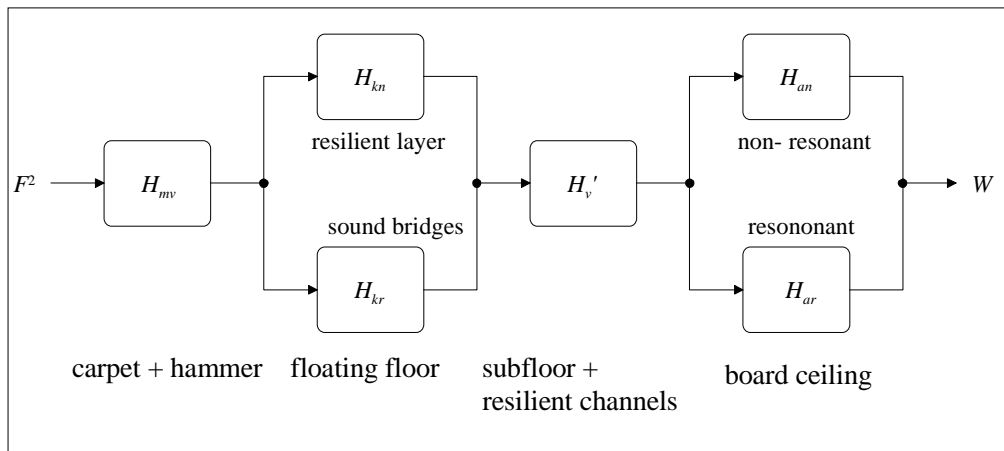


Figure 4. Model for impact sound insulation.

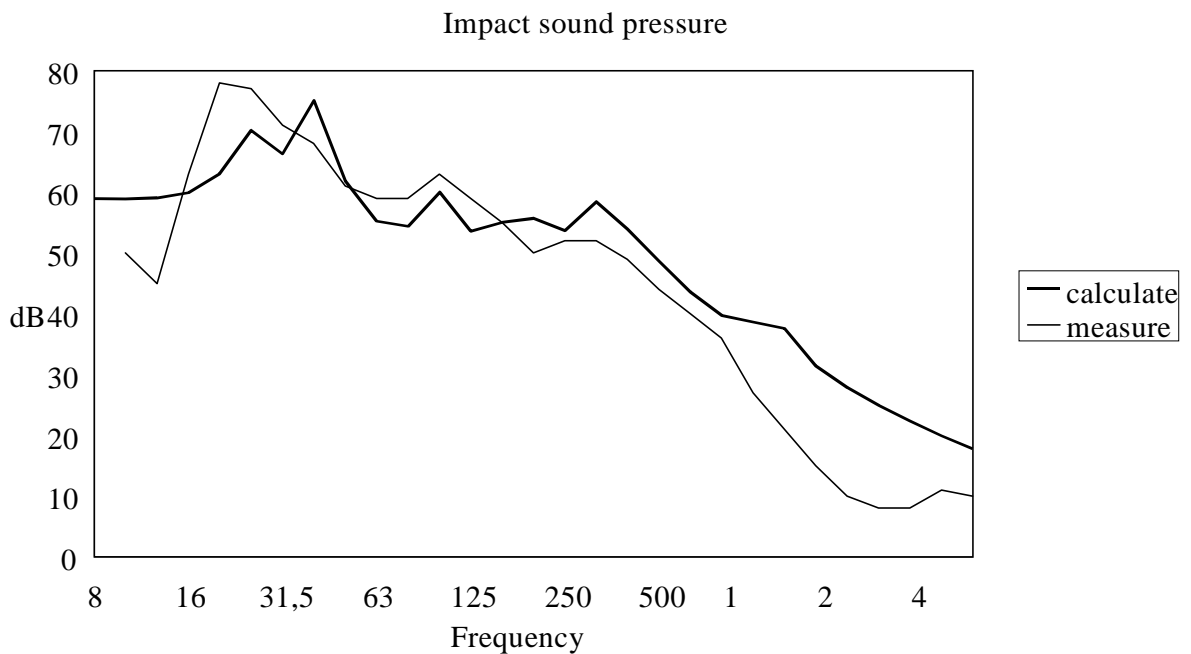


Figure 5. Measured and calculated impact sound pressure level of a wooden floor.

4 Laboratory and field tests

4.1 Floor structures

The tested floor constructions are illustrated in Figure 6. They represent wooden floor types widely used in modern buildings. Besides light weight floors with normal constructions, a more massive composite floor (concrete-timber) and a floor having double (leaf) structure were also studied. The structural details, spacing and stiffness of beams were varied in these tests, as was the construction of the floating floor. Impact sound insulation measurements were carried out with loaded and non-loaded floating floors. In addition, measurements were carried out with bare floors (no floating layer) or with floors with a carpet covering. Respective field measurements were carried out at sites with the same type of floors.

4.2 General aspects about impact sound insulation

Floors of multi-storey houses are generally built of rather heavy hollow core concrete slabs having great mass and stiffness. The impact sound insulation of these floors is theoretically well known. The impact sound pressure level of this kind of floor is sketched in Figure 7 and increases (impact sound insulation decreases) with increasing frequency. With this type of floor the high frequencies are the most problematic ones. Fortunately they can be damped with the aid of soft covering or a floating layer, and the requirements set for the impact sound insulation can be met quite easily with these measures. On the other hand, the impact sound insulation may be poor if especially hard coverings are used. For example, a mosaic parquet should not be used without a proper elastic under-layer.

A wooden floor is a multi-layered construction and its acoustical behaviour differs greatly from that of a massive and single-layered floor construction (e.g. a massive concrete floor). Due to its lightness and structural details, the impact sound insulation of a wooden floor is usually clearly poorer at low frequencies than that of a concrete floor. At higher frequencies the impact sound insulation is, on the contrary, significantly better (without a covering and partly also with a covering). The favourable effect of a soft floor covering begins at approximately 250 Hz and increases with increasing frequency. Respectively, the effect of a floating floor begins and increases from frequencies of 100–200 Hz upwards. The use of a floating layer or soft floor covering with a wooden floor will not be as effective as with concrete floors, since at high frequencies the impact sound pressure levels are already inherently low.

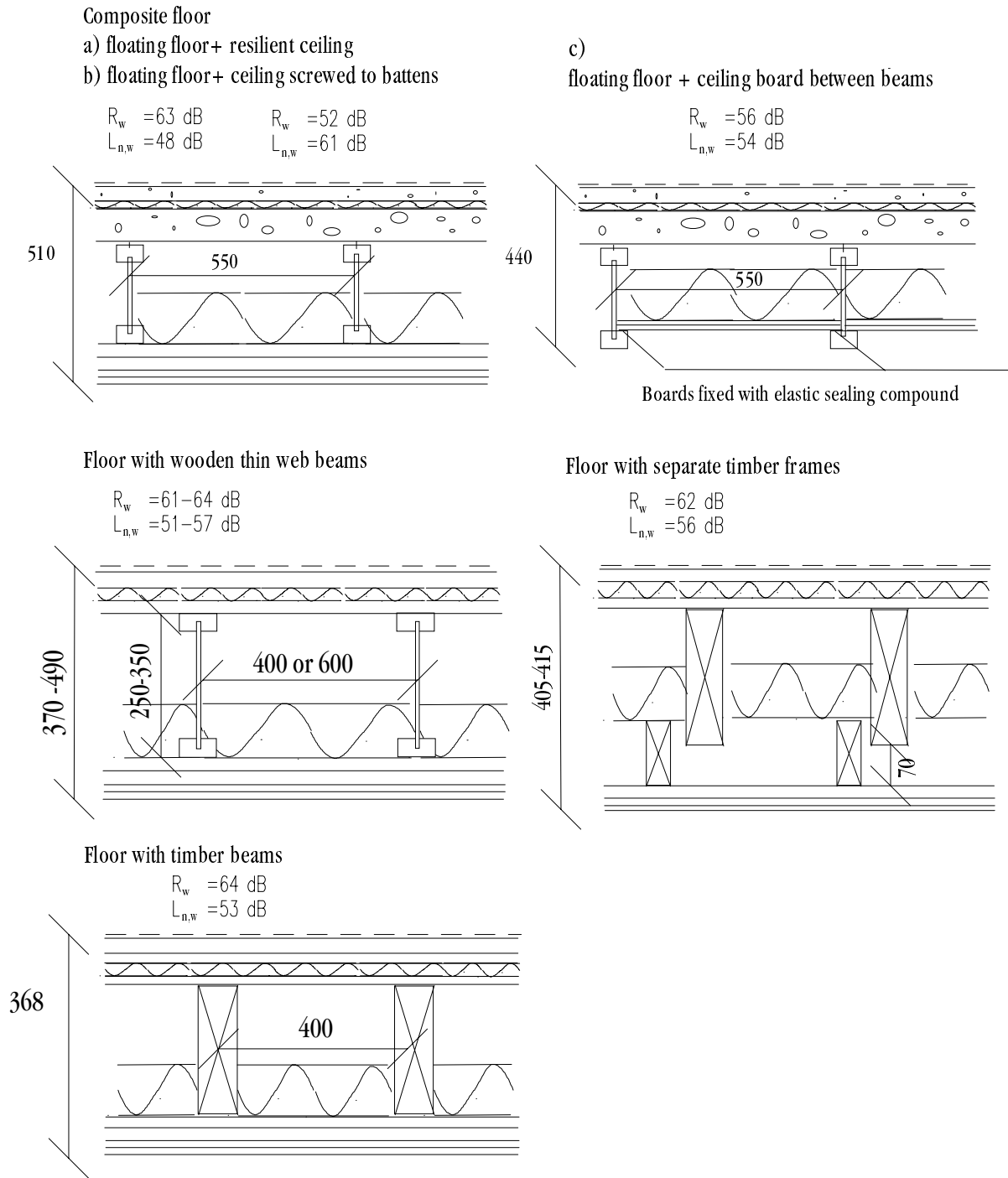


Figure 6. Tested floor types. Impact and airborne sound insulation values are valid for loaded floors without floor covering.

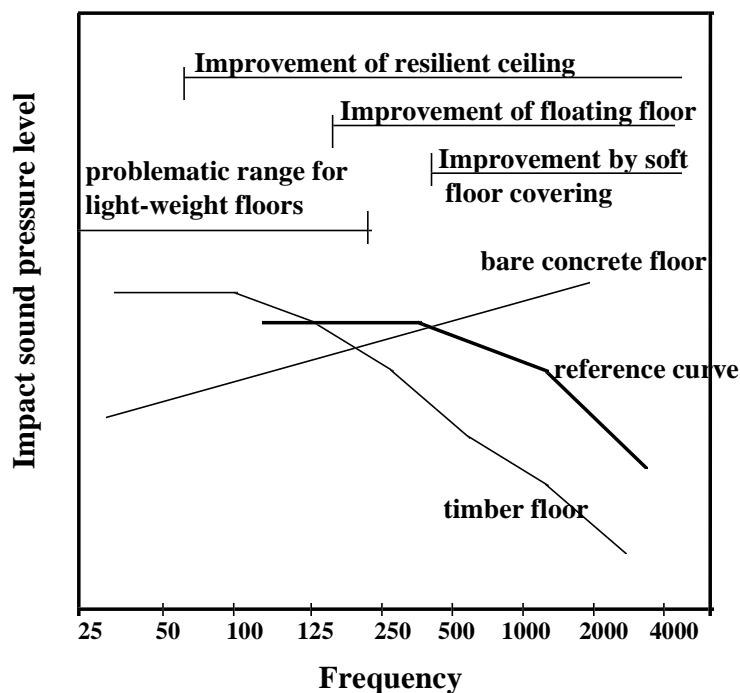


Figure 7. Impact sound insulation of a wooden and a concrete floor.

4.3 Acoustic behaviour of a wooden floor

Ceiling: Customarily a board ceiling is fixed to a wooden floor, and boards are fixed to load bearing beams with resilient channels (a resilient ceiling). The sound reducing effect of this type of resilient ceiling begins at 50 Hz and increases with increasing frequency. A resilient ceiling is of utmost importance for both impact and airborne sound insulation (Figure 8). The use of resilient channels improves the impact and airborne sound insulation by 10–15 dB compared with boards fixed directly to wooden constructions. On the other hand, according to Figure 8 it is clear that resilient channels harmfully decreases the impact sound insulation at frequencies under 50 Hz.

Floating layer: The improvement in impact sound insulation due to the floating layer starts and increases from a certain threshold frequency. With floating floors with a relatively light board surface layer this threshold frequency is usually above 100 Hz. Based on tapping machine tests the improvement of impact sound insulation (measured with $L_{n,w}$) is of the order of 5–8 dB (loaded floors). Especially at higher frequencies, the improvement (reduction of impact sound pressure levels) is distinctly smaller with a wooden floor than with a concrete floor. In the tests the use of a floating floor improved the impact sound insulation of wooden floors over a wide frequency range without any clear threshold value. The reductions of impact sound pressure level with different types of floating floors are shown in Figure 9.

A floating layer distinctly improves the airborne sound insulation of a floor, as well, and in practice it is estimated that the floating layer is needed if an airborne sound insulation R'_w of over 55 dB is required.

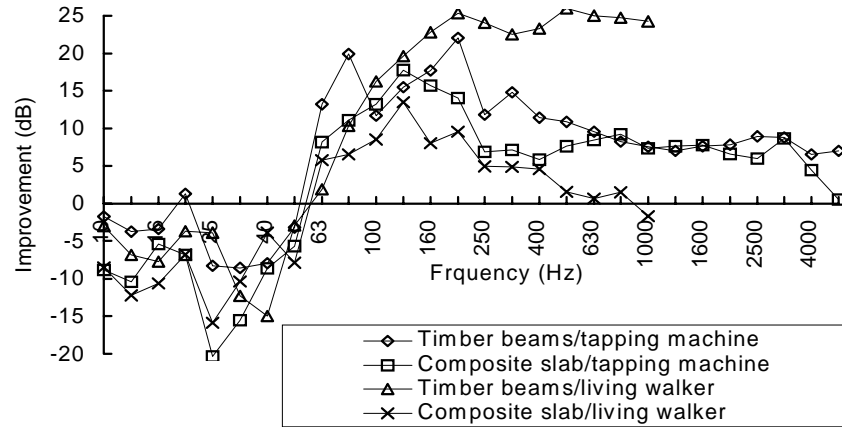


Figure 8. Improvement effect of a resilient board ceiling compared with boards fixed directly to wooden battens.

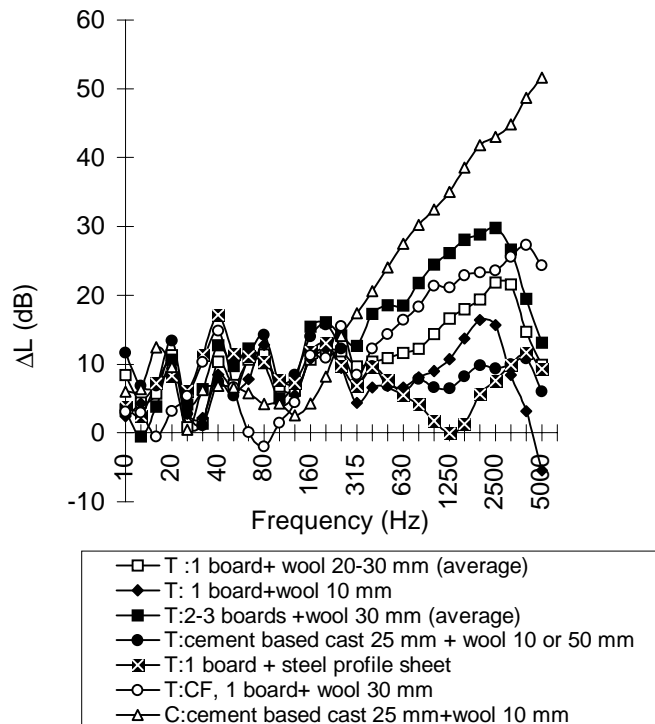


Figure 9. Reductions of impact sound pressure level with floating layers. (T= timber floor, C= composite floor, CF = no resilient channels, boards screwed directly to wooden battens fixed to beams.) Note the significance of the effect with a composite slab at high frequencies.

Floor covering: With a light-weight wooden floor the improvement of impact sound insulation (measured with $L_{n,w}$) due to a floor covering is minor, and can be neglected in the case of airborne sound insulation (this also holds for concrete floors). In part, the effect of a covering is significantly reduced by the effects of a floating layer and a resilient ceiling. Reductions of impact sound pressure level with a good floor covering are shown in Figure 10. Theoretically the reduction should begin only above 160 Hz (the reductions shown in Figure 10 are reliable only over 160 Hz). Improvement of the impact sound insulation (reduction of impact sound pressure levels) may be of significance in cases where either a floating floor or a resilient ceiling is not used. However, customarily a floating layer or resilient ceiling restricts the effect of a covering (i.e. $L_{n,w}$ may not be affected at all).

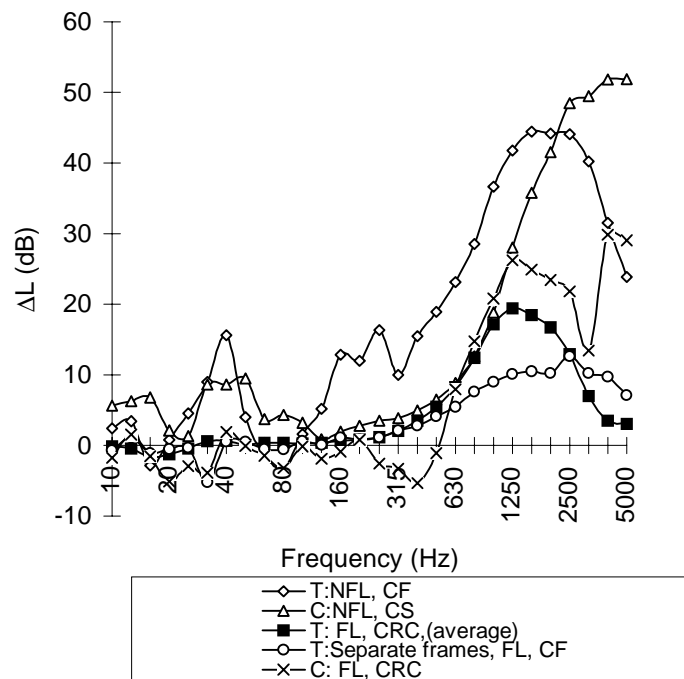


Figure 10. Reduction of impact sound pressure level with a covering. (*T* = timber floor, *C* = composite floor, *NFL* = without floating layer, *FL* = with floating layer, *CF* = board ceiling screwed directly to battens, *CS* = ceiling boards hung between the beams with the help of an elastic sealing compound, *CRC* = ceiling boards hung with the aid of resilient channels.)

4.4 Special features of walking as an impact source

Laboratory and field measurements show clearly that walking on a wooden floor produces low frequency sounds mainly at 20–200 Hz. The most relevant sound pressure levels are normally at frequencies of 40–100 Hz. The results comply with observations made in other studies and experiments.

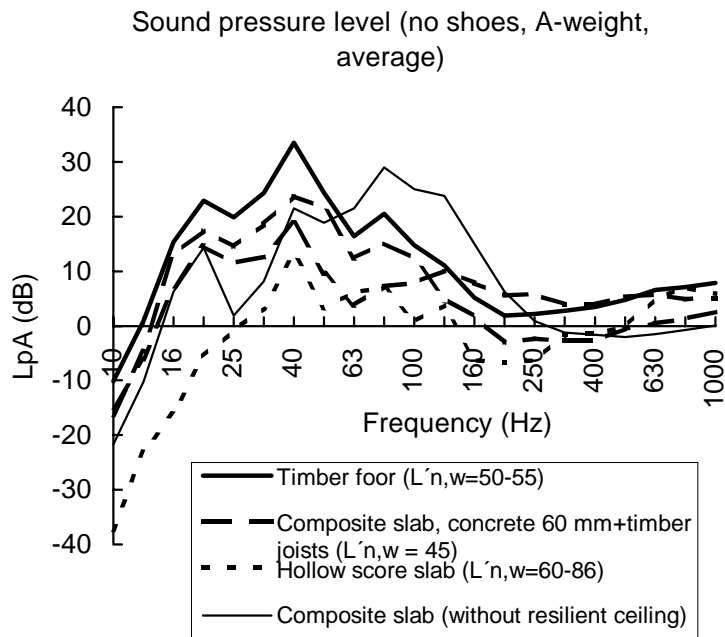


Figure 11. Sound pressure levels due to walking (laboratory measurement, A-weighted and normalised to an absorption area of 10 m^2). Note the sound pressure levels of a composite and a hollow core concrete slab floor at low frequencies.

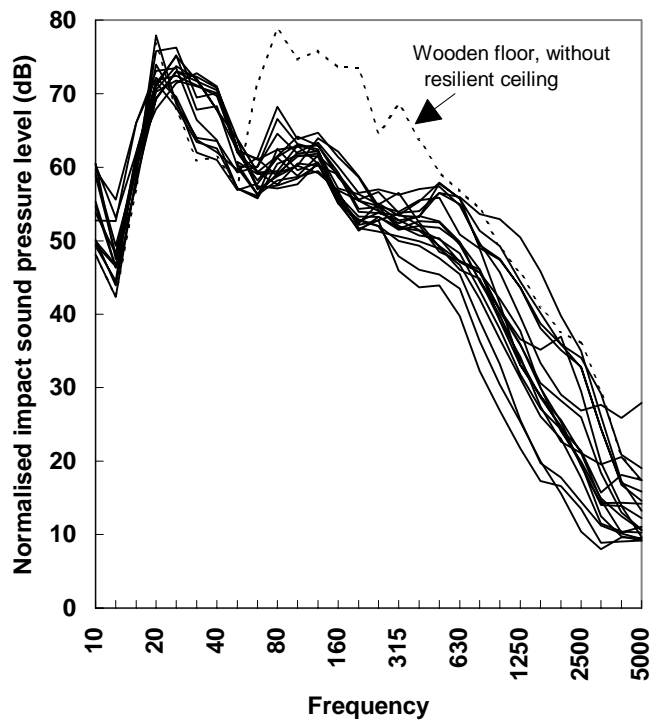


Figure 12. Normalised impact sound pressure levels due to a tapping machine (laboratory measurement).

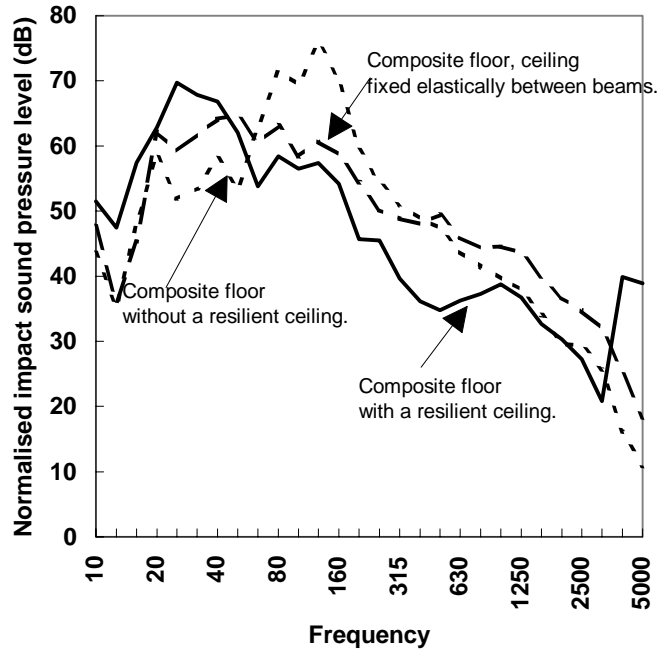


Figure 13. Normalised impact sound pressure level with composite floor (laboratory measurement, tapping machine).

At low frequencies sound pressure levels due to walking are smaller the heavier the floor (Figure 11). Laboratory measurements also shows that a floating floor does not inevitably improve the impact sound insulation against normal walking.

The impact sound pressure levels of different wooden floors are presented for comparison in Figures 12 and 13. Clearly the results deviate little from each other. The effect of the resilient ceiling on impact sound insulation can also be seen in Figures 12 and 13. In contrast, the resilient ceiling structure causes slight deterioration of the impact sound insulation properties below 50 Hz.

5 Conclusions and needs for further research

The competitiveness of high rise buildings made of timber is strongly influenced by the impressions of inhabitants. How inhabitants experience and judge the impact sound insulation of wooden floors in practice is central issue. The impression they receive (judgement they give) does not necessarily correspond to the one afforded by the value of $L_{n,w}$. This can be regarded as the most serious acoustical problem or a possible risk for wooden multi-storey buildings.

Different rating methods and rating values have been studied in the light of subjective scoring. According to these the rating method proposed by Fasold seems to be the most promising. Future research and studies should be targeted to collect the experiences of inhabitants from different floors and to develop and refine Fasold's method regarding current living (impacts of normal living) and floor structures used.

With the tested layered wooden floor structures the target level ($R_w \geq 55$ dB) for airborne sound insulation was reached with a sufficient margin. With most of the floors the target level for impact sound insulation ($L_{n,w} \leq 53$ dB) was also met. It should, however, be borne in mind that it is possible to produce acoustically good floors even with greater values of $L_{n,w}$, provided that harmful effects due to low frequencies can be reduced. As expected, the best impact sound insulation was measured with the composite floor construction. Also one modification of a composite floor without a resilient ceiling had a fairly good impact sound insulation (for the frequency range 50–5 000 Hz). In practice, one possibility would be to make the concrete slab of the composite floor even thicker and heavier in order to build the floor without a floating layer or otherwise to optimise the floor structurally.

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