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CHARACTERISATION OF SANITARY INSTALLATIONS AS SOUND SOURCES – WHAT DO WE HAVE, WHAT DO WE NEED?

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Abstract

Sanitary installations are among the most disruptive sources of noise in buildings. At the same time, they are some of the most complex examples of building service equipment since they usually consist of several active and passive components such as toilets, washbasins, taps, valves, pipes and pipe clamps etc. and complex interactions. To design systems that meet target values given as requirements in national building codes, a prediction based on EN 12354-5 is required. This in turn requires laboratory measurement methods that provide input data for the prediction. The standard EN 14366-1, which covers wastewater installations, was recently revised. The development of a future standard EN 14366-2 covering freshwater installations is underway in a CEN working group. Both standards refer to the general methods for the characterisation of building service equipment in EN 15657, which are reviewed in a companion paper by Höller et al. A significant challenge in developing EN 14366-2 is the role of appliances such as taps or valves that have so far been targeted by EN ISO 3822, but not in a way that enables predictions. This contribution provides an overview of the current situation regarding the acoustical laboratory characterisation of sanitary installations and identifies needs for future research and standardization work.

Keywords: *sanitary installations, building service equipment, laboratory measurement*

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1. Introduction

Sanitary installations are among the most disruptive sources of noise in residential buildings. The noise of water-carrying pipes is in most cases dominated by structure-borne sound: flow excites vibrations that are transmitted to the building structure through pipe clamps and radiated as airborne sound into adjacent rooms. To design installations that comply with national building codes, the resulting levels have to be predictable at the design stage. In Europe this prediction is provided by EN 12354-5 [1], which requires input data from a standardised laboratory characterisation of the sources. The prediction method itself, and the literature on it, are reviewed in a companion contribution [2].

Those standards have grown apart. The methods of EN 15657 [3] were transferred to EN 14366-1 [4] for wastewater installations in 2023, and a second part for freshwater installations is under development; both are elaborated in Working Group 7 of CEN/TC 126, EN 12354-5 in Working Group 2. Appliances, in contrast, are governed by EN ISO 3822 [5], whose reference source method Fischer [6] showed to rest on an assumption that is generally not fulfilled. Bridging that gap is one of the central challenges in the development of EN 14366-2, and it is against this background that the present contribution reviews the current state of the laboratory characterisation and identifies the resulting needs.

2. Prediction and the need for laboratory characterisation

Predicting the sound pressure level that a sanitary installation produces in a neighbouring room requires two independent descriptions: one of the source, which must not depend on the building, and one of the building, which must not depend on the source. EN 12354-5 [1] provides the framework in which they are combined; its structure and validation are reviewed in [2]. What matters here is what the laboratory has to deliver: for the structure-borne path the equivalent blocked force or the free velocity with the source mobility, for the airborne path the radiated sound power.

Laboratory data describe the source in the test set-up and under the operating conditions in which it was measured. EN 14366-1 [4] prescribes a building-like test facility with a defined pipe routing and reports the source data for a set of volume flow rates. The source quantities are independent of the receiving structure, but they remain tied to the installation geometry and to the operating point; how far they may be transferred to installations that differ substantially from the test set-up is one of the open questions.

A second restriction concerns the time structure of the excitation. The laboratory methods and the prediction model assume stationary operation, whereas the noise perceived in a dwelling is largely transient: a flush, a tap being opened and closed, a cistern refilling. Rieger et al. [7] show how the room correction of such transient levels can be treated consistently, but the procedures have not yet been taken up in the standards.

Finally, a bathroom is not a single source. Several stationary and transient sources may operate at the same time and inject structure-borne sound at different points. The most common example is the pre-wall installation system, whose frame carries cistern, toilet and washbasin and is fixed to the same wall as the wastewater pipe. Such a frame is a compact source and falls under EN 15657 [3]: it has to be characterised on a reception plate test bench [8], [9]. A prediction for a real bathroom thus has to merge data from different test procedures, and user-generated noise is covered by none of them.

3. Characterisation of wastewater installations: EN 14366-1

Wastewater installations differ from most other building service equipment in that they are extended, distributed sources. The excitation by the falling water acts along the whole pipework, in particular at discontinuities such as inlet tees and basement bends [10], and the vibration enters the building structure at several fixing points. A reception plate test bench in the sense of EN 15657 [3] is not ruled out, but it has to be laid out for such specimens; one exists at TH Rosenheim, so far with conventional concrete plates, and a current project is extending it to lightweight plates [11]. In EN 14366-1 [4] the installation is characterised in a building-like test facility in which the piping system extends over several storeys, operated at 0.5 l/s, 1 l/s, 2 l/s and 4 l/s.

The first edition, published in 2004, delivered a normalised sound pressure level from airborne sound measurements complemented by the structural sensitivity of the test wall. It ranks piping systems against each other but is not a source quantity [1]. The revision published in 2023 adopts the methods of EN 15657 and delivers the complete source data set: equivalent blocked force, free velocity, source mobility and the airborne sound power radiated into the installation room.

Within this framework several measurement procedures are possible; the power substitution method and the determination of airborne sound power are contained in EN 15657 [3]. The particular feature of EN 14366-1 is that all source quantities come from one and the same test set-up (Figure 1), made possible by a single calibration with a reference structure-borne sound source: an instrumented hammer or a shaker, as suggested in Annex C of EN 15657, is applied at each contact point of the pipe clamps, and the injected power follows from the measured force and the velocity there [12].

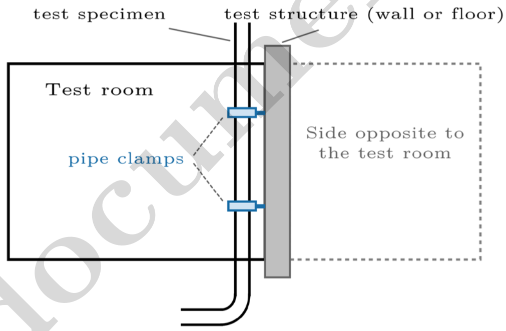

Figure 1 – Test set-up for the characterisation of wastewater piping systems according to EN 14366-1.

The source quantities of the piping system follow by substitution. Comparing the wall velocity level caused by the piping system with that caused by the calibration source yields the injected structure-borne sound power,

$$L_{\mathrm{Ws}} = L_{\mathrm{Ws,cal}} + L_{\mathrm{v}} - L_{\mathrm{v,cal}} \tag{1}$$

where the index cal denotes the calibration source and levels are summed energetically over all contact points. The airborne sound power radiated by the wall as a consequence of structure-borne excitation follows from the same calibration data,

$$L_{\mathrm{Wa,struc}} = L_{\mathrm{Wa,struc,cal}} + L_{\mathrm{Ws}} - L_{\mathrm{Ws,cal}} \tag{2}$$

Since a piping system radiates airborne sound both through the wall and directly, the latter can be separated as

$$L_{\mathrm{Wa}} = 10\lg\left(10^{\frac{L_{\mathrm{Wa,total}}}{10}} - 10^{\frac{L_{\mathrm{Wa,struc}}}{10}}\right) \tag{3}$$

The blocked force follows from the injected structure-borne sound power and the real part of the receiver mobility at the contact points [2].

The free velocity is measured directly instead, with the piping system operated without any connection to the installation wall. Following EN 15657 [3] the velocity is measured on the clamps at two fixing points, and the single equivalent free velocity level $L_{\mathrm{vf,eq}}$ follows by energetic summation. The magnitude of the single

equivalent source mobility $|Y_{S,eq}|$ is then estimated from the difference between this level and the equivalent blocked force level. That estimate is not accurate: direct measurement at the contact points gives the better value, and the difference method serves mainly as a check of the force source condition [12].
The uncertainty of these methods has not yet been quantified on a European level. CEN/TC 126/WG 7 has therefore initiated a dedicated interlaboratory test for wastewater installations according to EN 14366-1. The earlier one [13] addressed compact sources on reception plate test benches and covered the structure-borne quantities only; a statement on the uncertainty of the airborne sound power is needed just as much. The new round robin covers both paths and reports in 2026.
How the source data are condensed into single-number ratings has been discussed intensively. EN 14366-1 keeps the two paths strictly apart, since they are radiated by different parts of the installation and weighted differently by the receiving structure. For the airborne part the rating is straightforward: the A-weighted sound power level $L_{Wa,A}$ follows directly from the radiated spectrum and can be compared between test facilities without further assumptions.
For the structure-borne part no such route exists, because the power installed in a building depends on the mobility of the supporting element. The rating quantity is therefore the A-weighted normalised sound pressure level produced in a building, which is situation dependent. As no reference situations have been agreed, Annex G.4 of EN 12354-5 [1] provides two examples: a heavyweight one, in which the transmission path is described by the normalised impact sound pressure level $L_{n,wall}$ according to EN ISO 12354-2 [14], and a timber frame one, described by the normalised sound pressure level for 1 W of installed power $L'_{ne,s,0}$ according to EN ISO 10848-1 [15].
These values are comparison quantities only; the standard states explicitly that they must not be used in connection with requirements in other buildings. That the structure-borne path ends up with two of them rather than one is much debated: manufacturers, planners and building regulations ask for a single figure of merit, whereas the physics does not permit a receiver-independent single number. They are nevertheless useful, since they rank piping systems consistently with the prediction model rather than with an arbitrary laboratory situation [16].
EN 14366-1 also covers measures that reduce the noise of an installation, in its normative Annex B. For a pipe enclosure only the airborne path is evaluated, as the difference of the airborne sound power levels without and with it. A pipe lining affects both paths: its structure-borne performance is a power-based insertion loss, for receiving elements of low mobility the difference of the equivalent blocked force levels, in the general case the difference of the installed power levels. The single-number descriptors follow the logic of the source quantities. The revision under discussion in CEN/TC 126/WG 7 adds sound-isolated pipe clamps.
As for the source quantities, the results are valid for the tested installation only.

4. Towards characterisation of freshwater installations: EN 14366-2

A second part of EN 14366, dealing with water supply installations, is a current work item of CEN/TC 126/WG 7. Its guiding idea is to keep methods and test facility identical to those of Part 1, so that the source data remain compatible with EN 12354-5 [1]. The intended scope is wider than that of EN ISO 3822, whose structural shortcomings are set out in Section 5: not only appliances have to be covered, but also different piping configurations and mounting elements, in particular pipe clamps with and without elastomer inlays. Annex B of Part 1 already treats such clamps as a mitigation measure at the pipe, but there they are a property of one complete installation rather than of the clamp.
Two investigations support this guiding idea. In [17] a one-inch galvanised steel pipe fixed with two rigid clamps was characterised on a reception plate test bench according to EN 15657 [3], with the INS of EN ISO 3822 [5] as the internal source (Figure 2). The blocked force served as input for a prediction in the building-like installation test facility; measured and predicted A-weighted normalised sound pressure levels agreed in their frequency dependence, the prediction underestimating the measurement by about 4 dB. In [12] the same system was characterised directly in that facility with the power substitution method of EN 14366-1, and the blocked forces from the two test benches agree very well.

Figure 2 – Freshwater piping system mounted and operated on the reception plate test bench according to EN 15657. Blue arrows indicate the direction of the water flow.

Two findings delimit the open questions. First, the result depends strongly on the configuration: a long pipe running through several storeys yielded a considerably lower blocked force than a short section within one storey, although on the reception plate the pipe geometry had had little influence [12]. Second, it depends strongly on the internal source: a tap and a shower head connected in place of the INS produced markedly lower blocked forces [17]. Using the INS is conservative in that respect, and a worst-case operating condition is what [2] recommends for a prediction.

For the test set-up of EN 14366-2, however, a different worst case has to be fixed: the position at which the appliance is connected to the pipework. An appliance feeds the pipe by two mechanisms – primary structure-borne sound injected directly into the pipe wall, and secondary structure-borne sound arising where fluid-borne sound is converted at bends and other discontinuities [6], [18]. The primary contribution is attenuated as it propagates along the pipe, the secondary one is generated along the pipe itself. If the appliance sits close to the fixing points, the primary contribution reaches the clamps almost undiminished and the installed structure-borne sound is at its highest; mounted far away it is largely lost on the way. Separating the two would be the better answer [6], [18], but no method makes that routine in a test facility, so the position has to be prescribed, and prescribing the unfavourable one is the safe choice.

Complete freshwater installations can therefore be characterised according to EN 14366-2 in the same way as wastewater installations are according to Part 1 – [12] has shown that the methods work. The single-number ratings of the preceding section can be formed for freshwater systems as well and even compared with those of wastewater systems, subject to the entirely different flow conditions. What still has to be agreed are the specifications of the test set-up, above all the position of the appliance; the test values are then valid for the complete system and for nothing less. One quantity escapes that restriction: the insertion loss of pipe clamps, which depends neither substantially on the appliance nor on the pipe geometry [19], [20].

These observations point to the same difficulty. A test according to EN 14366-1 characterises one specific combination of pipe, mounting elements and appliance, and for water supply installations the number of combinations is far larger than for wastewater systems. For the manufacturer of a single component, testing complete systems is neither affordable nor informative. What is needed in addition is component testing, and two routes have to be kept apart.

The first stays inside the installation test facility: a component is exchanged in an otherwise unchanged installation and its effect expressed as an insertion loss. This is what Annex B of EN 14366-1 does, and it is the route the working group regards as realistic in the preparation of EN 14366-2. Its limits are clear: the source quantities stay tied to the components of the system tested, and the appliance itself is not characterised by it.

The second route tests the component on its own. For pipe clamps such a rig has been built at HFT Stuttgart following EN ISO 10846-4 [21]: the clamp is held by a rigid steel fixture between two heavy blocking masses and closed around a solid aluminium dummy standing in for the pipe, and the insertion loss is obtained as the velocity level difference against a rigid reference fixing [22]. The rig delivers that insertion loss and nothing else. The result is free of the modes of the pipework but holds for the dummy used, and whether the values agree with those from a complete installation has not been checked yet. That this matters is clear from the system measurements, where the insertion loss proved strongly dependent on the combination of pipe and clamp [19], [20]. Only a route of this kind would eventually let EN 14366-2 take the place of EN ISO 3822.

5. Appliances: taps and valves (EN ISO 3822) and the prediction gap

In a test according to EN ISO 3822 [5] the appliance is connected to the end of a measuring pipe – a one-inch galvanised steel pipe held to the measuring wall by four rigid clamps without any resilient inlay – and the quantity evaluated is the sound pressure level recorded in the receiving room into which that wall radiates (Figure 3). Because that level depends on the individual test set-up, the appliance is evaluated against a reference source: the installation noise standard (INS), in essence a special valve, a brass body with a perforated disc generating a defined flow noise at 0.3 MPa. The appliance noise level is formed octave by octave as

$$L_{\mathrm{apn}} = L_{\mathrm{n}} - L_{\mathrm{sn}} + L_{\mathrm{srn}} \tag{4}$$

where L_{n} is the octave band level produced by the appliance, L_{sn} that produced by the INS in the same set-up and L_{srn} the reference spectrum of the INS laid down in the standard [5]. This is the reference source principle: $(L_{\mathrm{n}} - L_{\mathrm{sn}})$ characterises the appliance relative to the INS and is assumed to be independent of the test set-up, so that adding the reference spectrum transfers it to a nominal situation.

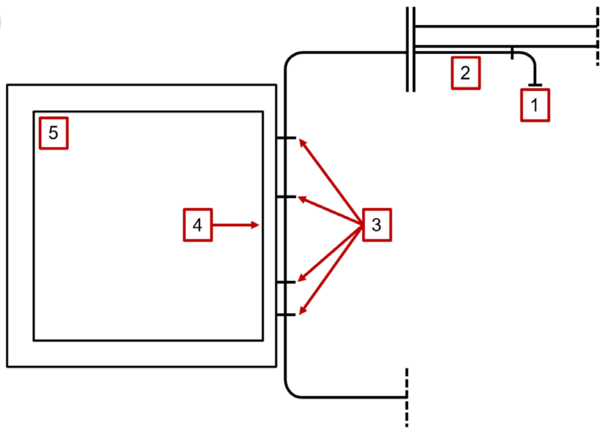

Figure 3 – Test set-up of EN ISO 3822: 1 tap connection, 2 steel measuring pipe, 3 rigid clamps, 4 measuring wall, 5 receiving room.

That assumption holds under one condition only. Structure-borne sound on the pipe wall is fed both by the fluid-borne sound of the water column and by primary structure-borne sound injected directly by the appliance, and the two reach the wall through different transfer functions. Fischer [6] introduced a power coefficient, the ratio of the two contributions at the source, and showed that $(L_{\mathrm{n}} - L_{\mathrm{sn}})$ is free of the transfer path only if that coefficient is the same for appliance and INS. It generally is not. The INS is very nearly a pure fluid-borne sound source – where it is used to excite a pipe system it is connected through a short flexible hose [23] – whereas a real tap does inject structure-borne sound, unless it too is joined by flexible hoses [24]. The standard has answered the resulting scatter with ever more detailed prescriptions for the test set-up, which contradicts the very principle of a reference source method. The coefficient also changes with the hydraulic operating point of one and the same appliance. Moreover, only steady flow noise is evaluated, whereas the opening, closing and adjusting of a valve is not covered at all.

The direction of a solution has been available for some time. Alber et al. characterised valves on a power basis, treating the structure-borne [18] and the fluid-borne [23] emission separately. That work also shows why a purely component-based appliance quantity remains difficult. To convert the fluid-borne emission of a tap into the structure-borne power injected into the wall, they measured the ratio of the two on ten pipe assemblies with an increasing number of bends [23]. That ratio only settles, at about 30 dB, above 1 kHz; below that it is strongly frequency dependent and specific to the combination of pipe material, connectors and receiving structure. Since the A-weighted level in a receiving room is governed by the low-frequency range [8], the transformation is least reliable where it matters most.

How this is resolved is a question of years rather than of the next revision. The expectation in the working group is that EN 14366-2 will in time cover what EN ISO 3822 is meant to deliver and cannot, and that EN ISO 3822 will be kept until then but not developed further. One further possibility should at least be named: EN ISO 3822 could itself be converted to the methods of EN 15657, so that the existing appliance test facilities would deliver source data suitable for prediction. That would preserve a considerable investment, since the facilities are operated by test institutes and by manufacturers, and the two arrangements are not far apart – Figure 2 uses the same one-inch pipe, a comparable number of bends and the same INS – but the discussions in the standards committees so far do not suggest that this is the route that will be taken.

6. What do we have, what do we need?

The picture that emerges can be put into two lists: what is available is a framework that is consistent in itself, and what is missing is specific enough to be named.

What do we have

- EN 15657 [3] defines how a source is characterised and EN 12354-5 [1] how the data are combined with a building.
- EN 14366-1 [4] delivers, for the first time, a complete source data set for an extended source and thus input data for prediction and product comparison.
- The reception plate method covers compact sources such as pre-wall installation systems and shower trays [8], [9].
- Annex B of EN 14366-1 brings mitigation measures at the pipe into the same framework: at present pipe enclosures and linings, in the revision under discussion also sound-isolated clamps.
- The methods are not restricted to wastewater; for freshwater installations they have been shown to work [12], [17].
- Test and prediction methods for transient sources are available [7].
- For pipe clamps, a component test rig outside the standards yields the insertion loss of the clamp alone [22].

What do we need

- An uncertainty for the methods of EN 14366-1. The round robin under way will supply it for the structure-borne quantities; for the airborne sound power no interlaboratory test has ever been carried out. Until then a predicted level cannot be compared with a requirement in a defensible way.
- An uncertainty for the prediction itself, above all for several simultaneous sources and for lightweight construction, where the ranking of two pipe systems obtained on a heavy wall was found not to be preserved [25].
- User-friendly tools that make the prediction usable in practice [2], [26].
- An agreed test procedure for complete freshwater systems in EN 14366-2, with a rule for where the appliance is connected.
- A characterisation of the appliance itself. EN ISO 3822 delivers noise classes, not source data, and the reason is structural [6]: what is required is a separation of the fluid-borne from the structure-borne emission together with a transfer relation into the blocked force of the installation [18], [23]. Extending EN 14366-2 to components is one route towards it, converting EN ISO 3822 to the methods of EN 15657 another.
- Component quantities together with a rule for composing them, so that an installation can be predicted from component tests rather than reproduced in a test facility. This is the most demanding of these items and the one furthest away.
- A validation of component results against complete installations; for pipe clamps, whose insertion loss depends on the combination of pipe and clamp [19], [20], this comparison is still missing.
- Normative implementation of the methods for transient sources [7].

One question runs through all of these and is answered by none of them. Single-number ratings for the structure-borne path are receiver dependent by their physics, and the events that generate complaints are transient, so that descriptors derived for stationary signals do not describe them. Which quantity corresponds to perceived annoyance is now being approached with psychoacoustic methods [11].

7. Acknowledgments

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