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Hydraulic Analyze of Risers of Heating System in High-rise Building

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Abstract
At present times, in the context of rising fuel and energy prices the energy saving is very actual phenomenon. A better building insulation and the replacement of large transparent constructions will significantly reduce heat loss of the building. The hydraulic adjustment of heating systems is also a essential requirement for optimum operation of buildings. The peak load of the heating system occurs only a few days a year, mostly the transitional period dominates. Correct settings of control valves and pumps can achieve significant savings from the energy requirement of the building. This study is focused on the hydraulic analysis of rising pipes in reference high-rise building in Bratislava. The main aim of this study was to determine hydraulic behavior of two reference risers and to analyze wall roughness of the old seamless steel pipes and buoyancy effect on hydraulic conditions.
Keywords
hydraulic evaluation, high-rise building, radiant heating, pressure loss, hydraulic balancing, circular pumps

1 Introduction

In large energy systems, for example in high-rise buildings is necessary to use balancing elements on problematic places. These are mainly the heels of rising pipes and places before each floor circuits. In static hydraulic systems with constant mass flow is recommended to use static balancing elements. Optimal flow distribution is ensured by correctly adjusting of balancing valves. In variable hydraulic systems with dynamic flow is recommended to use beyond static elements also dynamic balancing elements, such as pressure differential controller [1]. With these components, a constant pressure difference is maintained in balanced modules. In high-rise buildings is also worth considering an buoyancy, which can confuse the hydraulic stability of the energy system. The main aim of this study was to determine hydraulic behavior of two reference risers in high-rise reference building in Bratislava and to analyze wall roughness and buoyancy effect based on experimental measurements and numerical modelling.

2 Energy system of reference buildings

The reference building analyzed in this study was a 23-floor high high-rise building of the Faculty of Civil Engineering of the Slovak Technical University in Bratislava. The partial reconstruction of the building was carried out in 2011. It means the retrofit of the facade of high-rise building and partial renovation of heating system. The energy system is connected to the heat exchange station of central university building. In the high-rise building is designed a ceiling radiant system known as CRITTALL system with low temperature heating and high temperature cooling with forced circulation. Seamless steel tubes in dimension DN15 were installed in the reinforced concrete slab, which can be used for heating and cooling (Fig. 1). The ceiling system was not renovated, only the old shut-off valves were replaced by new valves Herz GP and Herz AS. The heating system in the high-rise building is divided into two pressure zones. The heating system was analyzed in this study on the 1st pressure zone, which supplies the building from 1st to 10th floor. Replaced heat distributor of the 1st pressure zone is installed in the basement of the high-rise building. It divides the energy system into four main branches, according to the buildings orientation: two northeast and two southwest zones (Fig. 2). The heating temperature gradient of the heating system was determined by previous measurements. The average measured heating temperature gradient was at the external temperature of -11°C 35/30.5°C

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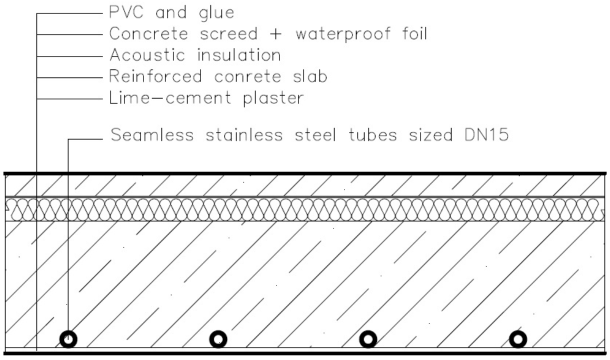

Fig. 1 Detail of the CRITTALL ceiling system

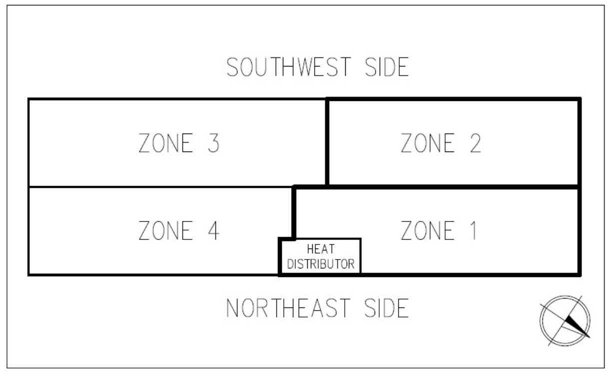

Fig. 2 Building plan with 4 main zones

in the Northeast zone and 35/31.5°C in the Southwest zone. The higher return temperature on the Southwest side can be explained by the high thermal gains, which can significantly increase indoor air temperature in the rooms.

The main branches are controlled qualitatively by change of inlet water temperature according to the outside air temperature. The volume flow is constant. The required inlet temperature is set by 3-way valves Siemens VXG 48.40.20 controlled by equithermal curve. The required pressure and flow rate are ensured by circulator pumps with three speed levels Grundfos UPS 40-120F sets to the highest level. The main branches of each zone are divided into risers, which supply the floors in 1st pressure zone (Fig. 3). The risers and the ceiling system were not reconstructed, only the old shut-off valves were replaced by new static balancing valves Danfoss MSV-BD installed on the risers and valves Herz GP and Herz AS installed before ceiling circuits. The length of ceiling circuits was determined by infrared camera. (Fig. 4).

3 Methodology

The hydraulic analyze was performed for two reference risers, named A and B. The riser A is in zone 1 (Northeast), and the riser B is in zone 2 (Southwest). Scheme of risers is shown in Fig. 5. The hydraulic analyze was based on two pillars: experimental measurements and numerical modelling. The methodology of each is described in the following section.

3.1 Methodology of measurements

The main aim of experimental measurements was the definition of main hydraulic parameters of the risers A and B. Experimental measurements were realized during the heating season in 2017/2018. The following physical data were measured:

- Q – volume flow in balancing valve (m^3/h),
- Δp_{valve} – pressure loss on balancing valve (Pa),
- Δp_{dif} – pressure difference (Pa).

Volume flow and pressure loss on balancing valve was measured by TA CBI balancing instrument. Measurements were realized on the balancing valves of the risers A and B (BV_A and BV_B – see Fig. 5). Measurements on balancing valves were repeated by constant central volume flow three times in different climatic conditions on the following days:

- 26.2.2018 – average outside air temperature between -10 and -5 °C,

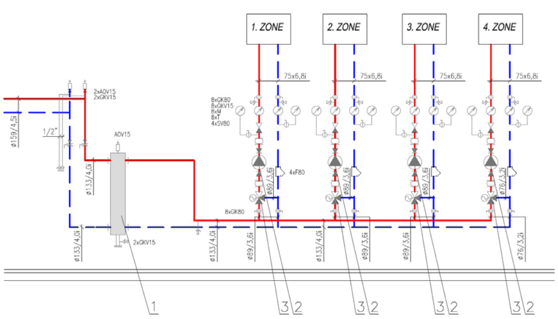

Fig. 3 Heat distributor of 1st pressure zone

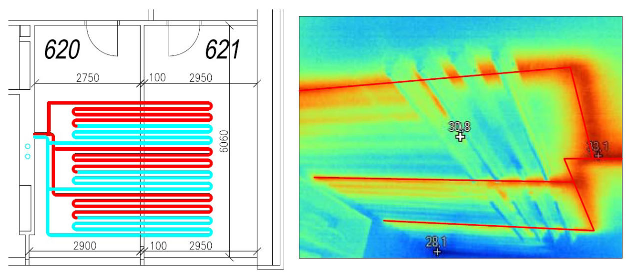

Fig. 4 Heating pipes in ceiling determined by thermocam (1 – hydraulic separator, 2 – circulator pump, 3 – three-way mixing valve)

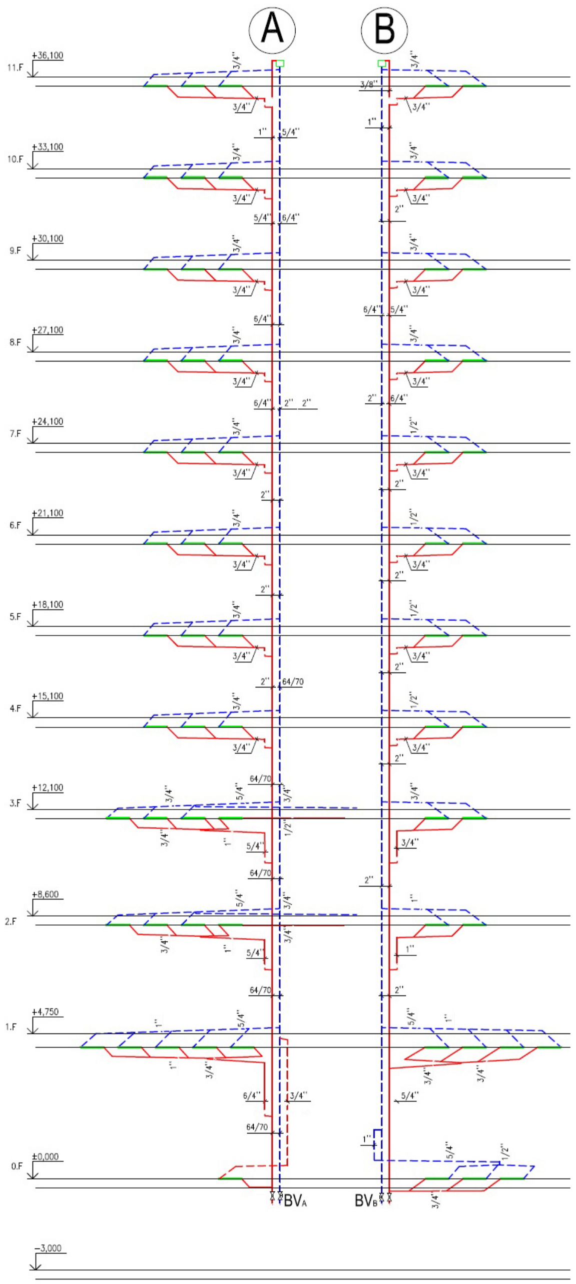

Fig. 5 Scheme of risers A and B
(BV_A, BV_B – balancing valves Danfoss MSV BD)

- 12.3.2018 – average outside air temperature between 10 and 15 °C,
- 26.3.2018 – average outside air temperature between 3 and 8 °C.

Pressure difference was measured using pressure meter Lutron PS-9303SD with pressure sensor PS 100-10bar. They measured the total pressure on the inlet and return pipe of the risers A and B. Pressure difference was defined from these values. Measurements of pressure parameters were realized on 12.3. and were repeated by different reference volume flows of risers A and B.

3.2 Methodology of numerical modelling

The hydraulic model parameters of the rising pipes (A and B) were defined as a numerical model of the pressure conditions. All hydraulic parameters were modelled, which could not be verified by experiments. The main aim of numerical model was to determine hydraulic behavior of the risers A and B, and graphically characterize of the hydraulic conditions by pressure diagrams. This model was based on the physical model of the risers A and B according to Fig. 5. As input were used the physical parameters of pipe elements and the central hydraulic parameters defined by experiments (flow temperatures, total volume flow of the risers). The numerical model was created in Excel. The principle of the model is based on node and circuit laws [2]:

$$\sum_{j=1}^{j=n} M_j - M_c = 0 \quad (\text{kg/s})$$

$$\Delta p_r + H = \Delta p_v + \sum_{j=1}^{j=n} \Delta p_j \quad (\text{Pa})$$

Where:

- M_j – is the mass flow flowing from the node (kg/s),
- M_c – mass flow flowing into the node (kg/s),
- Δp_r – pressure difference of riser (Pa),
- H – effective buoyancy (Pa),
- Δp_v – pressure loss of valve (Pa),
- Δp_r – pressure loss in pipe elements (Pa).

The numerical calculations were based on the basic equations for pipe network calculating. Total pressure losses were expressed according Darcy-Weisbach formula as follows [2]:

$$\Delta p = \left(\lambda \cdot \frac{l}{d} \sum \xi \right) \cdot \frac{\rho}{2} v^2 \quad (\text{Pa})$$

Where:

- λ – is pipe friction coefficient (-),
- l – pipe length (m),
- d – internal pipe diameter (m),
- ξ – resistance coefficient (-),
- ρ – density (kg/m³),
- v – velocity (m/s).

The friction coefficient of seamless steel pipe elements can be expressed using several equations, which depends on the flow profile and the roughness of the pipes wall [3-5]. The friction coefficients was determined individually for current profiles. Three zones were identified based on the Reynolds number, the friction coefficients were determined according the following equations:

1. laminar flow (Re < 2320) – Hagen-Poiseuille's method: $\lambda = f(\mathrm{Re})$ [6],
2. transitional area (2320 < Re < 3000) – by interpolation [7],
3. turbulent flow (Re > 3000) – Romeo, Royo and Monzon's method: $\lambda = f(\mathrm{Re}, d/k)$ [8, 9].

Where:

- Re – is Reynolds number (-),
- k – pipe roughness (m).

Resistance coefficients of armatures and fittings were defined by various calculation methods [1, 6, 10-12]. The pressure losses of the valves before ceiling circuits were determined using known flow factor (k_v) values.

4 Analyze of hydraulic system by measurements and numerical modelling

The analysis of hydraulic system was based on the results from the experiments and numerical modelling. The evaluation was focused in this study on two main issues. At first the pipe roughness was analyzed, which substantially affects the calculation of friction coefficient. Secondly the effect of buoyancy was examining, which can confuse the hydraulic stability of system.

4.1 Analyze of pipe roughness

The roughness of the old pipes is difficult to identify in some cases. The steel pipes are characterized by different roughness according to corrosion rate [4, 11]. To determine the real pipe roughness in reference system were compared measurements data and outputs from numerical modelling.

The measurements of differential pressure of the risers A and B was determined after the balancing valves by different reference volume flows. Due to low resolution of pressure meter, the uncertainty range is relatively high (± 0.5 kPa). Measurement values defined the minimum and maximum limit values.

The pipe characteristic curves were defined by the numerical model using different pipe roughness. The following values were used four reference roughness:

- k_1 = 0.15 mm (cleaned after long-term use),
- k_1 = 0.4 mm (light corrosion),
- k_1 = 1.0 mm (moderate corrosion),
- k_1 = 2.0 mm (severe corrosion).

Measurements data and results of numerical modelling were compared in Figs. 6 and 7. Striking curves define the limit values based on measurements data. The colored curves show pipe characteristics by different pipe roughness. Based on the results, we can note significant influence of the pipe roughness on the pressure losses. The measured pressure differences correspond by lower flows with calculated roughness values of 0.15 to 1.0. At higher volume flow they correspond to values 0.15 and 0.4. The

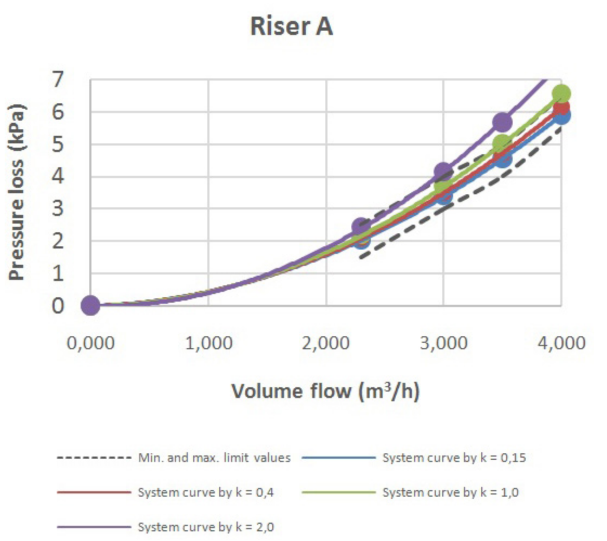

Fig. 6 Comparison of characteristic curves of risers A by various reference roughness with measurements data (by reference mean fluid temperature 25 °C)

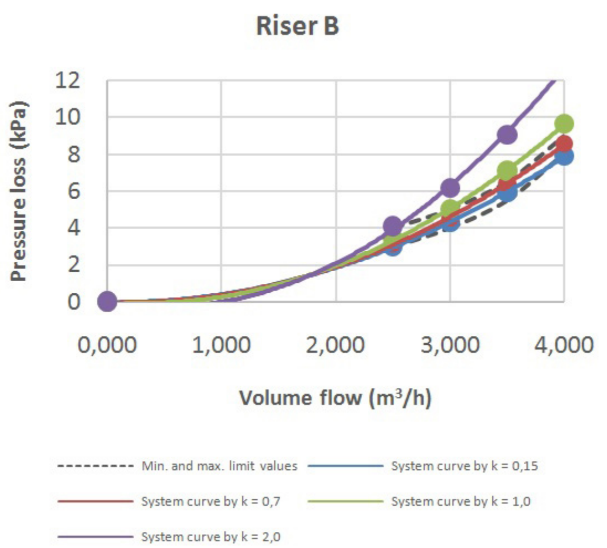

Fig. 7 Comparison of characteristic curves of risers B by various reference roughness with measurements data (by reference mean fluid temperature 25 °C)

assumed pipe roughness is based on the Figs. 6 and 7 about 0.4 mm, which means light corrosion in the pipe system. However, the pipe roughness doesn't need be constant in the whole system. In old systems is also necessary to calculate with other factors (plucking of fittings, pipe sections). The determined pipe roughness is characterizing all factors, which have impact on pressure losses in pipe system.

4.2 Analyze of Buoyancy

In the energy systems of high-rise buildings, we cannot neglect the buoyancy on pressure ratios. In this case buoyancy effect was analyzed by different boundary conditions on risers A and B. The analysis was based on experimental measurements and numerical modelling. Buoyancy was determined by different temperature drops selected according to real fluid temperature conditions (Section 2). Control temperature drops were also selected at lower temperature values but in the same differences. The inlet volume flow was defined by measurements data based on Section 3.1. Pipe roughness was selected 0.4 by Section 4.1. The results of calculations are presented in tables and graphical forms. The summary of the boundary conditions and results are shown in Table 1 and 2. Here are presented three reference floors with volume flow characteristic. Floors 0 to 3 are atypical with various flow requirements.

On the riser A can be observed significant impact of buoyancy at higher temperature drops, when higher floors volume flows increase significantly. On the riser B can be observed only a moderate influence of buoyancy. The reason of this is the higher pressure loss on riser B, which eliminates the impact of buoyancy. On the riser A can be observed significantly lower total pressure loss, than on riser B. Therefore is the influence ratio of buoyancy higher, it can confuse the hydraulic stability.

Results were also presented in graphical outputs for detailed overview. Graphs are determined for two temperature drops: for riser A by 35/30.5 and 25/25°C, and for riser B by 35/31.5 and 25/25°C. Graphically results are presented in Fig. 8 to 11. The graphs are showing the effect of buoyancy by a dotted line. It was defined on the inlet section as pressure gain. Volume flow distribution is presented by rectangles with corresponding values. The pressure diagrams allow to monitor the hydraulic behavior of the risers. Valves before floors were not specially balanced, they are all completely open. At temperature drop 25/25°C can we observed moderate decline of input volume flows in the direction of highest floor. At higher

Table 1 Influence of effective buoyancy on pressure ratios of risers A by different temperature drops

Outside air temperature	θ_o	°C	-11	-	-5.3	-	0.5	-	7.5	-	13.0
Inlet fluid temperature	θ_{in}	°C	35.00	32.50	32.50	30.00	30.00	27.50	27.00	25.00	25.00
Return fluid temperature	θ_{re}	°C	30.50	28.00	29.00	26.50	28.00	25.50	26.00	24.00	25.00
Temperature drope	$\Delta\theta$	K	4.50	4.50	3.50	3.50	2.00	2.00	1.00	1.00	0.00
Total pressure loss of riser	Δp	Pa	1843	1872	1936	1957	2017	2033	2069	2081	2095
Buoyancy on 10. floor	H	Pa	535	552	395	367	214	198	99	92	0
Volume flow on 3. floor	Q	l/h	193	193	193	193	193	193	193	193	192
Volume flow on 6. floor	Q	l/h	190	190	188	187	185	185	183	183	181
Volume flow on 10. floor	Q	l/h	189	188	183	182	177	177	173	173	169
Total volume flow	Q	l/h	2350	2350	2340	2339	2328	2329	2319	2320	2301

Table 2 Influence of effective buoyancy on pressure ratios of risers B by different temperature drops

Outside air temperature	θ_o	°C	-11	-	-5.3	-	0.5	-	7.5	-	13
Inlet fluid temperature	θ_{in}	°C	35	32.5	32.5	30	30	27.5	27	25	25
Return fluid temperature	θ_{re}	°C	31.5	29	30	27.5	28.5	26	26.5	24.5	25
Temperature drope	$\Delta\theta$	K	3.5	3.5	2.5	2.5	1.5	1.5	0.5	0.5	0
Total pressure loss of riser	Δp	Pa	7301	7233	7149	7092	6969	6900	6863	6808	6838
Buoyancy on 10. floor	H	Pa	422	395	286	266	162	150	50	46	0
Volume flow on 3. floor	Q	l/h	273	274	272	272	269	270	269	269	269
Volume flow on 6. floor	Q	l/h	266	266	263	264	260	260	259	259	259
Volume flow on 10. floor	Q	l/h	265	264	261	261	257	256	254	254	254
Total volume flow	Q	l/h	3700	3700	3670	3670	3630	3630	3615	3615	3600

Fig. 8 Pressure diagram and volume flow distribution of riser A by temperature drop 35/30.5°C

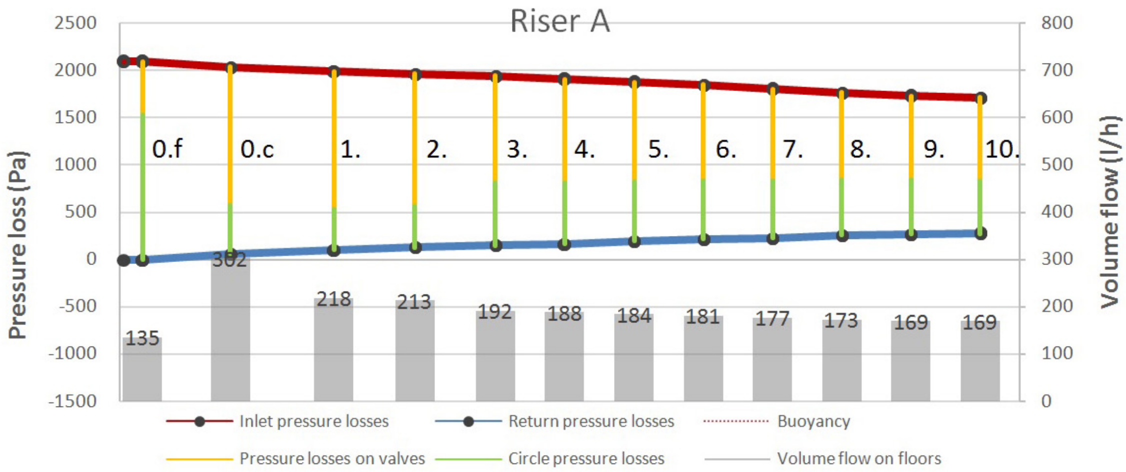

Fig. 9 Pressure diagram and volume flow distribution of riser A by temperature drop 25/25°C

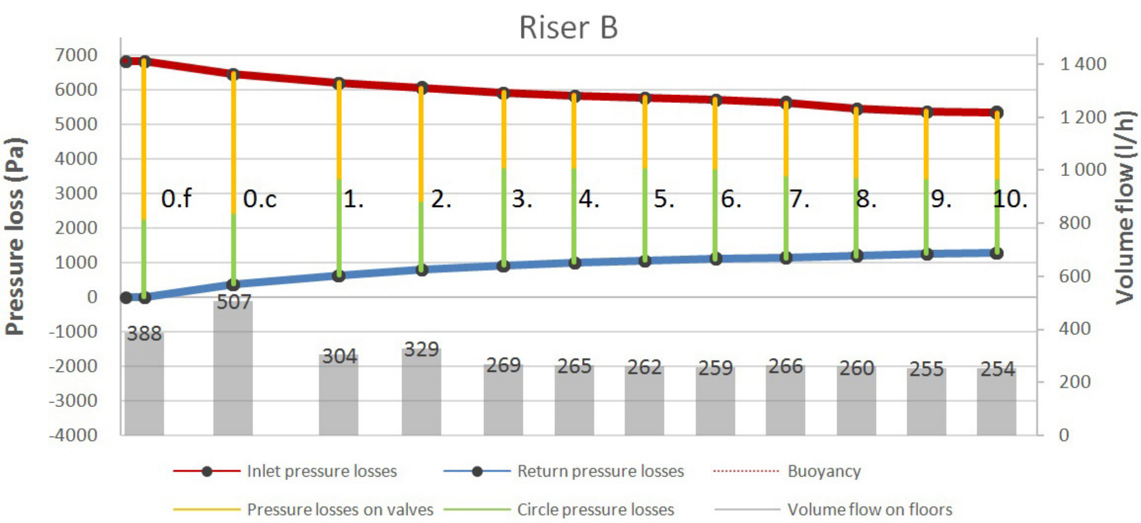

Fig. 10 Pressure diagram and volume flow distribution of riser B by temperature drop 35/31.5°C

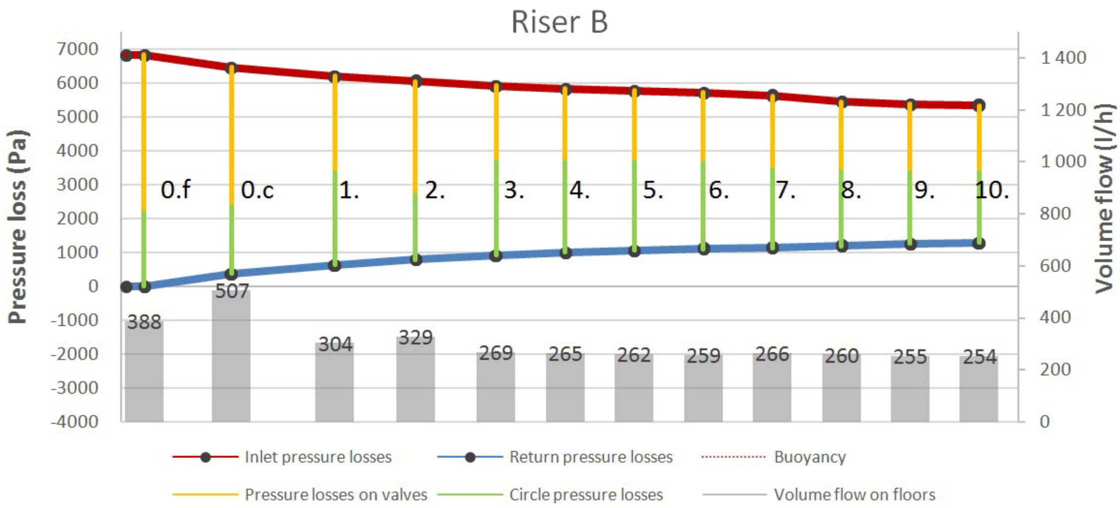

Fig. 11 Pressure diagram and volume flow distribution of riser B by temperature drop 25/25°C

temperature drop volume flows on typically floors (3 to 10) of riser A are naturally balanced by buoyancy effect. On the riser B is this effect less noticeable, there is no significant impact on pressure conditions and volume flows.

5 Conclusion

In a high-rise building, with partially restored energy systems with original pipes, the lifetime and wear of ingested material must be considered. The greatest risk of steel pipes is the corrosion, which has a significant affect to pipe roughness and friction factor. Higher friction factor can increase pressure losses in hydraulic system. Regular checking and cleaning is highly recommended in old (partially restored) energy systems to eliminate higher corrosion rate.

In the high-rise buildings is also worth considering the buoyancy, which can confuse the hydraulic stability of energy system. The effect of buoyancy is more pronounced in hydraulic systems with lower pressure resistance in vertical parts and in circuits on floors. Moreover, buoancy can significantly confuse pressure conditions by lower fluid temperatures and temperature drops. This problem concerns mainly the partially restored systems with original pipe sections, which are oversized for reduced heat requirements [13]. In order to eliminate the undesirable effect of buoyancy, it should be paid increased attention to the choice of balancing and control valves. Hydraulic balancing must be a necessary part of buildings restoration.

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References

[1] Csoknyai, I., Doholuczki, T. "Több, mint hidraulika" (More than hydraulics), Herz Armatúra Hungária Kft., Budapest, Hungary, 2013. (in Hungarian)

[2] Mäsiar, E., Kamenský, J. "Hydraulika" (Hydraulics), 3rd ed., STU v Bratislave, Bratislava, Slovak Republic, 2001. (in Slovak)

[3] Colebrook, C. F., White, C. M. "Experiments with fluid-friction roughened pipes", Proceedings of the Royal Society of London. Series A – Mathematical and Physical Sciences, 161(906), pp. 367–381, 1937.
https://doi.org/10.1098/rspa.1937.0150

[4] Colebrook, C. F. "Turbulent flow in pipes, with particular reference to the transition region between the smooth and rough pipe laws", Journal of the Institution of Civil Engineers, 11(4), pp. 133–156, 1939.
https://doi.org/10.1680/ijoti.1939.13150

[5] Genić, S., Arandjelović, I., Kolendić, P., Jarić, M., Budimir, N., Genić, V. "A Review of Explicit Approximations of Colebrook's Equation", FME Transactions, 39(2), pp. 67–71, 2011.

[6] Green, D. W., Perry, R. H. "Perry's chemical engineer's handbook", 8th ed., McGraw-Hill Education, Blacklick, USA, 2007.

[7] Cheng, N.-S. "Formulas for Friction Factor in Transitional Regimes", Journal of Hydraulic Engineering, 134(9), pp. 1357–1362, 2008. https://doi.org/10.1061/(ASCE)0733-9429(2008)134:9(1357)

[8] Brkić, D. "New explicit correlations for turbulent flow friction factor", Nuclear Engineering and Design, 241(9), pp. 4055–4059, 2011. https://doi.org/10.1016/j.nucengdes.2011.07.042

[9] Romeo, E., Royo, C., Monzón, A. "Improved explicit equations for estimation of the friction factor in rough and smooth pipes", Chemical Engineering Journal, 86(3), pp. 369–374, 2002. https://doi.org/10.1016/S1385-8947(01)00254-6

[10] Blevins, R. D. "Applied fluid dynamics handbook", Van Nostrand Reinhold Co., New York, NY, USA, 1984.

[11] Garbai, L. "Hidraulikai számítások az épületgépészetben és az energetikában" (Hydraulic calculations in building services and energetics), Akadémiai Kiadó, Budapest, Hungary, 2007. (in Hungarian)

[12] Kilkovský, B., Jegla, Z., Stehlík, P. "Comparision of Different Methods for Pressure Drop Calculation in 90° and 180° Elbows", Chemical Engineering Transactions, 25, pp. 243–248, 2011. https://doi.org/10.3303/CET1125041

[13] Szánthó, Z., Varga, B. "The Balance of Gravitational Effect and Pressure Los sin Two-Pipe Heatig Systems", In: Proceedings of the 2nd IASME/WSEAS International Conference on Continuum Mechanics", Portoroz, Slovenia, 2007, pp. 12–15.