Bio-aerosols in building drainage and plumbing systems: cross contamination, monitoring and prevention.

Dr Michael Gormley
Drainage Research Group
School of the Built Environment
Heriot-Watt University
Edinburgh
Contents

• The building drainage system as a bioaerosol transmission route

• Transmission study of the drainage system of a hospital

• Monitoring method for minimising bioaerosol transmission from the drainage system
Bio-aerosols are defined as airborne particles, large molecules or volatile compounds that are living, contain living organisms or were released from living organisms. The size of a bioaerosol particle may vary from 100 microns to 0.01 micron. The behaviour of bioaerosols is governed by the principles of gravitation, electromagnetism, turbulence and diffusion.
This is a scale representation of the relative size of pollen, pollen spores, bacteria and viruses. The scale of this diagram is roughly 8000:1. Each of the dots on this screen version represent 15 viruses, or virions. In this diagram, approximately 100,000 of these virions fit within the 100 micron circle representing the pollen. In actuality, many millions of virions could fit within the cross-section of a pollen.
Bio-aerosol generation and detection

- Bioaerosols, particularly those containing viruses are particularly difficult to isolate and identify.

- This task is made even more difficult due to the unsteady nature of flows in building drainage systems.
Building drainage system: mechanisms for air flow and pressure transient generation

Discharging appliance increases entrained airflow and generates negative transients.

Trap seal depletion

Increased entrained airflow

Increased water flow.

Negative transient
Building drainage system: mechanisms for air flow and pressure transient generation

operating appliance

Trap seal deflections

Positive transient affects all traps

Airflow reduced due to stack base surcharge
Pressure transients in system can cause traps to blow out-

http://www.youtube.com/watch?feature=player_detailpage&v=d_vNLMCZ9jQ

The attached video is an extreme example – but it is real – most common symptom of smaller pressure transients is bubbling through a trap, you may have seen this in a toilet bowl.
Airflow and pressure transient modelling- AIRNET and current limitations

• A method of characteristics based numerical model.

• Finite difference scheme

• Developed and validated over 30 years at Heriot- Watt University – initiated by, and continues to be inspired by, the work of John Swaffield.
Building Drainage System modelling in AIRNET

Building drainage system boundary conditions

For C⁺ - Line PR

\[ u_P - u_R + \frac{2}{\gamma - 1} (c_P - c_R) + 4 f_R u_R | u_R | \frac{\Delta t}{2D} = 0 \]

when

\[ \frac{dx}{dt} = u + c \]

For C⁻ - Line PS

\[ u_P - u_S - \frac{2}{\gamma - 1} (c_P - c_S) + 4 f_S u_S | u_S | \frac{\Delta t}{2D} = 0 \]

when

\[ \frac{dx}{dt} = u - c \]
AIRNET modelling

Modelling of complex networks such as the O2 Dome
This is the first sealed drainage system ever constructed. It has no penetrations through the roof. As drainage systems go, it is unique. The approach designed by M.Gormley and J.A.Swaffield from Heriot-Watt

50 Storey housing block in Hong Kong
Modelling led to novel approaches to preventing excessive positive pressures using P.A.P.A.™
modelling air pressure and flow in large systems

Combined waste fluids and waste in appliance water flows
Potential contaminated air ingress if trap seal lost

Airflow may be drawn from any of the connected sub-section drainage systems – total interconnection.
Limitations

- Calculations do not include important bioaerosol fluid dynamics such as:
  - Brownian Motion
  - Gravitation
  - Electrical Forces
  - Thermal Gradients & Electromagnetic Radiation
  - Turbulent Diffusion
  - Inertial Impaction
  - Particle Shape

However
- Flow direction and rate can be calculated – approximations of likely bio-aerosol transport mechanisms can be made.
Modelling flow rate and direction

Modelling confirms the establishment of an air exchange between the bathroom and the vertical.
The building drainage system
Interconnection- all parts of the building are interconnected

Waste water from other hospital buildings i.e. labs, morgue.
To main sewer
“droplets originating from virus-rich excreta…re-entered into residents apartments via sewage and drainage systems where there were strong upwards air flows, inadequate ‘traps’ and non-functional water seals.”
SARS Outbreak
Transmission route

Bioaerosols carried to adjacent buildings by wind current

Bioaerosols formed as waste is flushed

Bioaerosols transmitted to adjacent apartment

Infected person introduces virus to drainage system
The building drainage system
New threats

Global Alert and Response (GAR)

Coronavirus infections

Coronaviruses are a large family of viruses that includes viruses that may cause a range of illnesses in humans, from the common cold to SARS. Viruses of this family also cause a number of animal diseases.

Middle East respiratory syndrome coronavirus (MERS-CoV)
This particular strain of coronavirus has not been previously identified in humans. There is very limited information on transmission, severity and clinical impact with only a small number of cases reported thus far.
Airborne transmission evidence
Forgotten knowledge

1907: cultured airborne *Serratia marcescens* (then termed *Bacillus prodigiosus*) from drainage systems and detected airborne transport from one hospital building to another via the sewer drain.

Sir William Heaton Horrocks (1859-1941)
Horrocks – In good company
The Royal Society

Isaac Newton

Charles Babbage

James Watt
Horrocks – Other Successes

- Confirmed that the cause of ‘Malta Fever’ was bacteria passed on through goats milk.
- Developed methods for testing and purifying drinking water
- Published book on bacteriology of water, one of the first of its kind.

Pathogen transmission study
Hospital building

Environmental conditions

Norovirus Outbreak

Bioaerosol transmission

Waste water from other hospital buildings i.e. labs, morgue.

To main sewer

Wastewater contamination

GF

1F

2F

3F

4F
Pathogen transmission study
Hospital building

Air sampling

• Isolation of bioaerosols using collection swab (UTM-RT)

• Temperature and humidity within drainage stack (USB data logger)

• Air flow and direction (pitot tube)

Wastewater sampling

• Collection of wastewater from main underground drain
Pathogen transmission study
Real Time Polymerase Chain Reaction

Samples extracted using NucliSens® easyMAG™ system

Ct $\leq 29$  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)
# Pathogen transmission study

## RT-PCR Results

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<th>Norovirus GII</th>
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U: Undetected

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)

*a swab of the inside surface of Stack 1 taken on this date also returned undetected for all tests
Samples were also tested for Clostridium difficile but was undetected. This was due to the fact that Cdiff produces spores which are not amenable to many of the PCR assays available.
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Pathogen transmission study
Temperature and Humidity

Average humidity = 96.6%

Average temperature = 24.3%
Pathogen transmission study

Airflow results – this proves that the interconnection hypothesis is valid.
Additional Domestic system tests
Drainage System Schematic

Roof Level
(height above collection drain = 10 m)

Floor 3
Bath & sink
Open pipe for testing
(WC Removed)
Simulates open trap
Anemometer located here.

Floor 2
Kitchen
WC

Floor 1
2 x Bathrooms
Utility room
2 x WCs

Smoke Pellets inserted here

To main sewer
Collection drain
Note: Similar Airflows to those recorded in Amoy Gardens
The DYTEQTA System
Automated monitoring method

- Defective fixture trap seals increase risk of bioaerosol transmission via the building drainage network

- Dyteqta is a sonar-like method for establishing the status of each fixture trap seal in a building

- Based on reflected wave theory

- Using a sinusoidal air pressure wave ensures the test is non-destructive

- System validated by: modelling, laboratory investigations and extensive site testing
Case study Buildings
The DYTEQTA System
Case studies

Is $D_t > h$ over calibration period? NO, trace is reliable.
Is $D_t > h$ during test period? YES, at $t_D = 0.066$ seconds.
Depleted trap location? T12.
The DYTEQTA System
Case studies

- Dundee (AIRNET)
- Dundee (PROBE)
- Arrol (AIRNET)
- Arrol (PROBE)
- Glasgow (AIRNET)
- Glasgow (PROBE)
The building drainage system
Transmission of bioaerosols

- The building drainage system interconnects all parts of a building
- Potential cross-transmission route for bio-aerosols.
- Every building tested had empty water trap seals.
- Healthcare building drains have a distinctly ‘hospital smell’ they do not necessarily smell malodorous.
- Norovirus GII isolated from wastewater sampled from main drain of a hospital building, confirming contamination during an outbreak.
The building drainage system
Transmission of bioaerosols

• Environmental conditions within the drainage system are conducive to bio-aerosol circulation

• Current work underway to replicate the Horrocks work reported in the Royal Society proceedings in 1907 and extend the investigations on the identification of specific pathogens in airflows.

• This work has confirmed that bacteria such as *pseudomonas* spp. Can be carried on airstreams inside a building drainage system.
Thank you for listening