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Director
Prof. Dr. Philip Leistner
Prof. Dr. Klaus Peter Sedlbauer

Test Report P-BA 278/2016e

Determination of the Acoustic Performance of a Wastewater Installation System in the Laboratory according to EN 14366

Client: Rehau AG + CO
Rheniumhaus
Otto-Hahn-Str. 2
95111 Rehau
Germany

Test object: Wastewater installation system consisting of plastic pipes and fittings "Rehau Raupiano Light" (OD 110 x 2.7, manufacturer: Rehau AG + CO) with the corresponding fixing system "Sound-dampening bracket".

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Test date: The measurement was carried out on December 8, 2016 in the test facilities of the Fraunhofer Institute for Building Physics in Stuttgart.

Stuttgart, July 4, 2017

Responsible Test Engineer

Head of Laboratory:



M.Sc. B. Kalbeitzel



M.B.P. Dipl.-Ing.(FH) S. Öhler

The test was carried out in a laboratory, accredited according to DIN EN ISO/IEC 17025:2005 by DAkkS. The accreditation certificate is D-PL-11140-11-01.

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Determination of the Acoustic Performance of a Wastewater Installation System in the Laboratory

P-BA 278/2016e

Results sheet 1

- Client:** Rehau AG + CO, Rheniumhaus, Otto-Hahn-Str. 2, 95111 Rehau, Germany
- Test specimen:** Wastewater installation system consisting of plastic pipes and fittings "Rehau Raupiano Light" (OD 110 x 2.7, manufacturer: Rehau AG + CO) with the corresponding fixing system "Sound-dampening bracket". (test object no.: 11035-10)
- Test set-up:** The pipe system was mounted according to figure 4 and 5 (see also Annex A).
 - The pipe system "Rehau Raupiano Plus" consisted of straight wastewater pipes with the nominal size OD 110 x 2.7, with three layers of PP-MD (inner and outer layer) and PP mineral reinforced (middle layer), wall thickness 3.0 mm, density 1.2 g/cm³, weight 1.2 kg/m (measured by IBP). Single layer fittings size OD 110 (three inlet tees 87.5°, arched, two 45°-basement bends), material PP mineral reinforced, wall thickness 3.1 mm, density 1.2 g/cm³ (measured by IBP). The inlet tees in the basement and in the ground floor were closed by lids. Plug connection of the pipes and fittings (shaped pipe sockets).
 - Corresponding fixing system: "Sound-dampening bracket", consisting of a supporting/guidance clamp with a socket clamp and a single guidance clamp (all with quick-locking mechanism). In every storey (EG and UG) two pipe clamps were mounted: In the upper wall area a "Sound-dampening bracket" consisting of a supporting/guidance clamp and a socket clamp and in the lower wall area a single guidance clamp. The supporting and guidance clamps were fixed (without contact to the pipe) to the installation wall with dowels and thread rods.
- The wastewater installation system was mounted by a technician under the authority of Fraunhofer IBP.
- Test facility:** Installation test facility P12, mass per unit area of the installation wall: 220 kg/m², mass per unit area of the ceiling: 440 kg/m². Installation rooms: sub-basement (KG), basement (UG) front, ground floor (EG) front and top floor (DG), measuring rooms: UG front, UG rear (details in Annex P and EN 14366: 2005-02)
- Test method:** The measurements were performed according to EN 14366; noise excitation by steady water flow with 0.5 l/s, 1.0 l/s, 2.0 l/s and 4.0 l/s. Additional evaluation for comparison with requirements following German standards DIN 4109-1:2016-07 and VDI 4100:2012-10 (details in Annexes A, F and V).

Result:

Wastewater installation system consisting of plastic pipes and fittings "Rehau Raupiano Light" (OD 110 x 2.7, manufacturer: Rehau AG + CO) with the corresponding fixing system "Sound-dampening bracket".	Flow rate [l/s]				
	0.5	1.0	2.0	4.0	
Airborne sound pressure level $L_{a,A}$ [dB(A)] according to EN 14366 for the basement test-room	UG front	42	48	51	54
Structure-borne sound characteristic level $L_{sc,A}$ [dB(A)] according to EN 14366 for the basement test-room	UG rear	< 10	10	15	18
Installation sound level $L_{AFeq,n}$ [dB(A)] following DIN 4109 in the basement test-room	UG front	42	48	51	54
	UG rear	11	15	19	22
Installation sound level $\overline{L}_{AFeq,nT}$ [dB(A)] following VDI 4100 in the basement test-room	UG front	40	46	49	51
	UG rear	< 10	11	16	19

Test date: December 8, 2016

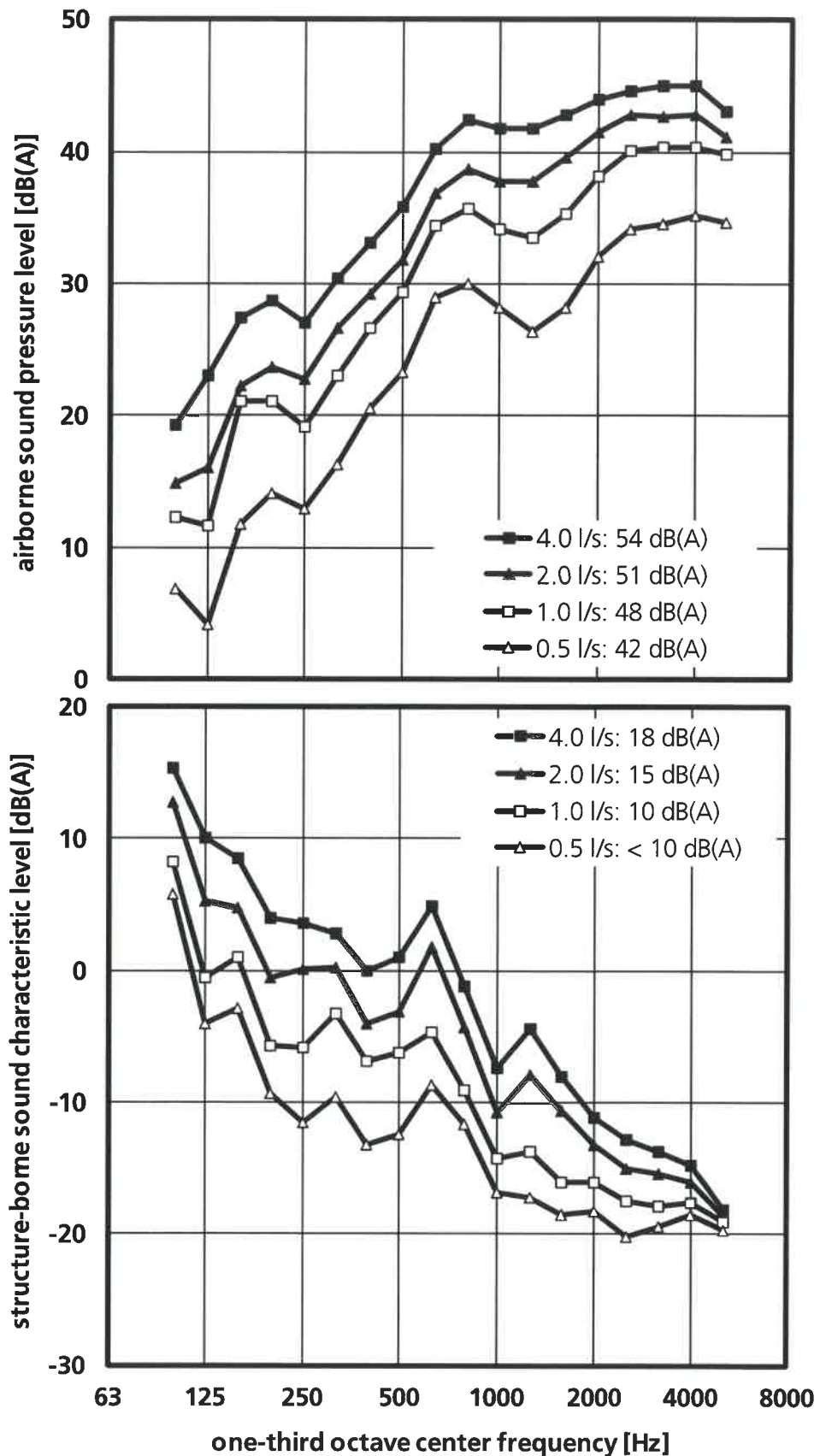
Notes:

- For comparing test results with requirements note Annex A.
- Sound levels below 10 dB(A) are not mentioned in the test report, since they are subject to an increased measurement uncertainty and moreover are not noticeable in a normal living environment.
- The test results require an accurate installation of the pipe clamps (see test set-up)



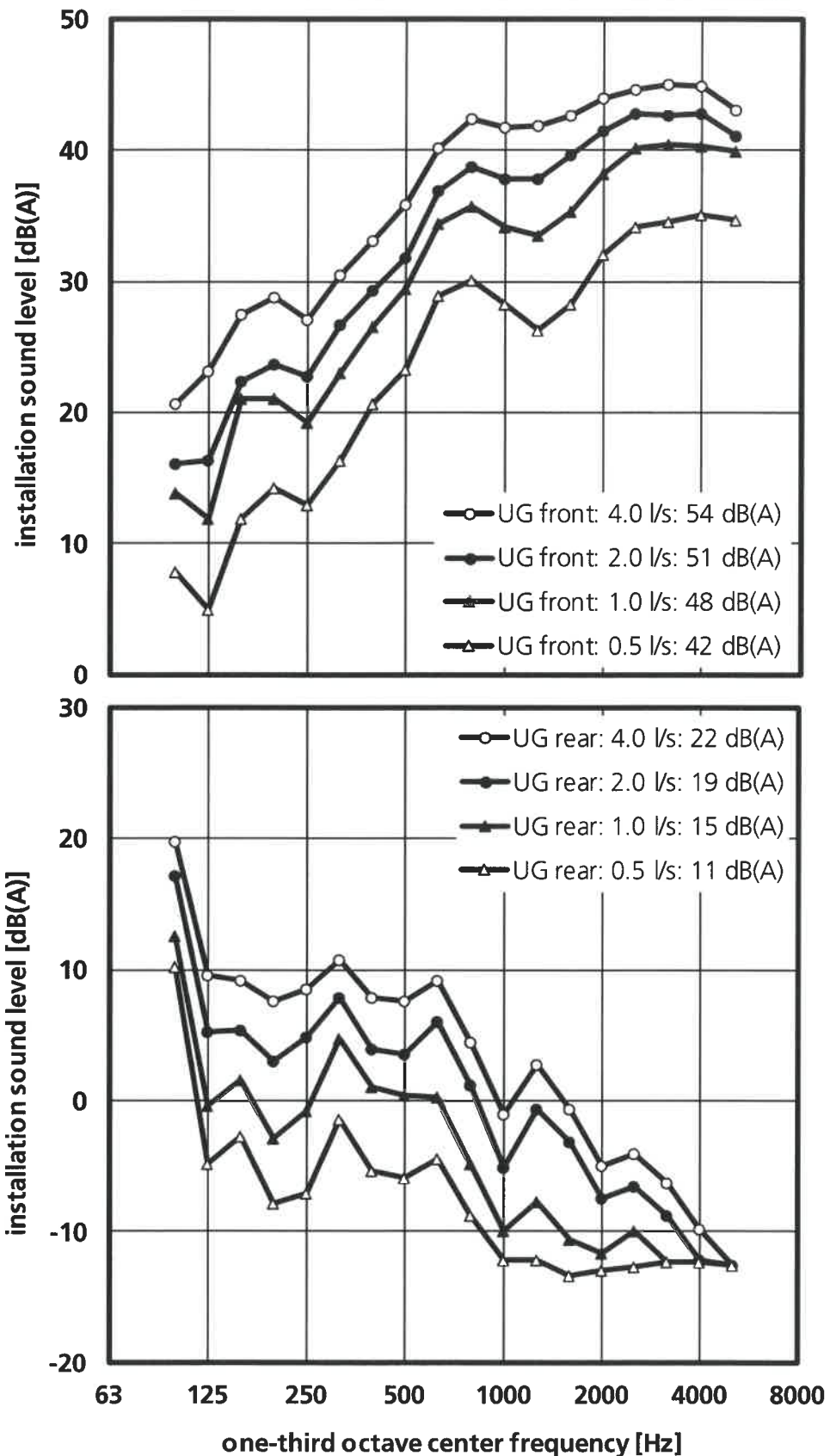
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Stuttgart, July 4, 2017
 Head of Laboratory:



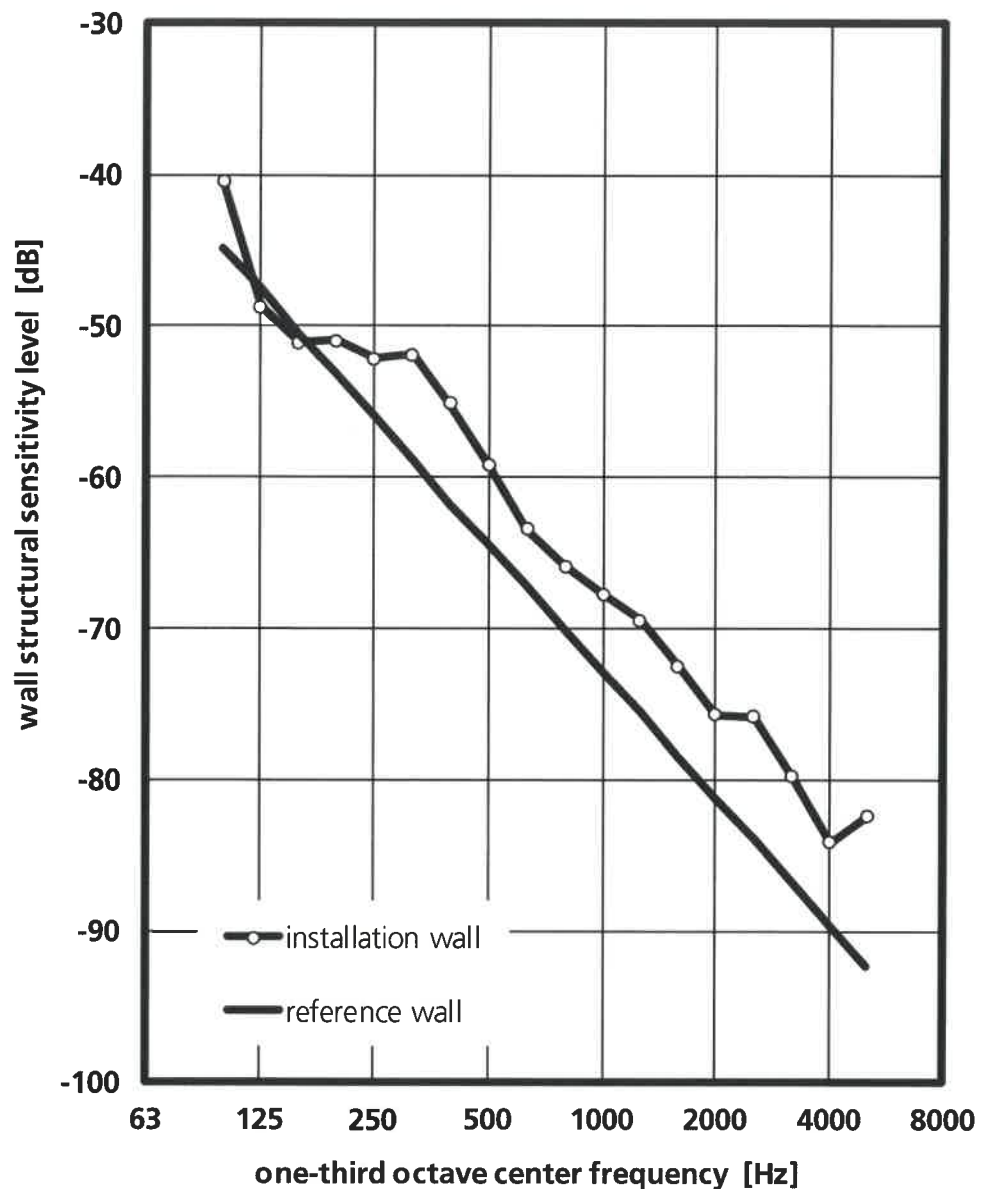
Frequency spectrum of the airborne sound pressure level $L_{a,A}$ (above) and structure-borne sound characteristic level $L_{sc,A}$ (below) measured at various flow rates **according to EN 14366**.

Test specimen: Wastewater installation system consisting of plastic pipes and fittings "Rehau Raupiano Light" (OD 110 x 2.7, manufacturer: Rehau AG + CO) with the corresponding fixing system "Sound-dampening bracket".



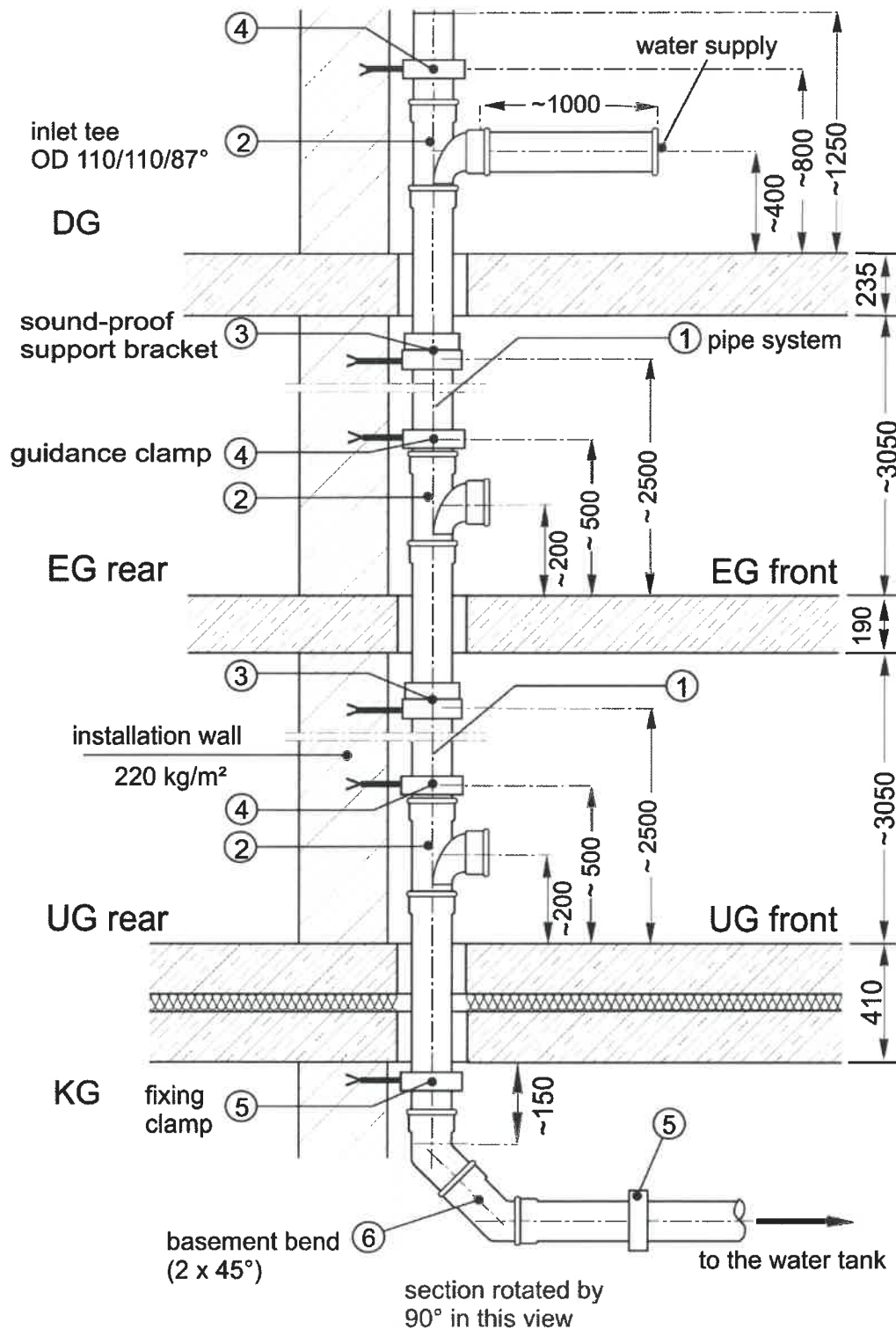
Frequency spectrum of the installation sound level $L_{A, \text{Freq}, n}$ measured at various flow rates in the test rooms UG front (above) and UG rear (below). The installation sound levels $L_{A, \text{Freq}, n}$ in dB(A) **following to DIN 4109**, for the reproduced frequency range from 100 to 5000 Hz, are represented in the legend.

Test specimen: Wastewater installation system consisting of plastic pipes and fittings "Rehau Raupiano Light" (OD 110 x 2.7, manufacturer: Rehau AG + CO) with the corresponding fixing system "Sound-dampening bracket".



Wall structural sensitivity level L_{SS} of the installation wall between the test rooms UG front and UG rear in the installation test facility in the Fraunhofer-Institute of Building Physics. The installation wall consists of calcium silicate blocks (thickness 115 mm, ceiled on both sides) with a mass per unit area of 220 kg/m². The indicated structural sensitivity level L_{SS} refers to the mounting position of the waste water system according to figure 4. For comparison the wall structural sensitivity level L_{SSR} of the reference wall is also indicated (evaluation according to DIN EN 14366).

Test specimen: Wastewater installation system consisting of plastic pipes and fittings "Rehau Raupiano Light" (OD 110 x 2.7, manufacturer: Rehau AG + CO) with the corresponding fixing system "Sound-dampening bracket".



Installation plan of the test set-up in the test facility. Illustration simplified, schematically drawn and not to scale.

Test specimen: Wastewater installation system consisting of plastic pipes and fittings "Rehau Raupiano Light" (OD 110 x 2.7, manufacturer: Rehau AG + CO) with the corresponding fixing system "Sound-dampening bracket".



Upper picture: Waste water system with "Sound-dampening bracket" in the upper wall area.

Lower picture: Waste water system with guidance clamp in the lower wall area.

Test specimen: Wastewater installation system consisting of plastic pipes and fittings "Rehau Raupiano Light" (OD 110 x 2.7, manufacturer: Rehau AG + CO) with the corresponding fixing system "Sound-dampening bracket".

Measurement set-up, noise excitation and evaluation parameters, comparison of measurement results with the requirements, comparability and reproducibility of measurement resultsMeasurement set-up (standard set-up)

In the water-installation test-facility run by the Fraunhofer Institute of Building Physics, a down pipe is installed leading from the top floor (DG) down to the sub-basement (KG) (for further details, please see Annex P). This down pipe is connected to a (OD 110) water inlet pipe on the top-floor level. The water is introduced through an S-shaped bend according to the standard EN 14366. In the sub-basement, the down pipe is connected to a bend (2 x 45 degree, usually) and merges into a horizontal discharge section, which in turn is joined to a water receptacle. The waste-water pipe on the ground floor (EG) and in the basement (UG) is fitted with conventional branches from main lines (usually, OD 110). Pipes and fittings are mounted according to the instructions given by the manufacturer. The air gaps between the tube and floor in the entrance and exit openings are stuffed with porous absorber in order to prevent any structure-borne sound bridges influencing the building. The waste-water piping is fastened to the installation wall (mass per unit surface $m'' = 220 \text{ kg/m}^2$) by means of pipe clamps supplied by the Client, which are adapted to the external diameter of the pipes. The locations of the fixation points and further dimensions are specified in the installation plan that is included in the test report.

Noise excitation and evaluation parameters

Any defined and metrological reproducible noise excitation requires steady state flow conditions inside the waste-water pipes. As the noise generation in waste water systems depends on the flow rate, noise measurements are performed at several flow rates Q which are typically encountered in practice:

- (1) $Q = 0.5 \text{ l/s}$, corresponding to $Q = 30 \text{ l/min}$,
- (2) $Q = 1.0 \text{ l/s}$, corresponding to $Q = 60 \text{ l/min}$,
- (3) $Q = 2.0 \text{ l/s}$, corresponding to $Q = 120 \text{ l/min}$,
- (4) $Q = 4.0 \text{ l/s}$, corresponding to $Q = 240 \text{ l/min}$.

Here, a flow rate of $Q = 2.0 \text{ l/s}$ roughly corresponds to the average flow rate required for flushing a toilet. According to Prandtl-Colebrook, the highest flow rate used results from the admissible hydraulic charge of the horizontal pipe sections, which is $Q_{\text{max}} = 4 \text{ l/s}$ for OD 110 pipes.

The measurements take place in the installation room (UG front) and in the room behind the installation wall (UG rear). The water flow generates vibrations of the wastewater pipe. These vibrations are transmitted to the installation wall through pipe clamps and/or other structure-borne sound bridges (e.g. fire protection sleeves), and then radiated by the wall (and to a lesser extent, also by the adjoining building parts) as airborne sound into the test room behind the installation wall. In the test room UG front additionally the airborne sound which is radiated from the waste water system is measured. According to DIN EN ISO 10 140-4 the sound pressure level is picked up at six points in the room, to be space and time-averaged and corrected for the background noise. With this value the airborne sound pressure level $L_{a,A}$ and the structure-borne sound characteristic level $L_{sc,A}$ is calculated according to EN 14366. The installation sound level is determined following Annex F or following to VDI 4100 per Annex V.

With stationary signals (e.g. waste water noise with a constant flow rate), in deviation from DIN 4109-4 and DIN EN ISO 10052 or VDI 4100 it is not the maximum value ($L_{AF\text{max},n}$, or $\overline{L_{AF\text{max},nT}}$) but rather the temporally and spatially averaged level ($L_{AF\text{eq},n}$, or $\overline{L_{AF\text{eq},nT}}$) that is measured. This guarantees compliance with the reproducibility

and accuracy requirements that are mandatory for test bench measurements (e.g. through the possibility of background noise correction), which would not be realisable with use of the maximum level that is determined according to the aforementioned standards for measurements on the building. On the basis of extensive experience, it is necessary to assume that the difference between $L_{AFmax,n}$ and $L_{AFeq,n}$, or between $\overline{L_{AFmax,nT}}$ and $\overline{L_{AFeq,nT}}$ is a maximum 2-3 dB under normal circumstances.

Comparison of measurement results with the requirements

The measurement results facilitate the comparison of products, materials and system components of waste water installations in terms of their noise insulation properties (component testing). Furthermore, it is also possible to compare the noise pressure levels (installation noise level) detected during the tests with the requirements in DIN 4109 and VDI 4100. A precondition for this is that the structural conditions in the real construction situation are comparable with or acoustically more favourable than those on the test bench at the Fraunhofer Institute for Building Physics. Furthermore, when comparing with the requirements, it is necessary to note that simultaneous operation of sanitary installations and possible interactions between the sanitary components could lead to other results. The measured value at a volumetric flow of 2 l/s should be used as a comparable value with the requirements, because this roughly equates to the mean volumetric flow when a WC is flushed.

With the standard DIN EN 12354-5, it is also possible to predict the noise pressure level in other rooms requiring sound insulation, also for deviating building situations and with consideration to additional values for the installation noise from further domestic systems, such as WC systems, shower cubicles, baths, etc. Alternatively, it is possible to perform so-called design model tests, in which waste water systems can be tested on our test benches in conjunction with further sanitary installations connected in accordance with practice (system measurement). The measured values can be subsequently compared directly with the noise insulation requirements.

Comparability and reproducibility of measurement results

For noise measurements of waste water systems, the results are dependent not only on the pipe clamps used, but to a large extent on the installation conditions, such as the precise vertical alignment of the pipes, the deburring of the pipe ends, and the insertion depth of the pipes in the sleeves. By optimising these influences, experience shows that it is possible to reduce the noise level by multiple dB.

A comparison between different waste water systems therefore requires that all systems be fitted with the same degree of care and attention.

Evaluation of Measurements

Stationary noise

The measured sound pressure level is given as time and space averaged one-third octave spectrum in the frequency range between 100 Hz and 5 kHz. First, the measured value is corrected for background noise. Subsequently, it is normalized to an equivalent sound absorption area of $A_0 = 10 \text{ m}^2$ and A-weighted:

$$(1) \quad L_{i,AFeq,n} = 10 \cdot \lg \left(10^{\frac{L_{i,F}}{10}} - 10^{\frac{L_{i,F,GG}}{10}} \right) + 10 \cdot \lg \frac{A_i}{A_0} + k(A)_i \quad [\text{dB(A)}]$$

$L_{i,F}$	space and time averaged sound pressure level in one-third octave band i (time constant: fast)	[dB]
$L_{i,F,GG}$	background noise level in one-third octave band i	[dB]
$A_i = \frac{0.16 \cdot V}{T_i}$	sound absorption area of test room for one-third octave band i	[m ²]
V	volume of test room	[m ³]
T_i	reverberation time of test room in one-third octave band i	[s]
$k(A)_i$	A-weighting for one-third octave band i	[dB]

If the difference between the measured one-third octave level and the background noise level is less than 3 dB, the correction for background noise will not be performed. Instead, the measured background noise level will be used as test result (as largest possible value). The total sound pressure level is obtained by energetically adding the one-third octave values.

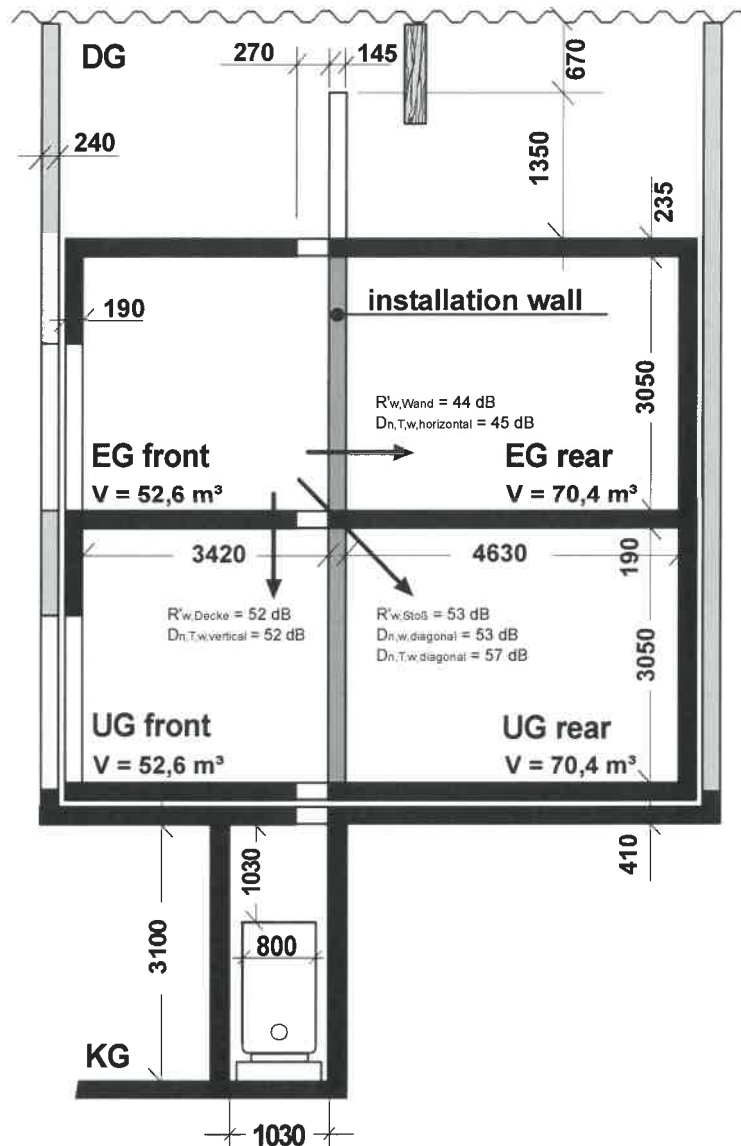
$$(2) \quad L_{AFeq,n} = 10 \cdot \lg \left(\sum_{i=1}^{18} 10^{\frac{L_{i,AFeq,n}}{10}} \right), \quad [\text{dB(A)}]$$

where i indicates the number of one-third octave bands from 100 Hz to 5 kHz. The calculated level $L_{AFeq,n}$ corresponds to the sound pressure level that would arise in a sparsely furnished reception room under otherwise equal conditions. The value represents the installation sound level in the test facility.

Time-dependent noise

In this case, the measurement signal consists of a series of one-third octave spectra (frequency range from 100 Hz through 5 kHz) which are consecutively measured at the same place with a time interval of 0.125 s. The evaluation is performed in the same way as in the case of stationary noise, with the exception that background noise correction is not performed. After evaluation the maximum value ($L_{AFmax,n}$) is determined from the measured time response.

Test facility



Sectional drawing of the installation test facility in the Fraunhofer-Institute of Building Physics (dimensions given in mm). The test facility comprises two couples of rooms in the ground floor (EG) and in the basement (UG) that are located above each other. Due to this construction, including the top floor (DG) and the sub-basement (KG), it is possible to perform tests on installation systems which extend across several floors, e.g. waste-water installation systems. The installation walls in the ground floor and in the basement can be substituted according to actual requirements. In the standard case, single-leaf solid walls with a mass per unit area of 220 kg/m² (according to German standard DIN 4109) are used. Since the sound insulation of these walls do not meet the requirements to be fulfilled by a wall separating different occupancies within the same building ($R'_w \geq 53$ dB), the next adjacent rooms to be protected from noise are located diagonally above or below the installation room (in case of a usual design of the ground plan). Due to its double-leaf construction with an additional structure-borne sound insulation, the installation test facility is particularly suited for measuring low sound pressure levels. The measuring rooms are designed in such a way that the reverberation times are between 1 s and 2 s within the examined frequency range. The flanking walls, with an average mass per unit area of approximately 440 kg/m², are made of concrete.

Measurement equipment

Following measurement equipment was used for the measurements in the installation test facility P12 of the Fraunhofer-Institute for Building Physics:

Device	Type	Manufacturer
Analyser	Soundbook_MK2_8L	Sinus Messtechnik
½"-microphone-Set	46 AF (Kapsel: Typ 40 AF-Free Field; Vorverstärker: Typ 26 TK)	G.R.A.S
1"-microphone-Set	40HF (Kapsel: Typ 40EH-LowNoise; Vorverstärker: Typ 26HF; Power Module: Typ 12HF)	G.R.A.S
1"-microphone	4179	Bruel & Kjaer
1"-preamplifier	2660	Bruel & Kjaer
Microphone-calibrator	4231	Bruel & Kjaer
Accelerometer	4371 und 4370	
Conditioning amplifier	Nexus 2692-A-014	Bruel & Kjaer
Accelerometer-calibrator	VC11	MMF
Amplifier	LBB 1935/20	Bosch Plena
Loudspeaker	MLS 82	Lanny
Reference sound source	382	Rox
Standard tapping machine	211	Norsonic

All measurement devices are tested frequently by internal and external testing laboratories and, if possible and necessary, are calibrated and gauged.

Assessment of increased noise protection according to VDI 4100

The directive VDI 4100 contains suggestions for increased sound insulation in apartments. These suggestions outreach the minimum requirements of DIN 4109, and in addition, can be agreed by the client and the responsible company.

The measurement of noise of sanitary installations is equally carried out in accordance with VDI 4100 and DIN 4109. Details of the method and the evaluation of the results are described in Annex F. The only difference between the two standards is that the measured sound levels in DIN 4109 are related to the equivalent sound absorption area of $A_0 = 10 \text{ m}^2$, whereas in VDI 4100 the reverberation time of $T_0 = 0.5 \text{ s}$ is used as a reference value. The relation between the two sound levels is as follows:

$$L_{AF,nT} = L_{AF,n} - 10 \lg(V) + 15$$

with $L_{AF,nT}$ = standardized sound level of noise of sanitary installations according to VDI 4100 [dB(A)]
 $L_{AF,n}$ = normalized sound level of noise of sanitary installations according to DIN 4109 [dB(A)]
 V = volume of the receiving room [m^3]

The indices A and F describe the frequency weighting "A" and the time weighting "Fast". Depending on whether a time-averaged value or a maximum level is measured, the index "eq" or "max" is added to these indices. This equally applies for the standardized and normalized sound level, for example $L_{AFeq,nT}$ Or $L_{AFmax,n}$.

The standardized sound level according to VDI 4100 and the normalized sound level according to DIN 4109 differ in a constant value which is only dependent on the volume of the receiving room. Whereas the normalized sound level (DIN 4109) is independent of the room volume, the standardized sound level (VDI 4100) is reduced by an increasing room volume. Since the requirements of sound insulation of VDI 4100 are related to the standardized sound level, the values measured in the test facilities of noise of sanitary installations of the IBP must be converted to the volume of the in-situ rooms in need of protection as verification of the requirements. Conversion is carried out according to the following relation:

$$L_{AF,nT,Building} = L_{AF,nT,Lab} + 10 \lg(V_{Lab}/V_{Building})$$

with $L_{AF,nT,Building}$ = standardized sound level of the tested installation at the building
 $L_{AF,nT,Lab}$ = standardized sound level of the tested installation in the test facility
 V_{Lab} = volume of the receiving room in the test facility
 $V_{Building}$ = volume of the room in the building in need of protection

The volumes of the three receiving rooms in the sanitary installation noise test facility of the IBP and diagrams of the previous calculation formula for direct reading of the results can be found in the following:

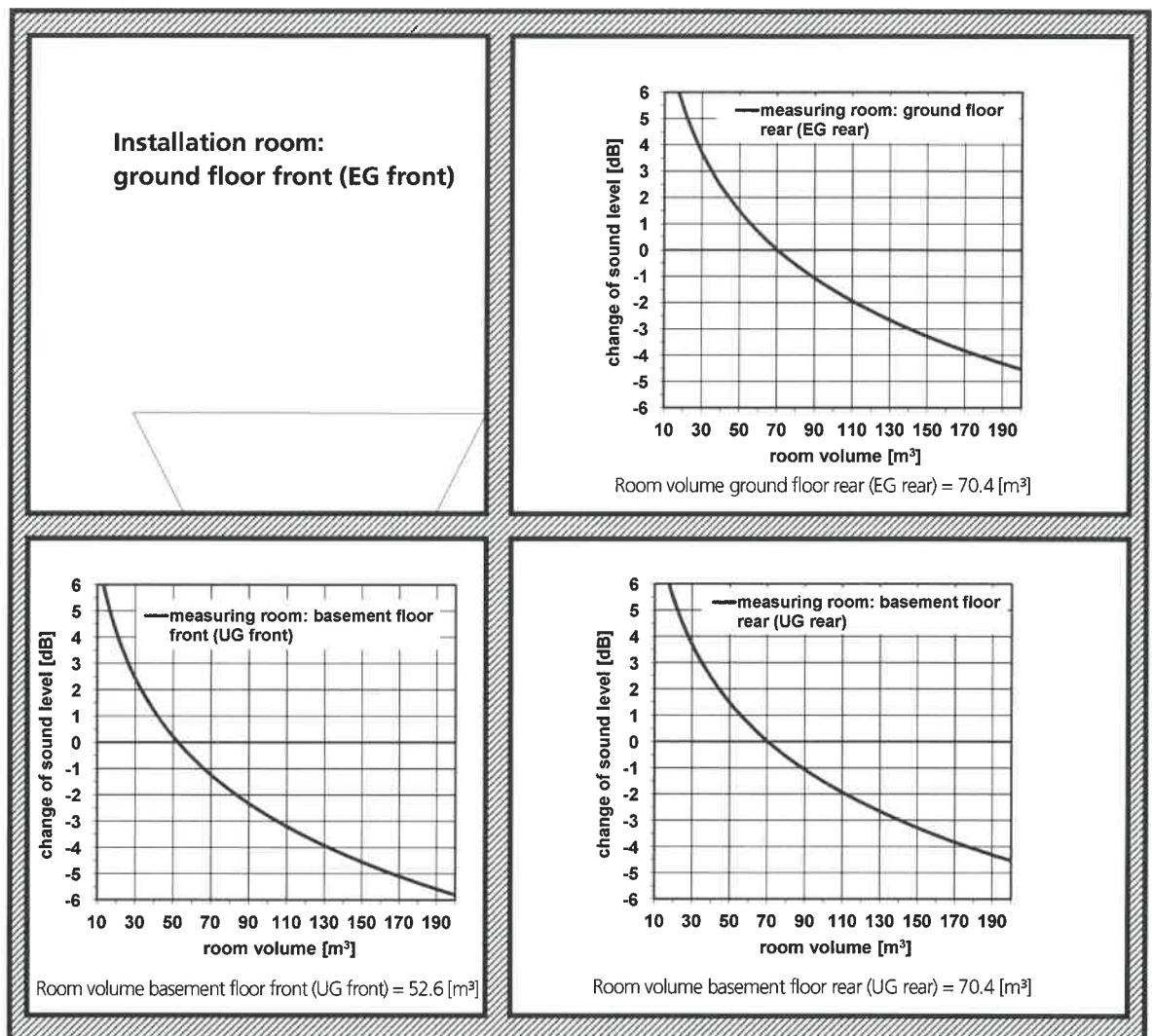


Fig. 1: Modification of the standardized sound level measured in the installation test facility P12 for rooms with deviating volume. The resulting change of sound level in comparison to the measured value indicated in the test report in dependence of the new room volume is specified in the diagrams for the three measuring rooms basement floor front (UG front), basement floor rear (UG rear), and ground floor rear (EG rear). If the volumes of the new room comply with the respective measuring room, the sound level will remain unchanged (modification of level $\Delta L = 0$ dB). If the new room is larger than the respective measuring room, the sound level will be reduced ($\Delta L < 0$). If it is smaller, the sound level will increase ($\Delta L > 0$).

Requirements

According to VDI 4100 all rooms in an apartment with a ground area ≥ 8 m² are considered as rooms in need of protection. Kitchens, bathrooms, WCs, halls and side rooms, however, are explicitly exempted from building installation noise and from impact sound. For common floor plan configuration (bathroom above bathroom) normally the room in the basement floor rear (UG rear) is for the values measured in the test facility the one to be primarily considered as room in need of protection.

The required values are divided according to the sound insulation levels (SSt) in VDI 4100 complying with various comfort levels:

Table 1: Comfort level and acoustic situation for the sound insulation levels I to III according to VDI 4100.

SSt I	„raised in the design and construction compared to a simple one regarding design and construction features“
	„unreasonable annoyance are in general avoided “
SSt II	„average requirements of comfort“
	„in general not disturbing“
SSt III	„special comfort requirements“
	„not or only seldom disturbing“

Different requirements are indicated respectively for the three sound protection levels in VDI 4100. Since sound insulation level III represents the highest comfort level the strictest requirements must be applied, i.e. sound levels allowable for noise of sanitary installations are lowest in this case. The required values for apartment houses or one-family terrace houses and one-family semi-detached houses are represented in the following table:

Table 2: The requirements of sound insulation of building service equipment in for apartment houses or one-family terrace houses and one-family semi-detached houses according to VDI 4100 for sound protection levels I to III. The requirements apply for sound transmission between separated apartments. Noise from water supply installations and sewage systems are considered together.

Building	Acoustic parameter [dB(A)]	Sound protection level I	Sound protection level II	Sound protection level III
Apartment houses	$\overline{L_{AFmax,nT}}$ or $\overline{L_{AFeq,nT}}$ a) b)	≤ 30	≤ 27	≤ 24
One-family terrace houses and one-family semi-detached houses	$\overline{L_{AFmax,nT}}$ or $\overline{L_{AFeq,nT}}$ a) b)	≤ 30	≤ 25	≤ 22

- a) Individual short-term noise peaks during actuation (opening, closing, adjusting, interrupting, etc.) the fittings and equipment of the plumbing system should not exceed the characteristic values of SSt II and SSt III by more than 10 dB. Here, the intended use is required
- b) Since noise of sanitary installations are frequently temporary changing signals, VDI 4100 provides for the measurement the maximum level $\overline{L_{AFmax,nT}}$. For stationary signals such as impact noise from water jets, however, it is more efficient to determine the average noise level $\overline{L_{AFeq,nT}}$ instead, since only in this way it is possible to observe the requirements for reproducibility and accuracy obligatory for measurements in the test facility. The measured average noise level is generally slightly lower than the maximum level, however, the difference is not more than a maximum of 2 to 3 dB according to extensive experience.

Besides the previously described requirements for sound transmission between separate apartments, VDI 4100 also contains recommendations for sound protection in one's own living space. The effective required values and the importance of the respective sound protection levels can be found in VDI 4100.

Note to handle noise emitted by users in VDI 4100:

For user noises, which often result in complaints (e.g. putting down a toothbrush tumbler on a storage board, opening and closing the toilet cover, use of toilets, sliding in the bath tub, striking the doors – also of wall cabinets and built-in cabinets, etc.) neither to the noise control classes SSt II and SSt III no characteristic values were specified, since these noises are very difficult to reproduce and depend on the specific building situation. It is assumed, however, that these noises – by intended use – are reduced as much as possible by application of conventional arrangements for the impact sound insulation when mounting the sanitary equipment.