Microbial transport in building drainage systems

M. Gormley, T.J. Aspray and D. A. Kelly

(1) m.gormley@hw.ac.uk
(2) t.j.aspray@hw.ac.uk
(3) d.a.kelly@hw.ac.uk

(1) and (3) School of the Built Environment,
Heriot-Watt University, Edinburgh, UK.
(2) School of Life Sciences, Heriot-Watt University, Edinburgh, UK.

Abstract

In the event of a defect in the Building Drainage System (BDS), a cross-transmission route exists from one part of a building to any other part via drainage airflows. A series of investigations establish the conditions necessary for this route to be effective. A 2 storey drainage stack was constructed with an inlet on floor 1 and a chamber with an extract fan, containing a removable WC, on floor 2. Airflow analysis and smoke visualisation tests have shown that airflows can traverse a system, and that cross-transmission of airflows occur. Laboratory investigations recorded the extent to which microbes are transported on the airflows found in building drains. Overnight, liquid cultures of the wild-type bacterial strain *Pseudomonas putida* KT2440 were prepared and diluted to between 10^6-10^9 colony forming units (cfu) per ml^{-1}. Six litres of diluted culture was introduced into the test rig to simulate a single WC flush for each experiment. Results showed airflow and velocities consistent with those experienced in real systems. Post- experimental sampling resulted in growth of a single morphotype on Pseudomonas isolation agar (PIA) which matched the appearance of the introduced *P. putida* strain. Use of tryptone soya agar (TSA) and PIA contact plates in the chamber and on inner toilet surfaces also provided supporting evidence of the transmission (and deposition) of the introduced bacterium throughout the drainage system with Pseudomonas specific colonies developing only in post experimental samples. Finally, in experiments including a partial toilet trap, colonies of the inoculum were successfully recovered from the pre-sterilized toilet trap solution. The results confirm that the hypothesized cross-transmission route exists and that it presents a credible risk to public health.

Keywords: Microbial transport, building drainage airflows, defects

1. Introduction

The very nature of the building drainage system, as the collection network for both solid and liquid waste (such as faecal solids, urine, toilet paper and vomit), means it is potentially a rich reservoir of pathogenic microorganisms. Empty fixture trap seals can therefore represent a potential transmission route for any pathogen that is released directly into the drainage system and that can be transported on an aerosol particle. A number of pathogens are amenable to aerosolised transmission, including, but not exclusively- *Pseudomonas aeruginosa*, *Clostridium difficile*, viral gastroenteritis, and *Norovirus* [1], yet there remains no empirical data relating the spread of such pathogens with their transmission via the building drainage system.

The assertion by the World Health Organisation (WHO) in 2003[2] that the building drainage system had been implicated in the spread of the SARS virus in Amoy Gardens has been quoted by many researchers as a touchstone for improving public health engineering design (especially building drainage system design). While this conjecture has been proven from an airflow point of view [1], [3], [4],[5] it has not been proven from a microbial transport point of view. Moreover, the case for applying more stringent controls on hospital systems has been stifled due to lack of such evidence to present to clinical staff. This paper seeks to prove that the WHO conjecture in relation to Amoy gardens is a tangible threat; that such cross-transmission is possible and that it is likely in the event of a defect in the building drainage system.

Such cross-contamination routes are shown to be viable, particularly, but not exclusively, in hospital buildings where the consequences of infection spread amongst patients is of great concern. The proof of such a possible cross contamination route depends on the following conditions being met;

1. the collection drain is a reservoir for pathogenic organisms
2. airflows within the drainage system can flow in all directions, up and down, and circulate between floors.
3. a defect in a building drainage water trap seal will lead to air entering the space from the main sewer via the drainage pipe network.
4. these airflows can carry pathogenic organisms from one part of the building to another and enter habitable space unnoticed.

Of the four conditions given above, numbers 1 and 2 have already been reported on [4],[6] and have been conclusively proven. This paper seeks to show that all four of these conditions are easily met.

2. Methodologies

In order to test the hypothesis that microbial transport, and therefore cross transmission of infection, can occur between two floors of a building, two test methodologies were adopted, namely; the airflow and smoke visualisation test and the model bacterial transfer test.

2.1 Airflow and smoke visualization test.

Tests were also carried out to further measure the naturally occurring airflows within a vertical drainage stack. For practical purposes it was not possible to carry out these tests in the

same hospital, instead a 3 storey domestic property was chosen. The system was a single stack system, 10 metres in height. Figure 1 shows a schematic of the installation. The WC on the top floor was removed to simulate a defect in the water trap seal, thus exposing the room to air ingress from the drainage and sewer system. An anemometer was installed near the exit of the pipe to measure airflow rate into the room. The arrangement is shown in Plate 1 below.

As an additional test, and as a visual aid, smoke pellets were lit and inserted in to the main collection drain (indicated in Figure 1). Video and photographic evidence of the direction and intensity of the smoke through the system was recorded also.

2.2 Model bacteria transfer test

A laboratory investigation was set up to test specifically whether bacteria could travel between one floor of a building to another on an airstream in the drainage system. The system is shown in Figure 2 and represents a two-storey building. The forces acting on the air were simulated by the extract fan in the chamber and airflow rates consistent with both the Amoy Gardens SARS outbreak and the domestic arrangement shown above.

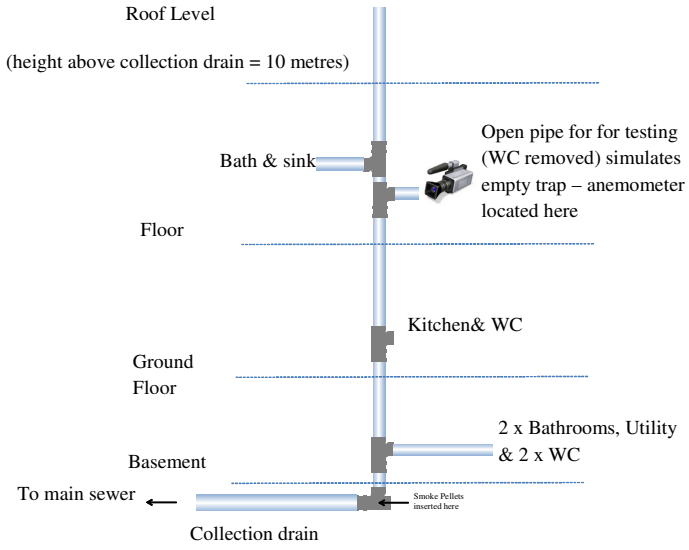


Figure 1. 3 Storey domestic house used for Airflow measurement and Smoke test

Plate 1. Installation of the Anemometer to measure airflow velocity and airflow rate

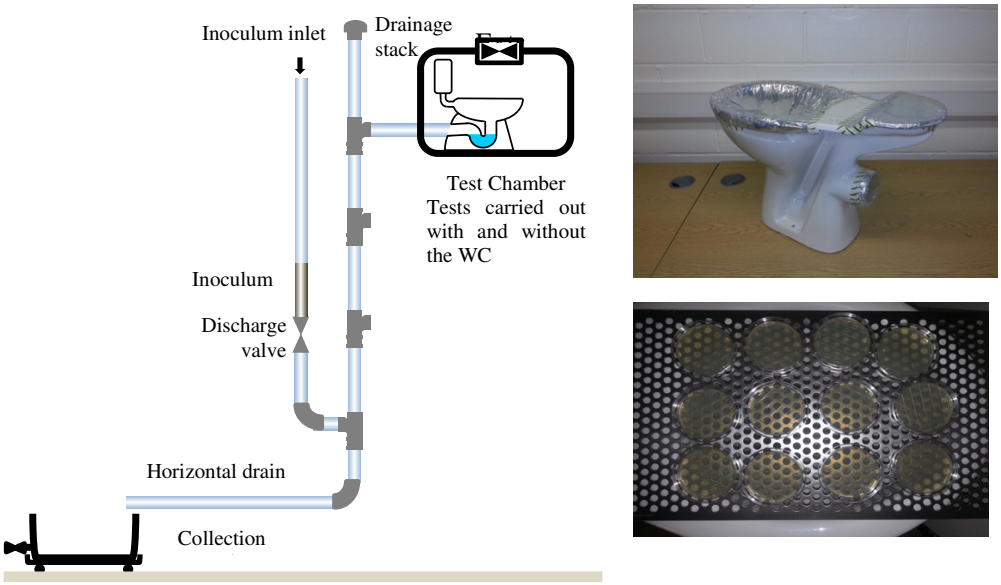


Figure 2. Laboratory test set-up for model bacteria transfer experiment
The setup chamber and, where applicable, toilet were surface sterilized using 96 % ethanol prior to each experiment. Where the toilet was installed, a partial water trap consisting of 200 ml of sterile 0.85 % NaCl solution was added.

Overnight, liquid cultures of the wild-type bacterial strain *Pseudomonas putida* KT2440 [7] were prepared and diluted to between 10^6-10^9 colony forming units (cfu) per ml^{-1} in 0.85 % (w/v) NaCl. Six litres of diluted culture were introduced into the setup (as indicated in Figure 3) as a single flush for each experiment. The transmission and deposition of *P. putida* through the setup was assessed by a number of approaches including (but not limited to) the following:

i) Tryptone soya agar (TSA) and selective Pseudomonas isolation agar (PIA) 55 mm diameter contact plates were used to sample from the setup chamber surfaces before and after each experiment. Colonies were counted after 24-48 h. Where non-selective TSA media was used, colonies which developed were picked and transferred to standard (90 mm diameter) PIA plates for confirmation.

ii) A Surface Air System (SAS SUPER IAQ; International PBI S.p.A) indoor air quality monitor was setup at the end of the ducting from the extractor fan containing a single 90 mm diameter PIA agar plate. The monitor was set to sample 250 litres of air before each experiment. The PIA was replaced and air sampling repeated following the introduction of the *P. putida* culture into the setup. Colonies which developed on the PIA were counted after 24 h.

iii) At the end of the experiment, the toilet water trap solution was collected and filtered through a 0.45 micron filter. The filter was incubated on a PIA standard (90 mm diameter) agar plate. Colonies were counted after 24-72 h.

3. Results and discussion

3.1 Airflow and smoke visualization test

Figure 3 shows the airflow rate measured in the drainage pipe by the anemometer and clearly shows large fluctuating airflows from the drainage system, thus confirming that under certain conditions air can flow into a room from the sewer which has also been proven to be a reservoir for pathogens such as norovirus.

While the anemometer did not record airflow direction, it was clear from observation, and a discernable odour, that there was a significant airflow into the room from the drain. The peak air velocity was recorded as 2.4 m/s which corresponds to an airflow rate of 18.6 l/s. Further tests under different conditions had also recorded air velocities of up to 3.4 m/s (26.7l/s). This velocity is significant as it is similar to the air velocity recorded at Amoy Gardens in Hong Kong in 2003[3] from an empty floor trap suspected of aiding the spread of the virus in that building.

The final smoke tests reveal the extent of the pulsing, plumes of air which will flow into a room if the water trap seal is missing. Plates 2 to 5 show a sequence captured over a number of seconds in which the smoke enters under a rapid flow, then pulses, much in keeping with the airflow measurements shown in Figure 4.

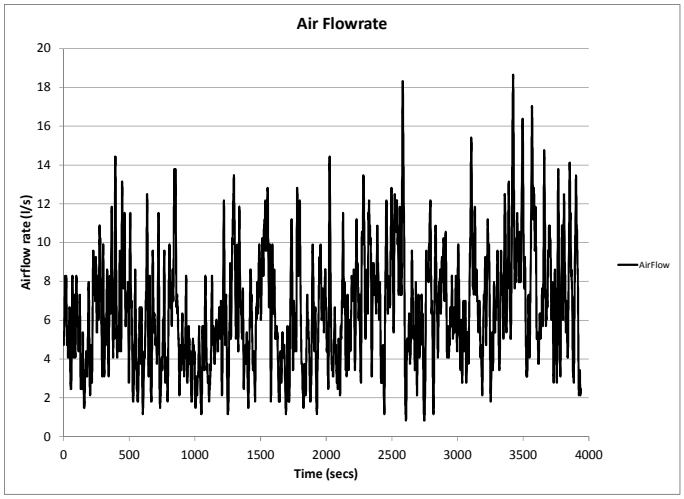


Figure 3. Airflow recorded in the drainage pipe.

Plate 2. Start

Plate 3. 1 sec

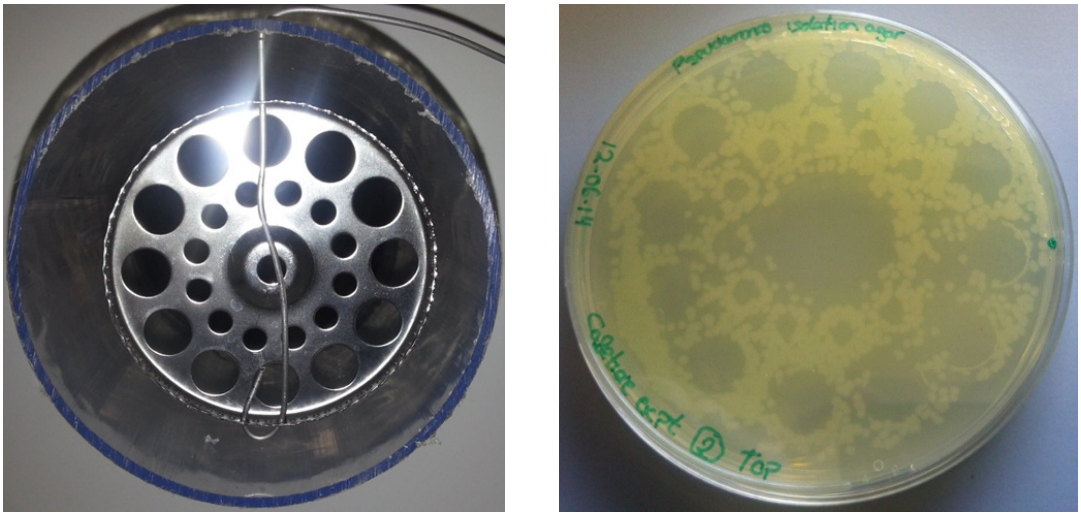
Plate 4. 2 secs

Plate 5. 10 secs (end)

It can clearly be seen from the above plates that the airflow carries the smoke into the room. Plates 2 to 5 show one event of ingress, several others were recorded also. It was only when the air pressure and airflow conditions within the system, which are constantly fluctuating, dictated the direction and rate of airflow, that the smoke entered the room.

3.2 Results and discussion: Bacterial transfer testing

No colonies developed on selective PIA agar from the indoor air quality monitor before the introduction of *P. putida*. In contrast, post experimental sampling resulted in growth of a single morphotype on PIA which matched the appearance of the introduced *P. putida* strain. Use of TSA and PIA contact plates in the chamber and on inner toilet surfaces also provided supporting evidence of the transmission (and deposition) of the introduced bacterium throughout the drainage system with Pseudomonas specific colonies developing only in post experimental samples. Finally, in experiments including a partial toilet trap, colonies of the inoculum were successfully recovered from the pre-sterilized toilet trap solution. Tables 1 and 2 show results for the tests carried out. Please note that while CFUs were counted and enumerated here, these are only used to indicate 'level of contamination', further work is required to fully quantify the most probable number (MPN) of microbes in the airstream.



(a) (b)

Figure 4 (a) Passive Pathogen Capture perforated plate (P^4 sampler)
(b) selective agar plate showing pseudomonas colonies formed due to contamination of airstream

Table 1 Test Results

Test number	Date	Volume inoculum (L)	P^4 sampler	Toilet	Inoculum cfu/mL	Air sample
1	05/03/2014	6+8+6	yes	No	1.93E+08	No
2	20/03/2014	8+6+6	yes	No	9.13E+09	Yes
3	27/03/2014	6	no	No	1.20E+07	Yes
4	03/04/2014	6	no	Yes	3.57E+08	Yes
5	10/04/2014	6	no	Yes	8.39E+08	Yes
6	30/05/2014	6	yes	No	7.33E+06	Yes
7	05/06/2014	6	yes	No	4.48E+06	No
8	05/06/2014	6	no	Yes	7.90E+06	Yes
9	12/06/2014	6	Yes	No		Yes
10	12/06/2014	6	yes	No		Yes

Table 2 Test results on toilet only

Toilet test	Contact Plates Room					Contact Plates Toilet bowl[#]				Contact plates perforated sheet[#]												Air sampler plate (CFU)
	B	L	T	R	F	1	2	3	4	1	2	3	4	5	6	7	8	9	10	11	12	
4	0	0	2	1	2	6	6	18	4	-	-	-	-	-	-	-	-	-	-	-	-	510
5	-	-	-	-	-	-	-	-	-	0	0	0	0	0	0	0	1	0	0	0	1	475
8	-	-	-	-	-	-	-	-	-	0	4	4	1	6	6	2	58	0	1	35	2	318

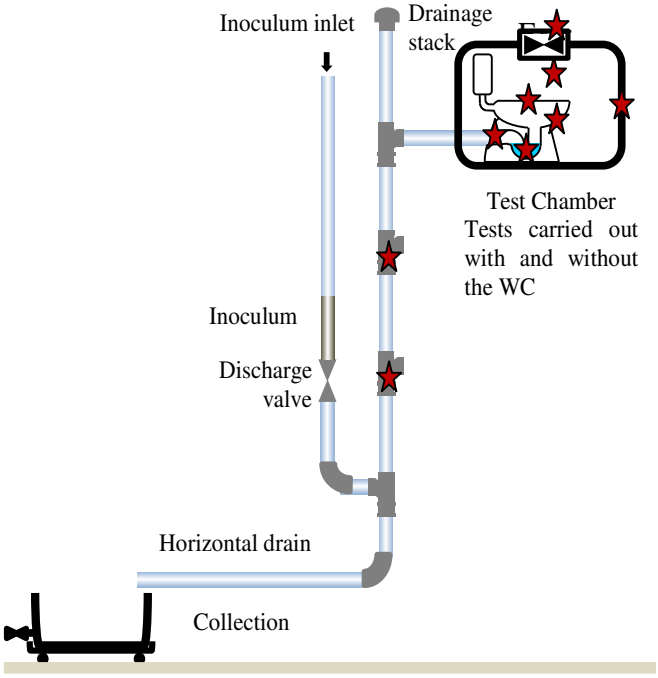


Figure 5 Test locations : Positive test results for *Pseudomonas putida*

It can clearly be seen from Figure 5 that all parts of the system (including the extract air) are contaminated by the aerosolised pseudomonas, and that any updraft from the sewer will cause this contamination to occur.

4. Conclusions

The research described in this paper sought to identify a hitherto unidentified source of bioaerosol cross – transmission in buildings. The work began with a particular focus on hospital buildings, however the principle applies to any building. All four conditions identified for this cross- transmission to occur have now been proven. The sewer network has been shown to be a pathogen reservoir; the building drainage system air has been shown to flow in all directions within the system and, under the right conditions, it has been shown to enter a room if a water trap seal (U-bend) has been compromised. The velocities recorded in a 3 storey house in Edinburgh (under normal operating conditions) are similar to those measured from an empty floor trap in Amoy gardens during the SARS outbreak in 2003. Significantly, this work proves that a cross-transmission route does exist between different parts of a building under normal operating conditions. This research continues to investigate and model pathogen transmission through a system. The positive results from the bacteria transfer tests carried out in the laboratory using *Pseudomonas putida* confirm that the transmission route exists and that further work is required to more fully establish the extent of the risk involved.

Finally, the WHO SARS cross transmission conjecture has been proven.

5. Acknowledgements

This work has been possible as a result of funding from Heriot-Watt University and DYTEQTA Ltd.

6. References

[1] Gormley, M., Swaffield, J.A., Sleigh, P.A. and Noakes, C.J. (2011). An assessment of, and response to, potential cross-contamination routes to defective appliance water trap seals in building drainage systems. *Building Services Engineering Research and Technology*, 1(1), 1-15.

[2] World Health Organisation (2003) *Final Report: Amoy Gardens*. WHO Environmental Investigation.

[3] Hung, H.C.K., Chan, D.W.T., Law, L.K.C., Chan, E.H.W. and Wong E.S.W. (2006). "Industrial experience and research into the causes of SARS virus transmission in a high-rise residential housing estate in Hong Kong," *Building Services Engineering Research and Technology*, **27**(2): 91-102

[4] Gormley, M., Templeton, K., Kelly, D.A. & Hardie, A. (2013) 'Environmental conditions and the prevalence of norovirus in hospital building drainage system wastewater and airflows' *Building Services Engineering Research and Technology*, 35(3), 244-253.

[5] Swaffield, J. (2010) *Transient airflow in building drainage systems*, Oxon: Spon Press.

[6] Gormley, M & Kelly, D.A. (2011) Pathogen loading and environmental conditions found in hospital building drainage system wastewater and airflows. CIBW62 International symposium for Water Supply and Drainage for Buildings, Aveiro, Portugal September 2011.

[7] Aspray, T.J., Hansen, S.K., Burns, R.G. (2005) A soil-based microbial biofilm exposed to 2,4-D: bacterial community development and establishment of conjugative plasmid pJP4. *FEMS Microbiology Ecology*, 54 (2): 317-327.

7. Authors

Dr. Michael Gormley is Associate Professor in Architectural Engineering and has been a member of the Drainage Research Group at Heriot - Watt University since 2000. His research interests are pressure transient modelling and suppression in drainage systems, solid transport in above ground drainage systems and Pathogen identification and control in building drainage and ventilation systems.

Dr. Thomas J Aspray is Assistant Professor in Microbiology in the School of Life Sciences at Heriot Watt University. Dr Aspray joined the School of Life Sciences in 2012 following seven years working in the environmental industry. His research areas of interests include waste/wastewater treatment and resource recovery, soil/water microbial ecology and soil carbon/nitrogen cycling.

Dr David Kelly is Assistant Lecturer in Building Design at Heriot-Watt University, he has been a member of the Drainage research Group since 2006. His research interests include the monitoring and prevention of cross-contamination from building drainage systems and the impact assessment of climate change on rainwater systems.