Water trap seal vulnerability monitoring: A case study of its application to a large hospital complex.

Dr. M.Gormley
m.gormley@sbe.hw.ac.uk
School of the Built Environment, Heriot-Watt University, Scotland, EH14 4AS.

Abstract

The reflected wave technique for the identification of defective water trap seals (Dyteqta) has become a reality. With the development of an integrated system for the commissioning and monitoring of building drainage and vent system (BDVS) terminations and components, information on the status of the required seal between the BDVS / public sewer and the habitable space can be made readily available to building operators and facilities managers for the first time.

The methodology for implementing the reflected wave technique has drawn heavily on the preceding seven years of academic research and industrial collaboration. This approach, combined with the site testing methodology adopted for validating theoretical designs, first implemented in the laboratory and inspired by the modelling of air pressure transient propagation, made possible by the use of the computer model AIRNET, have proved robust, repeatable and non-invasive.

This paper considers the application of the defective trap identification system to a hospital building and asks whether the building drainage system can actually be considered a 'threat' to occupants. An extensive review of published literature confirms that a threat does exist however the evidence is fragmented in nature. Evidence during the site trial of the system in a real hospital building confirm the system's effectiveness even under busy hospital usage conditions and also highlights the continued prevalence of problems with empty floor traps in plant rooms.

The research carried out in this area has highlighted the lack of any real monitoring of water trap seal status in buildings, and has put the issue firmly on the agenda for consideration by building owners and operators for whom the BDVS has long been categorised as 'fit and forget'. The inspiration for this work was the response to the SARS outbreak in 2002. Whilst the predicted pandemic of the virus failed to

materialise, and the outbreak has largely been consigned to history, it should serve as a constant reminder to professionals in the industry that we ‘fit and forget’ at our peril.

Keywords

Reflected wave technique, Case Study, healthcare buildings, Site testing.

1 Introduction

The outbreak of severe acute respiratory syndrome (SARS) first reported in 2002 caused severe disruption and led to many fatalities. Over and above the actual disruption and the relatively low number of fatalities (810 by June 2003) there was a great fear that the epidemic would spiral out of control and resist containment.

In response to this outbreak and the particularly severe concentration of cases in Amoy Gardens in Hong Kong, where the empty floor drains found in bathrooms were implicated in the transmission of the virus from one apartment to another. In response to this, the defective trap identification system was invented and developed at Heriot- Watt University. The subsequent body of research had been considerable [1] [2] [3] and the work has resulted in many other peer review publications, conference papers and a successfully defended PhD thesis.[4]

The reflected wave technique, developed and honed during this research period has moved from being a theoretical and laboratory based innovation to a commercially available system for the monitoring of the state of the seal between the building drainage system and the habitable space. Based on well understood pressure surge analysis techniques and supported by the method of characteristics based AIRNET simulation model, the development of the techniques and methodologies for testing represent a concerted effort to join together many different aspects of already understood engineering methodologies, in a totally unique way.

The extensive laboratory investigation coupled with 4 significant site trials [5] have established that the system can work in a wide range of building types, from housing apartments to a University building to an occupied office block to a busy hospital building. The robustness of the methodology has been firmly established.

While it was well established that the spread of the SARS virus was assisted by poor plumbing maintenance [2], [6] in Amoy gardens leading to empty water trap seals, it has not been widely accepted that the building drainage and vent system poses a threat to the health of the inhabitants of a building, from a pathogen transmission point of view.

Trialling the defective trap identification system (Dyteqta) in a hospital has offered insight into the massive challenges presented to infection control teams. Infection control is a multi-dimensional, multi-faceted, complex issue with many different approaches and disciplines vying for attention. The difficulty in linking cause and effect and the relative success of some simple and effective strategies such as hand washing means that some significant areas are ignored.

This paper seeks to establish a case for including the building drainage and vent system in infection control strategies in a more prominent way, particularly in buildings of high risk such as hospitals.

2 Application in Healthcare Buildings: The case for monitoring

Current practice in healthcare buildings relies on physical inspection of the building drainage and vent system to establish a fault or to affect a repair. In most cases (if not all) maintenance on the system is not governed by a regulatory framework in the same way as, for example, the water supply network or the heating ventilation and air conditioning systems are. In these cases direct links to propagation of micro-organisms such as legionella and cryptosporidium have led to illnesses and fatalities thus instigating the regulation of maintenance of these systems.

With the exception of the SARS outbreak in South East Asia there is no precedent of a direct link between the building drainage system and patient illness or death to instigate compulsory, regulated maintenance of the building drainage system. There is therefore a tendency to ignore this important 'service' in a building and hospitals are no exception. Is there evidence to suggest that such regulation should be introduced, or at the very least, should regular monitoring of this important system be seen as 'best practice'? Of most concern to healthcare professionals are the diseases contracted while a patient is recovering from an entirely different illness, these are known as nosocomial infections.

The definition of a nosocomial infection is a secondary disorder associated with being under medical care but unrelated to the patient's primary condition. Over the years this definition has been reduced to pertain to diseases and infections acquired in hospital buildings. [7]

The building drainage system is possibly the only engineered fluid carrying system which interconnects all parts of a building. In a healthcare building this means that there is a system which links wards, laboratories, mortuaries, isolation rooms, operating theatres, public waiting spaces, offices and plant rooms. This extensive pipe network is sealed from the building population, in the main, by a small volume of water in a water trap seal or U-bend. The flows found in building drainage systems are a combination of solid and liquid waste; faecal solids, urine, toilet paper in the main. However other products are commonly discharged into the system, for example; feminine sanitary protection pads, tampons, used condoms and items containing blood are not uncommon items to be found in a building drainage system. Water is used to transport waste from the building and the sewer to a processing plant. As such the building drainage system can be viewed as a rich reservoir of viruses and bacteria.

It might seem obvious that the design of a building drainage system involves sizing the pipe network to facilitate the efficient discharge of the water/solids mixture described above. It is less obvious that the main design consideration is the flow of air and the attendant air pressure regime in the system. The mechanism for airflow in a building drainage system is principally the shear force at the water/air interface and since the water flow is unsteady in nature, due to the random discharge of appliances, then the airflow and the air pressure are also unsteady. The study of building drainage performance therefore necessitates the study of air pressure transients (surges) in the system.

The protection afforded by the water trap seal is substantial. However it has a number of weaknesses which make it vulnerable. The air pressure transients described above can be of sufficient magnitude and duration to either suck the water out of the water trap seal (negative air pressure transients) or blow the water out of the appliance (positive air pressure transients). Either of these scenarios will result in an empty water trap seal. The water in the trap seal of an unused appliance can also evaporate over time leading to an empty trap. It should be noted that all of the above weaknesses are possible even in a system designed to meet all building regulations and standards and subject to a proper maintenance regime.

The consequences of an empty water trap are that the required seal between the habitable space containing the population of the building and the source of potential infection has been lost. The empty water trap seal also acts as a vent for the system so air can flow into and out of the drainage system thus allowing the possibility of pathogen infected aerosols entering the habitable space. It should be noted that because of the interconnection of the drainage system, infected aerosols can originate in any part of the building, not just in the vicinity of the empty trap. Extensive work has been carried out to prove that pathogenic microorganisms can be transmitted in airborne aerosols[8],[9],[10].

The mode of cross infection depends on the route of the infective pathogens once aerosolized. They may either be deposited on surfaces, leading to self-inoculation through hand-to-mouth contact [11], or remain airborne [12] and thus spread the disease further afield through ingestion or inhalation by uninfected victims. Airborne transmission, through the transfer of infectious droplets and aerosols, remains the most important mechanism of uncontrollable dissemination of disease and studies have shown that aerosolized pathogens can travel up to 1.5 km from source [13], [14].

3 Building Drainage System – A real threat?

While the discussion above has shown that in theory infectious micro-organisms can survive and propagate through a building drainage system it must be asked whether there is any actual evidence to suggest that this is likely. Inspection of the possible routes of transmission and a literature search for actual cases serve to highlight both the importance of the building drainage system in this area and the lack of hard research results available.
There are five accepted routes of transmission for diseases

- Contact – direct contact with an infected person
- Droplet- from coughing, sneezing and diahorreal spray
- Airborne- carried through the medium of air
- Common Vehicle- contact with a contaminated item
- Vector- disease carried by insects and other invertebrates e.g. mosquitoes transmitting malarial parasites.

While there are five distinct routes of transmission the same micro-organism may be transmitted by more than one route, thus complicating the forensic analysis of an outbreak in a building.

Associated with the routes of transmission are the sources or reservoirs of infections. It can be considered that the building drainage system is in fact a reservoir in itself. Viruses such as adenoviruses, astrovirus, enteroviruses, hepatovirus, norovirus, reoviruses and rotavirus and bacteria such as Escherichia coli (*E. coli*), Legionella pneumophila, Salmonella and Shigella passed in the excreta of infected people have been found not only to exist within the building drainage system but are also amenable to airborne transmission within aerosolised water particles [15]. Other bacteria such as psuedomonas aerugonos can be found in biofilm formations where they can feed off waste and organic material found in water.

Is there any evidence that these micro-organisms are found in building drainage systems and appliances? There is some evidence but it is fragmented. Research by Blanc *et al* [16] found that faucets were a substantial reservoir for psuedomonas aerugonos in intensive care units in the U.S. Whilst Inglis *et al* [17] found a contaminated water trap seal on a wash basin to be a reservoir for the same bacteria. In both cases illnesses were directly linked to the presence of these micro-organisms

Farr *et al* [18] described the actual numbers of nosocomial infections identified to be the tip of the iceberg'. The fear illustrated here is that the human reservoir for the spread of antibiotic – resistant nosocomial pathogens consistes of a relatively small number of patients with clinically obvious infection and a much larger subset of colonized patients who remain unrecognised.

Noble *et al* [19]first identified the toilet as a transmission route for vancomycin – resistant enterococci (VRE). Enterococci are amongst the most antibiotic resistant bacteria isolated from humans and can cause serious complications for immune compromised patients.

Amongst the most disruptive of the viruses is the Norovirus. It is the most frequent cause of virus-induced gastroenteritis. It is resistant to disinfection and retains its infectivity well for a long time. The virus induces, amongst its symptoms, diahorrea, and is thus present in the faeces of the patient. A Norovirus outbreak is often controlled by costly temporary ward closures, however outbreaks can last a long time. One particular outbreak of note at the Helsinki University Central Hospital in Finland lasted from November 2006 to June 2007. During this time 240 (18%) of patients and 205

(19%) of healthcare workers fell ill. A total of 9 people died as a direct result of the outbreak [20].

Despite the considerable evidence to suggest that, at the very least, the building drainage system should be considered a significant reservoir for infectious bacteria and viruses, little is done to ensure that the same design and maintenance rigour be afforded the BDVS as other important systems such as water supply and HVAC. There is virtually no advice given on how to protect the people in the building from this reservoir. In a recent paper on how to incorporate infection control measures into building new hospitals, Stockley *et al* [21] devote only one paragraph to the 'foul drainage system' A quote of this paragraph serves to illustrate the lack of any understanding on the matter;

> "The decision of whether to install bedpan washer – disinfectors or macerators will be influenced by the capacity of the foul drainage system and the load which the water company can take into the public drainage system. The diameter of the pipework will determine the likelihood of blockage"

It is clear that most professionals in this area do not understand the complex relationship between air and water in a building drainage system.

The evidence clearly exists that the building drainage system is a significant reservoir for viruses and bacteria and there is also evidence to prove that the mechanisms for these to be transmitted are probable under the correct circumstances. However there is little published data to link the two. There is clearly a data gap in relation to this. In many cases the evidence is circumstantial in that the effect cannot be directly linked to a specific cause. The quote from Stockley *et al* above illustrates why this connection cannot be made, since many of the professionals involved in infection control know little about the mechanisms at play in a building drainage system. As further evidence from a recent inspection of Glasgow Royal Infimary illustrates [22]. This evidence, while published, is still anecdotal in character, based on observation alone.

During the inspection it was observed that the drain pipes from a Renal Dialysis machine were connected to an unsealed pipe on the building drainage system. There appeared to be no water trap at all, although it was not possible to tell from the report if there was a running trap on the pipe after it went through the wall. If there is actually no water trap seal on the drain for the dialysis machine then the drainage pipes will act as a vent on the whole branch thus causing a potential route for infection spread. It is noteworthy that renal patients and those on dialysis have the highest nosocomial infection rates amongst hospital populations [22]. While it is not possible to confirm this link it should be noted that this arrangement should never be allowed in any circumstance. It must also be highlighted that the inspections picked this up and the inspectors identified the problem instantly where plumbing maintenance staff had not.

Evidence therefore exists, yet the complex nature of the possible routes of transmission makes pinning the cause on the building drainage system extremely difficult. There is enough evidence however to clearly conclude that there is a high probability that nosocomial infections could be transmitted from the reservoir of the building drainage system if a water trap seal is lost.

4 Infection control and surveillance strategies

'Primum Non Nocere'
(First, do no harm)

A fundamental of medical ethics is to prevent harm, illness or death due to the intervention itself. This guiding principle has underpinned the development of the defective trap identification system. Great care and attention has been paid to ensure that in the first place the system does not interfere with the normal operation of the building drainage system or interfere with the day to day running of the building. Work by Gormley and Beattie has served to ensure that the air pressure wave introduced into the system is verifiably non destructive [23].

Application to a large health care building poses many other practical difficulties as reported previously [5], however these difficulties aren't entirely technical. The World Health Organisation's (WHO) practical guide to dealing with infection control in hospitals proposes a system for surveillance of infected patient cases in a way that can be collated and trends identified. While this system is used for patient morbidity data the principle works for monitoring the vulnerability of water trap seals also [24].

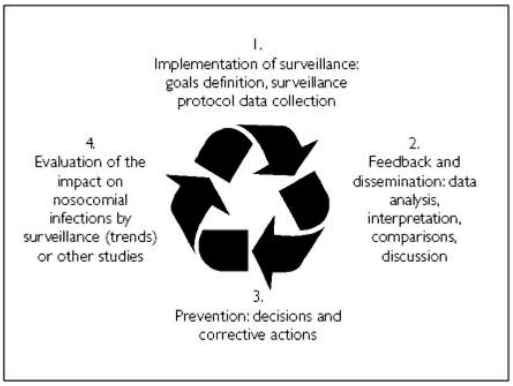

Figure 1 - Surveillance is a circular process.

Regular reporting on the state of water trap seals contribute to the overall strategy. Given that organisations role in identifying the routes of transmission of the SARS virus in Amoy Gardens it is not surprising that the WHO also advocate regular monitoring of the plumbing and water supply systems, recognising their importance in creating healthy healing environments for patients. However this is not given a lot of prominence in their Practical Guide to Infection Control [24].

5 Site Trial - RIE

Figure 2 - Aerial view of the Royal Infirmary Edinburgh

The testing strategy adopted for the Royal Infirmary Edinburgh (RIE) was to locate the equipment in plant room so as to avoid any disturbance in the clinical areas of the hospital. The intention was to carry out testing during normal working hours without the need to interfere with any clinical procedures being carried out.

Since this was a controlled experimental trial of the system where connections to the building drainage system were being made and remade, changed and modified, there was a great need to take extreme care not to cause an outbreak of HAI by our actions (*primum non nocere)*. Frequent hand sanitization and extensive use of latex examination gloves with stringent procedures for waste management and disposal were adhered to in accordance with the strict requirements of the Infection Control team and Facilities Management group at the hospital.

The purpose of the site trial at the RIE was not to validate the technology but rather to place the technology in the context of a real scenario. The benefits of site testing, particularly in the context of a large complex building, is that it highlights the practical application in a way that cannot be achieved by computer modelling or laboratory investigation. The lessons learned from these site trials have been invaluable in making the fundamentally sound ideas incorporated in the embedded techniques used in the defective trap identification system a reality in the Dyteqta system.

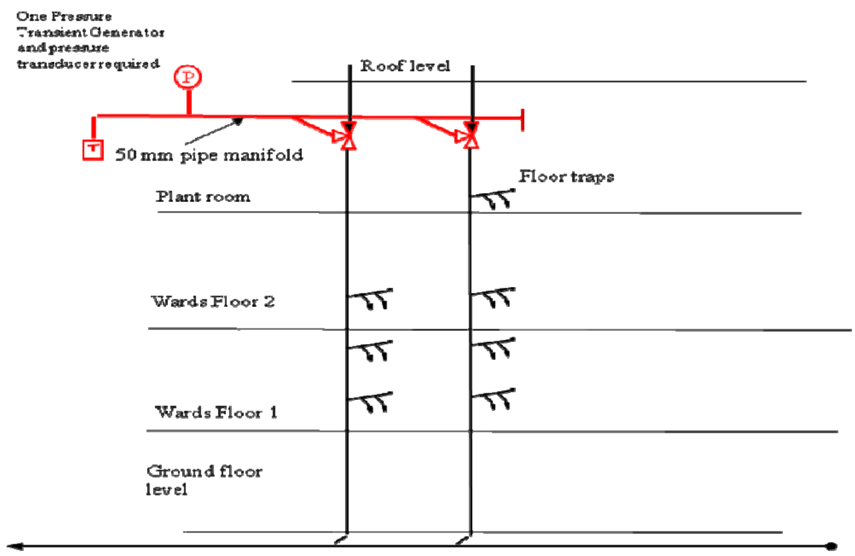

Figure 3 - Schematic of trial installation at RIE

In total 30 water traps attached to branches on 2 vertical stacks were tested to verify that empty traps could be identified. All 30 water traps could be easily identified however there was considerable confusion over results obtained on one particular stack due to the fact that a floor trap in the plant room was permanently empty. This was a common issue in most of the buildings trialled. Of the 3 occupied buildings used in field trials, 2 had persistent problems with empty water trap seals in plant rooms, while the other had a similar problem just outside the scope of testing of that particular installation.

This is a considerable concern given the discussion above on nosocomial infections in hospitals. While the defective traps were unlikely to transmit micro-organisms directly into wards, a defective water trap in a top floor plant room will vent the entire system into the plant room space. It is of concern to note that these spaces also hold air handling units which, while sealed, cannot be fully sealed from the surrounding environment. It is possible to postulate a scenario where multiple routes of transmission coincide to propagate a disease to other parts of a hospital. The prospect of multiple transmission routes also raises the possibility that maintenance staff may unwittingly transmit micro-organisms picked up in plant rooms and transfer them to other parts of a building where more susceptible patients may become infected.

Table 1 - Collated results from all site trials

Building	No. Of traps tested	No.of Stacks	All traps identifiable	Defects observed	Comments
Dundee Housing Block – 14 storey	54	1	Yes	None	Single stack – unoccupied building
HWU School of the Built Environment Building	24	1	Yes	Floor trap in plant room persistently empty	Equal diameter branch and stacks made identification difficult
RBS Glasgow 8 storey building	118	6	Yes	None – suspect condensate trap in basement	Multiple stacks tested – AAVs in plant room
Royal Infirmary Edinburgh 4 storey – 650 stacks approx	30	2	Yes	Floor trap in plant room persistently empty	Complex building – possible to interconnect large number of stacks tested.

Table 1 collates the results from all the site trials carried out for the defective trap identification system. It can be clearly seen that the system was effective at identifying empty water traps in all these setting and that floor traps in plant rooms are a considerable problem that should not be ignored.

6 Conclusions

The defective trap identification system has been shown in previous papers to be an effective engineering response to the issue of addressing the required seal between the building drainage/sewerage system and the habitable space. While the system has been shown to be effective in many building types, there has been a persistent understanding that the system could be an effective weapon in the fight against infection spread in hospital and healthcare buildings. While this is true from an engineering standpoint, an extensive literature review has shown that this perspective is not shared with many infection control professionals. This paper has sought to highlight specific cases where nosocomial infections could potentially be spread through building drainage related installations. This paper has shown that there is a considerable amount of published evidence to suggest that the building drainage system could pose a threat however the evidence is still fragmented in many ways. Finally, the site trial reported here has demonstrated that the system is effective even in a busy hospital building. It fulfils the basic requirements of a protective system which introduces no addition risks.

7 Acknowledgements

The author would like to thank the following people for their help and assistance in producing this paper. Firstly, the personnel at the Royal Infirmary Edinburgh; For Balfour Beatty Workplace - Ricky Barr and Andy Dimond, for Consort Healthcare; Scott Lawson. It isn't possible to do such complex on-site field work without the help of others; at Heriot –Watt University the author would like to thank Professor John Swaffield for his input on the defective trap identification technology; Dr. David Kelly for assistance with assistance on the infection spread sections of this paper and help with site testing; Mr. Charles Hartley for his major contribution to the design and execution of the site testing reported in this paper and the development and commercialisation of the Defective trap identification system in the Dyteqta form. Mr. David Walker contributed immensely to the overall effort by providing technical support. Finally the author would like to acknowledge the considerable contribution made by Studor in funding this final stage of system development.

8. References

[1] Kelly, D.A, Swaffield, J.A. , Jack, L.B, Campbell, D.P, and Gormley, M. 'Pressure transient identification of depleted appliance trap seals: a sinusoidal wave technique' *Building Service Engineering Research and Technology, Aug 2008; vol. 29: pp. 219 - 232.*

[2] 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

[3] Kelly D.A 'Reducing the risk of cross-contamination from the building drainage system using the reflected wave technique to identify depleted trap seals' *35th CIBW62 Symposium on Water Supply and Drainage for Buildings, Dusseldorf.*

[4] Kelly D.A (2009) 'Controlling the risk of cross-contamination from the building drainage system using the reflected wave technique to identify depleted water trap seals'. Heriot Watt University theses collection. Edinburgh, U.K.

[5] Gormley M. (2009) ' From desktop to plant room: Development of an innovative system for mapping and assessing trap seal vulnerabilities in building drainage systems – lessons from the field. *35th CIBW62 Symposium on Water Supply and Drainage for Buildings, Dusseldorf.*

[6] World Health Organisation. (WHO) (2003a). Final Report: Amoy Gardens, WHO Environmental Investigation.

[7] Stone S.P., Cooper B.S., Kibbler C.C., Cookson B.D. *et al* 'The ORION statement: guidelines for transparent reporting of outbreak reports and intervention studies of nosocomial infection.' *The Lancet* (2007) Vol (7) Issue(4) pp 282-288

[7] Hutchison R.L. (1956) ' Some observations on the method of spread of some dysentery' *Mon Bull Minist Health Pulic Kealth Lab Serv* 15, pp 110-118

[8] Darlow H.M. and Bale W.R. (1959) ' Infective hazards of water closets' *The Lancet ii* pp 1196-1200

[9] Baylor, E.R., Peters, V. and Baylor, M.B. (1977). "Water-to-air transfer of virus." *Science*, **197**, 763-764.

[10] Gebra, C.P., Wallis, C. and Melnick, J.L. (1975). "Microbiological hazards of household toilets: droplet production and the fate of residual organisms." *Applied Environmental Microbiology*, **30**, 229-237.

[11] Hendley, J.O. Wenzel, R.P. and Gwaltney, J.M. (1973). "Transmission of rhinovirus colds by self-inoculation." *New Eng.l J Med.*, **288**, 1361-1364.

[12] Couch R.B., Cate T.R., Douglas R.G., Gerone P.J. and Knight V. (1966) ' Effect of route of inoculation on experimental respiratory viral disease in volunteers and evidence for airborne transmission'. *Bacteriol Rev.,* 30, pp 517-529.

[13] Parker D.T., Spendlove J.C., Bondurant J.A. and Smith J.H. (1977). 'Microbial aerosols from food processing waste spray fields' *Journal of the Water Pollution Control Federation'* 49, pp 2359-2365.

[14] Cronholm L.S. (1980) ' Potential health hazards from microbial aerosols in densely populated regions' *Applied and Environmental Microbiology*, 39 pp 6-12.

[15] Feachem, R.G., Bradley, D.G., Garelick, H. and Mara, D.D. (1983). "Sanitation and disease: Health aspects of excreta and wastewater management," Wiley and Sons.

[16] Blanc D.S., Nahimani I., Petignat C., Wenger A., Billie J., Francolli P. 'Faucets as a reservoir of endemic *Psuedomonas aeruginosa* colonization / infections in intensive care units' (2004) *Intensive Care Med.* 30: 1964-1968.

[17] Inglis T.J.J., Benson K., O'Reilly L.O., Bradbury R., Hodge M., Speers D., Heath C.H. ' Emergence of multi-resistant *Psuedomonas aeruginosa* in a Western Australia hospital.' *Journal of Hospital Infection* (2010) 76; pp 60-65

[18] Farr B., Sal dago D, Karchner T.B. and Sheretz R.J. 'Can antibiotic resistant nosocomial infections be controlled' *The Lancet, Infectious Diseases* pp 38-45 August 2001.

[19] Noble M.A., Isaac-Renton J.L. Bryce E .A, Roscoe D.L., Roberts F.J., Walker M., Schraf A., Walsh., Altamirano – Dimas M., Gribble M. 'The toilet as a transmission vector of vancomycin – resistant enterococci.' *Journal of Hospital Infection* (1998); 40 pp237-241

[20] Kanerva L., Maunula L., Lappulaineu M., Mannonen L., Von Bonsdorff C.H. & Autilla V.J. 'Prolonged norovirus outbreak in a Finnish tertiary care hospital carried by GII.4-2006b subvariants' *Journal of Hospital Infection* (2009) 71; pp206-213

[21] Stockley J.M., Constantine C.E., Orr K.E. ' Building new hospitals; a UK infection control perspective.' *Journal of Hospital Infection* (2006) 62; pp 285-299

[22] Healthcare Environment Inspectorate (2010) 'Announced Hospital Inspection Report: Glasgow Royal Infirmary' NHS Quality Improvement Scotland.

[23] Gormley M. And Beattie R.K. ' Derivation of an empirical frequency- dependent friction factor for transient response analysis of water trap seals in building drainage systems.' (2010) *Building Service Engineering Research and Technology ; vol. 31:3 pp. 221 - 236.*

[24] World Health Organisation (2002) ' Prevention of hospital-acquired infections: A practical guide. 2nd Edition.

8 Author

Dr. Michael Gormley is a lecturer in Architectural Engineering and member of the Drainage Research Group at Heriot - Watt University. His research interests are pressure transient modelling and suppression in drainage systems and solid transport in above ground drainage systems.