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Comparison of the results of a laboratory experiment and a field study with regard to acoustic quality in wooden buildings and recommendations for classification of acoustic quality

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ABSTRACT

Within the European research project AcuWood a questionnaire-based field study in Germany and Switzerland as well as laboratory listening tests were conducted which aimed at the evaluation of low frequency impact noise in wooden buildings. Different building and construction types were reconsidered. Since the laboratory listening tests partly included recordings from buildings that were also included in the questionnaire-based field study, it is possible to compare the long-term acoustic satisfaction of inhabitants with the short-term subjective impression during the laboratory listening tests. The results which were already reported at the Internoise 2013 have been enriched by another dataset. Recordings and listening tests of a lower quality wooden building were added in order to test the reliability of the comparability between the laboratory test and the field study. It is also discussed to use data from listening tests as a basis for the classification of acoustic quality in order to ensure for the perceptibility of defined different acoustic qualities.

Keywords: impact noise, annoyance, validity I-INCE Classification of Subjects Number(s): 61

1. INTRODUCTION

An increasing number of buildings is constructed of wood, even multi-storey wooden buildings are becoming increasingly popular in Europe. The technical requirements applied to wooden buildings are mainly based on the experiences from solid construction. However, evidence exists that annoyance caused by noise – in particular impact noise – in lightweight wooden buildings is higher than in solid construction buildings (1). This even applies, when common requirements derived from solid constructions are met. Therefore it is reasonable to assume that lightweight wooden constructions have to be handled differently, as for example lower frequency noise is more prominent in wooden buildings. Additionally, technical requirements are often derived under the primary consideration of the practicability of the related measurement procedure, whereas the prediction accuracy with regard to annoyance reactions is put secondary. Therefore results from technical measurements and subjective perception do not necessarily match and correlations between technical ratings and subjective evaluations can be low (1).

In the AcuWood project, measurements and recordings on different intermediate timber floor constructions in the laboratory and the field were performed covering a wide range of intermediate timber floor constructions. The preliminary data reported here adds to the results which were already published (2, 3, 4). The correlations between subjective and objective parameters of impact noise are elaborately described in these publications. It was 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 $L'_{F,max,nT,A,20\text{-}2500}$, with a determination coefficient (R^2) of 0.75. The standardized tapping machine can also be utilized as impact noise source. $L'_{nT,w+ CI,50\text{-}2500}$ is an acceptable single number

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descriptor with a determination coefficient of R^2=0.58. The best single number descriptor when evaluating the standard tapping machine was $L'_{nT,w\ Hagberg\ 03}$ with R^2=0.63.

Since most scientific research is conducted under controlled laboratory conditions and short-term noise exposition of test persons, the question arises whether these results can be transferred to the subjective perception of residents in real buildings in the field after long-term noise exposition. The aim of the reported study therefore is to investigate the reliability of listening tests conducted in the laboratory as well as their validity compared to the results of a field survey.

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 often are difficult to compare since they have used different questions and answer options. Therefore the questionnaire used within this survey corresponded to the one developed within the COST TU 0901 research network action (5), 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, as to prevent the ratings of acoustics being overlain by other hassles. The questionnaire incorporated items aiming at overall and acoustic satisfaction.

The listening tests were also designed to guarantee for comparability. Thus standardized rating scales, namely the subjective annoyance rating scale according to ISO/TS 15666 (6) and the subjective loudness rating scale according to ISO 16832 (7) were used. Additionally a question addressing the individual noise sensitivity and a polar (yes-no) noise annoyance question were included.

2.1 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. 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 415 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 towards 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, labor 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. However, the results section will only cover the data from three buildings and the annoyance ratings with regard to walking noise. Additional information can be found in Liebl et al. (4).

2.2 Listening Test

The measurement and recording procedure of the impact noise sources is elaborately described in (2, 3) and will be pictured here in a shortened form only. Microphone recordings and binaural recordings with a dummy head 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 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 and ISO 140-7 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 described measurements comprise the standardized tapping machine, the modified tapping machine and the Japanese rubber ball according to ISO 10140-5. These technical sources were complemented by real-life sources, which were walking persons with different footwear. In all field measurements, the same male walker (with shoes and with socks) was engaged. But 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. 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. 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 used in the listening test adds up to 230 different sounds.

Three listening tests (n=18; n=22, n=20) with identical test design were conducted. However, different test persons were invited for the three experiments. As to guarantee for the comparability of the judgments, at least one identical recording was included in each listening test. The recordings were cut to a length in between 5 to 20 seconds and presented to the test persons via headphones (Sennheiser HD 280 Pro). The sound level was calibrated using an artificial ear (G.R.A.S. 43AA). 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. However, the results section will only cover the data from two listening tests and ratings of walking noise of a male walker with hard and soft footwear. Additional information can be found in Liebl et al. (4).

3. RESULTS

The questioned was raised whether the results from laboratory listening tests are reliable, which means that comparable results are achieved with different groups of test persons judging the same recordings. Additionally the validity of laboratory listening test is questioned, which means that the short-term subjective impression during laboratory listening tests is compared to the long-term acoustic satisfaction of residents.

In order to investigate the reliability of the laboratory listening tests, the data from two listening tests with different groups of test persons (n=22, n=20) is compared. Both groups judged the same recordings from two buildings which were also incorporated in the field survey. In order to address the question of validity, the results of the two laboratory listening tests are compared to the subjective ratings of residents in three buildings (n=18, n=29, n=17) which were part of the field study (Winterthur, Zürich I, Zürich II). However, one of the two laboratory listening tests incorporated only recordings from two buildings (Winterthur, Zürich I) whereas the other listening test incorporated recordings from three buildings (Winterthur, Zürich I, Zürich II). Since the same 11 point rating scale was used in the listening tests and the field survey the results can be directly compared. Figure 1 contrasts the annoyance ratings of the residents from the three buildings to the annoyance ratings given by the test persons during the laboratory listening tests, when judging the recordings from these buildings. The depicted data from the field survey only covers the annoyance ratings with regard to walking noise caused by neighbors. The annoyance ratings of the listening tests show an average of the annoyance ratings caused by a male walker with hard and soft footwear.

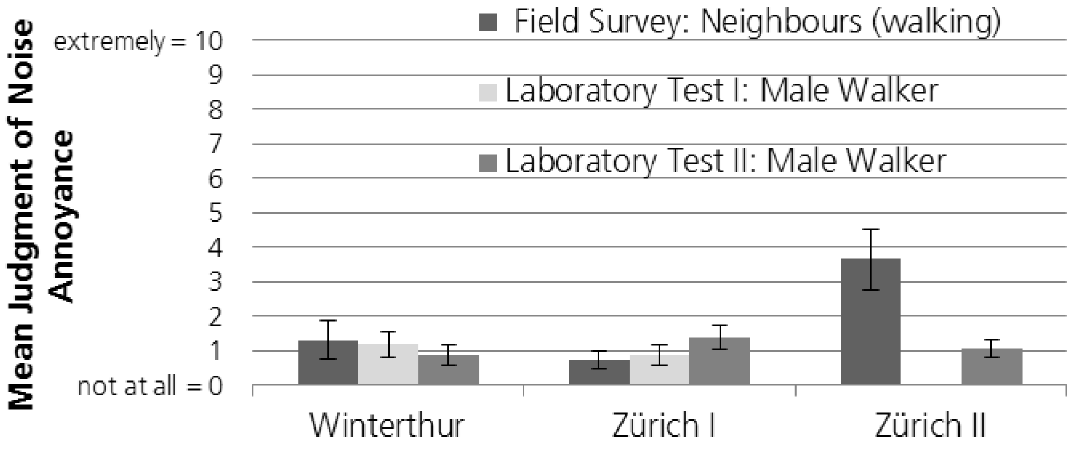

Figure 1 – Mean ratings of annoyance and standard errors with regard to perceived annoyance due to walking of neighbours in the field survey as compared to perceived annoyance due to male walking (average of soft and hard footwear) in the laboratory listening tests

A two factor (BUILDING; LISTENING TEST) mixed design ANOVA reveals no significant main effect of the factor BUILDING ($F(1, 40)<1$) and no significant main effect of the factor BUILDING ($F(1, 40)<1$). However, the interaction between both factors is significant ($F(1, 40)=16.10$, $p<.01$, $\eta2=.287$). While the judgments of the two test groups with regard to the recordings of Winterthur correspond, both groups differ with regard to the judgment of Zürich I. The second test group is more annoyed by the recordings than the first test group.

Table 1 depicts the results of pairwise comparisons between the judgments given by the residents of the three different buildings (FIELD). The judgments of the residents are also compared to the judgments of the participants of the listening tests (LABTEST I; LABTEST II).

Table 1 – Results of pairwise comparisons (t-tests)

Comparison	t	df	p
Winterthur FIELD vs. Zürich I FIELD	0.91	22.32	> .05
Winterthur FIELD vs. Zürich II FIELD	-2.46	27.48	< .05
Zürich I FIELD vs. Zürich II FIELD	-3.44	18.66	< .01
Winterthur FIELD vs. Winterthur LABTEST I	0.18	38	> .05
Winterthur FIELD vs. Winterthur LABTEST II	0.67	20.03	> .05
Winterthur LABTEST I vs. Winterthur LABTEST II	0.73	40	> .05
Zürich I FIELD vs. Zürich I LABTEST I	-0.40	49	> .05
Zürich I FIELD vs. Zürich I LABTEST II	-1.78	47	> .05
Zürich I LABTEST I vs. Zürich I LABTEST II	-1.34	40	> .05
Zürich II FIELD vs. Zürich II LABTEST II	3.13	17.61	< .01

The pairwise comparisons reveal that there are no significant differences between the judgments of the residents in Winterthur and Zurich I but the judgments between Winterthur and Zürich II as well as between Zürich I and Zürich II differ. Additionally all the comparisons of judgments of residents and laboratory test persons in Winterthur and Zürich I as well as Zürich II do not differ (note that different results between ANOVA and t-test are due to the statistical methods). Last but not least there is a significant difference between the judgments of residents of Zürich II and the participants of the laboratory listening test.

4. CONCLUSIONS

The results are inconclusive. The reliability of laboratory listening tests is restricted to the judgment of the recordings from Winterthur, whereas the judgments of Zürich I differ between laboratory test I and laboratory test II. An inconclusive picture also arises with regard to comparison of the long-term acoustic satisfaction of residents with the short-term acoustic satisfaction of laboratory test persons. In two out of three buildings the judgments correspond. However, the results of the data from the field survey in the third building are not covered by the results of laboratory test II. Since big differences with regard to the walking styles of people exist, the poor correspondence for the Zürich II may be explained by differences between walking styles of residents compared to the walking style of the male walker during the recording campaign. However, this is not very probable since the bad acoustic quality in Zürich II is reported by an average of 18 people. It is not very probable that all of them are exposed to neighbors with extraordinary walking styles. The variation of walking styles should be compensated by the sample size of residents. Further analysis is necessary which will correct for the noise sensitivity of the residents and participants of the laboratory experiments. Additional demographic variables like age and gender will also be investigated. Given that the effect of personality traits like noise sensitivity yield a significant effect it would be necessary to derive classification schemes which reconsider the different noise sensitivity of people. Last but not least it is possible that an interaction between quantity of noise exposition and duration of noise exposition exits, which means that the judgments of short-term and long-term exposition differ if the degree of noise exposition exceeds a certain threshold.

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