Risk of Impaired Indoor Environment Quality in the Buildings Served by Gravity Sewage Systems

Reasons for the Regulations Review of Design of the Buildings with Introduction of Security Measures on the Functional Gravity Sewerage Under Powerful Winds

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***Abstract*—Gravitational sewage systems interact dynamically with users, with inside and the outside environment. The result of this interaction can lead to impaired air quality in spaces served.**

SACS episode, produced in Hong Kong in 2003, it is a good example of the visibility of the high risk of impairment indoor air quality following the amendment normal functional conditions of gravity sewer systems in the conditions recent of the climatic changes. Climate change causes significant variations in wind speed, of the direction of wind and pressure exerted of the outside air currents on the contact surface of the ducts aeration of the gravity sewer installations with outdoor air can cause a suction of the hydraulic traps installations and these changes may cause alteration of indoor air quality. In other news, recently was promoted a new concept of quality of buildings - "NZBE" which aims to achieve high energy performance of buildings in terms of ensuring a quality indoor environment. Correlated with this was revised standard EN 15251 which establishes criteria for indoor environmental quality (thermal comfort, acoustic, visual and air quality). Sewerage gravity do not require energy for operation, but designed incorrect may cause damage indoor environmental quality. The revised standard does not guarantee, insurance and maintenance, indoor environmental quality conditions in the dynamic climate conditions. The purpose of this paper is to attract attention to the need, review & harmonization of design rules (and renovation) of buildings, indoor environment to avoid infection due to malfunctioning sewage systems during windy weather. The work presents some experimental research done on the behavior of systems under different functional conditions (different operational simultaneity strategies; different interaction conditions with the external environment; different ventilation solutions) in order to highlight the many failures that may occur, especially in existing buildings but also in new buildings where the appropriate measures are not taken for protection. The research was conducted in the laboratory Geberit of Switzerland.

Keywords*—*Component; Interaction Outside Environment – Sewage System – Inside Environment – User; Affecting Indoor Environment Quality; Gravity Sewer Systems Failures During Strong Winds

I. INTRODUCTION

The main functions of the technical system "gravity sewer installations" are: promptly sewage collection; disposal thereof as direct as possible to the receiving environment; protecting the interior space (against gas diffusion, the noise of the sewerage system and loss of water). Indoor environment gravity sewer installation is conducive to the development of bacteria, viruses and undesirable gases and / or toxic to humans. Therefore, the system must be sealed to gas diffusion in the interior of the building served. The sealing can be provided with specialized elements (connection of the sanitary equipment / receivers via the hydraulic traps, vent valves, positive pressure attenuators) and appropriate design measures that will prevent depressions and excessive pressure inside the installations. System components involved in ensuring sealing are multiple and with different performances. Design measures are based on simplifying the functional assumptions. Some of these may lead to design systems which fail to operate in other situations. Theoretically, the operating conditions considered in calculation assumptions foresee: the system allows gas exchange with the atmosphere in a controlled way at the top of it and it is sealed to gas diffusion into the interior of the building due to hydraulic traps associated with each collection point. Practically, in use, the system could have deviations from the calculating assumptions, deviations that attract malfunction of the system. The most common violations from the calculating assumptions with major impact on safety of interior space are: dynamic nature of the external environment parameters: speed, direction and pressure of the winds, air temperatures outside / inside, intensity of solar radiation, outdoor air quality characteristics. Speed and direction variations of atmospheric air currents on vent systems may finally result in interior penetration of gas with annoying or even toxic effects. In this work are presented results of research conducted by the authors, on air/water flow in sewer systems, to identify major failures and measures to take to prevent them in Nearly zero energy buildings.

II. CONSIDERATIONS ON TECHNICAL CONDITIONS AFFECTING THE SEALING SYSTEM INCLUDED IN VARIOUS TECHNICAL REGULATIONS

A. Important codes for gravitational sewage system design

The structural scheme for gravitational sewage system design and their calculation methods is indicated in design codes (national or regional). Among the most important are:

– European Standard EN 12056, promoted by France (NF EN12056), adopted by Germany, England and other European countries (including Romania) and also countries in the Middle East and Asia;

- German Standard DIN 1986-100;
- AS / NZS 3500-2000 adopted by Australia, New Zealand and other European countries as well as countries in the Middle East and Asia;
- BS 5572, British rule until 2000, still used in the Middle East and Asia;
- International plumbing code (International Plumbing Code) - IPC, a code used in the United States, adopted by 30 states;
- Unified plumbing code (Unified Plumbing Code) - UPC, used in the United States, adopted by 12 other states and recently also by the Association IUPC Indian plumbing engineers;
- In Romania: I9 norm, standard SR 1795 and SR EN 12056-2/2002 harmonized European standard.
- The rules / codes design cover different aspects of interest in the proper design of the system.

B. *Major differences between the various design rules included in the technical drainage systems codes design*

Parallel analysis of these design rules, revealed the existence of several differences regarding the technical design of interior drainage systems. We can mention the following:

- The solutions required for designing schemes and methods of calculation / sizing offered are not similar;
- Not covered every possible aspect [1];
- The technology has evolved and parts of the sewerage system recently promoted not find a place in rules (eg positive pressure attenuator PAPA for high-rise buildings) [7]
- Recommended values in norms, for hydraulic height of a siphon trap, varies from one country to another: a ≥ 50 mm in Romania and the NE 12056-2/2002; b.100 mm in Canadian Code; c. is not specified in the Australian Code.
- German Standard DIN 1986-100 contains several regulations regarding the security measures in the operation of sewage plants in relation to European standard;
- The standard AS / NZS 3500-2000 - size columns and aeration pipes are linked to underserved drain columns and flow process [11].
- Terms of connecting of the horizontal racord to columns or columns to horizontal collector pipes and the foam zones influence are given only in Canadian Code.
- More technical conditions in order to avoid aspiration of hydraulic traps are specified in Canadian Code.
- With regard to sewerage systems requiring individual/additional ventilation, the technical conditions imposed in various design codes are much different [1].

In Romania, the norm I9 provide some design rules which are different by the norms above.

So: in the present, the active norms do not prevent full range of failures that can occur in a buildings sewage system.

III. EXPERIMENTALFACILITY. SCHEME. MEASU REMENTINSTRUMENTATION,DATAACQUISITIONAN DPROCESSING, CONTROL MEASUREMENT

IV. PROCEDURES

"Gravitational sewer plant" is a technical system: a. complex, consisting of components with different functional characteristics and with a complex biological + physical + chemical processes evolution; b. open, because interact with inside environment of the building, which collect waste waters, and with outside environment in which discharge waste waters and gas (coming from fermentation processes initiated during this discharge); c. dynamic, with parameters evolving in time; d. with random functional behavior, depending on the user.

A. *Experimental system*

Experimental research of the behavior of such facilities in different operating conditions can provide important information about the mechanism of gas diffusion from the inside of facility into space served, about their size and the possible preventive measures. This work presents the results of experimental research on a full-scale model of the installation. Experimental system (Fig. 1) consists of:

- a sewer column, Dn = 110mm and H = 12m, prolonged of a aeration column to above the roof and connected to a horizontal drain pipe the base of this column, that discharge into a water tank;
- the connection pipes at the column for the un or more toilets located at different levels and distances from the column (for one or more vessels);
- additional columns and / or ducts ventilation to allow individual or group several toilet bowl connected at the column drain and valves manipulation to simulate different ventilation strategies;
- toilet bowl equipped with tanks with mechanisms unloading for different flow rates (3m / s and 6 l / s) and automatic control system downloads;
- additional connections to the column to simulate variable flow water discharge located at different heights, equipped with electric valve actuators and electromagnetic flow meters that record the flow circulating;
- a mechanical ventilation system of a column of sewage by inserting or removing air from the column equipped with a variable speed fan witches can control air velocity from 0 to 4 m / s;
- circulation pump (recirculation) for water supply system, with variable frequency (allows flow control between 0-10 l / s);
- tools to measure: the flow of water discharged through connections; pressure at different points of the installation: on the pipe wall or in the center of the pipe; air flow; air speed, air temperature introduced / extracted in / from the column;
- multifunction and portable data acquisition station, carrying also control / command automatic discharge of cisterns or closing / opening the automatic valve electrical connections.

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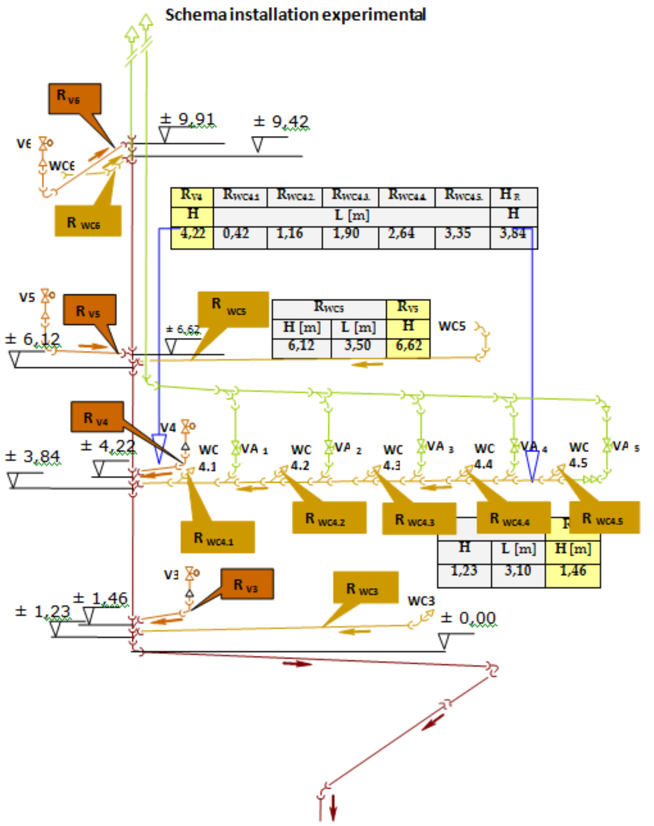


Fig. 1. Schema Experimental installation

During research, the sensors were positioned so that they can obtain information about pressure changes in every characteristic point.

B. Test procedure

A test procedure performed included well-chosen test sequences to achieve all possible combinations of discharges.

These tests have served to determine the influence of wind speed on the performance of the gravity sewage systems in different operational conditions:

- simultaneously discharging of the vessels situated on different connections;
- variable speed air flow in the ventilation column (1-5 m / s) (in introducing, in exhausting or in neutral (with fan off) conditions);
- various secondary ventilation solutions (individually for each toilet bowl, common to a group of 2,3,4,5 toilet bowls);
- different geometric configurations of connections/branch parts.

After discharging the water from the tanks into toilet bowls and after discharging this into the collector, were measured hydraulic guards inside toilet bowls. After each test, hydraulic guards were returned to normal for each toilet bowls.

V. RESEARCH RESULTS

The sealing system against the diffusion of gases of sewage into the interior is achieved by the hydraulic trap.

The hydraulic conditions which may be sucked guards are determined by the equilibrium between the pressure in the inside of the sewer and the air pressure in the spaces served.

They may be determined theoretically.

For an air pressure inside the spaces equal to atmospheric pressure, which can lead to suction hydraulic guards, the depression values are shown in tab. 1.

TABLE I. Pressure difference *inside sewerage system - interior room* for which it can absorb the hydraulic siphons guard.

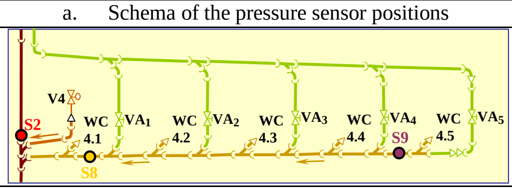
Hydraulic siphons guard ΔH	Difference *internal pressure of the sewerage system – internal pressure room* Δp	
[m]	[Pa]	[mbari]
0.05	490	4.90
0.06	588	5.88
0.07	686	6.86
0.08	784	7.84
0.09	882	8.82
0.10	980	9.80

These values were used for different analyzes of the results of research, designed to help to identify the technical requirements of design and operating conditions which can prevent hydraulic guards exhausting.

The results were processed to observe the influence of an additional ventilation of a horizontal drain branch pipes on the flow process It was noted that simultaneous downloading of the multiple toilet bowls connected to a horizontal collecting pipe, which is not ventilated supplementary, It followed by guards hydraulic suction toilets located at: a. on the upper floors b: opposite positions of connection to the drain column of the collecting pipes.

After repeating sequence of simultaneous discharges, the effect of depression on branch pipe increases. Pressure variation diagrams are shown in Fig. 2.

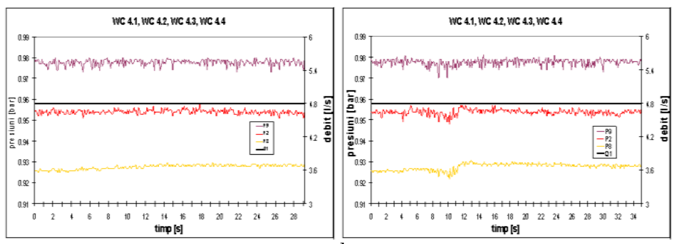
a. Schema of the pressure sensor positions



b. b. Characteristic values: b1. pressure: minimum, maximum, average; b2. Hydraulic guards.

speed air introduction: v=4,7 m/s											
Vent valves open						Vent valves closed					
Pressure values:				G.H.		Pressure values:				G.H.	
P9 / P2 / P8 [bar]				[cm]		P9 / P2 / P8 [bar]				[cm]	
P_{min}	0.973	0.951	0.925	WC4.1	0	P_{min}	0.970	0.948	0.922	WC4.1	-4,3
P_{med}	0.978	0.954	0.928	WC4.2	0	P_{med}	0.978	0.954	0.928	WC4.2	-3,0
P_{max}	0.980	0.958	0.930	WC4.3	0	P_{max}	0.981	0.957	0.931	WC4.3	-2,0
ΔP	0.007	0.007	0.005	WC4.4	0	ΔP	0.011	0.009	0.009	WC4.4	-0,5
ΔP^{+}	0.002	0.004	0.002	WC4.5	0	ΔP^{+}	0.003	0.003	0.003	WC4.5	-2,5
ΔP^{-}	0.005	0.003	0.003			ΔP^{-}	0.008	0.006	0.006		

c. Variation of the pressure measuring points S_2, S_8, S_9.



d.

Fig.. 2. The influence on the flow of the additional ventilation ducts branch.

In Fig. 3.is presents the evolution of hydraulic guards after a discharge sequence.

WC 4.1.	WC 4.2.	WC 4.3.	WC 4.4.	WC 4.5.

Fig. 3. Developments Hydraulic guard vessels from the fourth floor closet in the following experimental conditions: a. download simultaneously: all toilet bowls; b. all the valves vent: closed; c. marker inferior / superior: -5cm / + 5cm.)

– Analysis of operational behavior of derivations which take more toilet bowls.

The investigations have revealed that:

a) under simultaneous unloading of toilet bowls (fan off) malfunction occurs in situations where at the collector duct is connected more than 3 toilet bowls, without secondary ventilation;

b) the introduction of air into the hydraulic column determine the aspiration guards of toilet bowls connected of the horizontal collector at higher levels. This phenomenon can be seen in Figure 3.

– Analysis of the fan speed on the performance of the flow into sewage systems.

Fan speed variation simulates wind velocity variation.

Analysis observed the functionality of the systems in terms of introduction / extraction of an air flow into /from a ventilation pipe in relation to the situation of plant operating at atmospheric pressure.

The results revealed that: a velocity stream of air introduced / removed to / from the top of the ventilation column of v = 5m / s give rise to overpressure / major depression at different points in the system.

Depending on the type connections and simultaneous operation may be higher or lower.

In Fig. 4 and 5 shows the variation of pressure in various points of interest in terms of insertion / extraction air to the plant.

It highlights the emergence of depressions □p = 0.011 / 0.014 / 0.012 bar higher than the critical values.

Depending on operational connections and simultaneity, the effect can be higher or lower.

In fig. 4 and 5 is shown the evolution of pressure at various points of interest in terms of introduction / extraction air in system.

It highlights the apparition of depressions Δp= 0.011/0.014/0.012 bar, higher than critical values.

– The influence of geometry of connections on the flow process.

To show the influence, they were tested six types of connections with different geometric features.

The geometrical characteristics that differentiate connections are tested: the angle of slope of the connection,”*β*”; angle connection column, *”α*;; share difference between the lowest point of joining the column and the generator connection, ”*x”* (see Table 2).

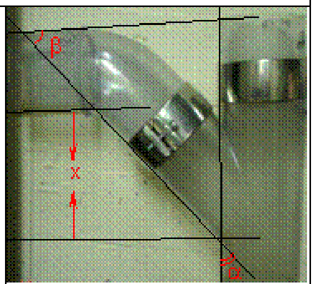
– Analysis of hydraulic jump occurrence bottoms.

Measurement results showed the emergence hydraulic jump simultaneously downloading more than 2 vessels closet.

– Determination of the time course the functions of the pressure measuring points in relation to the discharged flow, the speed of introduction / extraction of the air and the geometric characteristics of the nozzle.

Table 2 documents the features of the evolution of the pressure P2, P4, P9.

TABLE II. Functions pressure variation characteristic points

P2=974,799-0,015t-4.471v+0.14Q,	
P9=977,294-0,005t+0.346v-0.478Q,	
P9 =989,671-0,007 t+ 0,036 v- 0,023 x–0 α - 0,162β - 0,099 Q , pt. tε($t_{îd}$÷ t_{sd})	
P4=974,799-0,015t-4.471v+0.14Q,	
Where: – - t is the time, in [s], – - v is the air velocity, in [m/s], measured at the center of the ventilation column at the upper part; – - Q, is the download flow in the installation – - α, angle-column connection – - β, angle of slope of the connection.	

V. CONCLUSION

1. Recent Climate change causes extreme weather events with wind speed higher than 25m / s, in which case, under certain operational conditions, air pressure can increase in the ventilation columns, causing depressions / overpressure higher than those for which they were designed installations: hydraulic guard vessel closet at higher levels in the vicinity of columns and those located at the tip of derivatives with more than 2 vessels closet connected without additional ventilation pipe aspirate.

2. For buildings energy performance / NZBE (new buildings and, especially those modernized): is possible infection of the air inside the building due to aspiration guards Hydraulic if presented certain extreme weather conditions (v air), the presence of infectious agents (bacteria airborne, viruses, ...) into the gravity sewer system and a sewage plant structures classics. It is necessary to introduce the rules of design and operational elements to avoid infection indoor air.

3. At the base of the columns is necessary to mount a takeover leap pieces allowing hydraulic and hydraulic guards to prevent aspiration shares placed at the bottom of the plant.

4. The geometry of the connections has a great influence on functional performance.

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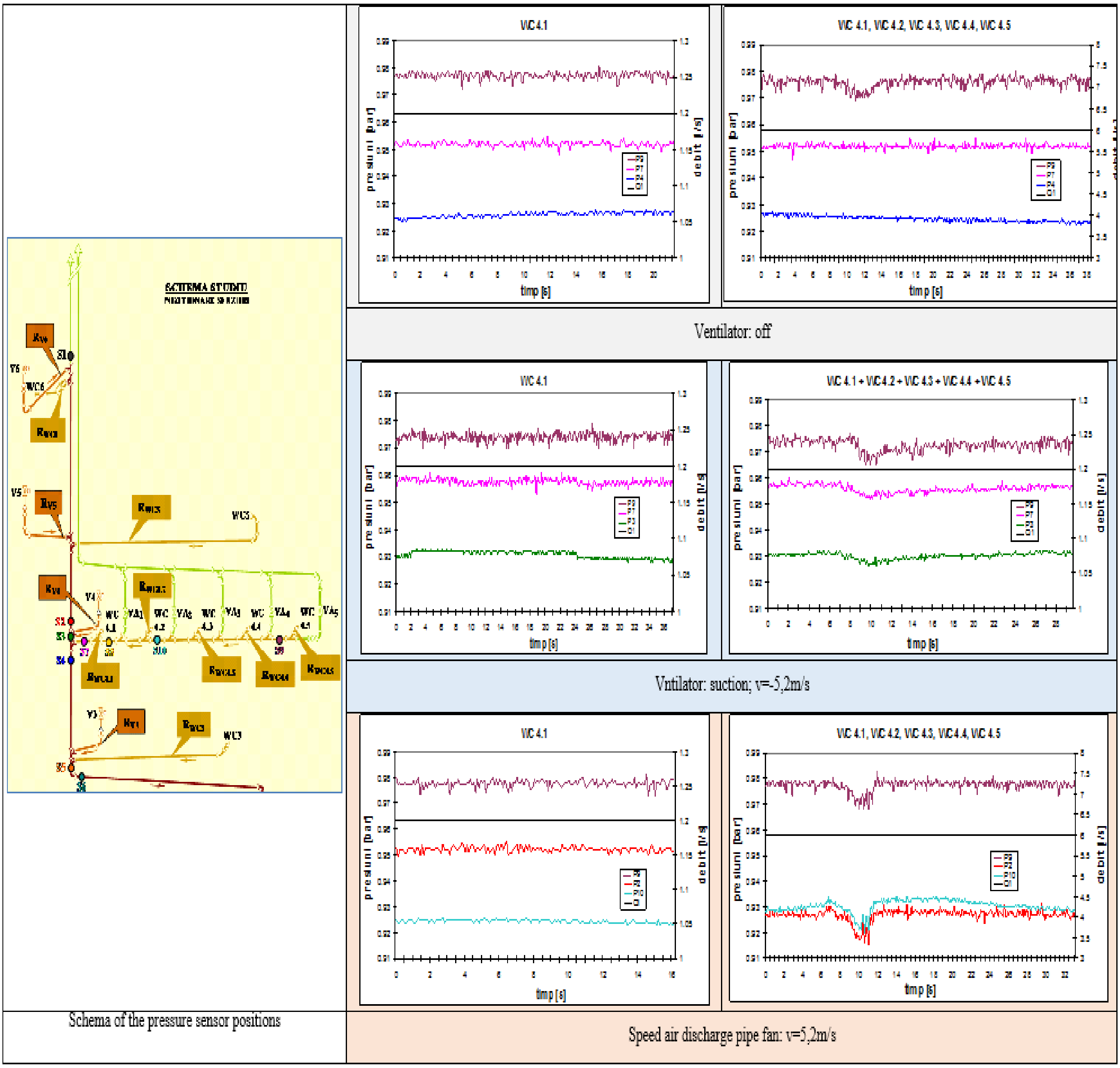
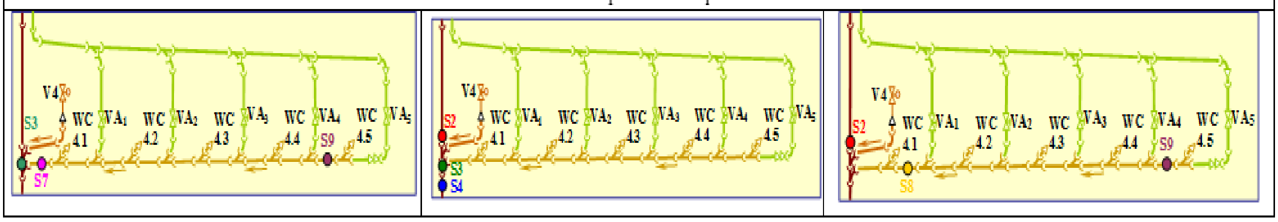


Fig.4. Influence fan speed on the development pressures in sewage plant in different operating conditions; Additional non-ventilated bypass pipe.

Schema of the pressure sensor positions



Ventilator: off	Pressure: P2 / P3 / P4 [bar]	P2	P3	P4	Variation G.H. [cm]	
	P_{min}	970	948	922	WC4.1	-7,0
	P_{mc}	976	951	925	WC4.2	-3,0
	P_{ma}	979	954	928	WC4.3	-2,5
	ΔP	9	6	6	WC4.4	-5,0
	ΔP^+	3	3	3	WC4.5	-3,3
	ΔP^-	6	3	3		

Ventilator: extr. v=5,2m/s	Pressure: P9 / P7 / P3 [bar]	P9	P7	P3	Variation G.H. [cm]	
	P_{min}	965	951	927	WC4.1	+2,6
	P_{med}	974	957	931	WC4.2	-1,0
	P_{max}	980	961	934	WC4.3	-1,3
	ΔP	15	10	7	WC4.4	+0,4
	ΔP^+	6	4	3	WC4.5	+1,2
	ΔP^-	9	6	04		

Ventilator: intr. v=4,7m/s	Pressure: P9 / P2 / P8 [bar]	P9	P2	P8	Variation G.H. [cm]	
	P_{min}	967	940	916	WC4.1	-7,7
	P_{med}	978	954	928	WC4.2	-4,0
	P_{max}	981	960	932	WC4.3	-4,2
	ΔP	14	20	16	WC4.4	-5,0
	ΔP^+	3	6	04	WC4.5	-3,3
	ΔP^-	11	14	12		

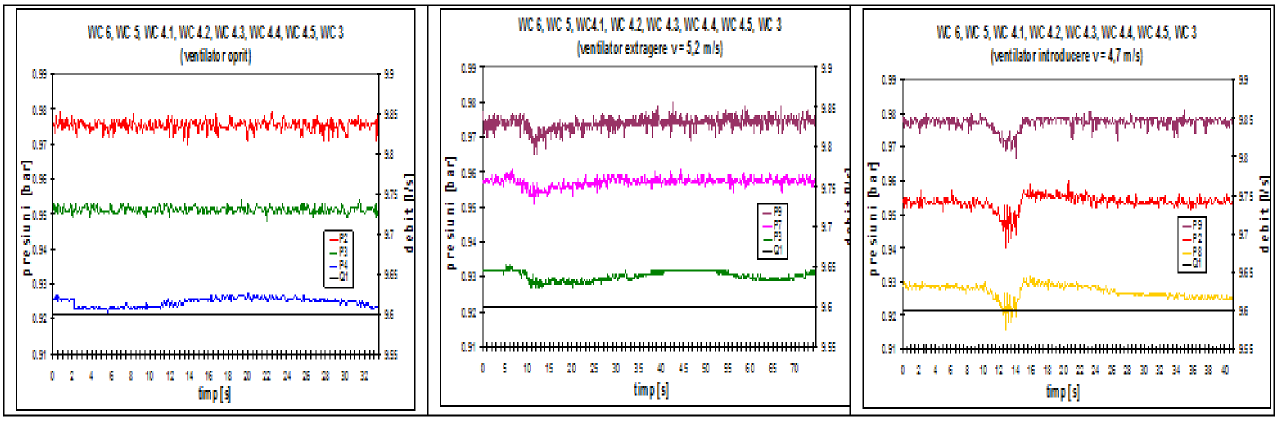


Figure 5. Evolution of pressure characteristic points of the plant in different functional assumptions.

Conditions making measurements: Download: all vessels closet; All vent valves: closed; Fan: OFF / extraction / insertion

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