Acoustic Solutions for Wooden Intermediate Floors

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ABSTRACT

In Switzerland multi-storey timber construction has been very successful in recent years. This is primarily due to the 2005 amended fire safety regulations. This development brought with it new challenges with regard to sound mitigation. Apart from requirements governed by national standards, there are requirements driven by occupants. These are based on subjective human perception and can lead to complaints about low-frequency sound even if the values specified in the standard are met. Research was therefore carried out on the subjective assessment with in-situ measurements, a broad survey and auditory tests. Additionally common details and their robustness where evaluated and within 4 case studies examined. The results of the research project in short are:

- The frequency range for sound insulation needs to be considered from 50 Hz
- Building elements show a wide range of construction principles and acoustic properties. A structured online catalogue with robust details was developed
- With good floor build-ups, the flanking transmission is of minor importance
- One main reasons for the small sound insulation properties of timber constructions in the low frequency range is the low mass
- The quality of elements/buildings must be guaranteed. Timber constructions can be controlled significantly in industrialised building systems

Keywords: Timber Constrution, Subjective Preception, Sound Insulation
I-INCE Classification of Subjects Number(s): 51.3

1. INTRODUCTION

The goal of acoustic design is to create intact conditions for residents. In construction, this means the insulation of airborne sound from internal and external noises, the damping of impact noise and structure-borne noise and the absorption of sound (acoustics). The normative demanded single number values in most European countries include the frequency range of 100-3150 Hz, the low frequency range either not being included at all or only barley through weighted C-values, usually also from 100-2500 Hz.

In addition to the standards resident-related requirements exist. These are based on the subjective perception of sound. Questionnaires [1, 2] have shown the most annoying noise is impact sound from other residential areas in lightweight buildings. This noise is mainly caused by steps, but also e.g. by running children or the movement of chairs [3]. These common noises in multi-storey buildings are made of mainly low to very low frequencies, having significant components below 100 Hz.

Within the research project 'Sound insulation in timber construction' by Lignum the acoustic quality of timber structures is investigated in deep. The results presented herewith have been studied in the context to gain insight into the acoustic satisfaction of the inhabitants of timber houses and to develop sound building-details. The focus was on the impact sound transmission.

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2. SUBJECTIVE PERCEPTION OF SOUND IN TIMBER BUILDINGS

2.1 Method

To explore the acoustic quality of modern timber buildings, a web-based questionnaire field survey and laboratory listening tests were conducted. Ca. 250 modern multi-storey timber buildings have been incorporated. Besides acoustics other building properties were addressed in the field survey, to prevent the ratings of acoustics being overlain by other hassles.

2.1.1 Questionnaire

Only buildings where information on the exact build-up was available were included. The questionnaire incorporated 41 questions. It started with an explanation of the purpose of the survey. Then general questions were asked regarding ownership, attitude towards timber constructions, living environment, object location and living situation. The questionnaire also included questions addressing neighbourhood, hassles and ideas of improvement. 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 had to be rated with regard to satisfaction. This was proceeded with a question about noise sensitivity.

2.1.2 Measurements

The measurement and recording procedure is elaborately described in [4] 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) were conducted at IBP's laboratories and in the field. The dummy head recordings were used for the conduction of the listening tests. The recordings of the dummy head were made at a height of 1.2 m, representing a sitting person. The impact noise sources comprised the standardised tapping machine, the modified tapping machine and the Japanese rubber ball (ISO 10140-5). These technical sources were complemented by real-life sources, which were walking persons (male walker with shoes and with socks and female walker with hard heeled shoes) and a chair drawn across the floor.

The measurements were made on a wooden beam floor, on a wooden beam floor with suspended ceiling and on a concrete floor. Additionally measurements were made at 4 different, contemporary multi-story-buildings in Switzerland.

Two main listening tests (n=18, n=22) with identical test design were conducted. The recordings were cut to a length of 1-20 s, depending on the source, and where played to the test persons via headphones (Sennheiser HD 280 Pro). The rating scales used to assess perceived annoyance and perceived loudness corresponded to ISO/TS 15666 and ISO 16832. The 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.

2.2 Results

2.2.1 Questionnaire

About 1500 flats have been invited to fill out the questionnaire. Of the 355 completed datasets that have been filled out, 33% were completed by female and 67% by male. The median age was 46 years. The average number of people living in the household was 2.65. The majority of the respondents, namely 59%, were renters (tenants), whereas 36% of the respondents were owners and 4% were members of a cooperative. Among other things, the respondents were asked to rank different aspects of the living environment individually according to the perceived importance (cp. Figure 1).

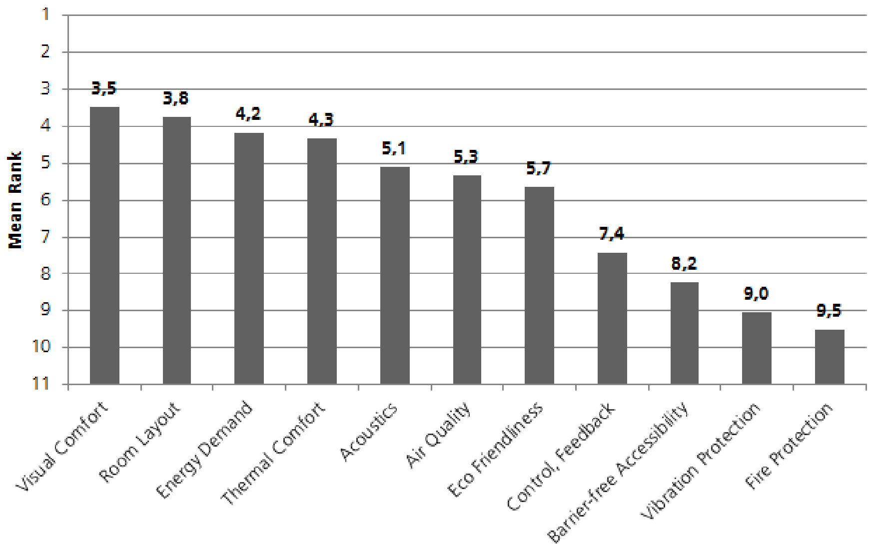

Figure 1 – Ranking (mean rank) of the perceived individual importance with regard to different characteristics of the living environment (n=354). Acoustics are ranked in a middle position.

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 (cp. Figure 2).

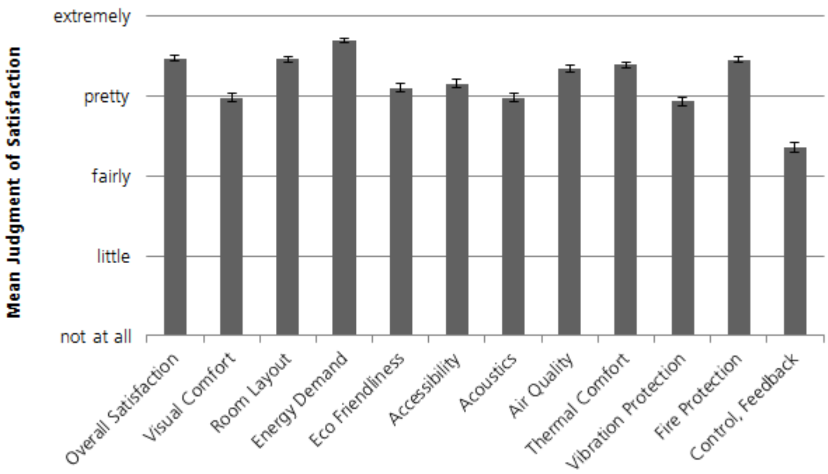

Figure 1. Judgment (mean rating) of the perceived individual satisfaction with regard to different characteristics of the living environment (n_{max}=355; n_{min}=285). Overall, the respondents reported to be pretty satisfied with the living environment.

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 COST TU 0901 [cp. 5]. The results of this can be read in detail in [2].

2.2.2 Comparison of the field survey and the listening test

In the case of two buildings (Winterthur and Zürich) it has been possible to conduct measurements and to ask the residents to fill out the questionnaire. With these data it is possible to compare the acoustic long term satisfaction with the short term rating by test persons (cp. Figure 3).

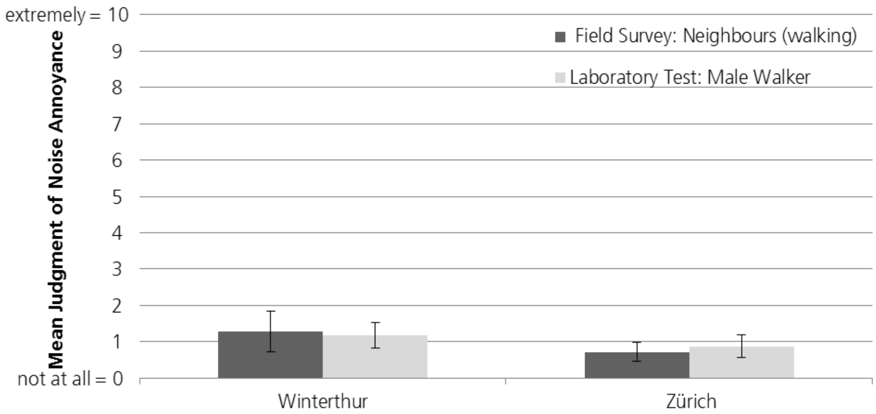

Figure 2. Mean ratings of annoyance with regard to perceived annoyance due to walking of neighbours in the field survey compared to perceived annoyance due to male walking in the laboratory listening test.

An ANOVA reveals no significant main effect of the factor place (Winterthur vs. Zürich) and no significant main effect 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.

3. DESIGN MEASURES

Since mainly lightweight materials are used in timber construction and therefore the basis weight of components is low compared to other types of construction (massive construction), timber elements usually are composed of several layers. In modern timber construction the same sound insulation values can be achieved as with massive construction but with the advantage of having a significantly lower mass by making use of multi-shell structures and non-rigid suspended ceilings and cavity insulation.

The impact of a single component layer depends on various parameters. Depending on the type of construction the individual elements of intermediate floors affect each other and there may be systems with multiple resonances. In the design stage of intermediate floors made in timber, the properties of the individual systems must be coordinated. Design measures and rules are set out in the following chapters.

3.1 Bare floor

Due to the relatively low mass and the sound bridges between the shells, high sound transmission in the low frequency range is characteristically high for bare wooden floors. Figure 4 shows the normalised impact sound level L_n frequency curves of common bare floors [6]. The curve for the ribbed timber bare floor shows the typical high standard impact sound at low frequencies as well as the steep drop in the impact sound curves at the high frequencies. The much heavier reinforced concrete slab in comparison shows significantly lower L_n values in the lower frequencies. Improvement measures for timber floor structures must be - as previously described and therefore - particularly at low frequencies effectively.

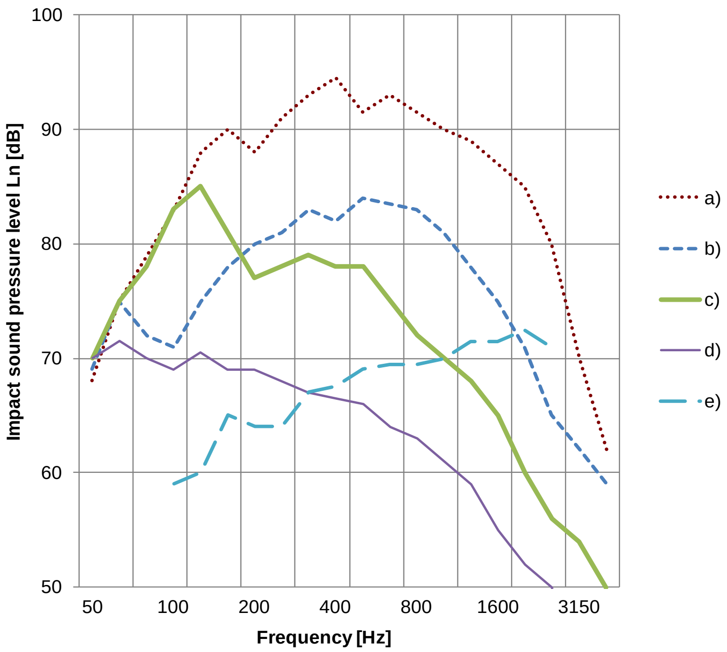

Figure 3 [6]. Typical curves of various bare floors made of timber and concrete:
a) wooden ribbed floor; b) solid wood floor; c) wooden ribbed floor with suspended ceiling on laths;
d) wooden ribbed floor with a non-rigid mounted suspended ceiling; e) concrete bare floor

3.2 Loading of bare floor

By adding mass wooden ceilings achieved much better L_n in the low frequency bands. A ribbed floor with an added load of 120 kg/m^2 or a solid timber floor with an added load of 150 kg/m^2 provide approximately equal good sound insulation as a reinforced concrete floor.

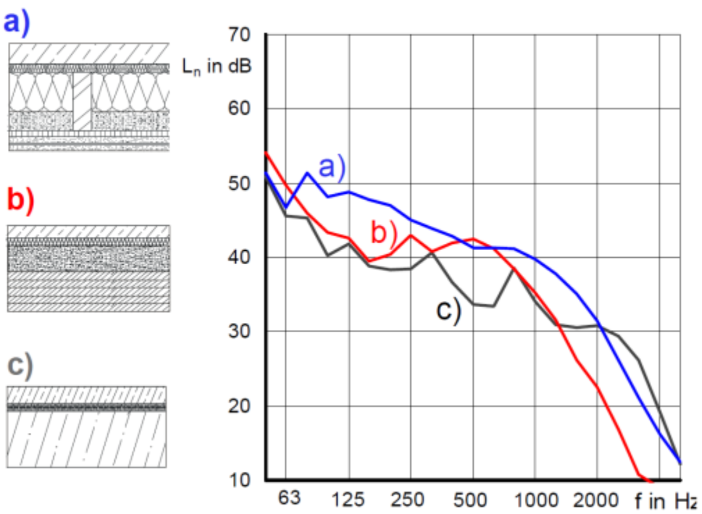

Figure 4 [7]. L_n of optimised wooden floors and of a concrete floor:
a) ripped timber floor with floating floor on mineral wool and wood fibre impact sound insulation, loaded with 80 mm gravel between the rips: $L_{n,w} + C_{I,50\text{-}2500} = 44$ dB;
b) Solid wood floor with floating floor on mineral wool impact sound insulation, loaded with 100 mm gravel: $L_{n,w} + C_{I,50\text{-}2500} = 42$ dB;
c) concrete floor with floating floor on mineral wool impact sound insulation: $L_{n,w} + C_{I,50\text{-}2500} = 40$ dB

The comparison of different types of mass' on the same solid timber floor build-ups (50 mm cement screed on 35 mm mineral fibre sound insulation with a dynamic stiffness s' = 7 MN/m^3) shows that the sound reduction gets continuously better with more load [8]. The increase of the total weight of the bare floor causes a positive displacement of the mass-spring-mass-resonance of the screed and the bare floor and along with that comes a sound reduction.

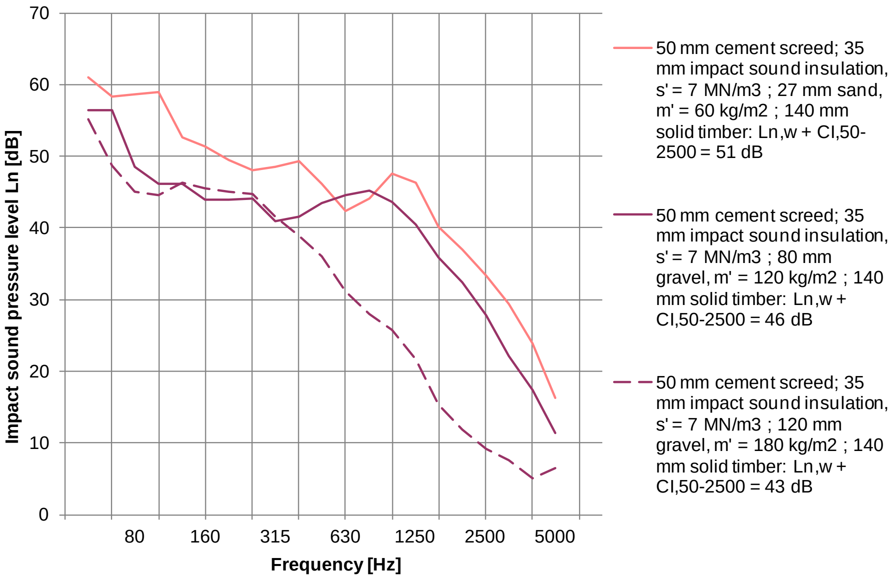

Figure 5 [8]. L_n of three intermediate floors, having different loads added to the same base, a solid timber floor with - beside that - identical build-ups.

3.3 Floor construction

An important method for improving the sound insulation of intermediate floors is to use a floor structure with impact insulation and a floating screed. With that a mass-spring-mass system is being created, consisting of the floating floor as mass, the impact sound insulation as a spring and the bare floor as mass again. The resonance frequency f_0 is the most important factor in the dimensioning of the whole floor build up. To achieve good results with impact noise reduction, it is essential to plan f_0 for the floor system to be as low as possible, i.e. below the human hearing range. Hence systems must be tailored so that f_0 is at least below 50 Hz.

The effectiveness of the screed is influenced significantly by its mass per unit area and the mass per unit area of the bare floor and the dynamic stiffness s' of the impact sound insulation. The mass of the screed and the bare floor must be sufficiently high and the impact sound insulation shall have the lowest possible dynamic stiffness s' to achieve acoustically optimal results in the low resonant frequencies.

Another criterion is the loss factor of the impact sound insulation. The impact sound values become bigger in the region of f_0. As shown in studies [9], the noise levels increase depends in the first place on the loss factor of the damping material. For materials with large loss factors this so-called resonant peak is less pronounced than in materials with a small loss factor.

A selection of test results with the same bare floor construction from laboratory tests is shown in Figure 7. The dashed curve shows that - compared to the bare floor (green curve) - impact noise improvements with a lightweight dry floating floor (25 mm gypsum fibreboard on 22 mm wood fibre board with s' = 45 MN/m^3) added to the bare floor only take effect from 125 Hz on. On the other hand better results were achieve with a significantly heavier dry floating floor (18 mm gypsum fibreboard and 60 mm concrete slabs on 30 mm mineral wool impact sound insulation with s' = 30 MN/m^3) and with a wet floating floor (80 mm cement floating floor on 40 mm mineral wool impact sound insulation with s' = 9 MN/m^3) on the bare floor.

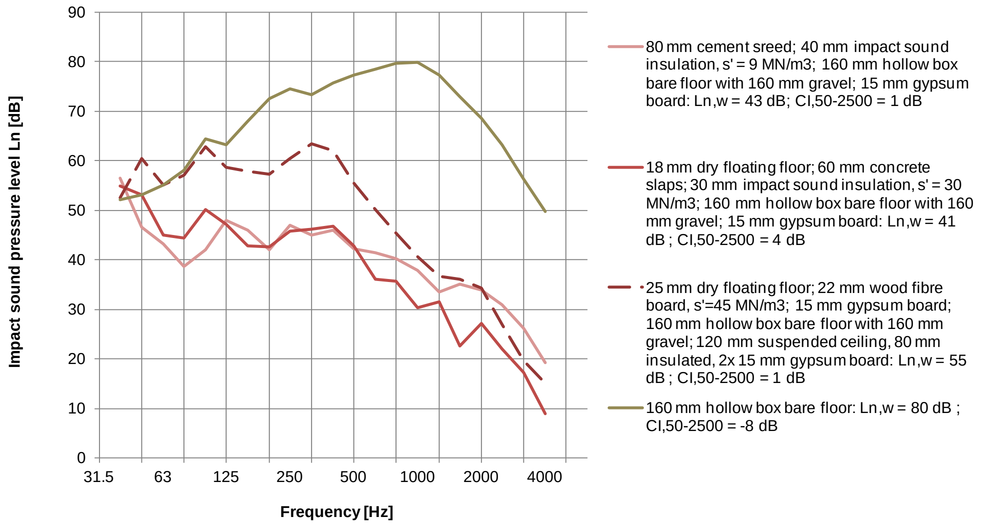

Figure 6 [10]. Comparison of L_n of different floor build-ups on a hollow box bare floor with added load (gravel) within the hollow boxes.

3.4 Suspended ceilings

In addition to the mass-spring-mass floor construction described a further mass-spring-mass system may be added to the bare floor with a suspended ceiling. It consists of a flexible shell (mass) and a disconnecting system with air/cavity insulation (spring). For most effectiveness the flexible shell (facing boards) must have the largest possible mass per unit area and a low bending stiffness. In addition, the clearance between the soffit of the bare floor and the suspended ceiling must be as large as possible. Further it is of great importance the suspended ceiling is detached from the soffit (resilient mounting).

Build-ups of suspended ceilings with little clearance between soffit and suspended ceiling (e.g. with solid timber bare floors or hollow box bare floors) show only in the third-octave bands above 100 Hz better performance and therefore improve the sound insulation of the intermediate floor in the standard frequency range only. Hence with small clearances the impact sound insulation below 100 Hz is generally not reduced, in fact, the sound insulation may deteriorate around the resonance frequency f_0.

With ribbed timber floors in contrast, f_0 is shifted to the lower frequency bands with suspended ceilings. Herewith laying the potential for the improvement of the standard impact sound level L_n. Measurements within the project have shown that with large clearances of 32 cm excellent values can be achieved from 50 Hz - even with relatively low added loads to the bare floor.

The improvements of the standard impact sound level L_n for an intermediate floor build up with 80 mm floating cement screed and 40 mm mineral fibre sound insulation (s' = 9 MN/m^3) on a 160 mm hollow box bare floor, filled with gravel and having a resilient mounted suspended ceiling with a clearance of 120 mm and 80 mm cavity insulation are shown in Figure 8. It can be clearly seen the improvement only occurs above 100 Hz.

It can also be seen in Figure 8 that in contrast to the hollow box floor build-up without any suspended ceiling, the impact sound transmissions is significantly higher in the third octave bands from 63 to 160 Hz for the same floor with a non-resilient mounted suspended ceiling with only little clearance of 40 mm and one layer of 15 mm plasterboard.

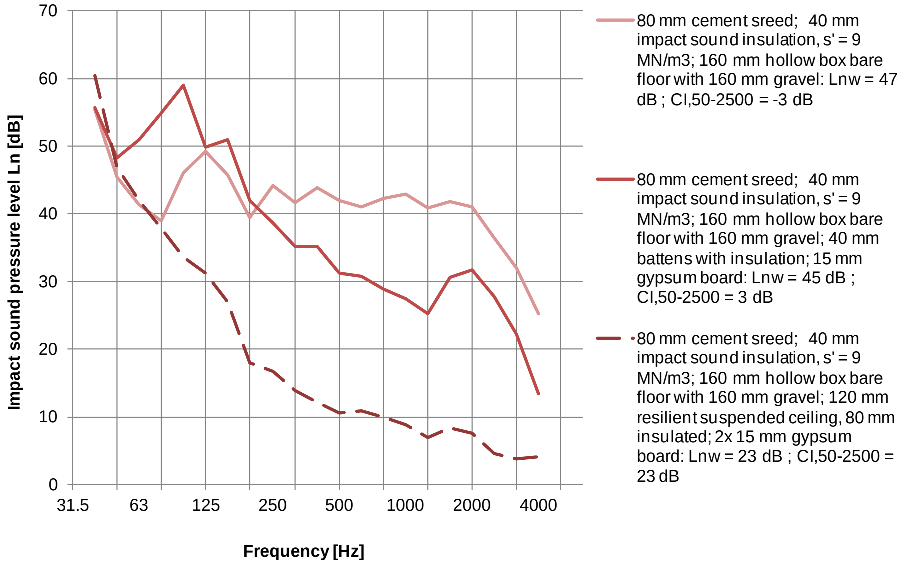

Figure 7 [10]. Comparison of L_n of different suspended ceilings mounted to a hollow box bare floor with added load within the hollow boxes in comparison to the same bare floor without any suspended ceiling.

4. CONCLUSIONS

From the studies it can be concluded that the overall satisfaction with the living environment in multi-storey timber buildings in Switzerland is very positive. However, people are bothered by the disturbance caused by noise in the overall context, but they are not overly dissatisfied. Timber floor structures reach the air borne requirements easily [6]. The challenge for timber construction lies in impact sound (low range frequencies). The project shows low frequency optimised intermediate floor structures can be accomplished and with different types of build-ups. Essential is a deep resonance frequency f_0 within the system.

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