Latest results on the characterization of waste water pipes according to the draft EN 14366 (session "Characterisation of structure-borne sound sources") "Euronoise 2021"

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Abstract
Structure-borne sound of waste water pipe systems often dominates disturbing noise from sanitary installations in buildings. While flushing the cistern of a WC, water runs through the ceramic into the down pipe of the waste water system and causes there intensive vibrations on the pipe structure. These vibrations are led into building elements (e.g. installation wall) passing fixing elements like pipe clamps. For the determination of the acoustic performance of the pipe system, including the fixing elements, it can be separated from the sanitary installation and build up in a special test facility according standard EN 14366 [1]. The results of these measurements not only allow to compare different pipe systems, but also to create input data for prediction calculations according standard EN 12354-5 [3]. Therefore, EN 14366 will be updated soon. Besides the airborne sound power in the installation room, the output of the new measurement method will deliver blocked force, free velocity and source mobility as the complete source data.
The presentation will show first results of the draft standard EN 14366 [2], determined in the test facility at Fraunhofer IBP in Stuttgart.

Keywords: installation noise, wastewater installations, structure borne sound power, blocked force, source characterization.

1 Introduction

Noise from waste water installations is generated by the flow of water in a piping system. Depending on the volume flow rate inside the pipe, discontinuities in the down pipe installation, like inlet-tees or at the end the basement bend, cause structure borne vibrations on the pipe wall and the system itself. Due to the connection of the pipe system with fixing elements (pipe clamps) the vibrations are led into the building structure. Consequently, radiated as airborne sound, the waste water noise often is a problem in noise protection in adjacent rooms in need of protection in buildings.
A first standard on laboratory sound measurements of waste water installations (EN 14366) was published in 2004. The future standard will focus on laboratory characterization of waste water installations for both airborne and structure-borne sound by using the same characterization methods as for building service equipment with the measurements methods following EN 15657 "Acoustic properties of building elements and of buildings - Laboratory measurement of structure-borne sound from building service equipment for all installation conditions" [4]. The results of the measurements according the revised standard draft prEN 14366 [2] can be later used for comparing systems and as well for prediction calculations in standard EN 12354-5

"Building acoustics - Estimation of acoustic performance of building from the performance of elements - Part 5: Sounds levels due to the service equipment" [3].
The paper shows first measurement results of the structure borne sound of a plastic waste water pipe system according the draft prEN 14366 [2]. The other parameters such as airborne sound radiation and free velocity are not considered further here.

2 Test facility set-up and used waste water pipe system

The noise of sanitary installations can be measured in a special test facility at the Fraunhofer Institute for Building Physics in Stuttgart. This test facility, specially designed for measuring very low sound levels, can be used to test all types of domestic installations under practical conditions. The installation wall set-up in the test facility has a weight per unit area of 220 kg/m² and thus corresponds to the lightest single-shell solid wall permitted for mounting sanitary installations according to the German Standard DIN 4109 without special proof of suitability. These wall properties also comply with the specifications of EN 14366.
The test setup and the performance of the measurements are carried out according to EN 14366. In the test facility, the wastewater system extends over several floors, as in practice (see Figure 1). The measurements are performed at stationary water flow with volume flows of 0.5, 1.0, 2.0, and 4.0 l/s (for pipes with an inner diameter of 100 – 125 mm).
The sewage system used, consisted of a commercially available plastic pipe system (OD 110) with steel pipe clamps with rubber inserts. Detailed characteristics such as wall thickness and density of the tested pipes, as well as the fastening details of the pipe clamps, are listed in Table 1.

Table 1 – Detailed properties of the tested waste water pipe system (see. Figure 1).

Material:	„plastics", PP-MD, polypropylene with mineral additives
Straight pipes:	DN 110 (nominal diameter) / OD 110, wall thickness = 3,6 mm, density = 1,3 g/cm³
Fittings:	inlet-t 87° IR and 2 x 45° basement bend, wall thickness = 3,6 mm, density = 1,2 g/cm³
Pipe clamps:	steel parts with profiled rubber inlay, diameter 108-114 mm, torque 3 Nm, studs M10 and plastic dowels

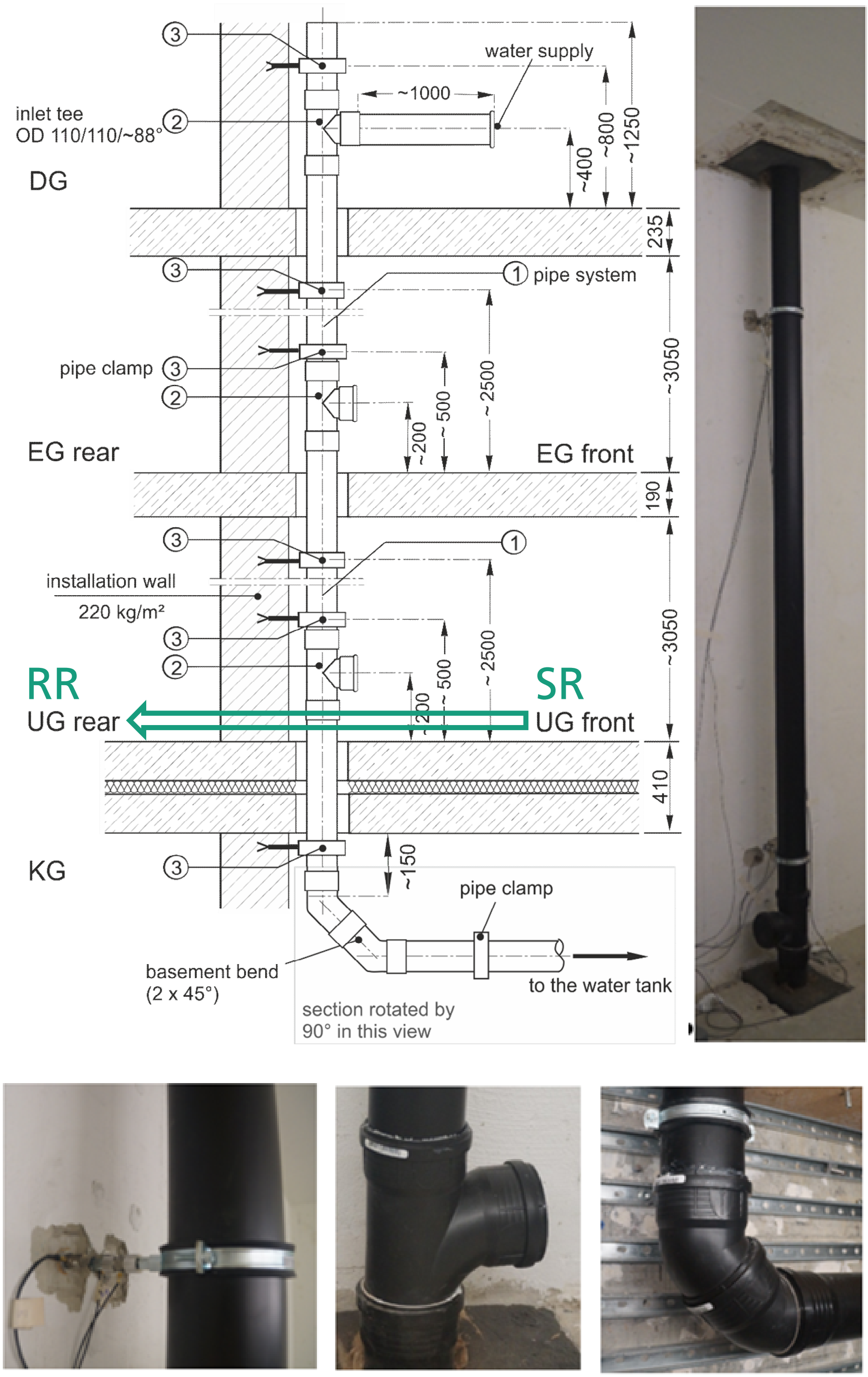

Figure 1 – Top left: Test facility with standard set-up for measurements according EN 14366 [1], [2]; (RR: receiving room, SR: source room).
Top right: Test object, waste water plastic pipe system (OD 110) with steel pipe clamps with rubber inlay installed in the test facility (SR), with measurement equipment.
Bottom (from left to right): - Details of waste water system: Straight pipe with steel pipe clamp with rubber inlay and measurement equipment. - Inlet tee, closed with end cap. - Basement bend (2 x 45°).

3 Measurement procedures

Several measurement methods are possible for determining the structure-borne sound power or blocked force of waste water pipes. Each method has its advantages and disadvantages, and the most important differences are described below. In general, the procedures can be divided into direct method (3.1) and indirect method (3.2). In addition, the current method (EN 14366:2020-02) is briefly presented in order to be able to draw a comparison at the end.

3.1 "Direct method", real part of the cross power spectrum

In order to directly determine the structure-borne sound power of a sewage system, in principle only one measurement is necessary. Only to determine the blocked force, the input mobilities at the discharge points should be determined separately. However, this measurement, together with a few additional measurements, also forms the basis for the indirect measurement methods and is therefore also referred to as the calibration of a reference structure borne sound source.

3.1.1 Calibration of the reference structure borne sound source (inertial shaker)

As a reference structure borne sound source an inertial shaker with a total mass of approx. 1.5 kg (see Figure 2) is chosen. The shaker was attached to the wall, exactly at the two contact points where later the two pipe clamps are mounted, with some adapters and a force transducer in between. With the two accelerometers straight next to the point of excitation it is possible to determine the real part of the receiver mobility ($Re(Y_{R,low,j})$) (installation wall) and also the real part of the cross-power-spectrum ($L_{Ws,cal,j}$) for the power substitution methods. The two mobilities of the two contact points were averaged according equation (2). Within the same measurement, the average velocity ($L_{<v>,cal,j}$) of the wall (Figure 2, right picture) was measured. To determine the average velocity at the wall 32 positions were measured, of which four representative positions were selected for further measurements. In addition to that, the average sound pressure level ($L_{<a>,cal,j}$) is measured in the receiving room behind the installation wall.

Figure 2 – Test set-up for the measurements with a reference structure borne sound source. Force and velocity (real part of the cross-power-spectrum) measured on the contact point of a shaker with the installation wall (left, source room). In addition, the average velocity of the wall (right picture) and the sound pressure level is measured in the receiving room.

3.1.2 Direct characterization of the installed waste water pipe system

Since waste water systems are only connected to the wall via two contact points, it is also very easy to measure the structure borne sound power directly. The method is the same as for the reference source and L_{Ws} corresponds to the real part of the measured cross power spectrum. For the measurements, two force transducers and four accelerometers are required to simultaneously determine the introduced structure-borne sound power $L_{Ws,j}$ at both pipe clamps (see Figure 3). The two $L_{Ws,j}$ are summed up to L_{Ws} and according equation (1) $L_{Fb,eq,<direct>}$ can be calculated with the measured real part of the receiver mobility. The advantage of this method is, that it does not require the measurement of an average velocity level on a receiving structure (e.g. installation wall), but for practical application in the day-to-day operation of a test laboratory, it is too time-consuming to install the force transducers.

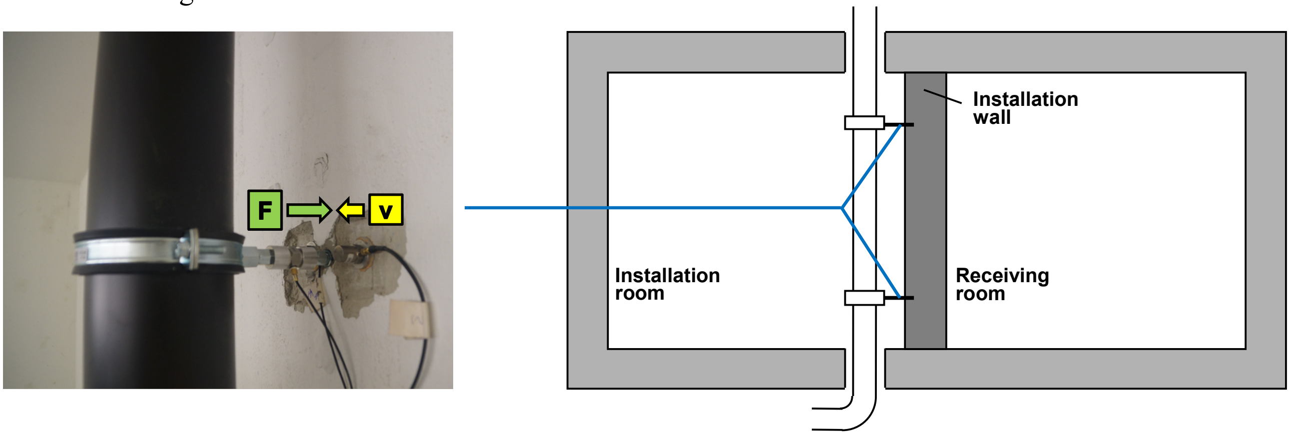

Figure 3 – Test set-up for direct measurement of the structure borne sound power of the pipe system. Force and velocity (real part of the cross-power-spectrum) measured on the contact points of the pipe clamps with the installation wall (source room) caused by the installed pipe system at various flow rates.

3.2 „Indirect methods“ or “Power substitution methods”

The indirect methods as the power substitution method are more practical for day-to-day operation of a test laboratory. The measurements can be performed in two steps. First a calibration of the test facility is necessary which is done here according chapter 3.1.1. This reference measurement “can be done once and checked periodically” ([2], 5.2.1). With the reference measurement, it is possible to determine the structure borne sound power or the blocked force of a specimen in a two room test lab (lab with source and receiving room) in two different ways. One is described in draft prEN 14366:2021-06 for which even only one room (source room) with an installation wall or receiving plate is required (see 3.2.1). The other method requires both, a source room and a receiving room behind an installation wall (see 3.2.2).

3.2.1 “Power substitution method” according draft standard prEN 14366:2021-06

For the method described in the draft of future EN 14366 the velocity on a receiving plate (installation wall) is measured. The difficulty here is to get the “real” average velocity, for which it is recommended to do some pre-measurements to evaluate some suitable positions on the plate (see 3.1.1). A second problem can occur when the systems are highly optimised and the induced velocity becomes very small, requiring a good choice of accelerometers with a high sensitivity but also a possible measuring range up to at least 4 to 5 kHz. The measurement itself is a combination of calibrating the wall with a reference source as described in 3.1.1 and measuring the pipe practically installed on the wall (see Figure 4). With the obtained measurands it is possible to calculate the structure borne sound power acc. equation (1). With the real part of the mobility (equation (2), measurement acc. 3.1.1) at both connecting points, the blocked force $L_{Fb,eq,<v>}$ is calculated acc. equation (3).

$$L_{Ws} = 10\lg\left(\frac{1}{2}\sum_j^2 10^{L_{Ws,cal,j}/10}\right) + L_{<v>} - 10\lg\left(\frac{1}{2}\sum_j^2 10^{L_{<v>,cal,j}/10}\right) \quad (1)$$

$$\mathrm{Re}(Y_{R,low,eq}) = \frac{1}{2}\sum_j^2 Re(Y_{R,low,j}) \quad (2)$$

$$L_{Fb,eq} = L_{Ws} - 10\lg\left(\frac{Re(Y_{R,low,eq})}{Y_0}\right);\ Y_0 = 1\ m/Ns \quad (3)$$

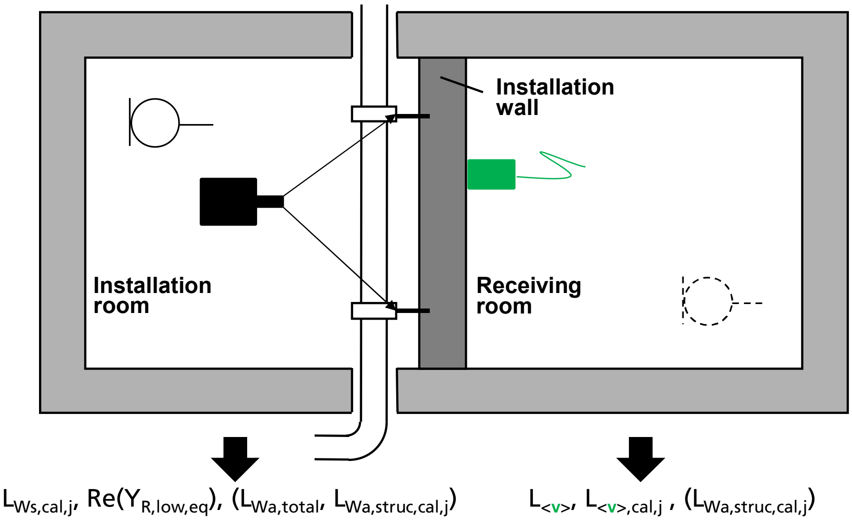

Figure 4 – Test set-up according draft standard prEN 14366:2021-06 [2]. Airborne sound pressure level (airborne sound power) measured in the installation room (source room) with pipe installation and measurement of the blocked force of the pipe system with results of the calibrated reference source and the mean velocity level on the installation wall caused by the installed pipe system.

3.2.2 "Power substitution method" using the "structure borne/airborne transfer function"

It is also possible to measure the airborne sound in a receiving room behind the installation wall (see Figure 5) and calculate, using the airborne sound pressure level and the sound power level from measurements with the reference source, the structure-borne sound power acc. equation (4) [5]. The advantage of this method is, there is no need of sensitive velocity measurements in the day-to-day operation of the test laboratory and only one high sensitive microphone on a rotating microphone boom with several fixed positions is sufficient to evaluate the blocked force $L_{Fb,eq,<a>}$ acc. equation (3).

$$L_{Ws} = 10\lg\left(\frac{1}{2}\sum_{j}^{2} 10^{L_{Ws,cal,j}/10}\right) + L_{<a>} - 10\lg\left(\frac{1}{2}\sum_{j}^{2} 10^{L_{<a>,cal,j}/10}\right) \quad (4)$$

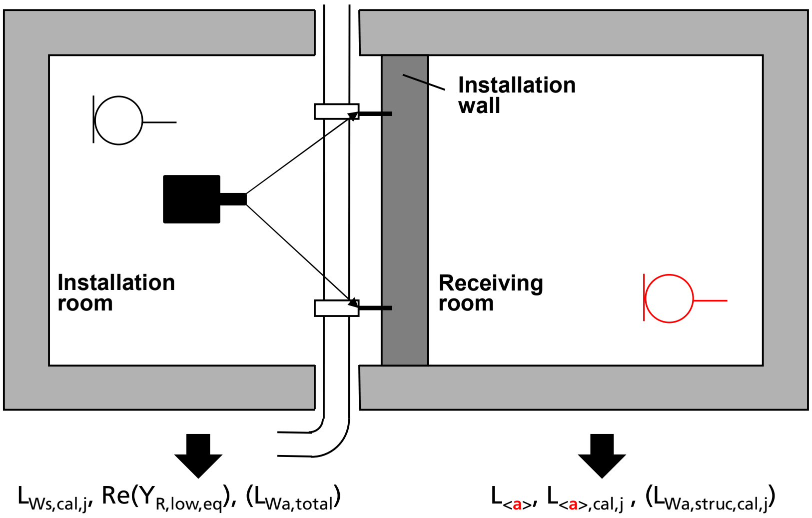

Figure 5 – Test set-up with structure-borne/airborne transfer function. Airborne sound pressure level (airborne sound power) measured in the installation room (source room) with pipe installation and measurement of the blocked force of the pipe system with results of the calibrated reference source and the mean airborne sound pressure level in the receiving room behind the installation wall caused by the installed pipe system.

3.3 Standard method according current standard EN 14366:2020-02 and link to the new draft

The current method relies exclusively on airborne sound measurements in the sending and receiving room (see Figure 6) and a special measurement of the wall structural sensitivity. The results of this standard are sound pressure levels and no structure borne sound power or blocked force, as they are needed for prediction models described in EN 12354-5 [3]. However, in the draft of the future standard (draft prEN 14366:2021-06 [2], Annex C) there is a link to calculate blocked forces from the airborne sound levels according the current standard EN 14366:2020-02. With the “normalized structure borne sound level” L_{sn} (only airborne sound measurements acc. EN 14366:2020-02) it is possible to calculate a sound power $L_{Wa,struc}$ (equation (5)) and together with the test wall structural sensitivity L_{SS} (also acc. EN 14366:2020-02) the calculation of a blocked force $L_{Fb,eq,<2020>}$ acc. equation (6) is applicable.

$$L_{Wa,struc} = L_{sn} + 4\ dB \quad (5)$$

$$L_{Fb,eq} = L_{Wa,struc} - L_{SS} + 10\lg(\rho c W_0 / F_0^2 k^2) \quad (6)$$

LSS: test wall structural sensitivity acc. EN 14366:2020-02; ρc: characteristic impedance of air (ρ in kg/m², c in m/s); k: wave number (m^{-1}); W_0: reference power ($W_0 = 10^{-12}$ Watt); F_0: reference force ($F_0 = 10^{-6}$ N).

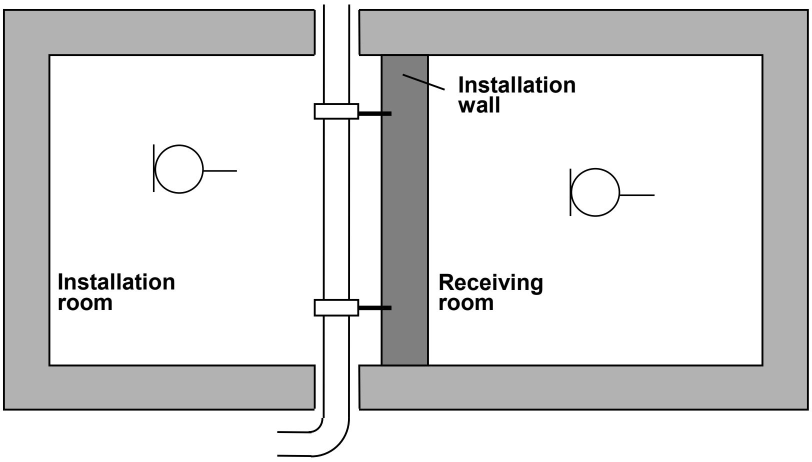

Figure 6 – Test set-up according the current standard EN 14366:2020-02 [1]. Airborne sound pressure level measured in the installation room (source room) with pipe installation and in the receiving room behind the installation wall.

4 Comparison of the different measurement methods

All methods provide a spectrum of the blocked force and according the draft of the standard there is no single number value to compare the results directly. For comparison, we first look at the spectra (see 4.1.1). In order to be able to easily compare the quality of the measurement results, it is now possible to calculate single number values following EN 12354-5 [3] (see 4.1.2).

4.1.1 Comparison of "direct method", "draft prEN 14366", "structure borne/airborne transfer function" and link to EN 14366:2020-02

For the comparison of the three different methods ("direct method", "draft prEN 14366", "structure borne/airborne transfer function") and the comparison with the current EN 14366 (link to EN 14366:2020-02) we choose the measurements of a pipe system as described in 2. The results of the measurements with a volume flow rate of 4.0 l/s and 0.5 l/s are shown in Figure 7. The results at 4.0 l/s are an example, where the values match very well, because there is no problem with flow interruptions or ground noise level issues. The flow rates at 2.0 l/s and 1.0 l/s, which are also required to measure acc. the standard, are in the same range of deviations. At flow rates 4.0 l/s, 2.0 l/s and 1.0 l/s the water slides down on the pipe wall and provides a stable excitation of the pipe system. The results with 0.5 l/s have slightly larger deviations between the methods. One reason for the poor reproducibility of the results at 0.5 l/s are quite often interruptions of the water flow inside the pipe as a result of the small flow rate. Another reason is (maybe not with this not acoustically optimized system), that the methods have different limits because of the effect of background noise on the results. Overall, the results vary within a range of approx. 3 dB (averaged over all four volume flows and all one-third octave bands from 50 Hz to 5 kHz). In higher and low frequencies there are deviations up to approx. ±5 dB. In the middle frequencies, the deviations in all one-third octave bands are less than ±1 dB.

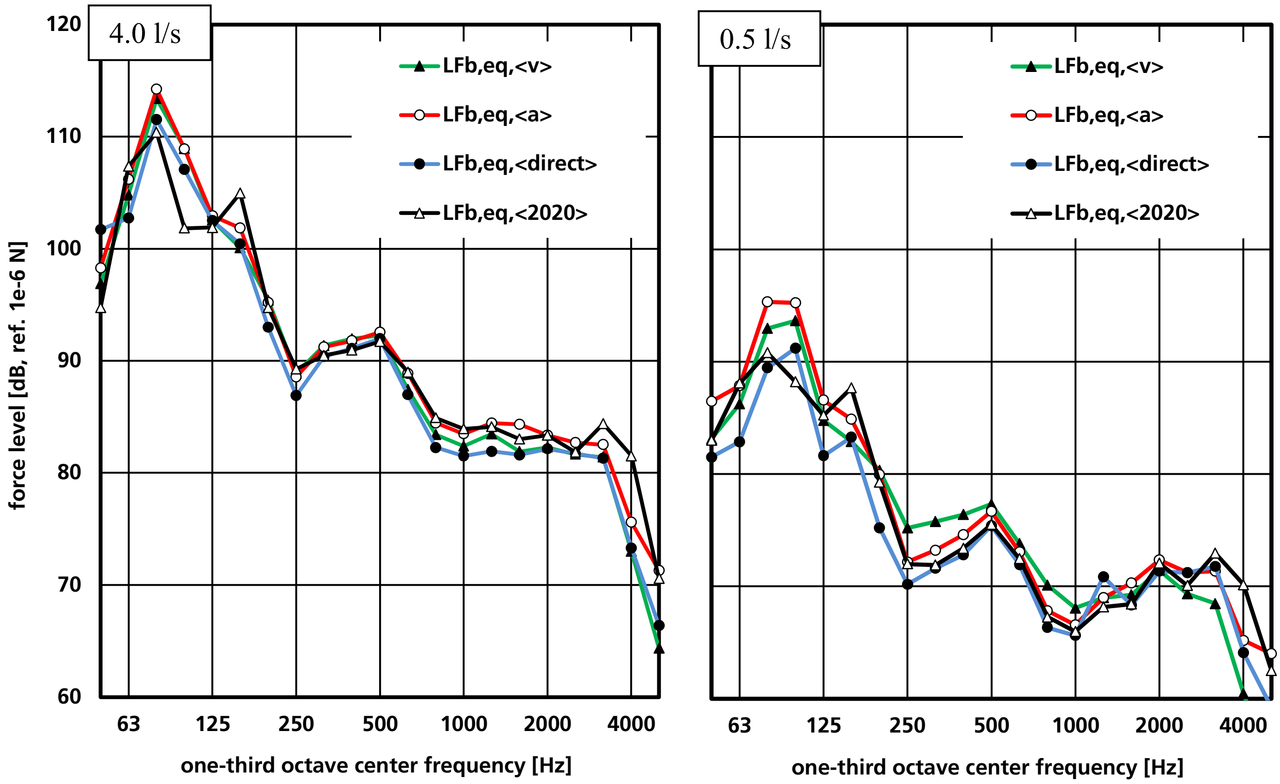

Figure 7 – Comparison of the measurement results from the different methods to determine the blocked force of the pipe system at two different flow rates. Left: 4.0 l/s, Right: 0.5 l/s.
green curve: "Power substitution method, according draft standard prEN 14366", $L_{Fb,eq,<v>}$, red curve: "Power substitution method, using the structure borne/airborne transfer function" $L_{Fb,eq,<a>}$, blue curve: "direct method", $L_{Fb,eq,<direct>}$, black curve: Link to EN 14366:2020, $L_{Fb,eq,<2020>}$

For the calculation of $L_{Fb,eq,<2020>}$ (see 3.3) the measurement of LSS was not redone at this time, so a "practical" case is simulated if the comparison of an "old" measurement according to EN 14366:2004/2020 with the new method is aimed. In some one-third octave bands we have slightly higher deviations of the $L_{F,eq,<2020>}$ to the new methods, but overall the deviations are in the range described above. The influence of the deviations on a simply comparable single number value is shown below (4.1.2).

4.1.2 Comparison of the single number values, calculated following EN 12354-5, with the blocked forces derived from the different methods

With the current EN 14366 it is possible to compare different pipes or systems directly with single number values, but with the future standard this is no longer desired. To obtain single number values, these must be calculated in a simulation or prediction model for buildings, e.g. to determine the sound pressure level in a room and compare it with requirements or the acoustic performance of other products. For buildings in solid construction, only the blocked force ($L_{Fb,eq}$) is initially required as the input variable of the pipe system. At the IBP we chose a model following EN 12354-5 and used the IBP test facility (see Figure 1) as a reference building to obtain comparative values. In the model, the direct transmission through the test wall and the flanking transmissions are taken into account. At this early stage of the model and the first calculations with the presented results of $L_{Fb,eq}$ we have sum levels that are systematically about 3 dB below the directly measured values, but for the direct comparison of the different presented methods, this is not essential at the moment. Table 2 shows the results for all four volume flow rates and all four methods. To determine the deviations between the methods, the method according to draft preEN 14366:2021-6 is chosen as reference (Table 1, #1). As we can see in the last column, the average deviation between the different methods is about

±1 dB and if we look more closely in the table, a maximum of only 2 dB between two discrete methods/volume flows.

Table 2 – Calculated Installation sound levels ($L'_{n,s,total}$ [dB(A)]) with the different blocked forces ($L_{Fb,eq}$). The method of draft prEN 14366_2021-06 was chosen as the reference to show deviations in a single number between the results/methods of determining $L_{Fb,eq}$.

#	$L'_{n,s,total}$ [dB(A)]	4.0 l/s	2.0 l/s	1.0 l/s	0.5 l/s	Average deviation
1	$L'_{n,s,total}$ ($L_{Fb,eq,<v>}$)	24,3	20,7	17,4	9,3	reference
2	$L'_{n,s,total}$ ($L_{Fb,eq,<a>}$)	24,8	21,2	17,7	9,2	+ 0,3
3	$L'_{n,s,total}$ ($L_{Fb,eq,<direct>}$)	23,4	19,8	16,6	7,6	- 1,1
4	$L'_{n,s,total}$ ($L_{Fb,eq,<2020>}$)	25,4	21,8	18,2	9,3	+ 0,8

5 Conclusions

All the methods (“direct method”, “draft prEN 14366”, “structure borne/airborne transfer function” and “link to EN 14366:2020-02”) considered for determining the blocked force of a wastewater system working satisfactorily. Although in some one-third octave bands of the blocked forces the deviation is up to ±5 dB, the “final results” of a practically comparable single number value calculated in a model (following EN 12354-5) are highly comparable. According to the current state of research, this is only one of the first measurements in relation to draft prEN 14366:2021-06, and in order to verify these results, it is necessary to test further pipe systems, which is in progress at the Fraunhofer Institute for Building Physics IBP in Stuttgart.
Even though the draft standard suggests measuring the velocity on a receiving plate, in laboratories with an existing receiving room, the “structure borne/airborne transfer function-method” can be used equally. Measurements of airborne sound pressure levels are much less time consuming and sensitive in practical “everyday” laboratory use compared to the structure-borne sound measurements with several individually attached accelerometers. Furthermore in terms of signal-to-noise ratio, a measurement with high-sensitivity microphones in a well-isolated test laboratory could prove advantageous for the characterisation of well-optimised waste water pipe systems.
The theories and studies to date assume a uniform introduction of structure borne sound at the attachment points, but many systems used in practice have very different mounting conditions of the pipe clamps at the top and bottom positions on the installation wall. In future studies, these variants must be investigated and compared more detailed. In addition, the practical implementation of the missing values to be determined in accordance with draft prEN 14366:2021-06 must be tested. These include the measurement of the free velocity, the source mobility and the radiated airborne sound power of the pipe system in the installation room.

References

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