Special Systems of Foul Water Stacks in High-Rise Buildings

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Abstract. Due to maximum usage of building lands in cities, the construction of high-rise buildings is currently having the greater importance. High-rise buildings are buildings that, due to their height, must be designed in a different technical, technological and constructional way. In addition to height, the dominant element of high-rise buildings compared to buildings with a smaller number of floors is the usable area, which is an important factor for an investor. The more floors a building has, the more complicated it is to provide requirements of hygiene and quality of sanitary installations. In sanitary technology, the biggest problem is in the design of foul water stacks, which must be given higher attention. The issue of foul water stacks in high-rise buildings is a relatively complex and demanding topic, due to the complicated hydraulic conditions in the flow of foul water in drainage pipes. The design must be based mainly on research and knowledge, which is obtained mainly from foreign sources. This topic is not so developed in our country. Stacks must be designed in such a way that the negative pressure and the overpressure created in them do not cause suction of water from traps. When there is no water in the trap, an annoying smell from the drainage occurs in the building. Extraction of water from traps is not the only one problem. Other problems are excessive vibration and noise spreading from stacks through building structures to the interior. This can be caused, for example, by an incorrectly chosen system, piping material, anchoring, or offset of the stack. Special fittings and systems have been designed for high-rise buildings, which eliminates most of disadvantages of conventional solutions. The paper deals with the analysis of modern technical solutions that favourably affect the hydraulic conditions in stacks and thus help to improve the comfort users of building.

Keywords. high-rise buildings, foul water stacks, hydraulic, pressure fluctuation.
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1. Introduction

Nowadays, high-rise buildings are coming into the forefront in urban development of cities, because it mininaze necessary build-up area. With increase of number ofhigh-rise buildings, large demand for new solutions in the field of technical equipment of buildings come into the foreground. Qualitative development in the design of all parts of drainage systems began. In sanitary technology, the biggest problem in high-rise buildings occurs in the design of stacks, which must be given higher attention. The biggest changes are in the design and installation of stacks in buildings with 9 – 16 floors belonging to the 1st group, Tab. 1.

Tab. 1 – Types of high-rise buildings [7]

The class	Number of floors	Height (m)
Multi-storey – I. group	9 - 16	< 50
Multi-storey – II. group	17 - 25	50 - 70
Multi-storey – III. group	26 - 40	75 - 120
High	41 - 60	120 - 200
Very high	> 60	> 200

Stacks must be designed so, that the negative pressure and the overpressure achieved in them do not cause suction of water from traps. If is no water in the trap, an annoying smell occurs in the building. Another problematic part of vertical piping is direction change of stack (offset), which causes excessive vibration and noisiness.

Conventional stacks systems are stacks with direct vent and stacks with additional vent pipe, which are insufficient for high-rise buildings. The reasons are higher investment piping costs for bigger piping diameter, fire stop elements, and piping anchoring. To achieve higher quality of distribution systems for high-rise buildings, special systems and fittings have been developed. Properly designed fittings ensure optimal water flow in stacks. Special systems for stacks in high-rise buildings are:

- stacks with flow-optimized Sovent fitting which is suitable solution for buildings with more than 5 floors, Fig. 1a,
- stacks equipped with elements of active protection which is suitable solution for buildings with more than 10 floors, Fig. 1b.

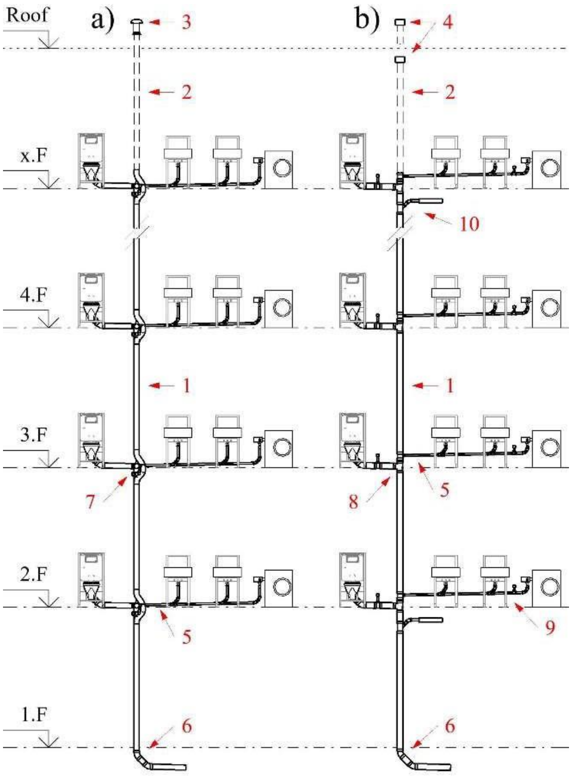

Fig. 1 – Special stack systems

a) stack with Sovent fitting, b) stack equipped with active protection elements, 1 – stack, 2 – vent pipe, 3 – vent head, 4 – air admittance valve on the stack (above or below a roof), 5 – branch pipe, 6 – transition to the drain (2 x 45° bend, base), 7 – Sovent fitting, 8 – simple Y-branch, 9 – air admittance valve on a branch pipe, 10 – positive air pressure attenuator

2. Water flow and hydraulic conditions in a foul water stack

The water in the stack flows around the inner wall of the pipe and forms a cylinder with an air core in the middle of it, Fig. 2. At the connection of the branch pipe with a larger flow, the air core can be closed (interrupted) and piston effect occurs, which causes a negative pressure. During the piston effect large amount of air is sucked to the stack from the vent pipe. Incorrect design of the stack can cause, an air can be sucked from branch pipes, which causes the extraction of water from traps.

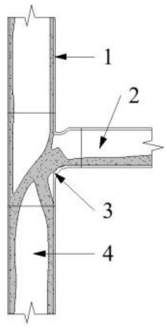

Fig. 2 – Water flow in the stack

1 – water flow around the inner wall of the stack, 2 – water flow from the branch pipe, 3 – occuring of the piston effect, 4 – air core

In the case of low water flow or no water flow in the stack, air flows through the stack from the bottom up to the exterior. The pressure loss which occurs at the airflow is main reason which causes exceeding of maximum negative pressure in the stack.

Fluctuation of pressure in the stack is by the system of stack venting, by used branch fittings, by offsets and the accessories used in the stack affected.

If the direction of the stack changes for more than 45°, hydraulic jump occurs which is caused by sudden change of velocity of the water flow. The water stops flowing around the inner wall of the pipe and the pipe begins to fill up. Above the direction change is an overpressure and below the change of direction is negative pressure. Besides that, the water which hits the inner wall of the bottom bend will cause excessive vibration and noisiness.

2.1 The velocity of water flow in foul water stacks

Fig. 3 shows two cases of falling velocity of water in the stack. Curve one shows the theoretical falling velocity according to Torricelli´s law. Curve two shows real falling velocity of water in the stack which includes friction losses and the air resistance in the stack.

Curve two shows that after approximately 20 meters, the falling velocity of water reaches 12 m/s. Increasing of velocity is not significant for higher stacks. After approximately 35 meters, water reaches maximal velocity of 13 m/s and does not increases due to air resistance and friction losses in the stack.

From the Fig. 3 it’s clear, that it is not important to design offsets on the stack in order to reduce the falling velocity of water. The biggest increasing of falling velocity is in the highest 10 meters of the stack.

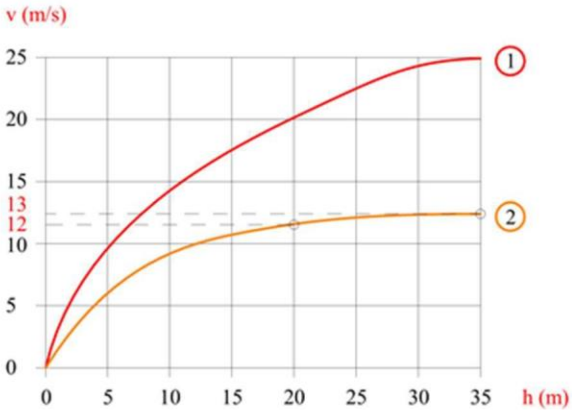

Fig. 3 – Theoretical falling velocity and real falling velocity in the stack [2]

1 – theoretical falling velocity, 2 – real falling velocity in the stack (water film with air column), v – falling velocity (m/s), h – height of the fall (m)

3. Technical solutions of special systems and fittings for stacks

Special systems and fittings for stacks in high-rise buildings ensure a significant reduction of pressure fluctuation in stacks, vibration and noisiness and also an optimal foul water flow in the stack. Other benefits of these solutions are lower piping costs due to smaller dimensions, lower anchorage costs, and lower fire protection costs.

3.1 Stack with Sovent fitting

The Sovent fitting is designed to prevent hydraulic blockage from forming and creating a piston effect in the stack, Fig. 1a. The swirl of the flow creates a rotation that allows the flow of foul water to move along the inner wall of the fitting and forms a continuous air column along the entire height of the stack, Fig. 4.

Fig. 4 – Simulation of swirl flow in the Sovent fitting [10]

This flow effect increases the discharge rate of the stack by 30 %, in comparison to conventional systems, Tab. 2. The main flow of wastewater in the stack is adjusted around the connection points of the branch pipes by divider. Incoming wastewater from branch pipe has time to switch to the vertical main flow, Fig. 5a. This minimises collision turbulences and reduces the pressure fluctuation in the system. This solution is intended to reduce the water velocity, which limits the kinetic pressure.

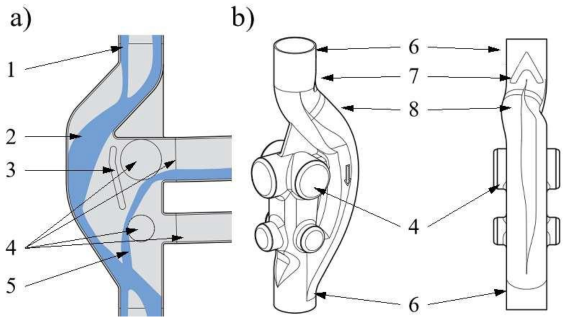

Fig. 5 – Sovent fitting [10]

a) function of the fitting, b) zones of the fitting,
1 – main flow falling around the inner wall, 2 – directed flow, 3 – protection against collision of two streams,
4 – connection points of branch pipes, 5 – flow of wastewater from branch pipe, 6 – connection to the stack, 7 – flow divider, 8 – swirl zone

Tab. 2 shows maximum flow rate Q_{max} in the stack with Sovent fitting and discharge units (DU) for the drainage factor K = 0,5.

Tab. 2 – Maximum flow rate in the stack with Sovent fitting [10]

Nominal diameter of the stack DN	Maximum ∑DU (l/s) for K = 0,5	Maximum flow rate Q_{max} (l/s)
100	576	12,0
150	1156	17,0

3.2 Stack with active protection elements

The stack can be supplemented (equipped) with active protection elements which protect the stack from critical negative pressure and overpressure. The elements of active protection are following:

- positive air pressure attenuator on the stack, Fig. 1d, and Fig. 6a,
- air admittance valve on each branch pipe, Fig. 1d, and Fig. 6b,
- air admittance valve on the stack, Fig. 1d, and Fig, 6c.

Correct design of the stack with elements of active system prevents the stack from exceeding the limit values of negative pressure and overpressure. Air admittance valves installed at the branch protects traps against increasing of limit negative pressure in the stack, which causes suction of water. Air admittance valves should be placed at the stack on each floor, to be able to suck the necessary amount of air at any place. The air admittance valve on the stack placed in exterior prevents creation of critical negative pressure due to the wind, which flows above the roof of a high-rise building. The valve opens only when an negative pressure occurs in the stack. A positive air pressure attenuator prevents overflowing of water from sanitary appliance due to overpressure, which arises mainly above the offset of the stack.

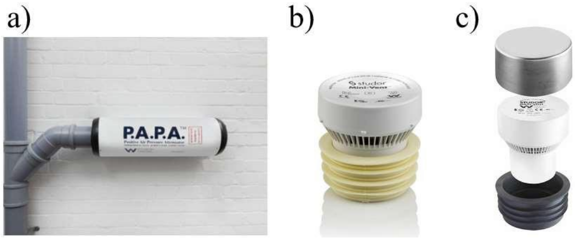

Fig. 6 – Elements of active protection [11]

a) positive air pressure attenuator, b) air admittance valve for the branch pipe, c) air admittance valve for the stack with aluminum cover for external usage

For sufficient protection of whole system, main requirements for the placement of the positive air pressure attenuator are given in the Tab. 3.

Tab. 3 – Requirements for installation of the positive air pressure attenuator connected to one stack [11]

Number of floors	Placement of the positive air pressure attenuator
5 - 10	one unit at the base
11 - 15	one unit at the base and one in the middle of the stack
16 - 25	one unit on the base, one unit on 5th floor, one unit between 5th floor and the end of the stack
26 - 50	two units in series on the base, then one unit on every 5th floor to the 25th floor, then every 10th floor
50 +	a necessary consultation with the supplier

It is possible to connect two stacks to one positive air pressure attenuator, what saves lot of initial investment costs. In this case, it is not possible to apply requirements from the Tab. 3.

Tab. 4 – Maximum flow in the stack with active protection elements [11]

Nominal diameter of the stack DN	Maximum ∑DU (l/s) for K = 0,5	Maximum flow rate Q_{max} (l/s)
100	213	7,3
125	400	10,0
150	1339	18,3

While using active protection elements, it is possible to design transitions of stacks to the drain in high-rise buildings more economical. Tab. 4 shows maximum discharge units for stacks with active protection elements and the calculated maximum flow rate Q_{max} for the drainage factor K = 0,5.

4. Experimental measurements of hydraulic conditions in stacks

The following part of the paper describes experimental measurements which were made for evaluating negative pressure and overpressure in stacks in various stacks systems. Experimental measurements were performed by two foreign companies:

- in the company Geberit in Switzerland was pressure fluctuation in stacks with Sovent fittings and a 88,5° single Y- branches compared,
- in the company Studor in China was pressure fluctuation in stacks with direct vent and stacks with the active protection elements compared.

U-tube pressure manometers are used to measure the negative pressure in stacks and are placed on each floor at the connection points of branch pipes. When the flow condition is complete, the water drop in manometers is read in mm of the water column and then converted to Pa. After the reading is recorded, the water level in the manometers is replenished and the measurements are repeated. In the following figures the maximum allowed negative pressure of - 464 Pa is indicated. This value represents the water level in the trap after 2 weeks without using of the sanitary appliance. When is this limit exceeded, there is no water in the trap which would prevent the interior for annoying smell from the drainage.

4.1 The Pressure fluctuation in the stack with Sovent fitting and 88,5° simple Y-branch

In the company Geberit were two different experimental measurements preformed:

I. Measurement of pressure fluctuation in the stack with DN 100 in the 6-floor building using Sovent fittings and the stack with 88,5° simple Y-branches were compared, Fig. 7. Two flow states were applicated. In the first flow state the WC on 5th floor was flushed, Fig. 7a. In the second flow state the WC on the 5th floor was flushed and the steady flow of 0,5 l/s from the 6th floor was simulated, Fig. 7b.

II. Measurement consisted of monitoring of pressure fluctuation in the stack in the 20-floor building with Sovent fittings; where flushing of WC was simulated with toilet paper on the marked floors Fig.8.

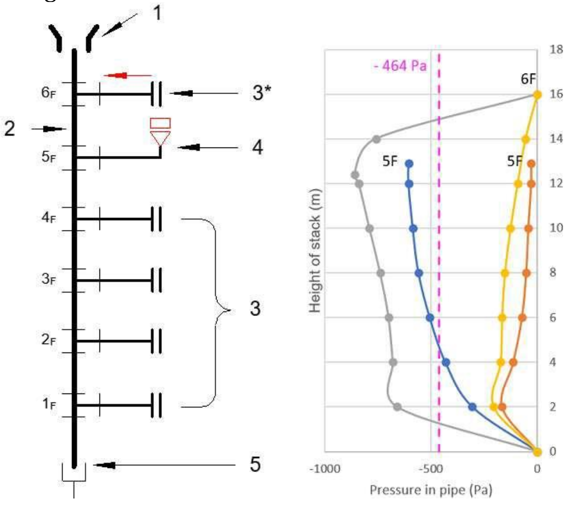

Fig. 7 – Pressure fluctuation in the stack with Sovent fitting and 88,5° simple Y-branch [10]

Fig. 7 description:
a) flushing the WC on 5th floor: ● 88,5°simple Y-branch, ● Sovent fitting,
b) flushing the WC on 5th floor and steady flow 0,5 l/s from 6th floor: ■ 88,5°simple Y-branch, ● Sovent fitting, 1 – air inlet, 2 – stack DN 100, 3 – branch pipes without flow, 3* – branch pipe on the 6th floor with steady flow, 4 – branch pipe with WC, 5 – free discharge

In the first flow state, the pressure in the stack with 88,5° simple Y-branches exceeded the maximum negative pressure of - 464 Pa between 2nd to 5th floor. The pressure in the stack with the Sovent fitting did not significantly change Fig. 7a. During the second flow state in the stack with 88,5° simple Y-branches, a negative pressure of - 900 Pa reached at mostly whole height of the stack Fig. 7b. Negative pressure in the stack with the Sovent fitting did not significantly change, fig. 7.

The best results were achieved in the stack with Sovent fitting.This fitting significantly eliminates the risk of extraction of water from traps. Maximum negative pressure was - 250 Pa.

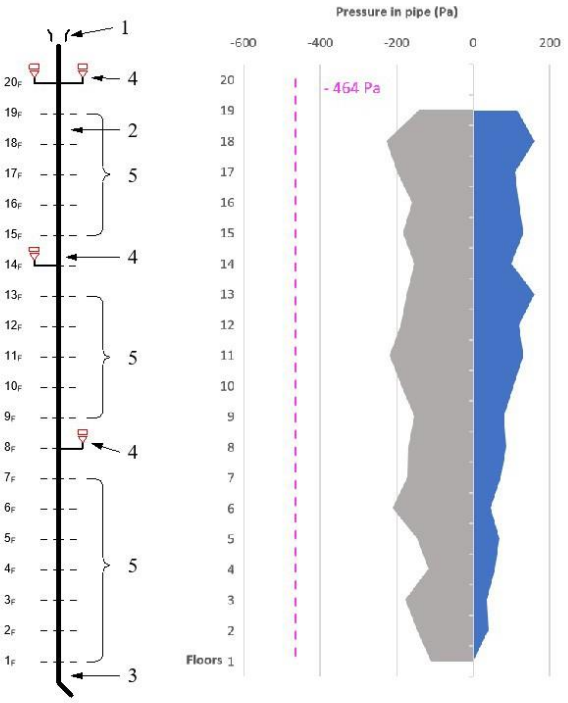

Fig. 8 – Pressure fluctuation in the stack in 20 floor building with Sovent fitting [10]

1 – air inlet, 2 – stack DN 100, 3 – transition to the drain, 4 – branch pipe with WC, 5 – branch pipe without flow

Fig. 8 shows the pressure fluctuation in the stack with Sovent fittings which were installed on each floor. WC´s were installed on the 20th floor (two WC´s), 14th and 8th floor. By flushing was toilet paper used. Pressure characteristic of the flow of water in various flushing mode was analysed. The area chart, which was created when the individual pressure curves were overlapped. The maximum allowed negative pressure was not exceeded. The pressure in the stack fluctuated approximately in the range of -250 to +180 Pa.

By comparing the drainage stack system with direct vent with 88,5° simple Y-branches and the system with Sovent fittings, diameter of conventional system must have been around DN 150 which is not economical solution.

4.2 Pressure fluctuation in the stack with direct vent and stack with active protection elements

In the company Studor was an experimental measurement in a 33-story building with different type of the stack DN100 performed. The stack with direct vent and the stack with active protection elements were compared. Construction of the stack with active protection is described in the chapter 3.2. Water flow was simulated from branch pipes on the 30th to 33th floor. The maximum water flow in the stack was 6,0 l/s.

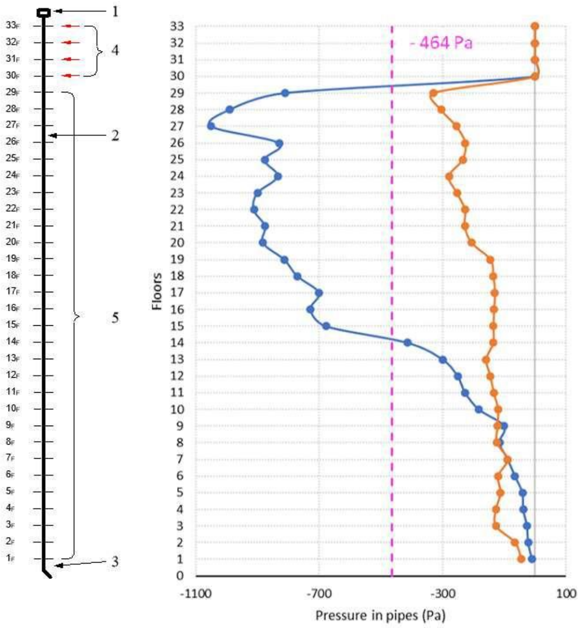

Fig. 9 – Pressure fluctuation in the stack with direct vent and the stack with active protection elements [8]

● stack with direct vent, ● stack with active protection elements,
1 – air admittance valve, 2 – stack DN 100, 3 – transition to the drain, 4 – branch pipes with flow, 5 – branch pipe without flow

Fig. 9 shows the stack with direct vent where the maximum negative pressure exceeded between 15th to 29th floor. The maximum negative pressure was - 1050 Pa. In the stack with active protection elements the maximum negative pressure didn't occur. The best results were achieved by the stack equipped with active protection elements. The active elements eliminate the risk of extraction of water from traps. The maximum negative pressure was - 350 Pa.

To avoid the high negative pressure in the stackwith direct vent, the dimension of the stack must have been at minimum DN 200. Comparing with the stack with active elements DN 100 this would be an uneconomical solution.

5. Conclusion

From the analysis of special drainage systems and fitting for stacks in high-rise buildings, it is possible to state:

• special systems and fittings for stacks ensure optimal flow of foul water while comparing with conventional systems,

• stacks equipped with special systems and fittings can be designed for much bigger flow than conventional stack systems,

• the Sovent fitting ensures a continuous column of air along the entire height of the stack,

• the biggest increasing of falling velocity in the stack is in the highest 10 m, for this reason, it is not important to design offsets on stacks to reduce the velocity,

• above the offset of the stack overpressure occurs, and under offset negative pressure occurs.

The issue of hydraulic conditions of wastewater flow in stacks is a challenging and extensive topic, especially in high-rise buildings. To avoid the problem with high overpressure and negative pressure in stacks, with spreading of nosiness and vibration, it is necessary to follow the principles from standards and installation regulations.

Due to increasing of height of buildings also the requirements on drainage piping systems became more important. Therefore, new technical and material solutions are necessary to improve the quality of drainage systems.

6. Acknowledgments

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Data Statement

Data sharing not applicable to this article as no datasets were generated or analyzed during the current study.