Propagation of bioaerosols from the building drainage system; cross-transmission, detection and prevention.

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Abstract

The building drainage system is one of only a small number of engineered fluid carrying systems which interconnects all parts of a building. As such, it permits air propagation throughout the entire building. Protection between the pathogen–laden sewer system and habitable space relies on the water seal within fixture traps (or U-bends). This water seal is vulnerable to a number of potential threats, such as naturally occurring system pressure fluctuations and evaporation, which can compromise the integrity of the seal and present a potential cross-transmission route for aerosolised pathogens.

Investigations into the potential for pathogen cross-transmission via Bioaerosols in the building drainage network, is discussed, and further details of a series of experiments previously reported are presented. Transmission routes are investigated using a transient airflow analysis methodology identifying directional airflow movement patterns within the system. Recent research on the isolation of Bioaerosols in hospital building drainage systems using *Polymerase Chain Reaction* techniques is reported also, confirming that the network is a pathogen reservoir and conducive to the production of aerosolised pathogen-laden air streams. Physical observations of empty fixture trap seals in a number of building drainage networks confirms there is potential for cross-transmission of aerosolised pathogens via the building drainage network and a potential threat to the health of inhabitants.

Keywords: cross-transmission, SARS, norovirus, building drainage network, defect detection

1 Introduction

The building drainage system is one of only a few engineered fluid carrying systems which interconnect all parts of a building. As such, it permits the propagation of potentially harmful air throughout the entire building, the only protection form which is provided by the physical barrier created by the water seal within fixture traps (U-bends). However, this water seal is vulnerable to a number of threats, such as system pressure fluctuations and evaporation due to lack of use (Swaffield, 2010), which can compromise the integrity of the seal and ultimately lead to its depletion and the formation of a potential cross-transmission route for aerosolised pathogens.

The interconnectedness of all systems in a building is highlighted in Figure 1. This refers to a hospital building, but it is relevant to any building. It can clearly be seen that the pathways available to air are in any direction. Infectious agents in the air, carried by droplet nuclei, skin flakes and fine particles, move sufficiently slowly relative to the air that they are essentially carried by the airflow(Tang *et al*, 2011). It is therefore imperative to understand airflows, both in the drainage system and in rooms in order track transmission routes.

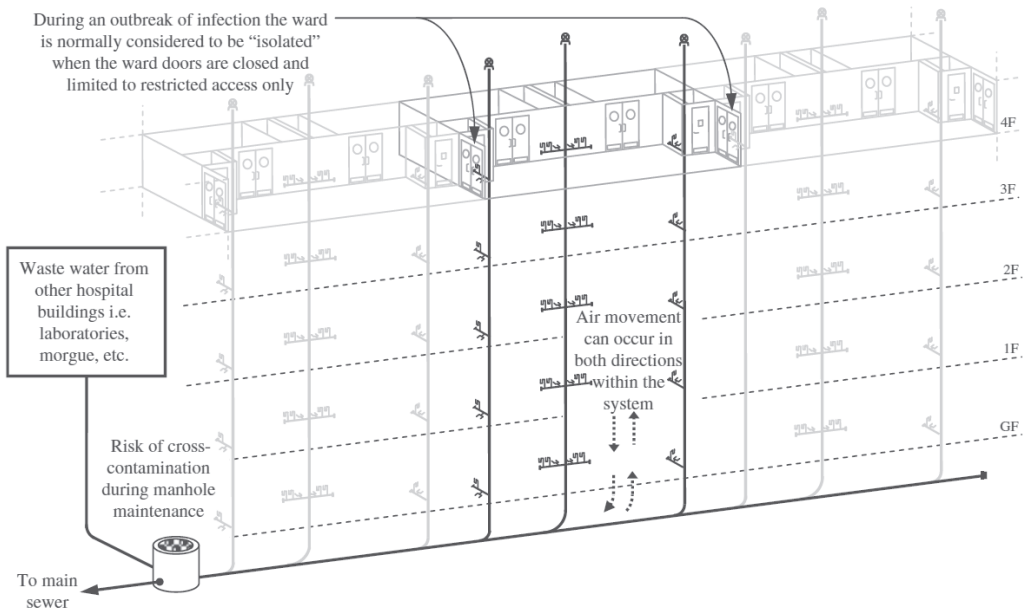


Figure 1. Interconnection of the entire building through the building drainage system

This mode of transmission was implicated in the rapid spread of Severe Acute Respiratory Syndrome (SARS) at a residential estate in Hong Kong during the outbreak in 2003. This unusual cluster of cases, where 321 residents contracted the virus resulting in 42 fatalities, triggered a forensic investigation led by the World Health Organisation (WHO, 2003) that laid blame for the rapid spread of the virus on defects in the building drainage system. The

mode of viral transmission was identified as airborne aerosolised particles from virus-laden excreta emanating from the drainage system through empty fixture trap seals.

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 clostridium difficile, viral gastroenteritis, and norovirus (Gormley *et al.*, 2011), yet there remains no empirical data relating the spread of such pathogens with their transmission via the building drainage system.

Research efforts to find a link between pathogens in a building drainage system and its spread through the air in the form of Bioaerosols has, until now remained elusive. There have been some notable studies, mainly focussing on wc flushing and spray of potential pathogens as a result, however, little hard evidence has been forthcoming. That is until now – historical research into the topic has revealed a seminal piece of work by a Major Horrocks, published in the proceedings of the Royal Society in London in 1907[1]. In a series of experiments, Horrocks dosed drainage systems with a bacterium known as ***Bacillus prodigiosus,*** however, this is more commonly known now as ***Serratia marcescens*****,** a bacteria widely involved in nosocomial infections. (Horrocks, 1907) The results showed positive evidence of bacteria from the drainage system transported on the air – it also showed that bacteria from one building can travel to another building via the drainage system – as shown in Figures 2 and 3 below.

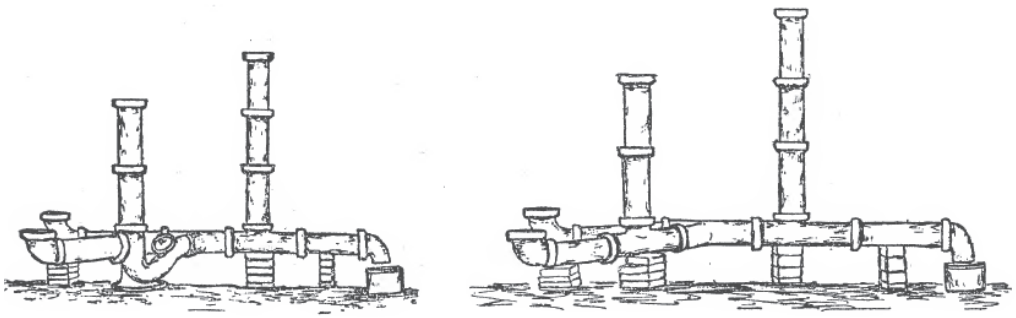


Figure 2. Horrocks' experiment to establish if bacteria dosed sewerage could form Bioaerosols and be transmitted on the air.

[1] The Royal Society (London) is possibly the the oldest learned society for the promotion of science, having been established in 1660 . It's former fellows include; Sir Isaac Newton, Charles Babbage, James Watt and Michael faraday – to name but a few.

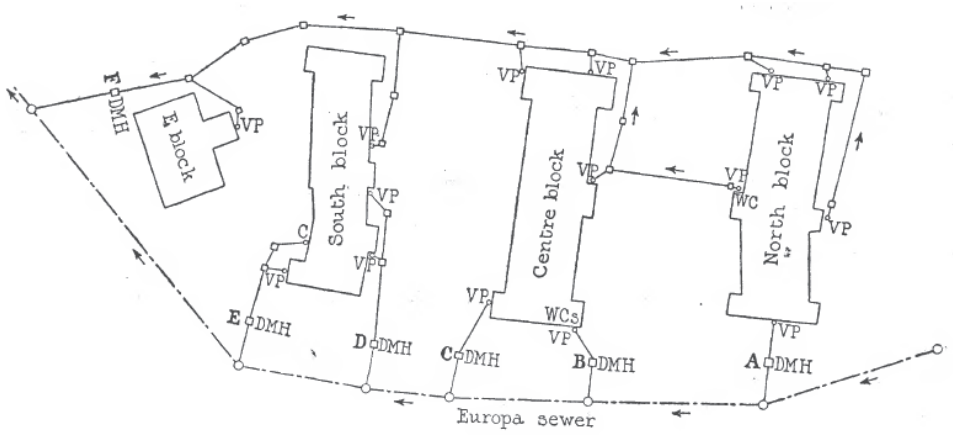


Figure 3. Layout of hospital block used by Horrocks to establish that airborne transport of pathogens can occur from one building to another via the sewer drain.

This work by Horrocks has largely gone un-noticed by both medical and the engineering community to date. It is considered likely that this has come to light as a result of a process of digitising old research papers. Their value is immense and it is hoped that such insightful research can be made more available in the future. The work also proves that Bioaerosols containing pathogens harmful to humans can be transported on the air from a drainage system.

This paper takes this hypothesis and places it in the wider context of Bioaerosols transmission in buildings through the drainage system. More detail is revealed on previously reported research on the potential for pathogen cross-transmission via the building drainage network (by using *Polymerase Chain Reaction* techniques to isolate norovirus from a drainage system, and analysing the environmental conditions and airflow patterns within the system).

2 Methodology

In order to test the hypothesis that pathogens exist within the building drainage system and are amenable to airborne transmission via aerosolised water particles, a study was conducted to test for the presence of pathogens in both the wastewater and airflows within the drainage system of a hospital building over a six week period. In this initial study, it was decided to test for norovirus (strains GI and GII) as at the time of testing, an outbreak of norovirus was present within the hospital. Although norovirus infections are generally mild and short lived, it often causes significant management burdens for hospitals due to resultant ward closures and staffing difficulties.

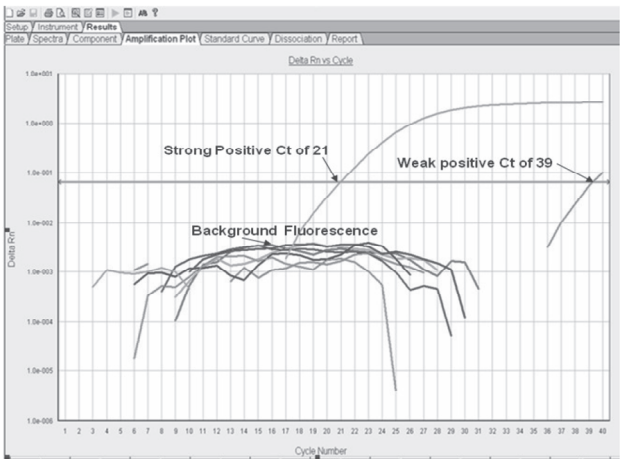
Wastewater samples were taken from the main collection drain while air samples were taken from three vertical drainage stacks using a clinical swab inserted into the centre of each stack. The wastewater and swabs from the air core were then tested using a modified in-house reverse transcription-polymerase chain reaction (RT-PCR) method (Kageyama *et al*., 2003) . . Samples consisted of 1 L which was allowed to settle and 1 ml of supernatant was used in the extraction. Samples were extracted using the NucliSens® easyMAG™ system (bioMérieux, Basingstoke, United Kingdom) according to the manufacturer's instructions. Purified nucleic acid was eluted in 110 µl of the re-suspension buffer. The real-time PCR was performed in a volume of 20 µl, consisting of 6 µl extracted nucleic acid, 14 µl of mastermix. Mastermix

contained: Express One-Step SuperScript qRT-PCR Kit including SuperScript Mix (Invitrogen, X, UK) 0.4 μM each primer

(COG1F CGYTGGATGCGNTTYCATGA
COG1R CTTAGACGCCATCATCATTYAC
COG2F CARGARBCNATGTTYAGRTGGATGAG
COG2R TCGACGCCATCTTCATTCACA
0.8 μM probe (Ring 1a HEX-AGATYGCGATCYCCTGTCCA-BHQ-1
Ring 1b HEX-AGATCGCGGTCTCCTGTCCA-BHQ-1
Ring 2 FAM-TGGGAGGGCGATCGCAATCT-BHQ-1)
The above sequence is required to replicate the tests

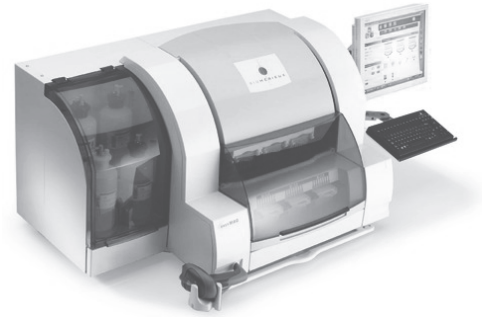
Amplification, detection and analysis were performed in an ABI 7500 real-time PCR system (Applied Biosystems, Warrington, United Kingdom) under the following conditions: 50°C for 15 min, 95°C for 20s, 45 cycles of 95°C for 3s, 60° for 30s (with fluorescence detection).
Figure 4 shows a sample graph of the PCR process with explanation of the CT value significance and Figure 5 shows the equipment used for nucleic extraction.

The environmental conditions within one of the drainage stacks were also monitored during the test period. Temperature and humidity was recorded using a standalone USB data logger, while airflow was recorded using three pitot-static tubes allowing both airflow rate and direction to be measured.



Ct ≤ 29	**Strong positive reaction** (abundant target nucleic acid)
Ct 30-37	**Positive reaction** (moderate amount of target nucleic acid)
Ct 38-40	**Weak reaction** (minimal amounts of target nucleic acid)

Figure 4. PCR interpretation of results



Samples extracted using NucliSens® easyMAG™ system

Figure 5. Extraction Equipment

3 Results and discussion

Norovirus GI was undetected by the tests carried out on both the wastewater and air samples. Norovirus GII was also undetected by the tests carried out on the air samples, however, the wastewater samples were in fact positive. This coincides with the detection of norovirus GII in samples from patients and indicates that the drainage system does contain infected material – see Table 1. Below.

Test date	Norovirus GI				Norovirus GII			
	Sewer	Stack 1	Stack 2	Stack 3	Sewer	Stack 1	Stack 2	Stack 3
01/03/2011	U	U	U	U	U	U	U	U
10/03/2011	U	U	U	U	25	U	U	U
16/03/2011	U	U	U	U	25	U	U	U
23/03/2011	U	U	U	U	35	U	U	U
30/03/2011	U	U	U	U	40	U	U	U
05/04/2011*	U	U	U	U	37	U	U	U
26/05/2011	N/A	U	U	U	N/A	U	U	U

Table 1 Results from PCR tests

It can clearly be seen that weeks beginning 10/03/2011 and 16/03/2011 are strong positives with positives being recorded in all but one of the other weeks. This is consistent with anecdotal evidence of the incidence of outbreak in the hospital.

Results from the environmental tests are shown in Figure 6 and Figure 7 below. They show that the average temperature within the drainage stack was 24.3^{o}C with an average humidity of 96.6%. Additionally, whilst airflow within the stack was generally in the downward direction, due to the action of appliance discharge, significant upward airflow was also recorded as shown in Figure 8. This is due to the natural buoyancy forces generated by the high temperatures within the stack which cause the air to travel towards the open termination at the top of the stack.

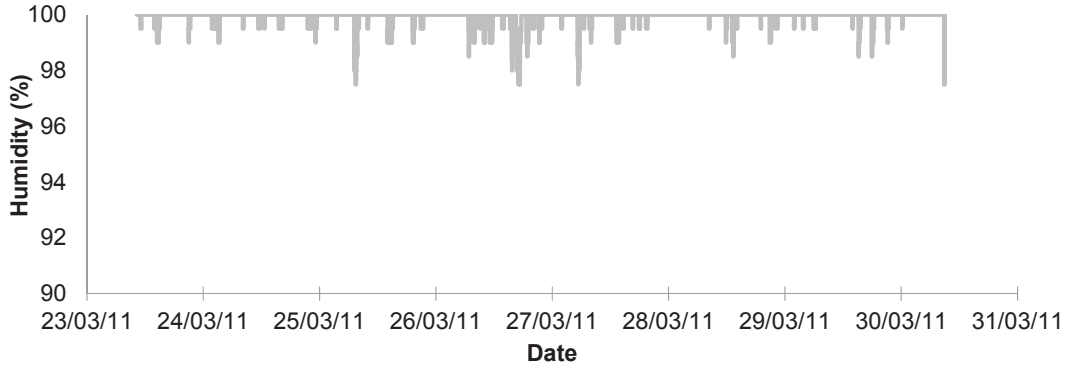


Figure 6 Relative Humidity in the vertical drainage stack

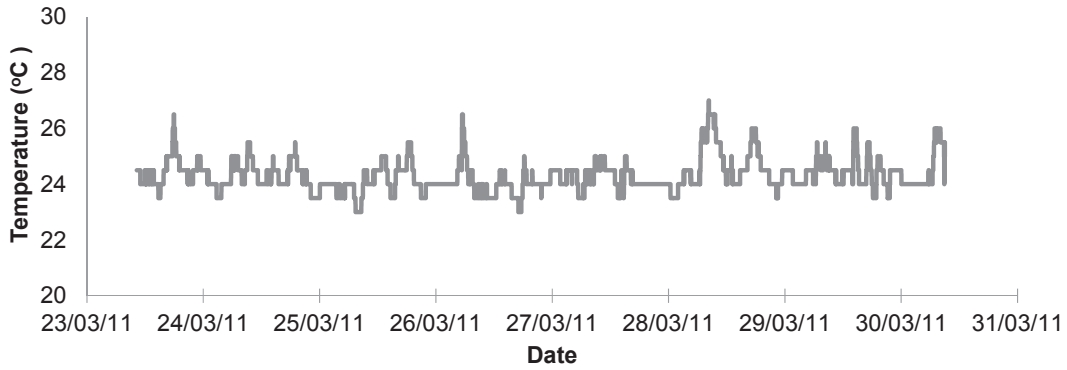


Figure 7 Temperature in the vertical drainage stack

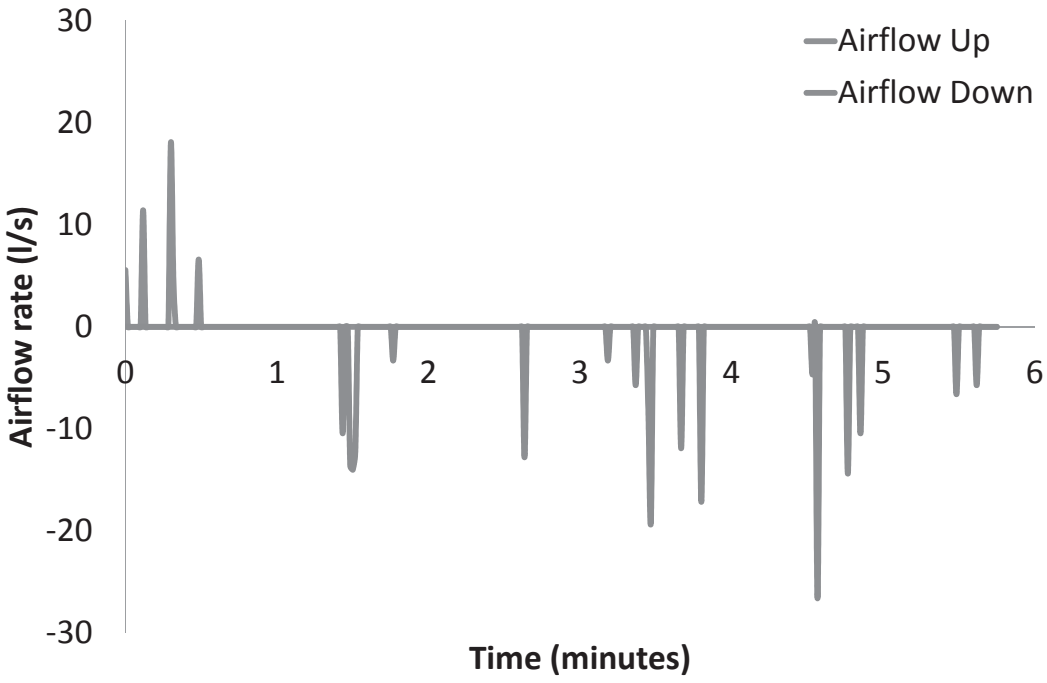


Figure 8. Confirmation of Airflow directional tests

4 Conclusions

The hypothesised transmission route of pathogens via the building drainage system has been partly proven. The detection of norovirus GII from wastewater samples taken from a collection drain confirm that pathogens released directly into the building drainage system will contaminate the wastewater within it. The difficulty experienced in isolating any pathogens from the airflow within the drainage system was due mainly to the absence of a verified collection methodology. However, it can be postulated that the warm and humid air shown to exist within the system, together with both downward and upward airflow movement, may facilitate the circulation of virus laden droplets within the drainage system and their emergence elsewhere via an empty fixture trap seal. Further discussions with academics in the field of detecting viruses in the air have revealed that this is a common problem in this area of study.

The discovery of the work by Horrocks in 1907 reminds us that there is a lot of forgotten knowledge out there. Validation of Horrocks' work forms a significant part of the next phase in this research.

The issue of bioaerosol transmission in building drainage systems present a new avenue of research possibilities. The abilty to model airflows has never been more needed. Only slight

modifications are required to the method of characteristics based model AIRNET in order to ensure that all possible Bioaerosols can be tracked in a system.

5 References

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