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Sound insulation of newly-built residential housing stock of Estonia

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In relation of assessment of technical conditions of newly-built residential housing stock of Estonia, also sound insulation (airborne and impact sound) conditions were analysed based on the measurement reports of various measurement bodies. The whole assessment report covers residential buildings built during 1990's to current date. The assessment report is carried out by Faculty of Civil Engineering of Tallinn University of Technology and is financed by State Fund KredEx. The actual report was published in May 2012. Totally 222 airborne and 129 impact sound insulation measurement reports have been analysed, which includes results for various most commonly used structural types. Since 1999 (Estonian Design Norm EPN 16.1) airborne sound insulation requirement between the apartments have been $R'_w \geq 55$ dB and for impact noise $L'_{n,w} \leq 53$ dB. In 2003 a national standard EVS842:2003 "Sound insulation requirements in buildings. Protection against noise" was approved; same requirements were overtaken and also spectrum adaption terms $C_{50\text{-}3150}$ and $C_{I,50\text{-}2500}$ were introduced (using of them is not compulsory). During design phase the basis for choosing the structures between apartments is based only on single-number quantities. Approximately half of the analysed measurement results fulfil the set requirements.

1 Introduction

In relation of assessment of technical conditions of newly-built residential housing stock of Estonia, which also includes suggestions for improvements, sound insulation between the apartments was one objective of the survey. Sufficient sound insulation (airborne sound insulation and impact sound insulation) between the apartments and low background noise levels (noise from technical equipment, traffic noise aso) are needed for inhabitants to provide acoustic comfort on adequate level.

According to Estonian Building Law § 3 clause 4 excessive noise transfer in buildings shall be avoided. Noise levels sensed by users can be on the level, which is not hazard for one's life and health and allows living or working on sufficient conditions. In addition to noise transferring from one apartment to another, it also brakes in from outside, from corridors and staircases and also inside one's apartment. Also noise created by technical equipment of same dwelling and neighbourhood buildings and other environmental noise sources (road traffic, railway traffic, aircrafts, and industrial sites) shall be taken into account.

The aim of the study was to assess sound insulation of newly-built residential housing stock of Estonia focusing on sound insulation between the apartments. As the quality criteria, requirements set in the Estonian national standard EVS 842:2003 "Sound insulation requirements in buildings. Protection against noise" [1] (later referred as EVS 842:2003) has been used. Survey was committed in dwellings with different structural solution built during period 1990-2011.

2 Sound insulation characteristics of newly-built housing stock

2.1 Indicators and requirements

According to the Estonian sound insulation concept main indicators are following:

- Weighted apparent sound reduction index R'_w for field measurements of airborne sound insulation between the rooms;
- Weighted normalized impact sound pressure level L'_{nw} for field measurements of impact sound insulation of floors;
- Spectrum adaption terms $C_{50\text{-}3150}$ and $C_{I,50\text{-}2500}$ in dB, which is added to result for taking into account spectrum of specific noise source.

In the first Estonian Design Norm regarding acoustics EPN 16 (1997) airborne sound insulation requirement between the apartments was $R'_w \geq 52$ dB and for impact sound insulation the requirement was $L'_{n,w} \leq 58$ dB. In 1999 a modification of EPN 16 was introduced called EPN 16.1, where the requirements had been increased - airborne sound insulation requirement between the apartments $R'_w \geq 55$ dB and for impact sound insulation the requirement was $L'_{n,w} \leq 53$ dB.

In 2003 the new Estonian national standard EVS 842:2003 was published, there were no chances compared to EPN 16.1, but spectrum adaption terms $C_{50\text{-}3150}$ for airborne sound insulation and $C_{I,50\text{-}2500}$ for impact noise insulation were introduced as new concept; still using of them is not compulsory (in everyday practice these are not used). The basis for EPN 16.1 and EVS 842:2003 were similar standards, their drafts and general concepts in the Nordic countries and in Germany. There is no acoustical classification scheme concept in Estonia. There is no obligation to perform any kind of acoustical measurements (sound insulation, traffic noise level, HVAC noise levels) in completed dwellings.

The minimum requirements, which shall be fulfilled between livings premises of apartments, are following (EVS 842:2003):

- Weighted apparent sound reduction index $R'_w \geq 55$ dB;
- Weighted normalized impact sound pressure level $L'_{n,w} \leq 53$ dB.

In addition to abovementioned, standard also specifies additional requirements for apartments:

- Between living premises of apartment and common premises/offices $R'_w \geq 55$ dB;
- Between apartments and noise generating premises $R'_w \geq 60$ dB;
- Between rooms inside apartment $R'_w \geq 43$ dB;
- Between apartment and common premises, if there is a door in wall $R'_w \geq 39$ dB;
- From balcony, stairs, corridor, bathroom and toilets to another apartment $L'_{n,w} \leq 58$ dB;
- From noise generating technical premise, work, service and restroom and garage to apartment $L'_{n,w} \leq 48$ dB;
- Between rooms inside one flat in two-storey apartment $L'_{n,w} \leq 63$ dB.

Based on the given information since 1999 all designed and built dwellings should fulfil between the apartments requirements $R'_w \geq 55$ dB and $L'_{n,w} \leq 53$ dB.

EVS 842:2003 sets also requirements for facades based on the outer noise levels, which ensures that allowable traffic noise levels inside apartment are satisfied. As these requirements are based on environmental noise levels, i.e. location of specific dwelling, there are not fixed requirements for sound insulation of facades. In every single case noise levels influencing the dwelling shall be determined by sound level measurements or by calculations. As stated, there are permitted noise levels for traffic inside apartments (requirements are set by the Minister of Social Affairs in its Regulation No 42 of 4 March 2002, "Standard noise exposure limits in residential and recreational areas, in residential and public/commercial buildings; and the methods for noise level measurement" and in EVS 842:2003):

- During daytime in living and bedrooms $L_{pAeqT} = 35$ dB;
- During night-time in bedrooms $L_{pAeqT} = 30$ dB.

It was decided that it would be necessary to evaluate sound insulation results regarding person's subjective feelings and this was done based on table given in Danish standard DS490 [2].

Table 1: Description of acoustic conditions of different sound classes (on the basis of Danish standard DS490)

Sound classes describing the acoustic conditions of buildings		Assessment of residents	
Class	Characteristics according to DS 490	Good or very good	Bad
A	Acoustic conditions are excellent. Noise rarely disturbs residents.	> 90 %	
B	Significant improvement as compared to the minimum requirements of class C. Residents are sometimes disturbed.	70−85 %	<10 %
C	Sound class meeting the minimum requirements of a new building.	50−65 %	< 30 %
D	Sound class of old buildings, acoustic conditions are unsatisfactory. Does not meet the requirements of new buildings.	30−45 %	25−50 %

Based on the summary tables for European countries [3], where acoustical classification schemes are used, Estonian requirements respond to class C, which are not too high – only 50-65 % on inhabitants are satisfied with acoustical conditions.

2.2 Assessment procedure

The assessment procedure consisted from three phases:

- Performing sound insulation measurements in newly-built residential housing stock (including survey of older measurement results);
- Comparing the results to requirements in EVS 842:2003;
- Evaluate different sound insulation improvement measures according to international calculation methods EN 12354-1 [4] and EN 12354-2 [5] (this part is not dealt in given paper).

Measurements performed during the survey where all carried out in apartments, which are in use by inhabitants and are all furnished. Most of the older measurements have been carried out just after the completion of building works of a dwelling before inhabitants had moved in (apartments were not furnished).

Field measurements of airborne sound insulation have been performed according to EVS–EN ISO 140-4:1998 [6] and weighted apparent sound reduction index R'_w and spectrum adaption terms have been found according to EVS-EN ISO 717-1:1996 [7]. Field measurements of impact sound insulation of floors have been performed according to EVS-EN ISO 140-7:1998 [8] and weighted normalized impact sound pressure level $L'_{n,w}$ and spectrum adaption terms have been found according to EVS-EN ISO 717-2:1996 [9]. In special cases guidelines given in standard EVS-EN ISO 140-14:2004 [10] were followed.

Single number quantities have been found for frequency range 100-3150 dB. Partly the measurements have been performed in extended frequency range 50-5000 Hz and additional spectrum adaption terms have been calculated where possible.

2.3 Structural solutions

Next the main structural solutions are described, which are used in design and construction of new dwellings. There are no specific restrictions for using different materials except fire safety demands.

The design target for partition walls between the apartments is fulfilling the requirements $R'_w \geq 55$ dB and usually no safety margin is considered. If there is a mistake in design phase, during construction works or inappropriate material replacement is made, the result will be below EVS 842:2003 requirements.

Various wall structures are used in new dwellings:

- Lightweight wall on wooden or steel studs (typically 2+2 gypsum boards on both side of double studs), total thickness 200-300 mm;

- Monolithic concrete walls (in-situ) or monolithic concrete panels, wall thickness 180-200 mm;
- Concrete hollow blocks (filled with concrete), wall thickness 190 and 240 mm;
- Double wall from autoclaved aerated concrete blocks (100 mm block/100 mm void filled with mineral wool/ 150 mm block);
- Single or double wall from light expanded clay aggregate blocks (single layer 250-300 mm, double wall 100 mm block/ 100 mm void filled with mineral wool/ 150 mm block or other similar);
- Combined wall structures (blocks and lightweight cladding).

Total thicknesses of walls vary between 180-400 mm. Lightweight block walls are usually double walls or with one side or two side gypsum board cladding. Normal mineral wool (15-40 kg/m^3) is used as sound absorbing material in the cavity. All described wall structures fulfil single number requirement $R'_w \geq 55$ dB. If spectrum adaption term $C_{50\text{-}3150}$ should be included, then fulfilling the requirement $R'_w+C_{50\text{-}3150} \geq 55$ dB with lightweight wall structures would be complicated.

Various floor structures are used in new dwellings:

- Concrete hollow-core panels (220, 265, 320 mm) with concrete floating floors (60-80 mm) on load bearing mineral wool or EPS boards (30-50 mm);
- Monolithic concrete slabs (180-250 mm) with concrete floating floors (60-80 mm) on load bearing mineral wool or EPS boards (30-50 mm);
- Seldom are used lightweight floating floors on hollow-core panels or on massive concrete slabs (lightweight floating floor means building boards of load bearing mineral wool);
- Lightweight floor structures on wooden beams, glulam beams, trusses, steel beams with lightweight floating floor or flooring material on elastic underlay.

Impact sound insulation requirement $L'_{n,w} \leq 53$ dB assumes that in most cases floating floor structure shall be used or special underlay is used under the flooring material (very seldom used).

Pictures 1, 2 and 3 describe the most common structures and their connection details between apartments.

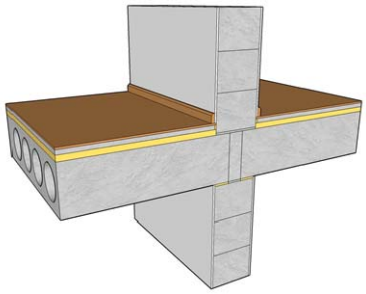


Figure 1: Massive wall structure and concrete floating floor on hollow-core panels

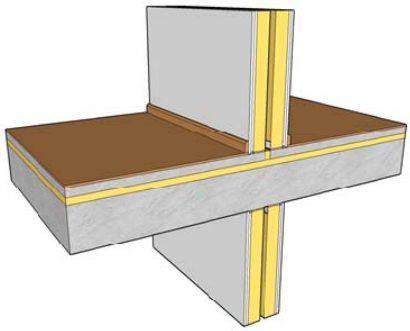


Figure 2: Lightweight wall structure and concrete floating floor on monolithic concrete slab

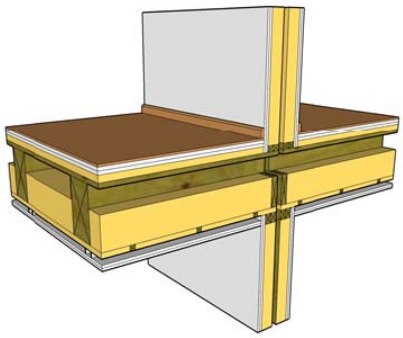


Figure 3: Lightweight wall structure and lightweight floating floor on wooden beams

2.4 Analyse of measurement results

For assessing sound insulation between apartments, during the survey field measurements of airborne sound insulation and impact sound insulation were performed in vertical and horizontal direction in 6 different dwellings; totally 23 measurements were performed.

Measurements were carried out in dwellings with different structural solution:

- Concrete hollow-core panels, block wall between apartments;
- Lightweight volume element dwellings;
- Monolithic concrete walls and floor slabs;
- Monolithic concrete floors, lightweight walls between apartments.

For large-scale overview about existing situation in newly-built residential housing stock, all available sound insulation measurement reports were gathered and analysed. Earliest measurements reports are from beginning of 2000. Results from 3 measurement laboratories have been used: physics laboratory of Central laboratory of Estonian Health Board, Jõgioja Building Physics KB Ltd and Akukon Ltd Estonian branch. All mentioned laboratories have accreditation according to EN ISO/IEC 17025 [11]. The protocols cover major part of the measurements performed in newly-built dwellings.

Totally 222 field measurements of airborne sound insulation and 129 field measurements of impact sound insulation were analysed. Measurements have been performed in 69 different dwellings. Results describe conditions in dwellings with major sound insulation problems, after repair works caused by poor sound insulation, and normal control measurements in completed dwellings. Only general information is known for the building structures and connection details, no detail solutions are known; clarification of these was not a goal of this survey.

After analysis of all results, it can be stated that weighted apparent sound reduction index R'_w is in horizontal and in vertical direction in the range of 50-60 dB, weighted normalized impact sound pressure level $L'_{n,w}$ is in horizontal direction 45-60 dB and in vertical direction 45-55 dB (if floating floor is used, the results are typically $L'_{n,w} \leq 50$ dB). The median value for R'_w is 55 dB and for L'_{nw} 51 dB.

In tables 2 and 3 are shown distribution of results in 4 dB intervals.

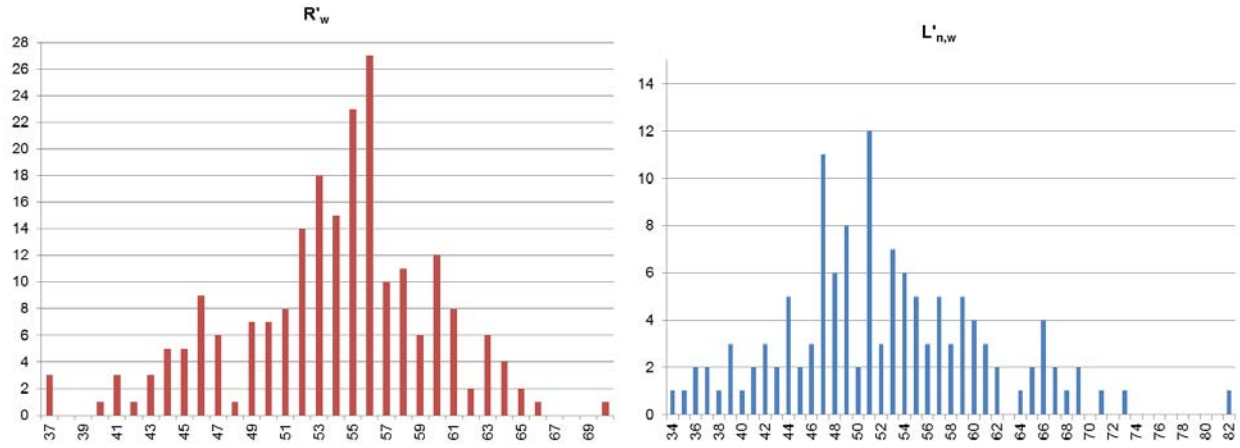
Table 2: Distribution of weighted apparent sound reduction index R'w

R'_w interval, dB	percentage from all measurements, %
≤ 44	8
45 – 48	10
49 – 52	16
53 – 56	38
57 – 60	18
≥ 61	11

Table 3: Distribution of weighted normalized impact sound pressure level $L'_{n,w}$

$L'_{n,w}$ interval (dB)	percentage from all measurements, %
≤ 44	18
45 – 48	17
49 – 52	20
53 – 56	16
57 – 60	13
≥ 61	16

Figures 4 and 5 show distribution of analysed single number measurement results.



Figures 4 and 5: Distribution of analysed measurement results (R'_w on the left and $L'_{n,w}$ on the right), on vertical axis number of measurements

Measurement results fulfilling the requirements set in EVS 842:2003 are as follows:

- 50% of airborne sound insulation measurements ($R'_w \geq 55$ dB);
- 59% of impact sound insulation measurements ($L'_{n,w} \leq 53$ dB).

There are no major airborne sound insulation problems in vertical direction due to widely used massive intermediate floor slabs. The results $R'_w \geq 53$ dB should be considered as providing sufficient sound insulation (as a rule no complains); if in design phase or during construction works have been slipped against principles set in EVS 842:2003, then result is usually 48-52 dB. In case of major design and/or construction mistake the results are < 48 dB.

Due to the widely used concrete floating floors on massive panels/slab there are no major impact sound insulation problems in vertical directions. The weighted normalized impact sound pressure level $L'_{n,w}$ is typically ≤ 48-50 dB (also exceptionally good results occurred $L'_{n,w} \leq 45$ dB). Nonsufficient results are usually 58-63 dB or worse.

Part of the survey was also a subjective questionnaire/interview, where also was question about sound insulation. The results show that 13% of inhabitants complain often about poor sound insulation in vertical directions (38% complain some time) and 21% of inhabitants in horizontal direction (21% complain some time). Measurement results are only available partly for the dwellings where subjective survey was carried out, so unfortunately no conclusion can be made at this moment, but it requires further studies (measurements in dwellings where number of complains was higher compared to other dwellings). Another future work should contain subjective study in dwellings where measurements were made, but no survey (for example questionnaire template from COST Action TU0901 [12]).

The main reasons for non-fulfilling results in horizontal directions are:

- Wrong structural solution/structural type (partly based due to the fact that data from suppliers is not on the same level);
- Substitution of designed wall structures (mainly block walls) to lighter structures;
- Construction mistake (for example nonsufficient plastering, filling joints, etc);

- Incorrect solution for connection detail between wall and intermediate slab (for example concrete floating floor continues under the wall from one apartment to another);
- Incorrect solution for connection detail between wall and lightweight façade (internal layers for façade continue from one apartment to another);
- Influence of power sockets in lightweight walls.

The main reasons for non-fulfilling results in vertical directions are:

- Nonsufficient elastic layer in floating floor structure (wrong properties, too thin layer);
- Mass of floor structure is not sufficient;
- Poor sound insulation of lightweight floor structures on low frequencies.

3 Summary

The aim of the survey was to analyse existing situation regarding sound insulation between the apartments among other properties of building physics and provide principle improvement suggestions.

Based on the analysis the number of results not satisfying the requirements set in the Estonian national standard EVS 842:2003 was surprisingly big; only 50% of R'_w measurements fulfilled the criteria $\geq$ 55 dB and only 59% of $L'_{n,w}$ measurements fulfilled the criteria $\leq$ 53 dB. There were also very good results, but it shall be stated that it had not been the design target – it has been consequence of structural solution.

Further studies are needed in dwellings where subjective questionnaires/interviews were organized, also possible reasons for noncomplying results shall be analysed and suggestions to be made regarding design and building of future dwellings.

References

[1] EVS 842:2003 “Sound insulation requirements in buildings. Protection against noise”

[2] B. Rasmussen, J-H. Rindel, Sound insulation between dwellings – Descriptors applied in building regulations in Europe, *Applied Acoustics*, 71, 2010, 171-180

[3] DS 490:2007, “Lydklassifikation af boliger” (Sound classification of dwellings), Denmark

[4] EN 12354-1 Building Acoustics. Estimation of acoustic performance of buildings from the performance of elements. Part 1: Airborne sound insulation between rooms

[5] EN 12354-2 Building acoustics. Estimation of acoustic performance of buildings from the performance of elements. Part 2: Impact sound insulation between rooms

[6] EVS–EN ISO 140-4:1998 „Acoustics — Measurement of sound insulation in buildings and of building elements — Part 4: Field measurements of airborne sound insulation between rooms“

[7] EVS-EN ISO 717-1:1996 „Acoustics – rating of sound insulation in buildings and of building elements – Part 1: Airborne sound insulation“.

[8] EVS-EN ISO 140-7:1998 „Acoustics — Measurement of sound insulation in buildings and of building elements — Part 7: Field measurements of impact sound insulation of floors“

[9] EVS-EN ISO 717-2:1996 „Acoustics – rating of sound insulation in buildings and of building elements – Part 2: Impact sound insulation“

[10] EVS-EN ISO 140-14:2004 „Acoustics – rating of sound insulation in buildings and of building elements – Part 14: Guidelines for special situations in the field“

[11] EN ISO/IEC 17025:2000 “General requirements for the competence of testing and calibration laboratories”

[12] COST Action TU0901 “Integrating and harmonizing sound insulation aspects in sustainable urban housing constructions”, www.costtu0901.eu