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Environmental conditions and the prevalence of norovirus in hospital building drainage system wastewater and airflows

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Abstract

A potential cross-transmission route, first identified in the spread of the SARs virus in South East Asia, in which infection was spread by virus-laden aerosolised droplets entering habitable space via defective water traps is investigated. The main aim of this work was to detect *norovirus* in wastewater from the collection drain in a hospital Building Drainage System and attempt to trace it in the BDS vent airflow. The methodology employed *polymerase chain reaction* tests on waste water samples and indicated strong positives for the *norovirus* GII strain from the collection drain, corresponding to an outbreak in the building, confirming that the BDS is contaminated in such circumstances and poses a threat. Pathogens were not detected in the BDS vertical stack airflows; however, the methodology employed to collect samples from the airflow was considered ineffective requiring further research. An average temperature of 24.3°C was recorded, together with an average humidity of 96.6%. This research also confirmed that inside the building drainage stack, air flow movement occurs in both the 'up' and 'down' direction. Thus, aerosolised pathogens could travel from the contaminated horizontal collection drains upwards and enter wards via defective traps or little used showers, sinks, baths and sluices.

Practical application: The detection of *norovirus* from raw, unprocessed samples taken from the collection drain of a hospital complex highlights the need for caution in dealing with these large contaminated systems. The obvious area affected by these findings is in the awareness by building managers and facilities managers that this contamination exists and that all appropriate measures are taken to minimise infection spread due to normal o&m operations. While it was not possible to detect the virus in the airflow itself, it is considered significant that the identification of the direction and magnitude of these airflows confirms that building drainage stacks could act as conduits for the transmission of aerosolised pathogen-laden

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water droplets. This research suggests that there is a need for a secure and verifiable seal between the building drainage/sewer network and habitable space within a building to minimize the likelihood of any potential cross-contamination and consequent risk to human health.

Keywords
Norovirus, hospital building drainage, environmental conditions, infection spread

Introduction

General

The building drainage system (BDS) is one of only a small number of engineered fluid carrying systems, which interconnect all parts of a building; the main other systems being the water supply system and the heating, ventilation and air conditioning system. These systems are subject to heavy regulation due mainly to the risks associated with the spread of *legionella pneumophila* and *psuedonomas aurogonis*—whose origins are often linked with these sources. Current regulations dictate little more than a simple pressure test to check the seal between drainage pipes at the time of commissioning, leaving the potential for functionally inadequate and poorly designed systems.

Designing to codes and standards for all these systems is straightforward, and the difficulty arises when attempting to predict performance. This is simple enough for air and water delivery systems; however, fluid flows in BDSs are driven by random discharges from appliances leading to transient effects in the system, which may compromise the main seal between the sewer and the habitable space—the water trap seal, more commonly known as the 'U-bend'.

The mechanisms for BDS fluid flow analysis are well understood, and predictive modelling using transient analysis is possible; however, these mechanisms are not widely known outside the field of BDS research.[1] The recognition of water as a key driver in the system is obvious; however, the role of air flow within the system is less so. In a system subject to appliance discharge into a vertical drainage stack, the water swirls around the pipe, clings to the wall and falls as a thin annular flow. Even at very high-discharge rates, the annulus is only a few millimetres thick. This annular flow has the effect of entraining an airflow from the vent inlet (either at the top of the stack or from an air admittance valve). As the air is drawn into the stack, it is subject to friction and traction forces, which lead to a complex air pressure regime in the system. Resultant air pressure transients can 'suck' out water trap seals (negative air pressure transients) or blow through the water trap (positive air pressure transients), thus compromising the seal between the habitable space and the sewer system. Once a seal has been compromised, it then becomes a vent for the entire sewer system leading to the possibility of harmful pathogens entering the habitable space.

The quantification of the risk posed by the BDS as a potential reservoir for harmful pathogens and a key element of a potential transmission route from person to person, via the interconnected drainage pipe network, represents the latest phase in a wider research programme initiated in the aftermath of the SARS outbreak in South East Asia in 2002/2003. The forensic analysis of the outbreak[2–4] and the subsequent invention of an innovative technique for identifying defective water trap seals[5–7] have led to the further requirement of a well-developed rationale for closer monitoring and investigation of the ongoing operation of a BDS.[8,9]

While norovirus infections are generally mild and self-limiting, more severe outcomes of infection frequently occur in elderly and immunocompromised people, and no treatment is

available. The observed pattern of continually emerging novel variants of the principal subtype (GII.4) causes elevated numbers of infections and has the potential to cause far greater number of infections in the future. In one health trust alone (Lothian Health Trust), there were 3678 bed closure days over a 2-year period at an estimated cost of £1.2 million.[10] Hand washing has been shown to reduce infection rates; however, it should be noted that this only removes the virus from a person's hands and moves it into a sink or a drain. By creating a new avenue of investigation and monitoring, this research seeks to place the UK at the foreground of research in tackling this difficult problem.

Norovirus was chosen for this study due to the prevalence of outbreaks during the winter months, the availability of a reliable assay for the detection of the virus and because it is not an airborne virus. The hypothesis is that aerosolised virus-laden droplets can act as a transport medium through the BDS and that, with an appropriate assay, this transmission route can be confirmed. Other viruses and pathogens could also be detected in this way, given appropriate virology investigative tools such as those employed in this research.

This work describes the methods employed to attempt to isolate a well-known cause of disruption in hospitals, *norovirus*, and presents the results of a study to identify the presence of this harmful pathogen in both the wastewater found in collection drains and in the airflows found in the vertical drainage stacks of a hospital building. Since this study was the first of its kind to attempt the identification of pathogens in a drainage system, many lessons were learned on dealing with such a complex issue. The methodologies assumed for isolating pathogens from the airflow, and from samples from the collection drain, proved troublesome and required refinement throughout the project. As a pilot study, the research was considered a success, quantifying the presence of particular pathogens (*norovirus*) from the collection drain samples while also identifying a knowledge gap in isolating microorganisms in the type of airflows found in BDS.

Transmission routes

The possible transmission route for infection spread being tested in this research is shown in Figure 1 below. Note the inclusion of the possible contamination of operatives.

This is a significant threat. Infection control teams often 'isolate' affected wards in an attempt to limit an outbreak. No consideration is given to the fact that operatives working on the BDS in the rest of the building may become contaminated, thus spreading infection involuntarily. This method understates the extent of the contamination. Figure 2 illustrates the network of interconnections through the BDS. It can be seen that isolating a contaminated ward only contains the area identified as contaminated due to patients falling ill, it does not isolate a potential pathogen reservoir—the BDS, which extends throughout the entire building.

The classification of possible transmission routes through environmental factors has proven elusive for many investigators[11] as there are always unknown variables to contend with. The transmission route hypothesised in this work is a very real one; however, there is little data to further prove the hypothesis. The results from this research go a considerable way in addressing this issue.

Methods

General

Data were collected from a large hospital building. The BDS in this hospital is both vast and complex, with ~650 vertical stacks connecting to the extensive underground horizontal collection network. To test the hypothesis that pathogenic microorganisms exist within the BDS and are amenable to airborne transmission within aerosolised water particles, it was necessary to test both the air and wastewater within the drainage system for traces of pathogens. As this is the first time that such tests have been performed, an

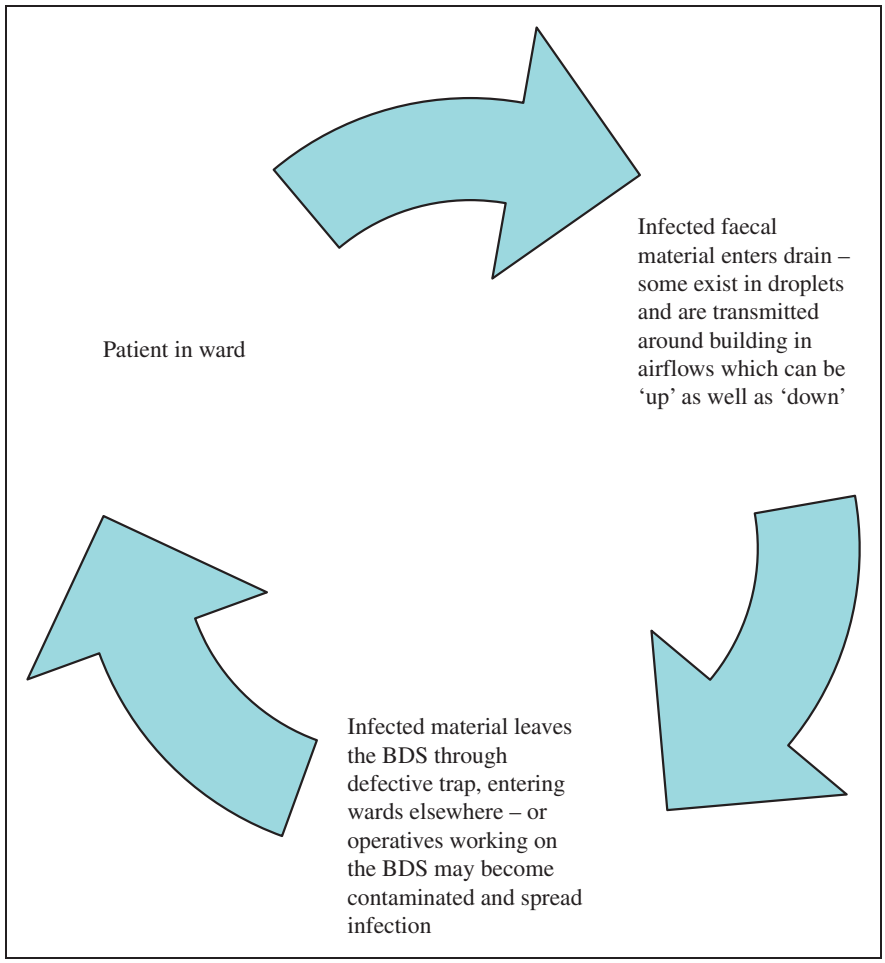

Figure 1. Transmission route hypothesis.

appropriate sampling methodology needed to be established.

Methodology

Air samples were taken by inserting a clinical collection swab (type UTM-RT) into the centre of the vertical stack at the lowest access point within the dry stack (first access point above highest discharge branch). The existing access cover was replaced with one which had been customised to include a fully sealed gland support, which allowed the collection swab to be easily and safely inserted, removed and replaced without having to remove the access panel. Due to the preliminary nature of these experimental investigations, in terms of the sampling methodology applied, it was decided to trial the proposed sampling approach in a small section of the building. Three stacks were selected that were known to serve significant ward areas within the hospital and which offered easy access.

In addition to testing for pathogens, the environmental conditions within one of the stacks were also measured. Temperature,

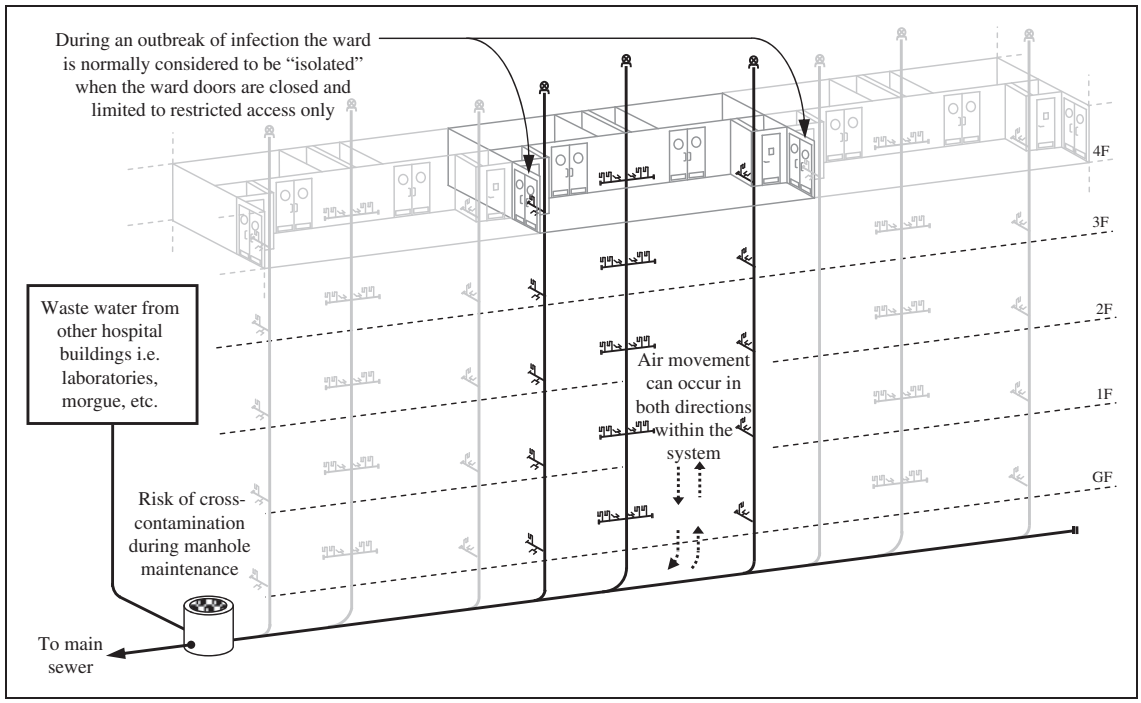

Figure 2. Interconnection of entire building through the building drainage system.

relative humidity and airflow rate measurements were taken to determine if the conditions within the stack were conducive to the survival and spread of pathogens. The experimental installation is shown in Figure 3. Temperature and relative humidity were measured using a standalone USB data logger capable of storing up to 16,382 readings each of temperature (over the range −35–+80°C) and relative humidity (over the range 0–100%). Airflow was measured using two pitot-tubes both aligned with the centre of the stack and facing opposite directions providing flow directionality. The output ports of both pitot-tubes were each connected to a differential pressure transducer, giving both the upward airflow total pressure, $P_{T(up)}$, and the downward airflow total pressure, $P_{T(down)}$. A third differential pressure transducer was used to measure static pressure, P_S, which was used together with $P_{T(up)}$ and $P_{T(down)}$ to determine both the upward and downward mean airflow velocity within the stack from the following expressions:

$$V_{m(up)} = \sqrt{\frac{2\left(P_{T(up)} - P_S\right)}{p}} \tag{1}$$

and

$$V_{m(down)} = \sqrt{\frac{2\left(P_{T(down)} - P_S\right)}{p}} \tag{2}$$

where $V_{m(up)}$ is the upward mean airflow velocity, $V_{m(down)}$ is the downward mean airflow velocity and ρ is air density.

Wastewater samples were taken from the main underground horizontal drain, which collected discharging wastewater from the majority of vertical stacks at the front of the hospital,

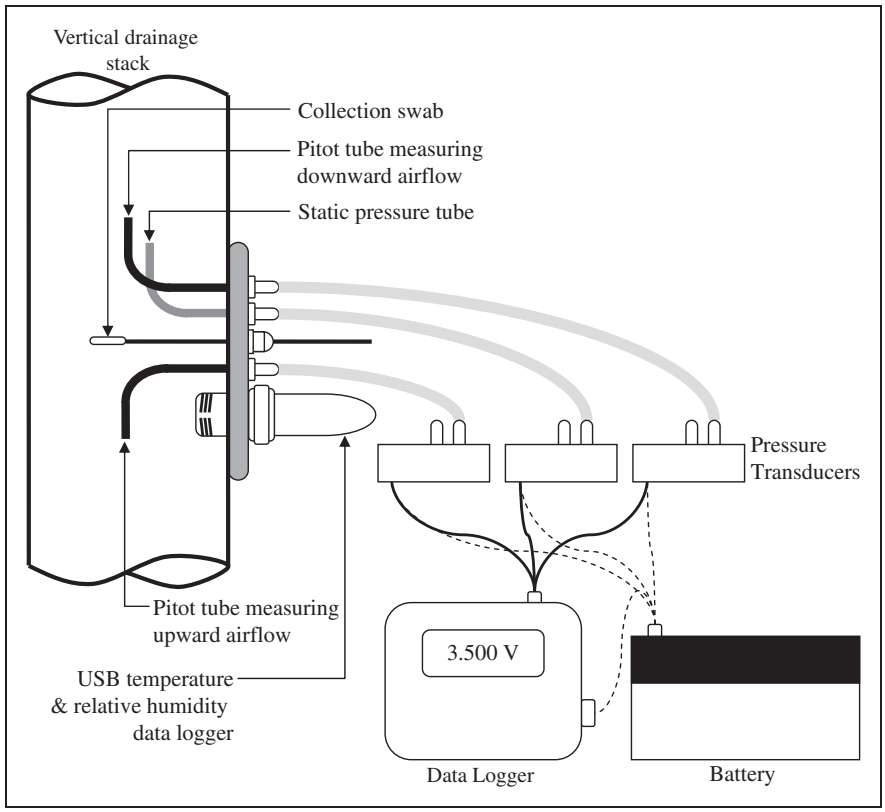

Figure 3. Schematic of test apparatus used to take air samples and measure airflow within the vertical drainage stack.

including the three selected for air sampling. Both wastewater and stool samples were retrieved from the drain (to a total volume of 1 L per test) using a long handled sampling device as, at the time of collection, it was unknown, which source would provide the best medium for testing.

Data collection

The collection swabs used to take samples of the air within the vertical stacks were replaced at weekly intervals. Temperature and relative humidity were recorded at 1-min intervals, and the data were stored directly to the USB data logger, and this was downloaded every week. The transducers used to measure airflow were connected to a data logger with an analogue to digital 24-bit resolution and an accuracy of 0.1%. A sample rate of 1 s was selected as a compromise between the need for high-speed resolution, file size, and available data storage over long test runs of 1 week. The USB data logger was powered by a long-life lithium battery. The pressure transducers and data logger were powered using a 12 V, 24Ah sealed regulated lead acid battery. In this installation, the battery provided up to 11 days of power and so was replaced on a weekly basis as to avoid loss of data, see Figure 3. Wastewater samples were taken at weekly intervals.

PCR method

Fecal specimens were preferred, but vomit samples were also accepted for virology testing. The

test methodology employed was first developed by Kageyama et al.[12] and utilises a modified in-house reverse transcription-polymerase chain reaction (RT-PCR) test for the detection of norovirus. Samples consisted of 1 L of waste water-containing fecal and vomit material, 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, UK) 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 and 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 CARGARBCNATGTTYAGRTGG ATGAG
COG2R TCGACGCCATCTTCATTCACA
0.8 µM probe (Ring 1a HEX-AGATYGCGA TCYCCTGTCCA-BHQ-1
Ring 1b HEX-AGATCGCGGTCTCCTGT CCA-BHQ-1
Ring 2 FAM-TGGGAGGGCGATCGCAA TCT-BHQ-1)

Amplification, detection and analysis were performed in an ABI 7500 real-time PCR system (Applied Biosystems, Warrington, UK) under the following conditions: 50°C for 15 min, 95°C for 20 s, 45 cycles of 95°C for 3 s and 60° for 30 s (with fluorescence detection).

Results

General

As stated earlier, the main aim of monitoring environmental conditions within the vertical stacks was to establish a benchmark temperature (Temp.) and relative humidity (RH) for a busy hospital system. An extensive literature review unearthed little data on this subject, and as such, the quantification of these variables is novel.

In addition to the temperature and RH recordings, equipment was installed to measure the airflow direction and airflow rate. These variables were recorded over a 6-week period, which amassed a considerable amount of data. A typical sample of the temperature and RH recordings for a short period is shown in Figure 4 below.

Temperature and relative humidity readings

The recordings shown in Figure 4 for a 1-week period are typical of all the readings taken over the 6-week period. A temperature between 22 and 28°C was common in the stack, and a relative humidity between 96% and 100% was measured throughout. These constantly warm and wet conditions were a little surprising, since it was thought that there may have been a greater fluctuation, particularly since these reading were taken above the wet stack and close to the open-end roof termination.

Published data on the typical environmental conditions within building drainage and sewer networks are, at present, relatively scarce. A field study, which measured the temperature of wastewater in a Tokyo sewer over a 14-year period, reported temperatures of 10–30°C.[13] Wastewater temperatures up to 24.5°C have been reported in sewers in Hong Kong[14] and up to 26°C in Germany.[15] Field measurements from rising main sewers in the Gold Coast area of Australia showed average wastewater temperatures of up to 28.4°C.[16]

A 2-month study carried out within a section of the Northwest Sydney sewer found that while the air temperature at a vent outlet varied between 14.3 and 24.4°C, the sewer air temperature ranged only between 19.1 and 22.2°C. The authors suggest that this reflects the fact that air temperatures found within the sewer network are intrinsically different from the ambient air temperatures.[17] Further field studies in Australia recorded average sewer air temperature of 22–28°C and relative humidity of 93%–100%.[18]

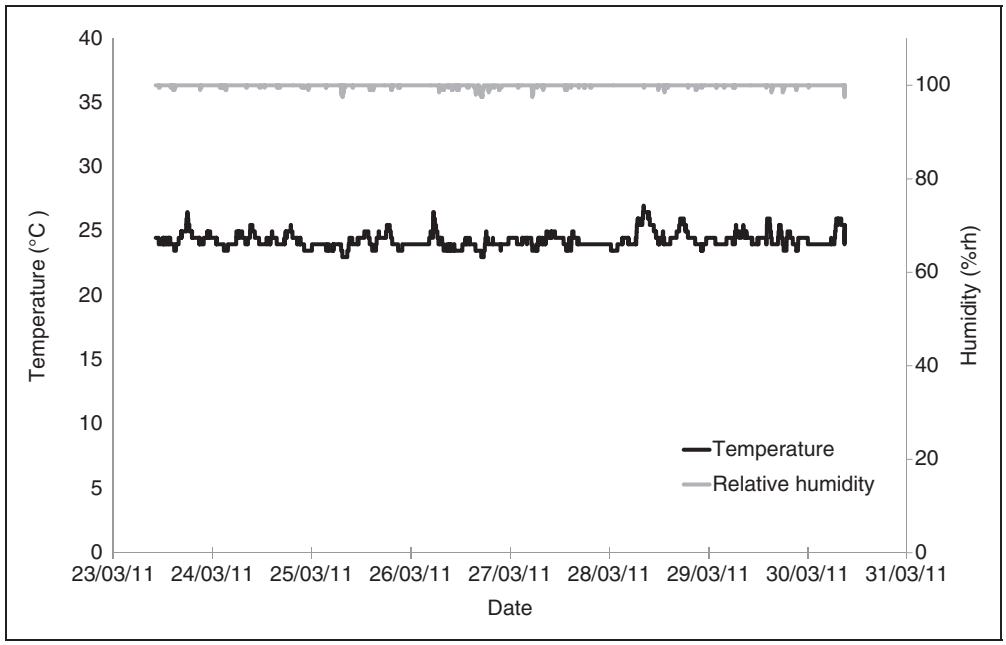

Figure 4. Typical relative humidity and temperature readings from vertical stack.

The temperatures recorded in the hospital vertical stack are consistent with the literature findings and higher than the surrounding service duct temperatures. A temperature gradient from the main collection drain to the top of the stack was assumed as a result of these findings; however, it was not possible to measure temperatures in the main collection drain.

Airflow readings

The recording of airflow direction and airflow rate proved considerably more troublesome than recording Temp and RH. In the main, this was because of the humidity in the vertical stack. The pitot static tube installation described earlier was deliberately located above the wet stack to avoid the air inlet tubes becoming blocked with water droplets; however, the moist air in the stack caused blockages on many separate occasions. Despite these difficulties, it was possible to observe both an airflow rate and an airflow direction in the vertical stack from the above method. A recording of airflow rate and airflow direction is shown in Figure 5 below. The graph shows recordings for a 5-min period.

As can be seen from Figure 5 over this short period of time, there is a significant upward airflow. This is easily explained by the high temperatures within the vertical stack, and the air naturally travelling towards the open-end termination under buoyancy forces. Whilst there is upward airflow, there is still a significant downward airflow as appliances discharge, and air is drawn in to equalize pressures in the system.

PCR results

The results of the tests carried out on the samples are shown below in Table 1. It can be seen that Norovirus GI was undetected in all samples of both air and wastewater. Again, Norovirus GII was undetected in all air samples; however, all wastewater samples (except for that taken on 01/03/2011) were positive for Norovirus GII. This indicates that at the time of an outbreak in the hospital, where Norovirus GII was

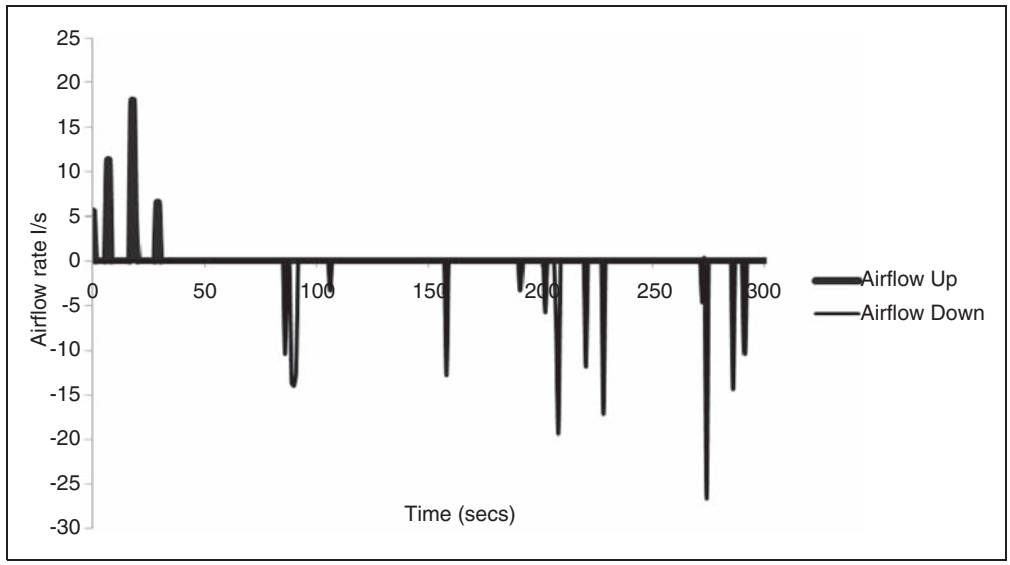

Figure 5. Typical airflow rate and direction for a 5-min period in the vertical stack (note: airflow down shown as negative).

Table 1. PCR results for all tests carried out.

	Norovirus GI				Norovirus GII			
Test date	Sewer 1	Stack 1	Stack 2	Stack 3	Sewer 1	Stack 1	Stack 2	Stack 3
01/03/2011	U	U	U	U	U	U	U	U
10/03/2011	U	U	U	U	POS	U	U	U
16/03/2011	U	U	U	U	POS	U	U	U
23/03/2011	U	U	U	U	POS	U	U	U
30/03/2011	U	U	U	U	POS	U	U	U
05/04/2011[a]	U	U	U	U	POS	U	U	U
26/05/2011	N/A	U	U	U	N/A	U	U	U

U: undetected, the virus was not detected.
POS: positive, the virus was detect.
[a]A swab of the inside surface of Stack 1 taken on this date also returned undetected for all tests.

detected in samples from patients, the collection drain for the hospital contained infected faecal material in large quantities.

Conclusions

The identification of Norovirus GII strain from the wastewater sampled from a collection drain over a 6-week period in early 2011 confirms that the BDS is contaminated when there is an infection outbreak in a hospital. The hypothesised transmission route has been partially proven in that faecal waste or vomit from an infected person will contaminate the wastewater in a collection drain. The warm and humid air within the system has also been shown to flow up, as well as down the stack, allowing for the possibility of virus-laden droplets to circulate within

the drainage system and to emerge elsewhere. Any transmission between the faecal/vomit material and the air can therefore arise. The presence of a diahorreal 'mist' clearly lends itself to being carried on the upward airflows. The conditions in the vertical drainage stack were recorded as being above room temperature and very moist. The difficulty in isolating any micro-organism from the airflow was due mainly to the absence of a verified collection methodology and presents a future research challenge in this area.

This study has gone a considerable way to advance the hypothesised transmission route described and has resulted in the proof that the collection drain is a reservoir for potentially harmful pathogens in hospitals. This study has also demonstrated that there is a significant upward airflow within the vertical drainage stack, which can potentially facilitate virus transmission, and that conditions within the vertical drainage stack are warm and humid, which may in fact aid the survival of harmful pathogens within the BDS. The difficulty in obtaining samples from the stack airflows, and the identification of further design anomalies, presents future challenges, which will be addressed in the next phase of this research.

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