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Acoustic performance of wastewater installation systems in heavy and lightweight buildings considering source-receiver mobility interaction

Yohko Aoki[1], Simon Müller[1], Sven Öhler[1]
[1]*Fraunhofer Institute for Building Physics IBP, Department Acoustics, Stuttgart, Germany*

Abstract

Drainpipe noise can be a prominent annoyance and privacy issue in modern housing. Heavy pipe systems with low vibration mobility are commonly used to achieve acoustic comfort in solid constructions. However, it remains unclear whether the vibroacoustic performance of pipe systems in massive constructions can be transferred to lightweight constructions.
This study examines the influence of source–receiver mobility interaction on drainpipe noise transmission. Laboratory measurements according to EN 14366-1 were performed for a heavy, low-mobility pipe system and a lighter standard system, each mounted on heavy and lightweight wall types. The measurements are complemented by EN 12354-5-based predictions, enabling systematic variation of the receiving construction.
For the investigated configurations, the results show that pipe performance depends on source–receiver mobility interaction and the normalized building transfer function. On the heavy wall, both pipe systems produced comparable sound pressure levels and single-number quantities. On lightweight constructions, this performance order was not necessarily preserved: depending on receiver mobility and low-frequency transfer behaviour, the advantage of one pipe could increase or reverse. These findings indicate that wastewater-system performance determined in one construction cannot be transferred directly to other constructions.

Keywords: *wastewater installation, structure-borne noise, lightweight construction, EN 14366-1*

Corresponding author: *yohko.aoki@ibp.fraunhofer.de*

1. Introduction

Drainpipe noise in residential buildings is typically moderate but clearly audible in adjacent rooms and dwellings. This audibility can cause annoyance and privacy concerns, as sanitary use and occupancy may become perceptible to others. Improving wastewater-system acoustics is therefore an important aspect of building quality.
Common noise-reduction practice is to increase pipe density, resulting in heavy wastewater pipe systems with low mobility. These systems are considered acoustically advanced and are tested according to EN 14366-1 [1] on heavy, solid, homogeneous walls at Fraunhofer IBP, Stuttgart. However, they require more material, are costlier, and have a higher environmental impact. Lightweight drainpipe systems offer economic and sustainability benefits but are generally considered acoustically less effective.
Prediction methods according to EN 12354-5 [2] are established for service-equipment noise on solid wall constructions. The 2023 update extends the method to all construction types, including lightweight walls such as drywall partitions. However, application data and experimental verification for wastewater installations on such partitions remain limited.
This study considers six combinations of two wastewater pipe systems and three wall constructions. The pipe systems comprise a heavier, acoustically advanced system and a lighter standard system. The wall constructions include one heavy wall and two lightweight walls: a drywall partition and an example timber frame structure in Annex G.4 of EN 12354-5 [2]. In lightweight constructions, source and receiver mobilities are of comparable magnitude and therefore interact. It is therefore unclear whether increasing pipe density and reducing mobility remains the most effective strategy. This study evaluates the effects of source–receiver mobility interaction and the building transfer function on drainpipe noise, compares measured and predicted results for selected pipe/wall

configurations, and assesses the applicability of the extended prediction method in [2] to lightweight constructions.

2. Experiments

Four pipe/wall configurations were tested in the IBP laboratories. A heavier acoustically advanced system (Pipe L) and a lighter standard wastewater system (Pipe H) were each mounted on a heavy sand-lime brick wall and a lightweight drywall partition. Both pipes consist of three-layer, mineral-reinforced polypropylene (PP-M) with shaped sockets; the fittings are single-layer PP-M components. Material and geometrical parameters are listed in Table 1. Images are omitted for confidentiality.

Table 1. Material and geometrical properties of the tested pipes.

	Pipe H	Pipe L
density, g/cm³	1.2	1.8
line density, kg/m	1.56	3.24
diameter, mm	110	110
wall thickness, mm	3.8	5.5

The heavy sand-lime brick wall is part of the existing P12 installation test facility at IBP, designed in accordance with EN 14366-1 [1]. It corresponds to the lightest single-shell solid wall permitted for sanitary installations under DIN 4109 without additional suitability proof.
The lightweight partition was built specifically for these experiments as an additional internal wall in the P10 installation test facility at IBP, where installations can be tested in combination with arbitrary installation walls, such as drywall partitions. It is a W112.de drywall partition (Knauf AG) [3], consisting of a 75 mm metal stud frame (CW 75, 625 mm stud spacing), 60 mm mineral wool (ISOVER Akustic TP1) in the cavity, and two 12.5 mm gypsum boards (Knauf Wallboard) on each side. The boards are screwed to the studs, joints are filled with gypsum filler, and perimeter joints are sealed with acrylic (Fig. 1 (a)). Both P12 and P10 are designed for very low sound-level measurements and allow domestic installations to be tested under practical two-floor conditions; room differences are therefore not expected to significantly affect the results. Key wall and facility parameters are summarized in Table 2.

Table 2. Material and geometrical properties of the Fraunhofer IBP installation test facilities P12 and P10.

	heavy wall in P12	lightweight wall in P10
surface density, kg/m²	220	---
wall thickness, mm	115+plaster	125
wall area, m²	15.25	12.3
sending room volume, m³	52.6	19.7
receiving room volume, m³	70.4	37.8

In both facilities, the pipe setup follows the standard configuration in [1]: vertical wastewater pipes, three inlet tees (≈87.5°), a basement bend (2 × 45°), and a horizontal drain section. During testing, the basement and ground-floor inlet tees are closed with manufacturer-supplied lids.
Both pipe systems are fixed to the installation wall with standard rubber-lined steel clamps. On each floor, one fixing clamp is installed in the upper wall area and one sliding clamp in the lower wall area (Fig. 1 (b)). The mounting concept is identical for both wall types; only the local reinforcements differ. In the lightweight wall, 20 mm wooden boards are inserted between the studs behind the gypsum boards at the clamp positions. The clamps are fixed to these reinforcements with M10 threaded rods. On the solid P12 wall, they are anchored directly using M10 bolts and plastic dowels.
Acoustic measurements were performed at steady water flow rates of 0.5, 1.0, 2.0, and 4.0 l/s. For each pipe/wall configuration, the A-weighted normalized equivalent sound pressure level in the receiving room, $L_{A,eq,n}$, was determined.

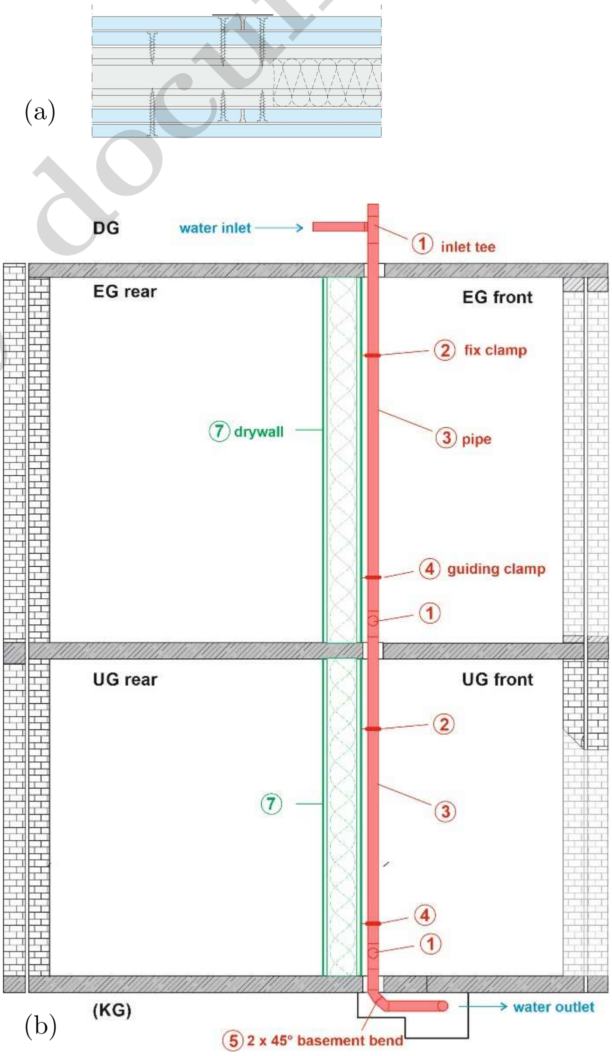

Figure 1. Sketch of the lightweight construction: (a) wall section view, ©Knauf [3]; (b) laboratory arrangement in P10, ©Fraunhofer IBP.

3. Prediction Method

To complement the experiments, receiving-room sound pressure levels in both test facilities were predicted according to EN 12354-5. In addition to the two tested IBP wall configurations, an example lightweight timber-frame wall with timber studs from Annex G.4 of EN 12354-5 [2] was considered as a third wall type.

The prediction separates structure-borne and airborne transmission paths. Following EN 12354-5, Annex G.4.1 [2], structure-borne transmission is assumed to dominate; the airborne path is therefore neglected. For the structure-borne path, the installed structure-borne power is determined first and then converted into the corresponding normalized receiving-room sound pressure level using the normalized building transfer function, $D_{TF,n}$, of each wall or transmission path:

$$L'_{ne,s} = L_{Ws} + D_{TF,n} \qquad (1)$$

Applying A-weighting to the apparent normalized sound pressure level $L'_{ne,s}$ from Eq. (1) gives the A-weighted normalized equivalent sound pressure level, $L_{\mathrm{A,eq,n}}$.

The installed power L_{Ws} in Eq. (1) is:

$$L_{Ws} \approx 10\log_{10}\left(\frac{\mathrm{Re}(Y_{R,eq}).Y_0}{1+\frac{|Y_{R,eq}|^2}{|Y_{S,eq}|^2}}\right) + L_{Fb,eq} \qquad (2)$$

where $Y_{R,eq}$ and $Y_{S,eq}$ are the equivalent receiver and source mobilities, respectively, and $L_{Fb,eq}$ is the single equivalent blocked force level of the source. With $Y_0 = 1$ (m/s)/N.

The method is applicable to any wall type and source-receiver combination using frequency-dependent source and receiver parameters. Pipe source properties ($L_{Fb,eq}$ and $|Y_{S,eq}|$) were derived indirectly from measurements on the heavy P12 wall, which fulfils the standard installation conditions of EN 14366-1. Receiver properties were measured according to EN ISO 10848-1 using a shaker as a calibrated structure-borne reference source.

4. Results

This section compares measured and predicted results for the investigated wastewater systems and wall configurations. For confidentiality, absolute pipe-system results are not reported. Instead, the source mobility and blocked force of the nominal case, Pipe H on the heavy wall at 4.0 l/s, are replaced by those of the example pipe in Ref. [5]. To preserve the relative source and receiver mobilities, the reference mobility was increased by 2 dB. All other values are given relative to the nominal case, V_n.

$$V'_{\mathrm{exp}} = V_{\mathrm{exp}} + (V_{\mathrm{Ref.[5]}} - V_n) \qquad (3)$$

where V denotes the source mobility or equivalent blocked force level, and V' the corresponding value used here.

4.1 Source and receiver mobility

Figure 2 shows the mobilities of the two wastewater systems and three wall configurations, expressed in decibels relative to 1 [(m/s)/N]. Although EN 14366-1 normally uses a linear mobility scale, Eq. (2) applies mobility logarithmically. A decibel representation is therefore more intuitive and directly comparable with installed power.

The coloured curves show the pipe mobilities. Due to its higher line density, Pipe L (blue) generally has lower mobility than Pipe H (red), particularly below 250 Hz, where the difference reaches about 5 dB. At individual frequencies, such as 320 Hz, this order is reversed.

The black curves show the receiver mobilities. The heavy wall remains well below both pipe mobilities over the entire range. The example lightweight wall [2] is closer to Pipe L but still clearly below both pipes. For lightweight wall P10, the receiver mobility lies between the two pipe mobilities at low frequencies and remains below them above 160 Hz, with smaller separation.

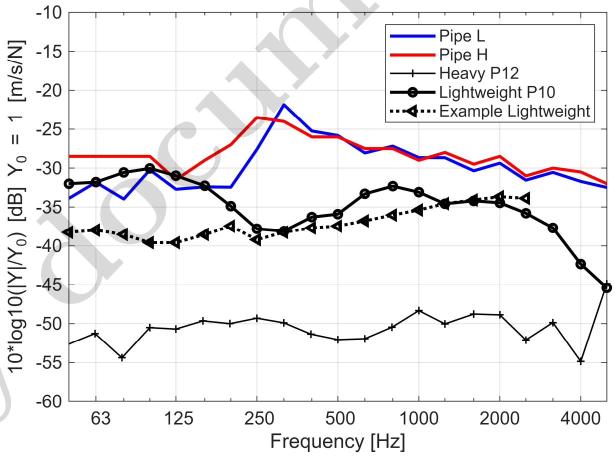

Figure 2. Measured source mobilities of Pipe L (blue) and Pipe H (red) at 4 l/s water flow; measured receiver mobilities of heavy wall P12 (black thin line with '+'), lightweight wall P10 (black solid line with 'o'), and the example lightweight wall G4 [2] (black dotted line with '<').

4.2 Installed power

Figure 3 compares the installed structure-borne power predicted with Eq. (2) for the two pipe systems on the two tested walls. On the heavy wall P12 (thin line with '+'), both systems show comparable installed power; neither pipe has a clear overall advantage. On the lightweight wall P10 (solid line with 'o'), the advantage of the lower-mobility Pipe L becomes more evident over most of the frequency range.

On the heavy wall, the installed-power difference is governed mainly by the equivalent blocked forces. Because the receiver mobility is much lower than the source mobilities, the source–receiver interaction term in Eq. (2) is negligible. Comparable installed power therefore indicates comparable blocked forces.

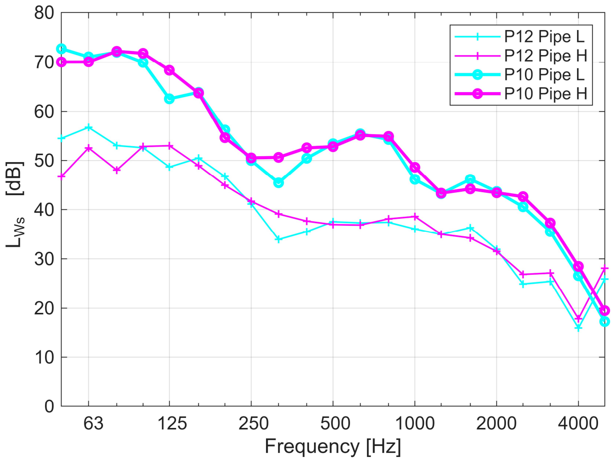

Figure 3. Predicted installed power at 4 l/s water flow on heavy wall P12 (thin line with '+') and lightweight wall P10 (solid line with 'o'); Pipe L (cyan) and Pipe H (magenta).

As receiver mobility increases towards source mobility, the interaction term in Eq. (2) becomes relevant. Figure 4 illustrates this behaviour: installed power rises with receiver mobility, reaches a maximum when source and receiver mobilities are comparable, and decreases again once receiver mobility exceeds source mobility.

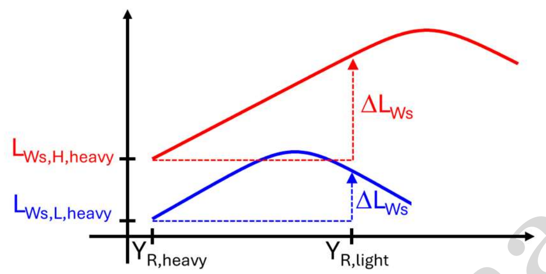

Figure 4. Schematic illustration of installed power as a function of receiver mobility according to Eq. (2): low-mobility Pipe L (blue) and high-mobility Pipe H (red).

As shown in Fig. 2, Pipe H remains above all receiver mobilities, so its installed power has not reached the maximum. In contrast, Pipe L has a lower mobility than lightweight wall P10 at some frequencies, placing its installed power close to, or beyond, the maximum as illustrated in Fig. 4. Therefore, the increase from the heavy to the lightweight wall is smaller for Pipe L, making its advantage more pronounced on P10.

In general, if receiver mobility remains below both source mobilities, the relative installed-power difference between the pipes is largely preserved. When receiver mobility approaches source mobility, the advantage of the lower-mobility source becomes more pronounced than on massive constructions. This conclusion is frequency-dependent: "lower mobility" must be assessed at each frequency, not treated as a fixed property of the denser pipe.

4.3 Normalized sound pressure level

Figure 5 shows the normalized building transfer function, $D_{TF,n}$, of the three receiving constructions. Over most of the investigated range, the heavy wall P12 has the highest values, followed by the example lightweight wall G4, while lightweight wall P10 has the lowest values. Thus, for equal installed power, P12 radiates most efficiently into the receiving room, whereas P10 shows the weakest conversion. At low frequencies, G4 approaches the heavy wall and even exceeds it at 50 Hz, indicating efficient low-frequency radiation.

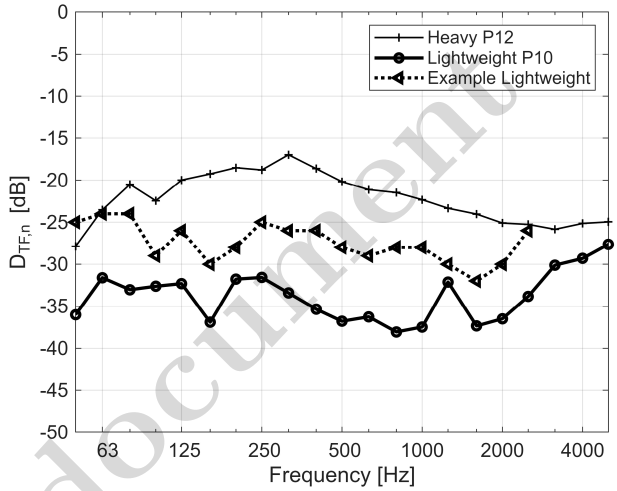

Figure 5. Measured $D_{TF,n}$ of heavy wall P12 (thin line with '+'), lightweight wall P10 (solid line with 'o'), and the example lightweight wall G4 [2] (dotted line with '<').

Figure 6 compares the measured (Exp.) and predicted (Sim.) A-weighted normalized equivalent sound pressure level, $L_{Aeq,n}$, for both pipes at 4 l/s. On the heavy wall P12 (Fig. 6 (a)), both systems show comparable levels. On lightweight wall P10 (Fig. 6 (b)), Pipe L is slightly lower over most of the spectrum, confirming that its performance advantage increases on the lightweight construction, as discussed in Section 4.2.

For the example lightweight wall G4 (Fig. 6 (c)), the trend differs: Pipe L (cyan) shows a higher low-frequency peak than Pipe H (magenta).

This behaviour results from two factors. First, Pipe L has higher installed power at low frequencies. Although Fig. 3 does not show G4, the tendency follows the heavy-wall case because G4 mobility remains more than 5 dB below both pipe mobilities (Fig. 2), making source–receiver interaction minor. Second, G4 has high $D_{TF,n}$ at low frequencies (Fig. 5), so it radiates structure-borne excitation efficiently in this range.

The combination of high installed power and high $D_{TF,n}$ therefore produces a higher low-frequency sound pressure level for Pipe L. Despite A-weighting, this peak remains the maximum within the considered spectrum.

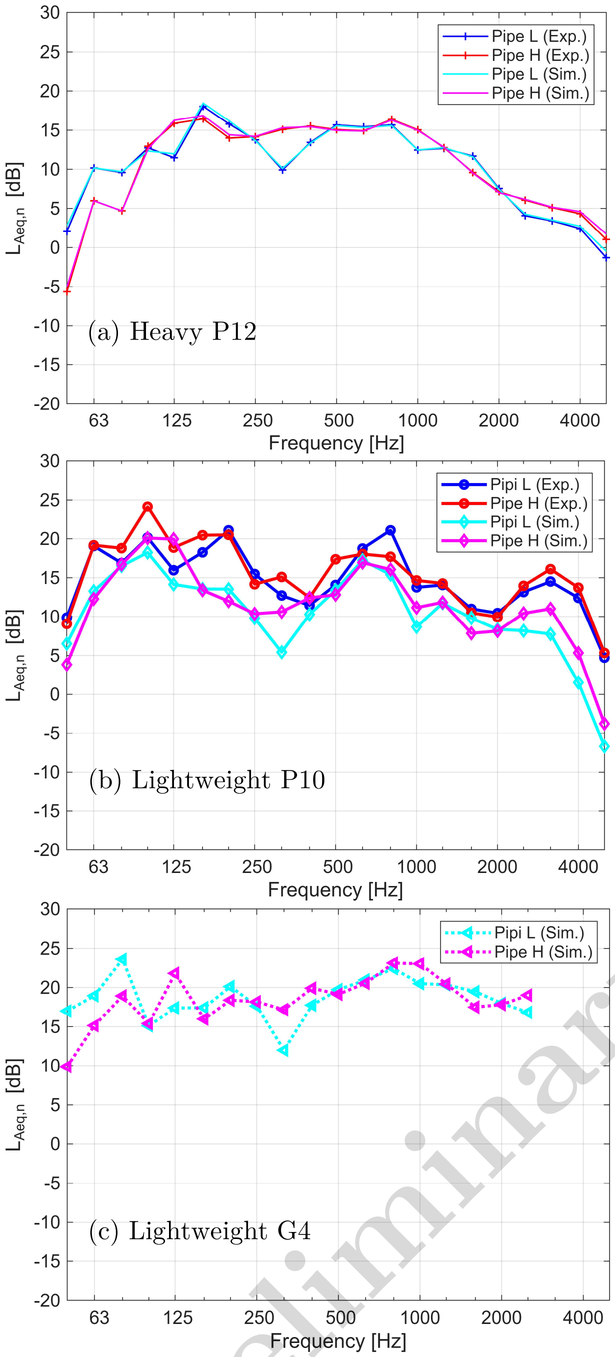

Figure 6. Comparison of measured and predicted $L_{Aeq,n}$ for Pipe L (blue measured, cyan predicted) and Pipe H (red measured, magenta predicted) at 4 l/s water flow on (a) heavy wall P12, (b) lightweight wall P10, and (c) example lightweight wall G4 [2].

4.4 Single-number quantity (SNQ)

The preceding discussion considered frequency-dependent spectra. For practical assessment, these spectra are often reduced to the single-number quantity (SNQ). Figure 7 summarizes measured and predicted SNQ values for both pipes on the three receiving constructions at 4 l/s.

On the heavy wall P12, both pipes show comparable SNQ values, with Pipe L slightly lower. On lightweight wall P10, Pipe L has a clearer advantage and lower SNQ values than Pipe H; measurements and predictions show the same tendency. On G4, the advantage reverses: Pipe L gives a slightly higher SNQ because its low-frequency peak in Fig. 6 (c) controls the maximum level. The difference is small but consistent with the spectra.

This comparison shows that the performance order of two pipes can reverse between constructions when their installed-power order changes with frequency. In such cases, $D_{TF,n}$ determines which frequency range dominates the resulting sound pressure level and thus the SNQ. Reversal is more likely for similarly performing pipes, but it can also occur when one pipe is clearly better in one construction if the installed-power order changes elsewhere in the spectrum. If one pipe has both lower blocked force and lower mobility over the full frequency range, its installed power remains lower for any receiver, and its SNQ advantage is preserved.

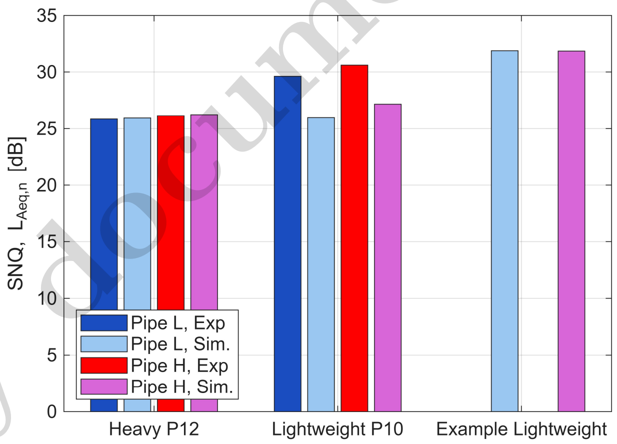

Figure 7. Measured (blue, red) and predicted (cyan, magenta) SNQ values of Pipe L and Pipe H at 4 l/s water flow on heavy wall P12, lightweight wall P10, and example lightweight wall G4 [2].

4.5 Measurement and prediction

Figures 6 (a) and 6 (b) compare measured (blue/red) and predicted (cyan/magenta) $L_{Aeq,n}$. On the heavy wall P12, predictions agree well with measurements, with deviations generally below 1 dB. On lightweight wall P10, predictions are mostly lower, especially at low frequencies, with deviations up to about 5 dB. The deviation is similar for both pipe systems.

Because Eq. (1) combines installed power with the building transfer function, deviations may originate from the transfer function, the prediction model, or the source properties. A major error in the receiver transfer function is unlikely, as it was measured directly in the drywall facility using the standard laboratory procedure. The good agreement on the heavy wall (Fig. 7) also supports the prediction method and the source-property measurements.

The transferability of source properties from P12 to P10 therefore remains a likely uncertainty. Although both installations follow EN 14366-1, their geometry differs: in P10, the basement bend is about 50 cm higher than in P12. Since this bend is the dominant low-frequency excitation source in the underground floor [5], the shorter distance to the wall fixing point may increase installed power. This may partly explain the low-frequency underestimation on P10. In addition, the same product types but not the same specimens were used, so production-related variation may also contribute.

Overall, predictions using source properties from P12 and receiver properties from P10 reproduce the general pipe-performance tendency but not the absolute measured levels. The deviations are mainly attributed to the installation sensitivity of the source properties, including water-flow conditions. Even within one facility, removing and reinstalling identical pipe specimens can cause deviations of about ±3 dB. Nevertheless, the method is suitable for A–B comparisons, identifying performance tendencies, and, with uncertainty considered, assessing compliance with sound-insulation requirements.

5. Conclusion

This paper investigated the acoustic performance of a heavy, low-mobility wastewater pipe system and a lighter standard system on heavy and lightweight receiving constructions. Laboratory measurements were combined with EN 12354-5-based predictions to assess the effects of source–receiver mobility interaction and the normalized building transfer function, $D_{TF,n}$, on drainpipe noise.

On the heavy wall P12, both pipe systems produced comparable sound pressure levels and SNQ values. Because receiver mobility was much lower than both source mobilities, source–receiver interaction was negligible and the installed-power difference was governed mainly by the equivalent blocked forces.

On lightweight wall P10, receiver mobility approached the pipe mobilities. The lower-mobility Pipe L therefore showed a clearer advantage, with lower sound pressure levels and lower SNQ than Pipe H. For the example lightweight wall G4, receiver mobility remained below both pipe mobilities, so source–receiver interaction was small. However, Pipe L had higher installed power at low frequencies, and the high low-frequency $D_{TF,n}$ of G4 converted this excitation efficiently into sound pressure. Consequently, Pipe L produced a slightly higher SNQ on G4.

The results show that pipe performance cannot be transferred directly between constructions. If the order of source mobility or blocked force changes with frequency, the performance ranking depends on both source–receiver interaction and $D_{TF,n}$, which determines the dominant frequency range for the resulting SNQ. If one pipe has lower blocked force and lower mobility over the full frequency range, its installed power remains lower for any receiver, and its SNQ advantage is preserved.

The prediction method reproduced the observed performance tendencies on the lightweight construction but underestimated absolute levels on the drywall partition, especially at low frequencies. The main uncertainty is the transferability of source properties between installations, including geometry, mounting conditions, water-flow excitation, and specimen variation. Nevertheless, the approach is suitable for A–B comparisons, identifying performance tendencies, and, with uncertainty considered, assessing compliance with sound-insulation requirements.

6. Acknowledgments

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