NOISE PROTECTION FROM SANITARY INSTALLATIONS

David Svoboda*[,1], Petra Berková[1], Karel Čupr[1]

*david.svoboda6@vutbr.cz
[1]Faculty of Civil Engineering, Brno University of Technology, Veveří 331/95, 602 00 Brno, Czech Republic

Abstract
This review article deals with noise and vibration arising from the operation of sanitary installations – wastewater and freshwater plumbing. The first part describes the most commonly occurring sources of noise and vibration from such installations and possible ways of propagation. The second part sets out the measurement methodology and the differences in legislative requirements among countries. In the third part of the paper, principles of noise protection and modifications to sanitary installations are described.

Keywords
Noise, sanitary installations, wastewater, freshwater, plumbing

1 INTRODUCTION

Noise, as an unwanted and disturbing sound, has adverse effects on human health. Prolonged exposure to noise can cause hearing impairment, and extremely loud noise can even cause injury to the hearing system, resulting in permanent hearing damage. Noise also has a negative effect on the heart and vascular system, causes sleep disturbances, impairs cognitive abilities, and has an overall negative effect on the human psyche [1].

The main sources of noise in the non-work environment include road, rail, and air traffic noise, as well as noise from cultural and sports facilities and noise associated with housing. Residential noise does not only include 'neighbourhood noise', which is e.g., watching television, vacuuming or loud conversations, but also the operation of building services such as ventilation, heating, or sanitary installations [2].

It is the noise and vibration from these installations that is a frequent cause of complaints, especially from users of residential buildings such as apartment blocks, hotels, or hospital bedsits. In a Wavin company survey on customer satisfaction in accommodation facilities, shortcomings such as noisy air conditioning, unpleasant noises when water flows through waste pipes or toilet flushing were listed in the third place – behind non-functioning internet connection and poor cleaning [3]. The problem of noise from the operation of building services has also been identified in many other surveys and studies, such as the study [4], where individual noise sources in a total of 26 empty apartments in Korea were analysed over a 24-hour period. Here, structural noise, which is caused by, among other things, the operation of building services, was identified as significantly more dominant than airborne noise (neighbours' conversations, loud television, etc.). In the Czech environment, noise in prefabricated apartment buildings was investigated in [5]. Noise from sanitary installations was found to be the most problematic here, with toilet flushing exceeding the permitted sound pressure level limits in neighbouring flats by up to 73%.

Although noise from the operation of sanitary installations occurs quite often and is addressed in Czech legislation and standards, it is often neglected in the design and implementation phase of construction projects and its elimination must be addressed post-construction. This review paper focuses on individual noise sources from such installations and possible ways of propagation, measurement methodology of noise sources, legislative and standard noise limits and noise protection principles and modifications to sanitary installations.

2 NOISE SOURCES AND WAYS OF PROPAGATION

Wastewater plumbing

In buildings with a combination of living rooms and sanitary facilities (e.g., apartment buildings, hotels, or hospitals), the noise of water flowing through waste pipes or flushing toilets is a common disturbance.

In wastewater (and rainwater) pipe systems, there are both airborne noise from the flow of sewage inside the pipe, and pipe-borne noise from the mass of the pipe, which is mainly caused by the impact of sewage on the pipe

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walls at points where the direction of flow changes abruptly (elbows, bends, etc.) [6]. Vibrations from the plumbing can also be transmitted to surrounding structures by fastening systems or penetrations through structures – see Fig. 1.

Noise is also caused by sewage runoff from sanitary appliances. In a paper [7] from a university in Korea, noise from the operation of toilets, bathtubs and sinks was measured in a total of 64 households with 14 different layouts. Here, noise was measured in lower floor bathrooms, upper floor bathrooms and several living rooms on the lower floors. Flushing toilets (up to 47.8 dB), followed by sink discharges, and finally bathtub discharges were rated as the noisiest sources in both the lower floor bathrooms and living rooms. Within the acoustic spectrum, flushing was in the middle and higher frequencies (500 to 1000 Hz). The position of the dwelling within the building height did not prove to be a significant factor here.

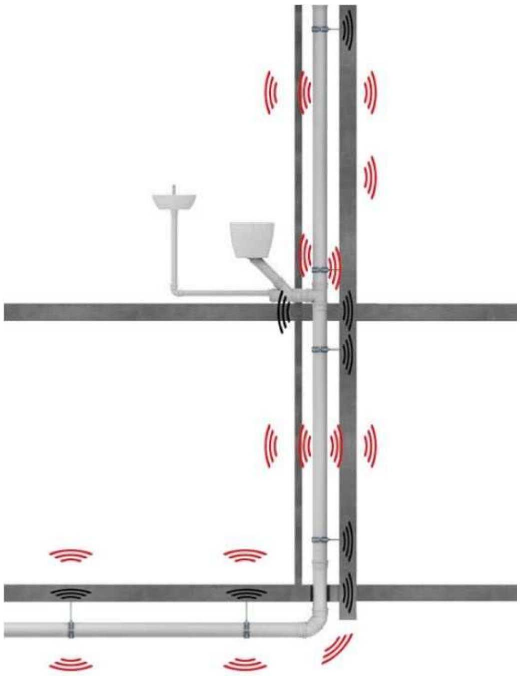

Fig. 1 Ways of noise propagation through indoor drainage [3].

Freshwater plumbing

Noise from freshwater plumbing is similar to noise from wastewater – it is mainly generated at the points where the water flows through the pipes and where there are sanitary appliances.

In indoor protected areas of a building, noise from water flowing in water supply pipes usually occurs when installations are routed in the walls of these protected rooms. This is usually caused by weakened structures when pipes are jammed or poor anchoring to the structure. Noise is caused in particular by points where the local pressure drop is higher than in the straight section of pipe, such as elbows, branch pipes or shut-off valves. There, a local increase in velocity is generated, which causes vibration of the pipe and the consequent emission of unwanted airborne and structural noise. Processes generating noise in the freshwater plumbing can include turbulent flow, cavitation, vortices, or hydraulic shocks when a valve is suddenly closed [8], [9]. These processes are described in more detail in the work of Helmut V. Fuchs, which is divided into parts [10], [11] and [12].

Another source of noise in connection with water supply pipes are the end elements at the sanitary appliances – the fittings and the faucets. During their actual use, noise is emitted by water hitting baths, washbasins, shower cubicles, etc. For example, in a study [13] from the Faculty of Civil Engineering of Brno University of Technology, noise from the filling and draining of a bathtub in a living room adjacent to a bathroom was measured. It was observed that the filling of the bathtub reached a higher noise intensity than its discharge, although the discharge was very erratic and fluctuating.

A more serious problem, however, is the vibration caused by the hydraulic shocks that propagate back into the pipes, known as water hammer. Therefore, their proper anchoring to the structures is also important in this case [8], [9]. A graphical description of the phenomenon is shown in Fig. 2.

The noise from sanitary installations can be considered as the most complex within the building services when the mechanisms of noise emission and transmission are considered [11].

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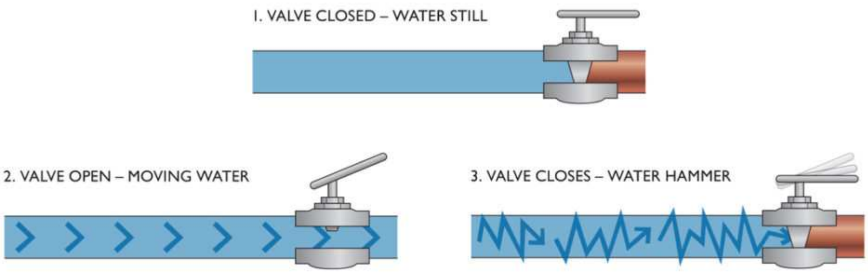

Fig. 2 The principle of water hammer in water taps and faucets [14].

3 MEASUREMENT METHODOLOGY

Measurement

Several methodologies and technical standards specify the operational method for measuring the sound pressure level of building services. The most important one is international standard ČSN EN ISO 16032 Acoustics – Measurement of sound pressure level from service equipment in buildings – Engineering method [15]. It deals with the measurement of sanitary facilities, ventilation, heating, cooling equipment, lifts, garbage disposal, boilers, fans, pumps and other auxiliary technical equipment and motor-driven garage doors. The methods described are suitable for rooms with volumes of 300 m^3 or less, but the standard is not generally intended for measurements in large auditoriums or concert halls. According to the standard, the determining factor for the noise performance of technical equipment is the maximum sound pressure level A or C, as appropriate. The values of the weighted functions A and C are calculated from measurements in octave bands.

A real-time octave band frequency analyser will be employed for the measurements. The overall measurement set-up, including microphone and cable, must comply with the requirements for a Class 1 instrument as specified in EN 61672-1 [15].

The sound pressure level of technical equipment shall be measured in octave bands in the frequency range 31.5 Hz/63 Hz to 8 000 Hz as a linear (unweighted) spectrum corresponding to the maximum sound pressure level. The results in octave bands will be corrected for background noise and normalized to the reverberation time. Windows and doors shall be closed and the person conducting the test shall be outside of the room during the measurement [15].

The standard also specifies a general measurement procedure. The sound pressure level is measured in three microphone positions – one position in the corner, two positions in the reverberation field. The standard specifies the exact microphone positioning of each location within the room and the number of measurements in each position. It also specifies procedures for averaging and normalizing the measurements, the measurement and effect of reverberation time, correction for background noise and the accuracy of the results. The last chapter of the standard contains a sample test report of the measured test [15].

Annex B of that standard then sets out the operating conditions and duty cycles for specific cases of noise from technical equipment in buildings. Specifically, for example, for a flushing toilet:

(a) Operating conditions:

L_{max} *and* L_{eq}*: The sound of a flushing toilet consists of the sound of flushing and the sound of filling the tank. The flush valves and flush tanks will operate until final closure. In the case of a tank flush, the sound pressure level is measured with the fill valve fully open and until the fill valve is closed.*

(b) Duty Cycle:

L_{max} *and* L_{eq}*: Measurements shall be taken throughout the flush/refill cycle.*

(NOTE 1: The maximum sound pressure level caused by flushing the toilet alone can be determined by pouring seven litres of water from the bucket directly into the bowl in approximately 3 seconds.

NOTE 2: For a flushing toilet, the maximum sound pressure level A shall be added to the equivalent sound pressure level) [15].

A simplified method for rooms with a maximum volume of 150 m^3 is described in ČSN EN ISO 10052 Acoustics – Field measurements of airborne and impact sound insulation and of service equipment sound – Survey method [16]. In this standard, the results for technical installations are given directly as A- or C-weighted sound

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pressure values. Measurement procedures, operating conditions and duty cycles are described similarly to the previous standard.

Calculation

Calculation methods in acoustics are generally not perceived as very accurate and it is always necessary to support their accuracy with additional laboratory or in-situ measurements. However, they can serve at least tentatively for preliminary design purposes. For the calculation of noise levels from building services, the standard ČSN EN 12354-5 [17] is used. This international standard describes the basic principles and relationships for airborne noise through pipes, airborne noise through structures, and structural noise through structures. These principles are then applied to individual HVAC applications, lifts, etc.

In [18], this standard is used to calculate the noise of ductwork in heavy and lightweight (timber) structures. However, an analysis and modification of this standard was necessary. Then, the computational results obtained were almost identical to the in-situ measurements made. This demonstrates the generality of the standard and the necessity to modify the calculation for specific situations.

4 LEGISLATIVE REQUIEREMENTS

Czech Republic

The primary legal document in the Czech legislation that ensures protection against noise as an undesirable sound is Act No. 258/2000 Coll., on the Protection of Public Health [19]. It defines protected indoor and outdoor areas in terms of noise protection. These areas specifically include living areas (bedrooms, living rooms etc.) of family and apartment buildings, hospital rooms, medical clinics, and school classrooms and lecture halls.

The specific noise limits in these areas and the decisive variables are set out in Government Regulation No. 272/2011 Coll., as amended, on the protection of health against the adverse effects of noise and vibration [20]. Noise from sanitary installations usually affects only protected indoor areas. The determining noise indicator for protected indoor spaces is the equivalent sound pressure level A $L_{Aeq,T}$ for airborne noise from outside and the maximum sound pressure level A L_{Amax} for noise propagating from sources inside the building. The hygienic limit for both quantities is 40 dB with corrections (see Tab. 1) considering the type of space protected and time of day. If there is noise with tonal components, an additional correction of −5 dB is read.

Tab. 1 Corrections for the determination of hygienic noise limits in the protected indoor areas of buildings [20].

Type of protected indoor area	Period of stay	Correction [dB]
hospital rooms	*from 6:00 to 22:00*	*0*
	from 22:00 to 6:00	*−15*
medical clinics	*for the period of use*	*−5*
living areas (bedrooms, living rooms etc.)	*from 6:00 to 22:00*	*0*
	from 22:00 to 6:00	*−10*
lecture halls, classrooms and education facilities	*for the period of use*	*+5*

Consequently, that the maximum permissible sound pressure level in living areas at night is 30 dB, and even 25 dB if there is a tonal component. If these rooms are located in the immediate vicinity of improperly located or implemented sanitary installations, it is quite likely that the noise limits will not be met, and the soundproofing solution will be complicated.

Furthermore, the Czech technical standard ČSN 73 0532 [21], which specifies requirements for acoustic properties of building structures and products, directly specifies requirements for noise from building services in living areas. The values correspond to the limits set by the government regulation, i.e., 30 dB at night and 40 dB if the source is proven to be in operation only during daytime hours – which is not the case for sanitary installations.

Other countries

In other countries, of course, the requirements for noise from sanitary installations differ. For example, in South Korea, there is no precise legislative limit for residential noise from wastewater and freshwater plumbing. Instead, the values of equivalent sound pressure level $L_{A,eq}$ and maximum sound pressure level $L_{A,max}$ for day and night time within the structural noise are considered. For airborne noise, only the equivalent sound pressure levels $L_{A,eq}$ for day and night are taken into account [7]. In a paper [22] from the University of South Korea, the following single-number values of $L_{A,eq}$ and $L_{A,max}$ are compared for the assessment of noise from sanitary facilities, their correlation with each other, and their correlation with subjective noise perception. In another research [23], a similar measurement and subjective evaluation was supplemented with virtual reality (VR). Listening tests were conducted in four modes – with headphones, with speakers, with headphones and VR, and with speakers and VR. It was found that virtual reality significantly influenced the perception of the test subjects. For example, the irritability level increased by 40% when using VR and speakers at the same volume.

5 NOISE PROTECTION PRINCIPLES

Noisy rooms with sanitary appliances, such as toilets, bathrooms and kitchens, should in principle not be located next to protected interior spaces, such as living rooms of neighbouring dwellings [21]. If wastewater or freshwater plumbing is to be routed through or near these spaces, it is advisable to avoid routing in acoustically separating structures (cutting into walls) during the design and construction phase. Instead, designated installation partitions or shafts for the pipes should be used, ensuring they are secured against possible noise and vibration. It is advisable to consider materials to prevent the propagation of noise (thick-walled three-layer pipe, additional insulation) and a special fastening system so that vibrations from the pipe are not transmitted to the surrounding building structures – see Fig. 3. Where this is not possible, it is recommended to increase the dimensions for water pipes [8], [24].

Fig. 3 Sound-insulating fastening system Wavin [25].

In case undesired noises appear only when the piping is commissioned, it is recommended to check the fit of the pipe headers, or to suspend additionally them with flexibility and acoustically isolate them. It is also possible to use soundproofing partitions or suspended ceilings [8]. In a study [26], laboratory measurements of a vertical wastewater pipe (straight and with a 2 × 45° bend) with a transition to a horizontal pipe under the ceiling showed less noise when using an acoustically suitable fixing system. It was also recommended to use a flexible pipe envelope at the downstands (but not too rigid) to avoid structural noise. The design principles and types of pipe or shaft encasements for acoustic attenuation were also described.

A study by the Technical University of Catalonia [9] looks at the noise issue of freshwater installations and fittings considering several factors – type of faucet, pipe material and mounting method. In the study, a total of 50 in-situ measurements were made in houses with different partition wall designs and different types of faucets. A silicone pipe was attached to the faucets with a drain to eliminate the noise of water falling on the fixture. In addition, laboratory measurements were taken with combinations of different partition wall materials, pipe materials, pipe attachments, type of sanitary appliances, types of faucet, and water line pressure. Several conclusions were drawn from this research. Class I faucets can be clearly recommended, as they achieved much lower noise levels than non-certified ones – a difference of 5–12 dB. It was shown that noise also increases with higher pressure (and therefore flow), and it is recommended not to exceed 150 kPa. The main noise-inducing process in faucets is, up to small flow rates (0.35 l/s), the fluctuation of the water mass caused by the flow restrictor in the faucet. At higher flow rates, cavitation takes over the noise. The material of the dividing wall cannot be clearly recommended. The SDK wall achieved greater attenuation when installed on the outside, but not when installed inside. The reason for this is the penetration of the pipe through the supporting CW profiles, which cause the whole structure to vibrate, even at low frequencies. However, the recommendation is to install a wall with separated profiles – see Fig. 4.

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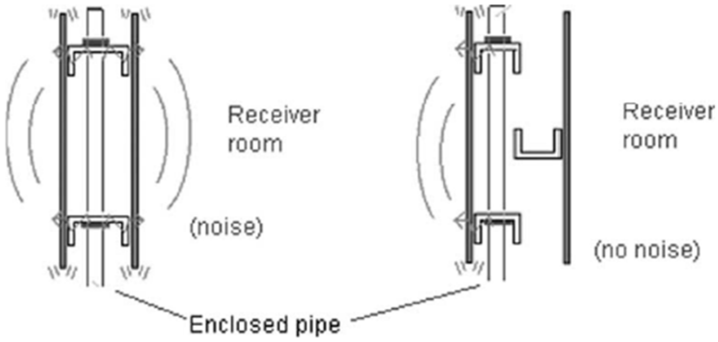

Fig. 4 Comparison of water installation in a conventional SDK wall (left) and a wall with independent load-bearing profiles (right) [9].

Polybutylene, which acts as a vibration absorber compared to copper, proved to be a suitable material for piping. However, in the case of pipes in grooves, the copper pipe in the protector performed better than the polybutylene pipe, which is not normally placed in the protector. The flexible fit of the pipe was only important for the copper pipe, as the differences in noise levels were not as significant for the polybutylene pipe [9].

Furthermore, the results of [7], indicate that the use of a prefabricated system core with built-in installations for constructing apartment buildings results in a greater attenuation of noise from water and sewerage installations compared to construction by wet processes, with a difference of up to 6 dB.

6 DISCUSSION

The paper delves into an often overlooked aspect of residential noise pollution – noise from sanitary installations. It systematically outlines the sources of this noise, methods of propagation, measurement techniques, legislative requirements, and principles for noise protection. The comprehensive analysis sheds light on the complexity of this issue and the necessity for detailed consideration during the design and construction phases of buildings.

The study presents a crucial aspect of residential discomfort often disregarded in construction planning. By highlighting the adverse effects of noise from wastewater and freshwater plumbing, it emphasizes its significance in impacting human health and well-being. The intricate nature of noise propagation, whether through wastewater or freshwater systems, is meticulously explored, providing a deeper understanding of its origin and transmission.

The paper offers a detailed insight into the technical aspects of measuring sound pressure levels and adhering to standards. The discussion on methodologies outlined in standards like ČSN EN ISO 16032 and ČSN EN ISO 10052 ensures a standardized approach for measuring noise levels. Moreover, the comparison of legislative requirements across countries underscores the variations in permissible noise limits, emphasizing the need for global harmonization in noise regulations.

The paper does not merely highlight the problem but also offers practical solutions and strategies. From the recommendation to avoid locating noisy sanitary spaces adjacent to protected areas to the suggestion of using specific materials or encasements to minimize noise propagation, the study provides actionable insights for architects, engineers, and policymakers.

The findings from the paper suggest crucial implications for construction practices, emphasizing the need for a proactive approach to mitigate noise from sanitary installations. It also hints at potential future research directions, such as exploring innovative materials or technologies to further reduce noise transmission.

7 CONCLUSION

Building services and their distribution systems are found in virtually every building and noise and vibration emanating from their operation is a common and usually neglected disturbance.

For successful elimination, it is first necessary to identify the source or combination of sources and the path of propagation to the protected areas of interest. In the case of wastewater and freshwater plumbing, this is usually airborne noise during pipe flow, pipe mass, vibration through anchoring elements and the fittings themselves.

According to the appropriate methodology (e.g. ČSN EN ISO 16032), the sound pressure is measured at the specified frequencies using a frequency analyser. The methodology includes instructions for the location of the

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equipment, the procedure and number of measurements, the duty cycles and the operating conditions depending on the specific technical equipment.

The results of the measurements are then compared with the prescribed maximum values according to the country's legislation and the need for the installation of noise protection measures is evaluated. In particular, efforts should always be made to eliminate noise pollution at the source if possible. Common measures are usually a combination of flexible anchoring and installation of functional elements or pipework. Finally, the propagation of noise from the locations of these installations can be reduced by installing soundproofing baffles and ceilings.

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