Technical Note

Fluctuation Behaviors of Air Pressure in a High-Rise Building Drainage System

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Abstract: Air pressure fluctuation behaviors in a high-rise building drainage system (HBDS) are presented by probability density functions and statistical analysis of measured data in the drainage stack in a real-life eighteen-floor building, the Li Ka-Shing (LKS), at PolyU of Hong Kong. Three observation points, at the mezzanine (M), 6th, and 12th floors, are arranged to record the air pressure in the primary building stack. The measured data are stored in a personal computer with a sampling period of 1 s. Statistical analysis revealed that there is an evident floor dependence of the air pressure in the real-life HBDS. The flatness factor of the pressure fluctuation increases with floor number, whereas the skewness factor has a reversed variation tendency; it decreases from a positive value in the M floor to negative values at higher floors. Probability density functions show the pressure fluctuation behaviors are far from normal distributions. **DOI: 10.1061/(ASCE)AE.1943-5568.0000029.**

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A building drainage system (BDS) has an unsteady nature causing air pressure oscillations in the stack (Swaffield et al. 2004). The recent numerical studies based on the solution of the St. Venant equations (Swaffield and Campbell 1992a, b) have emphasized the importance of trap seal retention with the aim of improving building management (McDougall and Swaffield 2000; Swaffield and Campbell 1995; Swaffield 1996, 2006; Swaffield and Jack 2004; Wright et al. 2006). Cross-contamination via the drainage system may be caused by the depletions of the trap seals (Kelly et al. 2008) and the bathroom floor drain traps (Gormley 2007), indicating the study of DBS has importance in safeguarding occupied space and improving building management.

The present interest in HBDS is motivated by the lesser concerns of the air pressure data in a real-life building drainage system. To examine this situation, the LKS building at PolyU of Hong Kong was tested as an example, where the air pressure in the building drainage stack was measured and analyzed to explore the pressure fluctuation behaviors which are crucial in drainage system assessment.

The LKS building is the tallest one at PolyU, has eighteen floors, and is located in the center of the campus. The drainage system of the LKS building is composed of sanitary appliances, a floor trap inlet, and branch and vertical stack pipes. The stack and branch pipes are made of hubless cast iron. The internal diameter of the stack is 150 mm, with a stack thickness of about 4 mm. The drainage system of the high-rise building was tested in April 2008; the air pressure in the primary drainage stack was measured at three survey stations that were arranged on the mezzanine (M), the 6th, and the 12th floors. The heights of the three survey stations were, respectively, about 7.95 m, 23.1 m, and 45.9 m above the stack bottom. A pressure sensor, IP67, of the WIKA type was used in the measurement. It has a measuring range of about ± 200 mbar, with an accuracy of about 0.25%. Calibration was done using a 150-mm-high U-tube manometer, which was connected to the pressure sensor and an air pump. The pressure sensor can detect the air pressure in the stack of the test building by providing electric current signals in mA units, which are transferred to a data logger.

The data logger had two parts: an analog input module used to convert mA signals to digital signals, and a programmable logic controller (PLC) used for signal control. The PLC was a Micrologix-1500. The software RSLogix-500 was used for data logging in the PLC. Digital signals were sent to the personal computer by using the DH485 communication port and cable. The data for the present statistical analysis was recorded in the daytime beginning at 8:00 a.m. on April 28, 2008. The data sampling period was 1 s.

A summary of the statistical analysis of measured air pressure in the primary stack of the test building is given in Table 1. The pressure evolutions during the time period 8:00–10:00 a.m. on April 28, 2008 are shown in Fig. 1(a)–1(c) and indicate that the floor dependence of pressure is quite evident, as reported previously (Wong et al. 2008). On the M floor, the air pressure had a positive mean value of roughly 1.2 mbar and a large standard deviation 0.87 mbar. The pressure fluctuation in the M floor had a positive skewness factor (C_S) of about 0.9 and a flatness factor (C_F) of 3.8, as shown in Table 1. The values of these statistical parameters depend on the floor number. In particular, the mean stack pressures on the 6th and 12th floors are negative, and the standard deviations are roughly one-third of that on the M floor, suggesting that the fluctuations have lower intensities.

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Table 1. Mean Pressure, Standard Deviation, and Skewness and Flatness Factors of Pressure Fluctuation

Floor	p_m (mbar)	s (mbar)	C_S	C_F	Record number
M	1.175	0.866	0.899	3.795	38,206
6th	−2.28	0.339	−0.52	8.632	38,055
12th	−2.05	0.303	−1.10	75.27	32,357

The skewness factors C_S on the 6th and 12th floors are negative, indicating that fluctuations with larger amplitude are negatively oriented, i.e., large amplitude negative pulsations are more common, with the evidence shown in Fig. 2(b) and 2(c). The C_S on the 12th floor is about twice the C_S on the 6th floor, showing that, on the 6th floor, there are more intensified and negatively oriented pulsations. The flatness factor C_F on the 12th floor is about 75, much higher than that on the 6th floor (8.6), implying that the pressure distribution is particularly narrow. As shown in Fig. 2(c), almost all the fluctuations were concentrated in the narrow range of p_r from −0.15 to 0.2.

Probability density functions (PDFs) were calculated in terms of the measured airpressure in the primary stack of the test building with the purpose of indicating the pressure fluctuation behaviors. The rescaled pressure is defined by

$$p_r = (p - p_m)/[p] \tag{1}$$

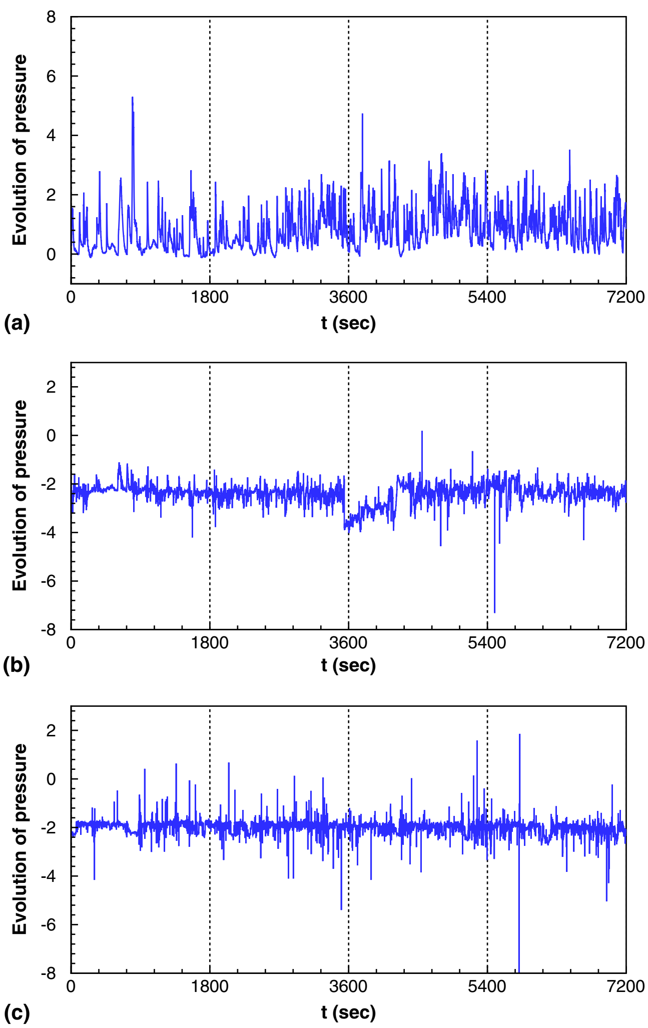

Fig. 1. Evolution of pressure: (a) M floor; (b) 6th floor; (c) 12th floor

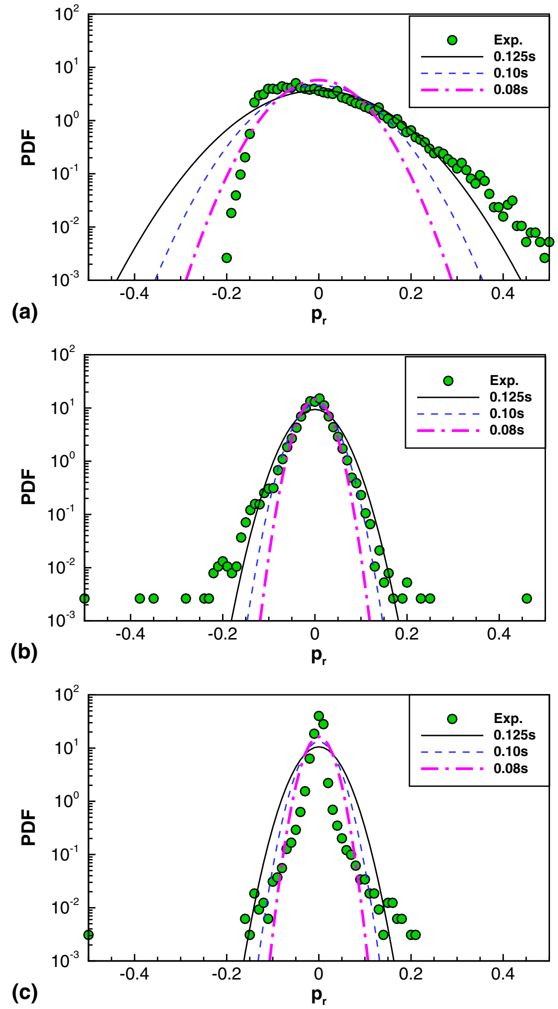

Fig. 2. PDFs of measured pressures and normal distributions with standard deviation C_0s: (a) M floor; (b) 6th floor; (c) 12th floor

and the pressure variation range

$$[p] = \max(p) - \min(p) \tag{2}$$

is shifted so that the midpoint of the range has the mean value p_m. As shown in Fig. 2, the pressure fluctuations are less similar to the PDFs (f_p) of normal distributions with standard deviations C_0s

$$f_p = \frac{1}{\sqrt{2\pi}C_0 s}\exp\left\{-\frac{p_r^2}{2(C_0 s)^2}\right\} \tag{3}$$

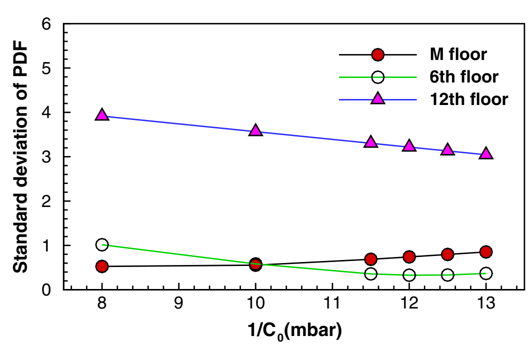

Fig. 3. Standard deviation between measured PDF and normal distribution with standard deviation, C_0s, plotted as a function of $1/C_0$; s denotes root mean square of pressure

Here the parameter of C_0 was chosen as 0.125, 0.10, or $0.08(1/\text{mbar})$. The shape of f_p becomes narrow with the reduction of C_0. In Fig. 2(a), it is seen that the negative pulsations with amplitude beyond 0.25 were scarce, since the air flow driven by the drained water in the stack is stagnated at the stack bottom. This fluctuation behavior determines the standard deviation of normal distribution PDF in relation to the measured PDF increase with the increase of $1/C_0$, a variation trend quite different from that of the pressure fluctuations on the 6th and 12th floors (Fig. 3).

In Fig. 2(b), the fitness of the normal distribution to the measured PDF is good for small amplitude pressure pulsations; large deviation occurs in the tails representing larger amplitude oscillations. The standard deviation of the normal distribution PDF, as shown by the line connected by unfilled circles in Fig. 3, has a minimum around $1/C_0 = 12$ mbar.

In Fig. 2(c), the measured PDF cannot be fitted by the normal distributions for $1/C_0$ in the range from 8 to 13 mbar, since the standard deviation of the PDF is almost more than 3, as shown by the line linked by filled deltas in Fig. 3.

In conclusion, the measurements of air pressure in the real-life LKS building show that (a) the air pressure distribution does not satisfy a kind of normal distribution—the distribution in the M floor appears the largest deviation from the normal distributions; (b) the air pressure in the mezzanine floor has a larger standard deviation that is two to three times larger than that for the 6th and 12th floors; and (c) the air pressures on the 6th and 12th floors have negative skewness factors and larger flatness factors. To release the excess positive air pressure near the stack bottom, pre ssure attenuator installation is a way to improve the performance of the drainage system, and the use of double cross-vent pipes at the tee joint of related floors is another option in design consideration.

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