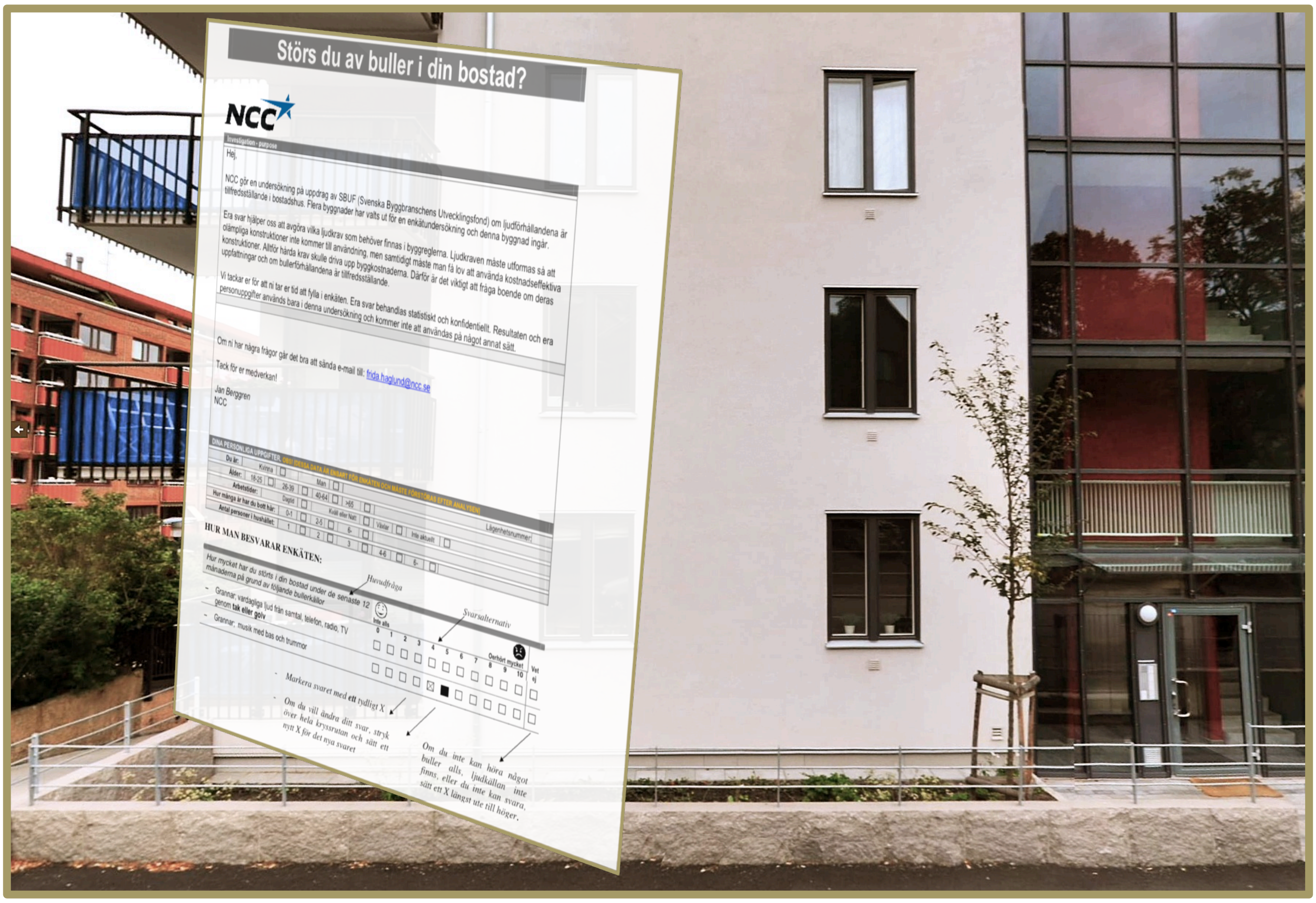
Acoustical Performance of Apartment Buildings - Resident's Survey and Field Measurements



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Summary

This study presents results from surveys made in 10 Swedish apartment buildings as well as field measurements in those buildings. The buildings have been selected by the manufacturers participating in two research programs (SBUF and AkuLite), being typical for their current productions and customers/ residents. The results of this study should be interpreted mainly with respect to these buildings since the selections of buildings and residents were not randomized. Bearing this limitation in mind, a few general conclusions are suggested about the noise protection offered by these types of building constructions. The results are complex and it is suggested to invite many parties to discuss them and to contribute to a comprehensive analysis. A few findings are highlighted and discussed.

Residents in the buildings with concrete floors and walls (built by NCC) were slightly disturbed by airborne noise from the neighbours and somewhat more disturbed by impact noise. Noise from technical equipments and traffic were more pronounced, taking compressor noise from the freezers and structure-borne sound from elevators and WC's as examples. The overall ratings by the residents may be considered satisfying or good, but several improvements are suggested to reduce disturbing sources of noise that were observed. The design goal was in most cases to fulfill sound class B according to the national standard SS 25267 (4 dB better than the minimum requirements of class C). In most cases the buildings did not fulfill this sound class (B) in all aspects, but after some minor improvements the probability of reaching this goal and to get better ratings by the residents would increase.

Residents in buildings with timber joist floors and walls were slightly disturbed by airborne noise from the neighbours and technical installations. However, a main finding, impact noise cause considerable disturbance in all of the timber frame buildings, where about 25-30 % of the residents are very disturbed, about 25 % are disturbed and about 10% are somewhat disturbed. The measurement results indicated satisfying performance but this was not confirmed by the residents ratings. Further analyses are needed of the measurements techniques and weighing procedures described by the international standards EN ISO 140 and EN ISO 717, a research that is already in progress in the AkuLite program.

The results from these surveys were amended by data from previous studies to search for correlations between subjective ratings (by residents) and objective measurement results. A reasonable correlation was found between ratings and the calculated and/or the measured normalized impact sound pressure level ($L'_{n,w} + C_{i,50\text{-}2500}$). From these results, it may be concluded that $L'_{n,w} + C_{i,50\text{-}2500}$ 53 dB is likely to serve as a minimum requirement. For airborne sound insulation ($R'_w + C_{50\text{-}3150}$), the correlation between the ratings and the $R'_w + C_{50\text{-}3150}$ was weak and no conclusion can be made with respect to the meaning of changing the current requirement. However, it is observed that new houses have better ratings than older with respect to airborne sound insulation in all buildings. Impact sound rating is better in new concrete buildings. This is certainly a positive result for the developers.

The questionnaire seem to work satisfactory. About 70% residents filled in the form and returned it properly. However, when a building is selected for a survey, it seems to be necessary to inform the residents beforehand, to explain the purpose of the study and to allow the residents to respond to at least one reminder. A few improvements have been made to the questionnaire after this survey was completed as well as some surveys in other EU member states. The average of the ratings turned out to be highly correlated to the fractions "% of residents rating ≥ x".

Listening tests and more detailed interviews with residents should be made to find out what reasons there might be behind the worst ratings of impact sound, whether it is a matter of its sound level, its frequency content or its time history. From our own impressions on site, it seems the speed of walking has a substantial effect on the annoyance from the impact sound in the dwelling below this floor. Only a slight increase of speed (impact force) changes the sound from barely audible to very unpleasant.

There are many details to improve on to achieve better ratings from the residents, especially better workmanship and choices of technical equipment. Taking sounds from WC, air terminals, elevators as examples, they may all be efficiently attenuated at low costs. The planning process (the design) could be improved by small means.

Content

Introduction

The purpose of this investigation was to describe relationships between the objective data for some apartment buildings and the subjective ratings of the sound climate given by their residents. The results may be used to study the effect of the current building regulations and to suggest new criteria for these but such analyses are uncertain due to statistical limitations. Another goal has been to develop the survey procedure.

The surveys are based on studies in occupied apartment buildings and they were made in parallel by two research teams during the same time period. One study was made in buildings with concrete floors and partition walls (the NCC/SBUF survey), the other in houses with timber joist floors and walls (the AkuLite survey). Some earlier studies[1 2 3 4] have been added as well in order to extend the comparisons with surveys made in older buildings.

The *objective descriptors* for acoustic performance (both airborne and impact sound insulation) of the buildings are taken from

- EN 12354-1 and 2 (calculations)
- EN-ISO 140-4 and 7 (field measurements)

The values are either calculated or measured standardized 1/3 octave band values in the 50-3150 Hz frequency range. From these 1/3 octave values, various weighted single number values were calculated according to EN ISO 717. Other weighted single number values may be derived from the third octave band values, with the aim to find a weighing or calculation procedure that gives equal objective values for the same subjective ratings, i.e. weighed single numbers for the sound insulation that are independent of type of structural elements (whether they are made of light or heavy materials).

The *subjective descriptors* are taken as the ratings made by the residents, who received a specially designed questionnaire for this purpose (figure 1).[5] In the first place, airborne sound insulation and impact sound insulation between apartments are investigated, but the questionnaire also includes other types of noise that may occur in apartments. This makes it possible to extend the analyses to such sources later on.

Acknowledgments

The work has been supported by NCC Teknik, SBUF, Boverket, Formas and Vinnova which are hereby gratefully acknowledged.

[1] Hagberg, K. Evaluating Field Measurements of Impact Sound. J of Building Acoustics Vol 17 · No 2 · 2010

[2] Bodlund, K. Alternative reference curves for evaluation of impact sound insulation between dwellings, Journal of Sound and Vibration 102(3), 381-402 (1985)

[3] Bodlund, K. Eslon, L., En kartläggning av ljudklimatet i några moderna svenska bostäder, Teknisk Rapport SP-RAPP 1983:37

[4] Hagberg C, Simmons C. Bostäder och höga ljudkrav. Boverkets byggkostnadsforum 2007. ISBN: 978-91-85751-43-3

[5] Simmons C, "Revision of sound classifications schemes in Sweden", Internoise 2010, Lisbon 2010

Survey – subjective rating of sound insulation by residents

The surveys among the residents were made by mail or by direct distribution in the buildings, where all residents in the selected blocks of houses received a letter and a questionnaire. Figures 1a and 1b show the two pages of the form used in the concrete houses. In the houses with wooden frames, a similar front page (referring to ÅF as responsible part for the survey) and an identical second page were used. The front page of the form gives an introduction and explanation to the questionnaire that followed on the back page. Thus, only one page comprised the questions, for the ease of the respondents. To collect the answers different types of methods were applied:

- A response envelope with address and stamp attached simplified the return of the form.
- A temporary postbox were mounted in the bottom floor close to entrance of the building

One reminding mail / form was posted or distributed about 2 weeks after the first mail in the NCC/SBUF buildings and in one of the AkuLite buildings, else no further contacts were taken with the residents.

The willingness to respond to the survey was acceptable. In the NCC/SBUF survey (in concrete houses), about 70% out of 30-90 residents returned the form filled in more or less adequately. Occasionally, some questions were not answered at all or the ’don’t know’ option was chosen, but the overall response rate was satisfying. In one building, with rented apartments, the response rate was 60% out of 150. In one building where the apartments are owned by the habitants association, up to 90% out of 80 returned the form. The blank and ’don’t know’ answers were not counted in the statistical analyses below.

In the AkuLite buildings where the “postbox method (no 2 above)” was used, the response rate was better than 70% in 3 objects, but in 2 objects only 50 and 35% responded and in these latter two cases no extra distribution of questionnaire were made, due to access problems. The number of residential units(apartments) in these objects were small compared to the other buildings.

A response of 70% may be considered rather typical and allows for a statistical analysis of the results for the buildings examined with a reasonable accuracy. The results in this report may also be representative for similar types of building and so be of interest to their developers. **However, the results cannot be interpreted as representative to all kind of multifamily buildings in Sweden** since the sampling of buildings and residents were not made for this purpose. Comprehensive results on the national level are presented in the national survey “BETSI” made in 2007[6], where the sampling of buildings and residents was made by Statistics Sweden (SCB) in order to make the results representative for the whole country.

The questionnaire in Figure 1b has been translated by Christian Simmons and Pontus Thorson (Chalmers university of technology) from an English original version, developed in September 2010 by a working group of European researchers within the EU network COST TU 0901, convened by Simmons. This work has been described in a separate report[7] (in English) as well as a conference paper (in English) presented at Forum Acusticum (Aalborg 2011, www.fa2011.org).

The questions are expressed as a degree of annoyance; ”*how bothered, disturbed or annoyed are you in your apartment by noise from xxx*” and the rating is expressed as a digit between 0 and 10 (i.e. 11-alternatives). The first question in the questionnaire gives an overview of the customer satisfaction with the noise protection of their building and the questions 2-13 give more detailed information about the performance of walls, floors and technical equipment.

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[6] God bebyggd miljö – förslag till nytt delmål för buller inomhus – resultat från projektet BETSI. Boverket juni 2010. www.boverket.se. ISBN pdf: 978-91-86342-57-9

[7] SAURa-1276C_Skanska_SBUF-12311_Enkätmallar.pdf. The questionnaire in the report C has been revised slightly compared to the version used in this survey, as presented in figure 1 above.

Störs du av buller i din bostad?

NCC

Investigation - purpose

Hej,

NCC gör en undersökning på uppdrag av SBUF (Svenska Byggbranschens Utvecklingsfond) om ljudförhållandena är tillfredsställande i bostadshus. Flera byggnader har valts ut för en enkätundersökning och denna byggnad ingår.

Era svar hjälper oss att avgöra vilka ljudkrav som behöver finnas i byggreglerna. Ljudkraven måste utformas så att olämpliga konstruktioner inte kommer till användning, men samtidigt måste man få lov att använda kostnadseffektiva konstruktioner. Alltför hårda krav skulle driva upp byggkostnaderna. Därför är det viktigt att fråga boende om deras uppfattningar och om bullerförhållandena är tillfredsställande.

Vi tackar er för att ni tar er tid att fylla i enkäten. Era svar behandlas statistiskt och konfidentiellt. Resultaten och era personuppgifter används bara i denna undersökning och kommer inte att användas på något annat sätt.

Om ni har några frågor går det bra att sända e-mail till: frida.haglund@ncc.se

Tack för er medverkan!

Jan Berggren
NCC

DINA PERSONLIGA UPPGIFTER. OBS! [DESSA DATA ÄR ENBART FÖR ENKÄTEN OCH MÅSTE FÖRSTÖRAS EFTER ANALYSEN]

Du är:	Kvinna	☐	Man	☐					Lägenhetsnummer:	
Ålder:	18-25	☐	26-39	☐	40-64	☐	>65	☐		
Arbetstider:	Dagtid	☐	Kväll eller Natt	☐	Växlar	☐	Inte aktuellt	☐		
Hur många år har du bott här:	0-1	☐	2-5	☐	6-	☐				
Antal personer i hushållet:	1	☐	2	☐	3	☐	4-6	☐	6-	☐

HUR MAN BESVARAR ENKÄTEN:

Huvudfråga *Svarsalternativ*

Hur mycket har du störts i din bostad under de senaste 12 månaderna på grund av följande bullerkällor	Inte alls 0	1	2	3	4	5	6	7	8	9	Oerhört mycket 10	Vet ej
– Grannar; vardagliga ljud från samtal, telefon, radio, TV genom **tak eller golv**	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
– Grannar; musik med bas och trummor	☐	☐	☐	☐	☒	■	☐	☐	☐	☐	☐	☐

- *Markera svaret med **ett** tydligt X*
- *Om du vill ändra ditt svar, stryk över hela kryssrutan och sätt ett nytt X för det nya svaret*

Om du inte kan höra något buller alls, ljudkällan inte finns, eller du inte kan svara, sätt ett X längst ute till höger.

Figure 1a. The questionnaire, explanatory front page. For the AkuLite survey, the responsible institute (ÅF) replaced the NCC-signature. The questionnaire is described in report SBUF 12311-C.

Instruktioner:

Välj en siffra på skalan 0-10 för hur mycket du besväras, störs eller irriteras av buller i din bostad:

Om du hör bullret men inte alls störs av det, **svara 0**	Om du upplever att bullret stör oerhört mycket**,** **svara 10**	Om du störs till viss del av bullret, svara med en siffra **mellan 1 och 9**	Om du inte hör något buller, eller bullerkällan inte finns, eller du inte kan svara på frågan, svara "**Vet ej**"

	Hur mycket har du störts i din bostad under de senaste 12 månaderna på grund av	0 Inte alls	1	2	3	4	5	6	7	8	9	10 Oerhört mycket	Vet ej
1	– Buller från grannar, tekniska installationer med mera	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

	Hur mycket har du störts i din bostad under de senaste 12 månaderna på grund av följande bullerkällor	0 Inte alls	1	2	3	4	5	6	7	8	9	10 Oerhört mycket	Vet ej
2	– Grannar; vardagliga ljud från samtal, telefon, radio, TV genom **väggarna**	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
3	– Grannar; vardagliga ljud från samtal, telefon, radio, TV genom **tak eller golv**	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
4	– Grannar; musik med bas och trummor	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
5	– Grannar; stegljud, dvs. du hör när de går på golvet	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
6	– Grannar; det skallrar eller klingar i **dina** möbler när folk rör sig i lägenheten ovanför	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
7	– Trapphus, loftgångar; samtal, dörrar som stängs	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
8	– Trapphus, loftgångar; stegljud, slag mot trappräcke	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
9	– Vatten- och avloppsrör; användande eller spolning i WC, dusch	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
10	– Värme, kyla och luftbehandling; radiatorer, luftkonditionering, till- och frånluftsdon	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
11	– Maskiner; hissar, tvättmaskiner, värmepumpar, fläktar	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
12	– Lokaler; garage, affärer, kontor, pubar, restauranger, tvättstugor o dyl, som hörs inomhus med stängda fönster	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
13	– Trafik; bilar, bussar, lastbilar, tåg eller flyg, som hörs inomhus med stängda fönster	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

	***Innan** du flyttade till din nuvarande bostad, hur viktig ansåg du **då** att ljudisoleringen var mot*	0 Inte alls viktig	1	2	3	4	5	6	7	8	9	10 Oerhört viktig
14	– Buller från grannar, tekniska installationer med mera	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

	*Hur **känslig** anser du dig vara mot*	0 Inte alls känslig	1	2	3	4	5	6	7	8	9	10 Oerhört känslig
15	– Buller från grannar, tekniska installationer med mera	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

Kommentarer:

Figure 1b. The one-page questionnaire was copied on the back page. Note: This version of the questionnaire is slightly different from the final version in English, c.f. SBUF 12311 report C.

In Swedish, the wording ”*hur mycket har du störts av buller från…*” has been judged satisfactory for this purpose and it conforms to earlier surveys on traffic noise in Sweden[8]. Each question focuses on one type of source. This procedure is based on the technical specification ISO/TS 15666[9].

The ratings have been evaluated by different means to enable comparisons to the building performances (airborne- and impact sound insulation):

- **Average rating** (A50) may be taken as a descriptor for the average (typical) annoyance among the residents in a building, considered as one group. It may be correlated (compared) with the measured or calculated sound insulation
- **Average rating increased by one standard deviation** (A16) may be a descriptor for the rating given by about 16% of the (N) residents[10] being more disturbed than the average
- **The standard deviation** (S) may also be used to estimate the reliability of the average. The 95% confidence interval of A50 (CI-95) is then calculated as $\pm 2S/\sqrt{N}$. The interpretation of "reliability" is not quite clear in this context since the variations of ratings are not randomly distributed, but it may help judge which differences are significant.

After consulting researchers at Chalmers university of technology, dep. of mathematical statistics, three fractional parameters were added to the evaluation, with some provisional goals

- **The fraction of residents responding 3** or higher (Fract 3) may be a descriptor for residents considering the source of noise as ”somewhat disturbing, disturbing or very disturbing”, indicating a lack of quality.

  A goal could be to reduce this figure to < 20%, at least 50% in minimum requirements. A substantial part of the residents may then be considered ”satisfied”
- **The fraction of residents responding 5** or higher (Fract 5) may be a descriptor for residents considering the source of noise as ”disturbing or very disturbing”, indicating a lack of quality.

  A goal could be to reduce this figure to ≤ 10%, at least <20% in minimum requirements of building codes etcetera
- **The fraction of residents responding 8** or higher (Fract 8) may be a descriptor for residents considering the source of noise as ”very disturbing”, indicating dysfunction of the separating constructions.

  A goal could be to reduce this figure to ≤ 5% in minimum requirements, building codes etcetera.

These three fractional parameters are considered easier to interpret from a subjective point of view ('% xx annoyed') than the averaged ratings. It may then be easier to adopt goals for the ratings.

[8] Ljudlandskap för bättre hälsa, www.ljudlandskap.acoustics.nu

[9] Both pages of the questionnaire have been slightly updated during a COST TU 0901 meeting 2011-05-10, to reflect experiences made in our surveys and comments from the working group members. An updated version 1.0 of the questionnaire is published in enclosures 2 and 3 to our report 12311-C, in English (encl 2) as well as in Swedish (encl 3).

[10] 16% is an approximate fraction, based on the assumption of Gaussian distribution of ratings, taking the single sided fraction of the most annoyed residents.

Ratings – responses by residents to the questionnaire

The results of the surveys are presented in Tables 1 and 2 below.

As can be observed in table 3 below, the fractional parameters seem to be highly correlated to the average parameters. The choice of descriptor could possibly be less sensitive than was suggested during the design of the questionnaire.

Ratings – NCC/SBUF survey in concrete houses

Table 1. Summary of NCC/SBUF-results. Yellow indicates >20% of fract 3, >10% of fract 5 or >5% of fract 8. Red indicates exceeded >2x.

NCC/SBUF	**Question** (see fig 1b):	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Building info:	Parameter	General	Walls	Floor	Bass	Footfall	Rattle	Stairwell	Stairs	Wat,San	Heater	Equipm	Premise	Traffic	Import	Sensit
Örebro	A50_Average	0,9	0,3	0,3	0,1	0,7	0,1	0,5	0,3	0,5	1,1	1,1	0,1	2,2	7,0	3,8
N=36	A50_CI-95 (±2S/√N):	±0,5	±0,2	±0,3	±0,1	±0,5	±0,1	±0,3	±0,3	±0,4	±0,7	±0,6	±0,1	±0,9	±1,0	±1,1
Age 18-25: 0 %	A16_Avg+StdDev	2,6	0,8	1,2	0,4	2,1	0,5	1,5	1,2	1,8	3,1	3,0	0,5	4,8	10,0	7,2
Age 26-39: 0 %	Fract >=3 Some Disturb	11,8%	0,0%	2,6%	0,0%	8,3%	0,0%	5,3%	2,8%	8,6%	13,5%	13,9%	0,0%	38,5%	86,8%	59,0%
Age 40-64: 7 %	Fract >=5 Disturbed	5,9%	0,0%	2,6%	0,0%	2,8%	0,0%	2,6%	2,8%	5,7%	8,1%	11,1%	0,0%	15,4%	81,6%	46,2%
Age 65 -: 93 %	Fract >=8 Very Disturb	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	2,7%	0,0%	0,0%	7,7%	57,9%	25,6%
Västerås	A50_Average	1,50	0,49	0,76	1,38	1,20	0,13	1,17	1,28	1,20	1,04	1,09	0,33	1,40	6,75	3,94
N=86	A50_CI-95 (±2S/√N):	±0,3	±0,1	±0,2	±0,3	±0,3	±0,0	±0,3	±0,3	±0,3	±0,2	±0,2	±0,1	±0,3	±1,5	±0,9
Age 18-25: 0 %	A16_Avg+StdDev	3,53	1,43	2,53	3,45	3,31	0,51	3,39	3,48	3,36	3,25	3,13	1,31	3,54	10,00	6,70
Age 26-39: 14%	Fract >=3 Some Disturb	21,4%	4,8%	9,4%	20,7%	15,9%	0,0%	14,0%	15,1%	15,3%	11,8%	14,8%	3,6%	20,9%	85,4%	61,8%
Age 40-64: 37%	Fract >=5 Disturbed	10,7%	1,2%	3,5%	11,5%	9,1%	0,0%	8,1%	9,3%	10,6%	9,4%	9,1%	1,2%	9,3%	77,5%	41,6%
Age 65 -: 49 %	Fract >=8 Very Disturb	2,4%	0,0%	3,5%	2,3%	3,4%	0,0%	4,7%	7,0%	4,7%	7,1%	3,4%	0,0%	4,7%	65,2%	19,1%
Umeå-D	A50_Average	2,8	0,8	1,2	1,7	1,2	0,4	1,4	1,3	1,1	1,4	1,8	0,1	1,1	6,2	3,2
N=79	A50_CI-95 (±2S/√N):	±0,6	±0,4	±0,5	±0,6	±0,5	±0,2	±0,4	±0,5	±0,4	±0,5	±0,6	±0,1	±0,3	±0,7	±0,6
Age 18-25: 25%	A16_Avg+StdDev	5,5	2,4	3,4	4,3	3,3	1,3	3,3	3,5	2,9	3,6	4,6	0,7	2,6	9,4	5,8
Age 26-39: 30%	Fract >=3 Some Disturb	46,1%	8,6%	17,7%	24,1%	14,3%	1,4%	18,8%	17,5%	17,1%	20,3%	26,9%	1,4%	12,3%	81,4%	52,3%
Age 40-64: 20%	Fract >=5 Disturbed	25,0%	4,9%	10,1%	12,7%	9,1%	1,4%	6,3%	11,3%	4,9%	16,2%	16,7%	0,0%	4,9%	72,1%	34,9%
Age 65 -: 25 %	Fract >=8 Very Disturb	7,9%	1,2%	2,5%	5,1%	3,9%	0,0%	2,5%	2,5%	1,2%	1,4%	6,4%	0,0%	0,0%	45,3%	5,8%
Umeå-S	A50_Average	1,4	0,3	0,8	0,7	1,8	0,3	1,1	0,6	1,8	1,6	1,2	0,0	3,3	7,3	3,2
N=71	A50_CI-95 (±2S/√N):	±0,5	±0,2	±0,4	±0,4	±0,6	±0,3	±0,5	±0,4	±0,6	±0,5	±0,5	±0,1	±0,8	±0,7	±0,6
Age 18-25: 0 %	A16_Avg+StdDev	3,4	1,1	2,6	2,5	4,5	1,5	3,3	2,2	4,5	3,8	3,4	0,3	6,5	10,3	5,6
Age 26-39: 8 %	Fract >=3 Some Disturb	17,7%	2,8%	8,5%	5,6%	21,1%	2,9%	14,9%	6,9%	20,5%	21,1%	16,9%	0,0%	42,7%	84,0%	53,3%
Age 40-64: 42%	Fract >=5 Disturbed	6,5%	1,4%	4,2%	2,8%	12,7%	1,5%	9,5%	2,8%	13,7%	9,9%	9,9%	0,0%	32,0%	78,7%	36,0%
Age 65 -: 50 %	Fract >=8 Very Disturb	3,2%	0,0%	2,8%	2,8%	8,5%	1,5%	4,1%	1,4%	6,8%	4,2%	2,8%	0,0%	14,7%	60,0%	5,3%
Göteborg-U	A50_Average	1,7	0,4	1,4	1,7	2,4	0,3	1,2	0,9	1,6	1,9	2,3	0,9	1,8	7,0	3,8
N=32	A50_CI-95 (±2S/√N):	±0,8	±0,3	±0,8	±0,9	±1,2	±0,2	±0,7	±0,6	±0,8	±1,0	±1,1	±0,6	±1,0	±1,0	±0,9
Age 18-25: 0 %	A16_Avg+StdDev	4,1	1,4	3,7	4,3	5,8	1,0	3,1	2,7	4,0	4,8	5,4	2,7	4,6	9,9	6,3
Age 26-39: 15%	Fract >=3 Some Disturb	25,8%	6,3%	27,3%	31,3%	27,3%	3,1%	15,6%	9,1%	21,2%	22,6%	38,7%	14,3%	29,0%	88,9%	69,4%
Age 40-64: 56%	Fract >=5 Disturbed	19,4%	0,0%	9,1%	21,9%	27,3%	0,0%	6,3%	6,1%	18,2%	12,9%	22,6%	10,7%	16,1%	80,6%	30,6%
Age 65 -: 29 %	Fract >=8 Very Disturb	3,2%	0,0%	3,0%	3,1%	15,2%	0,0%	0,0%	0,0%	3,0%	9,7%	9,7%	0,0%	6,5%	55,6%	11,1%

Ratings – AkuLite survey in wooden houses

Table 2. Summary of AkuLite-results. Yellow indicates >20% of fract 3, >10% of fract 5 or >5% of fract 8. Red indicates exceeded >2x.

AkuLite	**Question** (see fig 1b):	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Building info:	Parameter	General	Walls	Floor	Bass	Footfall	Rattle	Stairwell	Stairs	Wat,San	Heater	Equipm	Premise	Traffic	Import	Sensit
Göteborg K	A50_Average	1,0	0,2	1,2	0,9	3,6	1,1	2,1	2,1	0,3	1,0	0,9	0,2	1,9	7,0	4,6
N=24	A50_CI-95 ($\pm 2S/\sqrt{N}$):	±0,7	±0,2	±1,0	±0,7	±1,4	±0,8	±1,2	±1,0	±0,3	±0,9	±0,6	±0,2	±0,9	±1,2	±1,1
Age 18-25: 0 %	A16_Avg+StdDev	2,6	0,7	3,6	2,5	7,0	2,9	5,1	4,6	1,0	3,1	2,3	0,8	4,0	10,0	7,3
Age 26-39: 22%	Fract >=3 Some Disturb	9,1%	0,0%	16,7%	18,2%	44,0%	13,6%	25,0%	28,0%	0,0%	8,7%	12,0%	0,0%	30,8%	88,9%	80,8%
Age 40-64: 26%	Fract >=5 Disturbed	4,5%	0,0%	12,5%	4,5%	36,0%	13,6%	20,8%	24,0%	0,0%	8,7%	4,0%	0,0%	15,4%	81,5%	57,7%
Age 65 -: 52 %	Fract >=8 Very Disturb	0,0%	0,0%	8,3%	0,0%	24,0%	0,0%	8,3%	4,0%	0,0%	4,3%	0,0%	0,0%	3,8%	55,6%	11,5%
Växjö L	A50_Average	1,59	0,32	0,61	1,39	2,38	0,56	1,00	0,76	1,18	1,78	1,43	0,18	1,20	6,88	4,26
N=64	A50_CI-95 ($\pm 2S/\sqrt{N}$):	±0,6	±0,2	±0,3	±0,6	±0,7	±0,3	±0,4	±,3	±0,6	±0,6	±0,5	±0,1	±0,5	±0,8	±0,7
Age 18-25: 7 %	A16_Avg+StdDev	3,87	1,03	1,78	3,74	5,16	1,82	2,48	2,16	3,43	4,05	3,30	0,65	3,05	10,01	7,01
Age 26-39: 15%	Fract >=3 Some Disturb	18,8%	1,8%	8,1%	16,1%	32,4%	7,3%	13,8%	11,3%	8,5%	26,2%	20,3%	0,0%	18,8%	83,8%	69,9%
Age 40-64: 49%	Fract >=5 Disturbed	10,9%	0,0%	1,6%	11,3%	22,1%	1,8%	6,2%	4,8%	8,5%	9,2%	8,7%	0,0%	6,3%	78,4%	54,8%
Age 65 -: 29 %	Fract >=8 Very Disturb	4,7%	0,0%	0,0%	4,8%	8,8%	0,0%	0,0%	0,0%	5,6%	4,6%	2,9%	0,0%	3,1%	59,5%	12,3%
Linköping O	A50_Average	2,1	0,7	1,3	2,1	4,7	2,3	1,1	2,2	2,2	1,2	0,1	1,3	0,9	5,5	3,7
N=16	A50_CI-95 ($\pm 2S/\sqrt{N}$):	±1,2	±0,8	±1,0	±1,7	±1,9	±1,7	±0,9	±1,7	±1,2	±0,8	±0,1	±1,3	±0,7	±1,9	±1,3
Age 18-25: 6 %	A16_Avg+StdDev	4,4	2,3	3,3	5,6	8,5	5,7	3,0	5,5	4,7	2,9	0,4	3,9	2,2	9,3	6,4
Age 26-39: 29%	Fract >=3 Some Disturb	33,3%	11,1%	27,8%	25,0%	64,7%	29,4%	7,1%	23,5%	33,3%	20,0%	0,0%	21,4%	11,8%	70,6%	61,1%
Age 40-64: 29%	Fract >=5 Disturbed	13,3%	11,1%	11,1%	25,0%	52,9%	17,6%	7,1%	23,5%	27,8%	6,7%	0,0%	21,4%	5,9%	70,6%	44,4%
Age 65 -: 36 %	Fract >=8 Very Disturb	0,0%	0,0%	0,0%	12,5%	35,3%	17,6%	0,0%	11,8%	5,6%	0,0%	0,0%	7,1%	0,0%	41,2%	11,1%
Växjö P	A50_Average	2,0	0,2	1,1	1,5	2,9	0,6	1,0	0,6	1,4	0,4	1,4	0,2	1,4	7,9	5,1
N=21	A50_CI-95 ($\pm 2S/\sqrt{N}$):	±1,0	±0,2	±1,0	±1,2	±1,2	±0,6	±0,7	±0,5	±1,0	±0,3	±0,8	±0,2	±0,9	±0,8	±1,2
Age 18-25: 5 %	A16_Avg+StdDev	4,2	0,8	3,4	4,3	5,7	2,0	2,5	1,8	3,6	1,1	3,2	0,6	3,5	9,7	7,9
Age 26-39: 32%	Fract >=3 Some Disturb	35,0%	0,0%	19,0%	20,0%	45,5%	5,0%	13,0%	13,6%	22,7%	0,0%	17,4%	0,0%	17,4%	100%	78,3%
Age 40-64: 27%	Fract >=5 Disturbed	20,0%	0,0%	9,5%	20,0%	22,7%	5,0%	8,7%	0,0%	13,6%	0,0%	4,3%	0,0%	8,7%	95,7%	56,5%
Age 65 -: 36 %	Fract >=8 Very Disturb	0,0%	0,0%	0,0%	5,0%	9,1%	0,0%	0,0%	0,0%	4,5%	0,0%	0,0%	0,0%	4,3%	65,2%	21,7%
Växjö W	A50_Average	2,1	1,0	1,7	1,8	4,4	1,3	2,4	1,5	2,0	1,5	1,8	0,6	1,5	5,3	3,2
N=24	A50_CI-95 ($\pm 2S/\sqrt{N}$):	±0,8	±0,7	±1,1	±1,0	±1,3	±1,0	±1,0	±0,9	±0,8	±0,8	±1,1	±0,5	±1,0	±1,4	±1,1
Age 18-25: 17%	A16_Avg+StdDev	4,1	2,7	4,4	4,2	7,6	3,8	4,9	3,7	3,9	3,4	4,5	1,8	4,1	8,8	5,9
Age 26-39: 39%	Fract >=3 Some Disturb	30,0%	16,0%	20,8%	28,0%	62,5%	15,0%	32,0%	25,0%	32,0%	24,0%	16,7%	5,0%	16,7%	68,0%	44,0%
Age 40-64: 30%	Fract >=5 Disturbed	15,0%	8,0%	12,5%	20,0%	54,2%	10,0%	24,0%	12,5%	12,0%	12,0%	12,5%	5,0%	8,3%	56,0%	32,0%
Age 65 -: 14 %	Fract >=8 Very Disturb	0,0%	0,0%	8,3%	0,0%	16,7%	5,0%	4,0%	0,0%	0,0%	0,0%	8,3%	0,0%	8,3%	36,0%	4,0%

Table 3. Correlation coefficients between the averages A50 and the fractions R3, R5 and R7. Also for the averages minus one standard deviation (A16)

Correlation coefficients A50 vs Fractions ≥3, ≥5, ≥8				Correlation coefficients A16 vs Fractions ≥3, ≥5, ≥8		
Question	Fraction ≥ 3	Fraction ≥5	Fraction ≥8	Fraction ≥3	Fraction ≥5	Fraction ≥8
1	0,98	0,88	0,48	0,96	0,91	0,58
2	0,96	0,83	0,42	0,97	0,87	0,45
3	0,88	0,90	0,56	0,82	0,91	0,62
4	0,91	0,92	0,61	0,85	0,91	0,70
5	0,99	0,98	0,89	0,95	0,96	0,92
6	0,99	0,95	0,89	0,98	0,94	0,87
7	0,95	0,94	0,69	0,89	0,91	0,82
8	0,92	0,97	0,73	0,87	0,95	0,79
9	0,93	0,85	0,52	0,84	0,85	0,70
10	0,94	0,74	0,47	0,82	0,81	0,66
11	0,93	0,88	0,82	0,91	0,91	0,83
12	0,97	0,97	0,76	0,98	0,97	0,78
13	0,93	0,98	0,90	0,90	0,94	0,96
14	0,95	0,93	0,91	0,66	0,69	0,85
15	0,92	0,86	0,62	0,80	0,86	0,80

Measurements and calculations of sound insulation

Each building included in the survey has been analyzed by means of

- field measurements and calculations, or
- field measurements only, or
- calculations only

Their building constructions are described in a separate paragraph below.

In the houses with *timber floors and walls* (AkuLite), sample measurements were made in 4-12 apartments. In each case, the sound reduction indicies (EN ISO 717-1) and impact sound indices (EN ISO 717-2) were derived from third-octave band data in the frequency range 50-3150 Hz[11].

The values used for the analyses are the arithmetic averages of the small and large rooms of a typical floor plan for each building. Separate analyses have been made in the vertical and horizontal directions. The correlations have been calculated only in the vertical direction.

The variation of measured sound insulation in the apartments are typically 3 dB in the Göteborg K and Linköping O buildings, but considerably higher in Växjö P, Växjö W and Växjö L buildings. These variations may affect the subjective rating given by the residents in various apartments. Hence, they may reduce the correlation of the average rating to the measured average sound insulation in these buildings (see figures 7).

In some *concrete houses* (NCC/SBUF), the sound reduction indicies (EN ISO 717-1) and impact sound indices (EN ISO 717-2) were calculated in third-octave bands 50-3150 Hz according to SS-EN 12354 parts 1 and 2. The reasons for this choice were two-fold

- the subjective ratings indicated satisfactory sound insulation in most buildings but higher annoyance with noise from service equipment and traffic. Hence, it was more important to focus on these sources in the field measurements.
- earlier studies show a high correlation between calculated and measured sound insulation in buildings with concrete floors[12]. Calculated values are estimated to be as reliable as measured values in buildings with concrete floors and walls.*

Sample measurements have been taken in 3 buildings (supported by Boverket). In the Umeå D and S buildings the results agreed well with the calculated. In the Göteborg U building, the impact sound agreed well but the airborne sound insulation was 2 dB lower than calculated. The values in third octave band suggest that unforeseen flanking transmission has occurred, but this has not yet been confirmed. The data used for correlation with the questionnaire ratings have been adjusted to the measured insulation values in the Göteborg U and Umeå D buildings. For the Umeå S building, the measured impact sound insulation was used instead of the calculated.

The variation of sound insulation within the apartments are typically within 3 dB in the concrete buildings studied (the standard deviation was less than 1 dB).

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[11] Several buildings with timber floors are currently measured in a very wide frequency range (20-3150 Hz) to enable further analyses in the AkuLite project. Vibrations are measured as well. However, these results will be published separately.

[12] Managing uncertainty in building acoustics. Simmons C. Doctoral thesis at Luleå university of technology 2009. ISSN: 1402-1544. www.ltu.se, www.dissertations.se.

Weighed single number values, e.g. the $R'_w + C_{50\text{-}3150}$ as well as $L'_{n,w} + C_{I,50\text{-}2500}$, have been calculated from third octave band values according to EN ISO 717 (1996) parts 1 and 2.

Some variations of weighings or recalculations (compared to the EN ISO 717) may be made later on the basis of the data collected. This allows to further investigate newer procedures either already proposed or that will be proposed later this year or in 2012, to ISO TC 43/SC 2/WG 18 (working with the future version of EN ISO 717 (that will be denoted EN ISO 16717. This new standard will be available in parallel to current EN ISO ISO 717 and probably, after a transition period replace the current standards. Furthermore, other frequency ranges and sound absorption areas used for normalization of the receiving room sound pressure levels may then be analyzed. This work is coordinated with the COST actions TU 0901 and FP 0702, comprising a number of members from the ISO working groups as well.

The overall goal of the AkuLite project (and also the European AcuWood project) project is to develop single numbers with high degree of correlation to the subjective rating of the sound insulation, being independent of the type of structural materials that are used in the building.

The findings from these projects could be used to verify the choice for ISO and COST activities, which both have the mission to find agreement regarding use of common single numbers[13]. The results can be expressed as the coefficient of correlation (r) that is preferred to have >0,8. In the data presented in tables 1 and 2 as well as in the figures below, the correlation is unfortunately below this goal.

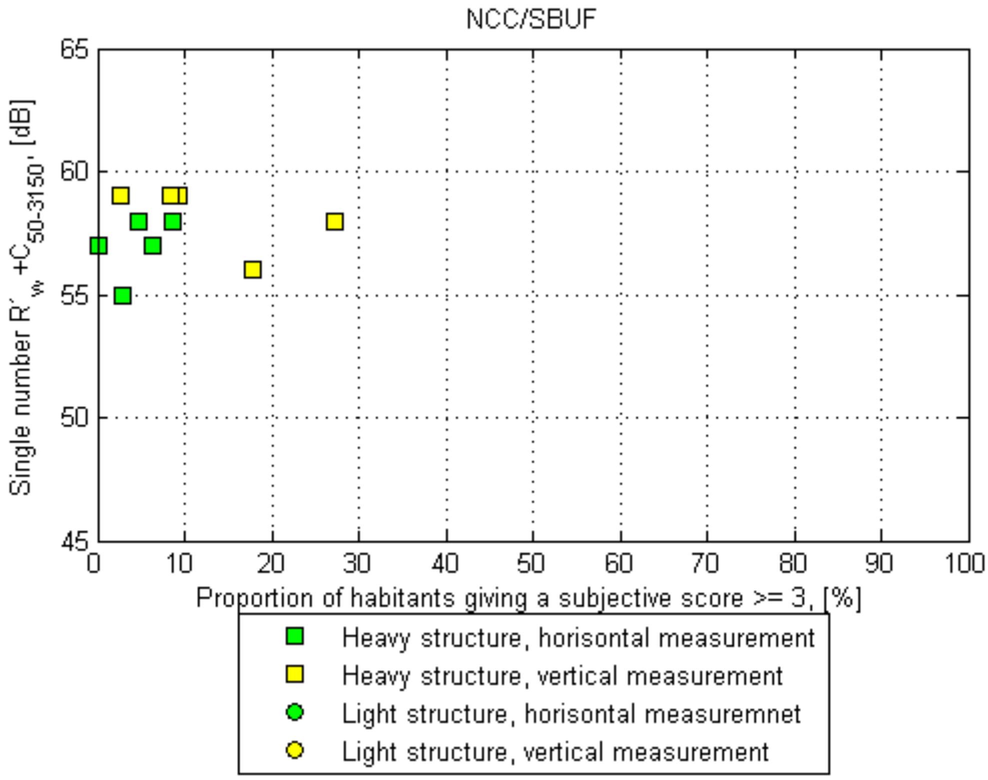
The correlation for airborne sound insulation was considerably weaker than the goal, in particular in the wooden frame buildings, which calls for more analyses to be made. This discrepancy is discussed further below.

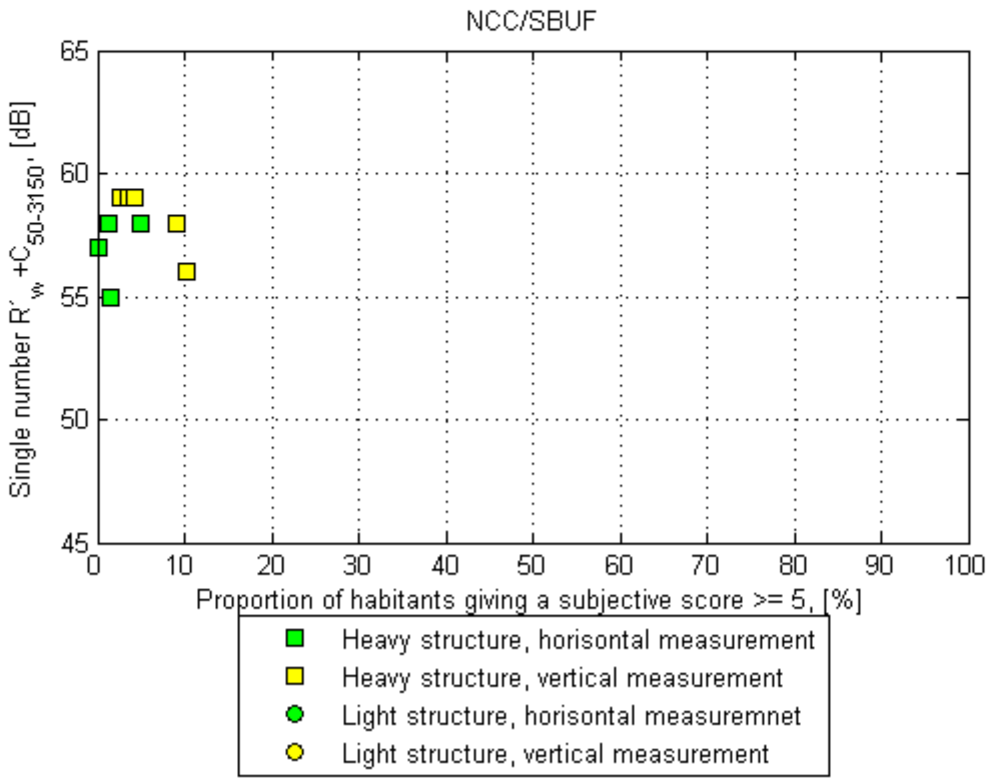
However, regarding the buildings as a group with similar acoustic performances, some interesting results can still be concluded.

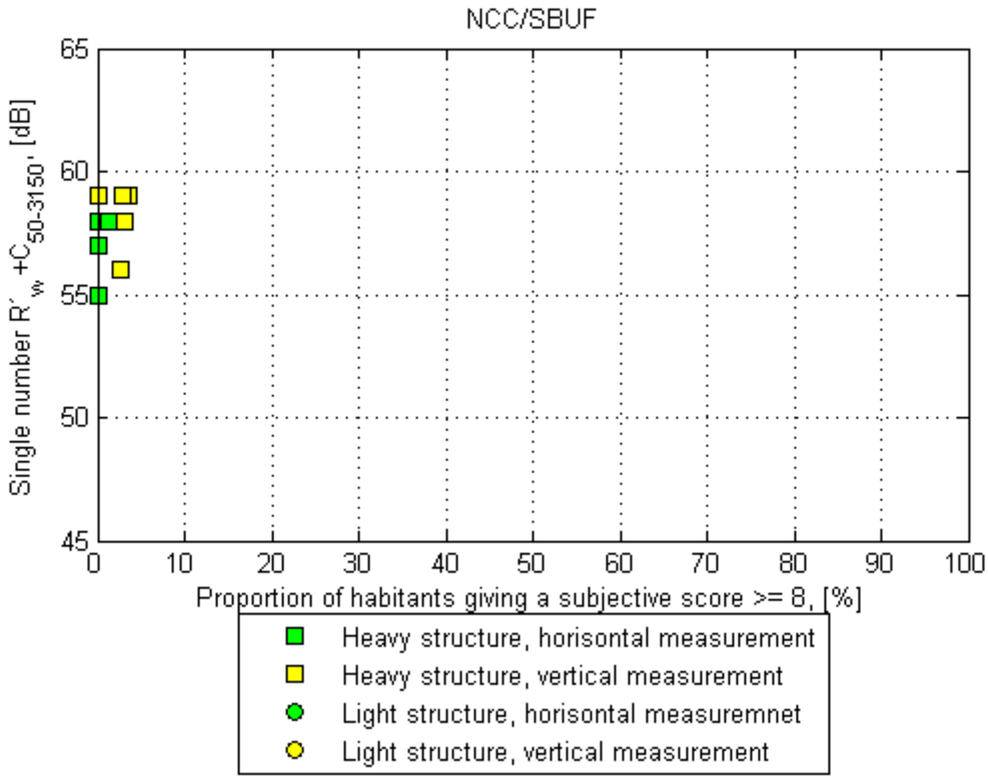
Figures 2 – 5 show the subjective ratings given as answers to questions 2 and 3 about airborne sound through walls and floors, as well as for question 5 on impact sounds. The ratings are plotted on the x-axis, where the y-axis are the measured or calculated $R'_w + C_{50\text{-}3150}$ for airborne sound insulation as well as $L'_{n,w} + C_{I,50\text{-}2500}$ for impact sound insulation.

Ratings vs sound insulation: NCC/SBUF – concrete houses

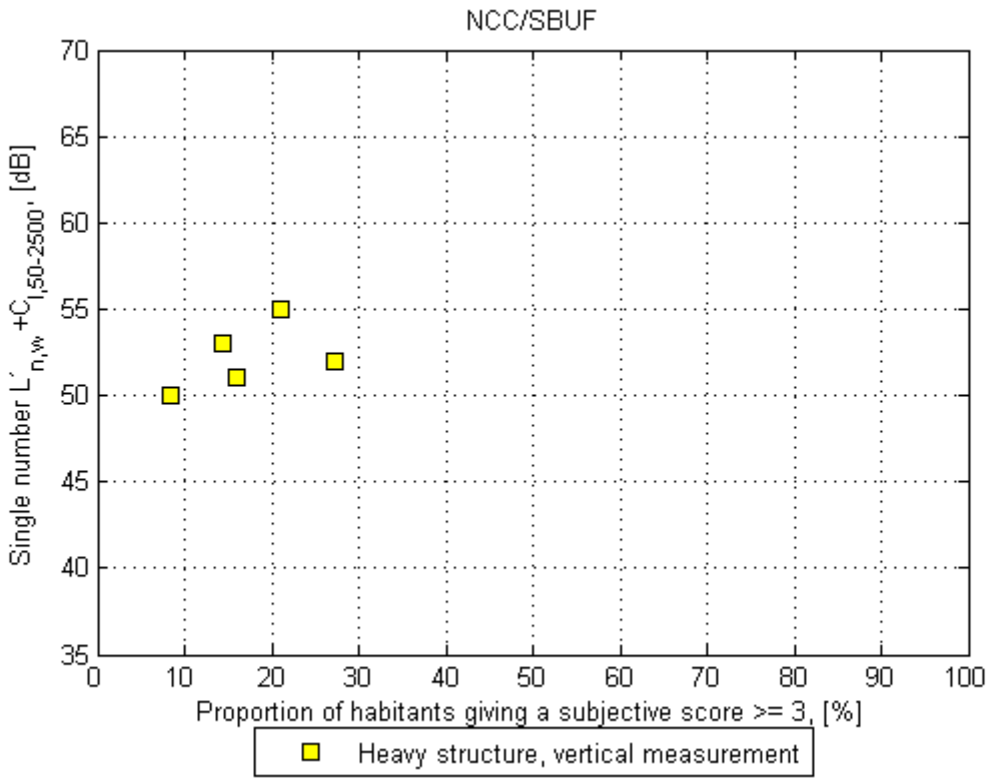
[13] The COST TU 0901 also works with a common European sound classification scheme. www.costtu0901.eu

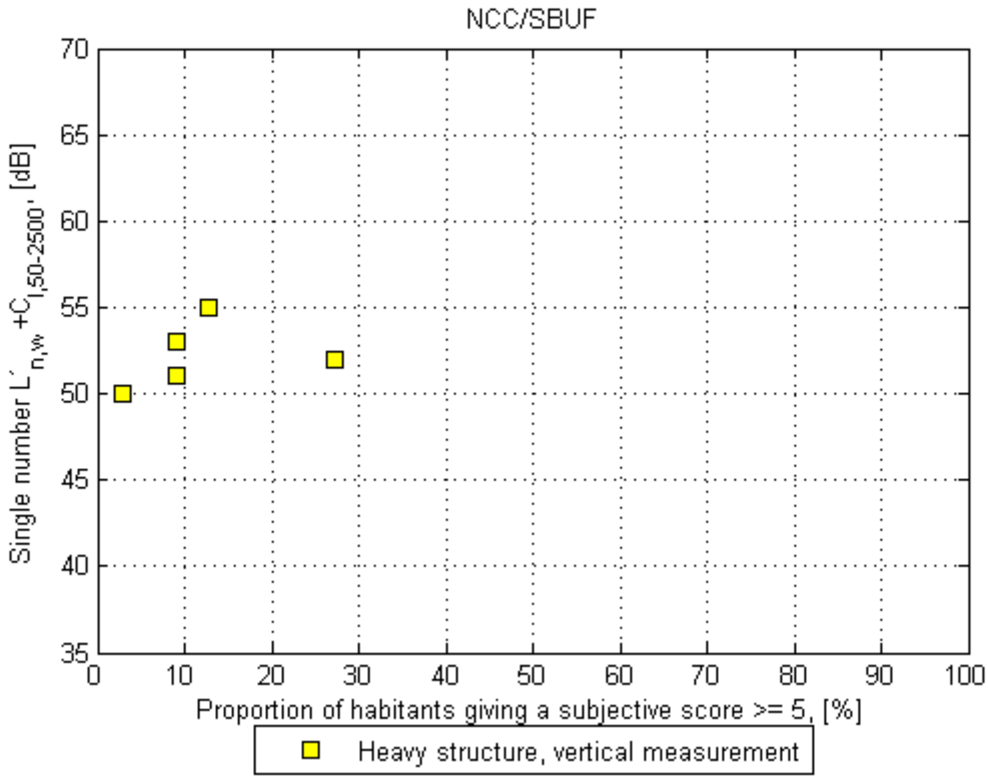

NCC/SBUF
Single number R´w +C50-3150' [dB]
65
60
55
50
45
0
10
20
30
40
50
60
70
80
90
100
Proportion of habitants giving a subjective score >= 3, [%]
Heavy structure, horisontal measurement
Heavy structure, vertical measurement
Light structure, horisontal measuremnet
Light structure, vertical measurement

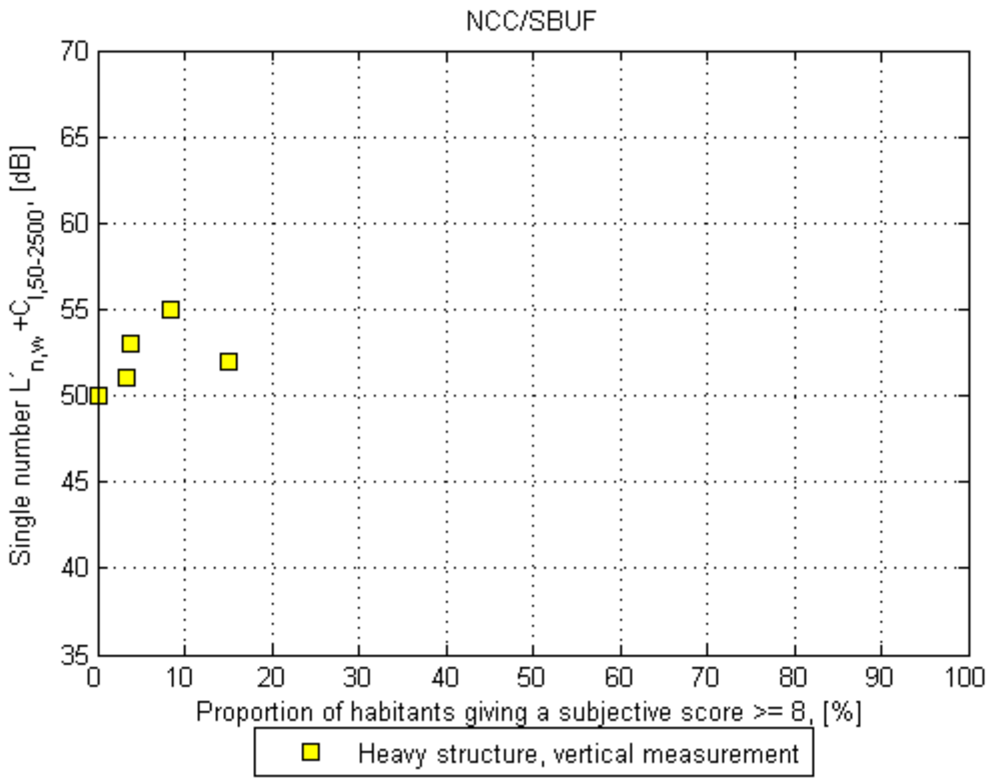

NCC/SBUF
Single number R´w +C50-3150' [dB]
65
60
55
50
45
0
10
20
30
40
50
60
70
80
90
100
Proportion of habitants giving a subjective score >= 5, [%]
Heavy structure, horisontal measurement
Heavy structure, vertical measurement
Light structure, horisontal measuremnet
Light structure, vertical measurement



Figures 2a – 2c. The measured or calculated airborne sound insulation R'_w + $C_{50\text{-}3150}$ plotted versus different subjective ratings, according to question 2 and 3. a) somewhat disturbed, disturbed or very disturbed (rating ≥ 3), disturbed or very disturbed (≥5), very disturbed only (≥8).







Figures 3a – 3c. The impact sound insulation $L'_{n,w} + C_{I,50\text{-}2500}$ plotted versus different subjective ratings, according to question 5. a) somewhat disturbed or disturbed or very disturbed (rating ≥ 3), disturbed or very disturbed (≥5), very disturbed only (≥8).

The concrete frame buildings in this study have been designed by NCC to have higher performance than required by the building regulations ($R'_w + C_{50\text{-}3150} \geq 53$ dB, $L'_{n,w}$ and $L'_{n,w} + C_{I,50\text{-}2500} \leq 56$ dB) by 2-4 dB and they actually meet this goal.

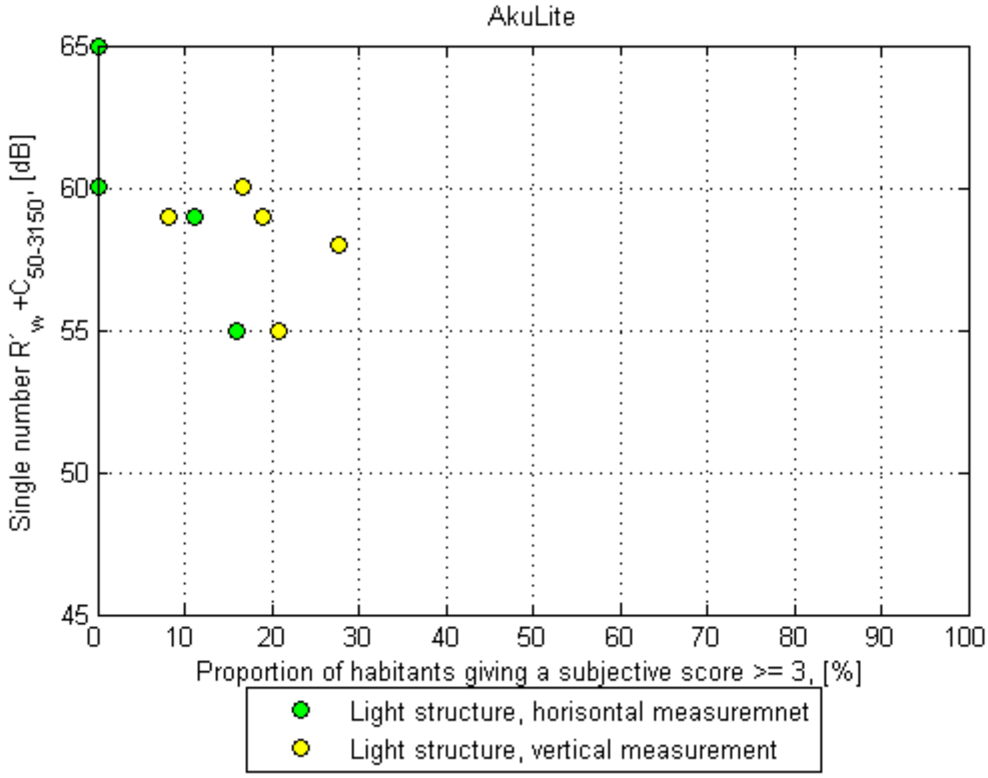
It may be concluded from figures 2a-2c that the residents in the NCC houses were disturbed to some extent by airborne noise from the neighbours in more than one of the buildings (included in the NCC/SBUF study):

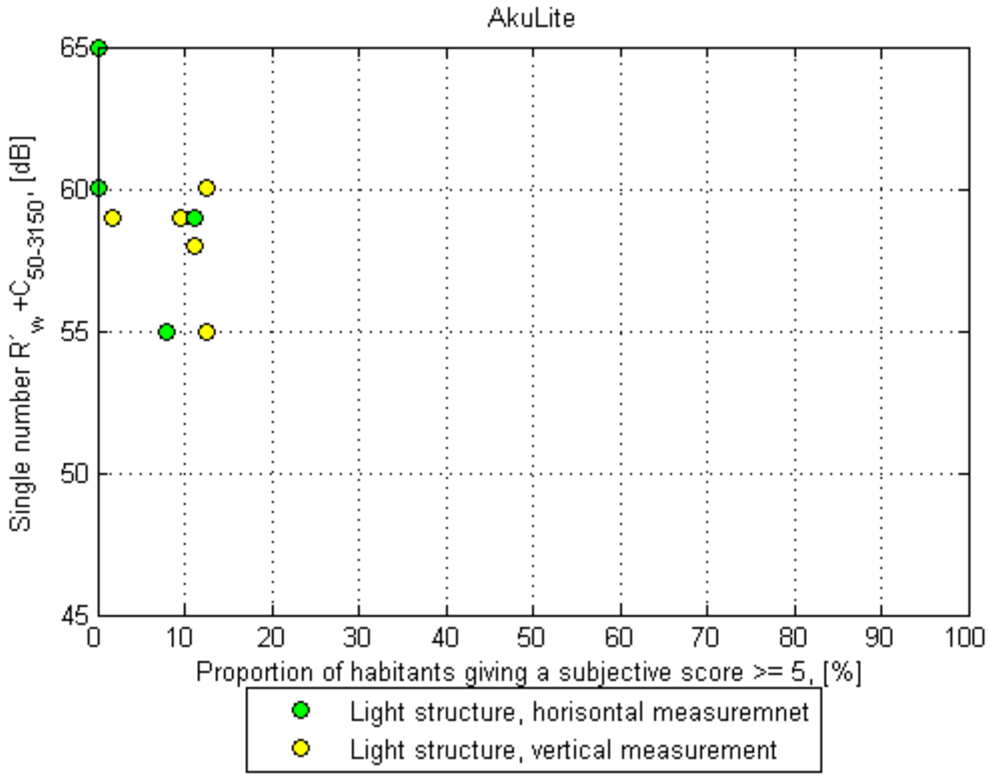
- about 5 % of the residents may be very disturbed
- about 10 % may be disturbed or very disturbed
- about 20 % are at least somewhat disturbed, disturbed or very disturbed
- these ratings agree with the provisional goals stated above.

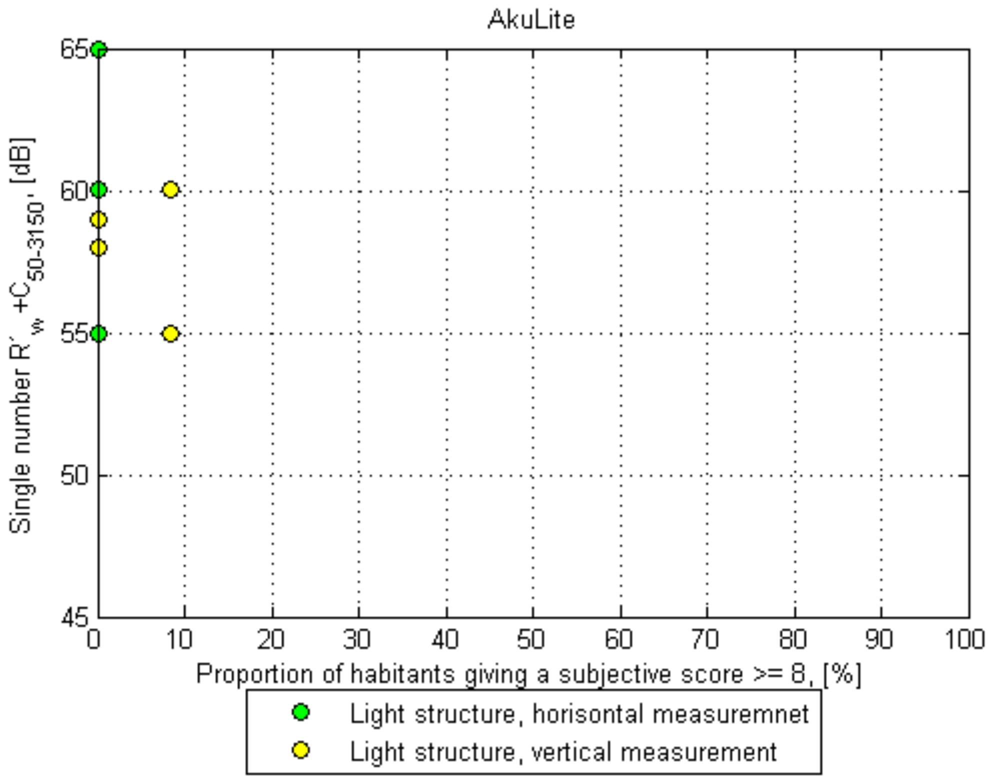
For impact sound insulation, the results indicate

- about 10 % may be very disturbed
- about 15 % may be disturbed or very disturbed
- about 20 % may be somewhat disturbed, disturbed or very disturbed
- these first two ratings are somewhat higher the goals stated above

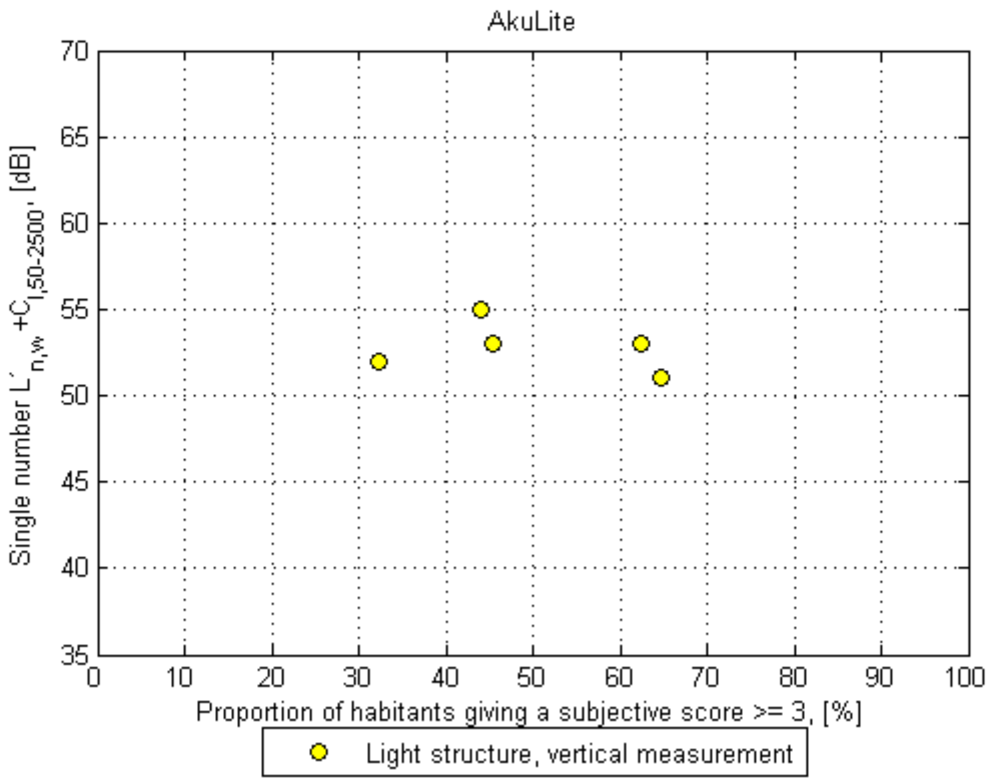
Ratings vs sound insulation: AkuLite – wooden houses

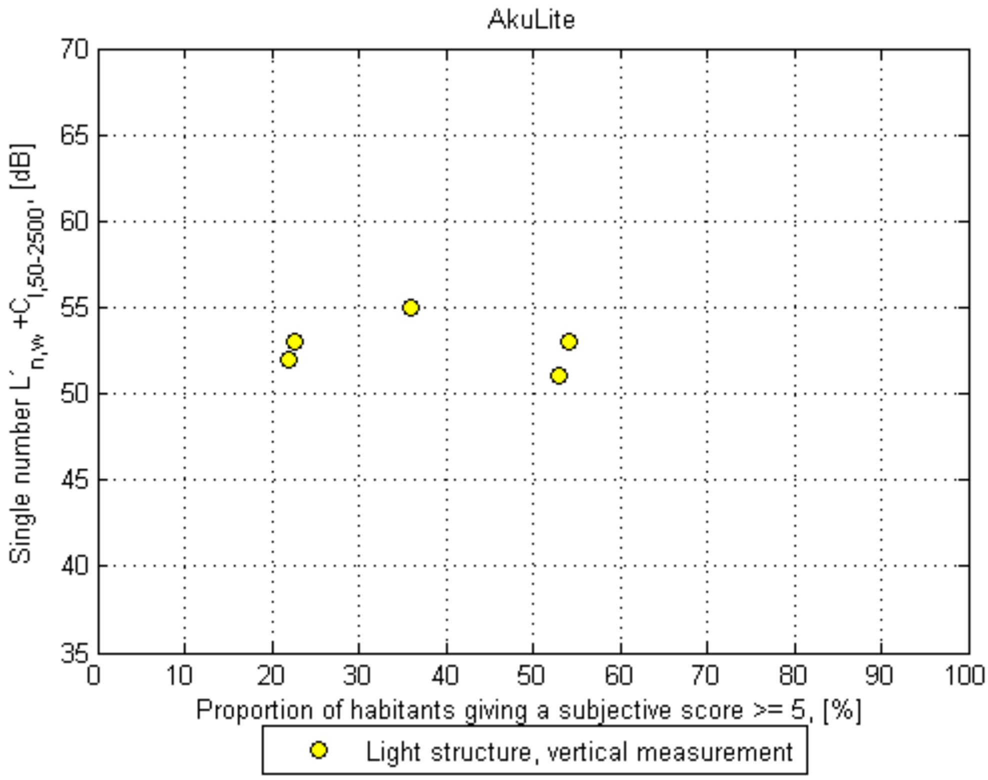


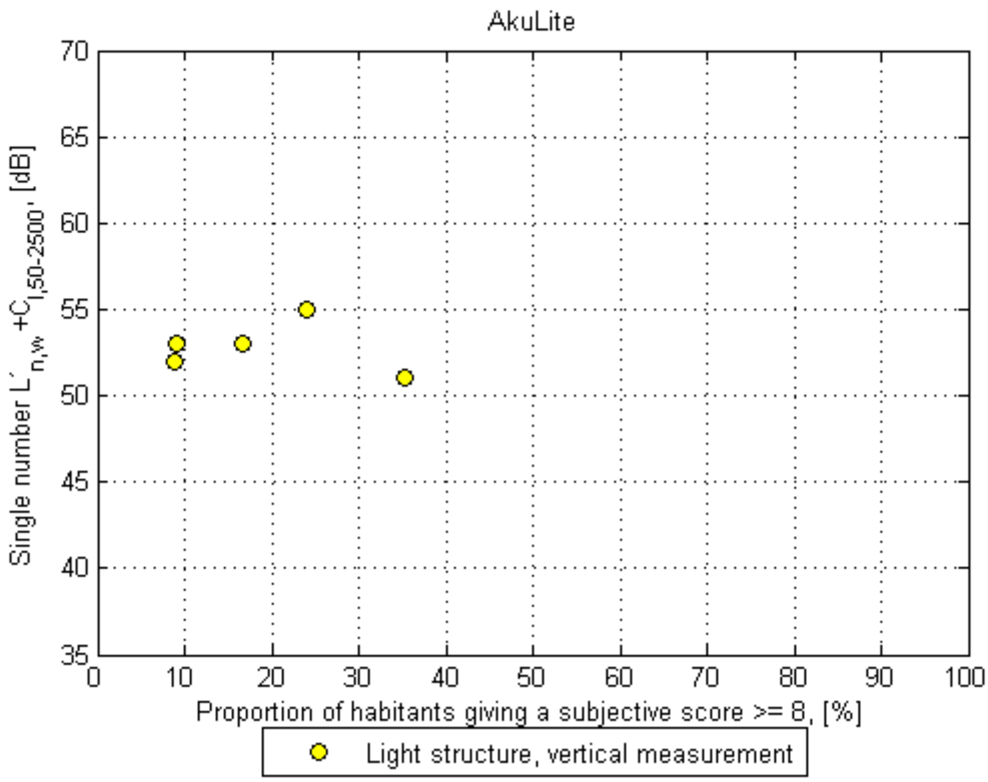




Figures 4a – 4c. The airborne sound insulation R'_w + $C_{50\text{-}3150}$ plotted versus different subjective ratings, responses to question 2 and 3.







Figures 5a – 5c. The impact sound insulation $L'_{n,w}$ + $C_{I,50\text{-}2500}$ plotted versus different subjective ratings, according to question 5.

The wooden frame buildings have been designed to exceed the building regulations ($R'_w + C_{50-3150} \geq$ 53 dB, $L'_{n,w}$ and $L'_{n,w} + C_{I,50-2500} \leq 56$ dB). Residents in these houses are disturbed at least to some extent by airborne and impact noise from the neighbours in more than one of the buildings:

- about 5-10 % of the residents are very disturbed
- about 10-12 % are disturbed or very disturbed by airborne noise
- about 20 % are at least somewhat disturbed
- these results almost agree with the provisional goals stated above

For impact sound insulation, the results are

- about 25-30 % of the residents are very disturbed
- about 50-55 % are disturbed or very disturbed
- about 60 % are at least somewhat disturbed
- **these results do not agree with the provisional goals stated above**
- **the results call for revision of the sound requirements, since the measured insulations are considerably better than required but large fractions of residents are disturbed.**

Ratings vs Sound insulation: All buildings, including previous studies

In the figures 7 and 8 below, data from both surveys are combined. Data from previous surveys made by Bodlund, Hagberg and others[1 2 3 4] have also been added to enable a comparison with older buildings, typically built with thinner concrete floors and walls or less well designed timber joist floors and walls (compared to the modern constructions discussed above).

However, such comparisons are uncertain, since the questionnaires used in those studies were based on a different rating scale, according to figure 6:

Table 1. Rating scale for quantifying subjective judgements

Quite *un*satisfactory						**Quite satisfactory**
1	2	3	4	5	6	7

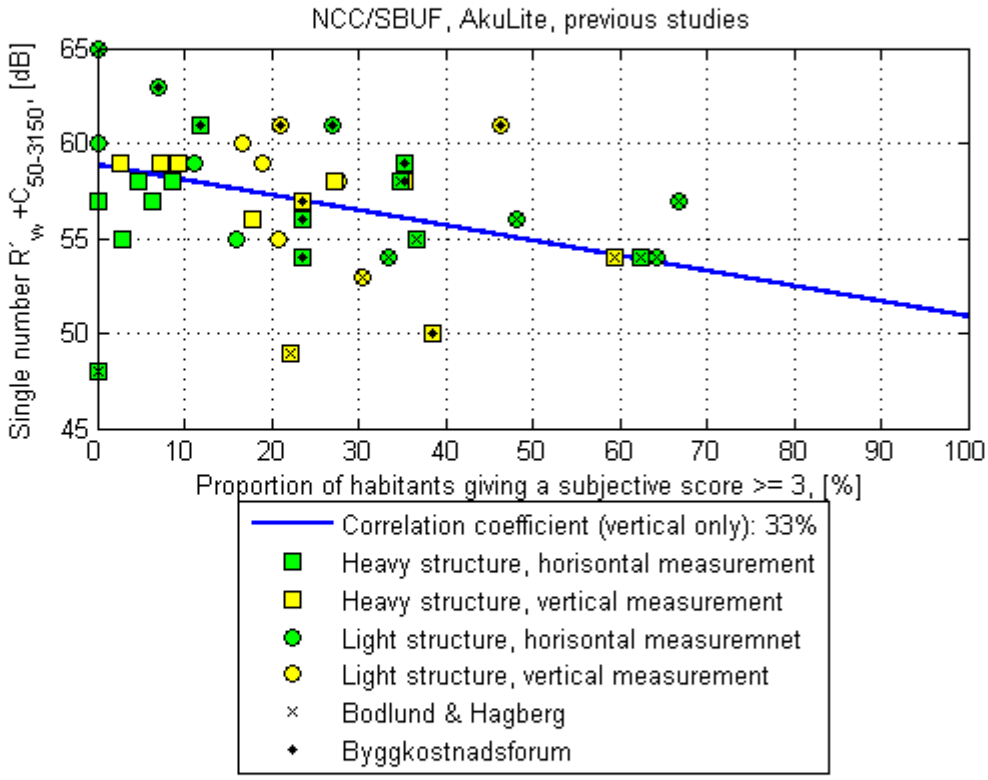
Figure 6. The 7 degree subjective rating scale used by Hagberg[1] and others. It has a reversed direction compared to the questionnaire in Figure 1b, i.e. higher rating indicates more satisfactory conditions and less disturbance by noise.

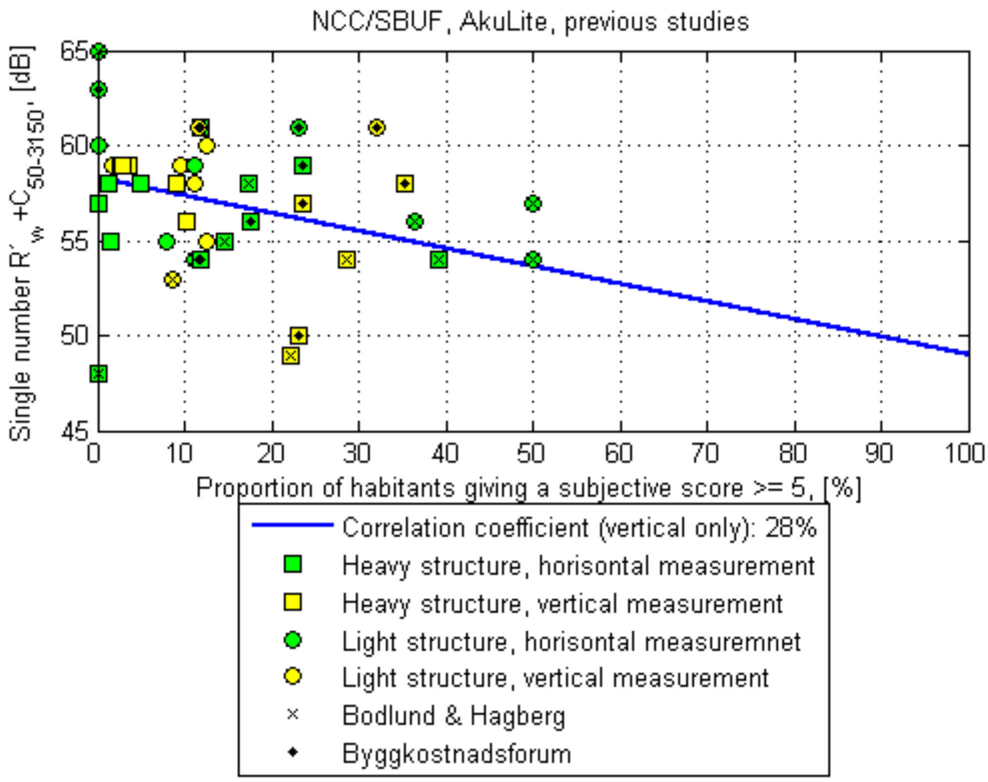
Since the scale had a reversed direction and contained fewer steps, a simple conversion was made according to table 4 to enable comparisons:

Table 4. Conversion of the 7-th nominal positive scale to the 10th nominal negative scale

Fraction being annoyed	***The 0-11 scale (Figure 1)***	***The 1-7 scale (Figure 6)***
Very disturbed	≥ 8 (i.e. 8+9+10)	≤ 2 (i.e. 1+2)
Disturbed	≥ 5	≤ 4
At least somewhat disturbed	≥ 3	≤ 6

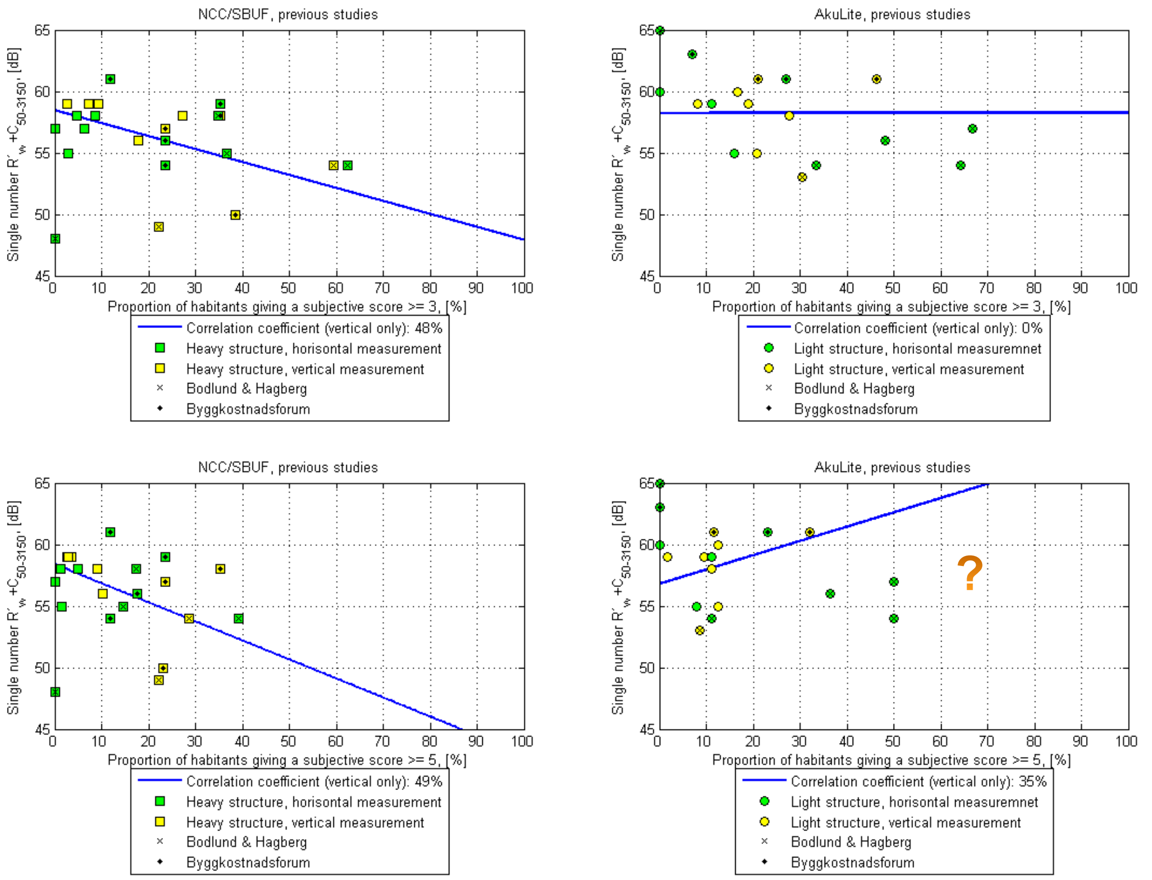
The figures 7 and 8 below summarize all results, including the NCC/SBUF study (square symbols), the AkuLite study (circle symbols) and the previous studies (squares with + or x signs for concrete buildings as well as circles with + or x signs for wooden buildings). Symbols with green colour denote horizontal measurements and symbols with yellow colour denote vertical measurements. The clustered data allow for a more general overview of the relations between sound insulation and subjective ratings, *albeit it may be uncertain* because of the differences in the subjective scales and the conversions described in figure 6 and table 4.



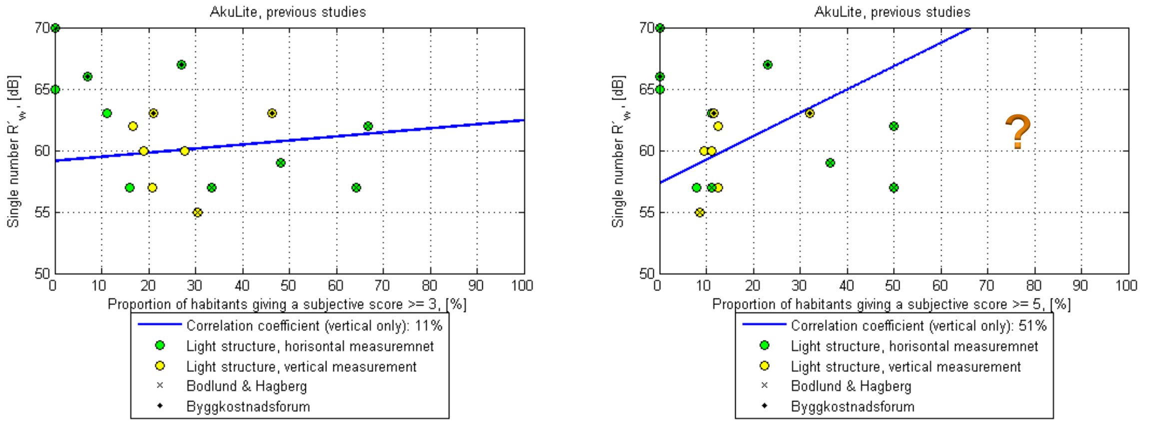


Figures 7a – 7b. The airborne sound insulation R'_w + $C_{50\text{-}3150}$ for all objects plotted versus different subjective ratings, according to table 1, 2 and from previous studies (ref 1-4).

Looking at heavy and light weight constructions separately; figures 7c-7f give an overview:

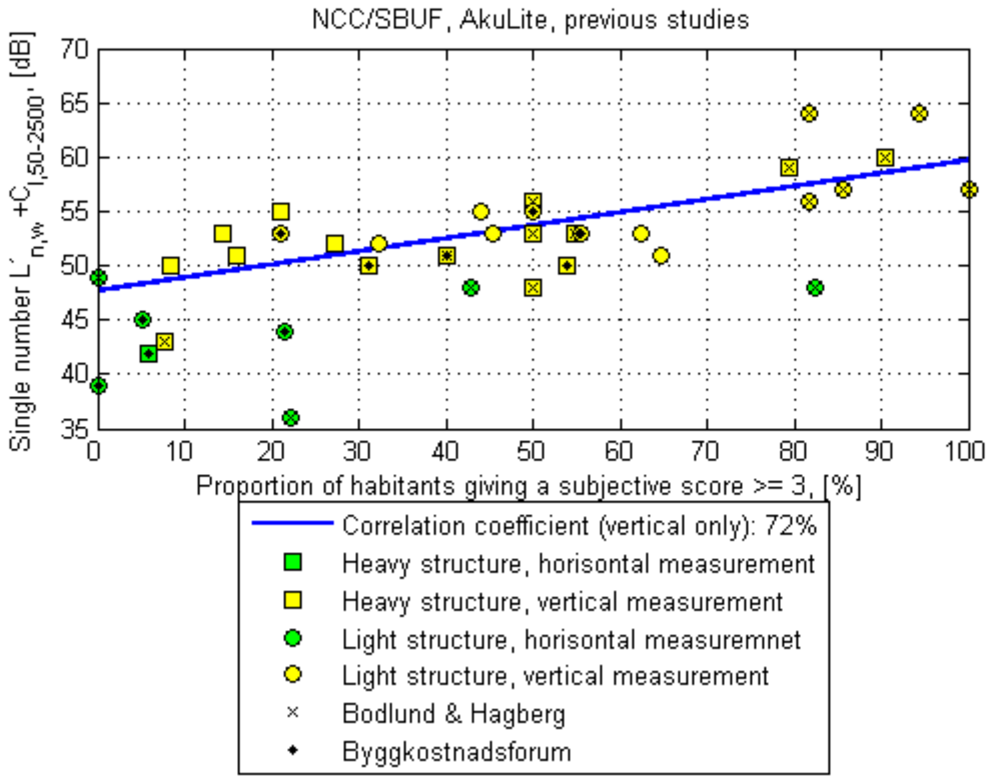


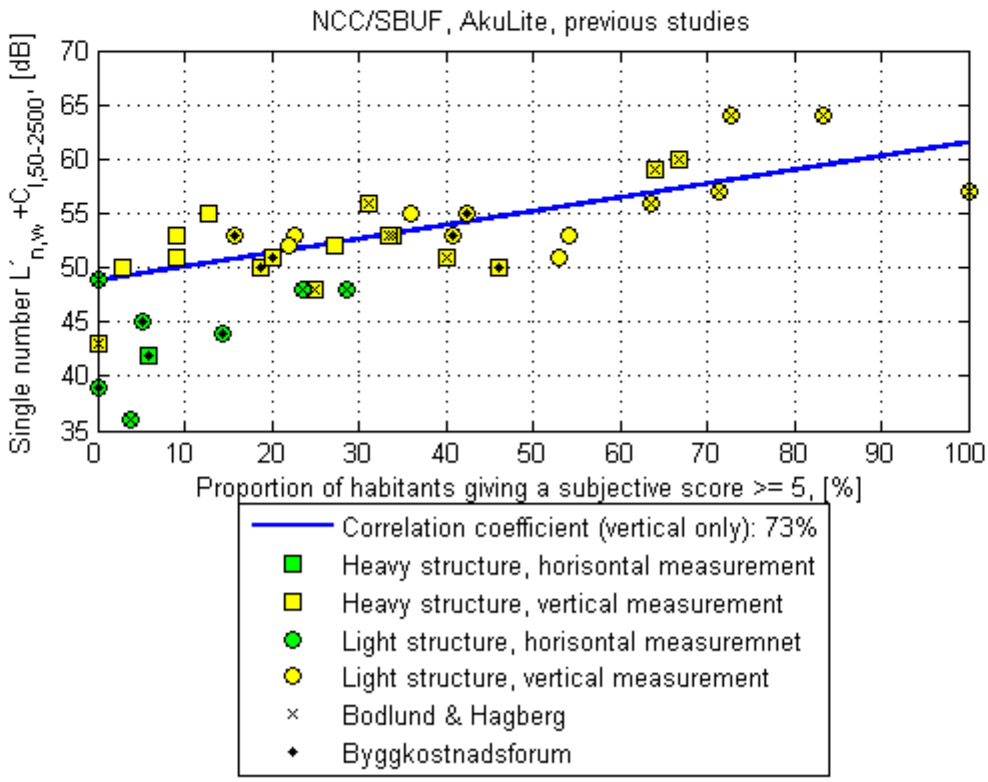
*Figures 7c – 7f. The airborne sound insulation R'_w + $C_{50\text{-}3150}$ for heavy objects (left) and light weight objects (right) plotted versus different subjective ratings (≥3 top, ≥5 bottom), according to table 1, 2 and from previous studies (ref 1-4). NB! The regressions are **very uncertain** or even erroneous, especially for the light weight objects, because of too few data points along the x-axis.*



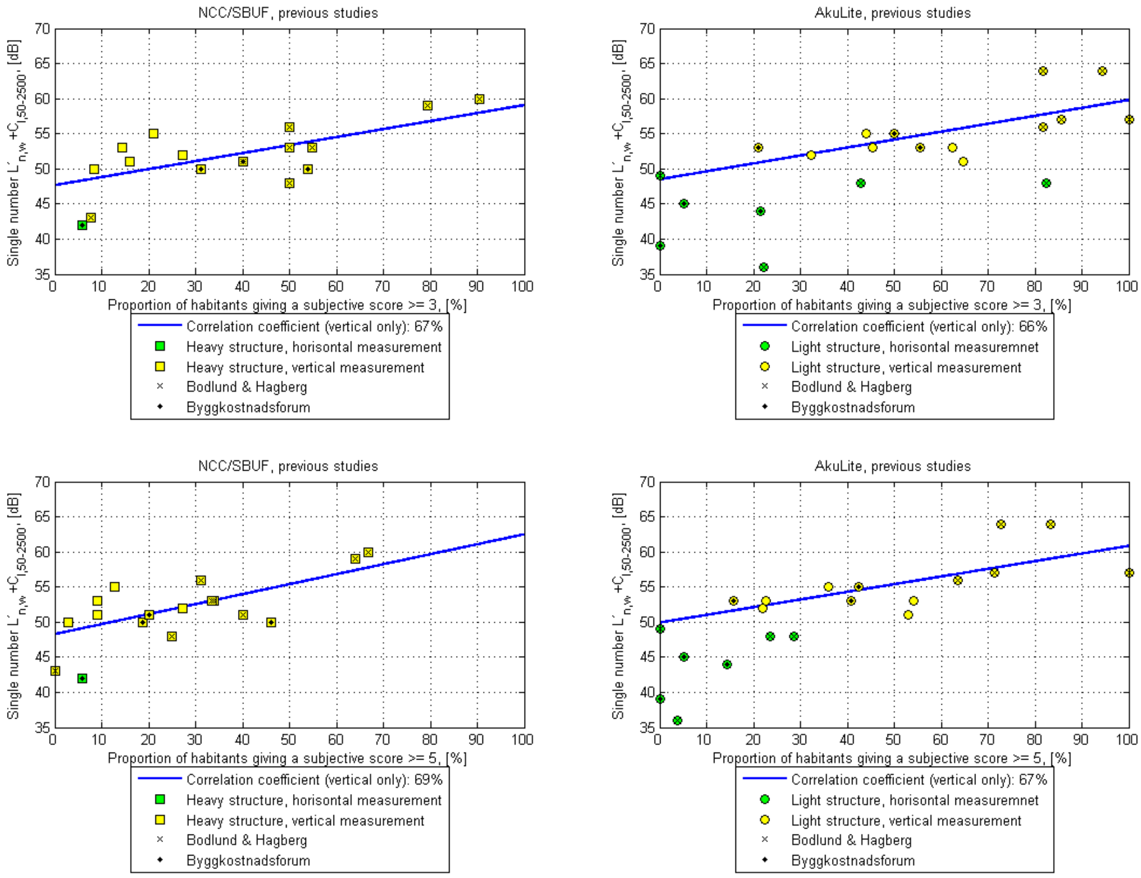
Figures 7g – 7h. The airborne sound insulation R'_w (without C-term) light weight objects plotted versus different subjective ratings (≥3 left, ≥5 right), according to table 1, 2 and from previous studies (ref 1-4). NB! The regressions are very uncertain or even erroneous, especially for the vertical direction in the light weight objects, where the data points are not distributed along the x-axis.

Figures 8 show the results for impact sound insulation.





Figures 8a – 8b. The impact sound insulation $L'_{n,w} + C_{I,50\text{-}2500}$ plotted versus different subjective ratings, according to table 1, 2 and from previous studies (ref 1-4).



Figures 8c – 8f. The impact sound insulation $L'_{n,w}$ + $C_{I,50\text{-}2500}$ for heavy objects (left) and light weight objects (right) plotted versus different subjective ratings, according to table 1, 2 and from previous studies (ref 1-4).

It may be concluded, that for all buildings studied, including the previous studies (ref 1-4), that when the current building regulations are fulfilled ($R'_w + C_{50\text{-}3150} \geq 53$ dB, $L'_{n,w}$ and $L'_{n,w} + C_{I,50\text{-}2500} \leq 56$ dB), people are disturbed to some extent by airborne noise from the neighbours in more than one of the buildings:

- about 65 % are at least somewhat disturbed
- about 40-50 % are disturbed
- these figures are determined by data from the previous studies that are more uncertain due to translation from the 7-scale to the 11-scale
- the correlation is about the same for heavy buildings and light weight

In newer buildings where the building regulations are exceed by 4 dB or more ($R'_w + C_{50\text{-}3150} \geq 53+4$ dB), people are less disturbed by airborne noise from the neighbours in more than one of the buildings:

- about 45 % are at least somewhat disturbed
- about 35 % are disturbed
- these figures are determined by data from the previous studies that are more uncertain due to translation from the 7-scale to the 11-scale

The reason for poor correlation, in particular of the wooden frame buildings, has not been examined. A few reasons may be considered in further analyses:

- the variation of the sound insulation may be large within each apartment, whereas noise in the bedrooms could be more disturbing than in the living room
- the variation of sound insulation between different apartments is large in some buildings, thus the average value may be less relevant for the individual resident.
- a subjectively poor *impact* sound insulation could cause a bias error in the *airborne* sound rating if the residents do not differ between airborne and impact sources of noise.
- excitation of the structure by sounds depend on the behaviour of the neighbours. Airborne sounds (e.g. TV, voices, music playing) may possibly vary in a more random way than impact sounds (e.g. walking, moving furniture, children playing etc), which calls for larger data sets to be analyzed.
- the sampling of buildings as well as residents in this study were not randomized. The selection may be too narrow to allow for regression analyses. The results could be regarded as representative for the type of buildings studied, but they do not allow for extrapolation to other building constructions nor residents in other areas
- it was suggested that $R'_w + C_{50\text{-}3150}$ could be a less relevant descriptor for insulation against typical airborne sound sources (speech) in the wooden frame buildings, where the sound insulation is very high in the frequency range being more relevant for speech. Figures 7g and 7h were added to test the correlation when the subjective ratings are plotted versus R'_w (without the C-term). The correlation was not improved significantly – in fact, the data set does not permit correlation analyses since the vertical data points are not distributed along the x-axis. One single point appears to improve the correlation and determine the slope of the regression line, but this is an artifact, not relevant for the purpose of this study.

For impact sound insulation, when the requirements are fulfilled ($L'_{n,w} + C_{I,50\text{-}2500} \leq 56$ dB),

- about 70 % may be at least somewhat disturbed
- about 60 % may be disturbed

With 4 dB margin to the requirements ($L'_{n,w} + C_{I,50\text{-}2500} \leq 56\text{-}4$ dB),

- about 55 % may be at least somewhat disturbed
- about 50 % may be disturbed

Looking at groups of impact sound data, there seem to be 3 groups, where the best contains the new houses. Some older houses seem to perform moderately but others are poor. This observation supports the meaning of the inclination of the regression curve, even if individual buildings deviate from the general trend and thus reduce the correlation.

Various regression tests have been made, where the spectrum adaptation term C_{tr} for traffic noise was used for the airborne sound insulation ($R'_w + C_{tr,100\text{-}3150}$), as well as $L'_{n,w}$ (without the *C*-term) and the maximal value of $L'_{n,w} + C_{I,50\text{-}2500}$ in each building. These parameters did not improve the correlation compared to the standardized parameters used in the above figures.

Measurements and observations of noise from traffic and equipments

Three buildings with concrete floors and walls (NCC/SBUF study) were examined briefly with respect to noise from traffic and building service equipments (technical installations). It was not possible to make fully standardized measurements at the sites but some sample measurements and visual inspections gave an overall impression of the conditions in the Umeå D, Umeå S and Göteborg U buildings.

Umeå D

The subjective ratings in these buildings (table 1) indicate there may be noise from the stairs, waste water and heating installations. Staff from ÅF Sound & Vibration went to the site and observed:

- Noise from supply air inlets L_{pAeq} ≤26 dB but contain some tones (whistling noise). Air outlet in kitchen makes audible noise in the living room but sound class C is fulfilled
- Noise from freezer audible in the kitchen and living room, sound class C fulfilled
- No noise from heaters observed, only audible being close to a heater
- Noise from WC (pouring water from 1 m height into the WC as well as flushing) is clearly disturbing, sound pressure levels exceed sound class C (L_{pAeq} 29-30 dB, L_{pAFmax} 31-33 dB, 4-5 and 1-3 dB above the limits). The method of measurement is not standardized.
- Shower and sink, running water, just about audible sounds
- Drying spinner clearly heard, sound pressure levels (L_{pAeq} 33 dB, does not fulfill sound class C). Outlet duct from spinner through bedroom covered by plasterboards. Washing machine at high speed is audible but fulfills the sound class
- Noise from the elevator has been annoying but has improved after adjustments have been made. L_{pAFmax} 33-39 dB does still not fulfill sound class C, is perceived disturbing. Brakes cause the high levels. L_{pAeq} 28-30 dB with a constant tone at 400 Hz during movements
- Noise from the mechanical room (containing the air handling unit) is sometimes disturbing in one apartment
- Speech from apartments may be heard in the stairwell which may be disturbing. The doors are classified R'w 35 dB which is 5 dB lower than typically used. The seals seem to work as intended. Sound absorbing materials in the stairwell reduce reverberation and noise but also improves speech intelligibility from inside the apartments which is not desirable for privacy.
- Noise from car traffic is low. An ambulance helicopter is clearly heard (L_{pAFmax} ≤ 45 dB, sound class C) but is not perceived as disturbing according to some residents opinions. It may be heard also when preparing for take-off from the roof of the nearby hospital. Heavy vehicles pass the houses on the local street which is disturbing, they are not supposed to drive on this street.

From these observations, suggestions for improvements of the equipments may be

- The supply air inlets seem to be correctly designed with respect to air flows, but there may be sharp edges causing the tones. Air pressure may vary between the inlets, some of them may then turn out to have too high air speeds. This may be corrected by appropriate adjustments. Low noise air handling requires good workmanship.
- Kitchen equipment, e.g. freezers, are available in low noise designs at very moderate additional costs. These should be offered to the residents, at least as optional choices
- Noise from WC may be attenuated efficiently by a resilient layer under the WC

- Equipment such as dry spinners and washing machines may be placed on concrete and rubber footings that attenuate structure borne sound transmission. Ceiling tiles should be heavy and sound absorbing. Floor with impact sound reduction reduces noise from laundry handling, trolleys etcetera as well as footfall noise with hard heeled shoes.
- Elevator noise may be reduced by appropriate adjustments (particularly of the breaks) and resilient mounting washers between the rails and the shaft walls
- Air handling units must be insulated both with respect to airborne sound and structure borne sound
- Entrance doors could be R'w 40 dB instead of 35 dB
- Heavy traffic close to the building may often be avoided by appropriate street design and restrictions (communicate responsibility to the urban planners of the municipality)

Umeå S

The subjective ratings in these buildings (table 1) indicate there may be some noise from the waste water and heating installations and traffic, but the ratings are fair with respect to the provisional goals. Staff from ÅF Sound & Vibration as well as Luleå technical university went to the site and observed:

- Heater noise from hot water circulation circuit has been reported by residents. At the time for the visit, the circulation system was not as hot as during cold periods and only low sound pressure levels could be observed (L_{pAeq} 29 dB in one apartment, including noise from air inlets and outlets as well as noise from remote traffic). The noise generation is known to vary with the amount of air resolved in the water, this is reduced with increasing temperature and noise may then increase
- WC noise at low levels, L_{pAFmax} below 30 dB, fulfills the sound class C
- Washing machine (in common laundry room) gives audible structure-borne sound L_{pAeq} 27 dB, L_{pAFmax} 29 dBA). Other equipments did not create audible sounds
- Sound pressure level differences from the outside to the inside was 37-40 dB. Indoor max levels below 30 dB which gives a good margin to the requirements for class C.

There are no obvious conclusions to draw from these observations. No traffic noise could be found that explain the relatively poor ratings. It may be valuable to interview the residents.

Göteborg U

The subjective ratings in these buildings (table 1) indicate there may be noise from neighbours through the floor, impact sounds, waste water, heating and technical equipments (installations). Staff from ÅF Sound & Vibration went to the site and measured sound insulation (to fill in missing measurement results from a WSP measurement in 2008).

- Both the ÅF and the WSP measurements resulted in $R'_w + C_{50\text{-}3150}$ 56 dB between the living rooms, which is 1 dB short from the goal 57 dB, but gives 3 dB margin to the minimum requirements. This is 2 dB from the calculated sound insulation and there is likely to be some flanking transmission that was not foreseen during the design stage. Between the bedrooms, ÅF measured 2-3 dB higher sound insulation.
- There are practically no partition walls between apartments, the stairwell and technical rooms are inbetween.
- The impact sound insulation meets the sound class B ($L'_{nT,w} + C_{I,50\text{-}2500} \leq 52$ dB). There are some families with small children in the house, playing with toys could cause some disturbing noise but this has not been confirmed.

- The living rooms are large and the reverberation could be longer than 0,5 seconds. It may be of interest to find out whether this is a room acoustics problem or a sound insulation problem

We made observations and measurements on other noise sources.

- Low reverberation in stairwell, sound absorbers in the ceilings
- The WSP measurements showed the sound insulation of the entrance doors did not comply with the sound class B (stated for this building), the shortage was 2 dB. WSP concluded the wall construction was not sufficient. We found several doors with leaking rubber seals, partly caused by a non-planar mounting of the doorset. According to the residents, there are no real problems with loud sounds in the stairwell
- According to the residents, the balcony doors had been leaking which increased the traffic noise from the local street, the remote high-way and the remote railway, but this problem had been solved by adjusting the doors. Since then, this traffic noise is only audible occasionally. There are some heavy vehicles during the morning (delivery to grocery shops nearby) but the traffic intensity is low. $L_{pAFmax} \leq 43$ dB was measured during some passages of heavy trucks. Once a week, garbage bins are emptied with a vacuum blower truck, which causes high noise levels during day time. The reason for the moderate ratings were not found
- Fridges are placed in the middle of the combined kitchen and living room. The compressor makes annoying noise which has been discussed by the residents and may explain the ratings given for equipment noise. Measured in 3 apartments, L_{pAeq} 32-33 dB at the dinner table and about 5 dB less in the living room is acceptable according to sound class C but not for B-class. The character is tonal which calls for lower levels to be acceptable. Without traffic and freezer, the background level was in the order of 20 dB, which makes the other noise sources more pronounced
- Flushing WC gave an audible sound at a low level. Using the WC gave L_{pAeq} 30 and L_{pAFmax} 35-38 dB which is not acceptable according to sound class C
- Elevator is placed between the stairs, no common part with the partition walls. Very low sounds from the brakes could be perceived but not measured
- The air handling is based on active outlets (fan driven) and passive inlets (under windows). No disturbing sounds from the outlets were detected

Some recommendations may be made from these observations:

- Sounds from the WC may be efficiently isolated with a resilient strip
- Entrance doors may be adjusted or mounted with better air seals to avoid leakages
- Kitchen equipment should be low-noise when placed in an open-space apartment

Discussion

The results of this study are discussed to some detail in the above sections. A few general results may be highlighted and discussed further in the working groups of AkuLite, ISO, COST and others.

- The questionnaire seem to work satisfactory. However, when a building is selected for a survey, it is necessary to inform the residents beforehand, to explain the purpose of the study and to allow the residents to respond to at least one reminder.
- Residents do not appear to take the opportunity to complain when they get the questionnaire (taking the Örebro building as an example). This is a common believe on the effect of subjective surveys which we do not find any evidence for.
- Measurements in buildings included in a survey should be extensive, to allow for determination not only of the average insulation but also for the variation inside the building.
- It remains to study whether another measurand than the average sound insulation would improve correlation to the subjective ratings, e.g. using the lower fraction of insulation within a series of measurements rather than their averages.
- New houses seem to have better ratings than older, especially with respect to airborne sound insulations. This is certainly a positive result for the developers.
- The correlation to the weighed single numbers should be improved to enable better predictions of the subjective acoustic comfort, in particular for airborne sound insulation.
- For impact sound insulation in buildings with light floors (timber joist floors), improvements are still needed to obtain better subjective ratings from the residents. The subjective ratings are poor in both old and new houses.
- Listening tests and more detailed interviews with residents should be made to find out what reasons there might be behind the worst ratings of impact sound, whether it is a matter of its sound level, its frequency content or its time history. From our own impressions on site, it seems the speed of walking has a substantial effect on the annoyance from the impact sound in the dwelling below this floor
- There are many details to improve on to achieve better ratings from the residents, especially better workmanship, better choices of technical equipment etcetera. Taking sounds from WC, air terminals, elevators as examples, they may all be efficiently attenuated at low costs. The planning process (the design) could be improved by small means.

Building descriptions

For the purpose of documentation and for future studies, some brief descriptions of the building constructions are given in this clause. However, the floor plans are only given as typical examples, since they may vary within the same building as well as between the block of buildings included in each object included in the survey.

The NCC/SBUF buildings – concrete floors and walls

Örebro

The sound insulation has been calculated according to EN 12354.

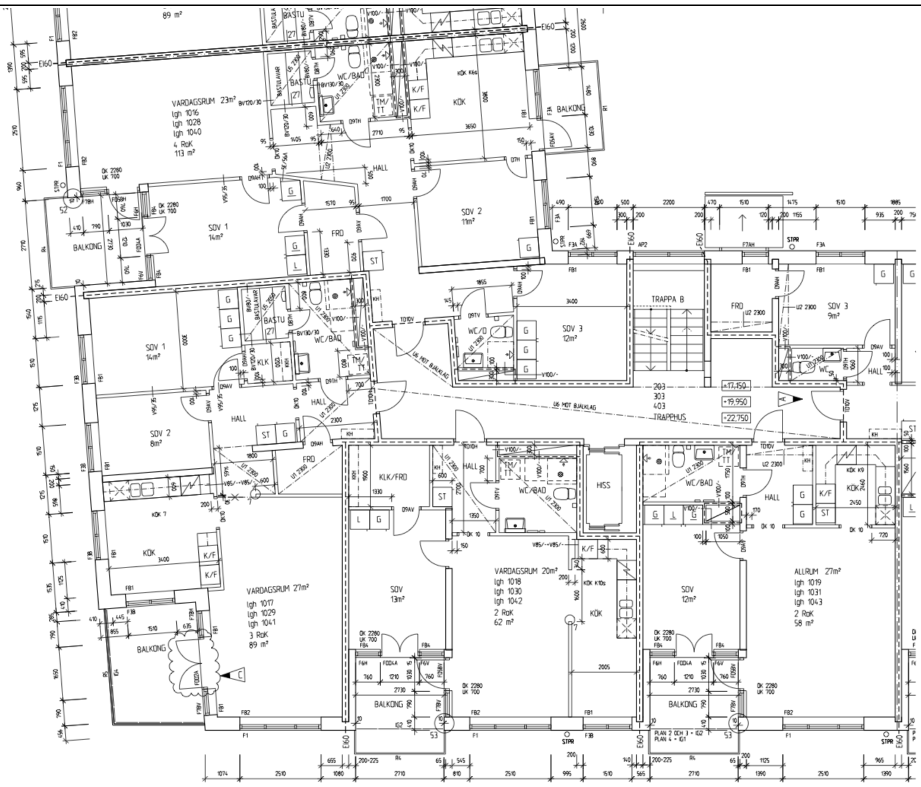
Floors: Concrete, 240 mm (180-200 *cast in situ* on 60 mm prefabricated reinforced slab)

Parquet 14-15 mm on polyethene foam 2 mm

Partitions: Concrete, 200 mm, prefabricated

Façades: Light weight, plasterboard on inside

f [Hz]	Vertical L´ [dB]	Horisontal R´ [dB]	Vertical R´ [dB]
50	43,7	39,5	42,4
63	48,7	38,8	40,5
80	51,6	38,8	40,8
100	52,2	39,7	42,4
125	53,2	41,6	44,7
160	54,6	43,6	45,9
200	55,9	46,2	48,4
250	56,2	48,7	50,7
315	57,6	49,7	51,2
400	56,1	49,4	51,5
500	50,4	53,6	55,1
630	42,6	59,1	61,6
800	38,2	62	65,8
1000	32,5	64,5	69,5
1250	27,1	66,9	71,7
1600	23,2	69,2	73,9
2000	18,6	71,2	75,8
2500	15,8	71,8	74,9
3150	13,3	73,9	76,9
$L'_{n,w}$	49		
$L'_{n,w}+C_{I,50\text{-}2500}$	50		
$R'_w+C_{50\text{-}3150}$		57	59



Västerås

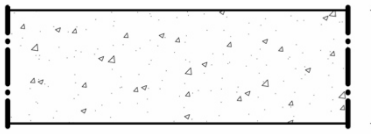
The sound insulation has been calculated according to EN 12354.

Floors: Concrete, 240 mm (180-200 *cast in situ* on 60 mm prefabricated reinforced slab)

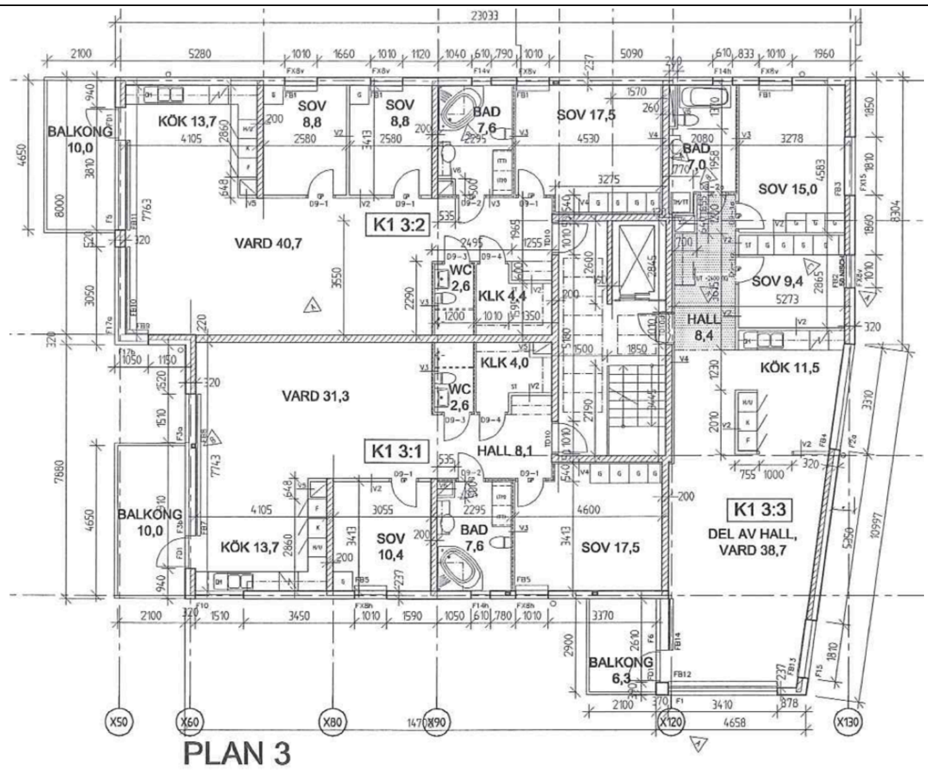
Parquet 14-15 mm on polyethene foam 2 mm

Partitions: Concrete, 200 mm, prefabricated

Façades: Light weight, plasterboard on inside



f [Hz]	Vertical L´ [dB]	Horisontal R´ [dB]	Vertical R´ [dB]
50	45,4	38,9	42,4
63	50,4	38,7	40,6
80	53,3	38,6	40,9
100	53,9	39,7	42,4
125	55,0	41,9	44,6
160	56,4	44,2	46,0
200	57,7	46,7	48,5
250	58,0	49,1	50,8
315	59,4	50,9	51,3
400	57,9	52,0	51,7
500	52,1	55,4	55,3
630	44,4	59,3	61,6
800	40,0	62,0	65,6
1000	34,3	64,5	69,1
1250	29,0	66,9	71,4
1600	25,0	69,1	73,5
2000	20,4	71,3	75,5
2500	17,5	72,4	75,3
3150	15,1	74,8	76,5
L'n,w	51		
L'n,w+CI,50-2500	51		
R´w+C50-3150		58	59



Umeå D

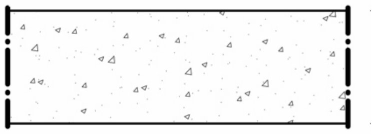
Measurements in the vertical direction have been made in these buildings according to EN ISO 140 - 4, -7. Horizontal airborne insulation is calculated according to EN 12354.

Floors: Concrete, 220 mm (160-180 *cast in situ* on 60 mm prefabricated reinforced slab)

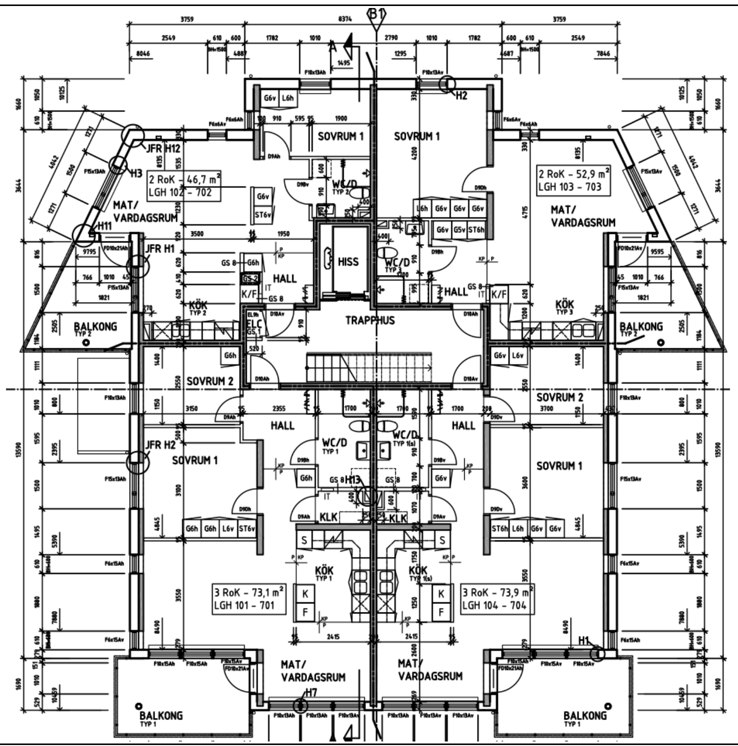
Parquet 14-15 mm on polyethene foam 2 mm

Partitions: Concrete, 200 mm, prefabricated

Façades: Light weight, plasterboard on inside



f [Hz]	Vertical L´ [dB]	Horisontal R´ [dB]	Vertical R´ [dB]
50	54,0	40,0	46,8
63	52,8	39,8	40,5
80	51,1	39,9	40,3
100	49,6	40,3	38,5
125	53,2	42,3	40,8
160	58,8	44,5	40,9
200	58,4	47,0	45,2
250	58,9	49,4	46,9
315	61,5	51,2	47,0
400	60,6	52,4	50,8
500	59,3	55,7	52,5
630	55,1	59,5	56,2
800	49,1	62,2	60,1
1000	42,4	64,6	63,2
1250	37,0	67,0	65,1
1600	31,3	69,3	67,7
2000	29,7	71,3	67,3
2500	26,1	71,5	68,0
3150	23,7	74,0	68,9
L'n,w	54		
L'n,w+CI,50-2500	53		
R´w+C50-3150		58	56



Umeå S

Measurements of impact sound insulation in the vertical direction have been made in these buildings according to EN ISO 140-7. Horizontal and vertical airborne insulations are calculated according to EN 12354.

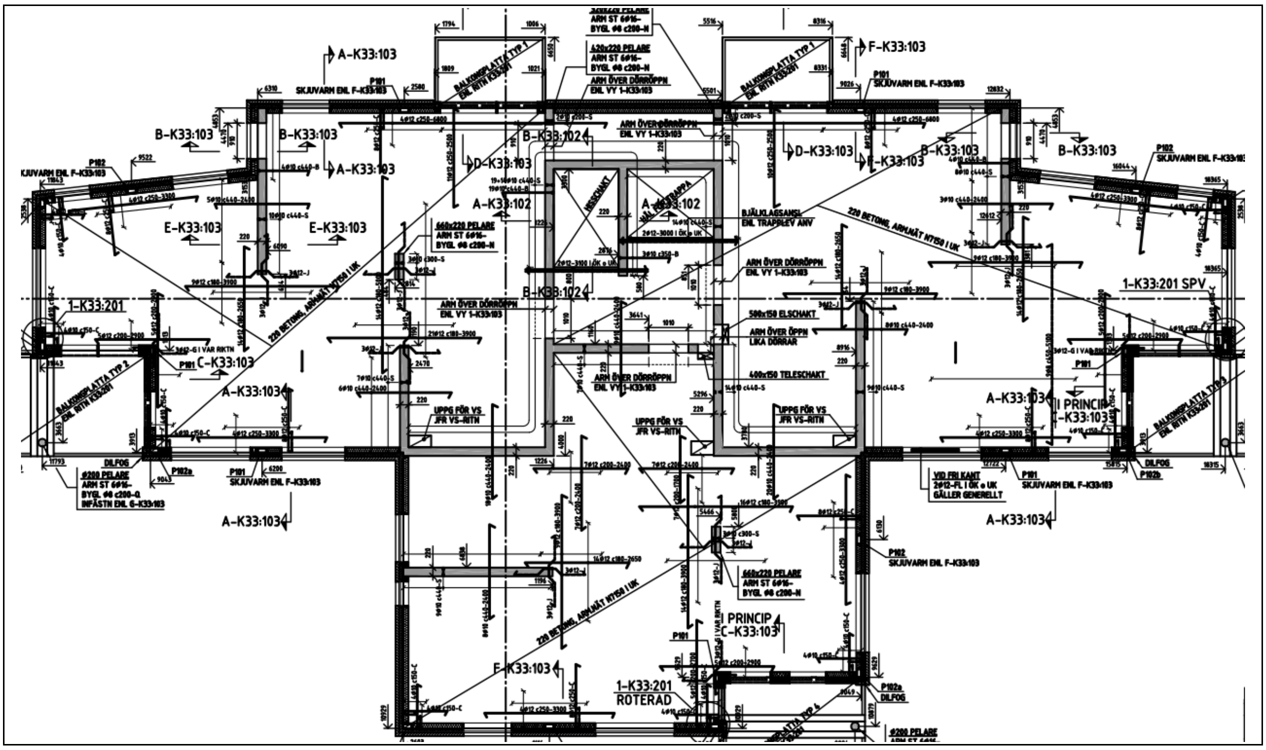
Floors: Concrete, 220 mm (160-180 *cast in situ* on 60 mm prefabricated reinforced slab)

Parquet 14-15 mm on polyethene foam 2 mm

Partitions: Concrete, 200 mm, prefabricated

Façades: Light weight, plasterboard on inside

f [Hz]	Vertical L´ [dB]	Horisontal R´ [dB]	Vertical R´ [dB]
50	48,2	35,6	43,4
63	52,1	35,4	41,3
80	57,4	35,4	41,8
100	55,9	36,3	42,2
125	59,3	38,4	45,2
160	60,7	40,7	46,3
200	59,1	43,3	48,8
250	60,3	45,8	51,1
315	61,5	47,8	51,4
400	63,5	49,1	51,6
500	57,2	52,4	55,4
630	44,5	56,0	61,9
800	39,3	58,6	66,3
1000	35,5	61,2	70,1
1250	32,7	63,6	72,4
1600	30	66,0	74,4
2000	27,2	68,2	76,0
2500	24,9	70,5	74,2
3150	22,2	72,7	75,8
L'n,w	55		
L'n,w+CI,50-2500	55		
R´w+C50-3150		55	59



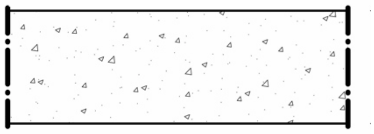
Göteborg U

Measurements in the vertical direction have been made in these buildings according to EN ISO 140 - 4, -7. Horizontal airborne insulation is calculated according to EN 12354.

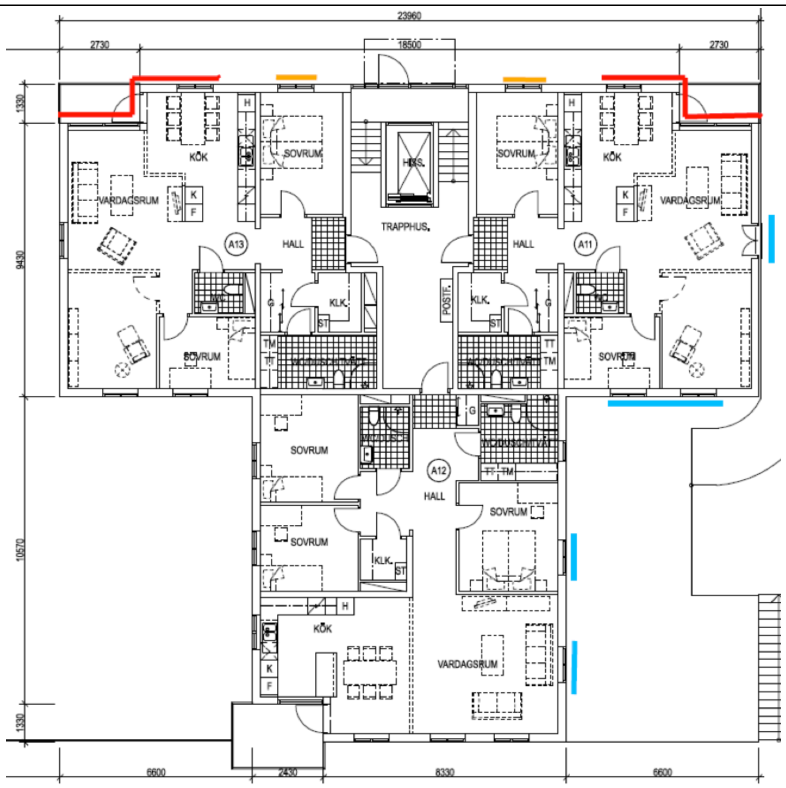
Floors: Concrete, 240 mm (160-180 *cast in situ* on 60 mm prefabricated reinforced slab)

Parquet 14-15 mm on polyethene foam 2 mm

Partitions: Concrete, 240 mm, prefabricated
Façades: Light weight, plasterboard on inside



	Vertical	Horisontal	Vertical
f [Hz]	L´ [dB]	R´ [dB]	R´ [dB]
50	54,1	37,5	37,1
63	55,5	37,8	35,3
80	53,2	37,7	40,7
100	53,7	38,4	40,4
125	54,1	40,5	42,9
160	56,1	42,9	44,0
200	58,1	45,5	46,9
250	58,7	48,1	49,3
315	59,5	50,6	50,1
400	59,8	53,1	52,7
500	56,1	55,5	55,4
630	47,7	58,0	57,9
800	42,1	60,6	63,2
1000	36,4	63,0	68,1
1250	31,3	65,3	72,1
1600	28,6	67,6	74,1
2000	25,3	69,9	74,2
2500	22,8	72,0	71,5
3150	19,4	74,2	73,4
L'n,w	52		
L'n,w+CI,50-2500	52		
R´w+C50-3150		57	58



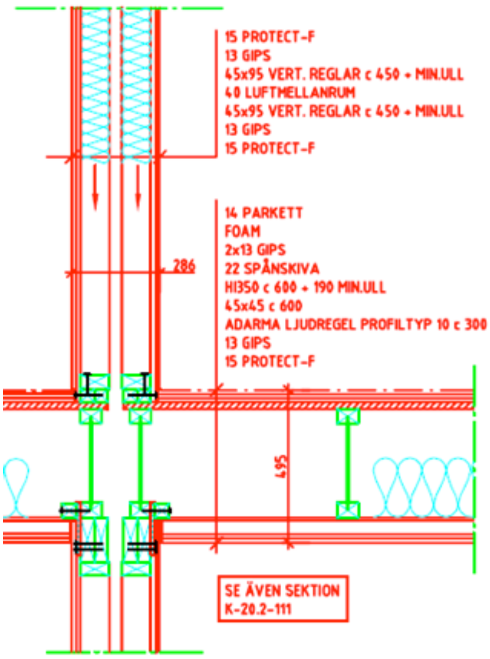
The AkuLite buildings – timber joist floors and walls

Göteborg K

The sound insulation has been measured according to EN ISO 140 -4,-7.

Floors: Wooden studs with wood particleboard and gypsum board, separately mounted ceiling

Parquet 14 mm on foam



Partitions: gypsum boards / studs + mineral wool / air gap / studs + mineral wool / gypsum boards
Façades: gypsum board + mineral wool / studs

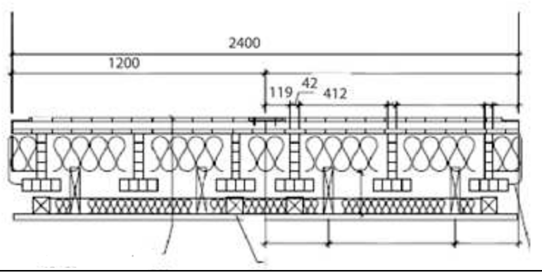
f [Hz]	Vertical L´ [dB]	Horisontal R´ [dB]	Vertical R´ [dB]
50	57,1	25,9	37,2
63	57,2	31,9	37,9
80	61,2	38,5	39,8
100	59,9	41,1	40,7
125	58,8	42,3	44,4
160	59,1	48,3	47,3
200	57,5	52,9	50,4
250	58,3	58,1	53,6
315	59,0	61,4	55,5
400	58,4	64,2	57,8
500	57,7	67,0	59,1
630	59,6	70,7	59,8
800	56,2	71,2	62,7
1000	55,1	72,4	64,4
1250	55,9	70,4	64,3
1600	53,5	65,5	64,5
2000	51,6	63,8	63,9
2500	47,8	66,5	64,9
3150	42,1	69,8	66,6
L'n,w	55		
L'n,w+CI,50-2500	52		
R´w+C50-3150		60	60

Part of floor 4

Växjö P

The sound insulation has been measured according to EN ISO 140 -4,-7.

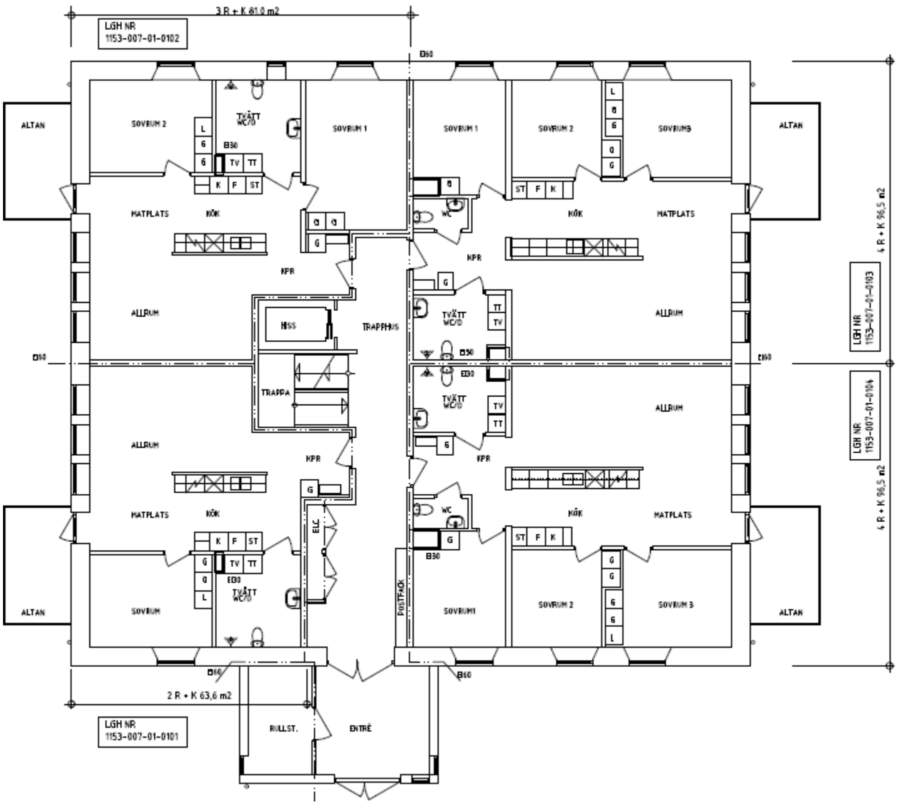
Floors: Massive wood elements, separate ceiling, parquet



Partitions: Wooden frames, plasterboards

Façades: Wooden frames, plasterboards, rendered

	Vertical	Horisontal	Vertical
f [Hz]	L´ [dB]	R´ [dB]	R´ [dB]
50	53,7	38,9	40,2
63	54,8	35,3	39,8
80	55,1	38,4	41,5
100	53,8	47,5	46,0
125	55,7	50,3	47,6
160	57,9	55,8	45,4
200	59,5	57,4	46,7
250	60,0	60,7	48,5
315	59,5	62,4	50,7
400	58,7	67,1	52,8
500	55,1	67,3	55,1
630	47,6	69,7	59,1
800	41,3	72,5	63,3
1000	36,3	77,9	66,6
1250	32,8	79,3	69,3
1600	29,1	79,8	70,0
2000	26,1	81,3	68,7
2500	21,0	85,8	71,5
3150	15,4	90,1	76,6
L'n,w	52		
L'n,w+CI,50-2500	53		
R´w+C50-3150		65	59

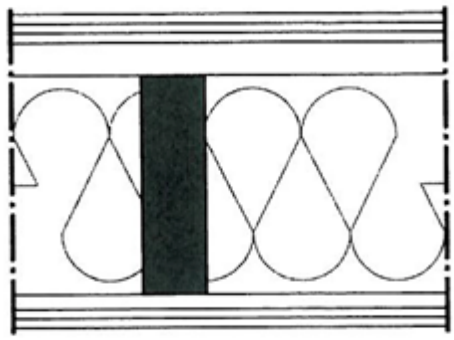


Floor 1

Växjö W

The sound insulation has been measured according to EN ISO 140 -4,-7.

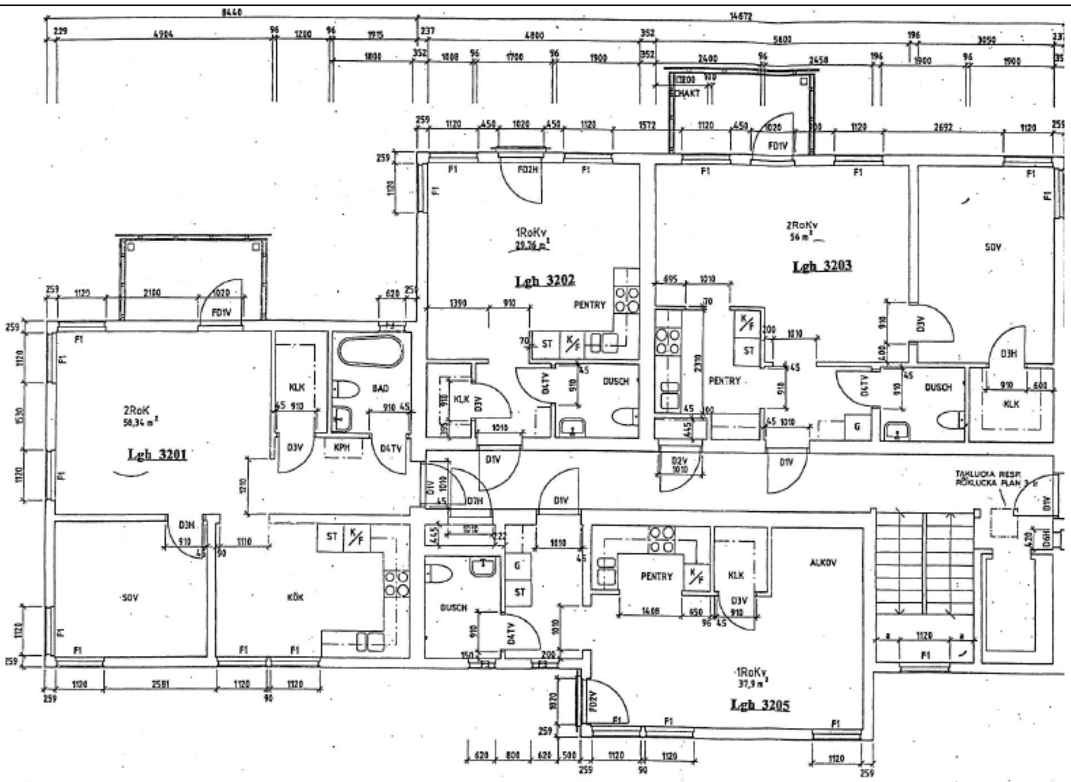
Floors: From above: carpet or gypsum / gypsum board / TRP 45 / wooden studs and mineral wool / resilent channels / gypsum boards



Partitions: Plaster boards 3+3 on 95+95 wooden studs, 190 mineral wool

Façades: light weight

	Vertical	Horisontal	Vertical
f [Hz]	L´ [dB]	R´ [dB]	R´ [dB]
50	58,7	30,3	29,2
63	59,0	30,5	27,7
80	58,9	34,4	33,6
100	57,4	41,2	39,6
125	56,7	40,3	41,8
160	58,4	42,6	42,6
200	58,9	49,6	43,6
250	57,3	50,3	45,6
315	54,9	51,5	47,3
400	53,4	52,4	47,8
500	50,5	57,6	54,5
630	47,1	57,5	56,3
800	44,0	58,8	60,5
1000	42,3	60,2	63,9
1250	38,6	61,5	66,1
1600	36,4	59,0	66,8
2000	32,6	56,2	67,7
2500	30,2	56,9	68,3
3150	24,2	58,3	72,1
L'n,w	51		
L'n,w+CI,50-2500	53		
R´w+C50-3150		55	55

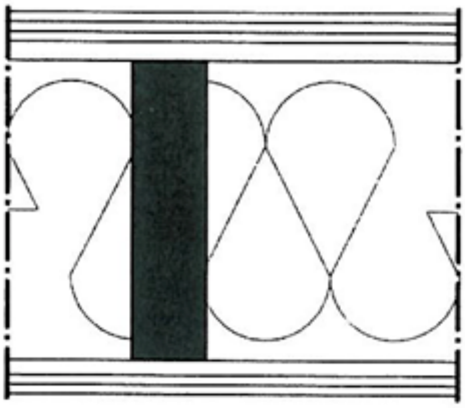


Part of floor 2

Linköping O

The sound insulation has been measured according to EN ISO 140 -4,-7.

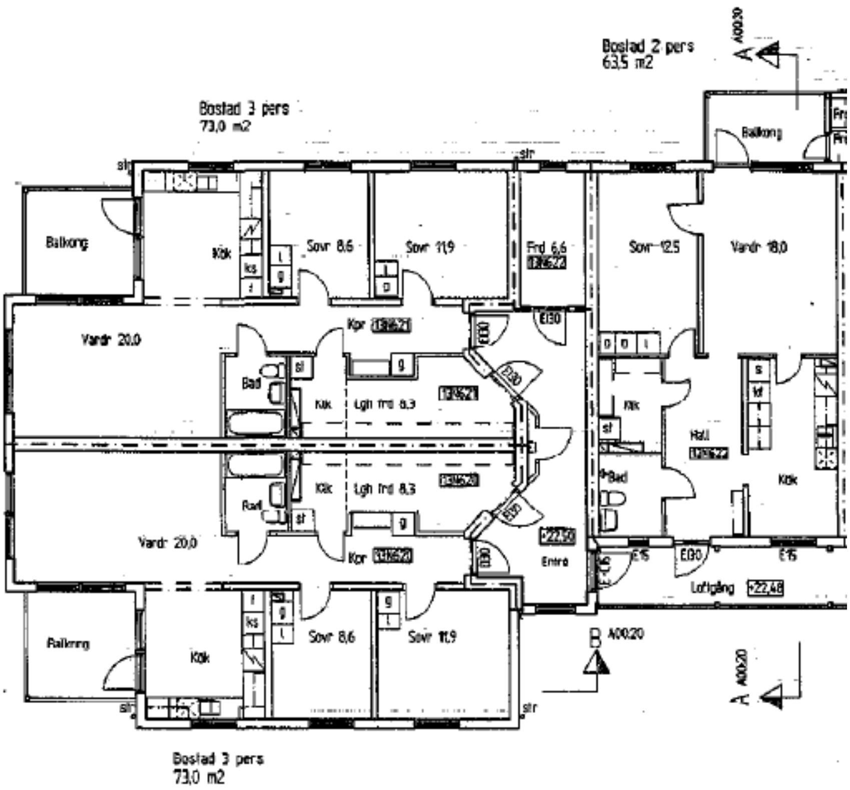
Floors: from above: carpet or gypsum / gypsum board / anhydrit / truss beams and mineral wool / resilent channels / gypsum boards



Partitions: light weight (3 layers of plaster boards on each side.

Façades:

f [Hz]	Vertical L´ [dB]	Horisontal R´ [dB]	Vertical R´ [dB]
50	58,8	32,6	34,7
63	55,2	32,0	40,0
80	55,5	30,7	38,6
100	54,2	40,3	41,5
125	51,8	49,0	50,3
160	54,9	47,7	46,9
200	55,1	50,0	47,8
250	56,0	53,6	50,0
315	55,8	54,1	51,5
400	56,2	55,6	51,1
500	52,4	58,6	53,5
630	44,7	60,6	57,4
800	38,6	63,8	61,1
1000	34,4	69,3	65,3
1250	31,4	70,5	66,7
1600	28,8	70,1	66,8
2000	25,7	69,9	67,4
2500	22,2	71,5	70,2
3150	21,1	72,3	71,8
L'n,w	49		
L'n,w+CI,50-2500	51		
R´w+C50-3150		59	58

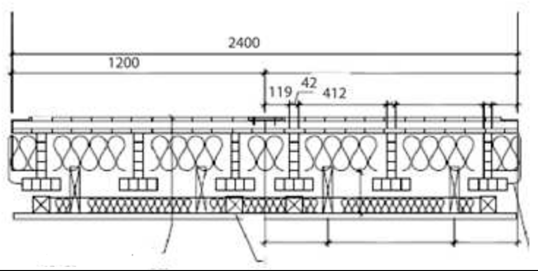


Part of floor 2

Växjö L

The sound insulation has been measured according to EN ISO 140 -4,-7 but only weighted single numbers were available for our analysis.

Floors: Massive wood elements, separate ceiling, parquet



Partitions: layers of massive wood in between gypsum boards

Façades:

f [Hz]	Vertical L´ [dB]	Horisontal R´ [dB]	Vertical R´ [dB]
50	-	-	-
63	-	-	-
80	-	-	-
100	-	-	-
125	-	-	-
160	-	-	-
200	-	-	-
250	-	-	-
315	-	-	-
400	-	-	-
500	-	-	-
630	-	-	-
800	-	-	-
1000	-	-	-
1250	-	-	-
1600	-	-	-
2000	-	-	-
2500	-	-	-
3150	-	-	-
Ln,w	50		
Ln,w+CI,50-2500	52		
R´w+C50-3150		-	59