Acoustics in wooden buildings – Evaluation of acoustic quality in wooden buildings: Listening tests and questionnaire field study

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Project Report No. 3

Evaluation of acoustic quality in wooden buildings: Listening tests and questionnaire field study

WoodWisdom-Net: AcuWood – Acoustics in Wooden Buildings

Development of advanced measurement and rating procedures for sound insulation in wooden buildings as basis for product optimisation

Research project 033R056

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Acknowledgements

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Summary

This report presents the results from a questionnaire-based field survey and listening tests, both aiming to gain insight into the acoustic satisfaction of inhabitants of wooden buildings and to find objective acoustic descriptors, which correlate with subjective human perception of acoustic quality. In total 414 responses were collected in the questionnaire-based field survey. Field measurements and recordings in part of the buildings, which were involved in the questionnaire-based field survey, were conducted to derive acoustic descriptors, which are correlated to the subjective judgements.

The questionnaire-based field survey reveals that the overall ratings by the residents may be considered as very satisfying. Ratings with regard to annoyance caused by noise are quite low. However, walking noise caused by neighbours raises the highest complaint compared to other noise sources. It can also be shown that building and floor construction types differ with regard to perceived acoustic annoyance caused by walking noise. Ratings of residents in single-family houses differ from ratings of residents in multi-family houses. In this sample floor constructions made from wood are not rated worse compared to floor constructions made from concrete. However, this only holds true, if wood-concrete composite floors are included in the group of wooden floors. Within the group of floor constructions made from wood, the different types of floors clearly differ from each other with regard to perceived acoustic annoyance caused by walking noise. This result from the survey is in accordance to the listening tests and the measurement results in the building when using an appropriate single number descriptor. In general it can be stated that the questionnaire used in this field-survey may be applied for post occupancy evaluation and identification of construction problems in wooden buildings.

The listening tests reveal that the test persons perceive clear differences between the different floor constructions, floor coverings and noise sources. It can also be shown, that the annoyance ratings in the laboratory listening test match with the ratings of noise caused by walking neighbours in the questionnaire-based field survey, which justifies the development of an algorithm to predict acoustic annoyance caused by walking noise based on the laboratory measurement and listening test data accompanied by an evaluation in the field.

1 Introduction

Within the European research project AcuWood, the acoustic quality of wooden buildings is investigated. The research intent is based on the fact that the correlation between standardized evaluation methods (e.g. EN ISO 717) and human perception of acoustic quality in wooden buildings has often been shown to be poor [1]. Noise and vibration disturbances experienced by residents in wooden buildings tend to increase, even if the building code requirements are fulfilled [1]. This is a well-known phenomenon and numerous investigations on propagation and human perception of impact and airborne sound in wooden buildings have been conducted. However, common rating criteria and requirements have not been established yet [1].

The aim of the reported study is twofold. On the one hand it is intended to gain insight into the acoustic satisfaction of inhabitants of wooden buildings depending on building and construction type. On the other hand it is intended to derive objective acoustic descriptors which better correlate with subjective human perception and which are capable to provide a classification of the acoustic quality of wooden buildings. A special focus is put upon impact noise of different technical and human sound sources. To achieve this, a questionnaire-based field survey in Germany and Switzerland as well as laboratory listening tests were conducted, which considered different building and construction types. Besides impact noise, other acoustic qualities and additional building properties were addressed in the field survey. The laboratory listening tests partly consisted of recordings from buildings that were included in the questionnaire-based field survey. Therefore it is possible to compare the long-term acoustic satisfaction of inhabitants with the short-term subjective impression during the laboratory listening tests for these buildings.

2 Method

A web-based questionnaire field survey in Germany and Switzerland as well as laboratory listening tests were conducted. Previous field surveys of residents' opinions with respect to the noise situation in their homes are often difficult to compare since they have used different questions and answer options. Therefore the questionnaire used within this survey corresponds to the one developed within the COST TU 0901 research network action [2], which aims at facilitating standardized surveys. The questionnaire was complemented by some additional items. Besides acoustics other building properties were also addressed in the field survey, to prevent the ratings of acoustics being overlain by other hassles. The questionnaire incorporated items aiming at overall and acoustic satisfaction. The complete questionnaire is included in Appendix 1.

The listening tests were designed to guarantee for comparability. Thus standardized rating scales, namely the subjective annoyance rating scale according to ISO/TS 15666 [3] and the subjective loudness rating scale according to ISO 16832 [4] were used. Additionally, a question addressing the individual noise sensitivity and a polar (yes-no) noise annoyance question were included. The complete item-set and instructions of the listening test are included in Appendix 2.

2.1 Questionnaire-based field survey

The invitation to participate in the web-based questionnaire field survey was either sent via e-mail or put into the post box of residents in selected buildings. In Germany residents were exclusively invited via e-mail and in Switzerland written invitations were exclusively put into post boxes. Only buildings where information on the construction type was available were included. E-mail addresses were extracted from the customer databases of the members of German timber construction associations. In total 414 usable datasets were returned by the residents.

The questionnaire incorporated 41 questions in total. However, some questions were only shown in dependency to the answers given beforehand, so the number of questions being asked per participant could slightly vary. The questionnaire started with an explanation of the purpose and objectives of the survey. Then general questions were asked regarding ownership, building type, attitude towards timber constructions, living environment, object location and living situation. These questions were followed by an overall rating of satisfaction with the living situation and a ranking of the individual priorities of different aspects of the living environment. Afterwards these different aspects also had to be rated with regard to satisfaction. The questionnaire also included questions addressing neighbourhood, hassles and ideas of improvement. Then a question about noise in general was asked, which was followed by questions about annoyance generated by different noise sources. This was proceeded by a question about noise sensitivity. At the end of the questionnaire personal data was collected. This included information on gender, age, number of people living in the household, labour condition, occupancy and building age. The web-based questionnaire in Germany was launched in May 2012 and closed in February 2013. In Switzerland the questionnaire was started in December 2012 and closed in April 2013. The average total processing time of the questionnaire was 16 minutes. The complete questionnaire is included in Appendix 1.

2.2 Listening test

The measurement and recording procedure is elaborately described in [5, 6] and will be pictured here in a shortened form only. Microphone recordings and binaural recordings with a dummy head (HMS III connected to SQLab III) of Head Acoustics GmbH were conducted in laboratories of the Fraunhofer IBP and in the field. The microphone recordings were used to derive technical descriptors whereas the dummy head recordings were used for the conduction of the listening tests. The frequency range of the dummy head recordings was 20 Hz to 20 kHz, which is the measurable frequency range of the given technical equipment and also corresponds to the frequency range of human hearing. The dummy head system provides binaural recordings, where localisation of the source (above the listener) is possible.

A pre-test aimed to prepare for further listening tests in terms of organisation, use of hardware etc. and to contrast the ratings of the recordings by microphone and dummy head. Dummy head recordings from 6 floor constructions (bare floor, floor with floating floor and additionally with 4 different floor covers) and 7 different impact noise sources gave 42 signals to be rated. Additionally the microphone recordings of the 7 sources on the bare floor were tested against the dummy head recordings. The recordings were conducted in a building acoustics laboratory for floor testing, the laboratory consisted of two rooms above each other, with the separating floor as test object. The sending room was located above, the receiving room below the floor. The listening test was conducted in an office like laboratory. The pre-test (n=23; 9 female, 14 male; Mdn=24 years) showed that the influence of localisation must not be neglected, as there was a significant interaction (cf. figure 1) between sound source and type of recording (ANOVA: $F(13.69, 3.24)=4.22$, $p<.01$, $\eta^2=.167$). This interaction seems to be due to the difference of the subjective judgements of moving sources (walkers) depending on the type of recording (microphone vs. dummy head). For stationary sources, like the tapping machine or the rubber ball, the subjective rating of annoyance for the microphone and dummy head recordings correspond but for moving sources, like walkers, they do differ (cf. figure 1).

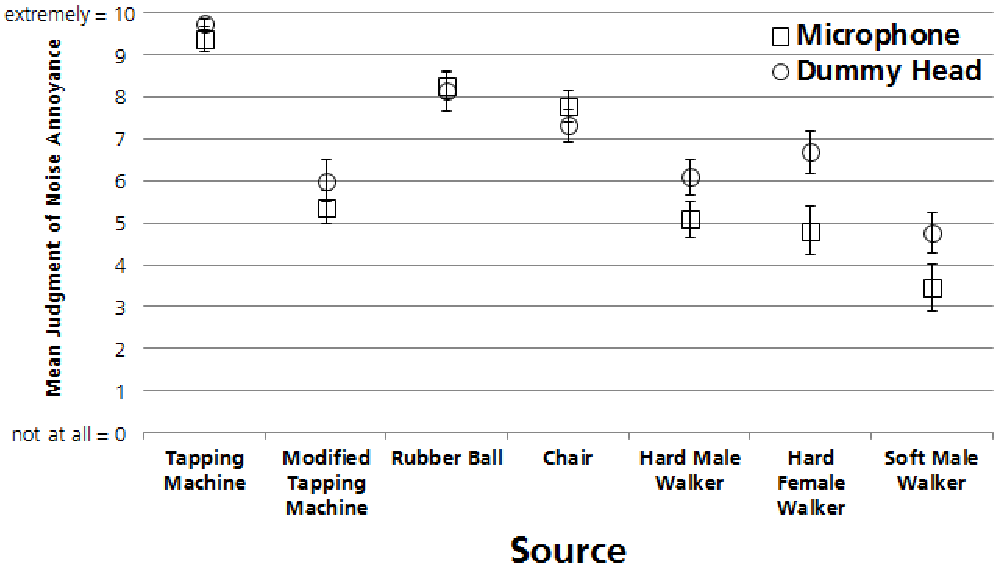

Figure 1: Mean ratings and standard errors with regard to perceived annoyance depending on sound source and type of recording.

For the main listening tests the impact noise produced by different sources in the sending room was measured and recorded in the receiving room. The measurements in the laboratory and in the field were conducted according to ISO 10140 [7] and ISO 140-7 [8], respectively. All recordings of the dummy head were made in a similar position in all receiving rooms at a height of 1.2 m, representing a sitting person. The impact noise sources that were employed in all measurements comprised the standardized tapping machine, the modified tapping machine according to [9] and the Japanese rubber ball according to ISO 10140-5 [10]. These technical sources were complemented by real-life sources, which were walking persons with different footwear and a chair drawn across the floor. In all field measurements, the same male walker (with shoes and with socks) was engaged. In the laboratory measurements different walking persons (male walker with shoes and with socks, and a female walker with hard heeled shoes) were engaged. Thus differences in the walking styles and excitation exist between the walkers in the laboratory. These differences were partly controlled by specification of a walking path (circle) and a frequency of steps (2 Hz). The second real-life source in all measurements was a chair, drawn across the floor. Laboratories of the Fraunhofer IBP comply with the requirements of ISO 10140-5. At the Fraunhofer IBP measurements were made on a wooden beam floor, on a wooden beam floor with suspended ceiling and on a concrete floor. These measurements were done on the bare floor or the floor was covered with a floating floor, a floating floor and laminate, a floating floor and parquet, a floating floor and tiles or a floating floor and carpet. Additionally measurements were made at 10 different buildings in the field (in some buildings measurements were repeated in two different room situations, resulting in total of a sum of 16 different floors measured). The buildings comprised modern multi-storey and multi-family wooden buildings and modern two-storey single family houses. The total number of measurements and recordings that were analysed in the listening tests adds up to 218 sounds. The recordings of the tapping machine, the modified tapping machine and the walkers were cut to a length of 20 s. The chair signals were cut to a length of 7 s, the ball drop recordings were cut to a length of 1 s for the listening tests. All recordings were aurally checked to be free of background noise or other not relevant artefacts and that they were representative for the source. For the walkers, cracking noises of the floor in the recordings could not always be avoided. They are typical of such floor constructions and thus also part of the signals to be judged.

It was decided to playback the signals to the test persons via headphones. The main reason for this was the intention to perform simultaneous listening tests with up to four test persons. The playback via loudspeakers always involves the room acoustics of the playback room. By the use of headphones, the transfer function of the room is excluded. For playback, two different systems were available: a professional playback system from Head Acoustics, which consists of an equalizer (PEQ IV), an amplifier (PVA IV.3) and headphones (HA III), and a semi-professional system consisting of filtered 24 bit wav signal files, iMac computers and Sennheiser HD 280 Pro headphones. As only one single Head Acoustics playback system was available, the system with Sennheiser headphones was used for simultaneous playback. This playback system was built up four times, so that four test persons were able to perform the listening test individually. The professional Head Acoustics system was used as a reference and the four playback systems were calibrated by comparison to the Head Acoustics system. The Head Acoustics recording and playback system includes a filtering method to enable a data interface, where the recorded signals of the dummy head are comparable to microphone recordings (cf. figure 2).

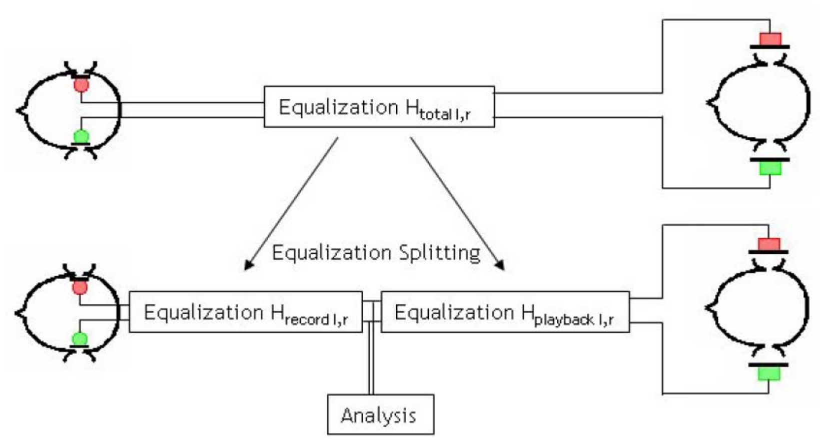

Figure 2: Filtering concept of the Head Acoustics dummy head recording and playback system. (Source: Head Acoustics)

The filtering of the signal gained by the dummy head is necessary, because the acoustic transfer path has to be corrected for the headphone playback (cf. figure 3).

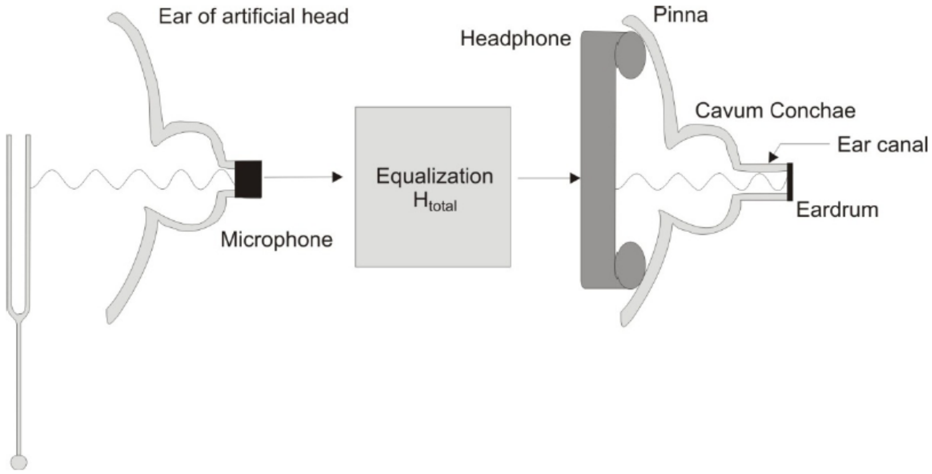

Figure 3: Concept of filtering the dummy head signals for headphone playback. (Source: Head Acoustics)

For the filtering, Head Acoustics suggests the use of the ID filter. This filter was used for all recordings within the AcuWood project. The ID filter of Head Acoustics is a mathematically calculated filter correcting for the ear canal (Cavum Conchae). At playback, the corresponding ID playback filter was used. This filter is provided by the digital signal processing hardware PEQ IV. Additionally, a filter for the headphones HA III is necessary. This filter is also implemented in PEQ IV. The ID filter is included in the PEQ IV but it is also possible to implement the appropriate filter in the data analysing software Head Acoustics Artemis. Thus it is possible to generate wav-files for the playback system with Sennheiser headphones corresponding to signals presented by the Head Acoustics playback system. The appropriate ID filter including a filter for the headphones (IDHD4) was provided by Head Acoustics. This filter was implemented in the data analysis software Artemis and was applied when exporting the data from Artemis into wav-files.

To ensure comparability of the signals played back, a comparison test was included in one listening test using the Head Acoustics playback system and the systems with Sennheiser headphones. The same signals were played back by both systems via headphones to the same dummy head. The resulting signals were again recorded and compared. Additionally, an artificial ear (G.R.A.S. 43AA) was used for comparison of both headphone signals. The drawback of the artificial ear is that the frequency range specified is 100 Hz to 4000 Hz, which does not explicitly include the low frequencies below 100 Hz. Nevertheless, the comparison of both playback systems showed, that an additional high pass filter of first order, with cut off frequency at 100 Hz, was necessary for the playback with the Sennheiser headphones, to get comparable low frequency characteristics. This filter was additionally implemented in the Artemis software and applied when exporting the signals into wav files. The level of playback was ensured by the Head Acoustics system automatically, for the Sennheiser headphones, the level was adjusted by comparison to the Head Acoustics system and additionally to the initial levels of the recordings. For comparison of the playback characteristics of both systems, Head Acoustics and Sennheiser headphones, a signal of pink noise was used. All described filters were implemented. The comparison of the measured spectra by the artificial ear is shown in figure 4, for the dummy head it is shown in figure 5.

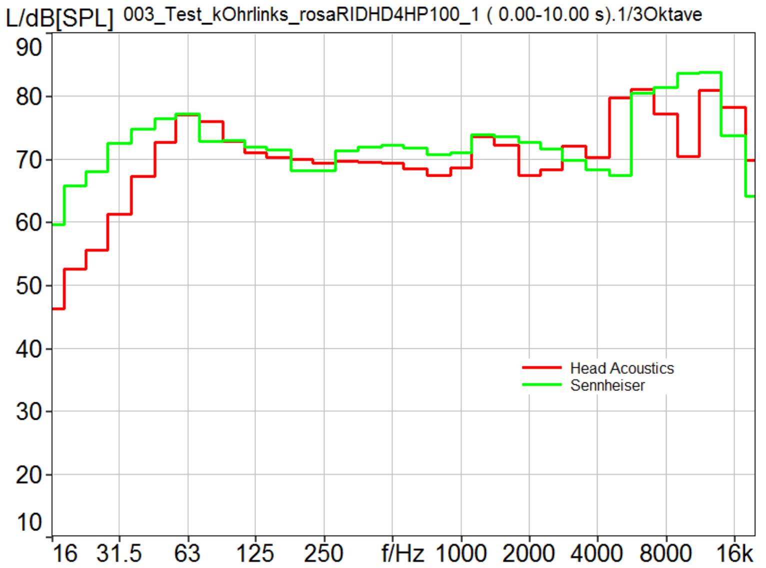

Figure 4: Comparison of both playback systems installed on the artificial ear. Red line Head Acoustics, green line Sennheiser headphones

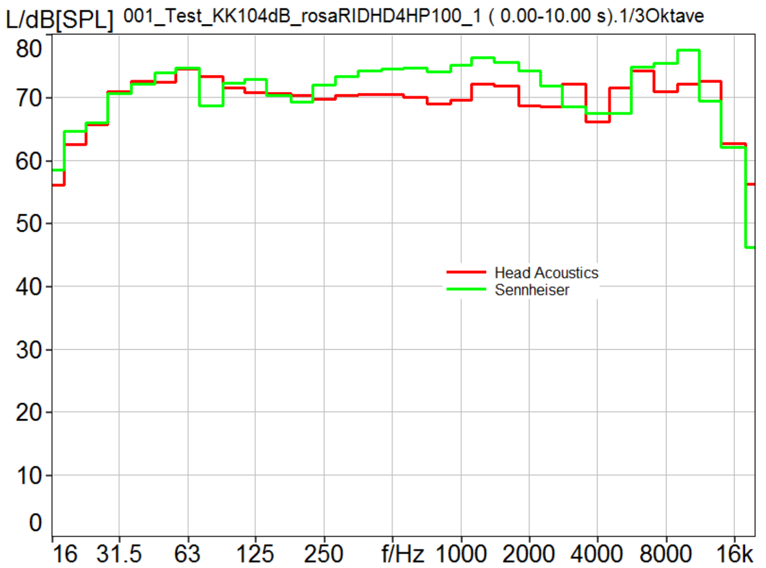

Figure 5: Comparison of both playback systems installed on the dummy head. Red line Head Acoustics, green line Sennheiser headphones

The comparison in figure 4 shows, that for very low frequencies there are differences of the signals played back to the artificial ear. For the dummy head, shown in figure 5, almost no differences occurred at very low frequencies between 16 and 63 Hz. At frequencies between 63 Hz and 250 Hz, the differences are quite low for both systems. Above 250 Hz, some bigger differences arise, especially for playback to the dummy head. However, pre-tests showed that the placing of the headphones on the dummy head can have some influence on the spectra measured with it. This also occurs when measuring with the artificial ear. The individual placing of the headphone on the test persons heads also causes uncertainty in the spectra played to the test person’s ear. Thus perfect congruence between the Head Acoustics playback system and the Sennheiser headphones cannot be expected. Therefore it was decided to use the filters IDHD4 and the high pass filter at 100 Hz for all signals played back by the Sennheiser headphones, as this signal is comparable to the signal of the Head Acoustics playback system on the dummy head at low frequencies, see figure 4.

Two main listening tests (n=18, 8=female, 10=male; n=22, 11=female, 11=male) with identical test design were conducted within this AcuWood project. The sound level was calibrated using an artificial ear (G.R.A.S. 43AA). The sound files were played randomly to the listeners over headphones. The answers were given by indication on a computer screen. Different test persons were invited for the two experiments. The first test group was aged between 20 to 35 years (Median = 24) and judged 125 different recordings. However, the total number of signals being judged in the first listening test was 250, as the two different presentation modes discussed above were contrasted. In two different test sessions the recordings where either presented via the playback system with the Sennheiser headphones or via the Head Acoustics playback system, to find out if there are relevant differences in the subjective ratings of the test persons depending on the playback system. Besides some differences in the spectra, other influences like wearing comfort of both headphone types could have some influence on the listening test results. In the first listening test (I), recordings of all laboratory measurements and of one field measurement were included. The results of listening test (I) showed that the subjective ratings of sounds played with the Head Acoustic system are comparable to the subjective ratings of sounds played with the system with Sennheiser headphones (cf. figure 6). Although there is a significant main effect of presentation mode (ANOVA: $F(1, 16)=10.05$, $p<.01$, $\eta^2=.386$), the quantity of the differences is small, within the same rating category. However, it must be stated that the perceived annoyance is constantly a little bit higher, when the Sennheiser headphones are used as compared to the Head Acousctis playback system. These small differences may be explained by subtle deviations during the level calibration.

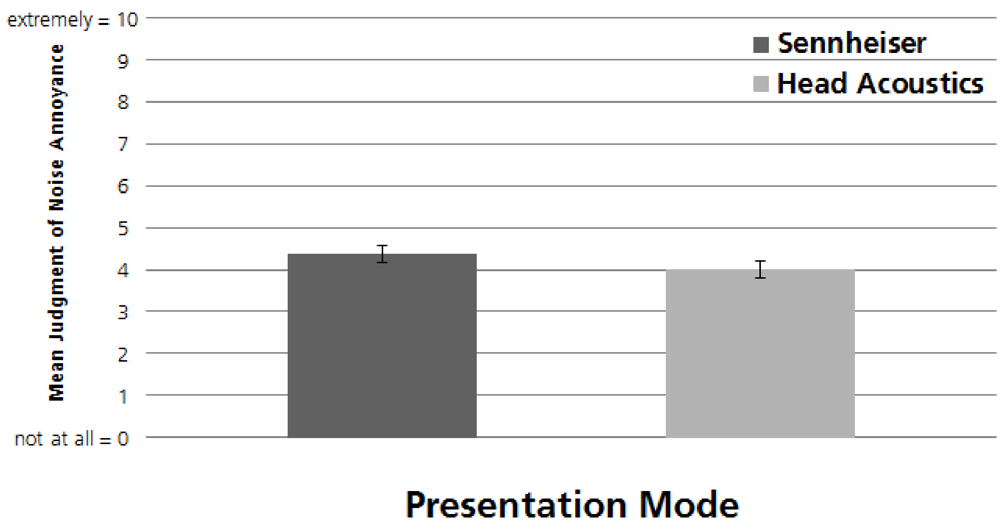

Figure 6: Mean ratings and standard errors with regard to perceived annoyance depending on presentation mode.

Following from this, it was decided for the second listening test (II) to only use the system with the Sennheiser headphones. The second test group was aged between 21 to 65 years (Median = 25) and judged 93 different recordings. These recordings only included field measurements. To guarantee for the comparability of the judgments of the different tests persons in listening test I and listening test II, the recordings from one field measurement were included in both listening tests. Statistical analysis proved that the two different groups of subjects gave comparable judgements (cf. figure 7) of annoyance to the identical recordings, as there was no significant statistical difference between the ratings (ANOVA: $F(1, 38)=1.02$, $p>.05$, $\eta^2=.026$).

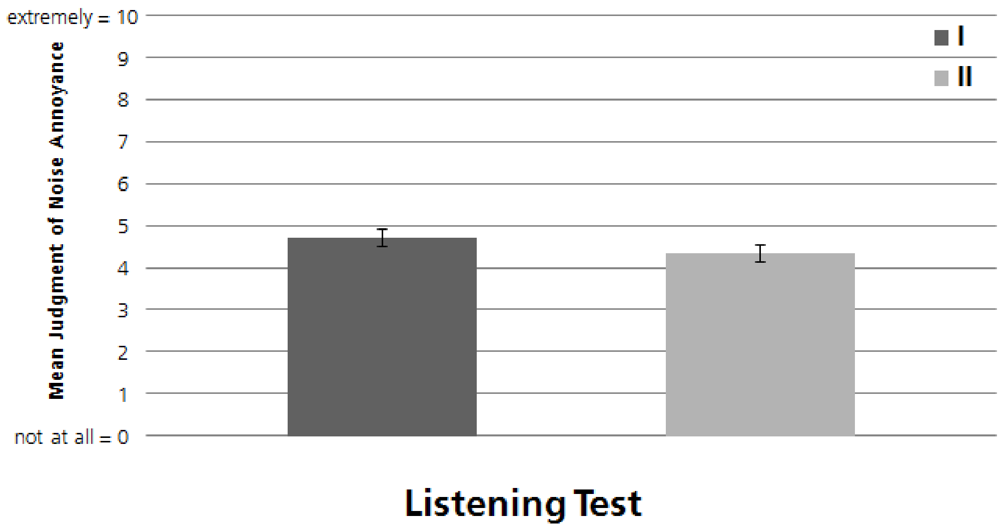

Figure 7: Mean ratings and standard errors with regard to perceived annoyance depending on listening test (I) or (II).

The rating scales used to assess perceived annoyance and perceived loudness corresponded to ISO/TS 15666 (11 point rating scale) and ISO 16832 (51 point rating scale). Additionally, individual noise sensitivity was questioned by a 11 point rating scale from "not at all" to "extremely" and a polar (yes-no) noise annoyance question was included. The latter asked test persons to judge, whether they would be annoyed by the sound, if they imagined being exposed to it for a prolonged time while reading a book or a newspaper at home. The complete item-set and instructions of the listening test are included in Appendix 2.

3 Results

For the field survey the total number of datasets (n=414) includes responses from buildings with floor constructions made from concrete (n=79). This is due to an error during the distribution of the invitations to participate in the study. Additionally, in some cases there is doubt (n=59) about the type of floor constructions. For that reason the total number of datasets, which is used in the analysis is reduced. However, the data from floor constructions made from concrete are included to compare the perceived quality of wooden and concrete floor constructions.

For the listening tests it was decided to combine all data from listening test I and listening test II of the Sennheiser playback system for the data analysis. The data from the pre-test and the Head Acoustics playback system (listening test I) is not reported here.

3.1 Questionnaire-based field survey

After exclusion of datasets, where there is doubt about the type of floor construction, 355 datasets remain. The average processing time of the questionnaire was 16 minutes. Not all questions had to be answered mandatorily, for that reason the number of responses to individual questions might vary.

Of the respondents 33% are female and 67% are male. The median age is 46 years with a range from 21 to 84 years. The average number of people living in the household is 2.65. The majority of the respondents, namely 59%, are renters (tenants) of the objects, whereas 36% of the respondents are owners and 4% are members of a cooperative. The remaining 1% chose the category "Other". The vast majority, namely 76%, of the respondents live in multi-family houses. An additional 15% live in single-family houses. About 2% of the respondents live in a flat within a single-family house and 4% live in a row house. About 3% of the respondents did not choose a category. A big portion, namely 39% of the respondents, indicated to have chosen a wooden house deliberately, whereas 41% stated, they had not deliberately chosen a wooden house and about 20% did not reply to this question. The biggest part of the respondents, namely 51%, live in the outskirts of cities. About 19% live in the city centre of a big town and 8% live in the city centre of a small town. About 19% indicate to live in a rural area and the remaining 3% chose the category "Other". The biggest part of the respondents, 42%, live in a family with kids, 38% live as couples and 14% describe their living situation as "Single". Another 2.5% are singles with kids and 2.5% live in an apartment-sharing community. About 1% of the respondents indicates to live in assisted living. A more extensive overview on demographics and general data can be seen in Appendix 3.

3.1.1 Measures of Satisfaction

Among other things, the respondents were asked to rank different aspects of the living environment individually according to the perceived importance. Figure 8 depicts the result of the ranking procedure. Acoustics are ranked in a middle position.

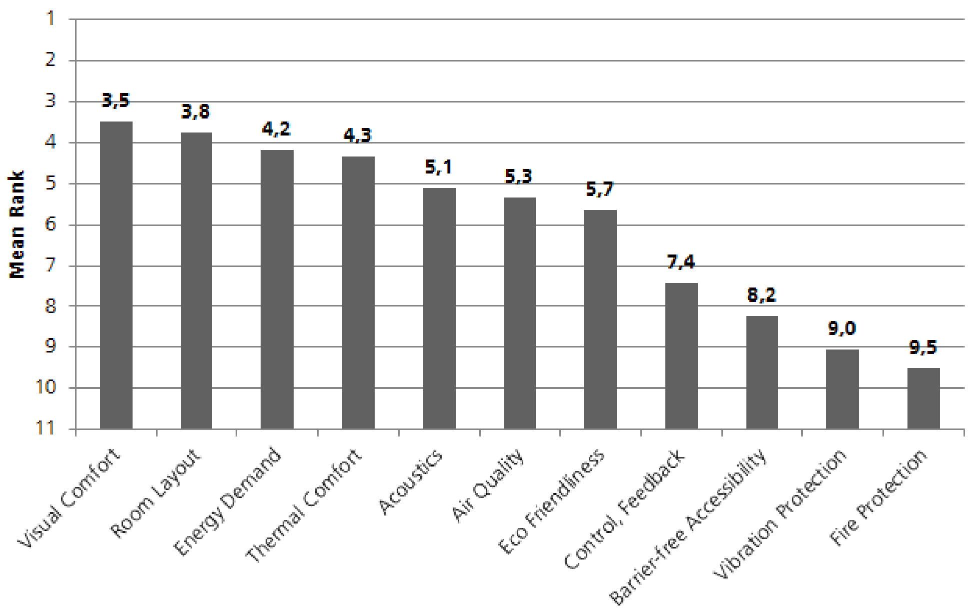

Figure 8: Ranking (mean rank) of the perceived individual importance with regard to different characteristics of the living environment. The different characteristics were ranked by each respondent individually (n=354).

Respondents were also asked to judge how satisfied they were with the living environment in general and with the different characteristics of the living environment. Figure 9 depicts the result of the judgment procedure. Overall, the respondents reported to be pretty satisfied with the living environment. Only the judgment of the possibility to control the living environment was a little lower.

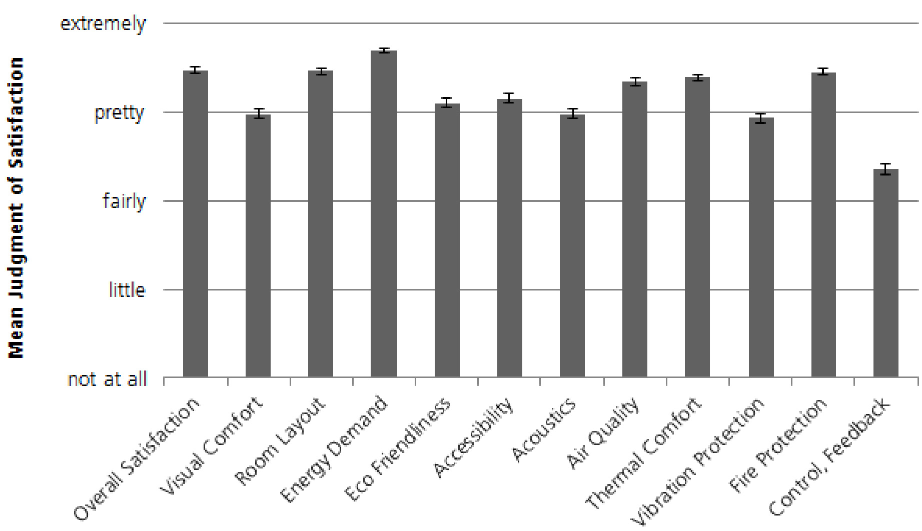

Figure 9: Judgment (mean rating) of the perceived individual satisfaction with regard to different characteristics of the living environment (n_{max}=355; n_{min}=285). Judgments were given on a five point scale.

3.1.2 Measures of Acoustic Annoyance

Acoustics were investigated in more detail, thus the questionnaire included a general noise annoyance question, which was followed by questions about annoyance generated by different noise sources. The wording and rating scales correspond to the COST TU 0901 research network action which again is consistent with the ISO/TS 15666 [3]. Since it would be beyond the scope of this report to provide a complete statistical analysis for all the items of the noise annoyance questionnaire, a special focus is put upon impact (walking) noise

3.1.2.1 Overall Acoustic Annoyance

Figures 10 to 12 depict the results of the noise annoyance questions. It stands out that noise annoyance is judged rather low but general noise annoyance is judged higher than individual noise sources. Thus general noise annoyance seems to be an aggregation of the annoyance caused by individual sources.

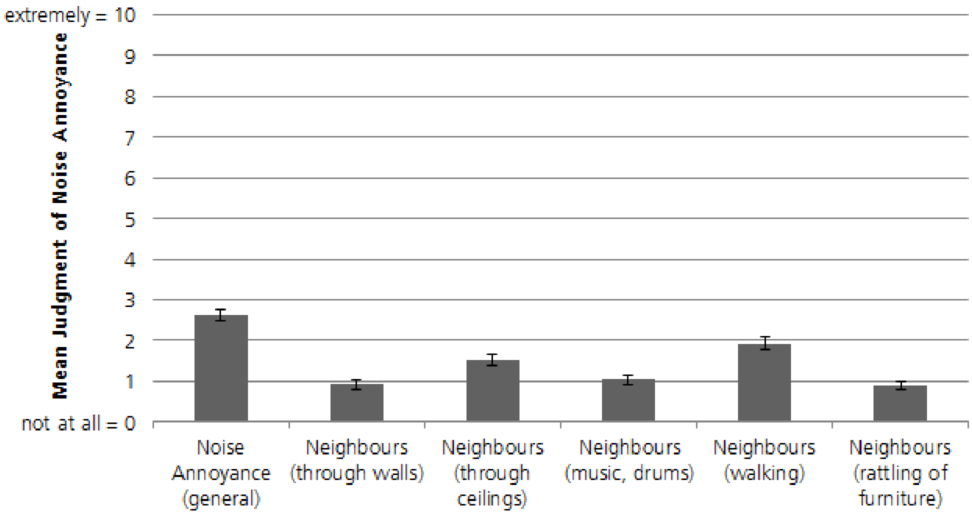

Figure 10: Judgment (mean rating) and standard errors of the perceived annoyance with regard to different noise sources in the living environment (n_{max}=344; n_{min}=276). Judgments were given on a 11 point scale.

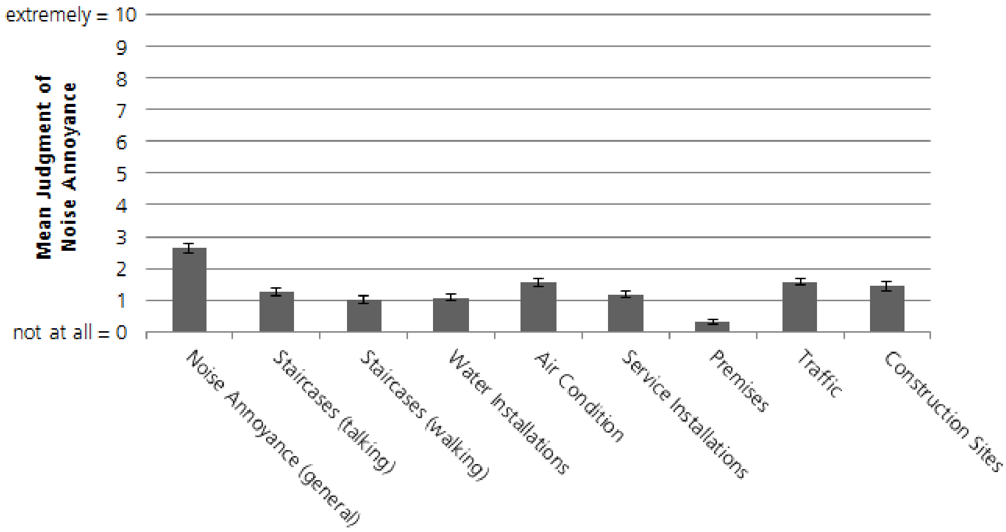

Figure 11: Judgment (mean rating) and standard errors of the perceived annoyance with regard to different noise sources in the living environment (n_{max}=344; n_{min}=276). Judgments were given on a 11 point scale.

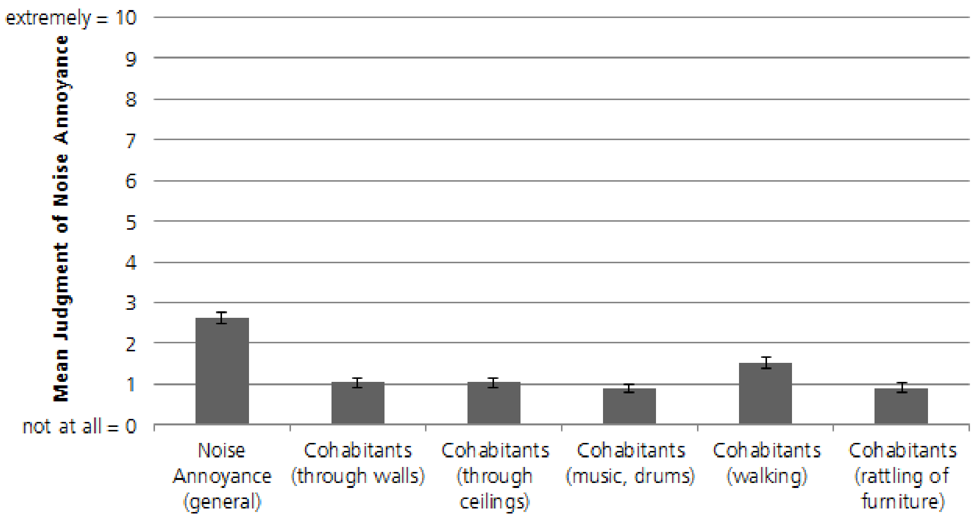

Figure 12: Judgment (mean rating) and standard errors of the perceived annoyance with regard to different noise sources in the living environment (n_{max}=344; n_{min}=276). Judgments were given on a 11 point scale.

For the project, which is focussing on impact noise, it is important to note that the impact noise caused by the walking of neighbours and the walking of cohabitants is the individual noise source, which causes the highest annoyance rating. The questionnaire used was aimed for both single family and multi-family dwellings. Therefore the differentiation between Cohabitants and Neighbours heard through walls and floor/ceiling was made. For walking noise, this differentiation seemed not necessary, as from the technical standpoint, walking noise is mostly transmitted from the floor/ceiling above the listener. In the Figures, floor/ceiling is abbreviated by "ceiling". Pairwise comparisons (t-tests) of the walking noise caused by neighbours (Neighbours (walking)) with all the other noise sources (Noise Annoyance (general), Neighbours (through walls), Neighbours (through ceilings), Neighbours (music, drums), Neighbours (rattling of furniture), Staircases (talking), Staircases (walking), Water Installations, Air Condition, Service Installations, Premises, Traffic, Construction Sites, Cohabitant (through walls), Cohabitant (through ceilings), Cohabitant (music, drums), Cohabitant (walking), Cohabitant (rattling of furniture)) reveal that it is always rated significantly ($p<0.05$) more annoying but for the comparison with Noise Annoyance (general). In the latter case Noise Annoyance (general) is rated significantly ($p<.01$) higher than Neighbours (walking). When comparing Cohabitant (walking) with all other noise sources it is also often rated significantly ($p<0.05$) higher, with the exception of the comparison with Noise Annoyance (general), Neighbours (through ceilings), (Neighbours (walking), Air Condition and Traffic and Construction Sites.

3.1.2.2 Acoustic Annoyance by building type

The survey data includes responses from the residents of 293 multi-family houses as compared to 62 single-family houses. Figures 13 to 15 show the results of the noise annoyance questions when separated by building type. There are obvious differences regarding the ratings of annoyance which are also confirmed by the significant result of a multivariate analysis of variance (MANOVA: $F(18, 274)=2.66$, $p>.01$, $\eta^2=.149$).

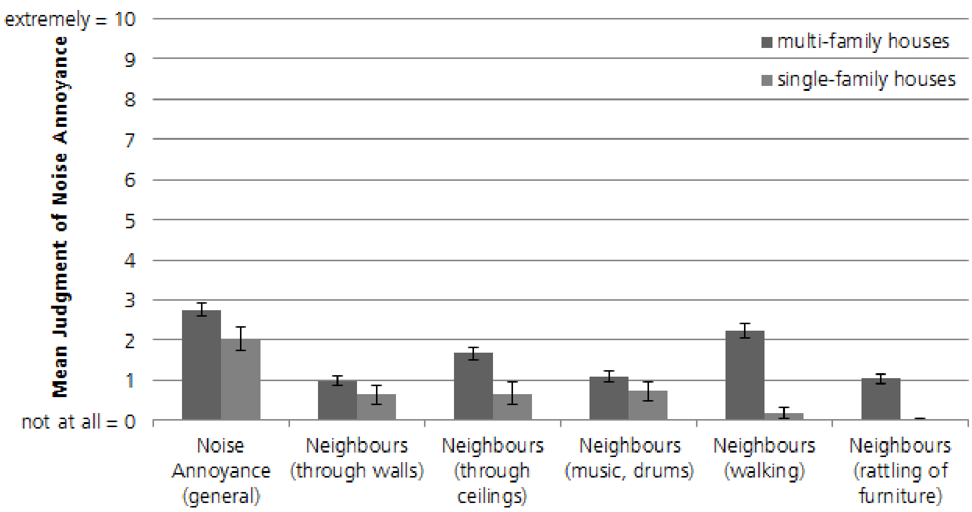

Figure 13: Judgment (mean rating) and standard errors of the perceived annoyance with regard to different noise sources in the living environment separated by building type ($n_{max}=289$; $n_{min}=49$). Judgments were given on a 11 point scale.

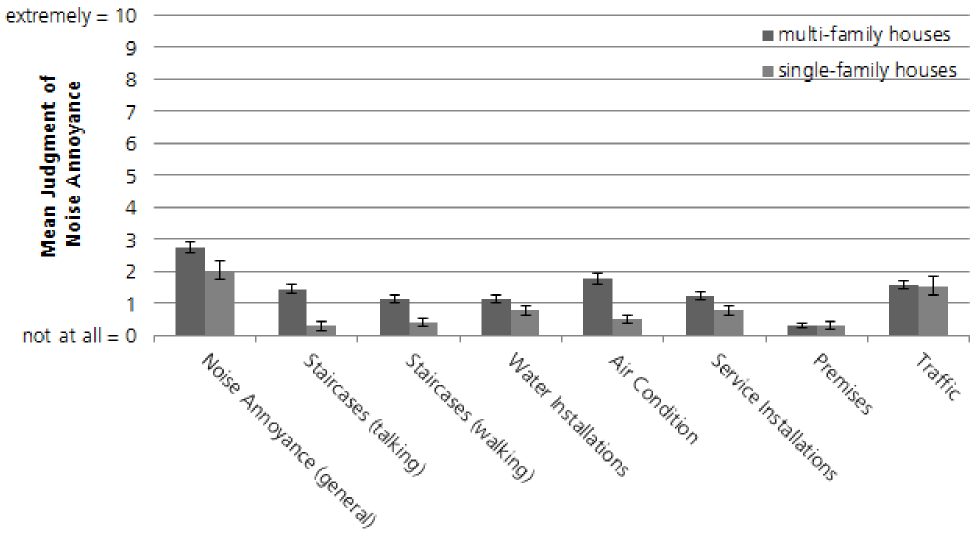

Figure 14: Judgment (mean rating) and standard errors of the perceived annoyance with regard to different noise sources in the living environment separated by building type (n_{max}=289; n_{min}=49). Judgments were given on a 11 point scale.

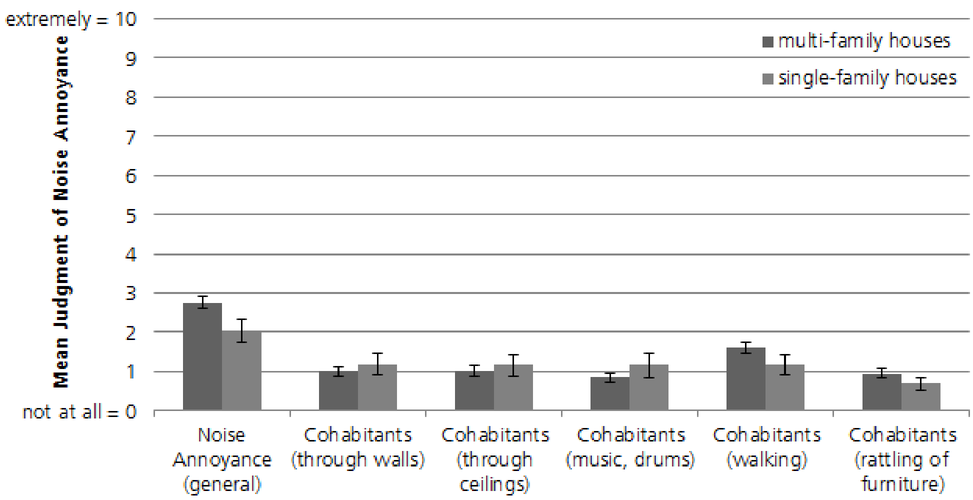

Figure 15: Judgment (mean rating) and standard errors of the perceived annoyance with regard to different noise sources in the living environment separated by building type (n_{max}=289; n_{min}=49). Judgments were given on a 11 point scale.

For the impact noise this means, that pairwise comparisons (t-tests) reveal a significant ($p<.01$) difference between the ratings in multi-family houses and single-family houses with regard to the annoyance caused by the walking of neighbours (Neighbours (walking)). But there is no significant difference with regard to the annoyance caused by the walking of cohabitants (Cohabitants (walking)). However, the first significant difference is not too much of a surprise, as there is a spatial separation between the neighbours in single-family houses but not in multi-family houses an. The walking noise caused by cohabitants is rated similarly in multi-family houses and single-family houses, even though the technical measurements revealed that the floor constructions in single family houses on average are worse than in multi-family houses. This result might be due to the fact that the noise caused by cohabitants causes lower annoyance because of the social relationship between listener and the walker. However, this assumption must be investigated

3.1.2.3 Acoustic Annoyance by floor material

The survey data also includes responses from the residents living in places where the floor is made from wood (n=276), and from concrete (n=79). Figures 16 to 18 depict the results of the noise annoyance questions when separated by floor material. This comparison is only made for multi-family houses as there is no data from single-family houses with concrete. Again there are obvious differences regarding the ratings of annoyance, which are also confirmed by the significant result of a multivariate analysis of variance (MANOVA: $F(19, 222)=2.30$, $p>.01$, $\eta^2=.165$).

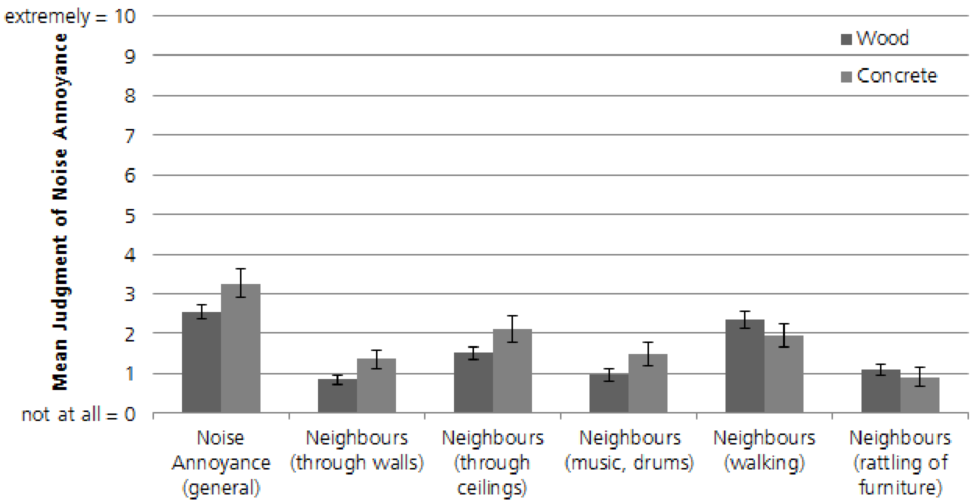

Figure 16: Judgment (mean rating) and standard errors of the perceived annoyance with regard to different noise sources in the living environment separated by floor material ($n_{max}=212$; $n_{min}=71$). Judgments were given on a 11 point scale.

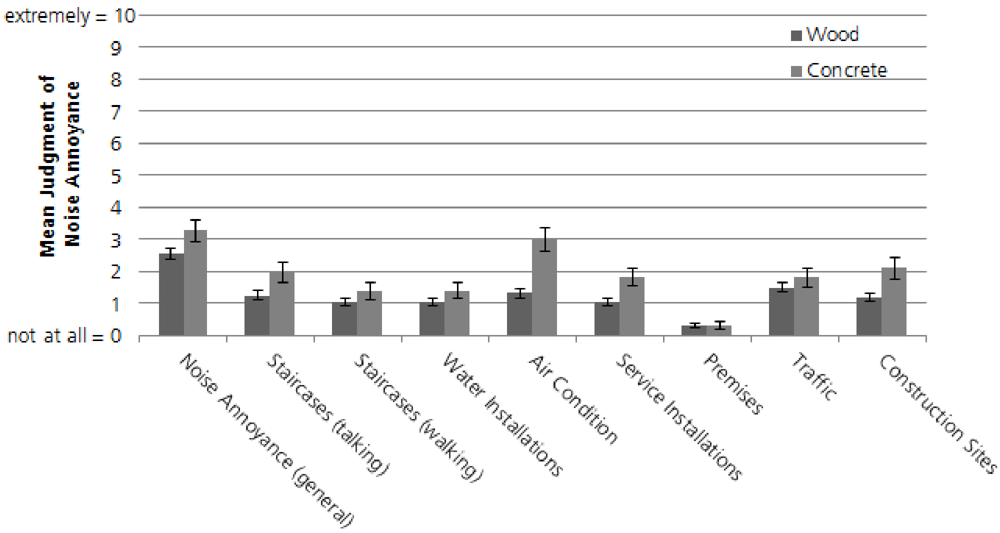

Figure 17: Judgment (mean rating) and standard errors of the perceived annoyance with regard to different noise sources in the living environment separated by floor material (n_{max}=212; n_{min}=71). Judgments were given on a 11 point scale.

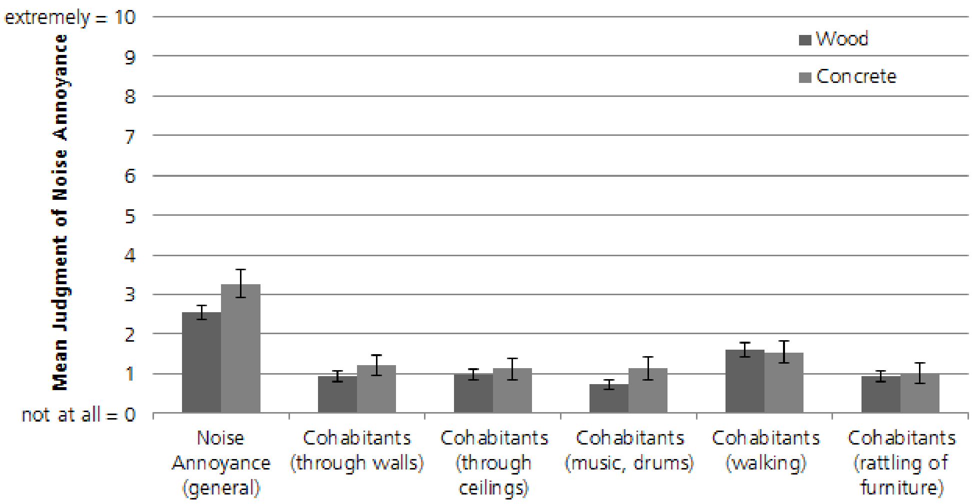

Figure 18: Judgment (mean rating) and standard errors of the perceived annoyance with regard to different noise sources in the living environment separated by floor material (n_{max}=212; n_{min}=71). Judgments were given on a 11 point scale.

Pairwise comparisons (t-tests) between floors made from wood and concrete with regard to the annoyance caused by the walking of neighbours (Neighbours (walking)) and the walking of co-habitants (Cohabitants (walking)) reveal that there is no significant difference ($p>.05$). This is surprising because one of the basic assumptions in this investigation was, that impact noise caused by walking is more of a problem, if the floor is made from wood. However, it must be emphasized that this result is limited to this sample of residents and buildings. Additionally the wooden floors comprise wood-concrete composite floors, which might also be categorized as concrete floors. If the wood-concrete composite floors are excluded, then wooden floors are rated significantly ($p<.05$) worse with regard to the annoyance caused by walking of neighbours (Neighbours (walking)) but not with regard to the walking of cohabitants (Cohabitants (walking)). Figures 19 to 21 depict the ratings after the exclusion of the wood-concrete composite floors.

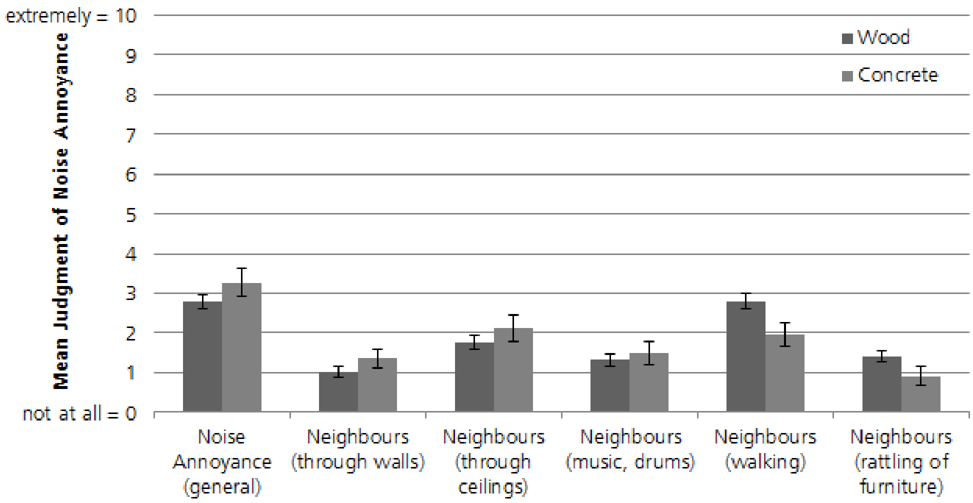

Figure 19: Judgment (mean rating) and standard errors of the perceived annoyance with regard to different noise sources in the living environment separated by floor material (n_{max}=137; n_{min}=78). Judgments were given on a 11 point scale.

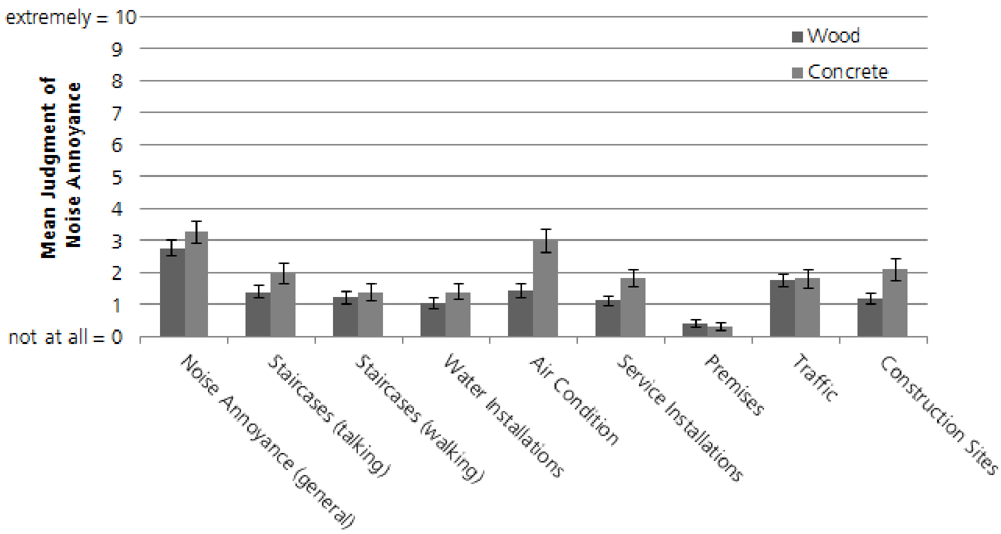

Figure 20: Judgment (mean rating) and standard errors of the perceived annoyance with regard to different noise sources in the living environment separated by floor material (n_{max}=137; n_{min}=78). Judgments were given on a 11 point scale.

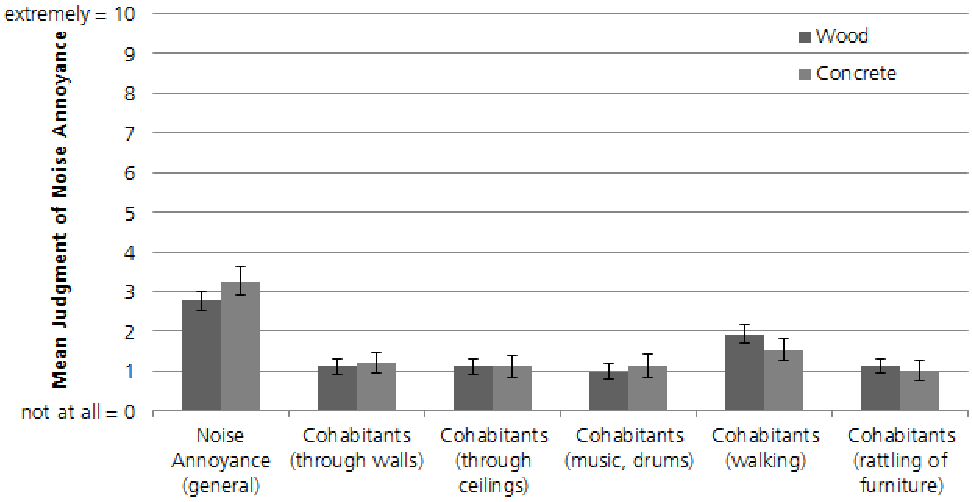

Figure 21: Judgment (mean rating) and standard errors of the perceived annoyance with regard to different noise sources in the living environment separated by floor material (n_{max}=137; n_{min}=78). Judgments were given on a 11 point scale.

3.1.2.4 Acoustic Annoyance by wooden floor construction

The survey data also includes responses from the residents living in multi-family houses with different wooden floor constructions. However, the total number of responses from residents sharing a comparable floor construction can be quite low. Therefore the analysis is restricted to constructions, which have been judged at least 15 times. Figures 22 to 24 depict the results of the noise annoyance questions when separated by different wooden floor construction. This comparison again is only made for multi-family houses as there is no data from single-family houses. Again there are obvious differences regarding the ratings of annoyance, which are also confirmed by the significant result of a multivariate analysis of variance (MANOVA: $F(72, 500)=2.02$, $p>.01$, $\eta^2=.225$).

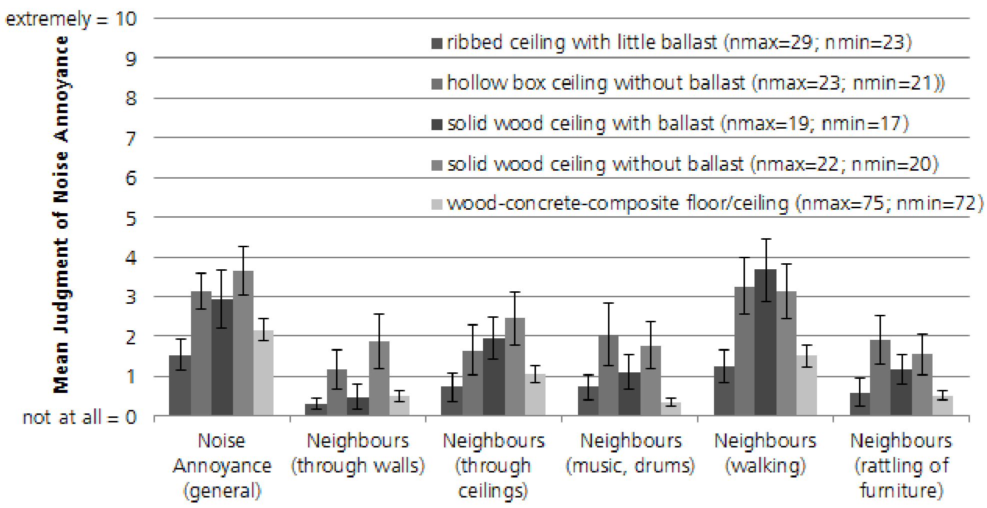

Figure 22: Judgment (mean rating) and standard errors of the perceived annoyance with regard to different noise sources in the living environment separated by floor construction (n_{max}=76; n_{min}=17). Judgments were given on a 11 point scale.

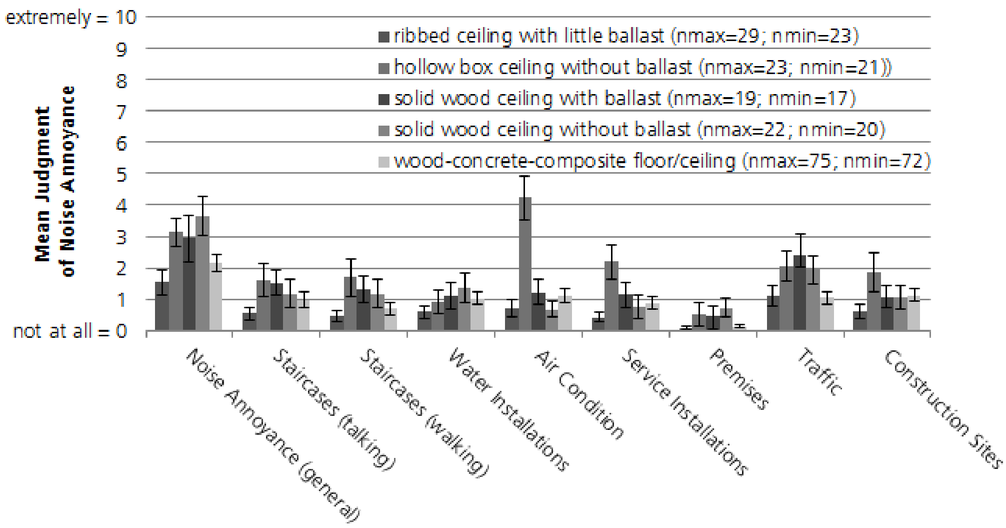

Figure 23: Judgment (mean rating) and standard errors of the perceived annoyance with regard to different noise sources in the living environment separated by floor construction (n_{max}=76; n_{min}=17). Judgments were given on a 11 point scale.

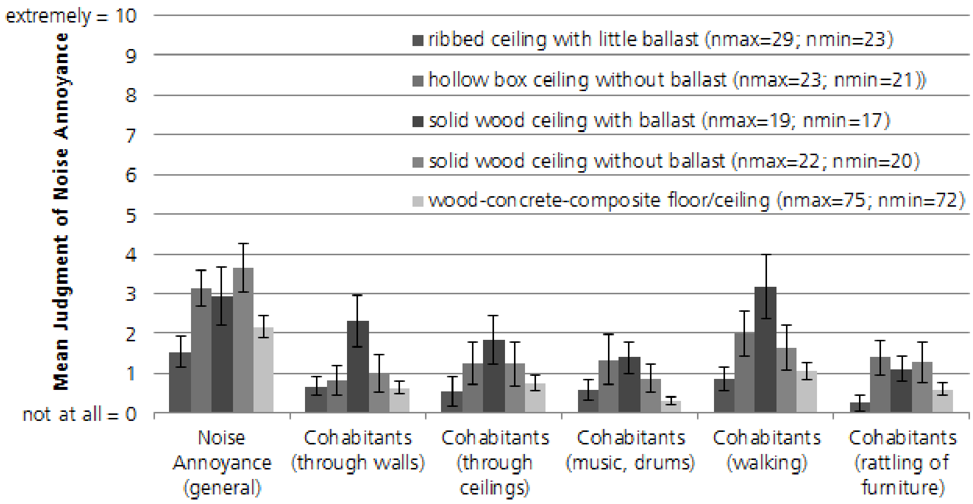

Figure 24: Judgment (mean rating) and standard errors of the perceived annoyance with regard to different noise sources in the living environment separated by floor construction (n_{max}=76; n_{min}=17). Judgments were given on a 11 point scale.

Two analyses of variances (ANOVAs) are calculated for impact noise caused by the walking of neighbours (Neighbours (walking)) and by the walking of cohabitants (Cohabitants (walking)) in order to find out, whether the different floor constructions are perceived significantly different. In both cases the ANOVAs reveal significant effects ($ANOVA_{Neighbours(walking)}$: $F(5, 184)=3.73$, $p>.01$, $\eta^2=.092$; $ANOVA_{Cohabitants(walking)}$: $F(5, 184)=3.33$, $p>.01$, $\eta^2=.083$). In order to find out which floor constructions are perceived differently, pairwise comparisons (t-tests) between the different floor constructions are calculated for the noise caused by walking neighbours and for walking cohabitants. For the walking noise caused by neighbours (Neighbours (walking)) it is to conclude, that the ribbed floor/ceiling with little ballast and the wood-concrete-composite floor/ceiling perform significantly ($p<0.5$) better than the hollow box floor/ceiling without ballast, the solid wood floor/ceiling with ballast and the solid wood floor/ceiling without ballast, but the ribbed floor/ceiling with little ballast and the wood-concrete-composite ceiling do not differ from each other. For the walking noise caused by cohabitants (Cohabitants (walking)) almost the same findings apply. However, the solid wood floor/ceiling without ballast is judged a little bit better and thus does not significantly differ from the ribbed floor/ceiling with ballast and the wood-concrete-composite floor/ceiling.

From table 1 it can be seen that the former results match with the technical measurements. The single-number value of $L_{n,w+}C_{I,50-2500}$ is also best for the wood-concrete composite floor and the ribbed floor/ceiling with ballast.

Table 1: Measured $L_{n,w}+C_{I,50-2500}$ for the different floor constructions at different buildings, which were involved in the questionnaire-based field survey

Floor Construction	**Location**	**$L_{n,w}+C_{I,50-2500}$**
hollow box floor with ballast	Bern small room	58.7
	Bern big room	55.7
wood-concrete composite floor	Zürich small room	46.7
	Zürich big room	48.3
solid wood floor without ballast	Küssnacht smalll room	55.8
	Küssnacht big room	55.0
ribbed floor with ballast	Winterthur small room	51.2
	Winterthur big room	50.3

3.1.2.5 Moderating variables of Acoustic Annoyance

It is known that only one third of the variance of acoustic annoyance reactions can be explained by the variance of acoustical features, whereas another third is explained by the variance of personal or social variables [11]. This is important to keep in mind, since costly and difficult technical measures may be accompanied by a psychological approach to the problem. For that reason the effect of some potential influencing variables is screened in this analysis. These variables include self-estimated noise sensitivity, ownership and attitude towards building with wood. These variables are included in an analysis of variance. Noise sensitivity is treated as a covariate and ownership as well as attitude towards building with wood (deliberate decision for wooden house) are treated as independent variables. The dependent variable is the judgement with regard to general noise annoyance. The analysis of variance reveals a significant effect of noise sensitivity (ANOVA: $F(1, 212)=11.01$, $p>.01$, $\eta^2=.049$). The analysis also reveals a tendency towards an effect of ownership (ANOVA: $F(1, 212)=2.96$, $p=.09$, $\eta^2=.014$) and a significant effect of the attitude towards building with wood (ANOVA: $F(1, 212)=19.14$, $p>.01$, $\eta^2=.083$). The interaction of the latter two variables is not significant. The meaning of these results is illustrated in figures 25, 26 and 27.

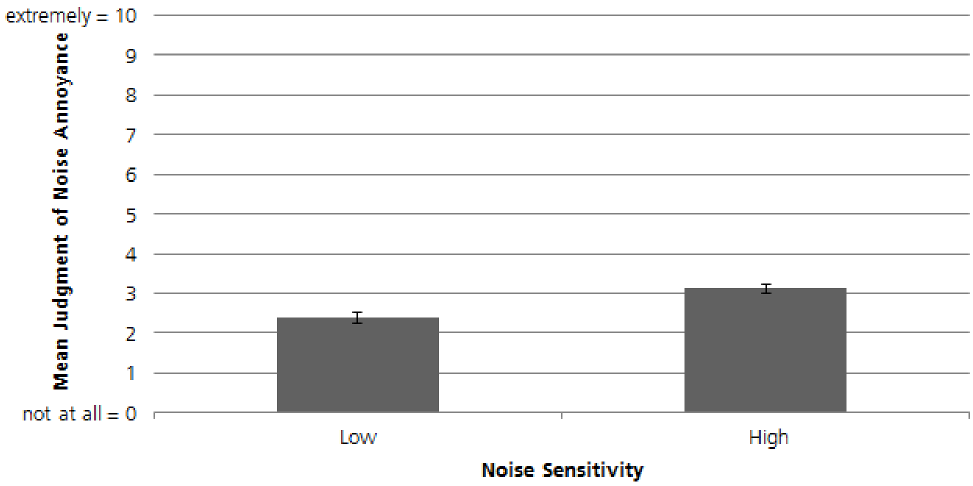

Figure 25: Judgment (mean rating) and standard errors of the perceived general noise annoyance depending on the noise sensitivity. The Low and High noise sensitivity groups are determined by a median split. Judgments were given on a 11 point scale.

A positive correlation (r=.236; p>01) between the rating of the individual noise sensitivity and the general noise annoyance ratings exists. Figure 25 reveals that the same sounds are rated more than half a scale unit higher depending on either belonging to the High or Low noise sensitivity group.

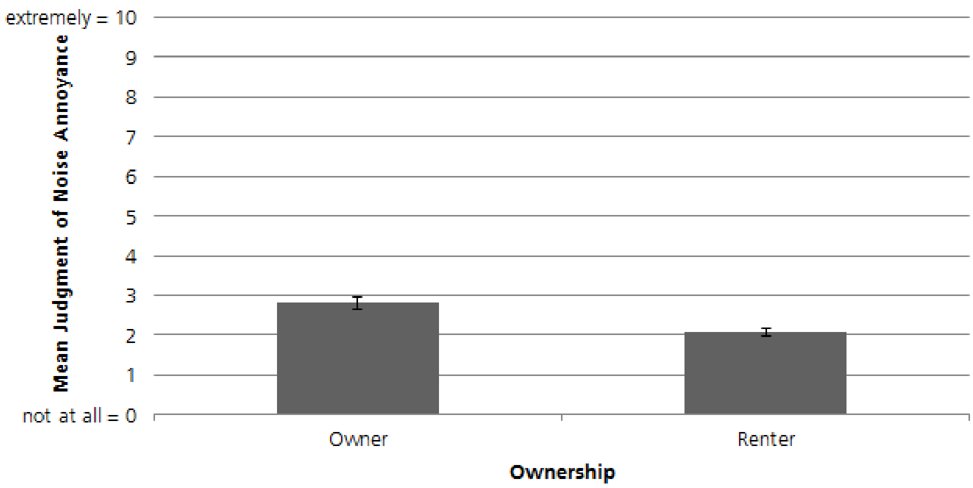

Figure 26: Judgment (mean rating) and standard errors of the perceived general noise annoyance depending on ownership. Judgments were given on a 11 point scale.

Figure 26 depicts that owners of an object gave higher ratings of general noise annoyance that renters of an object.

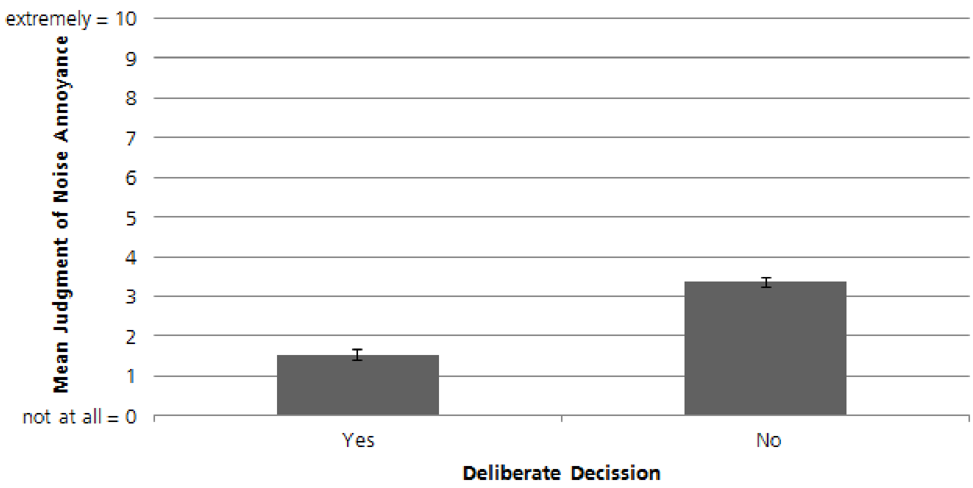

Figure 27: Judgment (mean rating) and standard errors of the perceived general noise annoyance depending on the attitude towards building with wood (deliberate decision for wooden building). Judgments were given on a 11 point scale.

Figure 27 depicts that those residents who have a positive attitude towards building with wood, which in this case is operationalized by the deliberate decision in favour of a wooden building, generally give much lower ratings of general annoyance as compared to those residents who did not deliberately decide in favour of a wooden building. It must be emphasized that there is no correlation between noise sensitivity and the annoyance ratings of the walking noise caused by neighbours and also no effect of ownership on the annoyance caused by the walking of neighbours but there is a significant effect of the attitude towards building with wood (deliberate decision in favour of a wooden building). These results show, that besides technical measures, like the type of floor construction, psychological variables determine the subjective evaluation of sound. Technical measures for noise abatement might be combined with psychological measures like information (campaigns), generating a positive or negative attitude towards building with wood.

3.2 Listening Test

The correlations between subjective and objective parameters of impact noise are described in [12]. There it is shown that the most appropriate technical source to represent walking noise is the Japanese rubber ball. The most appropriate tested single number rating for the ball is $L'_{nT,A,F,max,20\text{-}2500}$, with a determination coefficient of $R^2 = 0.75$. The determination coefficient for single number ratings based on the standardized tapping machine even in the best case ($L'_{nT,Hagberg,new,03}$) is lower ($R^2 = 0.63$). This additional analysis of the listening test data on the one hand focuses on the question whether the different noise sources, floor constructions and floor coverings are perceived differently. This knowledge is necessary, since costly technical improvements would be superfluous if they would not result in a noticeable difference of the acoustic perceptive impression. On the other hand the relationship between the short-term subjective impression during the laboratory listening test and the long-term acoustic satisfaction of inhabitants in the field study is investigated. Figures 28 to 30 depict the results of the listening tests.

3.2.1 Influence of the floor construction

A repeated measures ANOVA reveals a significant main effect ($F(2, 32)=506.56$, $p<.01$, $\eta^2=.969$) of the factor floor construction (wooden floor vs. wooden floor with suspended ceiling vs. concrete floor). Pairwise comparisons (t-tests) show that significant differences are perceived between all of the floor constructions ($p<.05$).

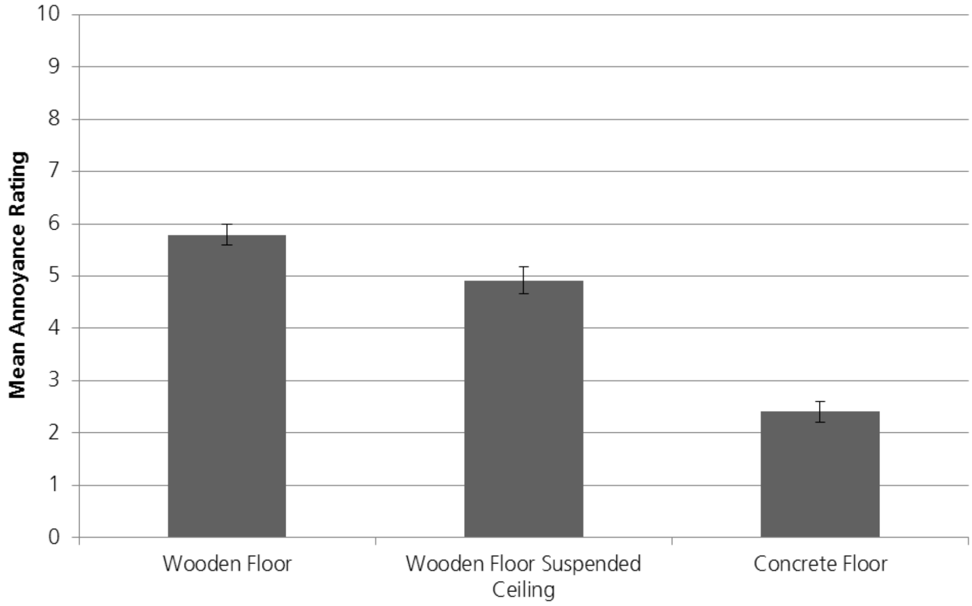

Figure 28: Mean ratings of annoyance and standard errors depending on the type of floor construction (results of listening test I)

From this result it is to conclude that floors made from concrete perform best with regard to perceived annoyance. This does not match the results from the questionnaire based field survey., where floors made from wood and floors made from concrete did not significantly differ with regard to perceived annoyance caused by walking of neighbours. However, it must be emphasized that the result depicted in figure 28 applies to listening test I, where only laboratory floor constructions and one filed recording were included. The floor construction that were judged by the residents in the questionnaire based field survey perform much better than the wooden beam floors build and investigated in listening test I.

3.2.2 Influence of the floor covering

The repeated measures ANOVA also shows a significant main effect ($F(4, 64)=73.55$, $p<.01$, $\eta^2=.821$) of the factor floor covering (bare floor vs. floor with floating floor vs. floor with floating floor and tiles vs. floor with floating floor and laminate vs. floor with floating floor and parquet vs. floor with floating floor and carpet). Pairwise comparisons (t-tests) show that the significant differences are perceived between all of the floor coverings ($p<.05$) except between tiles and parquet.

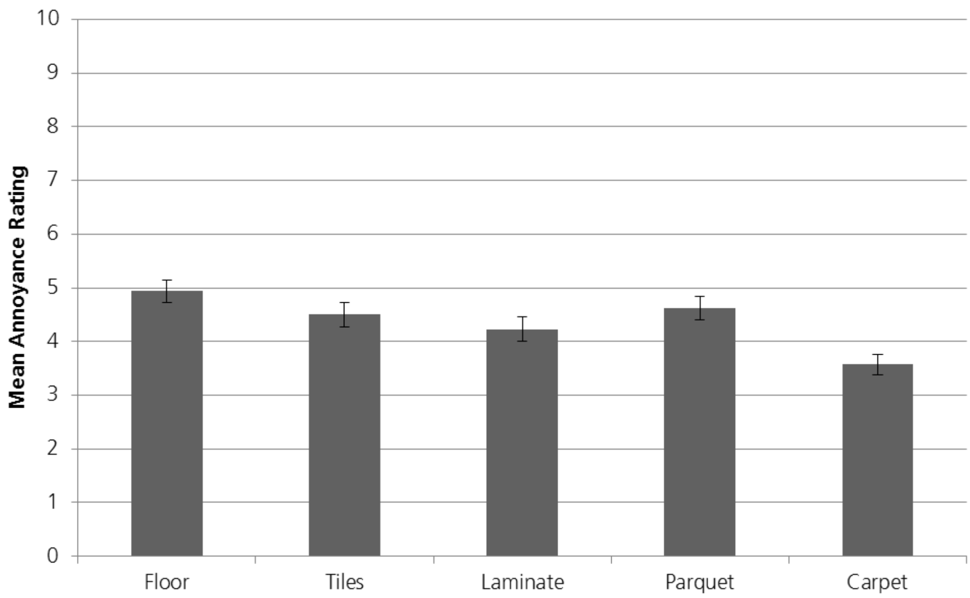

Figure 29:Mean ratings of annoyance and standard errors depending on the type of floor covering (results of listening test I)

The results shown in figure 29 reveal that covering the floor with a carpet is the best way to significantly reduce the annoyance caused by the walking of a person but the differences are little in quantity.

3.2.3 Influence of the noise source

The main effect of the factor noise source is also significant ($F(3.10, 49.65)=125.93$, $p<.01$, $\eta 2=.887$). Pairwise comparisons (t-tests) show that the significant differences are perceived between all of the noise sources ($p<.05$) except for the modified tapping machine and the female walker. This argues for the representativeness of the modified tapping machine.

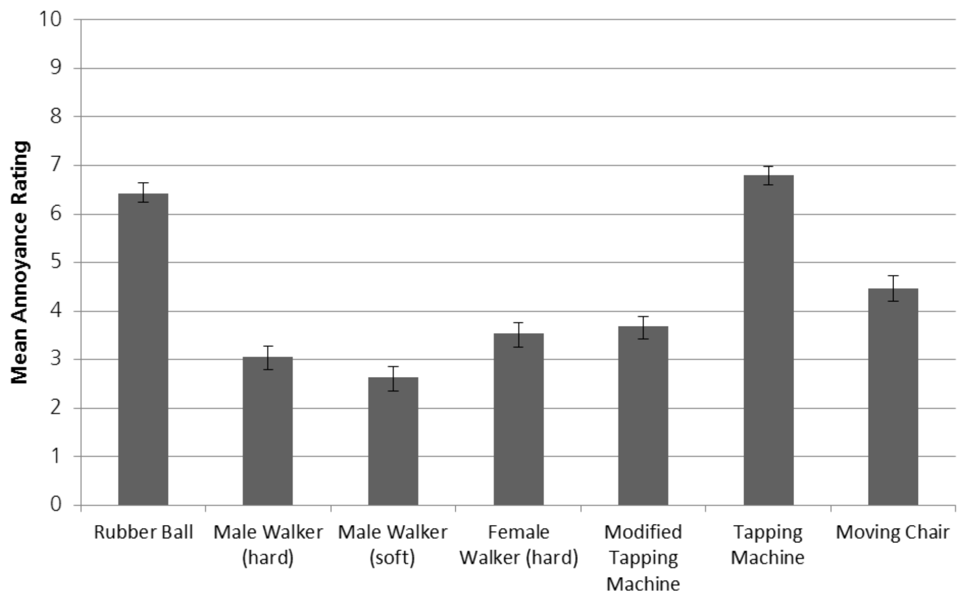

Figure 30: Mean ratings of annoyance and standard errors depending on the type of noise source (results of listening test I)

All interaction effects between the three factors (floor construction, floor covering, noise source) are also significant but for reasons of complexity these interactions are not discussed here.

3.3 Comparison of the field survey and the listening test

Last but not least the question is raised whether the long-term acoustic satisfaction of inhabitants differs from the short-term subjective impression during the laboratory listening test. Therefore the results from the listening test are contrasted to the results from the field survey. For two buildings in Winterthur and Zürich both data sets exist. Since the same 11 point rating scale was used in the listening test and the field survey, the results can be directly compared. Figure 31 contrasts the annoyance ratings from the residents from the two buildings to the annoyance ratings given by the test persons during the laboratory listening test, when judging the recordings from these two buildings.

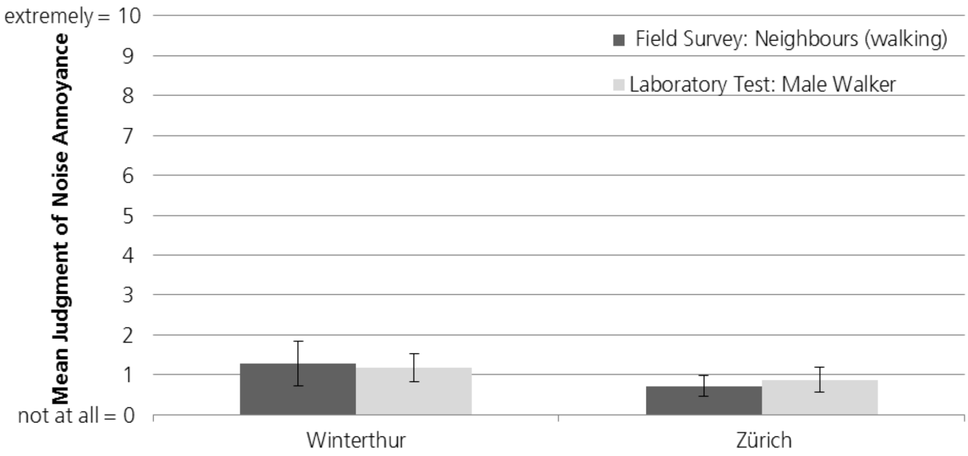

Figure 31: Mean ratings of annoyance and standard errors with regard to perceived annoyance due to walking of neighbours in the field survey compared to perceived annoyance due to male walking in the laboratory listening test

An ANOVA reveals no significant main effect ($F(1, 86)=1.56$, $p>.05$, $\eta 2=.018$) of the factor place (Winterthur vs. Zürich) and no significant main effect ($F(1, 86)<1$) of the factor setting (field survey vs. laboratory test). It must be emphasized that the latter insignificant results proves that the listening test in the laboratory give the same results as the questionnaire in the field. The interaction between both factors also is not significant ($F(1, 86)<1$). This means that in the field as well as in the laboratory the walking noise in Winterthur and Zürich are not considered significant different. Additionally there is no significant difference with regard to the ratings of annoyance in the field and laboratory even so the long-term acoustic satisfaction of inhabitants is contrasted to the short-term subjective impression during the laboratory listening tests.

Table 1 depicts $L_{n,w}+C_{I,50\text{-}2500}$ for Winterthur and Zürich which are also very close, thus it is not surprising, not to find significant differences with regard to the ratings of annoyance. However, the ranking in both cases match. Winterthur is performing a little bit better as compared to Zürich. It would be very insightful to have laboratory data and field data from buildings with greater differences with regard to $L_{n,w}+C_{I,50\text{-}2500}$.

Table 2: Measured $L_{n,w}+C_{I,50-2500}$ for the different floor constructions at different buildings, which were involved in the questionnaire-based field survey and laboratory listening test.

Floor Construction	Location	$L_{n,w}+C_{I,50-2500}$
hollow box with ballast	Zürich small room	46,7
	Zürich big room	48,3
wood-concrete composite	Winterthur small room	51,2
	Winterthur big room	50,3

4 Conclusions

It can be concluded that even so the general satisfaction with the living environment is rated quite positively there is some complaint about noise annoyance. The field survey revealed that the noise source which is mostly complained about in apartment houses is the noise caused by walking neighbours. This is a clear hint towards the need for improvement of impact noise in apartment houses. But this applies to both, constructions of wood and concrete.

The results of the listening test are, that clear differences are perceived between the different floor constructions in the laboratory. The concrete floor performs best, the wooden floor performs worst. The carpet is the best floor covering with regard to perceived annoyance but the differences to the other floor coverings are small. The tapping machine gives the highest annoyance rating, the male walker with socks the lowest. The modified tapping machine gave similar ratings then the male walker with hard footwear.

The analysis also revealed that the long-term acoustic satisfaction of inhabitants corresponds to the short-term subjective impression during the laboratory listening test. Thus the results from the listening test can be transferred to the situation in the field.

5 Literature

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Appendix 1: Questionnaire used in the web-based questionnaire survey

Introduction

Dear participant,

thank you very much for taking the time to fill in this questionnaire on the topic "The Quality of Timber Houses". In the context of a research project we are investigating the quality of timber houses in Switzerland and Germany. Your answers contribute to define the requirements, wishes and needs of users. In addition, you support us in defining adequate requirements for timber houses in the future and thus to increase the quality of these buildings.
It will not take more than 15 minutes to answer the questions. Your answers will be treated confidentially. The results and your personal data will only be used for this research work and will not be used for any other purpose.
If you have any questions or if you need help in filling in the questionnaire please contact:

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Questionnaire

Is the place being judged a dwelling or workplace? Please choose an answer and press "submit", you will be forwarded to the corresponding questionnaire.
Please choose only one of the following:

- o dwelling
- o workplace

Please click the 'Next' button in order to start the evaluation of your dwelling.

In a first step please describe your residential environment.

1 Are you owner or renter?
Please choose only one of the following:

- o owner
- o renter
- o Other:

2 The object to be assessed is a ...
Please choose all that apply:

- ☐ office / commercial building
- ☐ single family house
- ☐ single family house with accessory apartment
- ☐ accessory apartment in a single family house

- ☐ single family row house
- ☐ apartment house
- ☐ Other:

3 The object to be assessed is a timber house?
Please choose only one of the following:

- o Yes
- o No
- o I don’t know

If 3 = „yes“:
4 Did you deliberately decide for a timber house?
Please choose only one of the following:

- o Yes
- o No

If 4 = „yes“:
5 Why did you decide in favor of a timber house?
Please write your answer here:

if 3 = „no“:
6 Did you deliberately decide against a timber house?
Please choose only one of the following:

- o Yes
- o No

if 6 = „yes“:
7 Why did you decide against a timber house?
Please write your answer here:

8 In what kind of surroundings is the object located?
Please choose only one of the following:

- o rural
- o in the outskirts
- o center of a small town
- o city center
- o Other:

if 2 = “accessory apartment in a single family house”, “office / commercial building” or “apartment house”:
9 Is the object an attic story apartment?
Please choose only one of the following:

- o Yes
- o No

If 9 = “no”:

10 In which story is the apartment located?

Please choose only one of the following:

- o basement
- o ground floor
- o first floor
- o second floor
- o third floor
- o fourth floor
- o fifth floor
- o higher than fifth floor

If 9 = “yes”:

11 In which story is the apartment located?

Please choose only one of the following:

- o first floor
- o second floor
- o third floor
- o fourth floor
- o fifth floor
- o higher than fifth floor

if 2 = “single family house“ or “accessory apartment in a single family house”

12 How many apartments are on your floor?

Please write your answer here:

13 Give the number of rooms.

Please write your answer here:

14 Are you satisfied with the floor plan and layout?

Please choose only one of the following:

- o Yes
- o No

In a second step we ask you to give various aspects of your residential environment a rating according to importance and to assess them according to your satisfaction.

15 How satisfied are you ...

Please choose the appropriate response for each item:

	not at all	little	fairly well	pretty well	extremely well
with your living situation, i.e. with your	○	○	○	○	○

	not at all	little	fairly well	pretty well	extremely well
apartment, the neighbourhood, the living environment and location?					

16 Please rate the following aspects according to importance. The aspect with the highest importance must be given rank 1.
Please number each box in order of preference from 1 to 11

- ☐ air quality (e.g. odors, humidity, mold …)
- ☐ environmental friendliness, health protection (e.g. electro-magnetic pollution, recycling, no harmful substances …)
- ☐ protection against vibration (e.g. vibrations, oscillations ...)
- ☐ thermal comfort (e.g. ambient temperature, heat, cold …)
- ☐ fire protection (e.g. smoke detectors, escape ways …)
- ☐ acoustics (e.g. traffic noise, noise from neighbourhood, noise from sanitary equipment)
- ☐ visual comfort (e.g. size of windows, brightness, glaring …)
- ☐ control, feedback (e.g. controllability, thermostat, thermometer …)
- ☐ energy demand, costs for users (e.g. heating, thermal insulation, …)
- ☐ floor plan (e.g. solutions to arrange furniture, size, layout …)
- ☐ barrier-free accessibility (e.g. thresholds, stairs, elevator …)

17 How satisfied are you with ...
Please choose the appropriate response for each item:

	not at all	little	fairly well	pretty well	extremely well	do not know
thermal comfort (e.g. ambient temperature, heat, cold …)	○	○	○	○	○	○
energy demand, costs for users (e.g. heating, thermal insulation, …)	○	○	○	○	○	○
visual comfort (e.g. size of windows, brightness, glaring …)	○	○	○	○	○	○
air quality (e.g. odors, humidity, mold …)	○	○	○	○	○	○
acoustics (e.g. traffic noise, noise from neighborhood, noise from sanitary equipment …)	○	○	○	○	○	○

protection against vibration (e.g. vibrations, oscillations ...)	○	○	○	○	○	○
barrier-free accessibility (e.g. thresholds, stairs, elevator …)	○	○	○	○	○	○
environmental friendliness, health protection (e.g. electromagnetic pollution, recycling, no harmful substances …)	○	○	○	○	○	○
fire protection (e.g. smoke detectors, escape ways …)	○	○	○	○	○	○
floor plan (e.g. solutions to arrange furniture, size, layout …)	○	○	○	○	○	○
control, feedback (e.g. controllability, thermostat, thermometer …)	○	○	○	○	○	○

18 Which residents would you like to have as neighbours?
Please choose all that apply:

- ☐ family with children
- ☐ couple without children
- ☐ retired persons
- ☐ singles
- ☐ students/trainees
- ☐ Other:

19 Are there any factors in your residential environment, which are so annoying that you consider to move, if they persist (e.g. rent is too high, additional charges are too high, noise pollution ...)?
Please write your answer here:

20 If you had three free wishes to improve your living situation, what would be your most important wish?
Please write your answer(s) here:
first wish:
second wish:
third wish:

21 Are there any direct sources of noise pollution in your residential environment? Please mark the appropriate items.

Please choose all that apply:

- ☐ gastronomical firm (during the day)
- ☐ gastronomical firm (at night)
- ☐ recreational facility (during the day)
- ☐ recreational facility (at night)
- ☐ industrial plant
- ☐ transmitting station, transformer station
- ☐ intense road traffic
- ☐ rail traffic
- ☐ playground
- ☐ school/nursery
- ☐ air traffic
- ☐ construction site
- ☐ there is no source of noise pollution
- ☐ Other:

Thinking about the last 12 months, what number from 0 to 10 shows best how much you are bothered, disturbed or annoyed by these sources of noise? If you hear the noise but 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 hear anything at all, the source does not exist or if you cannot answer choose "I don't know".

22 Thinking about the last 12 months, how much are you bothered, disturbed or annoyed by...

Please choose the appropriate response for each item:

	not at all 0	1	2	3	4	5	6	7	8	9	extre-mely 10	I don't know/ no source of noise
noise in general e.g. from traffic, construction site, people talking, music, footstep noise, technical installations etcetera	○	○	○	○	○	○	○	○	○	○	○	○

23 Thinking about the last 12 months in your home, how much are you bothered, disturbed or annoyed by these sources of noise?

Please choose the appropriate response for each item:

	not at all 0	1	2	3	4	5	6	7	8	9	extre-mely 10	I don't know/ no source of noise

neighbours, daily living, e.g. people talking, audio, TV through the walls	○	○	○	○	○	○	○	○	○	○	○	○
neighbours; daily living, e.g. people talking, audio, TV through the floors/ceilings	○	○	○	○	○	○	○	○	○	○	○	○
neighbours; music with bass and drums	○	○	○	○	○	○	○	○	○	○	○	○
neighbours; footstep noise, i.e. you hear when they walk on the floor	○	○	○	○	○	○	○	○	○	○	○	○
neighbours; rattling and tinkling noise from your own furniture when neighbours move on the floor above you	○	○	○	○	○	○	○	○	○	○	○	○
staircases, access balconies etc; people talking, doors being closed	○	○	○	○	○	○	○	○	○	○	○	○
staircases, access balconies etc.; footsteps or other impact sounds	○	○	○	○	○	○	○	○	○	○	○	○
water installations; plumbing, using or flushing WC, shower	○	○	○	○	○	○	○	○	○	○	○	○
climate installations; heaters, air condition, air	○	○	○	○	○	○	○	○	○	○	○	○

terminal devices												
service installations; elevators, laundry machinery, ventilation machinery	○	○	○	○	○	○	○	○	○	○	○	○
premises; garages, shops, offices, pubs, restaurants, laundry rooms or other, heard indoors with windows closed	○	○	○	○	○	○	○	○	○	○	○	○
traffic (cars, buses, trucks, trains or aircraft); heard indoors with windows closed	○	○	○	○	○	○	○	○	○	○	○	○
construction site; heard indoors with windows closed	○	○	○	○	○	○	○	○	○	○	○	○
cohabitants; daily living, e.g. people talking, audio, TV through the walls	○	○	○	○	○	○	○	○	○	○	○	○
habitants; daily living, e.g. people talking, audio, TV through the floors/ceilings	○	○	○	○	○	○	○	○	○	○	○	○
co cohabitants; music with bass and drums	○	○	○	○	○	○	○	○	○	○	○	○
cohabitants; footstep noise, i.e. you hear when they walk on the floor	○	○	○	○	○	○	○	○	○	○	○	○

cohabitants; rattling or tinkling noise from your own furniture, if cohabitants move	○	○	○	○	○	○	○	○	○	○	○	○

24 Before moving to the apartment, how important was the sound insulation to you, with respect to ...
Please choose the appropriate response for each item:

	not at all 0	1	2	3	4	5	6	7	8	9	extremely 10	I don't know/ no source of noise
noise in general e.g. from traffic, construction site, people talking, music, footstep noise, technical installations etcetera	○	○	○	○	○	○	○	○	○	○	○	○

25 How sensitive are you to ...
Please choose the appropriate response for each item:

	not at all 0	1	2	3	4	5	6	7	8	9	extremely 10	I don't know/ no source of noise
noise in general e.g. from traffic, construction site, people talking, music, footstep noise, technical installations etcetera	○	○	○	○	○	○	○	○	○	○	○	○

Finally we ask you to give us some statistical data. These data will also be treated confidentially.

26 How do you describe your housing condition?
Please choose only one of the following:

- ☐ single
- ☐ single with child/children
- ☐ apartment sharing community
- ☐ couple/partners

- ☐ family with child/children
- ☐ assisted living
- ☐ Other

27 You are ...
Please choose only one of the following:
- o female
- o male

28 Year of birth?
Please write your answer here:

29 Working schedule
Please choose only one of the following:
- o day
- o night
- o mixed
- o not applicable

30 You have been living in this building since ... (year)?
Please write your answer here:

31 Do you know the year of construction of the building?
Please choose only one of the following:
- o Yes
- o No

If 31 = "yes":
32 When was the building constructed?
Please write your answer here:

33 Do you know the name of the builder/designer of this building?
Please choose only one of the following:
- o Yes
- o No

If 33 = "yes":
34 What is the name of the builder/designer?
Please choose all that apply and provide a comment:
- o builder
- o architect
- o timber construction
- o Other:

35 How many persons live in your household permanently?
Please write your answer here:

36 How many children under 18 are among the persons living in your household?
Please write your answer here:

37 You are ...
Please choose only one of the following:

- o working
- o housewife/househusband
- o pupil/student
- o non-working
- o Other

38 Do you know the housing conditions of your neighbours?
Please choose only one of the following:

- o Yes
- o No

If 38 = "yes":
39 How do you describe the housing conditions of your neighbours?
Please choose only one of the following:

- o single
- o single with child/children
- o apartment sharing community
- o couple/partners
- o family with child/children
- o assisted living

40 Please give the address of the building. We need this information to assign your ratings to a specific object.
Please write your answer(s) here:
Country:
City:
Postal code:
Address:

41 We would very much appreciate, if we were allowed to contact you in continuation to our investigation. For this purpose we need your complete name and contact details. You are free to give us this information. We assure you that your data are only used for this research project and will not be passed to third parties.
Please write your answer(s) here:
First name:
Surname:
Telephone:

Email:

Thank you very much for your cooperation!

Appendix 2: Procedure of the listening test

The listening test started with some questions addressing personal data. These included name, age, gender, diagnosed or perceived auditory defects, visual acuity, educational achievement and current occupation. Then the scope and procedure of the listening test was introduced to the subjects with the following wording:

In the following different impact sounds will be presented. Impact sound is the sound that is heard within a room but is caused by a walking person in a room above. Impact sound spreads through walls, floors and the air. It is your task to judge the different sounds with regard to perceived annoyance and perceived loudness. You are also considered to give a rating of your individual noise sensitivity. You are supposed to practise the use of the rating scales by means of two examples. These example sounds include a very soft and a loud sound so that you get an impression of the spread between the loudest and the softest sound within this listening test. Some sounds are very soft, so that it is completely possible that they are inaudible to you.

This introduction was followed by a general noise sensitivity question:

How sensitive are you to noise in general e.g. from neighbours, technical installations etcetera?

Not at all sensitive										Extremely sensitive
0	1	2	3	4	5	6	7	8	9	10
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

The noise sensitivity question was followed by the first sound example and rating scales. The ratings scales included both an annoyance and a loudness rating. The loudness rating consists of a cross verbal rating followed by a numerical fine-tuning:

Now start the playback of the first sound example by means of the player and give your ratings. You can also repeat the playback until you find a rating.

Please think about, what number from zero to ten best shows how much you are bothered, disturbed, or annoyed by the sound? If you are not at all annoyed choose zero, if you are extremely annoyed choose ten, if you are somewhere in between choose a number between zero and ten.

How much are you bothered, disturbed, or annoyed by the sound?

Not at all										Extremely
0	1	2	3	4	5	6	7	8	9	10
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

How loud is the sound? First assign the sound to one of the verbal categories of the scale (from “not heard” to “too loud”. As a second step you are supposed to apply a more precise rating. Therefore a numerical rating scale is presented which enables you to give ratings from 0 to 50.

The verbal labels of the rating categories are also shown. If, for example, you consider the sound to be "very soft" then you are supposed to give a more precise numerical rating whether your judgment tends towards "not heard" or "soft".
Please choose one of the following options.

not heard – very soft – soft – medium – loud – very loud – too loud

	1	2	3	4	5	6	7	8	9	10	
not heard	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	soft

Imagine you are at home and you would hear the just presented sound while you are reading a newspaper, journal or book. Would the sound bother, disturb, or annoy you?

yes	no
☐	☐

The first sound example was followed by the second sound example and rating scales:

Now start the playback of the second sound example by means of the player and give your ratings. You can also repeat the playback until you find a rating.

The second sound example was followed by some more information on the duration and processing of the listening test. Each sound was then judged with both the annoyance and loudness rating scales:

In total x sounds shall be judged. There will be a short break after 25 sounds respectively. You may also take breaks during the processing of the listening test autonomously but please work as fast and accurate as possible. The total processing time of the listening test depends on your individual processing time. In case you have questions, please ask the investigator now. Otherwise please start processing the listening test.

Appendix 3: Demographics of questionnaire-based field survey

Table 3: Material of the floor construction

Material	Frequency	Percentage	Valid Percentage	Cumulated Percentage
Wood	276	77,7	77,7	77,7
Concrete	79	22,3	22,3	100,0
Total	355	100,0	100,0	

Table 4: Construction type of the floor

Construction Type	Frequency	Percent-age	Valid Percentage	Cumulated Percentage
ribbed floor with ballast	29	8,2	13,7	13,7
ribbed floor with little ballast	6	1,7	2,8	16,5
ribbed floor without ballast	8	2,3	3,8	20,3
hollow box floor with ballast	23	6,5	10,8	31,1
hollow box floor with little ballast	19	5,4	9,0	40,1
hollow box floor without ballast	22	6,2	10,4	50,5
solid wood floor with ballast	76	21,4	35,8	86,3
solid wood floor without ballast	5	1,4	2,4	88,7
Total	212	59,7	100,0	

Table 5: Ownership of the object

Ownership	Frequency	Percent-age	Valid Percentage	Cumulated Percentage
Owner	128	36,1	36,1	36,1
Renter	210	59,2	59,2	95,2
Other	2	,6	,6	95,8
Member of cooperative	15	4,2	4,2	100,0
Total	355	100,0	100,0	

Table 6: Building type

Building Type	Frequency	Percent-age	Valid Percentage	Cumulated Percentage
Single-family house	53	14,9	15,4	15,4
Single-family house with Flat	6	1,7	1,7	17,1
Flat in single-family house	1	,3	,3	17,4
Row House	14	3,9	4,1	21,4
Multi-family house	271	76,3	78,6	100,0
Total	345	97,2	100,0	

Table 7: Deliberate decision for wood construction

Deliberate Decision	Frequency	Percentage	Valid Percentage	Cumulated Percentage
yes	137	38,6	48,2	48,2
no	147	41,4	51,8	100,0
Total	284	80,0	100,0	

Table 8: Location of object

Location	Frequency	Percent-age	Valid Percentage	Cumulated Percentage
City Center (big town)	66	18,6	18,6	18,6
City Center (small town)	29	8,2	8,2	26,8
Outskirts	181	51,0	51,0	77,7
Rural	67	18,9	18,9	96,6
Other	12	3,4	3,4	100,0
Total	355	100,0	100,0	

Table 9: Living situation

Living Situation	Frequency	Percent-age	Valid Percentage	Cumulated Percentage
Single	50	14,1	14,1	14,1
Single with kids	9	2,5	2,5	16,6
apartment-sharing community	9	2,5	2,5	19,2

Couple	134	37,7	37,7	56,9
Family with kids	149	42,0	42,0	98,9
Assisted living	3	,8	,8	99,7
Other	1	,3	,3	100,0
Total	355	100,0	100,0	

Table 10: Gender

Gender	Frequency	Percentage	Valid Percentage	Cumulated Percentage
female	117	33,0	33,0	33,0
male	238	67,0	67,0	100,0
Total	355	100,0	100,0	

Table 11: Year of birth

Year of Brith	Frequency	Percentage	Valid Percentage	Cumulated Percentage
1929	1	,3	,3	,8
1930	1	,3	,3	1,1
1932	2	,6	,6	1,7
1933	1	,3	,3	2,0
1934	1	,3	,3	2,3
1937	2	,6	,6	2,8
1938	1	,3	,3	3,1
1939	3	,8	,8	3,9
1940	1	,3	,3	4,2
1941	1	,3	,3	4,5
1942	2	,6	,6	5,1
1943	2	,6	,6	5,6
1944	2	,6	,6	6,2
1945	5	1,4	1,4	7,6
1946	10	2,8	2,8	10,4
1947	8	2,3	2,3	12,7
1948	8	2,3	2,3	14,9
1949	2	,6	,6	15,5
1950	3	,8	,8	16,3

	1951	4	1,1	1,1	17,5
	1952	4	1,1	1,1	18,6
	1953	8	2,3	2,3	20,8
	1954	4	1,1	1,1	22,0
	1955	13	3,7	3,7	25,6
	1956	5	1,4	1,4	27,0
	1957	4	1,1	1,1	28,2
	1958	5	1,4	1,4	29,6
	1959	10	2,8	2,8	32,4
	1960	9	2,5	2,5	34,9
	1961	9	2,5	2,5	37,5
	1962	4	1,1	1,1	38,6
	1963	7	2,0	2,0	40,6
	1964	13	3,7	3,7	44,2
	1965	9	2,5	2,5	46,8
	1966	9	2,5	2,5	49,3
	1967	4	1,1	1,1	50,4
	1968	8	2,3	2,3	52,7
	1969	12	3,4	3,4	56,1
	1970	16	4,5	4,5	60,6
	1971	5	1,4	1,4	62,0
	1972	11	3,1	3,1	65,1
	1973	13	3,7	3,7	68,7
	1974	17	4,8	4,8	73,5
	1975	12	3,4	3,4	76,9
	1976	7	2,0	2,0	78,9
	1977	14	3,9	3,9	82,8
	1978	9	2,5	2,5	85,4
	1979	12	3,4	3,4	88,7
	1980	5	1,4	1,4	90,1
	1981	12	3,4	3,4	93,5
	1982	5	1,4	1,4	94,9
	1983	1	,3	,3	95,2
	1984	8	2,3	2,3	97,5
	1985	2	,6	,6	98,0
	1986	1	,3	,3	98,3

1987	3	,8	,8	99,2
1989	1	,3	,3	99,4
1990	1	,3	,3	99,7
1992	1	,3	,3	100,0
Total	355	100,0	100,0	

Table 122: Occupancy

Occupancy	Frequency	Percentage	Valid Percentage	Cumulated Percentage
1992	1	,3	,3	,3
1995	1	,3	,3	,6
1996	1	,3	,3	,8
1997	1	,3	,3	1,1
1999	1	,3	,3	1,4
2000	3	,8	,8	2,3
2001	5	1,4	1,4	3,7
2002	9	2,5	2,5	6,2
2003	22	6,2	6,2	12,5
2004	8	2,3	2,3	14,7
2005	11	3,1	3,1	17,8
2006	14	3,9	4,0	21,8
2007	22	6,2	6,2	28,0
2008	14	3,9	4,0	32,0
2009	20	5,6	5,7	37,7
2010	47	13,2	13,3	51,0
2011	73	20,6	20,7	71,7
2012	73	20,6	20,7	92,4
2013	27	7,6	7,6	100,0
Total	353	99,4	100,0	

Table 13: Number of people living in the household

Number of people	Frequency	Percentage	Valid Percentage	Cumulated Percentage
0	2	,6	,6	,6
1	57	16,1	16,1	16,6

	2	142	40,0	40,0	56,6
	3	58	16,3	16,3	73,0
	4	75	21,1	21,1	94,1
	5	16	4,5	4,5	98,6
	6	1	,3	,3	98,9
	7	2	,6	,6	99,4
	8	1	,3	,3	99,7
	16	1	,3	,3	100,0
	Gesamt	355	100,0	100,0	

Table 14: Number of children

Number of children		Frequency	Percentage	Valid Percentage	Cumulated Percentage
	0	213	60,0	60,0	60,0
	1	59	16,6	16,6	76,6
	2	65	18,3	18,3	94,9
	3	16	4,5	4,5	99,4
	4	2	,6	,6	100,0
	Gesamt	355	100,0	100,0	

Table 15: Employment Relationship

Employment relationship		Frequency	Percentage	Valid Percentage	Cumulated Percentage
	Working	235	66,2	80,2	80,2
	Housewife/houseman	8	2,3	2,7	82,9
	Pupil	1	,3	,3	83,3
	Other	21	5,9	7,2	90,4
	Retired	28	7,9	9,6	100,0
	Total	293	82,5	100,0	

AcuWood –
Acoustics in wooden buildings

AcuWood is a project within the WoodWisdom-Net Research programme and running 2010-2013. It is performed in cooperation with research and industry partners from Germany, Sweden and Switzerland and coordinated by SP Wood Technology.

The main objectives are to find objective criteria for acoustic quality that is independent of the type of building system, to increase the knowledge base for future development and to increase the competitiveness of lightweight structures. The project is run in close contact with international R&D and standardization.

Fraunhofer Institut Bauphysik

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