Vibration Performance of Apartment Buildings with Wooden Lightweight Frame-work – Residents Survey and Field Measurements

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Preface

This report presents the results of an investigation performed within the national Swedish project AkuLite – Acoustics and vibrations in light weight buildings funded by the Formas and Vinnova together with the industry partners in the project.

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Summary

The survey has been performed in occupied apartment buildings in nine different cities, from Umeå in the north to Varberg in the south of Sweden. Seven of the buildings have a lightweight wooden framework and one a lightweight steel framework. Yet another building with concrete framework was included in the survey as a reference.

In the used questionnaire the residents were asked if they experience springiness and vibrations annoying. The questions dealt with different excitation sources as vibrations induced by the residents themselves or someone else walking in the same room, neighbours that induce vibrations, slamming doors and traffic. Also different ways to perceive vibrations were inquired about, i.e. are the vibrations perceived by feeling, hearing or sight. The residents' sensitivity to vibrations and if they have to adjust their way of walking not to disturb family members or neighbours were also asked about. The last question was about the satisfaction with the quality of floors and walls.

The questionnaire seems to work quite well in general. From the ratings it is not possible to say in what way the residents are most annoyed, by feeling the vibrations, hearing or seeing furniture or objects move. The vibrations appear to be perceived in several ways and it could be possible that the residents are not able to make difference between the perceived disturbances if they occur simultaneously. It may be concluded from the ratings that annoyance by vibrations is not a problem in buildings with concrete framework, but in buildings with lightweight framework the residents clearly are annoyed by vibrations.

The collection of objective data about vibration performance of floors were carried out by field measurements according to a common measurement protocol developed within the AkuLIte project. The physical objective parameters related to floor vibrations were the deflection *d* due to a point load at midspan, the fundamental frequency f_1 of the floor and the total maximum acceleration A_{max} of the floor when excited with an impulse ball at the centre of the floor. A principal component analysis and a linear regression analysis were performed to find relationships between subjective ratings and objective data a principal component analysis and a linear regression analysis were performed.

From the correlations analysis it may be concluded that the deflection *d* due to a concentrated point load at midspan of the floor is the best of the investigated parameter for predicting vibration disturbance. All the floors in the investigation do fulfill the deflection requirement for timber floors in the Swedish building regulation, which is a maximum deflection of 1.5 mm when loaded with a 1 kN point load at midspan of the floor. If considering the regression line of residents ratings of general vibration disturbance and deflection *d* it is found that a deflection of 1.5 mm would result in 52 % of the residents being "somewhat annoyed, annoyed or very annoyed". That is a rather high number and points to the fact that the limit should be sharpened. The result maybe not surprising as the methods and limits used today were developed at a time when timber joist floors were mostly used in single family housing. This investigation has involved apartment buildings and it is obvious that the tolerance is lower, even if it is not evident that the disturbance due to vibrations is induced by neighbours. To be able to propose any reliable new limits for the vibration criteria more data is needed, meaning that both measurements and surveys have to be carried out in more buildings. To have more reliable vibration values a common method for measurement and evaluation of fundamental frequency and acceleration levels have to be developed and included in the measurement protocol.

Sammanfattning – Swedish Summary

Undersökningen har utförts i flerbostadshus på nio olika orter, från Umeå till Varberg. Sju av dessa bostadshus har byggts med olika typer av prefabricerad trästomme och ett hus har stålreglar i stommen. Ytterligare ett bostadsobjekt med väggar och bjälklag av betong inkluderades i undersökningen, som referensobjekt.

I en enkätundersökning fick de boende frågor om de upplever att svikt och vibrationer är störande. Frågorna tog upp olika orsaker till vibrationer, exempelvis om vibrationer framkallas av de boende själva, eller om de uppstår då någon annan går inne i samma rum, om de orsakas av grannar, dörrar som slås igen eller trafik. Även olika sätt att uppfatta vibrationer ingick i undersökningen d.v.s. om man uppfattar en påverkan med känseln, hörseln eller synen. Också frågor om de boendes känslighet för vibrationer och om de måste anpassa sitt sätt att gå i sin bostad för att inte störa familjemedlemmar eller grannar inkluderades. Den sista frågan i enkäten, var om de boende var nöjda med kvaliteten på golv och väggar.

Enkäten verkar i stort sett fungera bra, men från de boendes bedömning är det inte möjligt att avgöra på vilket sätt de boende störs mest, om det är genom att känna vibrationerna, eller höra eller se möbler och föremål vibrera. Vibrationerna verkar uppfattas på flera olika sätt och det kan vara möjligt att de boende inte kan göra skillnad mellan olika störningar om de inträffar samtidigt. En slutsats från enkätundersökningen är att vibrationer inte är ett problem i byggnader med betongstomme, men att i byggnader med trä- eller stålregelstomme är de boende störda av vibrationer.

Insamlingen av objektiva data för vibrationer i bjälklag i de olika bostadsobjekten utfördes enligt en gemensam mätmall som utvecklades inom projektet, eftersom det inte finns några standardiserade metoder ännu. De fysiska objektiva parametrarna med anknytning till bjälklagsvibrationer var nedböjning d i en punkt på mitten av bjälklaget belastad med en punktlast, den första egenfrekvensen f_1 för bjälklaget och den totalt högsta accelerationen A_{max} i bjälklaget när man släpper en tung "boll" i mitten av bjälklaget. För att hitta samband mellan subjektiva omdömen (enkätsvar) och objektiva mätdata utfördes en principal komponent analys och olika korrelationsanalyser.

En slutsats från korrelationsanalyserna är att deformationen d orsakad av en koncentrerad punktlast på mitten av bjälklaget är den parameter som bäst kan förutsäga störning av vibrationer. Alla bjälklagen i undersökningen uppfyller deformationskravet för träbjälklag i de svenska bygg- och konstruktionsreglerna. Kravet är en största tillåten nedböjning på 1,5 mm vid belastning med 1 kN punktlast på mitten av bjälklaget. Med utgångspunkt från regressionslinjen för de boendes omdöme av allmän störning av vibrationer och nedböjningen d resulterar 1,5 mm nedböjning i att 52 % av de boende är "något störda, störda eller mycket störda". Det är ganska många och pekar på att det gällande deformationskravet borde skärpas. Resultatet kanske inte är förvånande eftersom de metoder och gränsvärden som används idag utvecklades vid en tidpunkt då trä träbjälklag mest användes i enfamiljshus. Denna undersökning har genomförts i flerbostadshus och det är uppenbart att toleransen för störande vibrationer är lägre hos de boende, även om det inte är klart om störningen orsakas av grannar. För att kunna föreslå tillförlitliga nya gränsvärden för vibrationer behövs mer data, vilket innebär att både fler mätningar och undersökningar måste utföras i fler byggnader. För att få mer tillförlitliga mätvärden för bjälklagens vibrationsegenskaper måste en gemensam metod för mätning och utvärdering av egenfrekvenser och accelerationsnivåer utvecklas och helst standardiseras. Utvärdering av bjälklagens dämpning bör också inkluderas i fortsatta studier.

Introduction and aim

The aim of this work was to investigate if the residents in multi-storey apartment buildings with lightweight framework consider springiness and vibrations disturbing or annoying, but also to find relationships between objective data of the floors (physical floor vibration) performance and subjective rating of the vibration performance. The results may be used as input to the current building regulations about the ability of the current design methods on human induced vibrations in timber floors to give constructions with properties that meet residents' demands. The work consist of three parts:

1. the residents´ survey about vibrations in several apartment buildings
2. the collection of objective data on vibration performance of floors by field measurements
3. the analysis of relationships between subjective ratings and objective data.

Acknowledgements

This report is the result of many people's work as the collection of data has been carried out by the researchers involved in the AkuLite project but also by their colleagues, many thanks to you all. Thanks also to Magdalena Sterley at SP Wood Technology for help and support with the principal component analysis and correlations.

The financial support from Formas and Vinnova together with the industrial partners is greatfully acknowledged.

1 Survey – subjective rating of springiness and vibrations by residents

1.1 The questionnaire

The questionnaire that has been used in the present investigation was developed by the authors during end of 2011 with the questionnaire earlier used for noise [1] as template. The original questionnaire on noise was English and developed in September 2010 by a working group of European researchers within the EU network COST TU 0901, convened by Simmons [2]. The aim of the present questionnaire was first of all to investigate if there is a problem with springiness and vibrations in multi-storey apartment buildings with lightweight framework and secondly if possible also to get information about what kind of disturbance is considered most annoying the felt vibrations, the sound from vibrating objects or the visible vibrations of objects. In Figure 1 and Figure 2 the English version of the two side questionnaire is presented and in Table 1 a summary of the questions is presented. The original Swedish version is presented in Annex A.

Table 1. Summary of questions.

No.	*Thinking about the last 12 months or so in your home, what number from 0 to 10 best shows how much you are bothered, disturbed or annoyed by:*
1	Vibrations in the floors or in the furniture, in general?
2	Deflection of the floor under your feet as you walk, e.g. the floor feels soft, elastic, springy or resilient?
3	Deflection of stairs, access balconies or balconies as you walk, please specify where?
4	Vibrations where you are seated or lying down, when somebody else walk on the floor in the same room?
5	Vibrations when the neighbours walk, or their children play on their floor?
6	Vibrations from nearby road or rail traffic?
7	Movements of furniture or objects when you or somebody else walk on the floors, e.g. tables, TV/computer screens, bookshelves, lamps, doors, paintings etc begin to swing?
8	Movements of furniture or objects when neighbours close their doors?
9	Sounds from your floor when you or somebody else walk on it, e.g. experienced as thuds, clicks or creaks?
10	Sounds from furniture or objects when you or somebody else walk on it, e.g. rattling or tinkling from cups, glasses, cupboards etc.?
11	Do you have to adjust your way of walking in your home in order to avoid disturbing your family or neighbours by vibrations, please specify?
12	Are you tolerant or sensitive with respect to vibrations in the floors or in the furniture?
13	Are you satisfied or dissatisfied as a whole with the quality of the floors and walls, with respect to vibrations in the floors or in the furniture?

Are you disturbed by vibrations?

Investigation – purpose

Hello!

SP participates in a national research program AkuLite. The project examines whether sound and vibration conditions are satisfactory in residential buildings. Several buildings have been selected to be included in the project and the building you live in is one of them. You have previously received a survey about noise and this one is about vibrations. Your answers will help us to determine what vibration requirements need to be set in the building regulations. Vibration requirements must be designed so that inappropriate designs are not used, but at the same time the used designs must be cost-effective. Excessive requirements would drive up construction costs. Therefore it is important to ask residents about their perceptions and if the vibration performance of the building structure is satisfactory.

We thank you for taking your time to complete the questionnaire and mail it back to us in the attached envelope. Your answers are processed statistically and confidentially. The results and your personal data is only used in this investigation and will not be used in any other way.

If you have any questions please do not hesitate to make a call or send a mail.

Thank you for your cooperation.

With kind regards

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YOUR PERSONAL DATA. N.B! [THESE DATA ARE ONLY FOR THIS SURVEY AND WILL BE DELETED AFTER THE ANALYSIS]

You are:	Female ☐	Male ☐		Room/Apartment ID:	[FILLED IN BY INST]
Age:	18-25 ☐	26-39 ☐	40-64 ☐	>65 ☐	
Working schedule:	Day ☐	Evening / night ☐	Mixed ☐	Not applicable ☐	
Years of residence:	0-1 ☐	2-5 ☐	6- ☐		
Nº of person in the household:	1 ☐	2 ☐	3 ☐	4-6 ☐	6- ☐

EXAMPLE: HOW TO ANSWER THE QUESTIONS ON NEXT PAGE:

Main question — *Answer Scale*

Thinking about the last 12 months or so in your home, what number from 0 to 10 best shows how much you are bothered, disturbed or annoyed by vibrations …(This could also be if vibrations interfers with your own activities, e.g resting, listening, reading etc.)

	Not at all 0	1	2	3	4	5	6	7	8	9	Extremely 10	Don't know
1. Neighbours; daily living, e.g. people talking, audio, TV **Vibrations** where you are seated..	☐	☐	☐	☐	☒	■	☐	☐	☐	☐	☐	☐

*Make an **X** in the box with your answer*

- *If you already marked out one box but you want to change your answer, fill the box in black and mark a new X in the new box. In case you do not feel anything at all, or it is not possible to answer, tick this box.*

Figure 1. The questionnaire explanatory first page in English .

Instructions: v0.3 2011-12-08

Choose an answer on the 0-to-10 scale for how much floor vibrations or walking sounds bother, disturb or annoy you:

if you experience a small amount AND you are NOT AT ALL disturbed by it, ***choose 0***	*if you are EXTREMELY bothered, disturbed or annoyed by it,* ***choose 10***	*if you are somewhere IN BETWEEN,* ***choose a number from 1 to 9***	*if you do not experience ANYTHING AT ALL or if you cannot answer,* ***choose "Don't know"***

Thinking about the last 12 months or so in your home, what number from 0 to 10 best shows how much you are bothered, disturbed or annoyed by	Not at all 0	1	2	3	4	5	6	7	8	9	Extremely 10	Don't know
1. Vibrations in the floors or in the furniture, in general	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

Thinking about the last 12 months or so in your home, what number from 0 to 10 best shows how much you are bothered, disturbed or annoyed by	Not at all 0	1	2	3	4	5	6	7	8	9	Extremely 10	Don't know
2. **Deflection** of the floor under your feet as you walk, e.g. the floor feels soft, elastic, springy or resilient	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
3. Deflection of **stairs**, access balconies or balconies as you walk, *please specify where:*______________________	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
4. **Vibrations** where you are seated or lying down, when **somebody else** walk on the floor in **the same** room	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
5. Vibrations when the **neighbours** walk, or their children play on **their** floor	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
6. Vibrations from nearby **road or rail traffic**	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
7. **Movements** of furniture or objects when you or somebody else **walk** on the floors, e.g. tables, TV/computer screens, bookshelfs, lamps, doors, paintings etc begin to swing	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
8. Movements of furniture or objects when neighbours close their **doors**	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
9. **Sounds** from **your floor** when you or somebody else walk on it, e.g. experienced as thuds, clicks or creaks	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
10. Sounds from **furniture or objects** when you or somebody else walk on it, e.g. rattling or tinkling from cups, glasses, cupboards etc	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

Do you have to adjust your way of walking in your home in order to avoid disturbing your family or neighbours by	No, not at all 0	1	2	3	4	5	6	7	8	9	Yes, I am extremely careful 10
11. Vibrations, *please specify:*__________________________	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

Are you tolerant or sensitive with respect to	Tolerant, not at all sensitive 0	1	2	3	4	5	6	7	8	9	Extremely sensitive 10
12. Vibrations in the floors or in the furniture	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

Are you satisfied or dissatisfied as a whole with the quality of the floors and walls, with respect to	Satisfied, not at all dissatisfied 0	1	2	3	4	5	6	7	8	9	Extremely dissatisfied 10
13. Vibrations in the floors or in the furniture	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

Comments (what kind of sources cause vibrations, which effects do you notice):

____

____

____

Figure 2. The questionnaire second page with questions in English.

The first page included an explanation of the investigation, implementers contact specifications, instructions about how to fill in the form and five questions with which to collect background information about the residents as gender, age, working hours, time in the building and number of persons in the household. The second page contained 13 questions and some space where it was possible to give comments. The answer scale was an eleven-point numerical scale, ranging from 0 to 10 expressing the degree of annoyance. Two labels, “not at all” and “extremely”, were attached to the ends of the scale, 0 and 10 respectively. There was also a twelfth choice of answer “Don´t know” to be used when no vibrations at all were experienced or if the resident could not answer. The first question was a general question about experienced annoyance with vibrations in floors and furniture. As a check of consistency, the last question was almost the same as the first one, but with the difference that it was formulated to enquire about the satisfaction with vibration performance of floors and walls. The second and third question considered deflection and springiness in the apartment floor and other construction parts as balconies respectively. Question 4-8 and 10 were all about vibrations excited by different sources as the residents themselves or someone else walking, neighbours walking or closing their door, road or rail traffic. The questions also covered three different ways to perceive vibrations by feeing, hearing or sight. Question 9 was a question considering the quality of the floor or rather the floor covering as it inquired about sounds as thuds, clicks or creaks from the floor when walking on it. Question 11 considered if the residents usually adjust their walking not to disturb family or neighbours with vibrations. Question 12 inquired about the residents´ sensitivity regarding vibrations.

1.2 Distribution and collection

The survey has been carried out in occupied apartment buildings in nine different cities, from Umeå in the north to Varberg in the south of Sweden. Seven of the buildings have a lightweight wooden framework from different suppliers active on the construction market, and one have a lightweight steel framework (Lägern). Yet another building with concrete framework (Dovhjorten) was included in the survey as a reference. As a main interest of the survey has been vibrations in floors the apartments have been divided in those with a lightweight wooden or steel framework in the floor (the presented residential areas) and those with a concrete foundation on polystyrene foam and crushed stone or a reinforced concrete plate (short spans) on concrete walls and foundations (the concrete group). An interesting side-result from the survey would be the results from the concrete group as it gives information regarding whether vibrations is a problem or not in apartments with concrete floor or framework. As the number of apartments with a concrete foundation or otherwise in concrete were small in each residential area with wooden or steel framework buildings these apartments were grouped together to one group (concrete). In Table 2 the nine residential areas with lightweight framework are presented together with the tenth concrete area.

The survey was sent by surface mail to the residents at all addresses or selected addresses in the residential area, depending on the number of buildings and apartments in each building. The letter received by the residents contained the questionnaire and an addressed return envelope. For identification the questionnaires were labelled with the address and apartment number. One reminding letter, with questionnaire and return envelope was sent to all areas a month after the first mail. For the ones marked with [2)] in the table a second reminder was sent another month later. To the area Glasäpplet the vibration and noise questionnaire were sent at the same time with no reminder and to the area Dovhjorten the questionnaire was just sent out once.

	BrunnbyPark 2)	Torghörnet	BoKlok 2)	Hyttkammaren 2)	Lägern 2)	Limnologen 2)	Portvakten 2)	Glasäpplet	Concrete 1)	Dovhjorten Concrete
Total	65	26	28	41	72	70	58	24	92	77
Lightweight	50	19	28	32	36	53	43	18	-	-
No. answers	18	15	16	21	12	34	27	15	51	25
%	36	79	57	66	33	64	63	83	55	32

1)Summarized number of apartments with concrete floor or otherwise in concrete from residential areas with wooden or steel framework buildings.

2)A second reminder was sent.

Table 2. Residential areas included in the survey. Total number of apartments, number of apartments with lightweight framework, number of answers and percentage of answer for each area.

The willingness to respond to the survey differed between the areas from 28 % to 79 % from apartments with lightweight framework and the number of answers from 13 to 34. In Brunnby Park the low number of answers may be due to that a large number of the residents seem to have foreign background and therefore maybe not comfortable to answer a questionnaire in Swedish. Maybe also the location in Greater Stockholm make people less willing to respond compared to smaller towns. The low number of answers from Lägern is probably owing to the fact that it is student flats. The returned forms were filled in more or less adequately. Occasionally some had not filled in the questions on the first page concerning background information and some questions were left blank on page two as if forgotten. The possibility to make comments was used in approximately 40 % of the answers. Mostly they were about springiness and vibrations, but occasionally the residents have used this possibility to complain about noise. Then it is difficult to decide if they have mixed up noise and vibrations or if they have taken the opportunity to give supplementary information about noise.

1.3 Analysis

For each residential area and question the ratings have been analyzed by different means to enable assessment of annoyance and possibility to later correlate ratings to measureable parameters that describe vibration performance. The calculated statistical parameters were:

- **Average rating** (A50) that may be taken as the descriptor of average (typical) annoyance among the residents.
- **Standard deviation** (S) that may be used as a measure of the average reliability. To judge which differences are significant the 95% confidence interval of the average (A50_CI_95) has been calculated from

$$ - \qquad (1) $$

where N is the number of ratings. As the variation of ratings is not randomly distributed the “reliability” is not quite clear in this case.

- **Average rating increased by one standard deviation** (A16) is the 84.13th percentile that may be interpreted as the rating given when 16 % of the residents are more disturbed than the average.

Three fractional parameters i.e. percentage of residents annoyed over a certain level of the annoyance scale, where calculated as it was considered in the earlier noise annoyance survey that they are easier to interpret from a subjective point of view. The parameters and suggestions of limits for minimum requirements were:

- **The fraction of residents responding ≥ 3** (Fraction ≥3) may be a descriptor for residents considering the vibration annoyance to be “somewhat annoying, annoying or very annoying” indicating a lack of quality. An ambition could be to reduce this value to < 20 % and at least 40 % in minimum requirements meaning so that a substantial part of the residents may be considered satisfied.
- **The fraction of residents responding ≥ 5** (Fraction ≥5) may be a descriptor for residents considering the vibration annoyance to be “annoying or very annoying” indicating a lack of quality. An ambition could be to reduce this value to < 10% and at least 20% in minimum requirements.
- **The fraction of residents responding ≥ 8** (Fraction ≥8) may be a descriptor for residents considering the vibration annoyance to be “very annoying” indicating malfunction of vibration performance. An ambition could be to reduce this value to ≤ 5% in minimum requirements.

1.4 Ratings – responses by residents to the questionnaire

In the Table 3 analyzed responses i.e. statistical and fractional parameters are presented for all the questions and the different residential areas for residents living in apartments with wooden framework and as a single group all of those residents living in apartments with concrete floor or framework. The age distribution amongst residents is included in the table and the number of answers N. The values of the fractional parameters that are higher than the suggested limits have been highlighted. The yellow colour corresponds to values between the suggested fractional limit and the double of that value. The red colour corresponds to values higher than the doubled limit value.

Looking at the vibration survey in Table 3, the ratings for the groups involving apartments with concrete floors and framework clearly differs from the other groups with lightweight floors and framework. The ratings in Dovhjorten with concrete framework are very low, which could be expected as vibrations should not be a problem in this type of structures. As it comes to the concrete group with apartments with concrete framework or just concrete floors the ratings are higher for almost all questions than in Dovhjorten but lower than in the areas with lightweight framework. There is a difference in rating for question 5 about vibrations induced by neighbours. The rating is of the same order as in the other apartments with lightweight floors, but it maybe is not surprising as the disturbance most likely is from the neighbours above and the floor structure there is lightweight. The rating of question 5 is rather high for also the other areas and there seems to be an interference from something else than just vibrations. Maybe the residents have here given expression to any annoyance due to noise or annoyance due to the neighbours.

The ratings for general disturbance and satisfaction with the floors and walls in the vibration survey are also of the same order as for the apartments with lightweight framework in the buildings. It implies that there might be a general vibration disturbance within apartments that is separate from springiness and vibrations in the floors. Question 9 about sounds as creaks from the floors has received somewhat higher ratings and could be due to the quality of the parquet flooring as it has occasionally been commented by the residents.

For comparison in Table 4 the ratings for the noise questionnaire from the same areas are presented. The noise survey as whole is presented in [3]. Only the statistical parameters average and standard deviation are given here together with the fractional parameters. The limits and colouring of the fractional parameters are the same as for the vibration results in Table 3. The number of answers N and the percentage of answers are given in the left side column. The question 5 in the survey is disturbance by footfall noise from neighbours and has given similar high or higher ratings in all areas as in the vibration survey, which could be an indication of interference as in the corresponding vibration question.

The question 6 in the noise survey in Table 4 is about rattling sound from objects moving due to vibrations. When comparing the residents' ratings with the overall impression of annoyance from the vibration survey it is seen that the areas with yellow and red marking for question 6 in the noise survey reflects quite well the vibration survey. The areas Brunnby Park, BoKlok and Hyttkammaren have more yellow and red marking also in the vibration survey, which means that the residents seems to been consistent in their conception. The general impression from the vibration survey is that there are lots of yellow and red markings in a majority of the questions in all areas indicating that the residents are annoyed with vibrations in lightweight structures. Vibrations induced by road or rail traffic seem not to be a problem, but it is hard to draw any conclusion regarding this aspect as the extent of nearby traffic is not known. When comparing the ratings with the ones for question 13 about traffic noise in the noise survey it is obvious that there could be interference with noise in the vibration rating. The rating from Glasäpplet clearly supports this assertion as the residents have answered the two questionnaires at the same occasion and the adverse rating is only found for the traffic noise.

An interesting observation for the area Lägern is that the residents are clearly more annoyed with noise than vibrations. From the ratings and also the comments it is seen that the main vibration annoyance is due to neighbours closing doors. A reason to this could be that the area consists of student flats with rather small rooms in which walking speed will be restricted and by that also excitation of vibrations by walking, but still the structure is weak and the closing of doors is enough to excite vibrations that are disturbing.

Vibrations		Question	1	2	3	4	5	6	7	8	9	10	11	12	13
		Parameter	General	Defl.Floor	Defl.Other	SameRoom	Neigbours	Traffic	MoveObj.	CloseDoor	SoundFloor	SoundObj.	Adjustment	Tolerance	Satisfaction
BrunnbyPark		A50_Average	3.7	2.3	2.2	2.9	3.6	1.4	2.8	2.3	2.7	3.0	3.0	1.9	3.1
N=	18	A50_CI-95 (±)	1.4	1.1	1.5	1.3	1.6	0.9	1.5	1.5	1.4	1.6	1.8	0.8	1.4
Age 18-25:	19%	A16_Avg+StdDev	6.7	4.6	5.4	5.7	7.1	3.5	6.0	5.5	5.7	6.4	6.8	3.7	6.3
Age 26-39:	23%	≥ 3 Some disturbed	50%	33%	22%	44%	44%	28%	39%	22%	33%	44%	28%	33%	39%
Age 40-64:	12%	≥ 5 Disturbed	39%	22%	11%	22%	28%	6%	22%	17%	22%	22%	28%	11%	28%
Age 65-:	15%	≥ 8 Very disturbed	11%	0%	11%	6%	22%	0%	11%	17%	11%	11%	22%	0%	11%
Torghörnet		A50_Average	1.7	1.9	0.1	1.7	2.5	1.5	1.1	1.3	1.0	1.9	0.6	1.0	1.3
N=	15	A50_CI-95 (±)	1.5	1.7	0.2	1.8	1.6	1.1	1.2	1.1	1.5	1.6	1.0	1.4	1.5
Age 18-25:	0%	A16_Avg+StdDev	4.8	5.2	0.4	5.2	5.7	3.7	3.5	3.6	3.9	5.0	2.6	3.7	4.2
Age 26-39:	10%	≥ 3 Some disturbed	20%	27%	0%	13%	40%	13%	13%	13%	7%	27%	7%	7%	13%
Age 40-64:	10%	≥ 5 Disturbed	20%	20%	0%	13%	13%	7%	7%	13%	7%	20%	7%	7%	7%
Age 65-:	65%	≥ 8 Very disturbed	7%	7%	0%	7%	13%	0%	7%	0%	7%	7%	0%	7%	7%
BoKlok		A50_Average	2.4	2.9	0.9	2.4	2.4	1.3	2.3	2.1	2.7	2.5	2.3	2.9	4.2
N=	16	A50_CI-95 (±)	1.8	2.0	1.0	1.6	1.8	1.0	1.8	1.6	1.7	1.9	1.7	1.1	2.0
Age 18-25:	6%	A16_Avg+StdDev	6.1	6.9	3.0	5.7	6.1	3.4	6.0	5.4	6.2	6.4	5.6	5.1	8.2
Age 26-39:	38%	≥ 3 Some disturbed	19%	38%	13%	31%	25%	31%	25%	19%	44%	25%	25%	56%	56%
Age 40-64:	44%	≥ 5 Disturbed	19%	25%	6%	25%	19%	13%	25%	19%	19%	25%	19%	38%	50%
Age 65-:	13%	≥ 8 Very disturbed	13%	25%	0%	6%	13%	0%	19%	13%	13%	25%	19%	0%	25%
Hyttkammaren		A50_Average	2.3	2.0	0.7	1.6	3.5	1.5	1.3	1.8	2.4	1.5	2.1	3.0	2.5
N=	21	A50_CI-95 (±)	1.6	1.4	1.0	1.4	1.8	1.1	1.0	1.5	1.5	1.0	1.5	1.4	1.5
Age 18-25:	0%	A16_Avg+StdDev	5.9	5.2	3.0	4.8	7.6	4.1	3.6	5.3	6.0	3.8	5.5	6.3	6.0
Age 26-39:	5%	≥ 3 Some disturbed	29%	24%	5%	24%	38%	19%	19%	19%	29%	24%	29%	52%	33%
Age 40-64:	38%	≥ 5 Disturbed	19%	24%	5%	14%	38%	10%	14%	19%	19%	14%	14%	33%	24%
Age 65-:	52%	≥ 8 Very disturbed	14%	10%	5%	10%	24%	5%	5%	14%	19%	5%	14%	10%	14%
Lägern		A50_Average	3.5	0.8	1.6	0.4	4.3	0.7	0.9	1.7	0.8	0.7	0.4	2.3	3.1
N=	12	A50_CI-95 (±)	1.6	0.6	1.6	0.4	1.6	0.5	0.6	1.0	0.5	0.6	0.5	0.9	1.6
Age 18-25:	75%	A16_Avg+StdDev	6.9	2.1	5.1	1.3	7.6	1.8	2.1	3.7	1.9	1.9	1.5	4.2	6.4
Age 26-39:	8%	≥ 3 Some disturbed	33%	25%	0%	0%	8%	8%	8%	42%	8%	17%	8%	42%	33%
Age 40-64:	0%	≥ 5 Disturbed	17%	17%	0%	0%	0%	8%	0%	17%	0%	17%	8%	25%	8%
Age 65-:	0%	≥ 8 Very disturbed	0%	0%	0%	0%	0%	0%	0%	8%	0%	0%	8%	0%	8%
Limnologen		A50_Average	2.3	2.5	1.6	1.2	2.3	0.6	1.0	1.0	2.6	1.4	1.1	2.4	2.0
N=	34	A50_CI-95 (±)	1.0	1.0	0.9	0.8	1.1	0.4	0.6	0.8	1.0	0.8	0.7	0.8	0.9
Age 18-25:	3%	A16_Avg+StdDev	5.2	5.6	4.2	3.5	5.6	1.8	2.9	3.4	5.6	3.9	3.1	5.0	4.8
Age 26-39:	15%	≥ 3 Some disturbed	24%	26%	18%	12%	21%	9%	15%	12%	38%	21%	21%	41%	21%
Age 40-64:	41%	≥ 5 Disturbed	21%	21%	12%	12%	21%	0%	6%	9%	24%	15%	12%	21%	18%
Age 65-:	24%	≥ 8 Very disturbed	3%	12%	6%	0%	9%	0%	0%	3%	9%	6%	0%	3%	6%
Portvakten		A50_Average	3.5	2.4	0.1	2.0	3.5	1.5	2.0	1.5	2.3	2.5	2.1	2.9	2.5
N=	27	A50_CI-95 (±)	1.3	1.0	0.1	1.0	1.5	1.0	1.1	1.0	1.1	1.1	1.3	0.9	1.3
Age 18-25:	4%	A16_Avg+StdDev	6.9	5.2	0.3	4.7	7.5	4.1	5.1	4.1	5.2	5.4	5.6	5.4	6.0
Age 26-39:	26%	≥ 3 Some disturbed	44%	30%	0%	30%	41%	19%	33%	22%	33%	37%	22%	44%	30%
Age 40-64:	22%	≥ 5 Disturbed	37%	26%	0%	19%	30%	11%	22%	15%	22%	26%	22%	30%	26%
Age 65-:	22%	≥ 8 Very disturbed	7%	0%	0%	0%	19%	4%	4%	4%	4%	0%	15%	4%	15%
Glasäpplet		A50_Average	2.9	0.9	0.2	1.3	2.8	0.2	0.4	0.8	1.1	0.7	3.1	2.3	2.0
N=	15	A50_CI-95 (±)	1.6	0.9	0.2	1.1	1.8	0.2	0.3	1.3	0.7	0.5	1.9	1.5	1.5
Age 18-25:	0%	A16_Avg+StdDev	6.0	2.7	0.6	3.4	6.3	0.5	1.1	3.5	2.5	1.6	6.9	5.3	5.0
Age 26-39:	13%	≥ 3 Some disturbed	33%	13%	0%	13%	33%	0%	0%	7%	7%	7%	40%	33%	20%
Age 40-64:	47%	≥ 5 Disturbed	27%	7%	0%	7%	27%	0%	0%	7%	7%	0%	27%	13%	13%
Age 65-:	7%	≥ 8 Very disturbed	13%	0%	0%	7%	20%	0%	0%	7%	0%	0%	20%	7%	7%
Dovhjorten		A50_Average	0.5	0.1	0.0	0.1	1.1	0.6	0.1	0.8	0.3	0.0	0.1	1.5	0.6
N=	25	A50_CI-95 (±)	0.4	0.1	0.1	0.1	1.0	0.5	0.1	0.9	0.2	-	0.1	0.7	0.8
Age 18-25:	5%	A16_Avg+StdDev	1.6	0.5	0.3	0.4	3.6	1.8	0.3	3.1	0.9	0.0	0.4	3.3	2.6
Age 26-39:	14%	≥ 3 Some disturbed	4%	0%	0%	0%	8%	4%	0%	8%	0%	0%	0%	28%	4%
Age 40-64:	14%	≥ 5 Disturbed	0%	0%	0%	0%	8%	4%	0%	4%	0%	0%	0%	4%	4%
Age 65-:	59%	≥ 8 Very disturbed	0%	0%	0%	0%	4%	0%	0%	4%	0%	0%	0%	0%	4%
Concrete		A50_Average	2.2	0.9	0.9	0.4	3.4	0.4	0.9	1.0	1.3	0.9	0.4	2.1	2.3
N=	54	A50_CI-95 (±)	0.6	0.3	0.5	0.3	0.9	0.2	0.4	0.5	0.5	0.4	0.3	0.6	0.7
Age 18-25:	33%	A16_Avg+StdDev	4.7	2.1	2.9	1.4	6.7	1.2	2.4	3.0	3.0	2.4	1.5	4.2	5.1
Age 26-39:	17%	≥ 3 Some disturbed	22%	13%	7%	6%	48%	6%	15%	15%	20%	11%	6%	33%	35%
Age 40-64:	9%	≥ 5 Disturbed	15%	2%	6%	2%	33%	0%	4%	7%	7%	2%	2%	17%	19%
Age 65-:	19%	≥ 8 Very disturbed	4%	0%	4%	0%	13%	0%	2%	0%	0%	2%	0%	2%	7%

Table 3. The analyzed responses by residents to the vibration questionnaire. The yellow colour corresponds to values between the suggested fractional limit and the double of that value. The red colour corresponds to values higher than the doubled limit value.

Noise		Question	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
		Parameter	General	Walls	Floor	Bass	Footfall	Rattle	Stairwell	Stairs	Wat.San.	Heater	Equipm.	Premise	Traffic	Import.	Sensit.
BrunnbyPark		A50_Average	3,1	0,8	1,9	1,4	4,3	2,0	3,1	2,0	0,5	2,3	2,3	0,3	2,8	7,5	5,0
N=	24	Std.Dev	2,9	1,4	2,4	1,8	4,1	2,6	3,8	2,6	0,8	3,0	2,5	0,8	3,1	2,6	2,7
	33%	≥ 3 Some disturbed	50%	13%	29%	21%	52%	36%	39%	29%	4%	30%	33%	5%	42%	96%	83%
		≥ 5 Disturbed	32%	4%	21%	13%	43%	18%	30%	17%	0%	26%	17%	0%	25%	88%	71%
		≥ 8 Very disturbed	14%	0%	0%	0%	30%	5%	17%	4%	0%	9%	8%	0%	17%	58%	17%
Torghörnet		A50_Average	0,6	0,0	0,1	0,2	1,3	0,4	0,5	0,4	0,2	0,9	0,1	0,3	1,4	4,2	2,1
N=	19	Std.Dev	1,3	0,0	0,3	0,8	2,1	0,9	1,1	1,1	0,4	1,8	0,3	0,8	1,6	3,7	2,1
	73%	≥ 3 Some disturbed	14%	0%	0%	6%	18%	8%	6%	6%	0%	13%	0%	7%	20%	50%	33%
		≥ 5 Disturbed	0%	0%	0%	0%	6%	0%	0%	0%	0%	7%	0%	0%	7%	50%	22%
		≥ 8 Very disturbed	0%	0%	0%	0%	6%	0%	0%	0%	0%	0%	0%	0%	0%	28%	0%
BoKlok		A50_Average	1,4	0,4	0,5	0,2	2,2	2,7	2,3	2,1	0,9	1,6	1,5	0,1	1,8	7,5	3,1
N=	19	Std.Dev	2,5	0,9	1,3	0,8	3,5	4,3	3,0	3,0	2,3	1,9	1,9	0,5	2,1	2,3	2,8
	68%	≥ 3 Some disturbed	22%	6%	6%	6%	28%	29%	28%	33%	11%	22%	28%	0%	32%	100%	42%
		≥ 5 Disturbed	6%	0%	6%	0%	22%	29%	17%	17%	6%	17%	11%	0%	16%	95%	26%
		≥ 8 Very disturbed	6%	0%	0%	0%	11%	29%	11%	11%	6%	0%	0%	0%	0%	58%	11%
Hyttkammaren		A50_Average	2,9	0,9	2,3	2,0	3,3	1,9	1,3	1,1	1,5	1,9	1,0	0,7	2,0	7,1	4,4
N=	30	Std.Dev	3,3	1,9	3,3	2,8	4,0	3,3	2,5	2,5	2,5	2,9	2,4	1,7	2,3	3,0	3,0
	65%	≥ 3 Some disturbed	41%	7%	32%	25%	39%	26%	18%	18%	21%	25%	10%	11%	30%	87%	70%
		≥ 5 Disturbed	22%	7%	25%	11%	32%	19%	11%	11%	11%	18%	7%	4%	13%	80%	50%
		≥ 8 Very disturbed	11%	4%	18%	7%	25%	15%	7%	7%	7%	7%	7%	0%	3%	60%	20%
Lägern		A50_Average	3,6	0,8	3,0	3,9	4,7	1,7	3,4	3,0	2,4	1,3	0,4	0,1	1,3	6,2	3,0
N=	28	Std.Dev	2,8	1,0	3,1	2,9	3,4	2,6	3,1	3,5	2,2	1,9	1,0	0,3	2,1	2,7	1,9
	39%	≥ 3 Some disturbed	57%	5%	43%	63%	62%	18%	50%	38%	35%	23%	6%	0%	16%	86%	57%
		≥ 5 Disturbed	35%	0%	26%	32%	52%	9%	29%	27%	22%	9%	0%	0%	8%	79%	14%
		≥ 8 Very disturbed	9%	0%	13%	15%	29%	9%	18%	23%	0%	0%	0%	0%	4%	32%	0%
Limnologen		A50_Average	1,6	0,3	0,6	1,4	2,4	0,6	1,0	0,8	1,2	1,8	1,4	0,2	1,2	6,9	4,3
N=	75	Std.Dev	2,3	0,7	1,2	2,4	2,8	1,3	1,5	1,4	2,2	2,3	1,9	0,5	1,8	3,1	2,7
	56%	≥ 3 Some disturbed	19%	2%	8%	16%	32%	7%	14%	11%	8%	26%	20%	0%	19%	84%	70%
		≥ 5 Disturbed	11%	0%	2%	11%	22%	2%	6%	5%	8%	9%	9%	0%	6%	78%	55%
		≥ 8 Very disturbed	5%	0%	0%	5%	9%	0%	0%	0%	6%	5%	3%	0%	3%	59%	12%
Portvakten		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=	23	Std.Dev	2,2	0,5	2,2	2,8	2,8	1,4	1,5	1,2	2,2	0,7	1,8	0,4	2,1	1,8	2,8
	36%	≥ 3 Some disturbed	35%	0%	19%	20%	45%	5%	13%	14%	23%	0%	17%	0%	17%	100%	78%
		≥ 5 Disturbed	20%	0%	10%	20%	23%	5%	9%	0%	14%	0%	4%	0%	9%	96%	57%
		≥ 8 Very disturbed	0%	0%	0%	5%	9%	0%	0%	0%	5%	0%	0%	0%	4%	65%	22%
Glasäpplet		A50_Average	2,3	0,8	0,8	0,9	3,4	1,3	0,7	0,7	2,6	2,6	1,8	0,1	0,1	6,7	2,9
N=	20	Std.Dev	2,6	2,4	2,4	2,6	3,4	3,0	1,0	1,0	2,8	2,7	2,2	0,3	0,2	2,5	3,0
	83%	≥ 3 Some disturbed	26%	6%	6%	13%	50%	15%	11%	11%	44%	37%	22%	0%	0%	95%	42%
		≥ 5 Disturbed	16%	6%	6%	6%	28%	15%	0%	0%	22%	16%	11%	0%	0%	89%	21%
		≥ 8 Very disturbed	5%	6%	6%	6%	22%	8%	0%	0%	6%	11%	6%	0%	0%	37%	11%
Dovhjorten		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	Std.Dev	2,7	1,6	2,2	2,6	2,1	0,9	1,9	2,2	1,8	2,2	2,8	0,6	1,5	3,2	2,6
	53%	≥ 3 Some disturbed	46%	9%	18%	24%	14%	1%	19%	18%	17%	20%	27%	1%	12%	81%	52%
		≥ 5 Disturbed	25%	5%	10%	13%	9%	1%	6%	11%	5%	16%	17%	0%	5%	72%	35%
		≥ 8 Very disturbed	8%	1%	3%	5%	4%	0%	3%	3%	1%	1%	6%	0%	0%	45%	6%

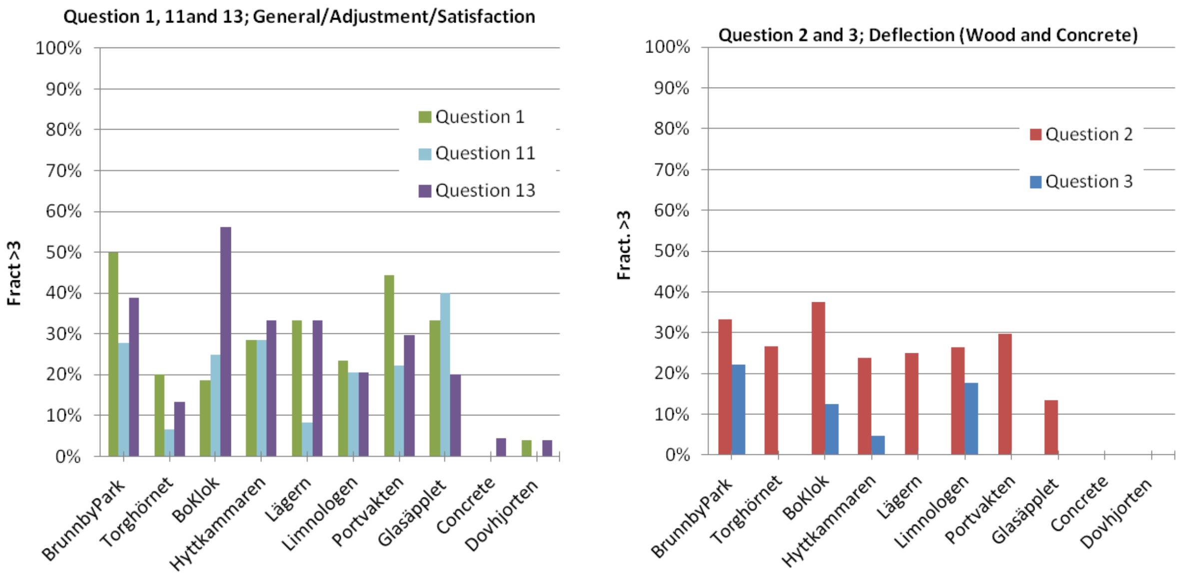
Table 4. Responses by residents to the earlier noise questionnaire. The yellow colour corresponds to values between the suggested fractional limit and the double of that value. The red colour corresponds to values higher than the doubled limit value.

When preparing the tables for the apartments with concrete floors it was for the project BoKlok first assumed that the ground floor was a cast concrete foundation. When comparing the ratings in Table 5 from these apartments with ratings from ground floor apartments in other areas (see concrete group in Table 3) it was obvious that there was something wrong. The residents were considerably more annoyed in BoKlok than in the other areas. After a check of the constructional drawings it was found that the ground floor structure was similar to the structure on the upper storeys. This observation was interesting as it clearly shows that the questionnaire has the ability to capture residents' vibration annoyance.

Vibrations		Question	1	2	3	4	5	6	7	8	9	10	11	12	13
		Parameter	General	Defl.Floor	Defl.Other	SameRoom	Neigbours	Traffic	MoveObj.	CloseDoor	SoundFloor	SoundObj.	Adjustment	Tolerance	Satisfaction
BoKlok		A50_Average	4.7	5.0	1.4	4.2	4.2	2.9	4.0	4.5	4.5	4.3	2.4	3.9	7.0
N=	7	A50_CI-95 (±)	3.6	3.2	2.3	2.9	3.4	1.6	3.2	3.1	3.2	3.6	2.4	1.4	2.5
Age 18-25:	14%	A16_Avg+StdDev	9.6	9.3	4.5	8.1	8.8	5.0	8.3	8.7	8.8	9.1	5.7	5.7	10.4
Age 26-39:	29%	≥ 3 Some disturbed	43%	57%	14%	43%	43%	71%	43%	43%	57%	43%	29%	71%	86%
Age 40-64:	29%	≥ 5 Disturbed	43%	43%	14%	43%	29%	29%	43%	43%	29%	43%	14%	57%	86%
Age 65-:	29%	≥ 8 Very disturbed	29%	43%	0%	14%	29%	0%	29%	29%	29%	43%	14%	0%	43%

Table 5. Ratings from apartments on the ground floor in BoKlok area.

For comparison, the responses to questions that could be considered related have been plotted together. The fraction ≥3 for each question has been plotted for the wooden framework apartments, the group including the apartments in all areas with concrete floor structure or otherwise with concrete framework (Concrete) and the area with completely concrete framework (Dovhjorten). In Figure 3 a) the questions 1, 11 and 13 about general annoyance during the past 12 months, adjustment of walking to not disturb family or neighbours and the satisfaction with the quality of floors and walls have been compared. It appears as the residents in general are consistent in their answering. The degree of annoyance corresponds to how satisfied they are as whole with the quality of the floors and walls and the adjustment of walking follows the rating of these two. As maybe could be expected the rating is also much lower for the apartments with concrete floor structure or complete concrete framework compared to the ones with wooden framework. However the residents in general seem to be somewhat more satisfied than annoyed. This is not true for BoKlok and Hyttkammaren, but as the difference for Hyttkammaren maybe is negligible the residents in BoKlok on the other hand clearly are dissatisfied with the performance of floors and walls. This is also supported by the fact that the rating of question 13 is the highest of all the areas (the higher the rating the higher the dissatisfaction).

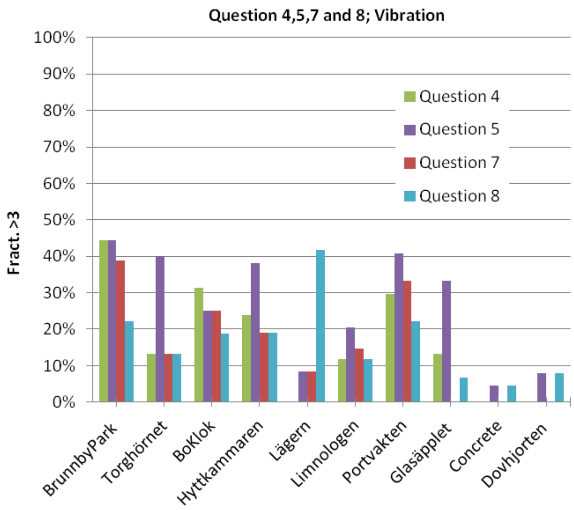


a) b)

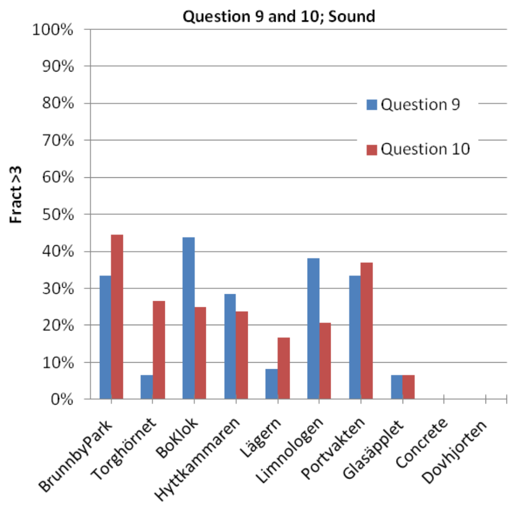
Figure 3. a) Rating for questions 1 and 13; general vibration annoyance and residents satisfaction with floors and walls. b) Rating for question 2 and 3; deflection in floors and other structural parts.

In Figure 3 b) the response to the two questions about deflection are presented together. Question 2 is about experienced springiness or deflection in the apartment floors and question 3 concerns other structural parts in the building as balconies and stairs. It seems that deflection mainly is a problem in the apartment floors than other structural parts. In Brunnby Park the deflection in balconies and stairs has been given as reason to the high adverse ratings for question 3. In Limnologen also the balconies and the stair between the two top floors inside the apartment have been commented as structural parts prone to deflection. For Hyttkammaren and BoKlok the adverse rating for question 3 is due to access balconies and stairs. When comparing the wooden framework ratings with the concrete ones there is no annoyance with the deflections in the concrete floors, which could be expected as deflections of a cast concrete floor are negligible. The few cases with experienced deflection and springiness could be due to flexibility in the top flooring and not the floor structure itself.

In Figure 4 a) the ratings for questions 4, 5, 7 and 8 about vibrations induced by the residents themselves or by the neighbours and experienced as vibration in the body or as movement in objects are presented. The question 5 and 8 about vibrations induced by neighbours and closing doors are the only questions that have ratings in the area Dovhjorten and the concrete group and the levels are lower than for other areas. The highest annoyance for closing doors is in the area Lägern, but the annoyance for vibrations induces by neighbours or the residents themselves are significantly lower in this area as discussed earlier in connection to Table 3. The rating of question 5 about disturbance by neighbours is generally higher for all the areas whereas it for the questions 4 and 7 about disturbance by the residents themselves and moving furniture or objects are lower. As discussed earlier there probably is interference from something else than vibration in the ratings of question 5. As noted earlier in Table 3 the area Brunnby Park has the higher ratings. From the diagram it is obvious that the performance of the area Portvakten for these questions has the second highest ratings followed by BoKlok.



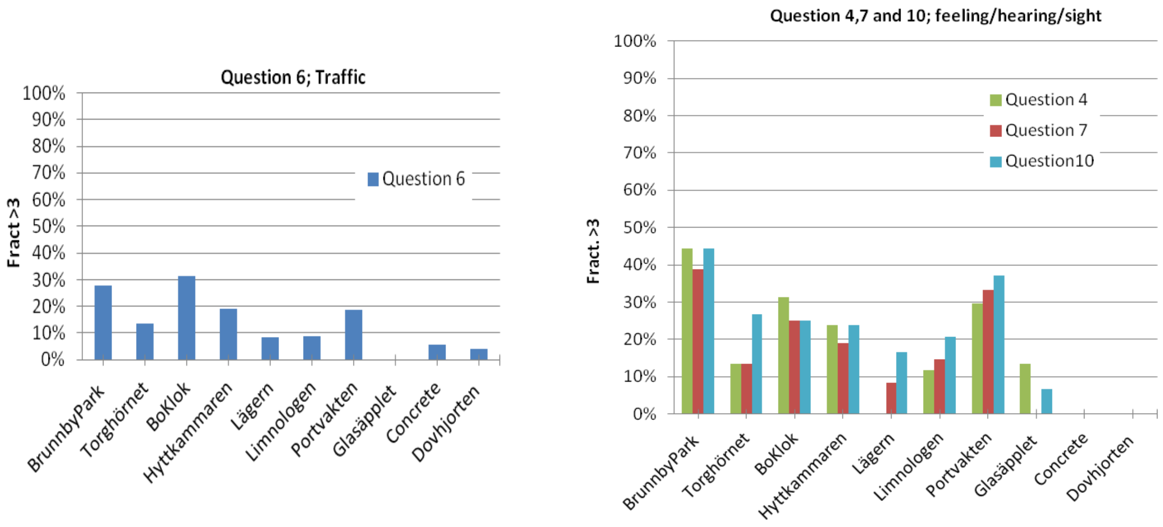
a)



b)

Figure 4. a) Ratings for questions 4, 5, 7 and 8; vibrations induced by the residents themselves or by the neighbours, disturbance experienced as vibration in body or as movement in object. b) Ratings for question 9 and 10; sound from the floor or from moving objects when someone walks on the floor.

In Figure 4 b) the ratings for question 9 and 10 about sound as creaks from the floor itself or from moving furniture or objects are given. It is only in the area Torghörnet and maybe Brunnby Park obvious that the residents are more annoyed with sounds from vibrating objects than sounds from the floor itself. The rating of sounds from the floor could be interpreted as a quality aspect of the top flooring that for all areas was parquet on a soft foam interlayer in all rooms except for bathrooms. In Figure 5 a) the ratings for vibrations induced by road and rail traffic are given. It is not possible to draw any certain conclusions from the results as the extent of nearby traffic is not known, but it seems as if road and rail traffic is more disturbing in apartments with lightweight framework than in concrete ones. As earlier mentioned there might be interference from traffic noise in the rating as the residents have rated noise from traffic in a similar way.



a) b)

Figure 5. a) Ratings for questions 6; vibrations induced by road or rail traffic. b) Questions that consider vibration perception by feeling, hearing or sight.

In Figure 5 b) the ratings for questions considering different ways to perceive vibrations by feeling, hearing or sight are plotted together. From the results it is not possible to say which sense is the most sensitive for vibration disturbance, the residents seem to be annoyed almost in the same extent irrespective of sense. The same phenomenon may be seen in the Table 3 where the yellow and red markings have a tendency to be spread horizontally over most of the questions indicating that the residents are annoyed by vibrations. The vibrations seem to be perceived in several ways and it could be possible that the residents are not able to make difference between the perceived disturbances if they occur simultaneously.

2 Building descriptions

For documentation and also to be able to make comparisons between the different residential areas the structural designs of the floors are summarized in Table 6 and Table 7. As structural designs of the floors are of greater importance for springiness and vibration behavior the floor designs are described in more detail. Information about the structural framework in general, building system i.e. built on site, prefabricated volume or planar elements are presented together with the supplier of the building system.

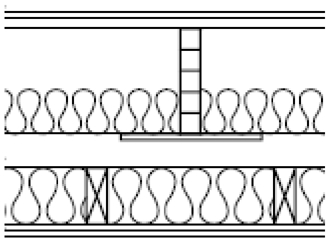
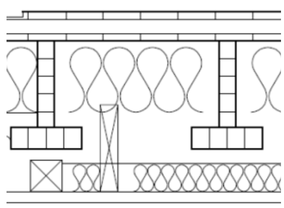
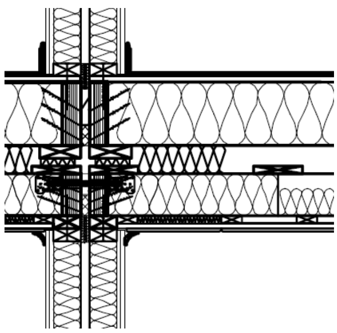
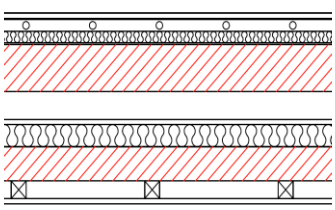
Residential area Locality	**Structural framework** (Supplier)	**Structural design of floors**	
Brunnby Park Upplands Väsby	Lightweight timber Glulam/plywood Volume element (Lindbäcks bygg)		**Load bearing structure:** 13 gypsum flooring board 22 particle board 42x225 c600 glulam beams 12x300 plywood flange on glulgam beam 95 mineral wool **Ceiling:** 45x120 c400 120 mineral wool 13 normal gypsum board 15 fire resistant gypsum board
Torghörnet Östervåla	Solid timber CLT , glulam (Martinsons) Plane element		**Load bearing structure:** 70 CLT 45x220 structural glued timber (webb) 56x180 glulam C40 (flange) 170 mineral wool **Ceiling:** 45x220 s1200 solid timber joists 70 mineral wool 28x70 c300 battens 2x13 gypsum board
BoKlok Alingsås	Lightweight timber Solid timber joists Volume element (Bo Klok)		**Load bearing structure:** 22 particle board 42x220 c600 solid timber joists 220 mineral wool Wind protection board 100 air gap **Ceiling:** 45x145 c1200 95 mineral wool 28x70 c300 battens 15 fire resistant gypsum board 12 particle board with PVC sheeting
Hyttkammaren Falun	Solid timber CLT Plane element (KLH)		**Load bearing structure:** 30 concrete + underfloor heating 30 mineral wool 4 pe-mat 120 CLT Airgap **Ceiling:** Sound insulation 87 CLT 45x45 s400 solid wood battens on elastic pads 13 gypsum board

Table 6. Structural framework and design of floors for residential areas Brunnby Park, Torghörnet, BoKlok and Hyttkammaren.

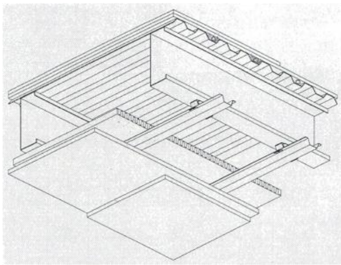
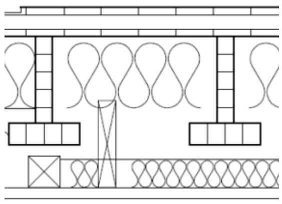
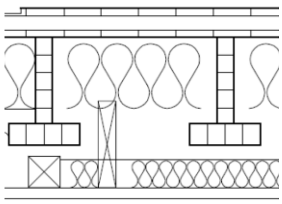
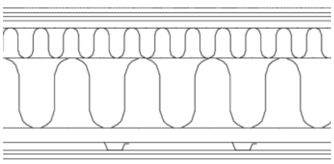
Residential area Locality	**Structural framework** (Supplier)	**Structural design of floors**	
Lägern Örebro	Lightweight steel Built on site (Knauf Danogips, Lindab Profil)		**Load bearing structure:** 13 glued gypsum flooring board 13 normal gypsum board 20 LLP20-1,0 troughed sheet 200 C200-1,5 c600 steel joists **Ceiling:** Resilient clamp c1200 30 mineral wool S 25/85 c400 steel battens 2x13 normal gypsum board
Limnologen Växjö	Solid timber CLT , glulam Plane element (Martinsons)		**Load bearing structure:** Underfloor heating in routed grooves on upper side of CLT 73 CLT 45x220 glulam C40 (webb) 56x180 glulam C40 (flange) 170 mineral wool **Ceiling:** 45x195 s600 solid timber joists 70 mineral wool 28x70 c600 battens 2x13 gypsum board
Portvakten Växjö	Solid timber CLT , glulam Plane element (Martinsons)		**Load bearing structure:** 73 CLT 45x220 structural glued timber (webb) 56x180 glulam C40 (flange) 170 mineral wool **Ceiling:** 45x220 s1200 solid timber joist 70 mineral wool 28x70 c300 battens 2x13 gypsum board
Glasäpplet Varberg	Lightweight timber LVL Plane element (Moelven)		**Load bearing structure:** 2x13 gypsum flooring board 22 particle board 45x360 c600 Kerto LVL 95+220 mineral wool Resilient channel 13 gypsum board 15 fire resistant gypsum board
Dovhjorten Umeå	Concrete		**Load bearing structure:** 220 in-situ concrete

Table 7. Structural framework and design of floors for residential areas Lägern, Limnologen, Portvakten, Glasäpplet and Dovhjorten.

3 Field measurements –objective data

Measurements of physical objective parameters that are used or could be used to describe vibrations have been performed in all the buildings included in the survey. The measurements have been performed according to a common measurement protocol developed within the project. The buildings and the results from the measurements are presented as whole in [3]. The parameters relating to vibrations extracted from the field measurements are the deflection *d* due to a point load at midspan, the fundamental frequency f_1 of the floors and the total maximum acceleration A_{max} of the floors when excited with an impulse ball at the centre of the floor. The deflection measurement and the impulse ball to excite vibrations are shown in Figure 6. The A_{max} value was evaluated as an acceleration average from two measurements points placed 0.5 m from the excitation point, parallel and perpendicular to the joist direction, for a frequency span 1-500 Hz. The values from all the measurements in different apartments in each area were averaged to get the presented value. The frequency f_1 value was evaluated from the same measurement. The main purpose with this particular measurement was to obtain data for comparison of the impulse ball and the tapping machine and not to provide data for extraction of the floor structures vibration properties. Therefore it was for some of the floors difficult to extract the fundamental frequency f_1 as it was indistinct in the response acceleration plots. This may happen if the excitation force level has a low level, but also caused by an excitation point that is located at a point on the floor from which the first mode of vibration is not adequately excited. A too small force impulse compared to the mass of the structure could also give the same effect. Another source of uncertainty in the measurement of the floors vibration properties, both frequency f_1 and maximum acceleration A_{max}, is the effect of the flooring on top of the load bearing structure.

a) b)

Figure 6. a) Measurement of floor deflection due to a point load and b) vibration excitation with standardized impulse ball.

The measured deflection and frequency values represents one specific room in the buildings, which in many areas and buildings may be one of several of the same kind, but maybe not representative for all apartments in the area. To have values that reflect the floor characteristics for all of the floors two new values were calculated by combining the floor span width *L* with the deflection and frequency values respectively. The deflection combined with the floor span width *d_L* was evaluated with the expression for calculating deflection of a simply supported beam loaded with a point load at midspan as basis and was taken as the deflection divided with the third power of the span width.

— ——— (2)

The frequency combined with the floor span width f_1_L was evaluated from the expression for frequency calculation of simply supported beam as basis and taken as the fundamental frequency multiplied with the second power of the span width.

(3)

In Table 8 the listed parameters for the included residential areas are presented. For the areas Hyttkammaren and Portvakten no value for the deflection was available and consequently the parameters *d_L* then also is missing. The measured deflection are all below 1.5 mm, which is the limiting value in building regulations in Sweden for deflection of timber joist floors due to a 1 kN point load at midspan of the floor.

Area	*d* (mm)	f_1 (Hz)	A_{max} m/s^2	*L* (m)	f_1_L	*d_L*
BrunnbyPark	1.4	19.0	7.1	3.8	274	0.0255
Torghörnet	0.4	9.0	3.2	6.7	404	0.0013
BoKlok	0.7	16.0	30.8	3.8	231	0.0128
Hyttkammaren	-	13.0	3.3	4.2	229	-
Lägern	0.7	13.5	18.7	5.4	165	0.0044
Limnologen	0.9	25.0	21.5	6.1	930	0.0040
Portvakten	-	16.7	9.3	7.4	914	-
Glasäpplet	0.8	12.0	4.3	7.5	675	0.0019
Dovhjorten	0.1	38.0	3.0	3.5	466	0.0023

Table 8. Measured objective parameters deflection *d*, fundamental frequency f_1 and maximum floor acceleration A_{max} together with span width *L* and parameters combined from deflection, frequency and span width, *d_L* and f_1_L.

4 Regression analysis - Ratings versus field measurements

Before the linear regression analysis between the ratings and the objective parameters from the field measurements was performed the parameters best suited to use had to be found. A correlation analysis between the different statistical and fractional parameters were carried out determine which of them to be used in the principal component analysis (PCA) and after that in the linear regression analysis. In Table 9 the statistical and fractional parameters for all the questions have been compared by calculating the correlation coefficient *R* by the formula

(4)

where and are the parameter values of every residential area and and are the mean values of each parameter. The correlation coefficient was calculated between the average rating (A50), the average rating increased by one standard deviation (A16) and the different fractional parameters (fraction 3, 5 and 8). The average rating (A50) has a high correlation with the fraction ≥3 and also with fraction ≥5. The correlation between the average rating increased by one standard deviation (A16) and the fractional parameters is not equally high.

A50	1	2	3	4	5	6	7	8	9	10	11	12	13
Fract 3	0.96	0.97	0.98	0.93	0.94	0.82	0.96	0.95	0.95	0.91	0.90	0.85	0.96
Fract 5	0.91	0.94	0.97	0.93	0.92	0.85	0.94	0.71	0.95	0.93	0.97	0.88	0.85
Fract 8	0.42	0.63	0.92	0.54	0.90	0.50	0.79	0.51	0.74	0.56	0.95	-0.03	0.82
A16	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
Fract 3	0.85	0.92	0.70	0.87	0.47	0.80	0.94	0.39	0.92	0.92	0.94	0.72	0.93
Fract 5	0.79	0.88	0.70	0.94	0.42	0.79	0.95	0.85	0.94	0.88	0.96	0.77	0.83
Fract 8	0.47	0.73	0.67	0.68	0.43	0.61	0.82	0.89	0.84	0.70	0.90	0.61	0.85

Table 9. Correlation coefficients *R* between statistical parameters A50 and A16 and the fractional parameters fract. 3, 5 and 8.

The best correlation *R* was found between the average ratings (A50) and fraction ≥3. The linear regression analysis between the objective measured parameters and ratings by the residents was performed with both of them. The rating fraction ≥3 may be interpreted as residents being "somewhat annoyed, annoyed or very annoyed", which is maybe more intuitive than the average as it shows that the residents are not fully satisfied with the vibration performance. In the following the fraction ≥3 have been chosen when presenting the regression diagrams as it is easier to make an assessment of the number of residents that could be allowed to be dissatisfied and by that setting a limit.

The linear regression analysis was carried out and plotted with confidence limit of 0.05 in the software Statistica 10 [4]. for all the objective parameters and the questions except for question 12 about the residents experienced sensitivity for vibrations. In Table 10 the squared *R* value R^2, which is the coefficient of determination, of all the linear regressions are given for the ratings fraction ≥3 and in Table 11 the linear regressions for the average ratings (A50).

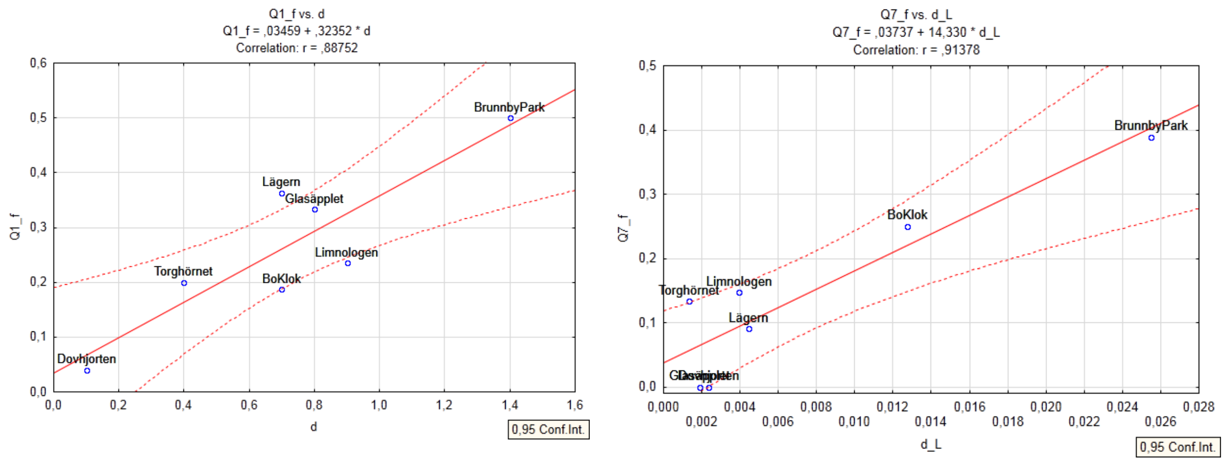
Fract ≥3	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q13
d	78.8%	40.1%	59.7%	54.3%	30.3%	22.0%	53.5%	10.5%	35.4%	50.4%	40.9%	33.5%
f_1	24.7%	27.7%	2.4%	8.1%	32.3%	5.7%	4.9%	12.3%	0.4%	12.3%	13.2%	15.6%
A_{max}	0.4%	24.1%	17.4%	0.7%	14.2%	15.1%	4.2%	11.9%	25.8%	0.3%	0.02%	37.8%
L	9.2%	0.1%	17.6%	3.0%	8.4%	20.7%	2.5%	1.9%	2.7%	0.01%	4.2%	9.8%
d_L	37.5%	37.2%	61.4%	79.7%	22.8%	65.5%	83.5%	12.1%	37.2%	63.2%	13.5%	47.4%
f_1***_L***	0.4%	0.5%	0.1%	0.5%	1.1%	15.4%	0.2%	20.6%	3.9%	0.1%	5.5%	13.3%

Table 10. R^2 values for linear regressions of objective parameters versus rating fraction ≥3 from vibration questionnaire.

A50	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q13
d	85.6%	34.2%	68.4%	55.2%	54.6%	4.8%	50.3%	10.1%	60.3%	48.0%	61.0%	38.1%
f_1	29.8%	19.1%	1.3%	27.3%	21.6%	16.1%	9.1%	12.4%	5.2%	24.2%	22.3%	20.3%
A_{max}	3.0%	38.0%	8.1%	5.3%	7.1%	0.1%	9.8%	15.2%	22.8%	11.9%	0.2%	46.0%
L	10.4%	0.1%	16.7%	0.3%	4.5%	4.8%	4.0%	7.2%	1.8%	0.03%	1.2%	4.8%
d_L	38.3%	24.9%	63.8%	64.5%	38.0%	32.0%	81.1%	13.4%	48.0%	58.7%	36.1%	40.3%
f_1***_L***	1.0%	0.1%	0.4%	3.1%	3.3%	14.9%	2.3%	41.0%	0.8%	2.8%	0.03%	13.0%

Table 11. R^2 values for linear regressions of objective parameters versus average rating (A50) from vibration questionnaire.

If looking just on the coefficient of determination, the R^2 values, the highest values are obtained for the parameters deflection *d* and the deflection combined with the span width *d_L*. The question 1 about general vibration annoyance has a R^2 value of 78.8 % for *d* which is the highest value for the question as whole and second highest value of all combinations of objective parameters and questions. In Figure 7 a), the regression diagram for the deflection *d* and the question 1 is presented. The fraction ≥3 values of the different residential areas are marked with circles with the area name given next to it, the continuous line is the linear regression line and the dashed lines are the boarder lines for the 95 % confidence interval. In the header under the name that gives the combination of question and objective parameter the regression line equation is given together with the correlation value *R*. The values for the deflection *d* versus question 1 seem to be well spread and the deflection seems to be in this case a good predictor for vibration related disturbance.

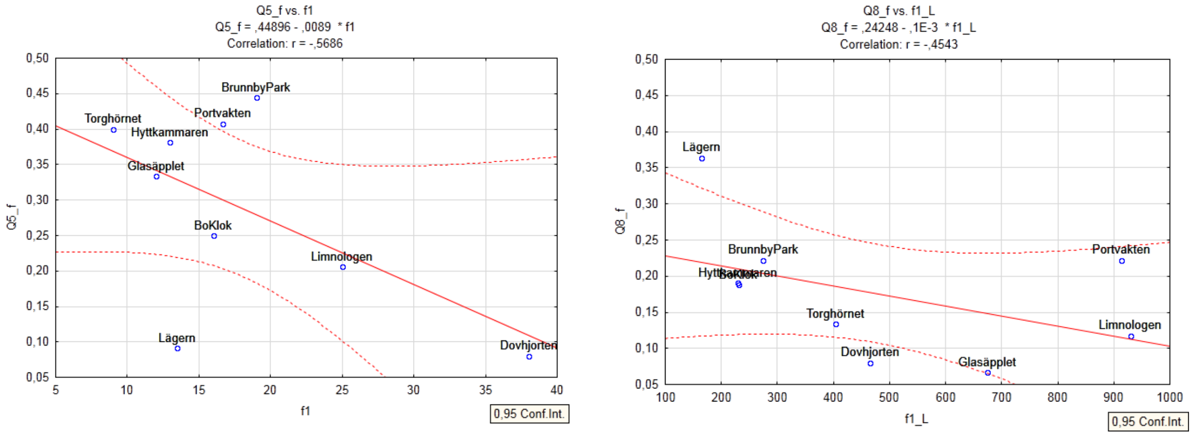


a) b)

Figure 7. a) The regression diagram for question 1 and deflection *d* (Q1_f vs. *d*) and b) the regression diagram for question 7 and deflection *d* combined with span width *d_L* (Q7_f vs. *d_L*).

As it comes to springiness or deflection of the floors as it is expressed in question 2 the R^2 value is surprisingly low 40.1 % although it should be closely related to the measured deflection *d*, but still it is the parameter that best correlates with this question. For question 3 regarding deflections in balconies and stairs the R^2 value is somewhat higher 59.7 %. Maybe the concept of springiness is more difficult for people to relate to than vibrations and therefore a lower R^2 value for this question than the questions about vibrations, but it may also be that vibrations actually are more annoying than springiness as vibrations can also be induced by someone else than the resident himself and therefore experienced as more annoying.

The *d_L* parameter has the highest correlation of all combinations of objective parameters and questions, a R^2 value of 83.5 % with the question 7 about moving objects and furniture when you or someone else is walking in the room. In Figure 7 a) the regression diagram for the *d_L* and the question 7 is presented. The values of residential area Brunnby Park together with BoKlok do to a high extent define the regression line and by that also contribute to the high R^2 value. The other areas are clustered in the lower left corner. This is not good when considering the reliability of the regressions and the R^2 values. Although an interesting observation is that the residential areas Brunnby Park and BoKlok, when comparing with the ratings in Table 3, are the areas that have the overall highest annoyance ratings considering the amount of yellow and red markings. They are clearly considered worse than the other areas with respect to disturbance. From the equation (1) it is found that the *d_L* parameter is a stiffness property that is independent of floor span width. The structural design of the floors do differ and the design of floors in the residential areas Brunnby Park and BoKlok are more traditional lightweight joist floors and the others include in some respect engineered products like LVL, CLT and glulam or steel joists as in the buildings in the residential area Lägern. In the regression diagram the floors with higher stiffness properties are found in the lower end of the *d_L* axis and the ones with lower stiffness properties are found in the higher end of the *d_L* axis. The result could be misinterpreted as if the floor span width does not matter for floor vibration performance, which it in reality does. As the deflection *d* of all the floors are within design limits, the *d_L* parameters are within design limits. This means that it is not possible to extend the span width of a floor with. The results for the *d_L* parameter have to be considered with care as the data are clustered and also as values from the two areas Hyttkammaren and Portvakten are missing, which increases the uncertainty of the model. By that the parameter *d* has to be considered as a better parameter for predicting vibration disturbance than *d_L*.



a) b)

Figure 8. a) The regression diagram for question 5 and fundamental frequency f_1 (Q5_f vs. f_1) and b) the regression diagram for question 8 and fundamental frequency f_1 combined with span width (Q8_f vs. f_1_L).

When considering the fundamental frequency f_1 and the frequency combined with the span width f_1_L the highest R^2 value is 29.8 % for f_1 in question 1 about general vibration annoyance. The questions 4, 5, 10, 11 and 13 have values above 20 %, which are questions concerning vibrations induced by neighbours, traffic, rattling sound from objects and adjustment to not disturb family or neighbours. The R^2 values for f_1_L are very low for all questions except for question 8 about vibrations induced by closing doors, for which it is 41.0 % and it is the parameter that gives the best correlation with this question. None of the two may be considered as good parameters for predicting vibration disturbance.

For the maximum acceleration *Amax* the best correlation with residents' ratings is 37.8 %, which is with question 13 about satisfaction with the vibration performance of floors and walls. The regression diagram is shown in Figure 9. As for the parameter *d_L* the two residential areas with traditional floor structures, Brunnby Park and BoKlok have the highest fraction of disturbed residents. The questions 2 and 9 about floor deflection and sound as creaks from the floor have ratings 24.1 % and 25.8 %. The rest of the questions have correlations below 18 %. As for the frequency dependent variables the A_{max} may not be considered a good parameter for predicting vibration disturbance.

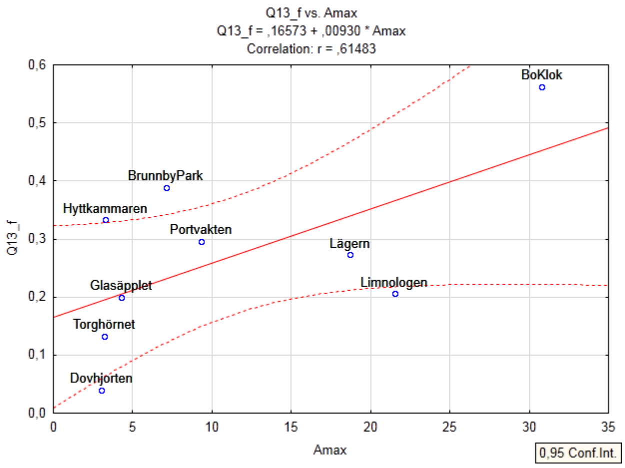


Figure 9. The regression diagram for question 13 and maximum acceleration A_{max} (Q13_f vs. A_{max}).

In order to see how the ratings of the questions and the objective parameters relate to each other and how they relate to the residential areas a principal component analysis (PCA) was performed with software Simca [5]. The variables were scaled to unit variance. An introduction to PCA may be found in [6].The plot of the PCA is shown in Figure 10. The ratings fraction ≥3 of the questions and the objective parameters are marked with blue triangles and labeled with the parameter name or the question number (Q1_f to Q13_f) and the residential areas are marked with blue squares and labeled with the area name. The PCA plot shows in a better way what is seen in Table 3 that the ratings of annoyance are highest in the areas Brunnby Park and BoKlok, found near to the cluster of questions, and lowest in the area Dovhjorten found farthest away from the questions and parameters. It is also seen that the ratings of questions are closely related as they have been clustered together, which also was seen in Table 3. The plot also confirms that the objective parameter best correlated to the ratings is the deflection *d* that is found next to question 2 (Q2_f) just above the horizontal axis. The other parameters are found farther away.

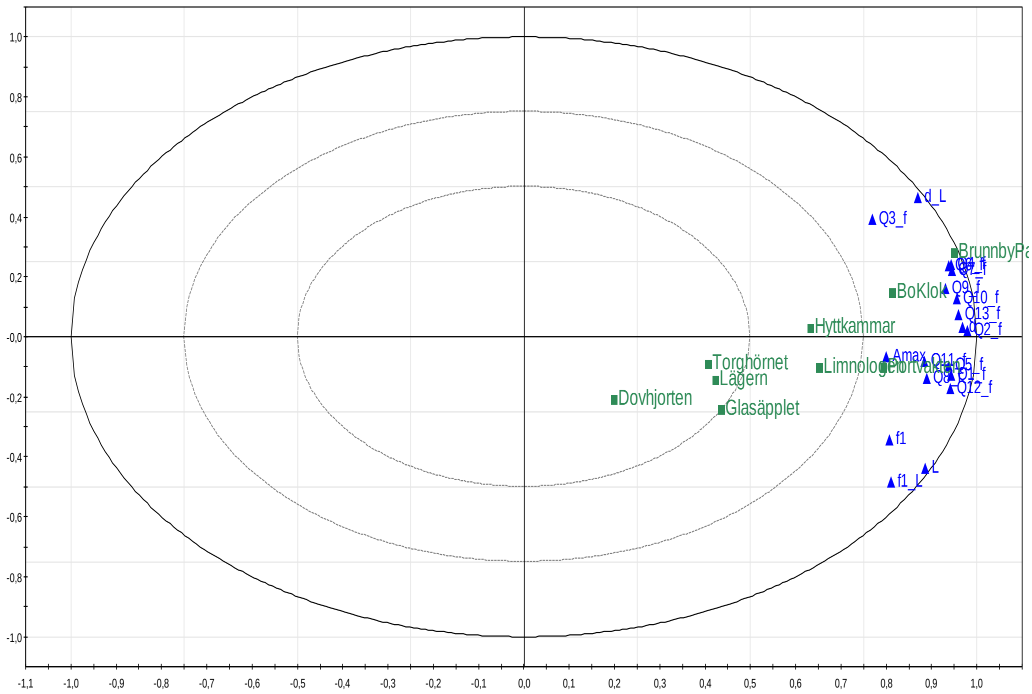


Figure 10. Principal component analysis (PCA) plot of data.

5 Discussion and conclusions

The obtained results have to be interpreted taking into account the type of buildings investigated and that only a small number of areas have been included in the investigation, which means that the sample of buildings and residents have not been random and that most of the differences will not be statistically significant. Still the percentage of answers is satisfactory for most of the areas and all the residents have had the possibility to answer in contrast to nationwide sampling tests in which only few samples at many areas would have been collected. Other sources to uncertainty than the few included areas are that the measurements have been performed just in one or few rooms in the included buildings and due to a lack of standardized measurement methods there may be a risk that the measured values differs when measurements have been carried out by different performers. Another consequence of the lack of standardized measurement methods may be that the extracted values might not accurately reflect the floor structures vibration properties. The main purpose with the performed vibration measurement was to obtain data for comparison of the impulse ball and the tapping machine and not to provide data for extraction the floor structures vibration properties. This could explain the much poorer correlation for the objective parameters that concerns vibrations, the maximum acceleration A_{max} and the fundamental frequency f_1. The poor correlation stands in contradiction with results from another investigation within the AkuLite project in which timber floor vibrations and experience of vibration performance were tested in laboratory. The investigation is presented in [7] and [8] and the results show that the fundamental frequency is a better predictor for vibration annoyance than the deflection is. Also damping was found to be important for the vibration perception.

From the obtained results, it may be concluded that the deflection *d* due to a concentrated point load at midspan of the floor is best of the investigated parameter for predicting vibration disturbance. All the floors in the investigation do fulfill the deflection requirement for timber floors in the Swedish building regulation, which is a maximum deflection of 1.5 mm when loaded with a 1 kN point load at midspan of the floor [9] and [10]. If using the regression line of rating fraction ≥3 for deflection *d* and question 1 in Figure 3 a) as basis of annoyance prediction, a deflection of 1.5 mm would result in 52 % of the residents being “somewhat annoyed, annoyed or very annoyed”. That is a rather high number and points to the fact that the limit should be sharpened. A deflection limit of 1.0 mm would similarly result in 36 % of the residents being “somewhat annoyed, annoyed or very annoyed”. If taking into account the uncertainty of the regression line, the 0.95 percentile limits, an average deflection of 1.0 mm would have an upper limit slightly above 1.5 mm and a lower limit at below 0.8 mm, as marked with dashed blue lines in Figure 11.

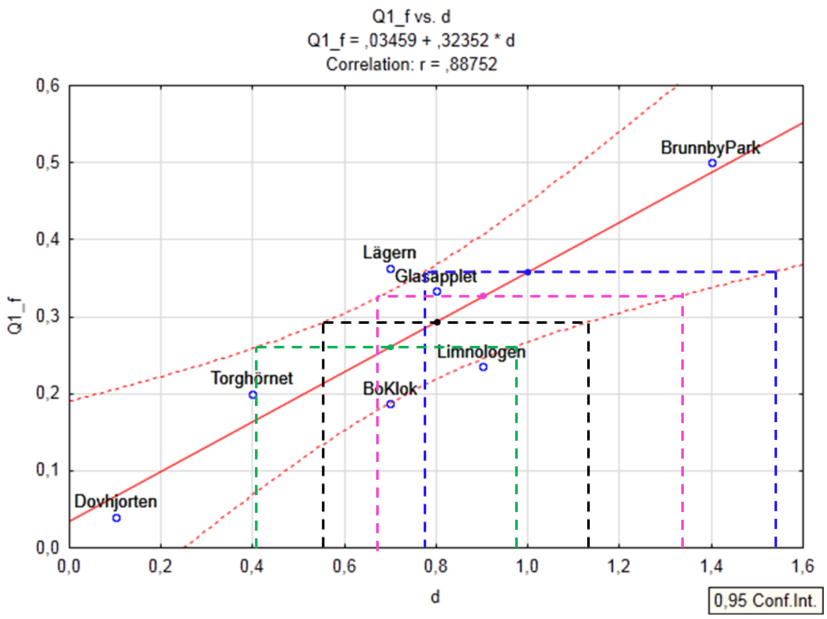


Figure 11. The regression diagram for question 1 and deflection *d* (Q1_f vs. *d*) with ranges with respect to the 0.95 confidence interval marked for different average deflection limits.

The corresponding value for fraction ≥3 annoyance and bounds for an average deflection 0.9 mm have been marked with dashed magenta lines in Figure 11, 32 % of residents would be annoyed and the bounds for deflection would approximately be 0.7 mm and slightly above 1.3 mm. Likewise for average deflections 0.8 mm and 0.7 mm, marked with black and green dashed lines respectively, would yield the fraction ≥3 annoyance of 29 % and 26 %. The corresponding bounds for deflection become approximately 0.55-1.35 mm and 0.41-0.97 mm respectively.

The result maybe not surprising as the methods and limits used today were developed at a time when timber joist floors were mostly used in single family housing, in which the tolerance most likely is higher as it only involves disturbance induced by the family. This investigation has involved apartment buildings and it is obvious that the tolerance is lower, even if it is not evident that the disturbance due to vibrations is induced by neighbours.

To be able to propose any reliable new limits for vibration criteria more data is needed, meaning that both measurements and surveys have to be carried out in more buildings. To have more reliable vibration values a common method for measurement and evaluation of fundamental frequency and acceleration levels have to be developed and included in the measurement protocol. The damping should also be included in further investigations. The developed measurement methods have to be able to take into account effects of the flooring on top the load bearing floor structure.

The questionnaire seems to work quite well in general. The question 5 about vibration induced by neighbours walking or their children playing on the their floors should maybe be reconsidered in some way as it seems as if there is interference with sound and possibly other issues as general annoyance with the neighbours. From the ratings it is not possible to say in what way the residents are most annoyed, by feeling the vibrations, hearing or seeing furniture or objects move. They seem to be annoyed almost in the same extent irrespective of sense. The vibrations appear to be perceived in several ways and it could be possible that the residents are not able to make difference between the perceived disturbances if they occur simultaneously. It may be concluded that annoyance by vibrations is not a problem in buildings with concrete framework, but in buildings with lightweight framework the residents clearly are annoyed by vibrations.

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Annex A

The questionnaire in Swedish is presented in Figure A and B.

Störs du av vibrationer i din bostad?

AkuLite

Undersökningens syfte

Hej !

SP medverkar i ett nationellt forskningsprogram AkuLite. I projektet undersöks om ljud- och vibrationsförhållandena är tillfredställande i bostadshus. Flera byggnader har valts ut att ingå i projektet och den byggnad ni bor i är en av dem. Ni har tidigare fått en enkät om ljud och denna handlar om vibrationer. Era svar hjälper oss att avgöra vilka vibrationskrav som behöver ställas i byggregler. Vibrationskraven 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 vibrationsförhållandena är tillfredsställande.

Vi tackar er för att ni tar er tid att fylla i enkäten och posten den tillbaka till oss i det bifogade kuvertet. 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 höra av sig.
Tack för er medverkan.

Med vänliga hälsningar

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

Du är:	Kvinna ☐	Man ☐			
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- ☐

EXEMPEL: HUR MAN BESVARAR ENKÄTEN

Huvudfråga — *Svarsalternativ*

Hur mycket har du besvärats, störts eller irriterats 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. Vibrationer i golv eller från inredning och föremål, i allmänhet	☐	☐	☐	☐	☒	■	☐	☐	☐	☐	☐	☐

- *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 uppfattat några vibrationer alls eller alls störts av vibrationer eller du inte kan svara sätt ett X längst ute till höger.*

FigureA. The questionnaire, explanatory first page in Swedish.

Instruktioner:
Välj en siffra på skalan 0-10 för hur mycket du besväras, störs eller irriteras av vibrationer eller ljud från golvet:

*Om du lägger märke till lite ljud eller vibrationer, och INTE ALLS störs av detta, **svara 0***	*Om du är OERHÖRT besvärad, störd eller irriterad av detta, **svara 10***	*Om du störs till viss del, svara med en siffra **mellan 1 och 9***	*Om du inte uppfattar några vibrationer eller ljud eller du inte kan svara på frågan, **svara "Vet ej"***

Hur mycket har du besvärats, störts eller irriterats i din bostad under de senaste 12 månaderna på grund av	Inte alls 0	1	2	3	4	5	6	7	8	9	Oerhört mycket 10	Vet ej
1. Vibrationer i golv eller från inredning och föremål, i allmänhet	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

Hur mycket har du besvärats, störts eller irriterats i din bostad under de senaste 12 månaderna på grund av	Inte alls 0	1	2	3	4	5	6	7	8	9	Oerhört mycket 10	Vet ej
2. **Svikt / nedfjädring** i golvet när du **själv går** på det	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
3. Svikt / nedfjädring i **trappor**, loftgångar eller balkonger när du själv går på dem, *specificera var*:__________________	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
4. **Vibrationer** där du sitter eller ligger ner, när **någon annan** går på golvet **i samma rum**	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
5. Vibrationer när **grannar** går eller när deras barn leker på **deras** golv	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
6. Vibrationer från närbelägen **väg- eller järnvägstrafik**	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
7. **Rörelser** i möbler eller föremål då du eller någon annan **går** på golvet, t.ex. att bord, TV/datorskärmar, bokhyllor, lampor, dörrar, tavlor etc. börjar att svänga	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
8. **Rörelser** i möbler eller föremål när grannar stänger sina **dörrar**	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
9. **Ljud** från **ditt golv** när du eller någon annan går på det, exempelvis dunsar, knäppningar eller knarr	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
10. **Ljud** från **inredning eller föremål** när du eller någon annan går på golvet, t.ex. skrammel eller skaller från koppar, glas, vitrinskåp och liknande	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

Måste du anpassa ditt sätt att gå i bostaden för att undvika att störa din familj eller dina grannar med	Nej, inte alls 0	1	2	3	4	5	6	7	8	9	Ja, jag är oerhört försiktig 10
11. Golvvibrationer, *specificera vad*:______________________	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

Är du tolerant eller känslig med avseende på	Tolerant, inte alls känslig 0	1	2	3	4	5	6	7	8	9	Oerhört känslig 10
12. Vibrationer i golven eller i inredning och föremål	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

Är du på det hela taget nöjd eller missnöjd med kvalitén på golv och väggar när det gäller	Nöjd, inte alls missnöjd 0	1	2	3	4	5	6	7	8	9	Oerhört missnöjd 10
13. Vibrationer i golven eller i inredning och föremål	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

Kommentarer (vad är det som orsakar vibrationer, vilka effekter upplever du):

____

____

____

Figure B. The questionnaire, the second page with questions in Swedish.

Vibration Performance of Apartments Buildings with Wooden Framework – Residents´ Survey and Field Measurements

The report presents results of extensive investigations on how residents in multi-storey apartment buildings with lightweight framework perceive springiness and vibrations. It also analyses relationships between objective data of the floors i.e. physical floor vibration performance and the subjective ratings by the residents.

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