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Swiss pendulous hammer for decoupling measurement of service equipment in wooden multi-storey building

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Summary

The latest Swiss standard SIA181 (6-2006 edition [1]) introduces a new methodology regarding the tests to be performed in new constructions for assessing noise induced by the manipulation of service equipment in bathrooms and kitchens. However, this method has been developed especially for massive constructions. In this study, we are investigating the relevance of such method for timber frame building, with typical structures including boxes, frames, massive floors, retrofitting solutions. Decoupling performances are particularly important in lightweight constructions, and the pendulous hammer method is actually aiming at evaluating the decoupling of service equipments.

The goals for this work are to determine the advantages and the limitations of this method for theses specific cases. For example, airborne contribution can become critical and deserves a specific control. This project should also identify the main propagation paths for equipment noise. A series of in-situ measurements has been performed for various building constructions and service equipments. Some additional laboratories investigations have been conducted to optimize the decoupling of service equipments to fulfill the Swiss SIA standard requirements.

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1. Introduction

Service equipment noise is one of the main sources of complaints in building noise. The annoyances do not only concern operation noise (the intensity and duration of which are almost independent of the mode of use) but also noise induced by human manipulation of service equipment and fixed installations of the building in bathrooms and kitchens although these latter type of noise are not considered in international standard [2].

Since 1988, the Swiss Standard SIA181 (Protection against noise in building) introduced a distinction between these two types of noise but the methodology of measurement for operation noise, based on a "normal" utilization by the expert, was found to be not reliable enough [3].

The latest version of the Swiss standard SIA181, published in 2006 [1,4] introduced a new methodology, utilizing a "pendulous hammer", with a view to assessing the manipulation noise, by evaluating the decoupling of service

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equipment, similarly to the methods employed for impact noise assessment.
The new methodology, which is very reproducible and reliable [5], was developed and tested in massive constructions, which are the most frequent type of construction in Switzerland.
However, in the last decade, the number of lightweight construction, especially in wooden types, has been significantly increased. This raises the question of the relevance of this new measurement method for timber frame buildings, in which the decoupling performances are particularly important and problems in the low frequency range can occur.
Our research project is a part of the COST action FP0702 [6]. Its aim is to try and determine the type of constructions and bindings that fulfill legal requirements. Furthermore, we analyze the limits (repeatability and reproducibility) of the evaluation method, in particular for the lightweight structures.
For example, in some cases, the insufficient airborne insulation can become critical and could have an impact on the outcomes of of equipment noise assessments.
Through the analysis of a significant number of in-situ measurement results using an impulse excitation of the equipment and structure, we wish to study the particular decoupling conditions and the main propagation paths (buffer floors, differences between ascending and descending insulation, etc.). Finally, additional laboratories investigations have been conducted in order to understand and optimize the influence of the fixation of service equipment to the structure.

2. Swiss standard SIA181:2006

2.1. Service equipment types

In 2006, the Swiss standard SIA181 was totally revised [1]. In this standard, noise of service equipments and fixed installations of the building are split into different categories. Depending on the temporal characteristics of the noise, different descriptors are used, L_{Aeq} for continuous noise and $L_{A,F}$ for short-time noise (duration<3 min.). The latter category is divided in two sub-categories. The first concerns “operation noise” the intensity and duration of which are almost independent of the mode of use (among which are the filling and emptying of sinks and bathtubs, toilet flushing, noise from usage of appliances, etc.). The second sub-category applies for “manipulation” noise, resulting from the human manipulation of service equipment and fixed installations of the building. In such category, the intensity and duration of noise are largely dependent of the mode of use (such as utilization of shower or bathtub, dropping the toilet seat, putting dishes or pans on a kitchen worktop, closing drawer or cabinet doors, etc.). Only manipulation noises will be studied within the frame of this study.

2.2. Assessment and limit value

The evaluated level of the service equipment and fixed installation of the building ($L_{H,tot}$) is calculated from:

$$L_{H,tot} = L_{A,F} + K1 + K4 + C_v \quad [dB(A)]$$

where:
$L_{A,F}$ = Average A-weighted maximal level
K1 = Correction factor according to absorption in the reception room (0/-2/-4 dB).
K4 = Correction factor for pendulous hammer according to installation type (-7 to -12 dB).
C_v= Volume correction (V>200 m3, 2 to 5 dB)

The minimal requirements according to SIA181 is L_H = 38 dB(A) for average noise sensitivity (bedroom, living-room). The limit value is 43 dB for less sensitive spaces (kitchen, bathroom), see Table 1. Increased requirements (applying e.g. for owner-occupied apartments) are 3 dB lower.

Table I. Minimal requirements (L_H) for short term service equipment noise according to SIA181 [1]

Sensitivity	Operation noise	Manipulation noise
Low	38	43
Medium	**33**	**38**
High	28	33

2.3. Pendulous hammer for manipulation noise

A new device has been developed by the EMPA and chosen to evaluate the usage noise of building service equipment in a simple and reproducible manner, based on numerous research results [4, 6]. The instructions about how to use this “pendulous hammer” (see Figure 1 and 2) are described in details in the appendix B.3.5 of the SIA181:2006 standard.

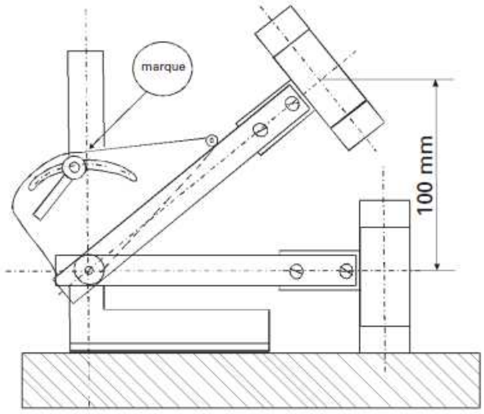

Figure 1. Swiss pendulous hammer (EMPA).

Figure 2: Horizontal measurement with the pendulous hammer.

3. Methodology

3.1. Construction types

For this study, numerous measurements (about 3’000 hammer impacts) have been conducted on seven wooden constructions types. The main constituents for the floors and walls are the following:

E1 (standard housing):
Floor: 2 cm thick wooden floor, screed + semi-floating 8 cm topping, 2 cm wood fiber insulation, 2 cm Oriented Strand Board (OSB) panel, 20 cm wood slab Lignatur Silence.
Common walls: 28 cm concrete, 1.25 cm drywall (plasterboard)+ 2.7 cm insulation on joists on each side.

E2 (student housing):
Floor: linoleum, 7.5 cm cement screed, PE sheet, mineral wool, 1.5 cm Fermacell, 12 cm solid slab.
Walls and bindings: the wood wall bindings are semi-rigid at supports and perimeter. The sanitary system is constituted of a bloc and independent prefabricated technical ducts (concrete 6 and 8 cm thick), placed on soft bases (resilient layer).

E3 (quality housing):
Floor: flooring, 5.5 cm anhydrite floor, 2 cm EPS insulation, 3 cm rock wool insulation, 5 cm EPS insulation, 1.5 cm OSB panel, 20 cm wood slab Lignatur Silence, 3 cm plenum, 2x1.25 cm suspended ceiling.
Common walls: 1.25+1.5 cm Fermacell (heavy plasterboard), 2x10 cm frame with Isofloc (cellulose insulation) , 1.25+1.5 cm Fermacell (see Figure 3).

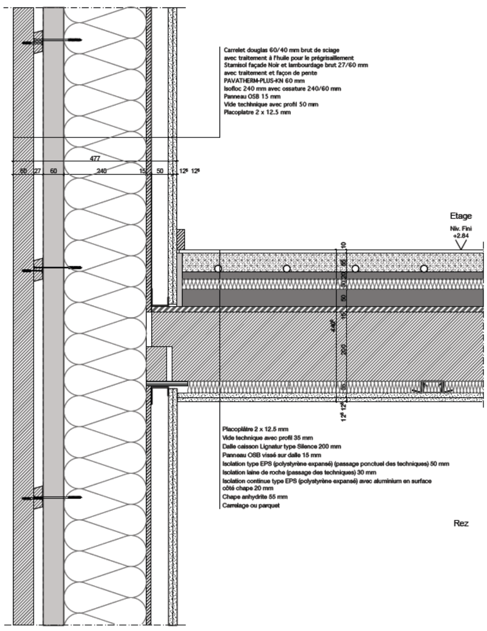

Figure 3. Cross-section of the structure for the case E3.

B1 (quality housing):):
Floor: 1 cm wooden floor, 7 cm floating screed, 2+1 cm insulation, 8 cm concrete rigidly connected to 12 cm solid slab.
Common walls: drywalls (plasterboard)

B2 (quality housing):
Floor: 1.5 cm flooring, 1.5 cm Fermacell +3.5 cm mineral wool, 6.5 cm screed, 2.2 cm OSB, 12x18 cm joists, 2.5 cm min. wool, 2x1.25 cm Fermacell suspended ceiling.
Common walls: 2x1.25 cm Fermacell, 2.5 cm plenum, 1.5 cm OSB, 90 mm min. wool, 2.5 cm plenum, 2x1.25 cm Fermacell

3.2. Measurements

For each building, several installations and configurations have been tested according to the directives of the SIA181:2006 standard, appendix B3.5 (a minimum of 6 hammer impacts with 2 microphone positions). In order to limit the number of measurements, only the main installations have been measured in the bath rooms (bathtubs, showers, sinks, toilets, shelves) and kitchens (worktops, sinks, cabinets). In order to allow for a more thorough analysis of the measurements later on, a part of them include temporal data, spectra and audio recordings, in addition to the maximum level $L_{A,F}$ for each hammer impact (according to SIA181). Wideband (1/3 octave from 50 to 5000 Hz) airborne noise insulation and impact noise have also been measured in each building.

An exhaustive documentation has been established for each building (maps, cross-sections, construction details for floors, walls and bindings, photos).

4. Results

4.1. Construction types

The global analysis of the vertical insulation results shows (see Table II) that all types, except the E2 case (simple construction for student housing), fulfill the minimal requirements of the SIA181 standard, with regards to airborne noise and shock noise insulation.

This is however not the case for the noise due to the manipulation of service equipment, where the limits are exceeded in 52% of the situations in bathrooms and in 64% of the cases in kitchens. In 20% of the measured premises, the average value over the measured situations is at least 5 dB higher than the requirements. Note that those buildings that fulfill the best these requirements (E2 and B2) have a favorable typology (bathroom and kitchen are not adjacent to noise sensitive rooms).

4.2. Measurement techniques

The detailed analysis of the measurements allows us to study different parameters related to the measurements (repeatability, comparison with requirements for impact noise, airborne contribution). The variability analysis of various measurements of a same installation (at least twelve measurements), shows that for toilets and sinks, the repeatability is good ($\sigma_{average}$ is respectively 0.6 and 1.2 dB). On another hand, there is a significant disparity for bathtub values ($\sigma_{average}$ = 4.4 dB). This latter can be explained by the difference between the hammer impact on the edge and the bottom of the bathtub (lower value on the bottom than on the periphery). Indeed rigid or semi-rigid contacts are generally located on the perimeter of the tub.

Table II Average results for airborne noise insulation, impact noise and manipulation noise of service equipment for various construction types (vertical insulation).

Minimal Requirements	>52 dB	<53 dB	<38 dB(A)	# Measurements (% exceeding requir)	<38 dB(A)	# Measurements (% exceeding requir)
Construction	Airborne	Impact	Manipulation in Kitchen		Manipulation in bathroom	
E1	54 ± 1	53 ± 0	44 ± 4	10 (100%)	39 ± 5	16 (62.5%)
E2	50 ± 2	58 ± 4	38 ± 2	4 (50%)	47 ± 4	6 (100%)
E3	55 ± 11	46 ± 7	28 ± 6	2 (0%)	35 ± 5	12 (25%)
B1	60 ± 2	50 ± 0	40 ± 2	8 (75%)	39 ± 7	8 (75%)
B2	64 ± 0	51 ± 12	37 ± 1	4 (0%)	26 ± 1	2 (0%)
Total				**28 (64%)**		**44 (52%)**

By measuring a floating screed floor and a walk-in shower using two different methodologies, we find that the minimum requirements are met for impact noise (standard tapping machine) but not for the manipulation noise of service equipment (EMPA pendulous hammer). For both considered floors (screed and shower), the requirements are on average 5 dB more severe with the pendulous hammer.

The fall of the pendulous hammer generates a relatively loud noise in the room where the measurement is conducted. If the airborne sound insulation is insufficient, the measurement of service equipment will be influenced by airborne transmission instead of just being related to the structure-borne transmission of the facility. Thus we observe in the E3 case a transmission, through the common ventilation ducts between the bathrooms, which causes insufficient airborne insulation between them (40 dB instead of 47 dB according to standards). This defect explains the significant increase (8 dB on average) of the manipulation noise of service equipment between the bathrooms compared to other measurements made in this building. To accurately measure the manipulation noise, we must thus first ensure that the airborne sound insulation complies with the requirements between the facilities.

4.3. Attenuation effects and reproducibility

A detailed analysis of the measurements allows us to study the attenuation in the constructions (buffer floor, ascending/descending) and the influence of the execution (reproducibility).The study of the attenuation performances of a buffer floor is used to evaluate the propagation conditions in the structure. In constructions E1 and E2, we have determined that the average difference between the direct transmission (floor *N* to *N-1*) and indirect (floor *N* to *N-2*) was 13.6±3.9 dB.

This attenuation depends largely on the type of connection between the wall supporting service equipment and the floor. If the junction is similar between the wall and the floor on one side, and between the wall and the ceiling on the other side, the measurement direction is irrelevant. Thus for the case E1 and the E2 kitchen, the difference between the results of ascending and descending measurements is only 1.0±3.1 dB on average. However, in the case of E2 bathrooms, built in concrete boxes, there was a difference of 20.3±3.2 dB between the ascending and descending results. This can be explained by the different junction boxes placed on the ground (rigid contact with the structure) without rigid connection to the ceiling.

The measurement results allow us to detect not only structural but also execution defects. We performed similar measurements in various apartments on thirteen setups. The differences between the apartments are 4.3±2.1 dB and correlate only slightly with the type of installation or construction. This variability in the implementation conditions can be partly explained by the high sensitivity of this type of measurement, as it relates closely to how the facilities and the structure are connected.

4.4. Laboratory measurements

Noise levels of service equipment facilities depend not only on the structures but also on the systems used for fastening. Given the high in-situ variability of performance, it is preferable to evaluate the performances of these systems in a laboratory where conditions are better controlled. A first campaign of measurements has been conducted on the best manner to fasten a shelf in order to optimize its sound insulation. Initial results show that fixing with soft pads on lightweight construction only leads to small improvement (2 to 3 dB(A)).
Damping of the shelf (reduction of impact with soft layer, thin and heavy damping layer) leads to 7 dB to 10 dB improvements (emission and transmission levels). In our experimental conditions, minimal requirements of the standard are fulfilled only with double frame construction. New optimized solutions for the fixation of service equipment and fixed installation in buildings have to be developed, as there are very few products actually available and tested on the market.

5. Discussion

These first measurements campaigns have raised various problems or issues.

In situ measurements include all the parameters related to the type of construction, mounting system and quality of execution. To dissociate these parameters, it is necessary to have either a sufficient number of situations to conduct a representative statistical analysis or to carry out measurements under specific conditions, e.g. in laboratory conditions.

Our results are based solely on wooden structures. It is important to compare them later to those obtained on massive constructions. This can be done either by analyzing a large amount of data obtained on both types of construction or by studying specific facilities. The Fermacell company has, for instance, tested the noise of the hammer falling on a Powerpanel TE shower tray under different installation conditions and different structures (concrete slabs or wooden floors). The results show better results on the wooden floor than on the concrete floor (from 16 dB for the simplest fixing to 2 dB for the most effective solution). This is partly explained by the fact that the base wooden floor is 11 dB better than the concrete floor.

Analysis of the results was carried only on the mean values of maximum level in dB(A). To account for the spectral characteristics of noise in wooden constructions, particularly at low frequencies, one should perform frequency and time analysis of various results. This would allow on one hand to better differentiate the response depending on the type of construction (light versus heavy) and on the other hand to obtain a finer characterization of the subjective response.

Conclusions from the analysis of the measurement technique (see §4.2) suggest several clarifications to add to the standard SIA181 regarding:

- the number and position of measurements for bathtubs and showers (breakdown between bottom and periphery).
- the need for a measurement of airborne insulation, in order to guarantee the purely structure-borne noise transmission of service equipment (airborne insulation must meet or exceed the minimum requirements of the standard).
- harmonizing the requirements for impact noise and noise from service equipment, for example by adapting the K4 coefficient for some installations.

6. Conclusions

The first results of our study on service equipment and fixed installation manipulation noise in wooden structure buildings show that:

- legal requirements are often exceeded (52% in the bathrooms and 64% in kitchens).
- it is necessary to further improve the reliability of the measurement technique (precise definition of the position of the hammer, checking the air contribution) and evaluation (consistency with the impact noise requirements).
- the measurement technique highlights the qualities and defects of constructions (in particular attenuation at junctions between walls and floor/ceiling) and the common execution problems (poor reproducibility).
- the limited efficiency of the fastening uncoupling systems for lightweight constructions and the need for double elements in order to meet the requirements.

The second part of this study, based on laboratory measurements, should allow a better distinction between the contributions related to fastening systems and those related to execution issues, and to minimize their effects.

Acknowledgement

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