Perceived sound quality in dwellings in Norway

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ABSTRACT

Based on field measurements of sound insulation in 600 dwellings, a questionnaire survey was sent to nearly 4000 residents from which 702 responses were obtained. Thus, the questionnaire responses could be evaluated based on the actual measured sound quality in the respective buildings. The quantity and range in the measurement results allowed for the establishment of exposure-effect relationships for annoyance caused by both airborne and impact sound insulation. Additionally, annoyance due to different sound sources and levels were assessed, as well as effects of using light or heavy building structures, frequency range required in the evaluation of sound insulation, willingness to pay for improved sound quality, and whether people limit themselves to ensure that neighbours are not annoyed.

INTRODUCTION

Sound quality and noise exposure affect the quality and well-being of residents. Presently, the Norwegian regulations on technical requirements for building works [1] are under revision. The purpose for issuing a revision from the government side is to make the regulations simpler, more effective, knowledge-based and verifiable. In order to form a basis for evaluation of the part of the regulations concerning sound quality, an extensive socio-acoustic survey has been done [2], aiming to assess whether present sound insulation and noise level requirements in dwellings are adequate or in need of revision. The survey mainly comprises multi-unit houses, as there are no sound requirements in single unit dwellings.

The present minimum sound insulation requirements between dwellings and towards common corridors or staircases in Norway are $R'_{w} \geq 55$ dB and $L'_{n,w} \leq 53$ dB [3], and have remained unchanged since 1997 [4]. Thus, only frequencies from 100 to 3150 Hz are considered, although the regulations have included a recommendation to consider frequencies down to 50 Hz by addition of the spectrum adaptation terms $C_{50\text{-}5000}$ and $C_{I,50\text{-}2500}$, which unfortunately rarely are strived for in practice. The inclusion of these low-frequency adaption terms are assessed, as well as employment of the standardised parameters $D_{nT,w}$ and $L'_{nT,w}$, as these can be calculated from the measurement data as described in ISO 717-1 [5] and ISO 717-2 [6].

Considering the population in Norway as a whole, only 17 % live in multi-unit houses [7]. Thus, the survey does not represent the average annoyance of the population as a whole, but give a solid basis for evaluation of sound insulation and noise level limits where they apply.

METHOD

The survey is based on field measurements carried out in 600 dwellings from 2002-2015. In projects with several equal multi-unit houses, residents in all houses received the survey, assuming the same building performance in all buildings. Questionnaires were sent to 3849 persons, of which 702 responded, giving a response rate of 18 %. The budget and time available did not open for a follow-up on those not answering in the first round. In addition, about 1500 students at three campus sites received questionnaires, from which 386 responded. These two selections are labelled the main and student selections, respectively.

The main motivation for including students were to enhance the data set for small units. As no measurements data were available for the student selection, sound insulation data were calculated based on available construction data.

The questionnaire developed in COST Action TU0901 [8] was used as basis, and adapted to the recommendations given in ISO/TS 15666 [9], using a 5-point scale. The questions used in social surveys on noise problems are paramount for the quality of the results, and details concerning the way questions were asked and the wording of the possible answers followed recommendations given in ISO/TS 15666 [9]. Annex B in the standard recommends wordings in various languages including Norwegian, as used in this investigation. The questions and possible answers are of this form: "Thinking about the last 12 month, when you are at home, how much are you annoyed of noise from … ? Not at all – Slightly – Moderately – Very – Extremely".

The questionnaire consisted of 35 different questions in addition to background information about the respondents. The questions can be grouped as:

- annoyance due to noise inside and outside of the dwelling
- noise sensitivity
- annoyance due to specific noise sources or neighbours
- restrictions on own behaviour not to disturb others
- willingness to pay for a better sound insulated dwelling

To obtain statistically reliable results, a good spread in the sound insulation and noise source levels is essential. Figure 1 (a) and (b) show the distribution in measurement results for weighted apparent sound reduction index, R'_{w}, and the weighted normalised impact sound pressure level, $L'_{n,w}$, respectively. Results are divided into light and heavy constructions in order to assess their perceived sound qualities separately. As expected, the heavy constructions are better than the light ones both for airborne and impact sound insulation.

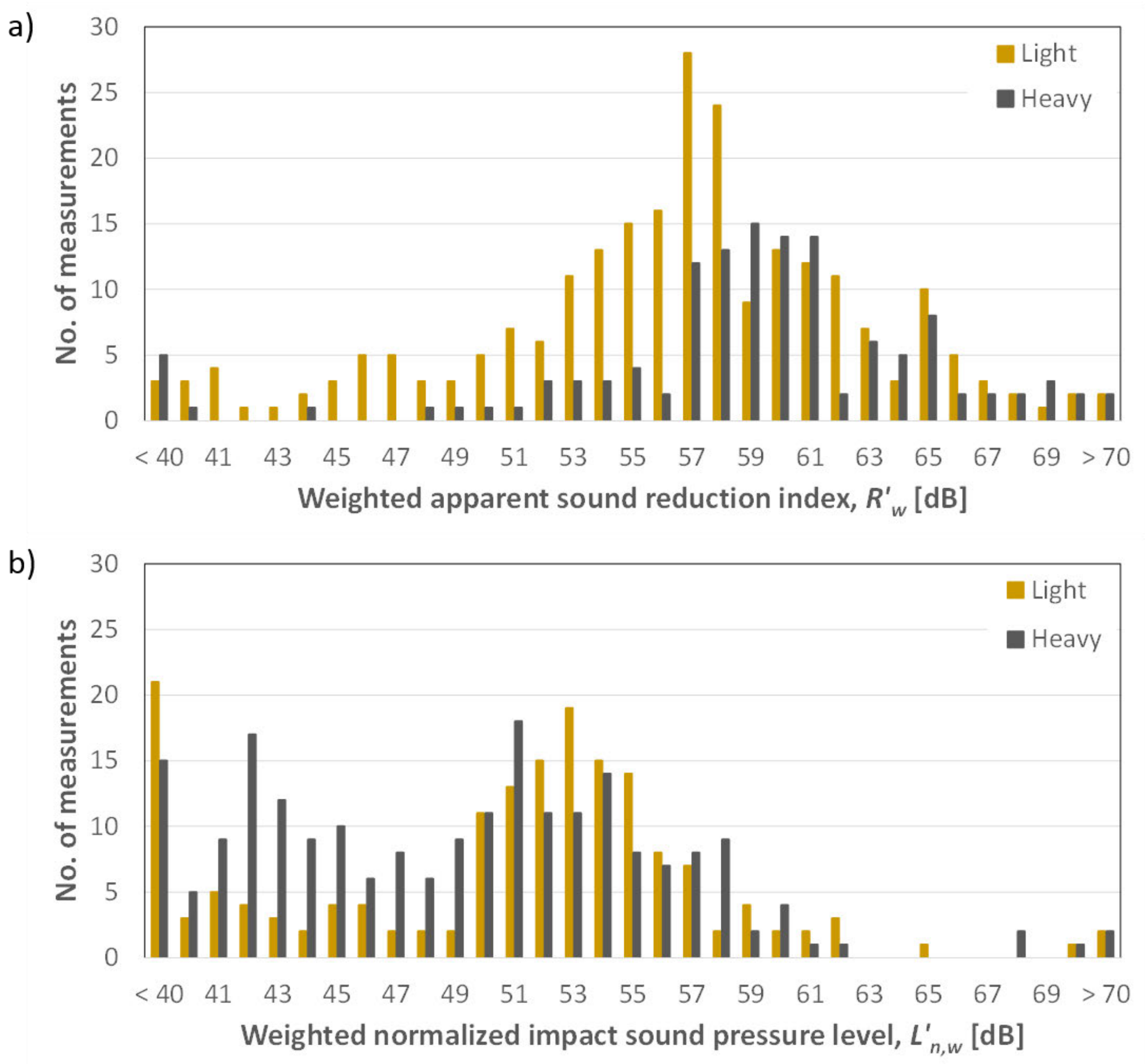

Figure 1: Distribution of measurement results for (a) R'_w and (b) $L'_{n,w}$.

GENERAL ANNOYANCE AND RESTRICTIVE BEHAVIOUR

Which noise sources contribute the most to the total sound level in and around a building depends on several factors, e.g. where and how the building is built, the neighbours, the residents' sensitivity to noise. Figure 2 shows the annoyance due to different sound sources, separated into extremely, very, moderately and slightly annoyed. It is found that around 2/3 of the residents are annoyed by noise to some extent.

10 % of the residents answer that they are moderately or more annoyed by speech or music. More surprisingly, footfall noise is reported to be comparable and even slightly more annoying than traffic noise as more than 40 % are annoyed to some extent, and 20 % are at least moderately annoyed from these noise sources. It was not within the scope of the project to evaluate traffic noise specifically, so noise exposure levels from traffic have not been correlated with the responses obtained. However, there is no reason to believe that these are particularly low. Complaints due to impact sound are well known, especially for lightweight constructions.

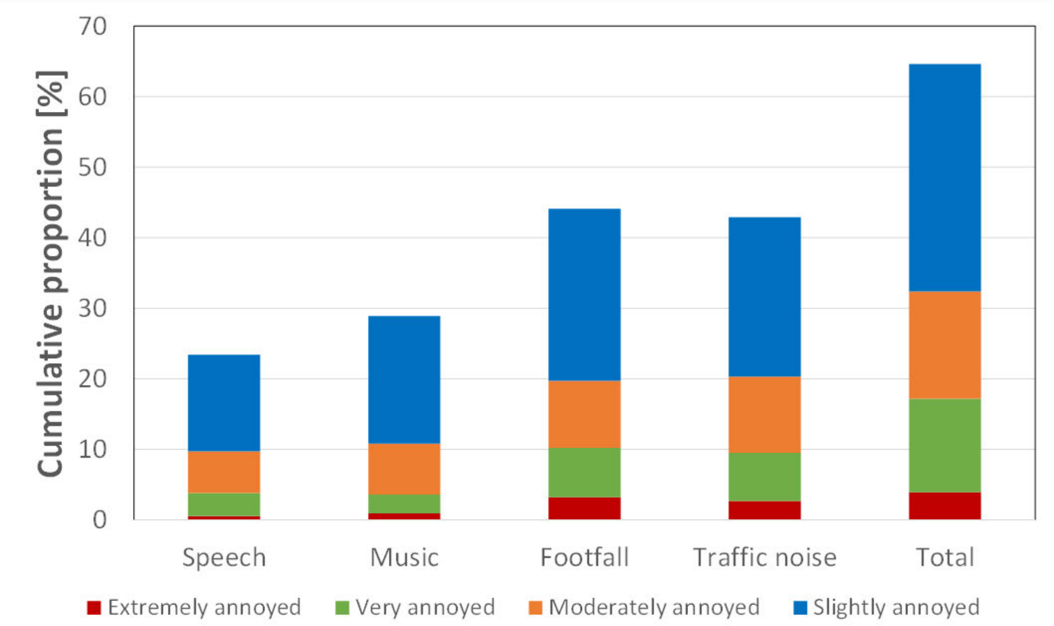

Figure 2: Cumulative proportion of annoyance due to different sound sources.

Negative effects of noise and lack of sound insulation are commonly related to health issues and reduced quality of living for the receiver being exposed to these high noise levels. Another interesting aspect is whether one restricts oneself in ones doings in fear of being a nuisance to neighbours and annoy them. In Figure 3, results from questions regarding annoyance and questions on whether one is worried about disturbing others are placed together.

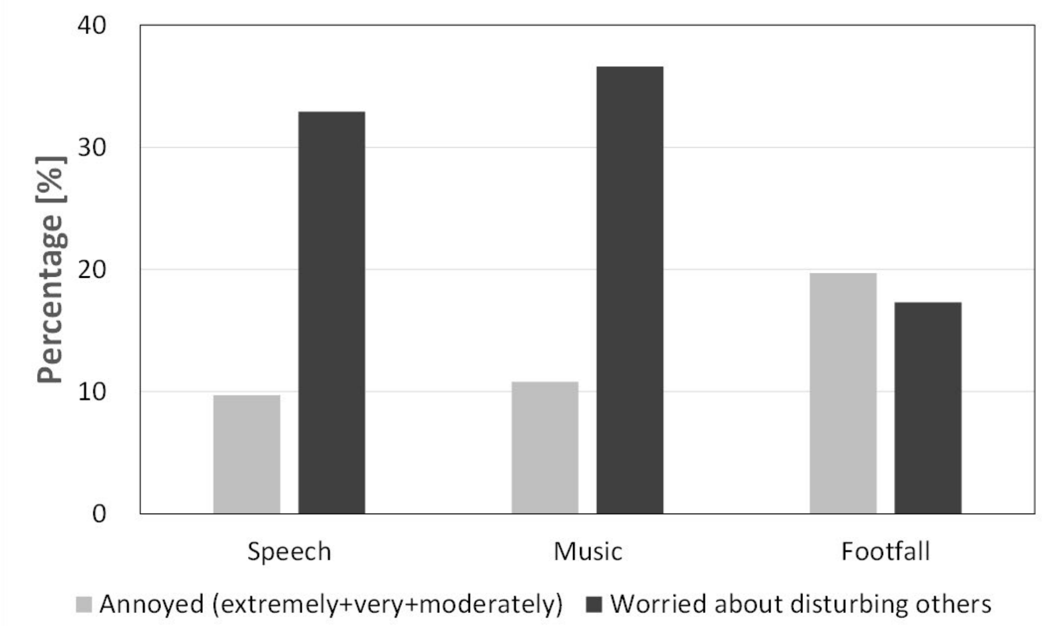

Figure 3: Annoyance due to different sound sources.

As many as 1 out of 3 report that they are worried that airborne noise sources such as TV, music, speech may annoy their neighbours, while only around 10 % reports to be moderately or more annoyed. This indicates that people are likely to limit themselves to a certain extent in consideration of their neighbours for these types of activities, which includes playing a musical instrument. With footfall noise this is not the case, and the percentage worried about disturbing others is slightly lower than the percentage of those annoyed by it.

WILLINGNESS TO PAY

Strict sound insulation requirements and noise limits will reduce annoyance, but in most cases housing units will be more expensive to build in order to acquire such qualities. When asked if the current regulations on noise and sound insulation are too strict or too lenient, only 1 % of the respondents in the main selection thinks the regulations are too strict, while 38 % answered that the requirements are too lenient, as shown in Figure 4a.

Around 50 % of the 702 replies in the main selection would not pay extra for better sound insulation, but around 20 % were willing to pay from 6 000 to 12 000 NOK extra per year, as Figure 4b shows. Figure 4c assesses the opposite question, less sound insulation for a reduced monthly payment. 86 % replied that this would be out of question; only 10 % would accept lower sound insulation against a lower payment of around 12 000 NOK per year.

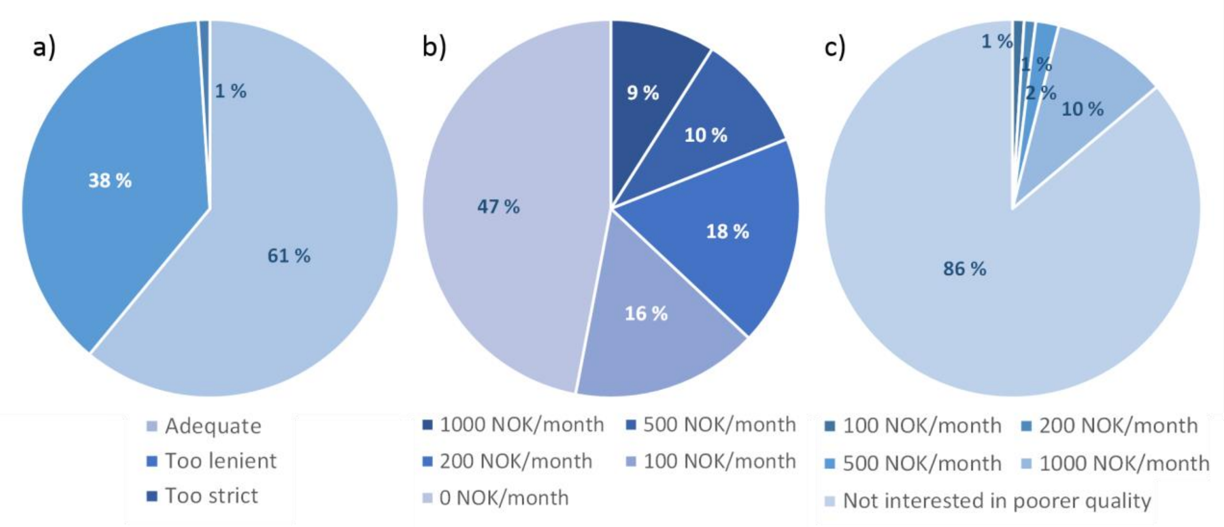

Figure 4: a) The respondents' opinion about the national sound insulation requirements for dwellings, b) Willingness to pay for better sound insulation, and c) willingness to accept poorer sound insulation for a compensatory amount.

AIRBORNE SOUND INSULATION

Annoyance levels due to airborne sound insulation between units indicated that the present requirement of $R'_w \geq 55$ dB is set at a reasonable level. Similar annoyance levels were found for normalised and standardised descriptors. For music with bass and drums, inclusion of the low-frequency spectrum adaptation term, $C_{50\text{-}5000}$, gave slightly better correspondence, but there was no significant difference, probably because the general level of sound insulation is quite high. These results are further discussed in [2,10].

As sound sources in dwellings enabling high volumes in the low frequency range 50-80 Hz become increasingly common in residential buildings, the low frequencies should be included in the evaluation and building requirements for airborne sound. Other researchers have found stronger evidence of the need to protect against these types of sounds, which are most critical and cause the most annoyance, as discussed by Rindel [11].

Small flats were of specific interest for the government in order to investigate whether building procedures could be simplified and be more area-effective. Present building regulations require two doors between corridors or common areas to comply with $R'_w \geq 55$ dB. In practice, the sound insulation comply with the regulations only when there is a separate hall or entrance. With just a single door between living room and corridor, the sound insulation is significantly below the requirement, typically in the range from $R'_w \geq 35\text{-}45$ dB.

Figure 5 shows cumulative annoyance due to sound insulation from corridors and staircases to housing units. The mean apparent sound reduction index value, R'_w, was 51.6 dB with a standard deviation of 7.0 dB. As mentioned above, there is a leap in sound insulation between situations where one or two doors are used. With two doors $R'_w \geq 55$ dB is achieved, while results are typically 10-15 dB below this limit with a single door between the housing unit and adjacent corridor or staircase. Thus, the measurement results are unevenly distributed, and therefore not the best basis for evaluation. Still, the results indicate that satisfactory sound insulation are achieved at around $R'_w \geq 50$ dB, but using one door between corridors and housing units are probably not sufficient in most cases. The degree of annoyance was found to be independent of at which floor the units were located.

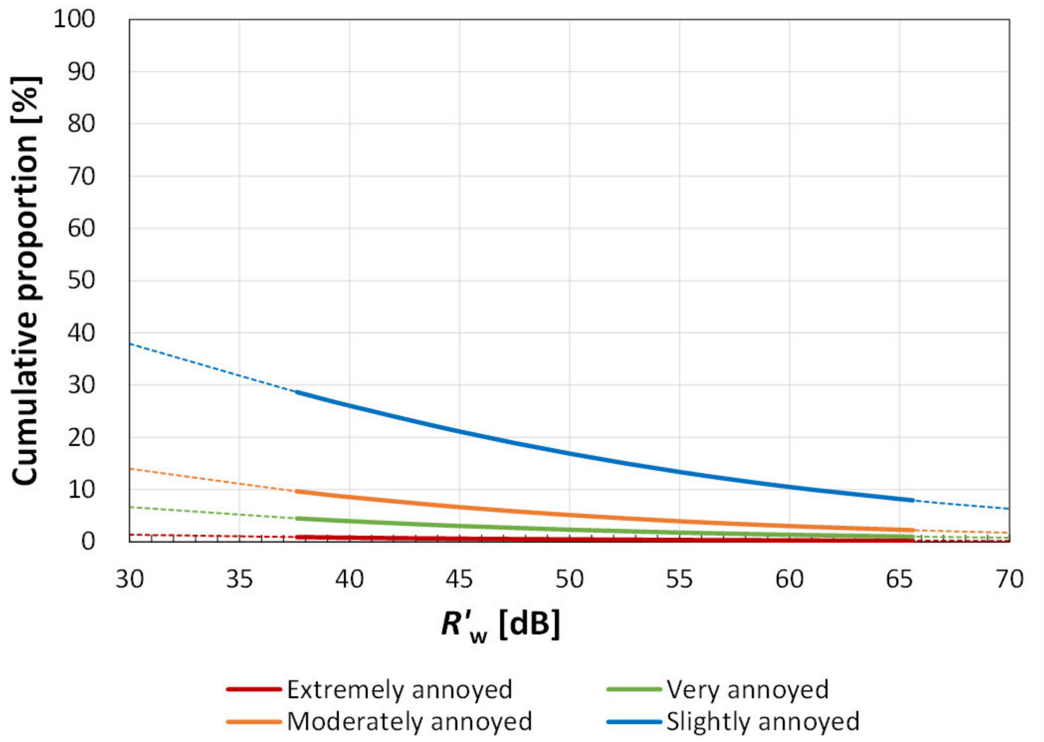

Figure 5: Cumulative proportion of annoyance due to sound insulation from corridor, staircase etc. to housing units. Solid lines are within 95 % of the range of the measured data.

Figure 6 shows the proportion of annoyance due to sound insulation between common staircases, corridors etc. and flats. The proportion of annoyance for the main selection is shown in a), while b) and c) show results for units in the student selection with two and one door towards the common corridor, respectively. The single doors in c) have a sound insulation of $R_w = 43$ dB and are mounted in good wall partitions, giving a total sound insulation of $R'_w = 43\text{-}45$ dB. Presently, units in the main selection with a single door towards the common staircase or corridor have not been analysed separately due to tight time schedule and budget in this project.

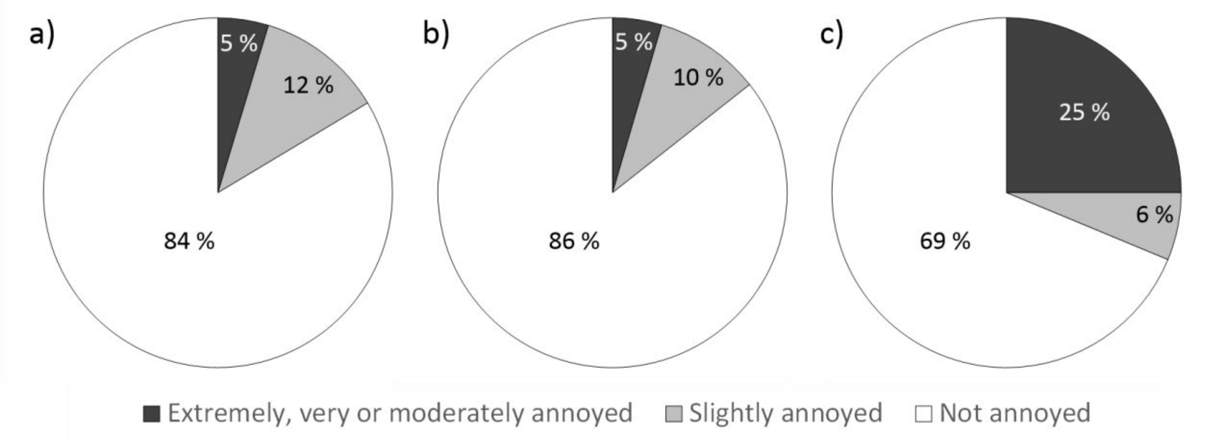

Figure 6: Proportion of annoyance due to sound insulation from corridor, staircase etc. to flats, in percent. a) Main selection. b) Student selection with two doors towards common corridor. c) Student selection with a single door towards the common corridor.

The results for the main selection and student selection with separate entrance are comparable, while there is clearly a higher degree of annoyance with only a single door towards the corridor. Student houses commonly have long corridors leading to several housing units, indicating that the traffic load might be higher in these cases than in other multi-unit houses. An interesting further investigation would be to assess the correlation between annoyance and number of units each corridor leads to.

These results indicate that the sound insulation requirement can be reduced to around R'_{w} = 50 dB, but there is still need for a door number two between housing units and common areas.

IMPACT SOUND INSULATION

Impact sound insulation data and results for the main selection are shown in Table 1. These data are in conjunction with Figure 1b, but deviate somewhat as these data are from the responses obtained while Figure 1 shows the measurement database. As questionnaires were sent to all residents living in houses at the same address, the response data differs from the measurement basis to a certain extent.

Table 1: Data for measured impact sound insulation and the degree of annoyance due to impact sound related to the mean value of impact sound insulation.

Study	$L'_{n,w}$	$L'_{n,w} + C_{I,50\text{-}2500}$	$L'_{nT,w}$	$L'_{nT,w} + C_{I,50\text{-}2500}$
Number	473	439	411	402
Mean, dB	49.4	53.7	45.3	50.1
Standard deviation, dB	4.1	3.0	5.0	2.0
Slightly annoyed	45.5 %	42.6 %	43.3 %	42.8 %
Moderately annoyed	22.2 %	19.9 %	20.0 %	19.1 %
Very annoyed	12.3 %	11.2 %	11.2 %	10.2 %
Extremely annoyed	4.5 %	3.8 %	4.3 %	3.8 %

The degree of annoyance is comparable for the four acoustic descriptors evaluated. More than 42 % are annoyed to some extent, and around 20 % are moderately or more annoyed. This indicates that annoyance levels are higher than presupposed, as the mean impact sound level $L'_{n,w}$ = 49.4 dB meets the requirement with almost 4 dB margin.

The normalised mean values are around 4 dB higher than the standardised values, which is explained by the room volume correction [10]. The mean spectrum adaptation term $C_{I,50-2500}$ is 4-5 dB, indicating that there is considerable transmission at low frequencies, and that floor construction used exhibit limited sound insulation below 100 Hz.

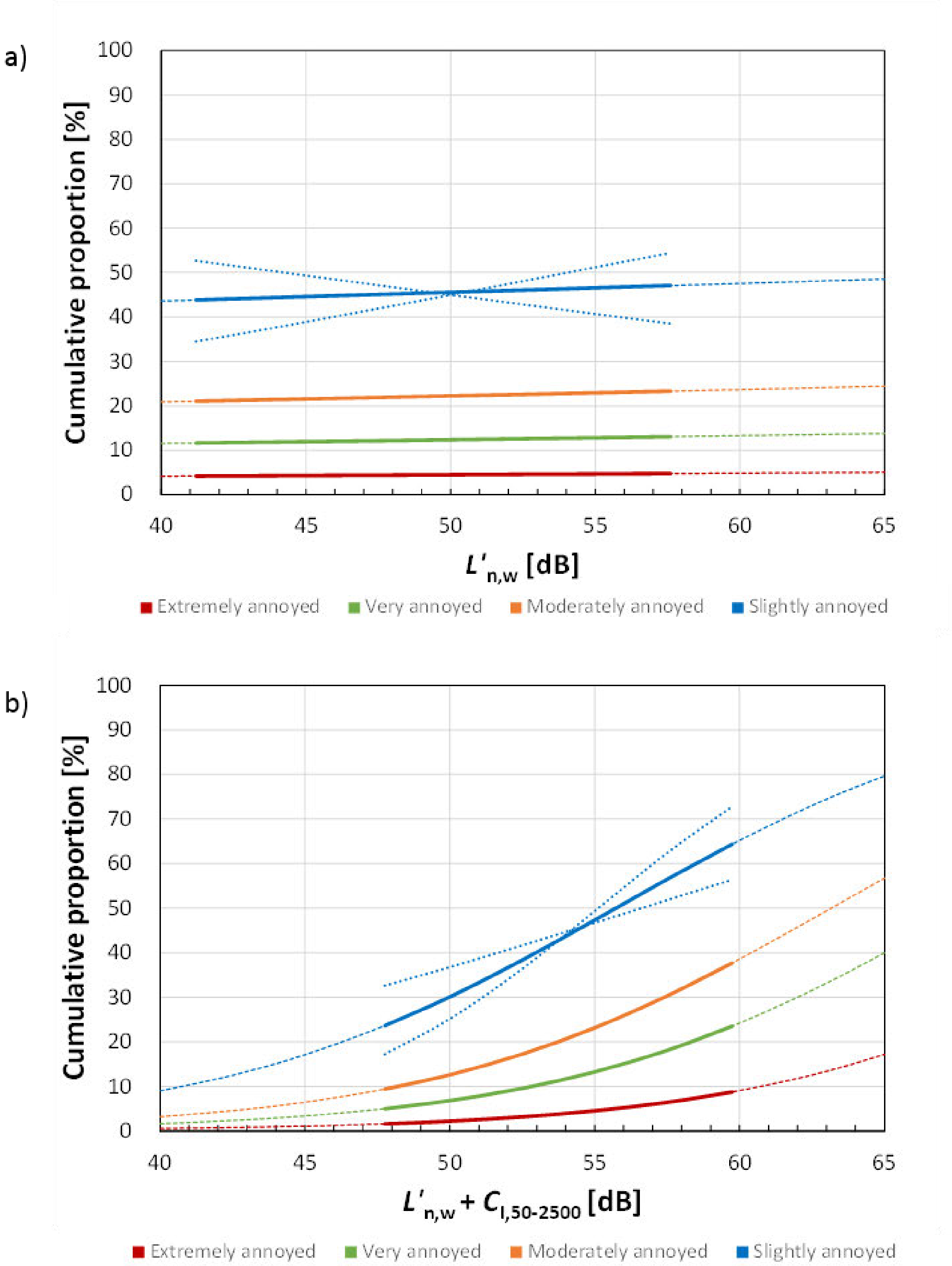

Figure 7: Cumulative proportion of annoyance due to impact sound insulation in vertical direction between housing units. Solid lines are within 95 % of the range of the measured data.

Figure 7 shows the cumulative proportion of annoyance due to impact sound in vertically separated housing units (i.e. units on different floors). In a) the weighted normalised impact sound pressure level, $L'_{n,w}$, is shown. It is clear that there is no correlation between the subjective annoyance reported by the residents and the objectively measured values. A similar result was found for $L'_{nT,w}$, but this is not shown here. When the spectrum adaptation term $C_{I,50-2500}$ is added, the cumulative annoyance correlate much better with the subjectively reported annoyance levels, as shown in Figure 7b. This was the case both for normalised and standardised descriptors.

Other researchers have also pointed out the poor low-frequency properties of timber and other light-weight constructions [12]. A certain proportion of the constructions included in the survey are heavy floors with thin floating floors, typically consisting of 30-40 mm lightweight concrete, anhydrite gypsum plaster or similar and 15-20 mm mineral wool insulation with parquet as the finishing layer. These constructions typically exhibit spectrum adaption terms in excess of 10 dB, so even if they comply with the regulations ($L'_{n,w} \leq 53$ dB) with good margins, impact sound levels below 100 Hz can be significant and induce annoyance in adjacent housing units. Similar results have recently been reported by Wolf and Burkhart [13].

SUMMARY

An extensive socio-acoustic survey comprising multi-unit houses has been carried out in Norway. It is found that 2/3 of the residents are annoyed by noise to some extent. Impact and traffic noise caused most nuisance, as 20 % reported to be moderately, very or extremely annoyed from these noise sources, which is twice as high as from speech or music. However, as many as 1 out of 3 report that they are worried that airborne noise sources such as TV, music, speech may annoy their neighbours, and are thus likely to limit themselves to a certain extent in consideration of their neighbours for these types of activities. With footfall noise this is not the case, and the percentage worried about disturbing others are slightly lower than those annoyed by it.

Only 1 % of the respondents in the main selection think the regulations are too strict, while 61 % answered that the requirements are adequate. Around 50 % of the main selection would not pay extra for better sound insulation, but around 20 % were willing to pay from 6 000 to 12 000 NOK extra per year. On the other hand, 86 % replied that less sound insulation for a reduced monthly payment is out of question.

Annoyance levels due to airborne sound insulation between units indicated that the present requirement of $R'_{w} \geq 55$ dB is set at a reasonable level. The results indicate that sound insulation between housing units and common corridors or staircases can be reduced to around $R'_{w} = 50$ dB, but there is still need for a second door between housing units and common areas.

Annoyance levels due to footfall noise are higher than presupposed, as the mean impact sound level $L'_{n,w} = 49.4$ dB meets the Norwegian requirement with almost 4 dB margin. No correlation between the subjective annoyance reported by the residents and the objectively measured values was found if the spectrum adaptation term $C_{I,50-2500}$ was not included, both for normalised and standardised descriptors. The mean value of the spectrum adaptation term $C_{I,50-2500}$ is 4-5 dB in this investigation, indicating that there is considerable transmission of impact sound at low frequencies. A main result is that it is necessary to include the low frequencies 50 – 80 Hz in measurements of impact sound insulation.

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REFERENCES

[1] National Office of Building Technology and Administration (2010), Regulations on technical requirements for building works (Technical regulations). Retrieved from https://dibk.no/globalassets/byggeregler/regulations_on_technical_requirements_for_building_works.pdf

[2] National Office of Building Technology and Administration (2016), Lydforhold i boliger. Evaluering av byggtekniske krav til lydforhold, (In Norwegian).

[3] Standards Norway (2012), NS 8175 Lydforhold i boliger. Lydklasser for ulike bygningstyper, (In Norwegian).

[4] Standards Norway (1997), NS 8175 Lydforhold i boliger. Lydklasser for ulike bygningstyper, (In Norwegian).

[5] International Organization for Standardization (2013), ISO 717-1:2013, Acoustics - Rating of sound insulation in buildings and of building elements - Part 1: Airborne sound insulation.

[6] International Organization for Standardization (2013), ISO 717-2:2013, Acoustics - Rating of sound insulation in buildings and of building elements - Part 2: Impact sound insulation.

[7] Statistics Norway (2011), Folke- og boligtellingen, boliger, (In Norwegian).

[8] European Cooperation in Science and Technology (2014), COST Action TU0901, Integrating and Harmonizing Sound Insulation Aspects in Sustainable Urban Housing Constructions.

[9] International Organization for Standardization (2003), ISO/TS 15666, Acoustics - Assessment of noise annoyance by means of social and socio-acoustic surveys.

[10] Rindel, J.H., Løvstad, A., & Klæboe R. (2016), Aiming at satisfactory sound conditions in dwellings – the use of dose-response curves, Proc. Baltic-Nordic Acoustic Meeting, Stockholm, Sweden.

[11] Rindel, J.H. (2017), A Comment on the Importance of Low Frequency Airborne Sound Insulation between Dwellings, *Acta Acustica united with Acustica*, 103, 164-168.

[12] Ljunggren, F., Simmons, C., & Hagberg K. (2014), Correlation between sound insulation and occupants' perception – Proposal of alternative single number rating of impact sound, *Applied Acoustics*, 85, 57-68.

[13] Wolf, M., & Burkhart C. (2016), Vermeidungsstrategien und Ansätze einer Vermeidung des Estrichdröhnens, (In German), Proc. DAGA 2016, Aachen, Germany.