The influence of sewer network airflows on the air flow and air pressure regime in Building Drainage Systems: Mechanisms and Modelling.

K.S.Sharif (1), M.Gormley(2),
1. kss32@hw.ac.uk
2. m.gormley@hw.ac.uk
(1) & (2) School of Energy, Geoscience, Infrastructure and Society, Heriot-Watt University, Edinburgh, Scotland, UK.

Abstract

Historically, sanitation systems sought to divert effluent away from inhabited areas, often driven by religious and cultural practices. Understanding this historical evolution provides a framework for comprehending the complexities of modern drainage systems and their susceptibility to various factors, including the influence sewer air has on the performance of the system inside buildings – the above-ground drainage system The performance of Building Drainage Systems (BDS) relies on complex air flow and pressure dynamics. Failures within BDS can compromise water trap seals, facilitating the entry of hazardous sewer gases into buildings. Moreover, external influences from the sewer network exacerbate these vulnerabilities. Presently, drainage system regulations lack provisions addressing these interactions. This research attempts to bridge this gap. Laboratory experiments were conducted, utilising a full-scale drainage test rig. The study focused on understanding the impact of sewer air on airflow and pressure dynamics within BDS, particularly concerning buildings of varying heights. The research confirmed that the airflow and air pressure regime within the vertical BDS stack is modified by and influenced by the connection to the main sewer in a manner consistent with an interaction analogous to a fan and system loss curve requiring the solution of simultaneous equations describing both. The findings of this study confirm a direct correlation between pressure fluctuations and building height when exposed to sewer air. Through a broad analysis, this research illuminates the previously overlooked ramifications of external airflows on BDS performance, providing insights and a model to incorporate the impact of external airflow into regulatory frameworks.

Keywords:

Sewer System, Building Drainage System, Network Integration, Air Movement, Pressure Regime

1 Historical Background of Sanitation Development

The evolution of sanitation and wastewater technologies is profoundly connected to the continuous emphasis on public health, safe water use, disease control, and environmental enhancement. Various factors, including climate, topography, geology, scientific knowledge, engineering capabilities, social values, and religious beliefs, have shaped local approaches to urban drainage (Angelakis and Rose, 2014). Throughout history, cultural and religious mores have significantly influenced water and wastewater management practices. Historically, the understanding of the link between sanitation and public health progressed gradually, with significant improvements emerging only after 19th-century public health crises, such as the cholera outbreak in London, which prompted an overhaul of water supply and waste management infrastructure. Technological strides in the 20th century, such as the advent of indoor plumbing, significantly advanced sanitation. The 21st century brings forth challenges like urbanisation, climate change, and the emergence of new diseases such as SARS in 2003 and COVID-19 in 2020. These issues require creative solutions and necessitate the revision of existing design standards. Figure 1 depicts the historical timeline of sanitation development, emphasising significant milestones and advancements that have shaped current practices. Historical context of drainage system provides a foundation for comprehending the complexities of modern drainage systems and their vulnerabilities to factors such as sewer air.

Ancient Civilisation Circa 4000 BCE - 476 CE	- Role of Culture and religion play a significant role in shaping attitudes towards drainage systems and water management practices. - There was limited understanding of the connection between sanitation and public health.
Middle age 5th -15th century	Improvement of interest in public health and sanitation, overall sanitation remained poor
Early Modern Era 14th-18th century	-Very little progress was made from 300 AD to mid 18th - Limited understanding of hygiene
Industrial Revolution 18th -19th century	Following the London cholera epidemic, significant investments were made in water supply and sanitation infrastructure, subsequently leading to the development of sewer systems
20th Century	Rapid technological progress in the 20th century - Indoor plumbing became common in developed countries, bringing clean water and sewage disposal inside homes. - Increase wastewater management system. - Governments put rules and standards in place to ensure plumbing systems were safe and efficient.
21st Century	- Advancements in sanitation and plumbing have continued, driven by technological innovation, sustainability concerns, and global health challenges. - Increasing interest in innovate drainage solutions. - The rise of tall buildings and urbanisation, and the impacts of climate change, underscores the necessity of updating design codes.

Ongoing development

Figure 1 Historical timeline of sanitation development

2 Network Integration

Network integration refers to the coordinated connection between above-ground building drainage systems and below-ground sewer systems. The term 'network integration' underscores the importance of both systems as critical components of a comprehensive network that ensures the effective management of wastewater and stormwater, thereby enhancing public health and environmental protection. Despite this interdependence, none of the design codes, specifically BS EN 2017 for sewer systems and BS EN 12056-2:2000 for building drainage systems, explicitly address the integration of these systems or their mutual reliance for ventilation purposes.

Sewer systems are primarily designed to manage the flow of sewage and wastewater, with less consideration given to air movement within the system. Consequently, the pressure in a sewer network at a certain location can build up and air can be released uncontrollably (Edwini-Bonsu and Steffler, 2004). While building drainage systems are designed to convey wastewater from within buildings to external sewer networks, it is essential to ensure proper ventilation to maintain effective air-water flow. Understanding the impacts of sewer air on building drainage systems (BDS) necessitates a thorough investigation of the relevant design codes. More details about this integration was published in 2021 in the peer-reviewed journal entitled "Integrating the Design of Tall Building Wastewater Drainage Systems into the Public Sewer Network: A Review of the Current State of the Art"(Sharif and Gormley, 2021).

These systems are typically designed separately due to different requirements and design considerations. These factors include different environmental impacts, localised control and maintenance, different functions, different design criteria, and regulatory requirements. Despite their separate design, both systems are interconnected through several linking factors such as environmental impacts, system ventilation, regulatory compliance, wastewater discharge, and building sewer connections. The responsibilities of homeowners and sewer agencies also play a role in this integration. Ultimately, the integration of building drainage systems and sewer systems is crucial for ensuring public health safety.

This research has identified air movement as a critical factor affecting both sewer and building drainage systems (BDS), emphasising the significant impact of sewer air ingress on the characteristics of BDS. This aspect has often been overlooked in previous studies. Comprehensive laboratory work has been conducted to develop a model-based experiment, which reveals the generation of pressure loss due to sewer air and its impacts on the BDS. The following sections provide an overview of this model and its application to the real-world test rig National Lift Tower (NLT).

3 Pressure loss along the drainage stack due to sewer air

Understanding pressure loss within building drainage systems is crucial for ensuring their effective operation, particularly when these systems are exposed to air from sewer networks. Pressure loss can significantly impact the performance and reliability of drainage systems, which is influenced by various factors including frictional resistance, pipe fittings and bends, pipe length and diameter, and changes in vertical elevation. as depicted in Figure 2. A model-based experiment was developed to examine single-phase airflow within a building drainage system exposed to sewer air. By isolating the air phase, this experiment aims to better understand and measure its behaviour and impact on pressure loss without the presence of water. In a dry pipe, the pressure loss can be quantified using principles derived from fluid mechanics, often applying the Darcy-Weisbach equation, which considers both major and minor losses.

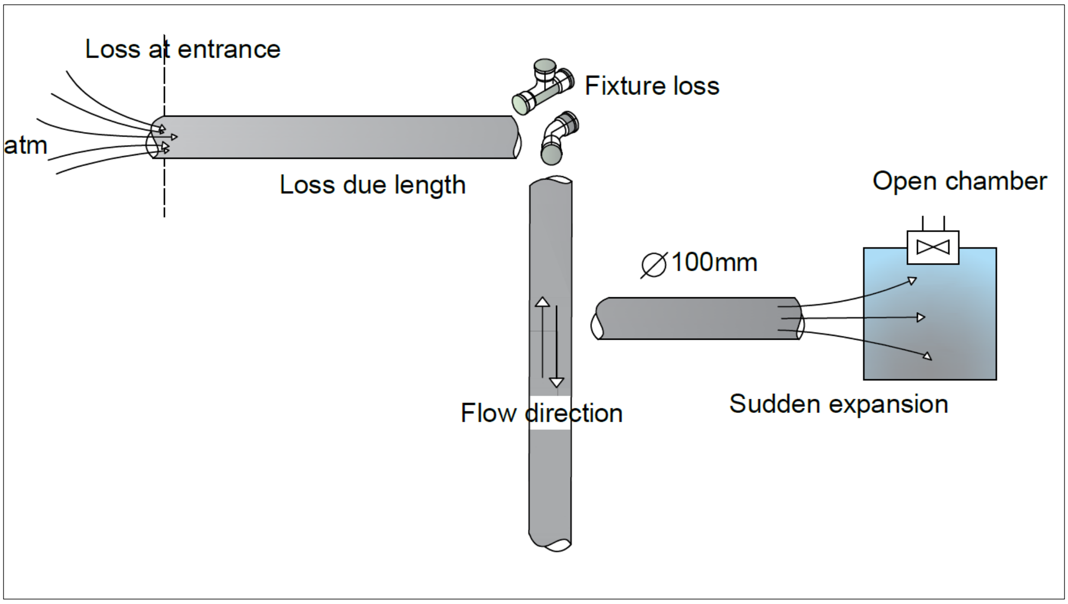

Figure 2 Various losses in the systems

A thorough series of laboratory experiments was conducted to collect data on system response and develop a model representing pressure loss when exposed to sewer air, applicable to buildings of various heights. A new testing apparatus was built at the HWU laboratory, involving an extractor fan connected to a 100mm diameter horizontal loop pipe of varying lengths Figure 3. This system helped measure the induced continuous airflow within the system, pressure fluctuations along different pipe lengths, and analyse the system's response to changes in pipe length. A new term introduced in this research, '$\Delta P_{\text{updraft air}}$,' represents pressure losses inside building drainage systems with sewer air. More details can be found in the conference paper titled "Modification of the Building Drainage System airflow and pressure regime due to airflow from the sewer network.', in CIBW062 symposium. Belgium".

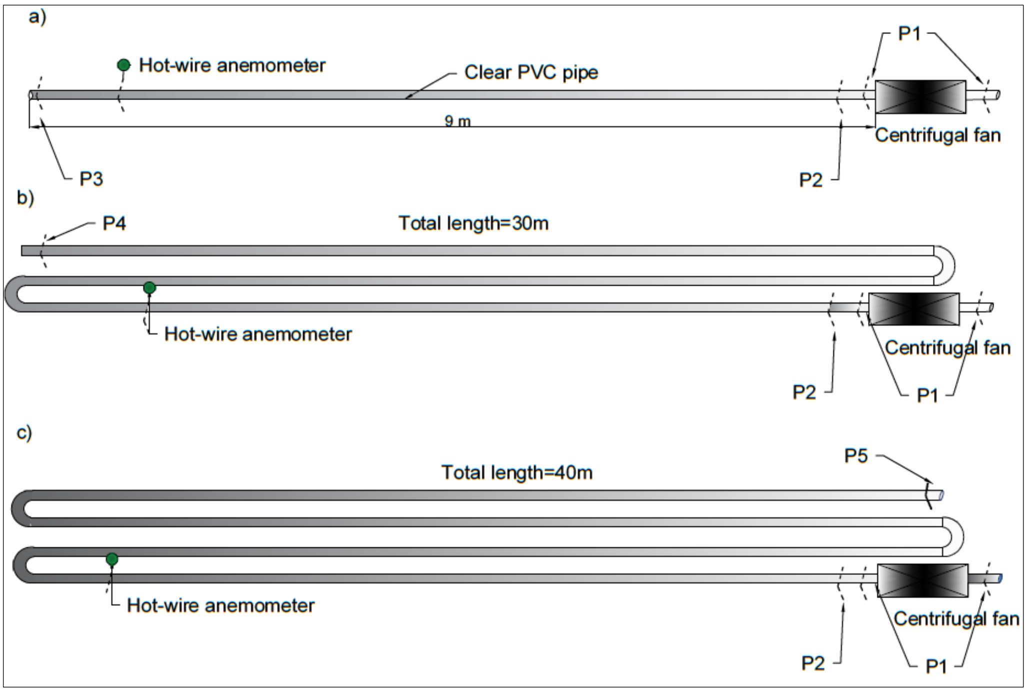

Figure 3 Sketch of the horizontal loop test rig

In this study, equation 1, was developed to represent $\Delta P_{\text{updraft air}}$. This equation is applicable for the entire BDS system length. A model was developed after the experimental tests to improve the system's performance by expressing the pressure changes as a function of airflow rate and system length, ΔP = f {Qas, L}. Equation1 was validated using the HWU laboratory test rig, which simulated a three-story building under both steady and unsteady flow conditions. There is a positive correlation between updraft airflow rates and the magnitude of static pressure changes. Increasing updraft airflow rates leads to higher pressure changes. Additionally, an increase in water flow rates results in larger negative and positive pressure changes.

$$\Delta P/L=\Delta Pmin+L\Delta PC \qquad (1)$$

Where:

$$\Delta Pmin=K1(Qas)2$$

$$\Delta PC=K2(Qas)2$$

L is a pipe length in meter

ΔP or $\Delta P_{\text{updraft air}}$ is the pressure loss along the stack due to the sewer air
$\Delta Pmin$ is a pressure changes per meter length
ΔPC is the rate of pressure changes due to increasing the pipe length
Qas is airflow rate, K1 and K1 are constant

4 Pressure changes along the drainage pipe

Variations in air pressure within a building's drainage stack are influenced by both dynamic and static factors. The conditions of fluid flow within the stack have the most immediate impact, with changes in the volume and velocity of both air and water significantly affecting internal pressure. Furthermore, the effect of wind across the stack opening and the operation of mechanical ventilation systems are also critical. Everyday activities, such as opening and closing doors and windows, can also have a notable impact on the air pressure in the drainage stack. Understanding these influences provides a wide view of why pressure variations occur along the stack. This study examines the pressure changes caused by discharging water and assesses the impact of updraft air on these established pressure dynamics, with the goal of preventing sudden changes within the system.

Examining the variations in pressure at different elevations provides valuable insights into how updraft airflow rates influence the system's pressure dynamics. This analysis deepens our understanding of the complex interplay between updraft airflow and pressure changes within the system, leading to modified the pressure profile.

5 Methodology

6 Experimental setup

To investigate the impact of sewer air on the air-pressure regime within building drainage systems and to validate laboratory-measured data, the National Lift Tower (NLT) was utilised as a primary facility for data collection. This setup provided a controlled and realistic environment to assess the interactions between sewer air and building drainage systems, ensuring the reliability and accuracy of the experimental findings. This tower is an ideal drainage test facility for understanding and addressing problems in high-rise buildings, particularly in one that is 128m tall. A drainage test setup 76.3m in height of single stack system was used, with toilets installed on the 8th floor. The stack has a single air inlet located on the 15th floor and an exit leading to a collection tank on the 4th floor. The toilets are flushed automatically by a control system situated on the 4th floor, and the toilet traps are filled at the beginning of all tests. The tower is equipped with a hot-wire anemometer and seven wall-mounted pressure transducers (p1-p7), as shown in Figure 4.

The experimental setup included the installation of a fan inside a 1-cubic-meter chamber on the 15th floor. A duct connects this chamber to a pipe with a diameter of 100 mm, similar to the one used in the laboratory test. Seven pressure sensors were positioned at elevated heights as detailed in Table 1, and a hot-wire anemometer was placed 1 meter away from the bend at the termination of the stack. All devices were linked to a data acquisition system (DAQ) located on the 9th floor.

The experiment was conducted on the 8th floor to ensure it was at the midpoint of the pipe, facilitating the measurement of pressure variations in both the dry and wet stack. Data was recorded three times for a single flush, with each test lasting 1 minute and a data recording frequency of 500 Hz. The data was collected under conditions with no airflow and with various updrafts of air generated by a fan during a single flush on the 8th floor. The toilet flush mechanism used was similar to that in the HWU-Lab. The collected data was crucial for validating the model used in the research. This validation determined whether the model could accurately predict pressure variations in both dry and wet stacks under different airflow conditions. Ultimately, the validation of the model provided greater confidence in the accuracy of the results and laid a foundation for further analysis and study in the field.

Table 1 Floors elevation and pressures location

Floor	H(m)	No. Pressures	Distance (m)
F4.5	18.1	**P1**	0
F5	26.1	**P2**	0
F6	37.1	**P3**	0.6
F7	43.7	**P4**	10.1
F8	47.0	**P5**	27.8
F9	50.3	**P6**	33.8
F11	57.3	**P7**	75.6
F13	70.1		
F14	81.1		
F15	92.1		
Top	94.1		

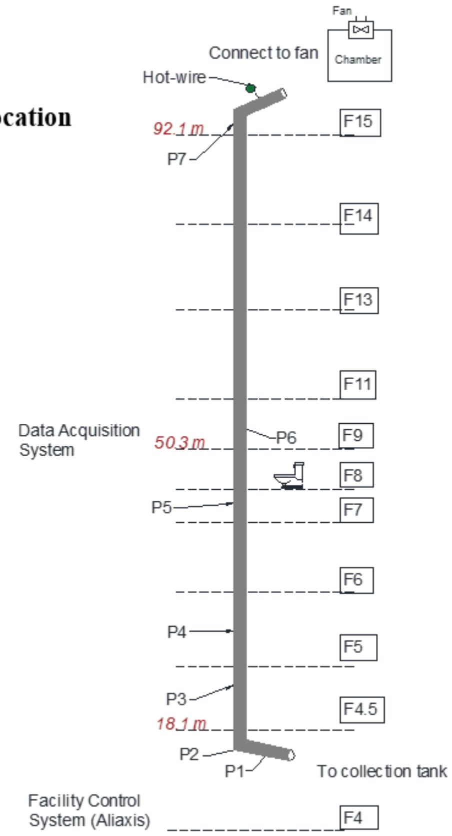

Figure 4 Sketch of National Lift Tower (NLT) test rig

7 Result and discussion

The relationships between updraft airflow rates and pressure changes are illustrated in Figure 5. Each pressure data point along the vertical stack represents an average from three repeated flushes, with measurements taken at the peak of each flush.

Figure 5 shows the x-axis representing the updraft airflow rate (Qas) (l/s), while the y-axis indicates the pressure measurements along the drainage stack (mm). The basic points represent the measured pressure when updraft air flow is 0. A slight updraft of 1 m/s was recorded, attributable to system conditions such as temperature differences from the top to the bottom of the stack and the height of the stack. The findings indicate that as the updraft airflow rate increases, the pressure drop (negative pressure) becomes more pronounced, and the pressure in the positive section also rises.

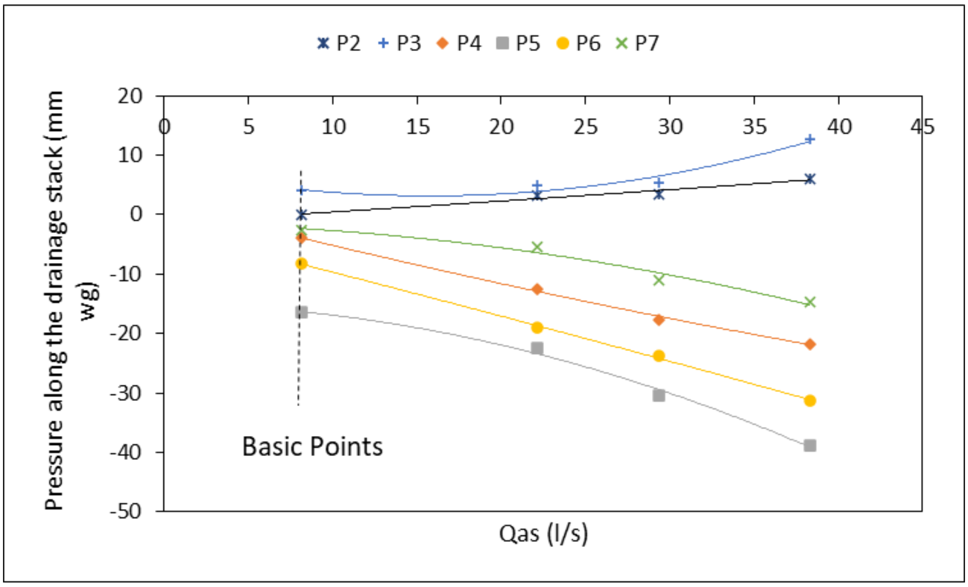

Figure 5 Pressure changes along the drainage stack with and without updraft airflow rate

The data measurements were then compared with the developed model using equation1. Figure 6 shows the pressure changes at various elevations along the stack. Pressure sensors P1 to P7 were placed at different locations along the stack, as specified in Table 1. The blue line represents the baseline pressure measurement, with natural updraft measurements recorded around 8.17 l/s due to the stack height, based on a single flush at floor 8. The subsequent coloured lines show the pressure measurements (P_{meas}) at updraft airflow rate of 22 l/s, achieved using a fan located at the top of the stack.

Additionally, the dashed lines represent the calculated pressure changes derived from the model (P_{adj}) and based on the baseline data (blue line). This comparison between the measured and adjusted pressure changes provides insights into the model's effectiveness in capturing the impact of updraft airflow rates on the pressure distribution within the system.

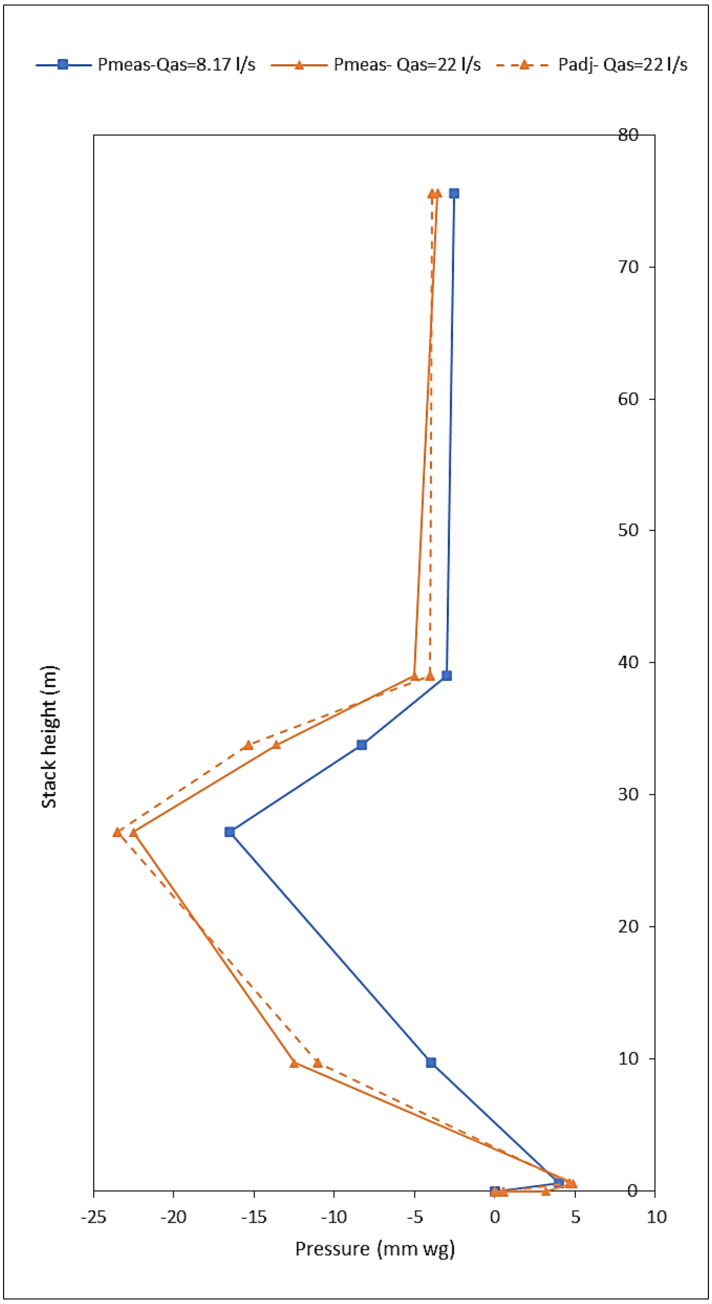

Figure 6 Comparison of data collected from NLT and the developed model under sewer air conditions with updraft airflows Qas =22 l/s

8 Conclusion

This study highlights the significant influence of sewer airflows on the airflow and pressure regime within Building Drainage Systems (BDS). Extensive laboratory experiments and data validation using the National Lift Tower, the research identified the critical impact of sewer air ingress on BDS performance, particularly in tall buildings.

The findings reveal a direct correlation between updraft airflow rates and pressure changes within the system. Increased updraft airflow rates result in higher pressure drops and more pronounced negative and positive pressure fluctuations. This study introduces the term '$\Delta P_{updraft\ air}$' to denote pressure losses due to sewer air, offering a novel perspective on pressure management within BDS. The model developed and validated under various conditions, including different airflow rates and building heights, confirms its reliability and applicability in real-world scenarios. This model serves as an invaluable tool for predicting pressure variations and enhancing the design of drainage systems to prevent failures and safeguard public health. In summary, this research addresses a critical gap in current drainage system regulations by incorporating the effects of external airflows from sewer networks.

9 References

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Khanda S. Sharif is a Research Associate within the Public Health and Environmental Engineering group at Heriot-Watt University. She has extensive industry experience and her research interests include: design integration of the building drainage system with the sewer network; the use of sustainable urban drainage systems (SUDs) for storm water management; and wastewater system monitoring.

Michael Gormley is Professor of Public Health and Environmental Engineering at the School of Energy, Geoscience, Infrastructure and Society at Heriot-Watt University. His research specialisms are: mathematical modelling of air and water flows in building drainage systems, infection spread via bioaerosols and product development.