Impact Sound Insulation and Perceived Sound Quality

Clas Ola HØSØIEN[1]; Jens Holger RINDEL[2]; Anders LØVSTAD[3]; Ronny KLÆBOE[4]

[1, 2, 3] Multiconsult ASA, Norway

[4] Institute of Transport of Economics, Norway

ABSTRACT

An investigation into objective and perceived value of sound quality in dwellings in Norway was carried out in 2015. Three main findings regarding impact sound are presented here. Firstly, impact sound from neighbours above is perceived as disturbing as traffic noise, with approximately 20 % of the respondents stating they are extremely, very or moderately annoyed with noise from both types of sources. Secondly, problems with low frequency impact sound has been connected to lightweight wood-based floors, but it is found to be equally significant also for floating floors on concrete constructions. Thirdly, when analysing the data using the single-number quantities $L'_{n,w}$ (weighted standardized impact sound pressure level) or $L'_{nT,w}$ (weighted normalized impact sound pressure level), it was not possible to establish a statistically significant connection between objective and subjective impact sound quality. By including the frequency adaptation term ($C_{I,50\text{-}2500}$), the connection proved significant. The analysis also showed that $L'_{nT,w} + C_{I,50\text{-}2500}$ seems to predict resident annoyance better than $L'_{n,w} + C_{I,50\text{-}2500}$.

1. INTRODUCTION

During the autumn of 2015, an extensive investigation into objective and perceived value of sound quality in dwellings in Norway was carried out (1). The results are to be used to assess the present sound insulation requirements given as qualitative statements in the "Regulations on technical requirements for building works" (2), e.g. "Satisfactory acoustic conditions shall be ensured for work, rest, recreation, sleep, concentration […]". Qualitative requirements are quantified as class C in the national classification standard, NS 8175 (3). For impact sound in dwellings the present "satisfactory acoustic condition" is defined as the single-number quantity (SNQ) $L'_{n,w} \leq 53$ dB. In accordance with ISO 717-2 (4) the frequency range for impact sound insulation rating is 100-3150 Hz.

The standard also states that the enlarged frequency spectrum adaptation term $C_{I,50\text{-}2000}$ should be taken into consideration, mainly because of low frequency problems in lightweight constructions, but this is not mandatory.

It is widely accepted that low end spectrum correction terms should be used for rating lightweight constructions. The socio-acoustic survey referred here shows that the frequency adaptation term is necessary also for heavy constructions to achieve correlation between objective and subjective impact sound rating.

2. SOCIO-ACOUSTIC SURVEY

The investigation is based on field measurements of sound insulation in 600 dwellings combined with a questionnaire survey sent to nearly 4000 residents. The response rate was 18 %.

The questionnaire was based on the questionnaire design developed in the COST Action TU0901 (5), reducing the annoyance categories to five (extremely, very, moderately, slightly and not annoyed) from the 11 categories (0-10) in the COST Action design.

Almost all respondents, 97 %, are living in multi-storey apartment buildings. 83 % of the respondents are living in buildings with concrete slabs as load bearing constructions, either reinforced

[1] clas.ola.hosoien@multiconsult.no
[2] jens.holger.rindel@multiconsult.no
[3] anders.lovstad@multiconsult.no
[4] ronny.klaeboe@toi.no

in situ cast concrete, or precast hollow core concrete. The remaining 17 % lives in buildings with lightweight floor constructions. For an overview of other aspects and results of the survey, see Løvstad (6) and Milford (7).

3. ANNOYANCE DUE TO IMPACT SOUND

The question about vertical impact sound in the survey was formulated (translated from Norwegian) "Thinking about the last 12 months at home, how annoyed are you by […] impact sound from neighbours living above you: walking, running, jumping, furniture being moved, other impacts and so on?". Speech (including TV etc.) and music was handled separately, without differentiating between sounds perceived coming from walls and sounds perceived coming from floors.

Figure 1 shows the responses for speech, music, footfall (i.e. impact noises), traffic and noise in general. "All sources" includes both indoor and outdoor sources, while speech, music and footfall are all indoor sources.

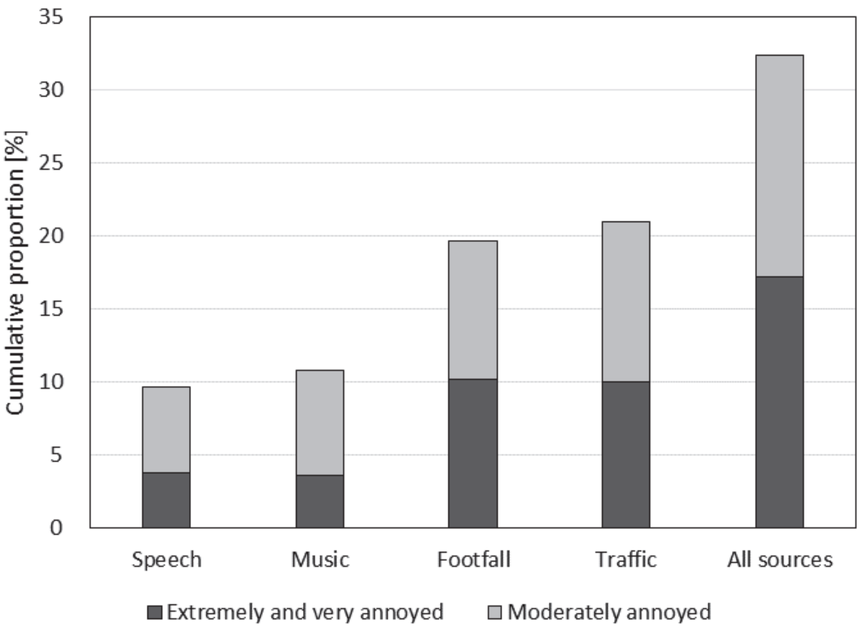

Figure 1: Proportion respondent reported annoyance (moderately or more) related to different noise sources.

According to the report "Helsetilstanden i Norge" ("State of the population health in Norway") (8), approximately 25 % of the population in Norway are exposed to traffic noise exceeding L_{DEN} = 55 dB. The report (8) also states that about half a million people are very disturbed by traffic noise, which amounts to approximately 10 % of the total population. Because of the survey sample selection, the results in Figure 1 does not represent the average annoyance of the population as a whole, but the survey results for traffic noise annoyance are comparable to the numbers reported on a national level. Thus the results from the survey are indicating the importance of impact sound insulation, and with a growing proportion of the population living in multi-storey buildings, the impact sound annoyance issue is likely to grow correspondingly.

Table 1 shows the total number of related responses-measurements for different impact sound descriptors, the minimum, maximum and mean values for lightweight and heavy load bearing constructions combined. The lightweight construction mean values for descriptors without the adaptation term is approximately 3 dB higher than the total mean. There is no difference between lightweight construction mean and total mean values for descriptors including the adaptation term.

Table 1: Number of responses, minimum, maximum and mean values for impact sound descriptors

Descriptor	Number	Minimum	Maximum	Mean	Standard dev.
$L'_{n,w}$	473	41 dB	60 dB	49,4 dB	4,1
$L'_{n,w} + C_{I,50\text{-}2500}$	439	44 dB	61 dB	53,7 dB	3,0
$L'_{nT,w}$	411	38 dB	56 dB	45,4 dB	5,0
$L'_{nT,w} + C_{I,50\text{-}2500}$	402	40 dB	57 dB	50,1 dB	2,0

When analysing the data, it was not possible to establish any correlation between perceived sound quality and measured impact sound pressure levels without the frequency adaptation term, i.e. $L'_{n,w}$ and $L'_{nT,w}$. This is evident from Figure 2, where predicted annoyance is constant for all SNQ values. In general an S-cure should be expected for such exposure-effect relationships (9).

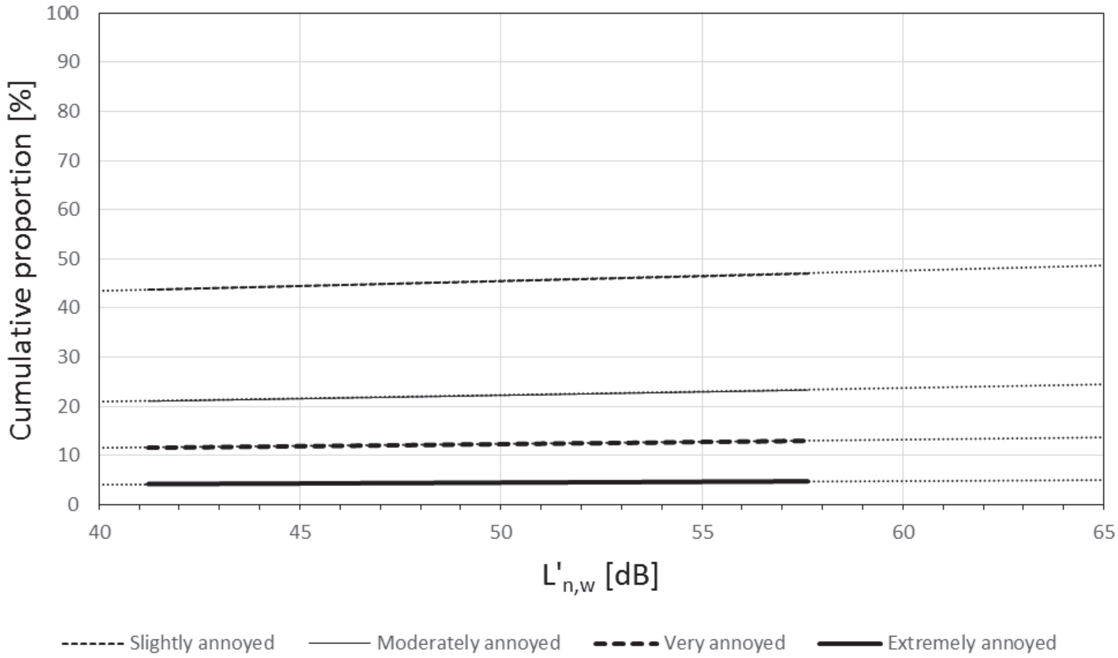

Figure 2: Cumulative proportion of annoyance for weighted normalized impact sound pressure level, $L'_{n,w}$.

Bold sections of the lines represents 95 % confidence interval of the range of the measured data.

Including the enlarged frequency adaptation term $C_{I,50\text{-}2500}$ for data analysis, the correlation between measurement data and responses was statistically significant, see Figure 3 and Figure 4. The interval of impact sound values for the standardized SNQ is rather narrow, see also Table 1, and the slopes are quite steep (Figure 3), approximately 6.7 % per dB for slightly annoyed.

The slope for slightly annoyed in Figure 3 is approximately 3.3 % per dB, and the normalized SNQ including adaptation term is therefore more in accordance with the range referred by Rindel (9), i.e. 2.96-4.43 % per dB.

The regression analysis showed that $L'_{nT,w} + C_{I,50\text{-}2500}$ predicts the resident perception slightly better than $L'_{n,w} + C_{I,50\text{-}2500}$. Because of the narrow confidence interval, the standardized SNQ should be used with care for resident annoyance predictions for constructions with $L'_{nT,w} + C_{I,50\text{-}2500} \geq 54$ dB.

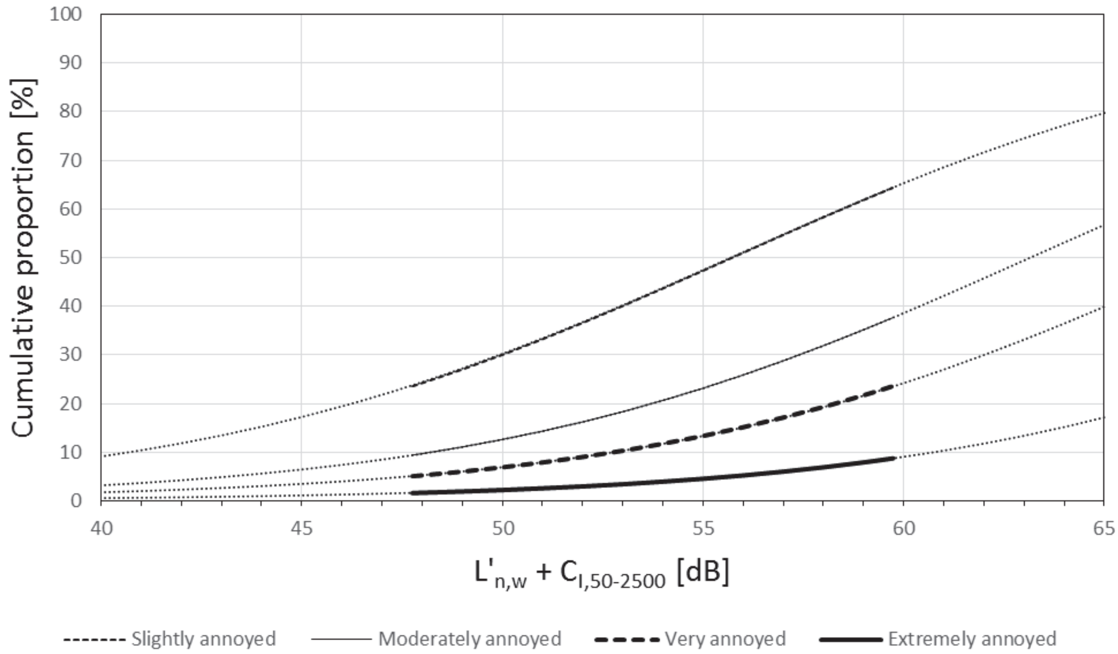

Figure 3: Cumulative proportion of annoyance for weighted normalized impact sound pressure level including spectrum adaptation term, $L'_{n,w} + C_{I,50\text{-}2500}$. Bold sections of the lines represents 95 % confidence interval of the range of the measured data.

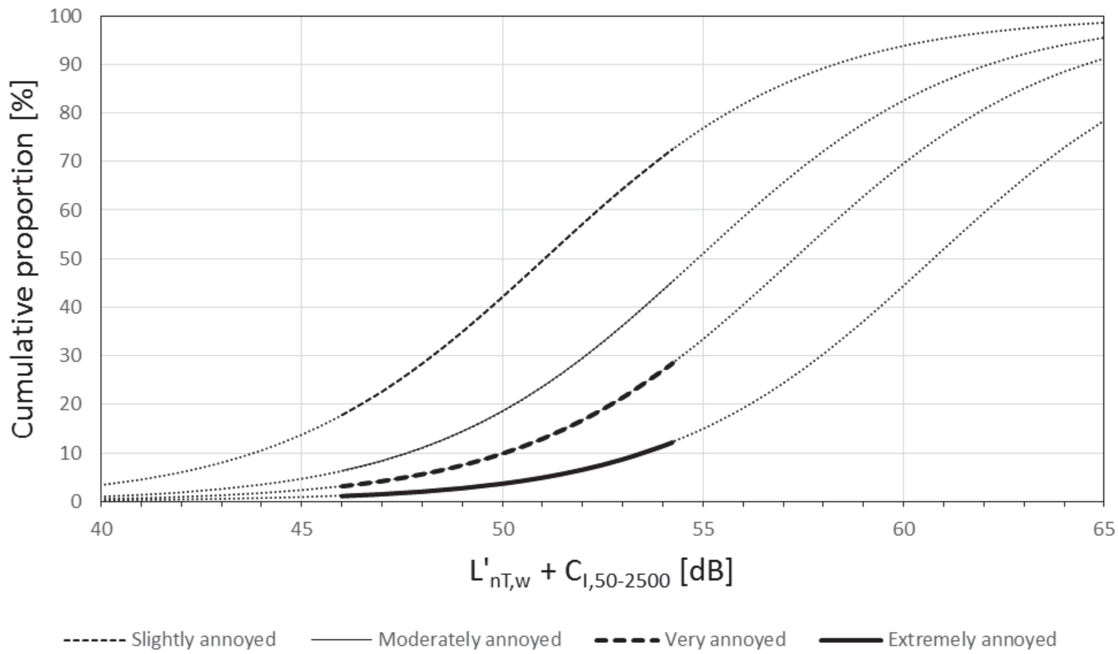

Figure 4: Cumulative proportion of annoyance for weighted standardized impact sound pressure level including spectrum adaptation term, $L'_{nT,w} + C_{I,50\text{-}2500}$. Bold sections of the lines represents 95 % confidence interval of the range of the measured data.

4. FLOOR CONSTRUCTIONS AND MEASUREMENT RESULTS

The main reason for lack of significance between subjective and objective value for SNQ's $L'_{n,w}$ and $L'_{nT,w}$ was found to be related to the floating floor constructions. Excluding lightweight floor constructions, approximately 50 % of the respondents, where the sound measurement data included the enlarged frequency range, are living in buildings with floating floors on concrete slabs. Flooring in the other half of the buildings is typically parquet and soft underlay directly on concrete slabs. Floating floor example

Figure 5 shows the principle for one of the buildings included in the survey where the construction consisted of floating floor on load bearing concrete.

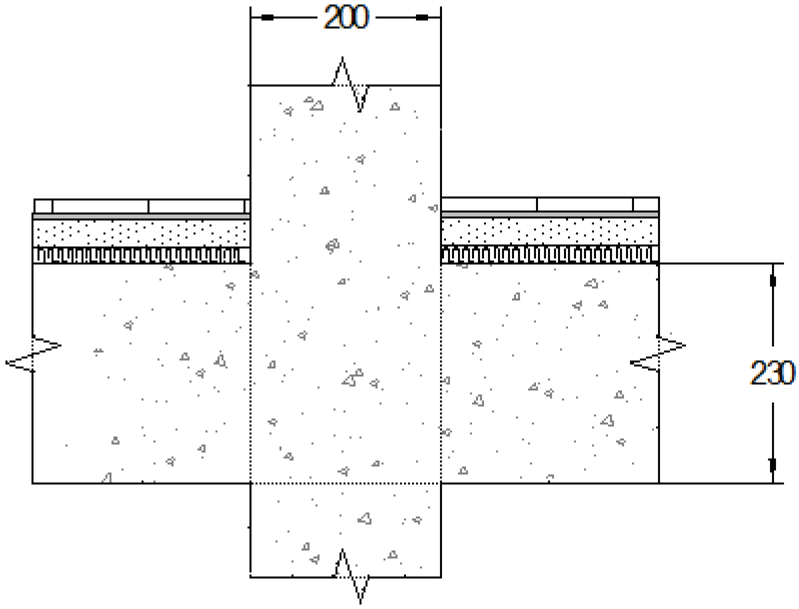

Figure 5: Example of load bearing construction combined with floating floor.

The example construction is 230 mm in situ cast concrete slabs combined with 200 mm in situ cast concrete walls. The floating floor is made of 14 mm multilayer parquet, 3 mm soft underlay, minimum 30 mm self levelling fibre-reinforced cementitious screed, and 15-20 mm mineral fibre board, which is typical dimensions for floating floors in Norway.

In this mass-spring-mass system, with the screed and the concrete slab as masses and the mineral fibre board as spring, the resonance frequency can be calculated by Equation 1:

$$f_0 = \frac{1}{2\pi}\sqrt{\frac{s}{m_1} + \frac{s}{m_2}} \tag{1}$$

where s is the total stiffness of the spring, which in this case is the sum of the mineral fibre board dynamic structural stiffness and the air cavity dynamic stiffness, m_1 the screed unit area mass (area density) and m_2 the unit area mass of the supporting structure.

Table 2 shows approximate material properties for the example in Figure 5 (mainly from (10)).

Table 2: Materials and properties

Material	Thickness	Density	Other properties
Reinforced concrete	230 mm	2400 kg/m^3	-
Mineral fibre board	15 mm	125 kg/m^3	s = 12 MN/m^3
Self levelling screed	30 mm	1900 kg/m^3	-

Inserting the parameters in Table 2 into Equation 1, the calculated resonance frequency is f_0 = 77 Hz. As a result, the floating floor resonance frequency does not affect ratings using descriptors limited to the frequency range f = 100-3150 Hz, but is within the the $C_{I,50\text{-}2500}$ adaptation term frequency range.

The resonance frequency for similar floating floors on precast hollow core concrete slabs is within the same frequency range. Unit area mass for hollow core slabs with thickness 200-420 mm is in the range m = 290-540 m^2 (11), resulting in resonance frequencies f_0 = 77-80 Hz according to Equation (1) given the same floating floor construction as described above.

4.1 Some measurement results

All field measurements included in the survey were carried out according to ISO 140-7 (12) using a standard tapping machine, and rated according to ISO 717-2 (4).

Table 3 and Figure 6 (a) shows the calculated mean values from measurements of impact sound in eight dwellings in a housing project with the floor construction described in Figure 5. The effect of the floating floor resonance is clearly apparent in Figure 6 (a) and Figure 7 (a), and strongly affects the impact sound ratings with and without the spectrum adaptation term.

Table 3 also shows the calculated mean value for one sample from each of seven other housing projects included in the survey. These housing projects were built with two types of slabs: 290-320 mm precast hollow core concrete and 220-250 mm in situ cast concrete, and parquet on soft underlay laid directly on the load bearing construction. Table 3, Figure 6 (b) and Figure 7 (b) shows that a relatively light parquet layer on a thin soft underlay does not affect the load bearing construction's low frequency properties. The resonance frequency for different parquet/underlay-combinations is visible in the 1/3 octave bands 315, 400 and 500 Hz in Figure 6 (b) and Figure 7 (b), depending on the parquet unit area mass and the underlay's dynamic stiffness.

Table 3: Mean values for floating floor and parquet on soft underlay on concrete load bearing constructions.

Floor	Mean $L'_{n,w}$	Mean $L'_{n,w} + C_{I,50\text{-}2500}$
Floating	44 dB	57 dB
Parquet on soft underlay	53 dB	53 dB

The mean spectrum adaptation term for the floating floor example is 13 dB. In a new high quality housing project in Germany with 250 mm concrete slabs, floating floor, and suspended ceiling, referred by Schirmer and Schirmer (13), the spectrum adaption term was as large as 20 dB, resulting in impact sound ratings $L'_{n,w}$ = 34 dB and $L'_{n,w} + C_{I,50\text{-}2500}$ = 54 dB.

Wolf and Burkhart (14) refer complaints about insufficient low frequency impact sound insulation from residents in multi-storey buildings, even though the requirements, given as SNQ $L'_{n,w}$, are fulfilled. The paper concludes that $L'_{n,w}$ alone is not suitable to assess impact sound transmission, and that floating floor design should as a minimum aim at mass-spring-mass resonance frequency lower than 40 Hz.

4.2 Objective and subjective rating of impact sound on concrete slabs

The socio-acoustic survey has established a correlation between objective and subjective rating of impact sound for concrete constructions based on SNQ's including the spectrum adaptation term $C_{I,50\text{-}2500}$. A study conducted by Kylliäinen et al. (15) found that walking with hard-heeled shoes and moving of furniture correlates well with SNQ's based on the standard tapping machine, $L'_{n,w}$, $L'_{n,w} + C_I$ and $L'_{n,w} + C_{I,50\text{-}2500}$. The latter was in general performing better than the two ratings limited to 100 Hz. Walking with socks did not correlate with the same SNQ's, while the correlation with walking with soft-heeled shoes was weak. The results in the socio-acoustic survey presented here includes a variety of impact sound sources, which might explain the obtained correlation.

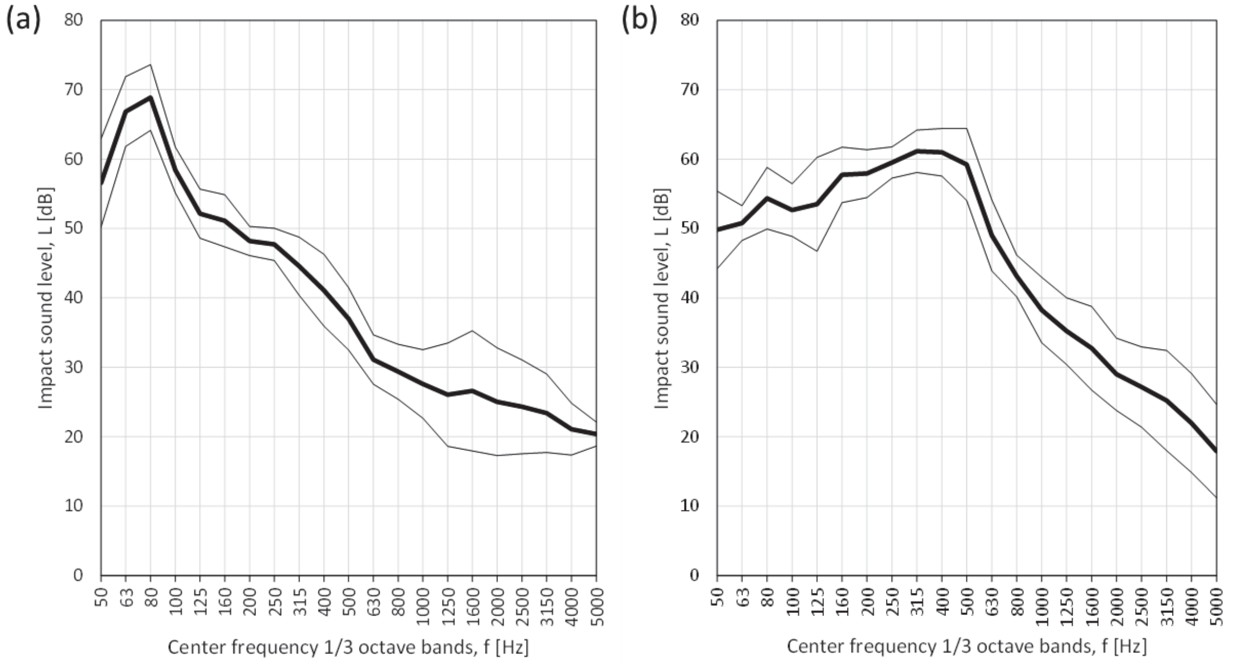

Figure 6: Mean impact sound spectrum (bold black), 95 % confidence interval (grey) for (a) floating floor and (b) parquet on soft underlay on concrete slabs.

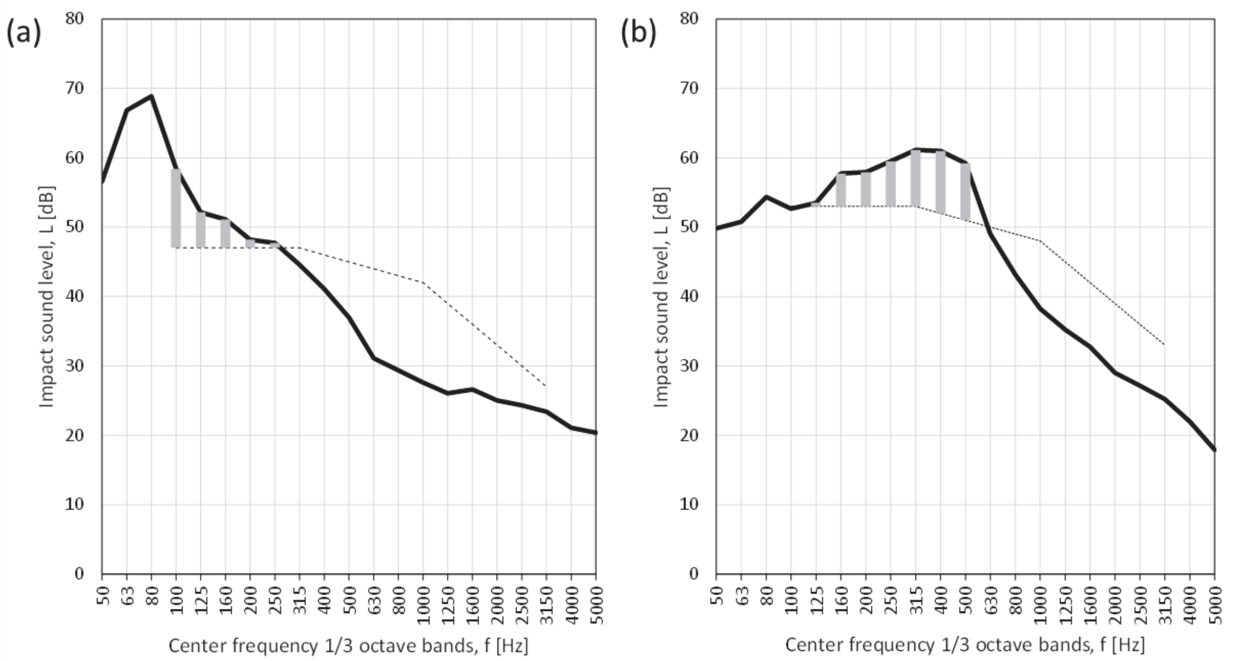

Figure 7: Mean impact sound spectrum (bold), shifted reference curve (dashed), and unfavourable deviations from the reference curve (grey columns) for (a) floating floor and (b) parquet on soft underlay on concrete slabs.

5. SUMMARY

An extensive socio-acoustic survey conducted in Norway in 2015 has found that impact sound is perceived as annoying as traffic noise. Given that a growing proportion of the population is living in multi-storey buildings, the impact sound annoyance issue is likely to grow correspondingly.

The survey has established several exposure-effect relationships. To obtain such correlation between impact sound and the respondents' subjective rating, it is necessary to expand the objective rating below 100 Hz. In this case the spectrum adaptation term $C_{I,50\text{-}2500}$ was used.

Most of the respondents in the survey are living in concrete construction buildings. Excluding respondents living in buildings with wooden floor constructions, approximately 50 % are living in buildings with floating floors, and the other half of the respondents are living in buildings with parquet and soft underlay directly on the concrete slabs.

One effect of introducing floating floors is that the mass-spring-mass resonance dramatically alters the low frequency response of the construction. The initial advantages related to large mass and stiffness disappear in both objective and subjective rating terms when the frequency range is extended to 50 Hz. This implies that low frequency impact sound transmission is not exclusively a wooden floor construction issue, but must also be addressed when in concrete floor constructions.

ACKNOWLEDGEMENTS

The socio-acoustic survey was supported by “Direktoratet for byggkvalitet” (DIBK), National Office of Building Technology and Administration, Norway. The initial preparation of the measured data from building sites were done by Sigrid Husebø Øygard. Hanne Beate Sundfør at the Institute of Transport Economics assisted with the preparation and analysis of the questionnaire.

REFERENCES

1. DiBK. Lydforhold i boliger. Evaluering av byggtekniske krav til lydforhold, (In Norwegian). Document code 127762-RIA-RAP-001. Oslo, Norway: Direktoratet for byggkvalitet (DiBK), National Office of Building Technology and Administration; 2016 mar.
2. Regulations on technical requirements for building works, (In Norwegian). Direktoratet for byggkvalitet (DiBK), National Office of Building Technology and Administration; 2010.
3. NS 8175. Lydforhold i boliger. Lydklasser for ulike bygningstyper, (In Norwegian). Norway: Standard Norge; 2012.
4. ISO 717-2. Acoustics. Rating of sound insulation in buildings and of building elements. Part 2: Impact sound insulation. Second Edition 1996, Third Edition 2013. Geneva, Switzerland: Organization for Standardization; 1996 2013.
5. COST Action TU0901. Integrating and Harmonizing Sound Insulation Aspects in Sustainable Urban Housing Constructions. European Cooperation in Science and Technology; 2014.
6. Løvstad A, Rindel JH, Høsøien CO, Klæboe R. Sound quality in dwellings in Norway - a socio-acoustic investigation. Proceedings of BNAM. Stockholm; 2016.
7. Milford I, Høsøien CO, Løvstad A, Rindel JH, Klæboe R. Socio-Acoustic Survey of Sound Quality in Dwellings in Norway. Proceedings of InterNoise. Hamburg; 2016.
8. Helsetilstanden i Norge, (In Norwegian). Folkehelseinstituttet; 2014 s. 261. Report No.: 2014:4.
9. Rindel JH. Acoustic Quality and Sound Insulation Between Dwellings. J Build Acoust. 1999;5(4):291–301.
10. Byggdetaljblad 573.420: Materialer med spesiell funksjon. Lyddata for materialer og konstruksjoner, (In Norwegian). Oslo, Norway: SINTEF Byggforsk; 1996 nov.
11. Betongelementboken - bind E, (In Norwegian). 2. utg. Betongelementforeningen; 2000.
12. ISO 140-7. Acoustics. Measurement of sound insulation in buildings and of building elements. Part 7: Field measurements of impact sound insulation of floors. Geneva, Switzerland: Organization for Standardization; 1998.
13. Schirmer H, Schirmer W. Schwimmender Estrich und Unterhangdecke mit schwach gedämpfter Eigenfrequenz fast gleicher Grösse als Ursache für erhöhe tieffrequente Trittshallübertragung, (In German). Proceedings of DAGA. Aachen; 2016.
14. Wolf M, Burkhart C. Vermeidungsstrategien und Ansätze einer Vermeidung des Estrichdröhns, (In German). Proceedings of DAGA. Aachen; 2016.
15. Kylliäinen M, Lietzén J, Kovalainen V, Hongisto V. Correlation Between Single-Number-Quantities of Impact Sound Insulation and Various Noise Ratings of Walking on Concrete Floors. Acta Acust United Acust. 2015;101:975–85.