B10 - MEASUREMENT OF THE NOISE PRODUCTION IN WATER PIPES

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Abstract
In the Netherlands new regulations for housing have come into force that require a lower noise level in domestic buildings caused by installations. The maximum allowed noise level is 30 dB(A). This low level has consequences for how the installations are designed and installed. The new regulations have initiated new methods in constructing buildings.
The question arises if the existing guidelines with practical information for noise reduction of sanitary appliances meets these new requirements.
TVVL and Uneto-VNI have initiated a study with the aim to give guidelines. These guidelines are used to update the current guidelines which enables consultants and installers to select the correct flow velocity, valves and pipe sizes for the materials used with respect to the noise level.
The scope of the study covers:
• Measuring the noise production caused by flow velocities in various pipe materials.
• Measuring the noise production caused by pipe fittings, pressure reducing valves, non return valves and valves.
This paper focuses on measurements on water piping-system noise in terms of noise transmission and noise emission. The first bullet mentioned above.

Keywords
Noise reduction, water pipelines, measurements

1 Introduction
Noise caused by sanitary installations both in the same house or the adjacent house plays an important role. With regard to tougher regulations on the quality of residential buildings in general, the reduction on the noise levels in residential buildings comes about.
The requirements in relation to noise levels caused by (sanitary) installations are determined in public (Bouwbesluit) and private regulations (GIW): the maximum allowed noise level has become 30 dB(A).
In residential buildings noise is generated in piping systems, which serve as transmission lines to transmit the noise through the structure. Solutions to this problem are usually not simple because of the many sources at which the noise may originate and because of the complex mechanism by which noise travels through the system and is eventually radiated to the air.
Designers and technicians need practical information how to design and install a pipe system in buildings to avoid too high noise levels in buildings. Guidelines are available, but it is unknown or the existing guidelines meets the new very strict permitted value of 30 dB(A).
A total of 550 measurements were carried out in the field of sanitary installations divided in four parts: (1) literature research, (2a) measurements on the noise production of water pipes, (2b) measurements on the noise production of horizontal drainage pipes and (3) publication of the report.
This paper is a summary of the report of stage 2a and covers the measurements on water pipes and describes:
1. The methodology used to measure the noise production in water pipes.
2. A summary of the results of the measurements; the measured noise levels for the various pipe materials in relation with the flow and velocity in the pipes.

2 Maximum flow velocity
Guidelines in the Netherlands gives values for the maximum velocity in pipelines in water systems. The maximum values are selected to avoid noise production and erosion in the pipe. Table 1 shows the different velocities.

Table 1 - Maximum water flow in water systems

System	Velocity (m/s)
Cold water system	2.0
Hot water system	1.5
In case of low noise requirements	1.0
Hot water circulation	0.7

In the Netherlands guidelines recommend for a water system a maximum flow velocity of 1.5 m/s.
These maximum values are also common in several European countries. The question was: on what theories are these velocities based and is there any scientific research available to support the choices? In the past research has been done by several researchers but the relation with the current way to construct a building and fastening the water pipes is unknown. This was the reason to start measurements to get reliable values for the noise production of water flow in several pipe systems fastened on the outside of walls and inside walls.

3 Water system

Water pipes in service shafts are generally fixed with pipe clamps with a rubber inlayer, mounted to a massive reinforced concrete or brick wall. Outside the shafts the pipes are typically mounted in the floor or hang up under a floor. The last few meters to the tap pipes are mounted in the wall. In brick walls first a groove is made, then the pipe whether with a coating or insulation is mounted in the groove and sealed with cement. In gypsum walls the pipes are fastened on a wooden panel in between the gypsum layers.
A water system consists of pipes and fittings. Its common to use the following pipe materials: copper, plastics (PVC-C. PB. PE-X and PP) and multi layer pipes (PE-X. Al and PE). Figure 1 shows the principle of the connections in copper pipes. The inside diameter of the fitting is equal to the diameter of the pipe. Figure 2 shows the principle of the "press" connection in plastic or multi layer pipes. With a "press" connection the inside diameter of the tube is reduced by a local narrowing in the fitting and this results in noise production. Technicians have to be aware of this problem.

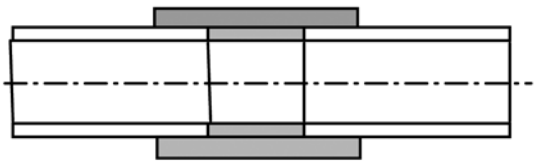

Fig.1: A connection with a copper fitting.

Fig.2: Typical "press" connection of plastic pipes (AluPEX)

The above mentioned research in the past was done when modern plastic pipe systems did not exist. So the influence of the narrowing in the fitting has not been measured. This is one of the reasons why there is a need for new measurements on the noise production in water systems.

4 Pipe systems

The following pipe materials and the sizes listed below are commonly used in the Netherlands for water systems:
Copper
outside diameter 10 (inside diameter 8),12 (10),15 (13), 22 (19.8), 28 (25.6), 35 (32.4), 43 (29.2) and 54 (51)

Plastic	PVC-C	16 (12.0)	20 (15.4)	25 (19.4)
	PB	16 (12.4)	20 (16.2)	25 (20.4)
	PE-X	16 (10.6)	20 (14.4)	25 (18.0)
	PP	16 (10.6)	20 (13.2)	25 (16.8)

Multi layer PE-X+Al+PE
16 (11.5) 20 (15.0) 26 (20.0)

5 Reducing costs

With a the view to reduce costs it is desirable to use a higher flow velocity in residential buildings: for example with a twice higher flow velocity one size smaller pipe can be selected, witch results in a 35% reduction of costs, less space is needed and less stagnation of water in the piping. At the same time the pipes with a higher water flow have better self cleaning properties.

6 Methodology used to measure the noise production

The variables as mentioned below have been examined:
• The constructive situation
• Material of the water pipes
• Flow velocity in the pipe, elbow or bend
• The way of mounting the pipe

The measurements were been done in the laboratory of Peutz bv in Mook in the Netherlands according NEN-EN ISO 3822:1999. See figure 3 and 4.

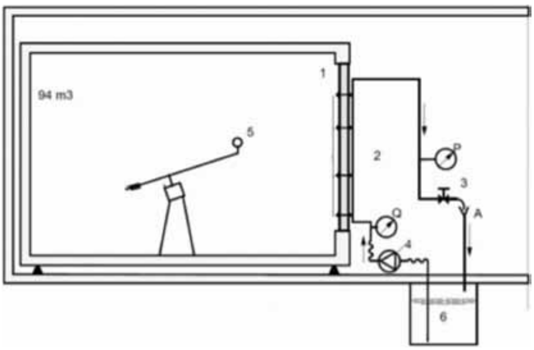

Fig.3: Cross section of the receiving room

Fig.4: Measurement setup

6.1 Different wall constructions

The measurements were executed with different wall materials, described as below:

1. Sand-lime bricks

A sand-lime bricks wall; breadth x height x thickness: 4300 x 2800 x 100 mm. Weight 180 kg/m2. One side has a plaster layer.

2. Gypsum blocks

A gypsum blocks wall; breadth x height x thickness: 4300 x 2800 x 100 mm. Size of the blocks 437 x 197 x 100 mm. Weight 84 kg/m^2. One side has a plaster layer.

3. Lightweight system panel 1

Type of wall: Gyproc MS 100/ 1.75.A

This wall with a total thickness of 100 mm is a composition of metal profiles with one layer of gypsum panel on each side, thickness 12.5 mm. mass of the gypsum panel 9.2 kg/m^2. In the 75 mm thick hollow space 40 mm thick Isover glaswool is placed. The total weight of this wall construction is 20 kg/m^2.

4. Lightweight system panel 2

Type of wall: Gyproc MS 100/ 2.50.2.A

This wall with a total thickness of 100 mm is a composition of metal profiles with two layers of gypsum panel on each side, thickness 2 x 12.5 mm. mass of the gypsum panel 2 x 9.2 kg/m^2. In the 75 mm thick hollow space 40 mm thick Isover glaswool is placed. The total weight of this wall construction is 38 kg/m^2.

6.2 Pipe materials

The following piping materials were used for the measurements:

- Copper. inside diameter 12, 15 and 22 mm
- AluPEX (Wavin Tigris). inside diameter 12, 12.5 and 20 mm
- Polybutylene (PB) (Hep2O). inside diameter 11.6, 18 and 22.8 mm

The pipes were fixed to the wall construction with pipe clamps with acoustic rubber layer.

The pipework was measured with and without insulation.

To determine the influence on the noise production of a narrow hole in a "press" connection, a so called standard burr on the inside of a copper pipe was made with a pipe cutter equipped with a blunt wheel.

7 Measurements

7.1 Methodology

The wall constructions were set up between a source room and receiving room in the laboratory. Depending on the kind of wall construction the water pipes were fastened both inside the wall construction or outside the wall construction. See figure 5 and 6.

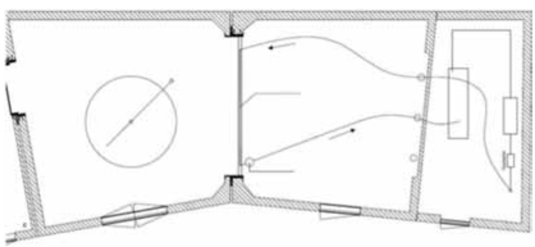

Fig.5: Plan of the receiving room and source room with in between the test panel

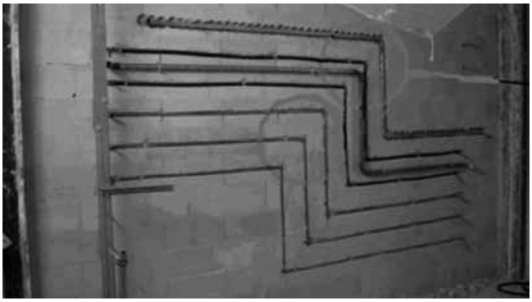

Fig.6: Example of a wall construction with gypsum blocks and pipes in the grooves

Grooves were made in the brick walls, each groove with a total length of 4 m including two bends. The pipes were fastened in the grooves. Each pipe has four bends including the inlet and outlet. Then the grooves were sealed with a gypsum or cement layer.
For the lightweight walls the pipes were fastened on wooden panels as underlayment. The wooden panels were fixed with screws to the metal profiles.
A pump in the sanitary room sucks water from a reservoir and is connected by a flexible hose to the examined pipe. After flowing trough the pipe the water returns to the reservoir. The pump has a variable speed.

7.2 Calculations

To compare the measured noise levels with other situations the measured values are recalculated to a standard reference sound pressure level L_n in dB(A). By measuring the reverberation time of the measure room the equivalent absorber area is calculated with:

(1)

$$A = 0{,}163 \frac{V}{T}$$

Where:
A = equivalent absorption area (m^2 area of opening)
V = Volume of the test room (m^3)
T = Reverberation time of the test room (s)

The measured sound pressured levels L_p for the various constructions are corrected for the actual absorber area A and recalculated to a standard reference sound pressure level L_n with a reference absorber area of 10 m^2 open window:

(2)

$$L_n = L_p + 10 \log \frac{A}{A_o}$$

Where:
L_n = sound pressure level (dB)
L_p = measured sound pressure level caused by the flow in the water pipe (dB)
A = according (1) determined absorption area (m^2 area of opening)
A_o = reference absorption area (10 m^2 area of opening)

7.3 Flow velocity

The noise production of the pipes was measured with flow velocities of 1, 2, 3 and 4 m/s. General a flow velocity below the 2 m/s in the pipe did not give a sufficient measurable value above the background level. Additionally some measurements were executed with flow velocities up to 6 m/s.

7.4 Airborne noise

Regarding pipes fixed in grooves and to compare the measured values the contribution of airborne noise from pipes fastened outside a sand-lime bricks wall was determined. The values are also applicable for pipes fastened on the outside of a wall as is sometimes used in the case of renovation of buildings.
The results of each individual measurement is figured in different frequency bands in a report. Figure 6 shows an example of a report with the results of the measurements of a copper pipe with a 12 mm outside diameter, fastened with pipe clamps with rubber layer outside a sand-lime bricks wall, thickness 100 mm. Table 2 shows a summary of the results of the measurements.

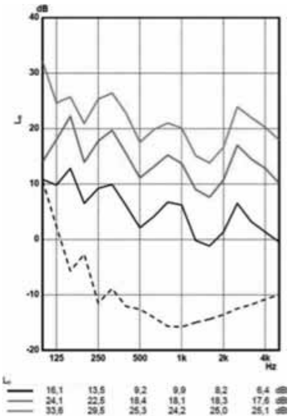

Fig.6: Example of a measurement report.

Table 2: Airborne noise L_n in dB(A) caused by pipes fastened outside a wall, depending on the flow velocity

Type of pipe, outside diameter, elbows unless otherwise indicated	Sound pressure level L_n [dB(A)]			
	1 m/s	2 m/s	3 m/s	4 m/s
Copper 12 mm	n.m.	15	25	32
Copper 12 mm with thermal insulation (Armaflex)	n.m.	15	25	31
Copper 15 mm	n.m.	13	23	30
Copper 22 mm bends	n.m.	10	16	24
PB 15 mm	n.m.	12	23	31
AluPEX 16 mm	21	36	52	70
n.m. = not measurable above background level				

Thermal insulation

Outside thermal insulation doesn't have any significant influence on the airborne sound level of a 12 mm copper pipe.

AluPEX

In comparison with the other pipes the noise level caused by a AluPex-pipe is much higher. The noise level is caused by a high frequency cavitation noise, produced by the narrow reduced cross sectional area in the "press" connection. The reduced inside diameter of the fitting is 7,5 mm, which increases the flow velocity on that particular spot by 2,5 times.

With a flow velocity of 2 m/s in the straight tube (= 5 m/s on the orifice in the fitting) the required maximum noise level of 30 dB(A) is exceeded.

7.5 Structure borne noise

7.5.1 Brick limes wall, thickness 100 mm

The structure borne noise caused by a water flow in a common way fastened pipe in a 100 mm thick brick limes wall is measured for three diameters copper pipe, two diameters PB-pipe and two diameters AluPEX-pipe. Table 3 shows a summary of the results of the measurements.

Table 3: Structure borne noise Ln in dB(A) caused by pipes fastened inside a 100 mm thick lime brick wall, depending on the flow velocity

Type of pipe, outside diameter, elbows unless otherwise indicated	Sound pressure level L_n [dB(A)]			
	1 m/s	2 m/s	3 m/s	4 m/s
Copper 12 mm	n.m.	13	23	29
Copper 15 mm	n.m.	13	21	28
Copper 22 mm	n.m.	12	22	31
Copper 22 mm bends	n.m.	n.m.	13	18
PB 15 mm	n.m.	10	19	27
PB 22 mm	n.m.	15	22	29
AluPEX 16 mm	24	37	44	60
AluPEX 20 mm	23	39	58	63
n.m. = not measurable above background level				

Copper and PB

In pipes with elbows a flow velocity of 4 m/s meets the maximum required noise level of 30 dB(A); in pipes with bended elbows even a flow velocity of 6 m/s meets the maximum required noise level of 30 dB(A).

AluPEX

In comparison with the other pipes the noise level caused by a AluPex-pipe is much higher. The noise level is determined by a high frequency cavitation noise, produced by the orifice in the "press" connection. The maximum required threshold of 30 dB(A) is already exceeded by a flow velocity of 2 m/s.

7.5.2 Gypsum blocks wall, thickness 100 mm

The structure borne noise caused by a water flow in a common way fastened pipe in a 100 mm thick gypsum blocks wall is measured for two diameters copper pipe, two diameters PB-pipe and two diameters AluPEX-pipe. Because of the material properties the radius of the bended elbows in the PB-pipes are smaller then the radius' of the bended elbows in the Copper and AluPEX pipes. Table 4 shows a summary of the results of the measurements.

Table 4: Structure borne noise L_n in dB(A) caused by pipes fastened inside a 100 mm thick gypsum blocks wall, depending on the flow velocity

Type of pipe, outside diameter, elbows unless otherwise indicated	Sound pressure level L_n [dB(A)]			
	1 m/s	2 m/s	3 m/s	4 m/s
Copper 15 mm	n.m.	12	22	31
Copper 15 mm bended elbows	n.m.	10	13	22
Copper 22 mm	n.m.	16	25	30
Copper 22 mm bends	n.m.	10	16	24
PB 15 mm	n.m.	12	23	31
PB 15 mm bends	n.m.	n.m.	n.m.	9
PB 22 mm bends	n.m.	n.m.	n.m.	10
AluPEX 16 mm	22	38	45	64
AluPEX 16 mm bends	n.m	9	20	26
AluPEX 20 mm	32	46	53	59
AluPEX 20 mm bends	n.m.	10	22	29
n.m. = not measurable above background level				

Copper and PB

The structure borne noise measured for both the copper pipes with elbows and PB-pipes with elbows are, with a flow velocity of 4 m/s, almost equal to each other and equal to the measured levels of the copper pipes in a 100 mm thick lime stone wall. With lower velocities a lower level of approximately 3 dB(A) is measured.

AluPEX

The maximum required noise level of 30 dB(A) is exceeded by a flow velocity of 2 m/s for the 16 mm AluPEX-pipe with elbows and by a flow velocity of 1 m/s for the 20 mm AluPEX-pipe with elbows.

Copper pipe pres connection with burrs

The pipes can be cut to length with suitable pipe cutters. The pipe ends must be de-burred both internally and externally after cutting. Sometimes this action is forgotten or the pipe cutter is worn. To determine the influence of a not re-burred pipe measurements were executed on two copper pipes, Sanco 15 x 1 mm, inside diameter 13 mm, 1 meter long with two bends. In the straight part of the pipe a "press" connection was made. In one of the pipe connections on both pipes a burr was made with a pipe cutter equipped with a blunt wheel. The local narrowing made with the pipe cutter has a diameter of 11 mm caused by the burr with a height of 1 mm. Figure 7 shows the pipe end and table 5 gives the measurements results.

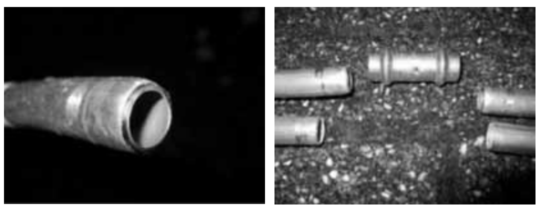

Fig.7: pipe end(s) with burr

Table 5: Structure borne noise L_n in dB(A) caused by a burrs in a pipe of 15 mm fastened inside a 100 mm thick gypsum blocks wall, depending on the flow velocity

Type of pipe, outside diameter, bended elbows	Normalised Sound pressure level L_n [dB(A)]			
	1 m/s	2 m/s	3 m/s	4 m/s
Copper 15 mm with burrs	n.m.	8.5	11.5	18.5
Copper 15 mm	n.m.	5.0	12.0	18.5
n.m. = not measurable above background level				

The results of the measurements doesn't show a significant difference at the velocity of 3 and 4 m/s (= respectively 4.2 and 5.6 just in the narrowing caused by the burr)

7.5.3 Lightweight system with a single gypsum panel

The structure borne noise caused by a water flow in a typically fastened pipe in a 100 mm thick lightweight system with a single gypsum panel was measured for respectively two diameters copper pipe, PB-pipe and AluPEX-pipe. As reference also a 15 mm copper pipe with bends was measured. Table 6 shows a summary of the results of the measurements.

Table 6: Structure borne noise L_n in dB(A) caused by pipes fastened inside a 100 mm thick lightweight system with a single gypsum panel, depending of the flow velocity

Type of pipe, outside diameter, elbows unless otherwise indicated	Sound pressure level L_n [dB(A)]					
	1 m/s	2 m/s	3 m/s	4 m/s	5 m/s	6 m/s
Copper 15 mm	n.m.	9	18	27	32	37
Copper 15 mm bends	n.m.	n.m	12	16	20	25
Copper 22 mm	n.m.	11	22	30	*)	*)
PB 15 mm	n.m.	15	27	35	40	44
PB 22 mm	n.m.	12	23	33	*)	*)
AluPEX 16 mm	25	37	45	66	*)	*)
AluPEX 20 mm	28	42	50	56	*)	*)
n.m. = not measurable above background level *) = not measured						

Copper

The structure borne noise L_n is about 12 dB(A) lower for bended elbows for velocities higher then 4 m/s. For the 22 mm and 15 mm copper pipes the measured value meets the required noise level of 30 dB(A).

AluPEX

Both the AluPEX-pipes meets the required noise level of 30 dB(A) at a flow velocity of 1 m/s. With a flow velocity of 2 m/s the former noise level is exceeded.

7.5.4 Lightweight system with double gypsum panel

The structure borne noise caused by a water flow in a common way fastened pipe in a 100 mm thick lightweight system with a double gypsum panel is measured for respectively two diameters copper pipe, PB-pipe and AluPEX-pipe. As reference also a 15 mm copper pipe with bends was measured. Table 7 shows a summary of the results of the measurements.

Table 7: Structure borne noise L_n in dB(A) caused by pipes fastened inside a 100 mm thick lightweight system with a double gypsum panel, depending on the flow velocity

Type of pipe, outside diameter, elbows unless otherwise indicated	Sound pressure level L_n [dB(A)]					
	1 m/s	2 m/s	3 m/s	4 m/s	5 m/s	6 m/s
Copper 15 mm	n.m.	10	15	22	27	32
Copper 15 mm bends	n.m.	n.m	4	12	17	21
Copper 22 mm	n.m.	7	17	25	*)	*)
PB 15 mm	n.m.	16	27	35	40	45
PB 22 mm	n.m.	13	25	32	*)	*)
AluPEX 16 mm	19	37	61	69	*)	*)
AluPEX 25 mm	27	38	47	53	*)	*)
n.m. = not measurable above background level *) = not measured						

Copper

A velocity of 5 m/s meets the required sound level of 30 dB(A) for the 15 mm copper pipe. A velocity of 4 m/s meets the required sound level of 30 dB(A) for the 22 mm copper pipe. With the appliance of bends a velocity of even 6 m/s is allowed to meet the maximum required sound level of 30 dB(A).

PB
In relation to the lightweight system with a single gypsum panel the measurements give almost equal structure borne noise levels.

AluPEX
The noise level of the 16 mm AluPEX pipe is caused by the high frequency cavitation noise, produced by the narrow cross sectional area in the "press" connection of the elbows. The noise level of the 25 mm AluPEX pipe is determined by the 250 Hz and 500 Hz middle frequency band in the "press" connection of the elbows.
Both diameters meet the required sound level of 30 dB(A) at a flow velocity of 1 m/s. With a flow of 2 m/s the maximum required level of 30 dB(A) is exceeded.

8 Conclusions
Based on the measurements in the laboratory and from an acoustic view it is possible and justified to chose a flow velocity of 3 m/s of higher without exceeding the maximum required sound pressure level of 30 dB(A). This rule affects copper pipes and PB-pipes, not for AluPEX-pipes.

It turns out to be that for copper pipes and PB-pipes with elbows the sound pressure level is about 25 dB(A) for a water velocity up to 3 m/s.
For the AluPEX-pipes the sound pressure levels are at least 25 dB(A) higher. To keep the sound pressure level under the maximum required level of 30 dB(A) the flow velocity in the AluPEX-pipes must keep at the maximum of about 1.5 m/s.
Elbows in pipe systems determine to a great extent the sound pressure level; application of bends instead of elbows leads to about 5 dB(A) lower sound pressure levels.
Thermal insulation of the pipe does not leads to a significant increasing of the sound pressure level.
If the pipes are fastened in lightweight walls with gypsum panels it turns out that the required maximum sound pressure level of 30 dB(A) not exceeds with a flow velocity up to 3 m/s.
For copper pipes with elbows, in lightweight walls with gypsum panels a flow velocity of 4 m/s is allowed. If these copper pipes are executed with bends even a flow velocity of 6 m/s is possible without exceeding the required sound pressure level of 30 dB(A).
Special note In piping system design the engineer should not overlook the noise production of taps, valves, pressure reducing valves and fittings. A badly selected fitting can easily override the noise production of the hole pipe system level.

9 References
1. Noise production of sanitary appliances and water systems; Stage 2a, Measurements on the noise production of water pipes caused by the flow velocity; July 2009; Peutz; in Dutch.

10 Presentation of author

Walter van der Schee is a member of the Dutch Technical Association for Building Installations (TVVL). He is a member of the board of the department Sanitary Technologies (ST). The objective of the association is to promote research and technology in the field of building services. This is done by networking; giving courses; lectures; organising symposia; research and co-financing university-chairs.
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