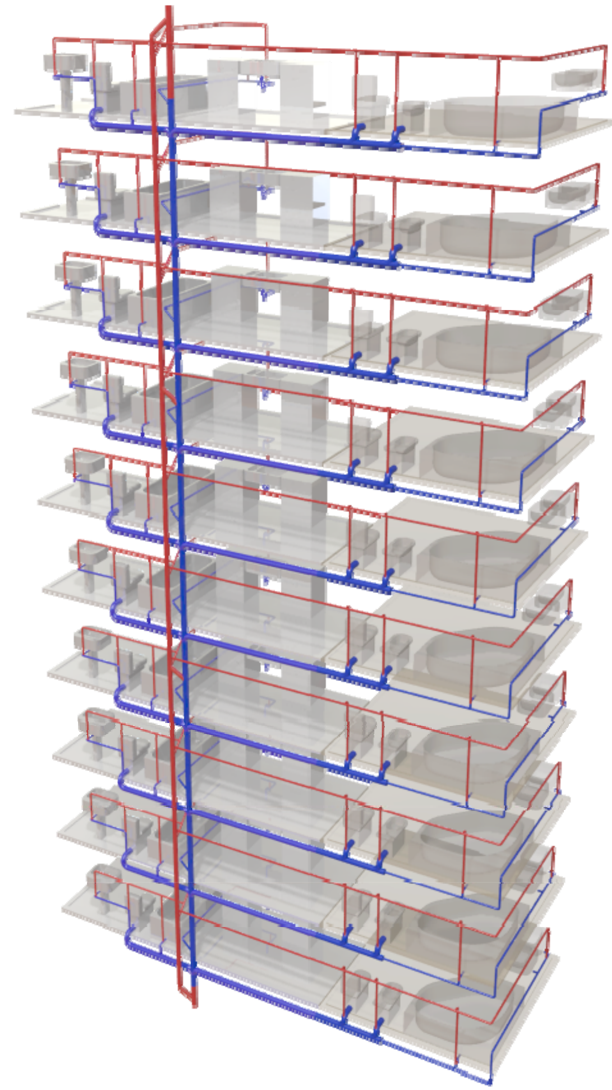
Bio-aerosols in building drainage and plumbing systems: cross contamination, monitoring and prevention.

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

Contents

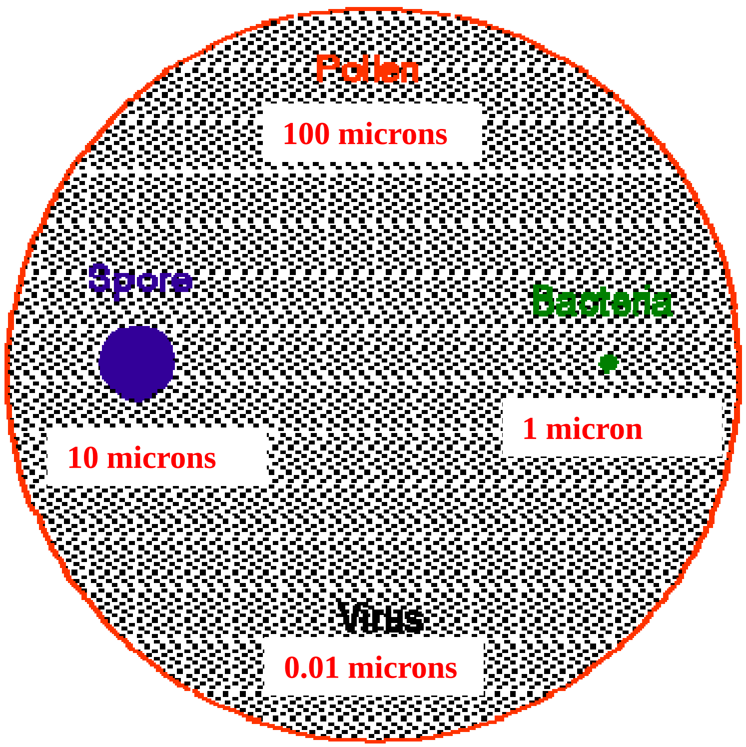
- The building drainage system as a bioaerosol transmission route
- Transmission study of the drainage system of a hospital
- Monitoring method for minimising bioaerosol transmission from the drainage system



Introduction
Bio-aerosols- what are they?

Bioaerosols 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.

Introduction
Relative size of particles



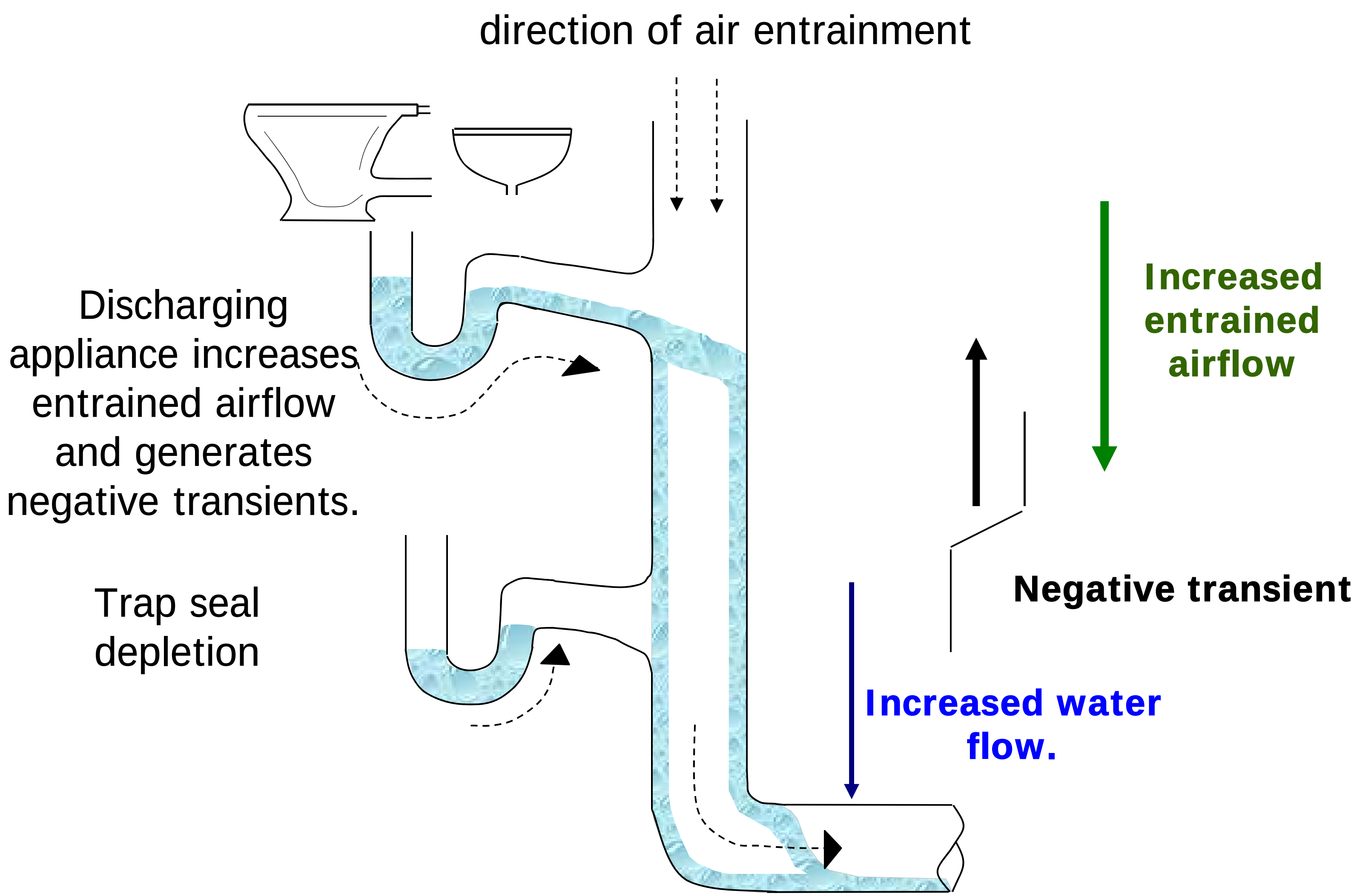
This is a scale representation of the relative size of pollen, pollen spores, bacteria and viruses. The scale of this diagram is roughly 8000:1. Each of the dots on this screen version represent 15 viruses, or virions. In this diagram, approximately 100,000 of these virions fit within the 100 micron circle representing the pollen. In actuality, many millions of virions could fit within the cross-section of a pollen.

Bio-aerosol generation and detection

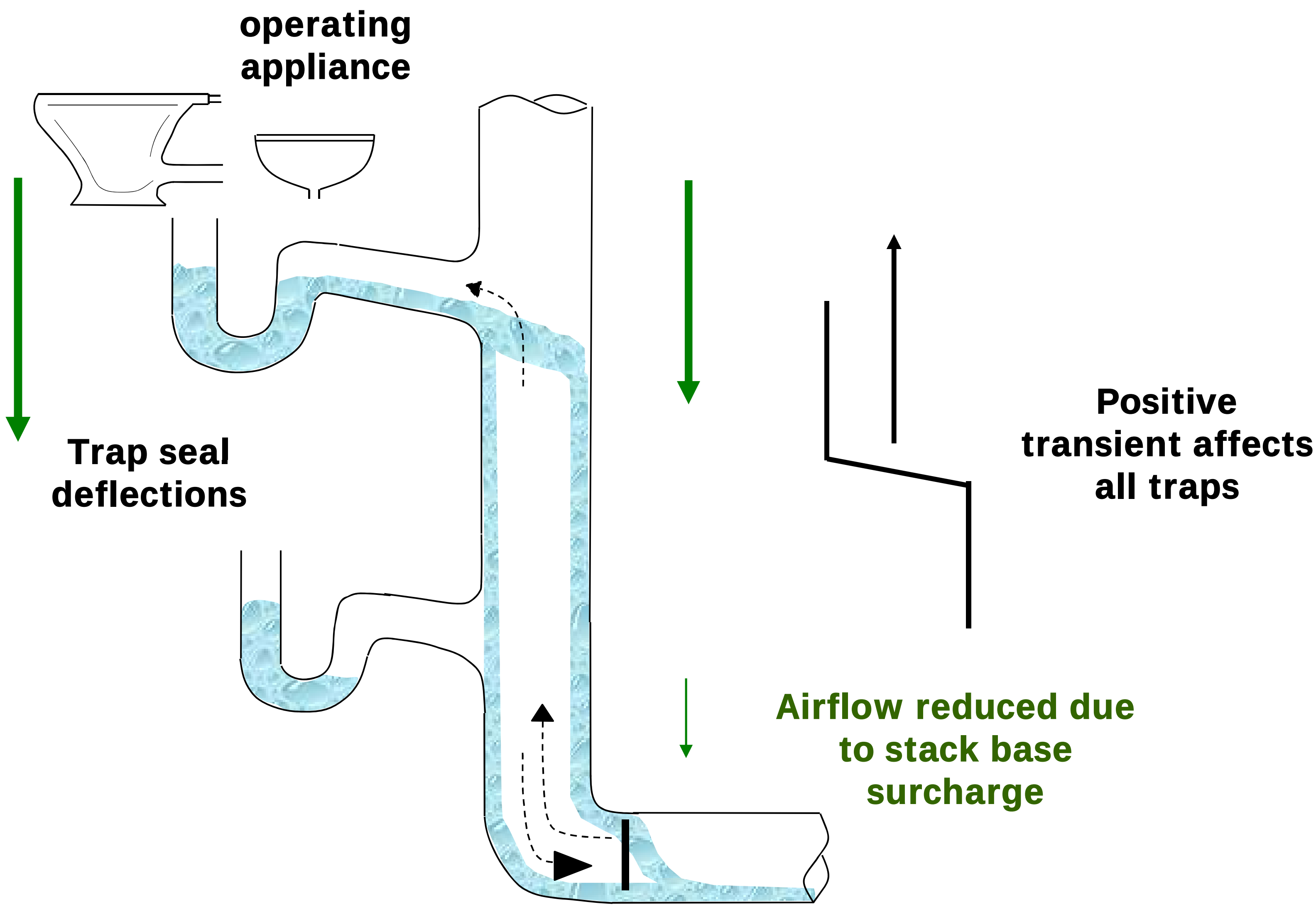
- Bioaerosols, particularly those containing viruses are particularly difficult to isolate and identify.

- This task is made even more difficult due to the unsteady nature of flows in building drainage systems.

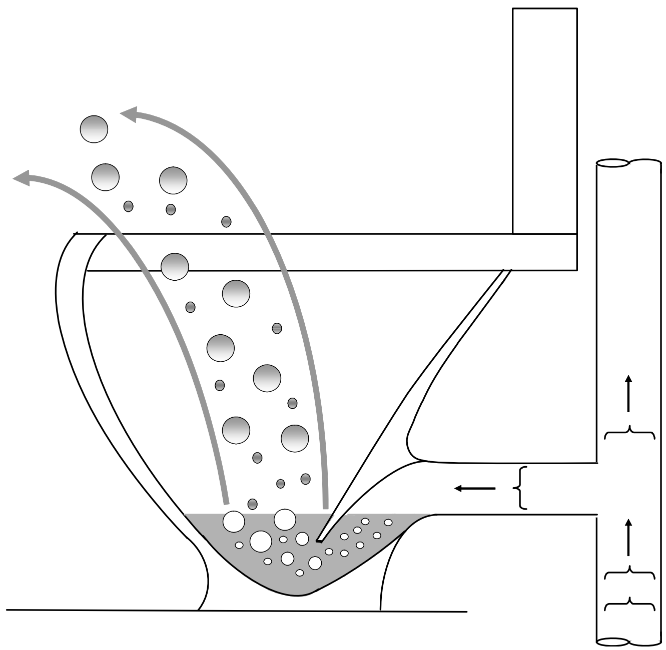
Building drainage system: mechanisms for air flow and pressure transient generation



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



Pressure transients in system can cause traps to blow out-



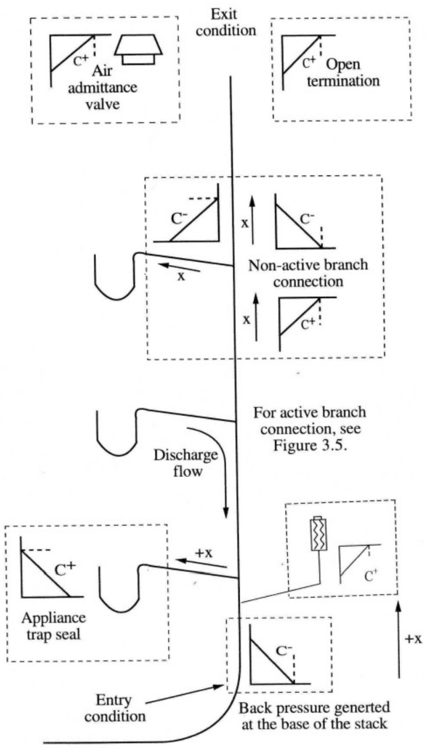
http://www.youtube.com/watch?feature=player_detailpage&v=d_vNLMCZ9jQ

[video](http://www.youtube.com/watch?feature=player_detailpage&v=d_vNLMCZ9jQ)

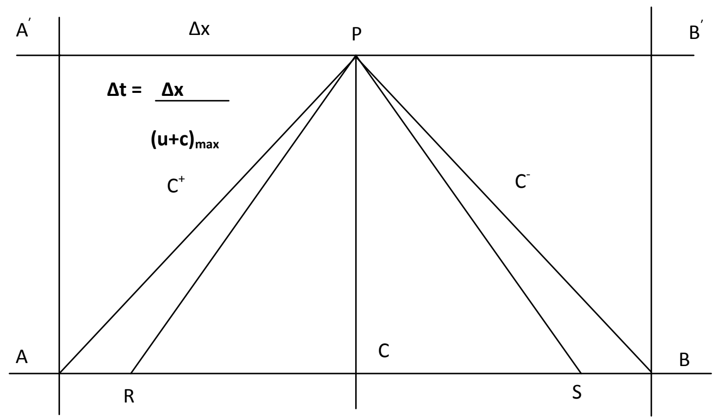
The attached video is an extreme example – but it is real – most common symptom of smaller pressure transients is bubbling through a trap, you may have seen this in a toilet bowl.

- 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

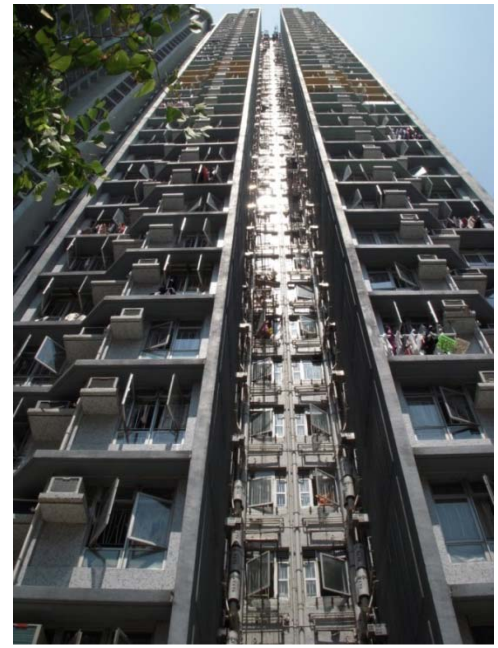
$$u_P - u_S - \frac{2}{\gamma - 1}(c_P - c_S) + 4 f_S u_S |u_S| \frac{\Delta t}{2D} = 0$$

when

$$\frac{dx}{dt} = u - c$$

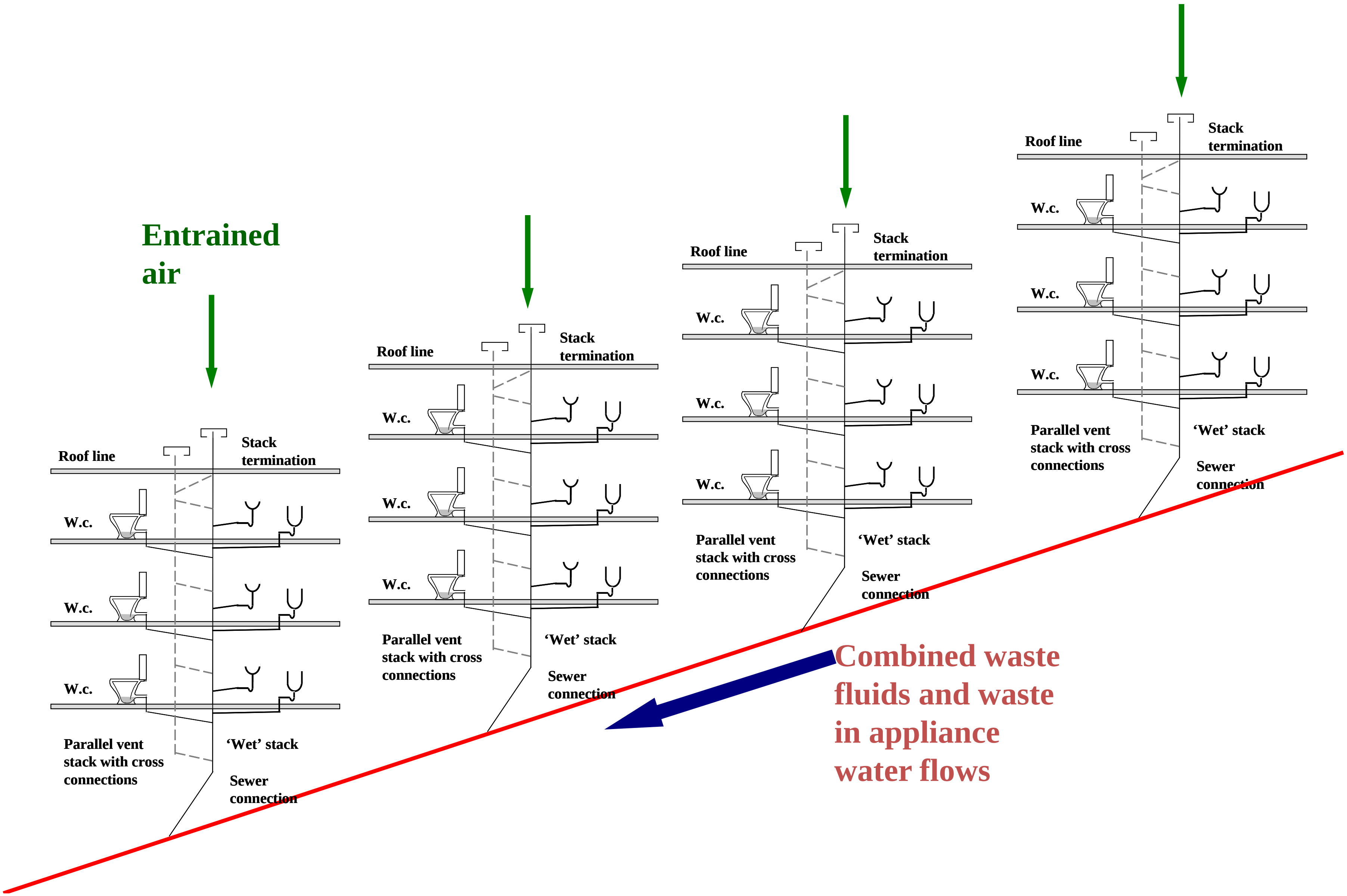
AIRNET modelling

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

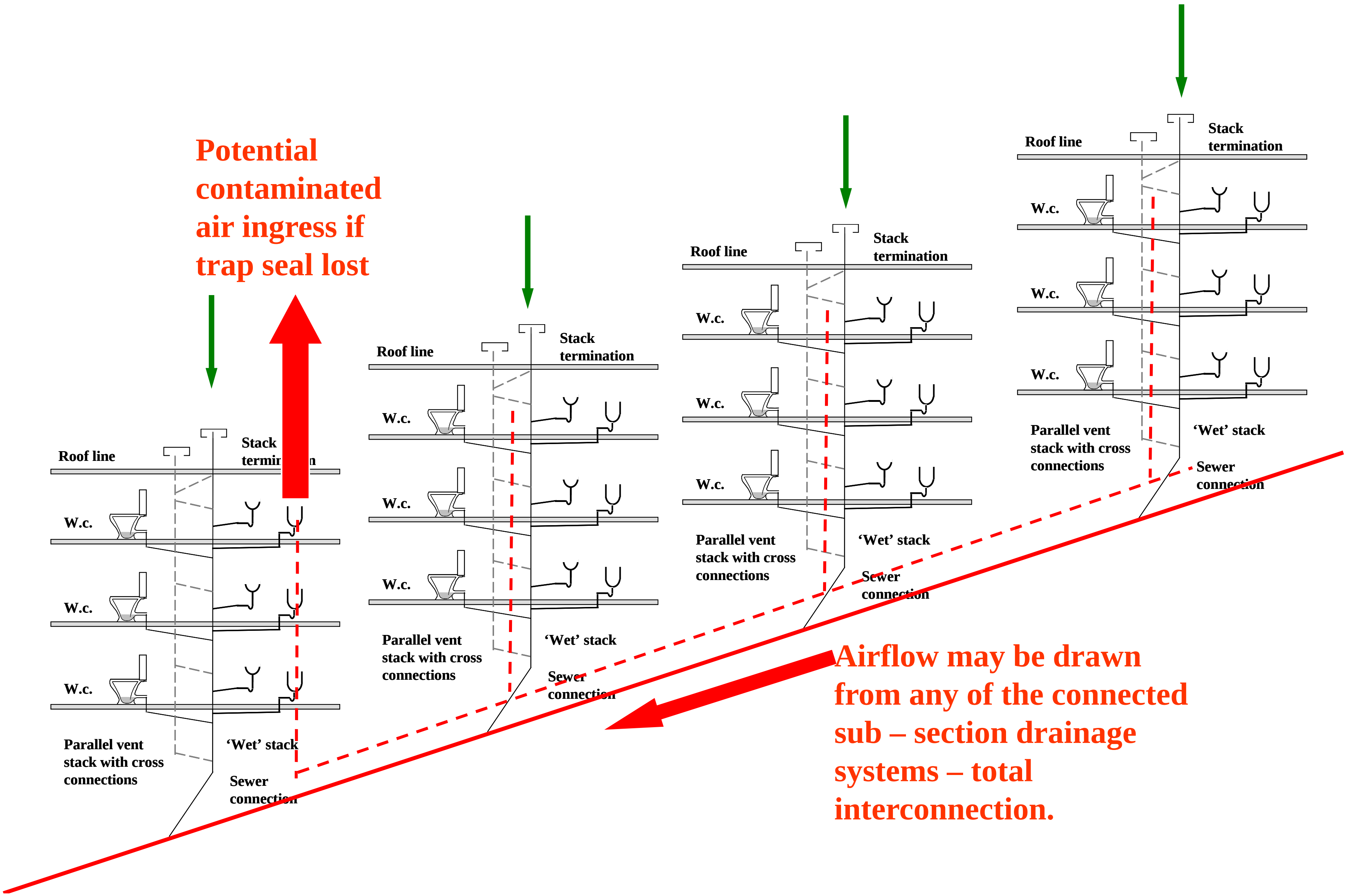


50 Storey housing block in Hong Kong
Modelling led to novel approaches to preventing excessive positive pressures using P.A.P.A.™

modelling air pressure and flow in large systems



Potential contaminated air ingress if trap seal lost



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

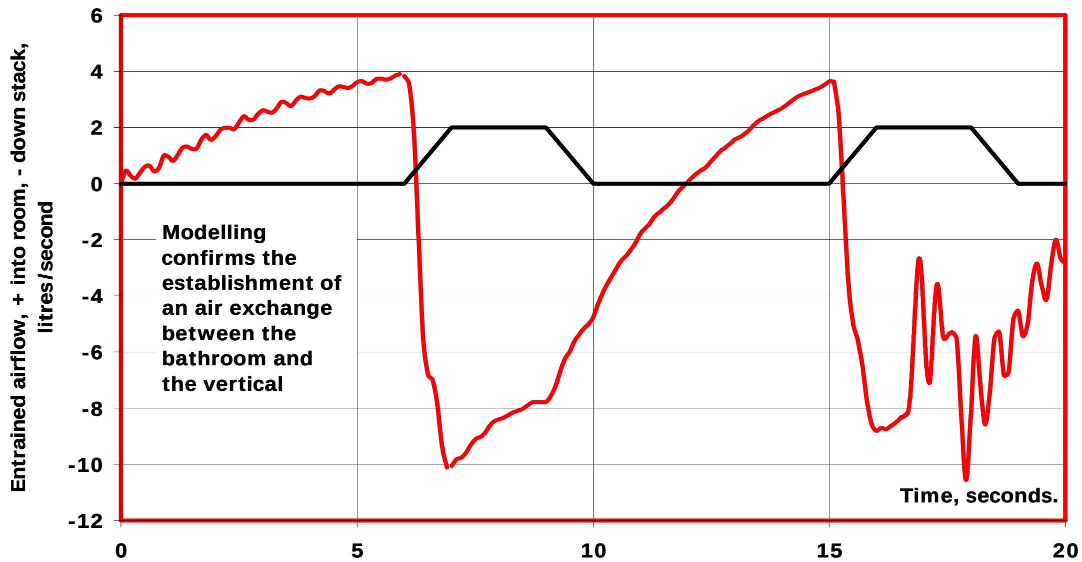
Limitations

- 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

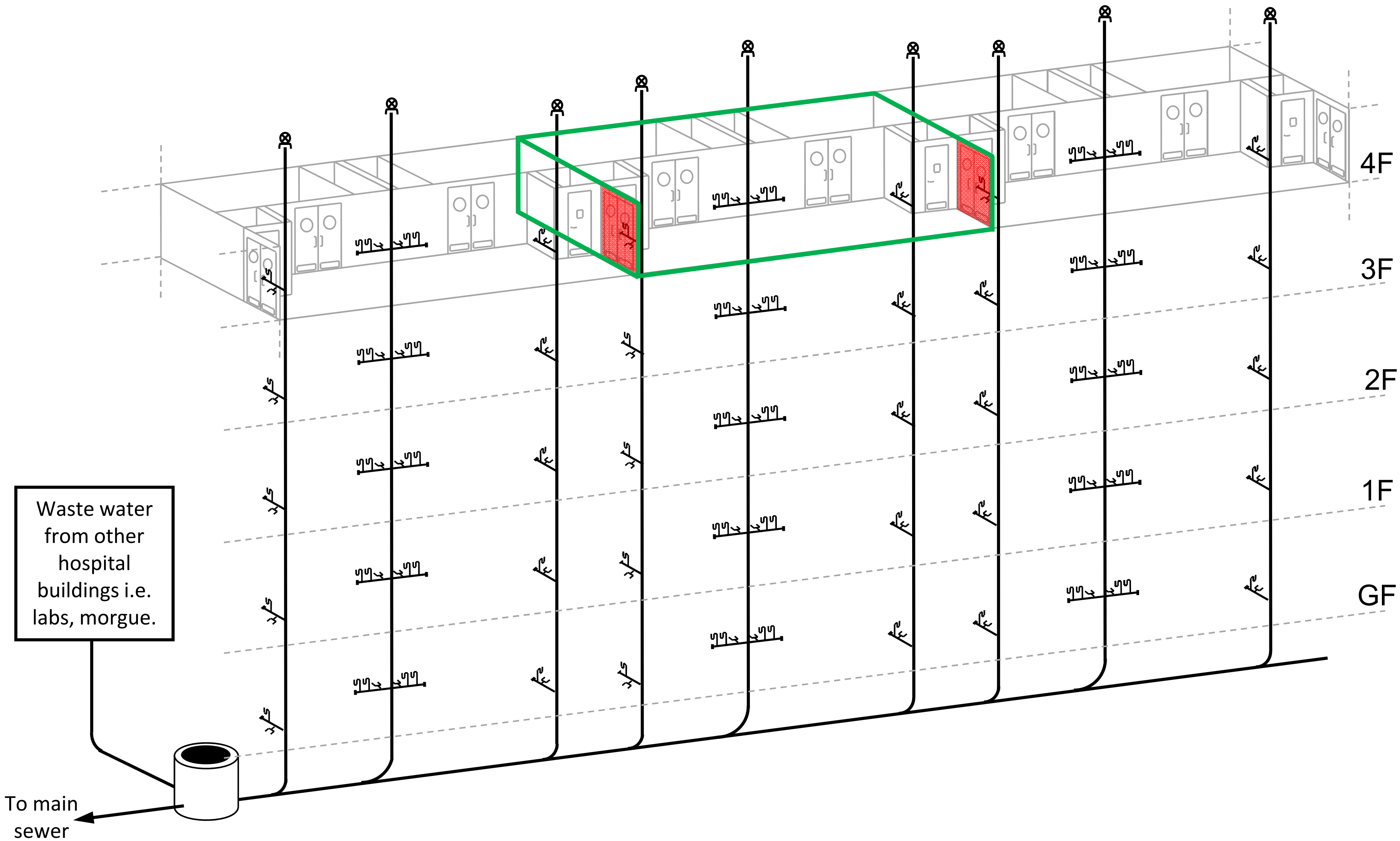
- Flow direction and rate can be calculated – approximations of likely bio-aerosol transport mechanisms can be made.

Modelling flow rate and direction



The building drainage system

Interconnection- all parts of the building are interconnected



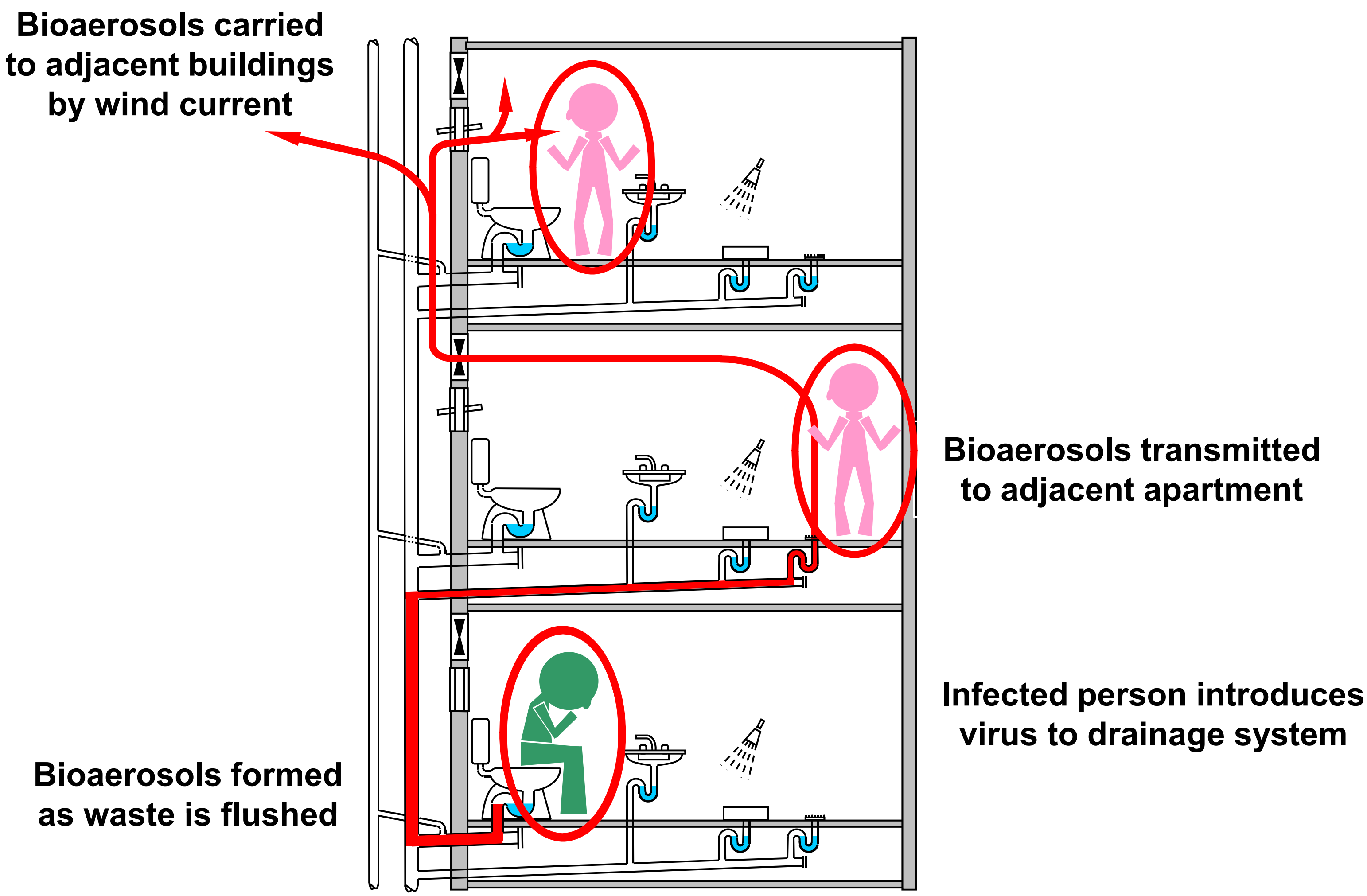
The building drainage system
SARS Outbreak

World Health Organization

Press Release WHO/70
26 September 2003:

"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



The building drainage system
New threats

World Health Organization

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.

WHO @WHO 7 Sep

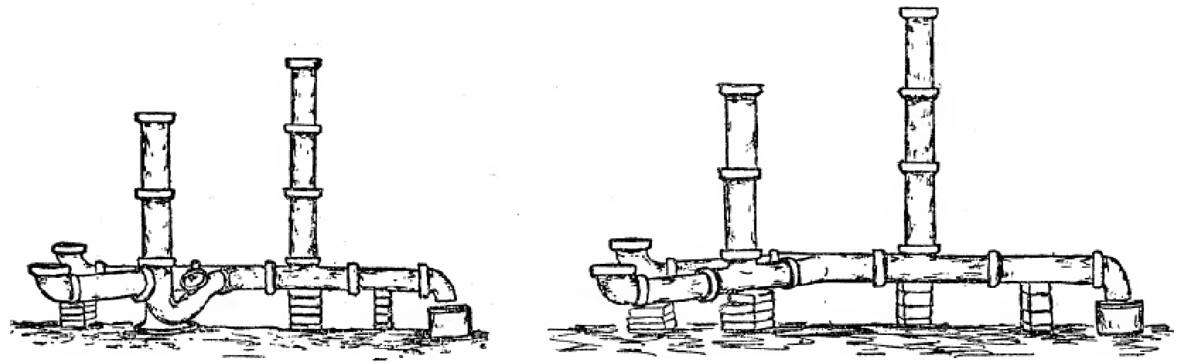
Globally, from Sept 2012 to date, WHO has been informed of 114 lab-confirmed cases of Middle East respiratory syndrome, incl 54 deaths #MERS

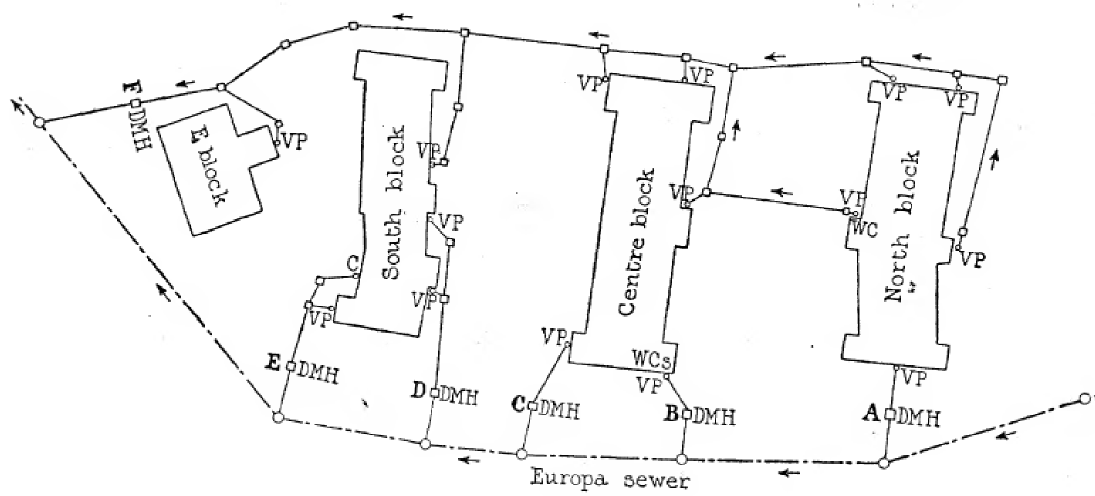
Expand

Airborne transmission evidence
Forgotten knowledge

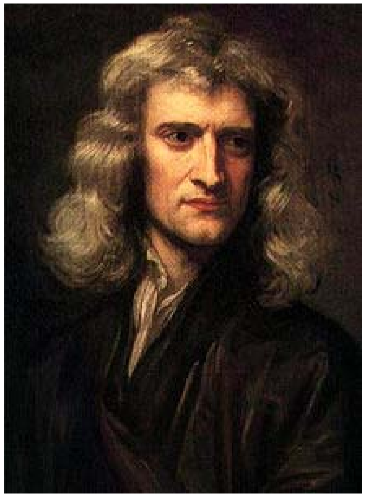
1907: cultured airborne ***Serratia marcescens*** (then termed ***Bacillus prodigiosus***) from drainage systems and detected airborne transport from one hospital building to another via the sewer drain.

Sir William Heaton Horrocks
(1859-1941)

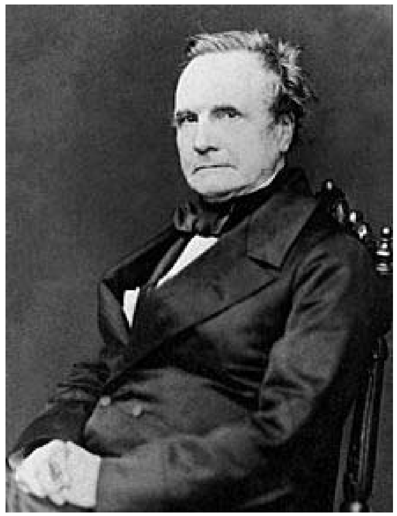




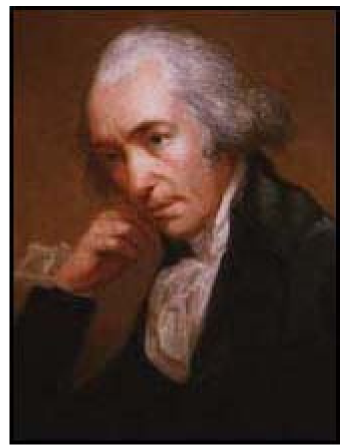
Horrocks – In good company
The Royal Society



Isaac Newton



Charles Babbage



James Watt

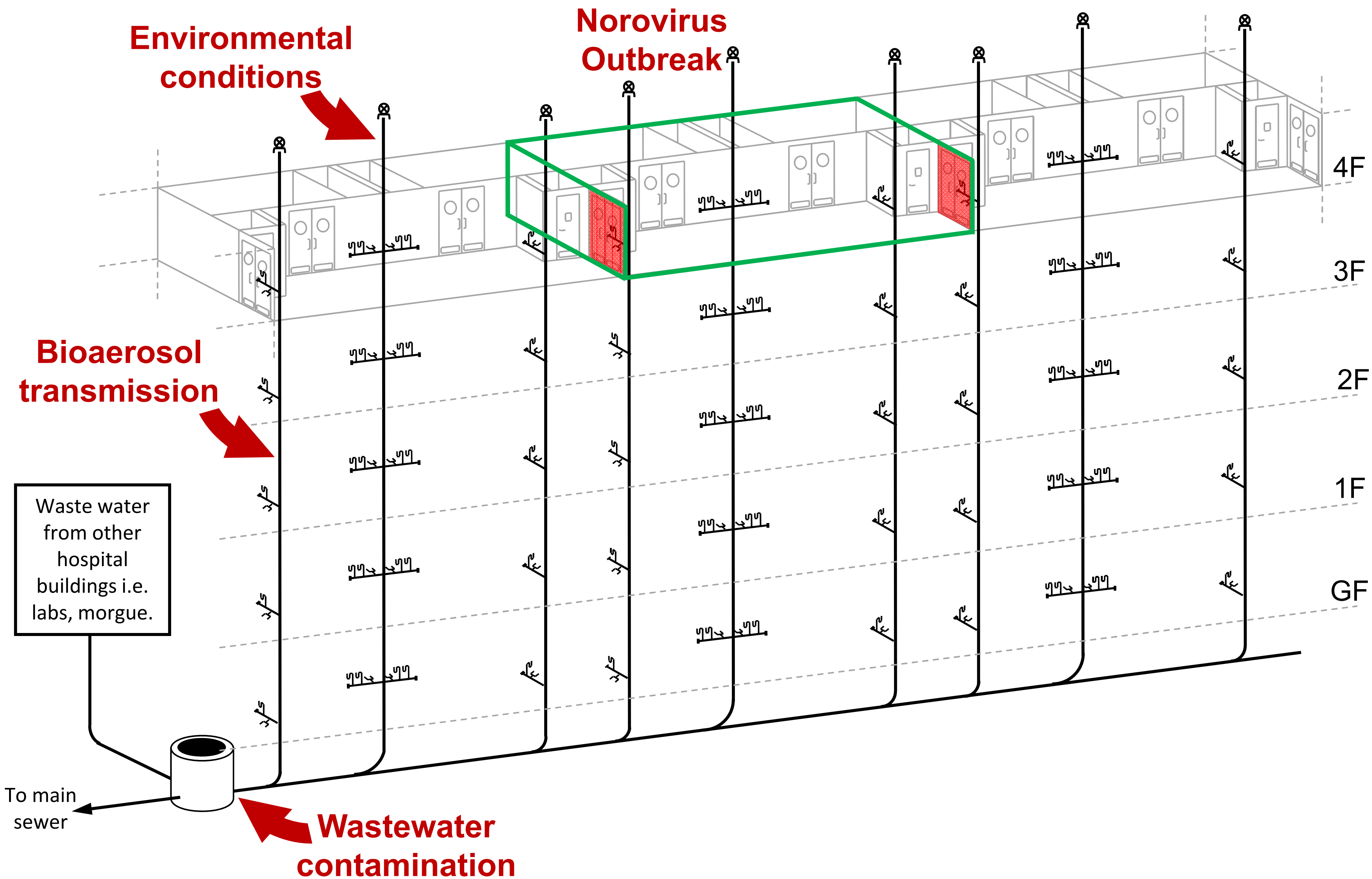
Horrocks – Other Successes

- 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.

Horrocks, William Heaton (1901). *An Introduction to the Bacteriological Examination of Water*. London: J. & A. Churchill.

Pathogen transmission study

Hospital building



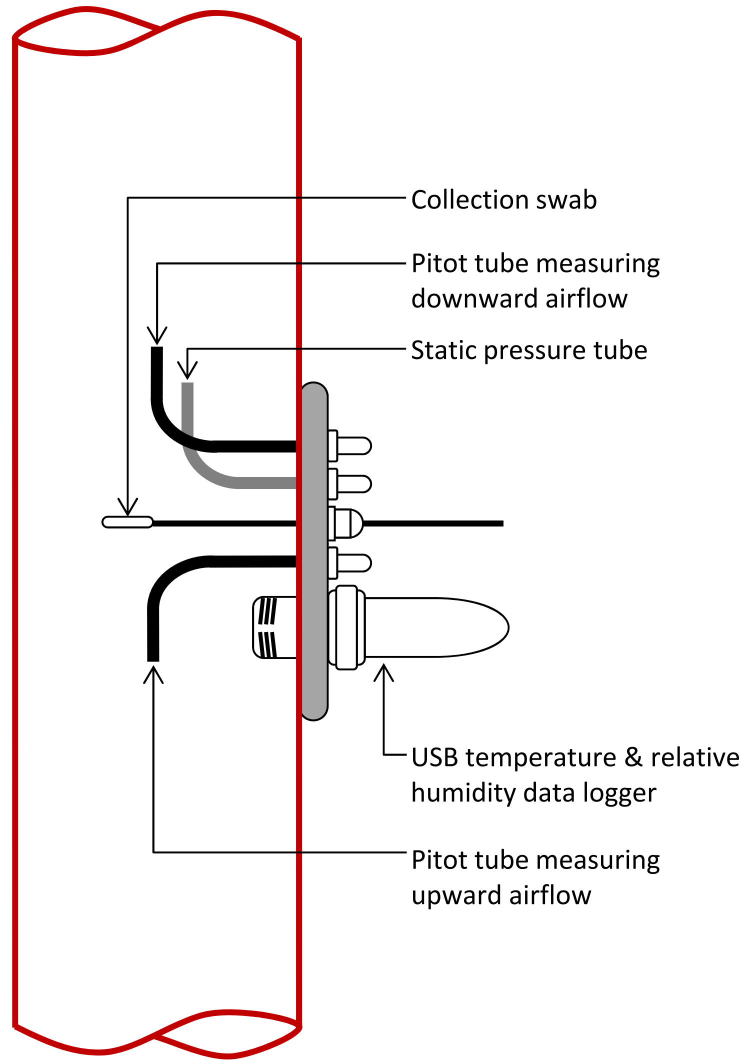
Pathogen transmission study
Hospital building

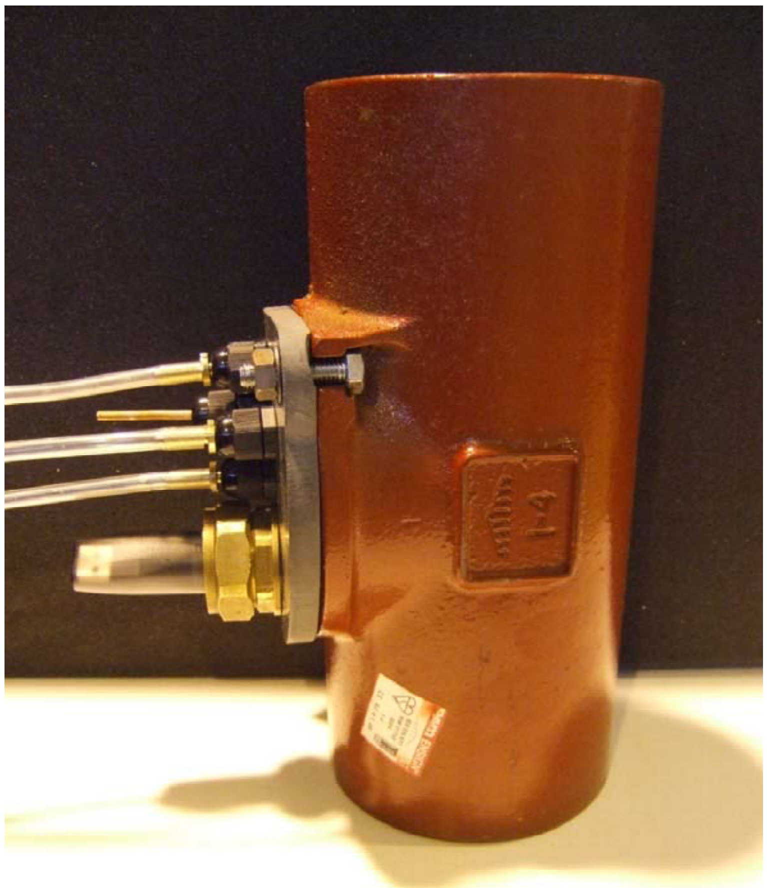
Air sampling

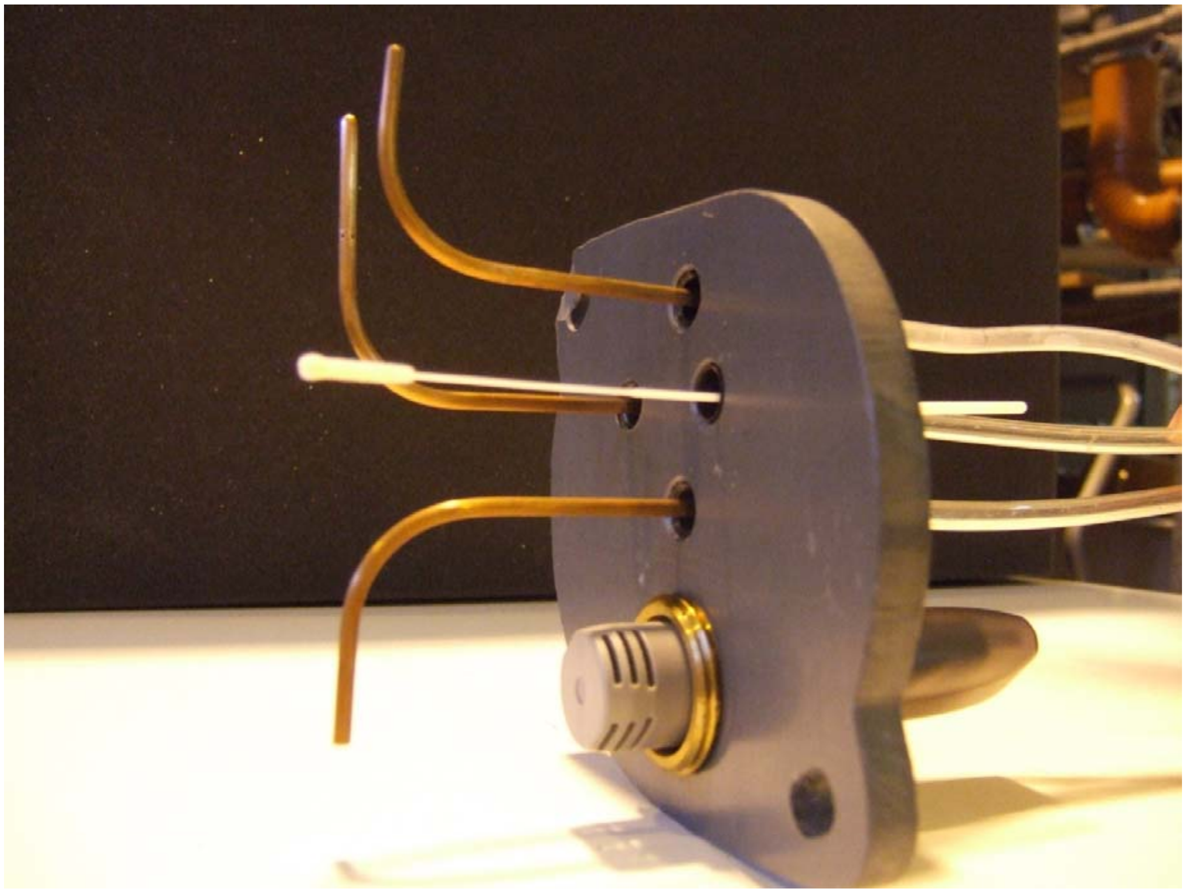
- Isolation of bioaerosols using collection swab (UTM-RT)
- Temperature and humidity within drainage stack (USB data logger)
- Air flow and direction (pitot tube)

Wastewater sampling

- Collection of wastewater from main underground drain





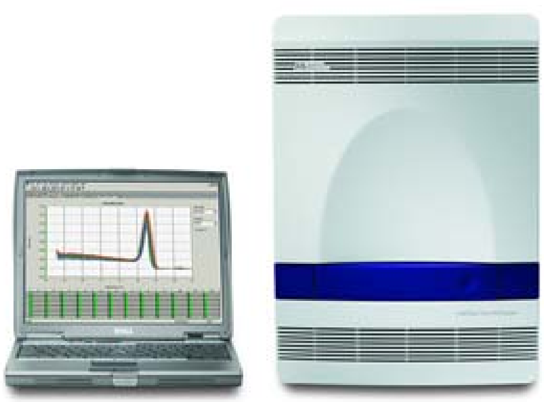



Grant
TEST EQUIPMENT
INSTALLED BY
HERIOT-WATT UNIVERSITY

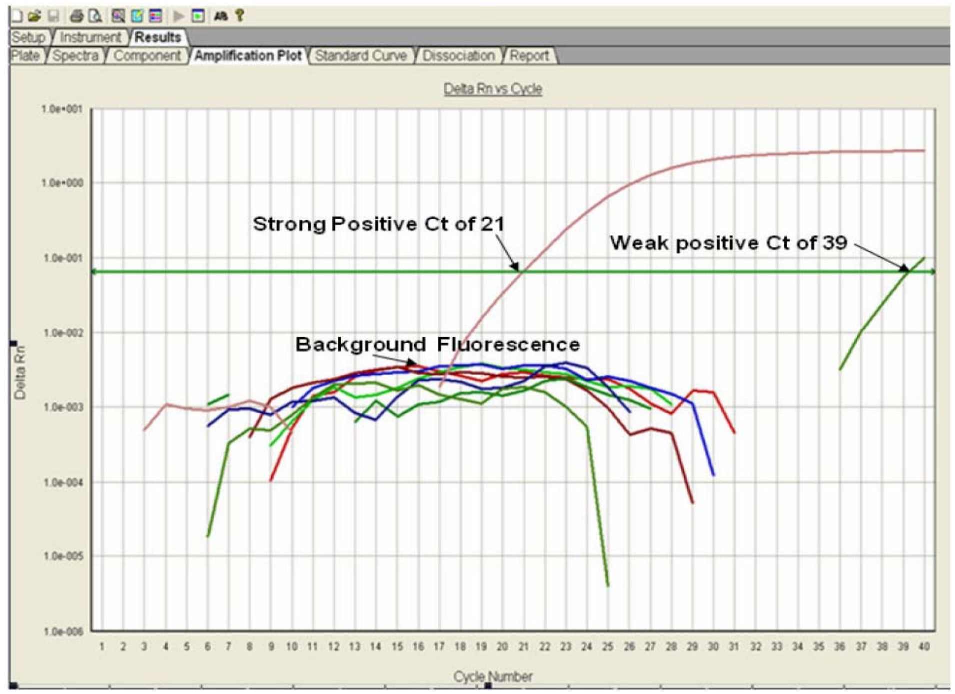
Pathogen transmission study

Real Time Polymerase Chain Reaction

Samples extracted using
NucliSens® easyMAG™ system



Amplification, detection and analysis
performed in an ABI 7500 RT-PCR system



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)

Pathogen transmission study
RT-PCR Results

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

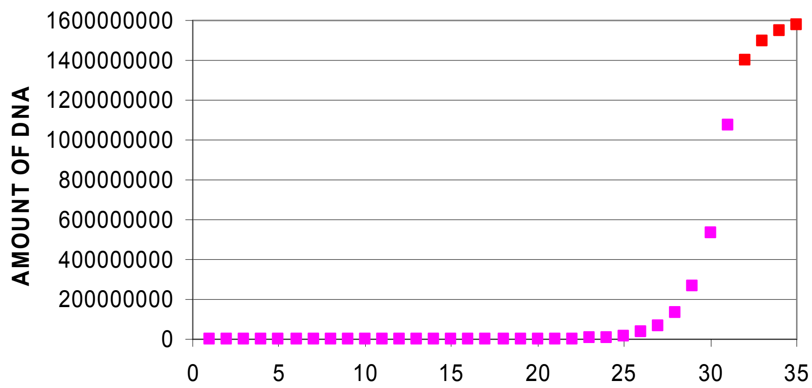
U	Undetected
Ct ≤ 29	Strong positive reaction (abundant target nucleic acid)
Ct 30-37	Positive reaction (moderate amount of target nucleic acid)
Ct 38-40	Weak reaction (minimal amounts of target nucleic acid)

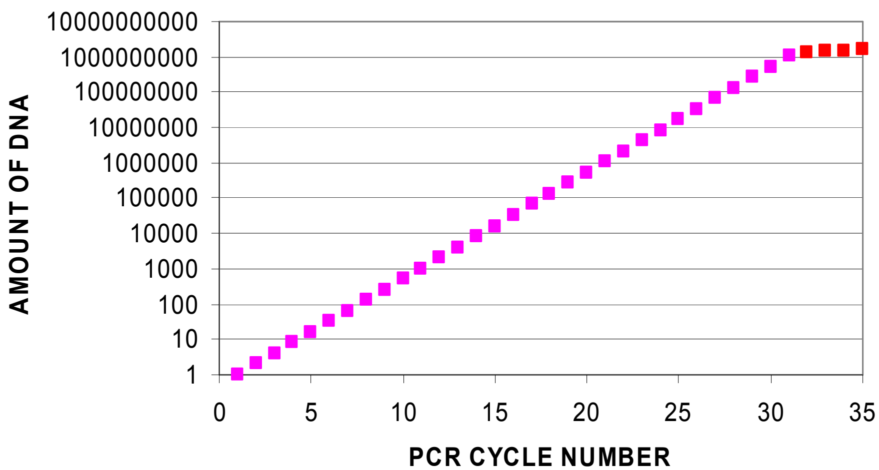
*a swab of the inside surface of Stack 1 taken on this date also returned undetected for all tests

Pathogen transmission study
RT-PCR Results

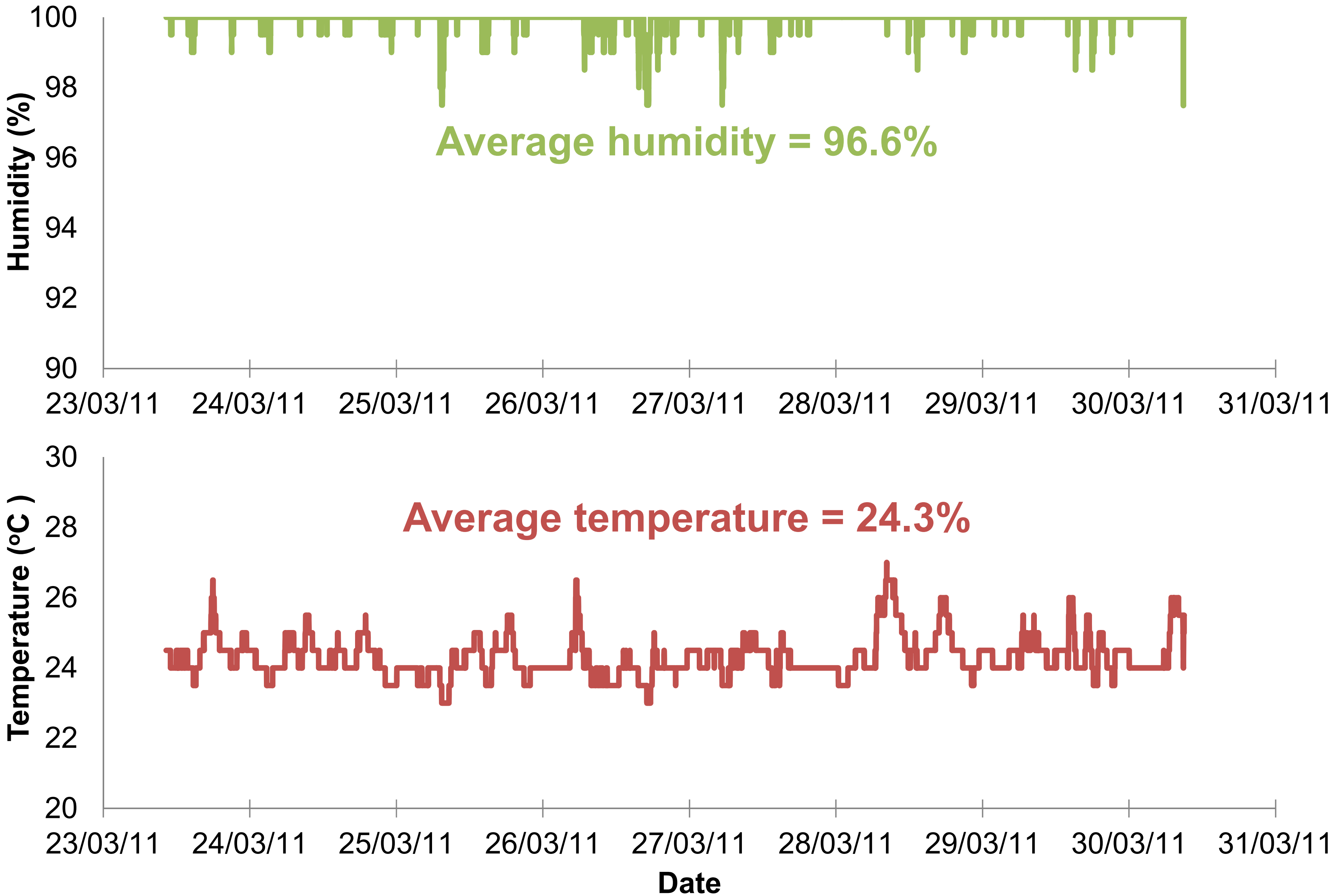
Samples were also tested for Clostridium deficile but was undetected.
This was due to the fact that *Cdiff* produces spores which are not amenable to many of the PCR assays available.

CYCLE NUMBER	AMOUNT OF DNA
0	1
1	2
2	4
3	8
4	16
5	32
6	64
7	128
8	256
9	512
10	1,024
11	2,048
12	4,096
13	8,192
14	16,384
15	32,768
16	65,536
17	131,072
18	262,144
19	524,288
20	1,048,576
21	2,097,152
22	4,194,304
23	8,388,608
24	16,777,216
25	33,554,432
26	67,108,864
27	134,217,728
28	268,435,456
29	536,870,912
30	1,073,741,824
31	1,400,000,000
32	1,500,000,000
33	1,550,000,000
34	1,580,000,000



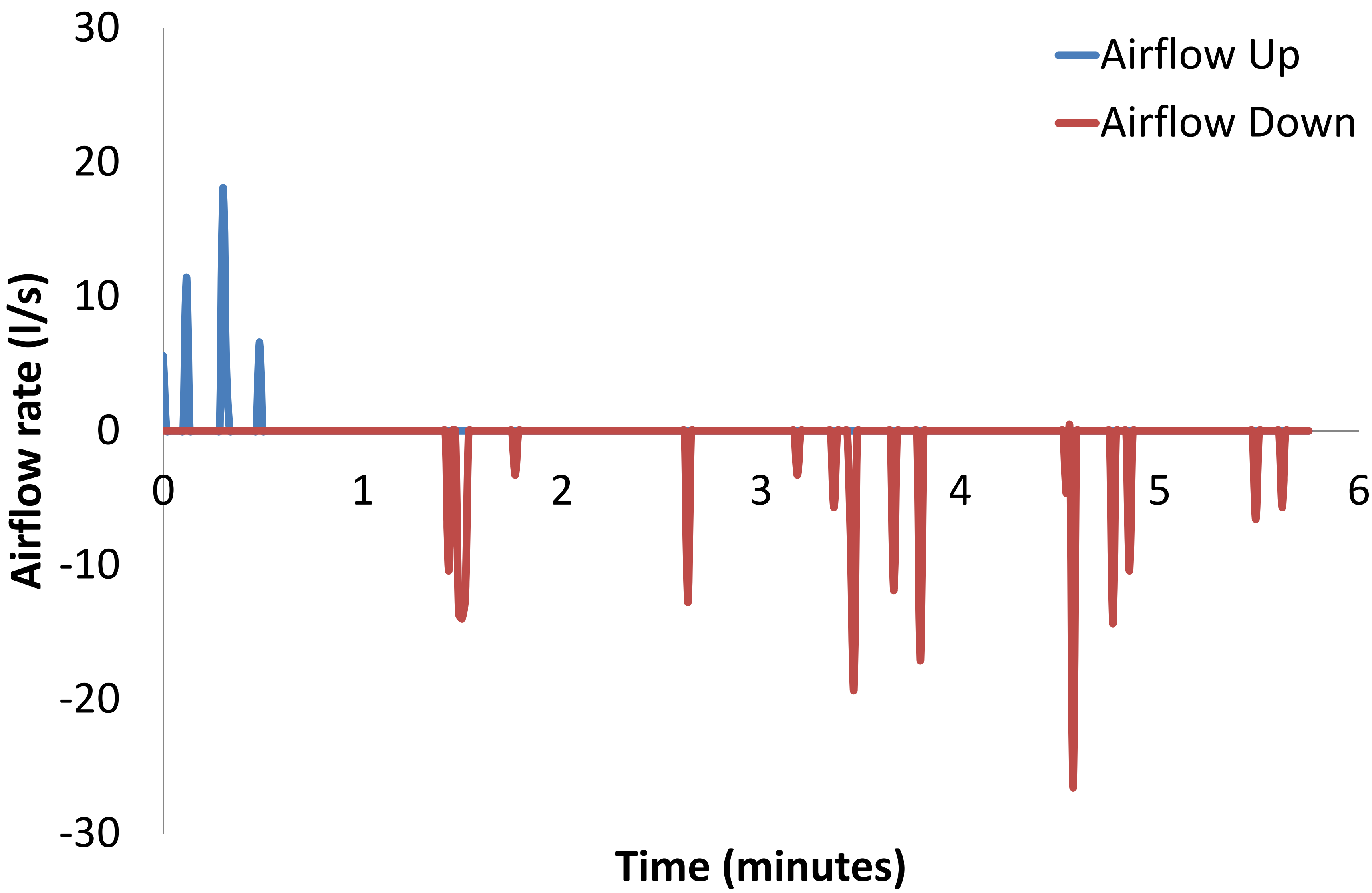


Pathogen transmission study
Temperature and Humidity

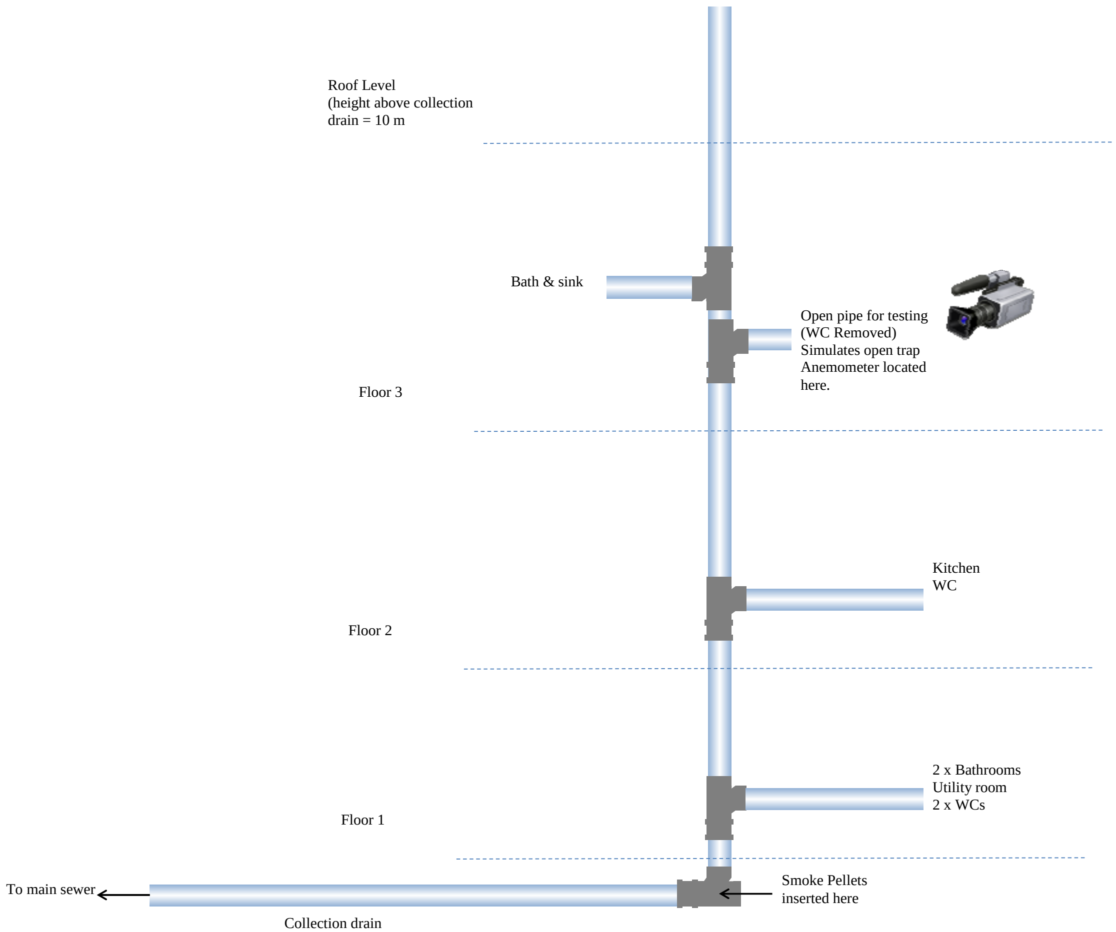


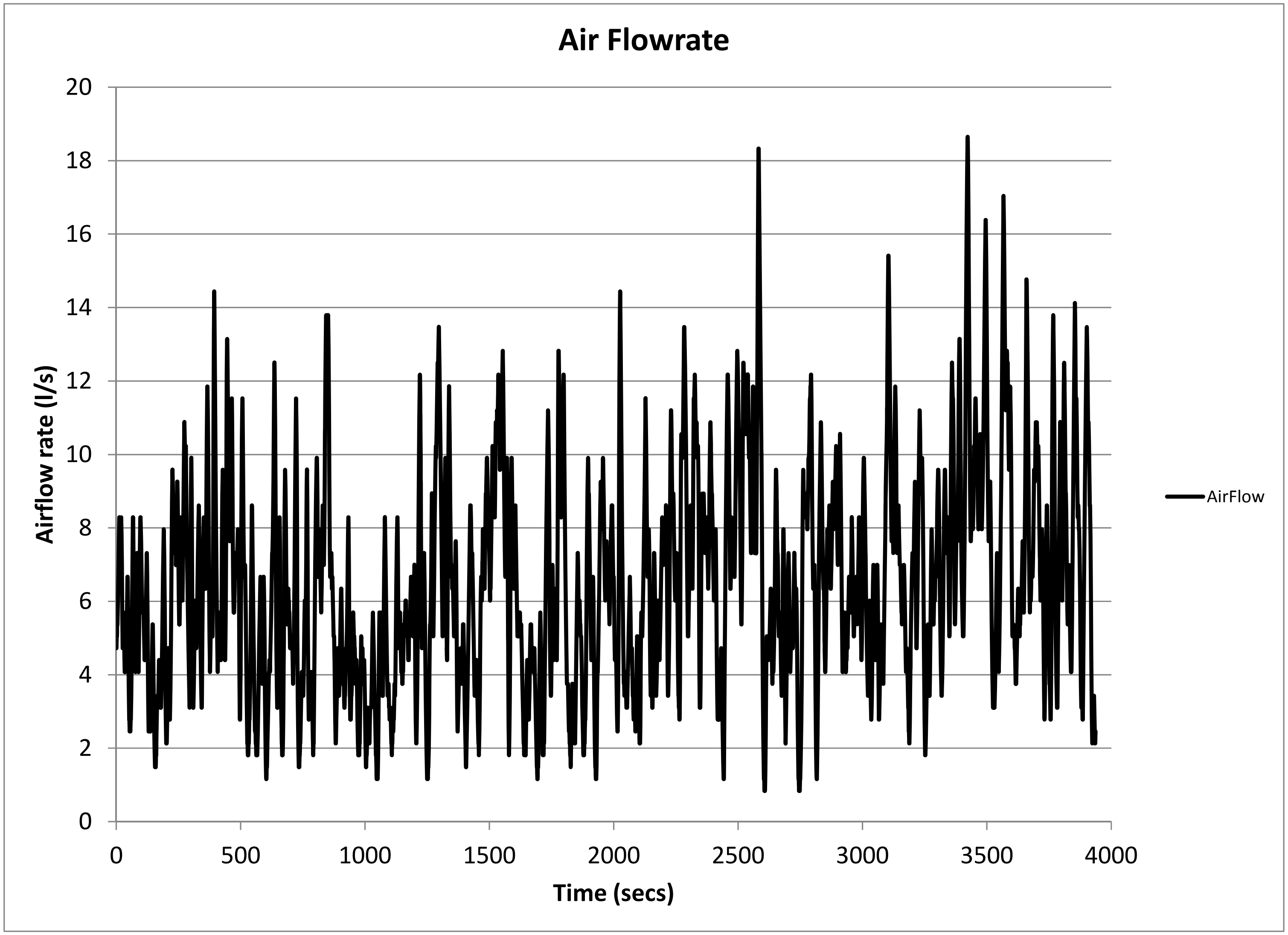
Pathogen transmission study

Airflow results – this proves that the interconnection hypothesis is valid



Additonal Domestic system tests
Drainage System Schematic



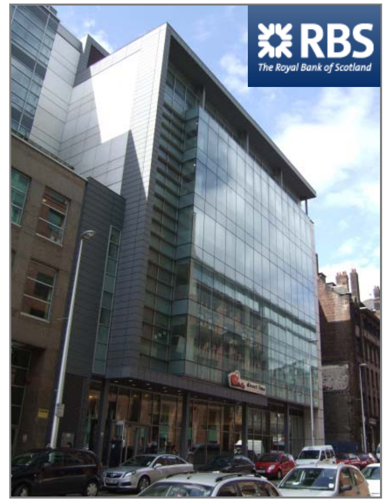


Note: Similar Airflows to those recorded in Amoy Gardens

The DYTEQTA System
Automated monitoring method

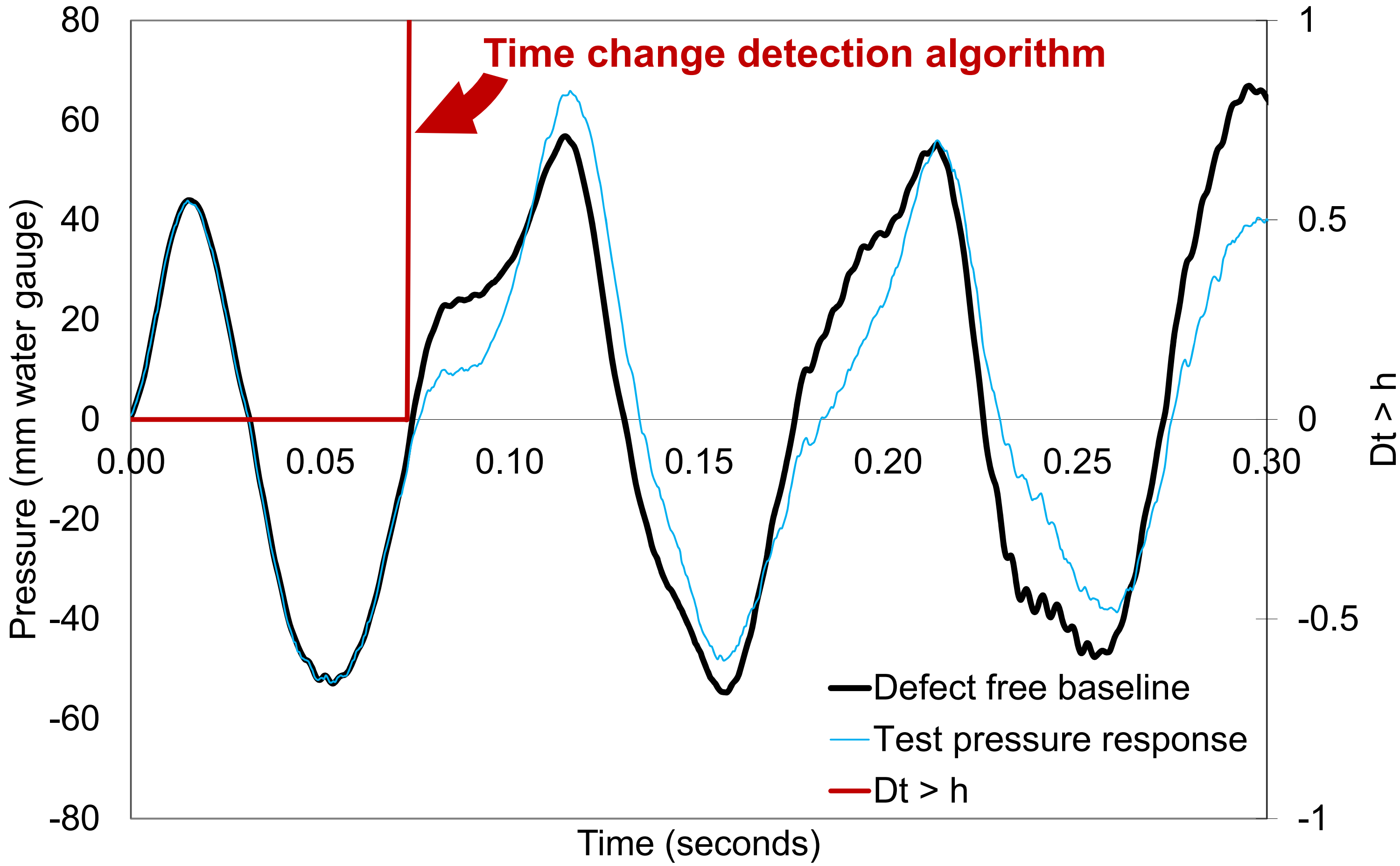
- Defective fixture trap seals increase risk of bioaerosol transmission via the building drainage network
- Dyteqta is a sonar-like method for establishing the status of each fixture trap seal in a building
- Based on reflected wave theory
- Using a sinusoidal air pressure wave ensures the test is non-destructive
- System validated by: modelling, laboratory investigations and extensive site testing

Case study Buildings



The DYTEQTA System

Case studies

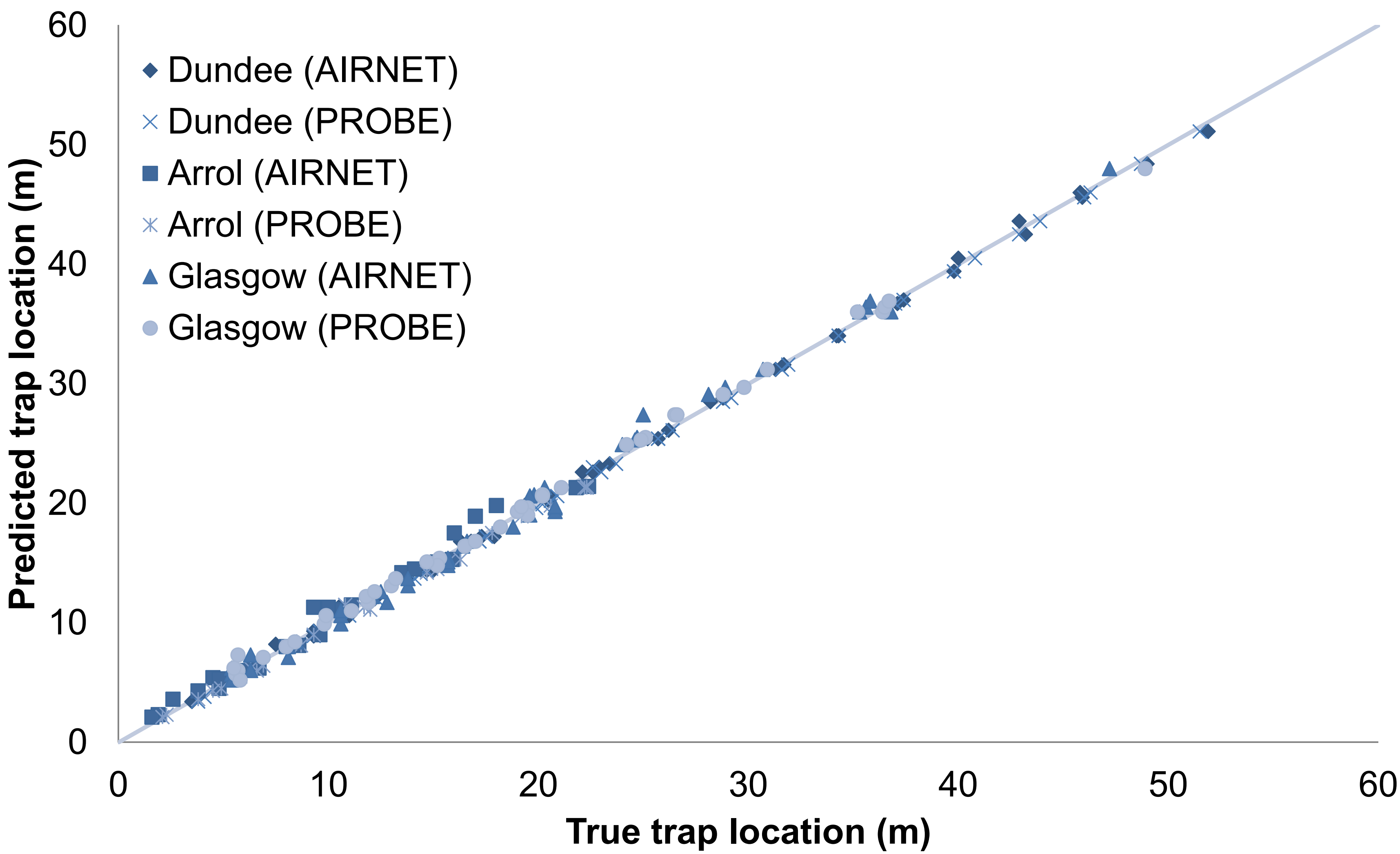


Is D_t > h over calibration period? NO, trace is reliable.

Is D_t > h during test period? YES, at t_D = 0.066 seconds.

Depleted trap location? T12.

The DYTEQTA System
Case studies



The building drainage system
Transmission of bioaerosols

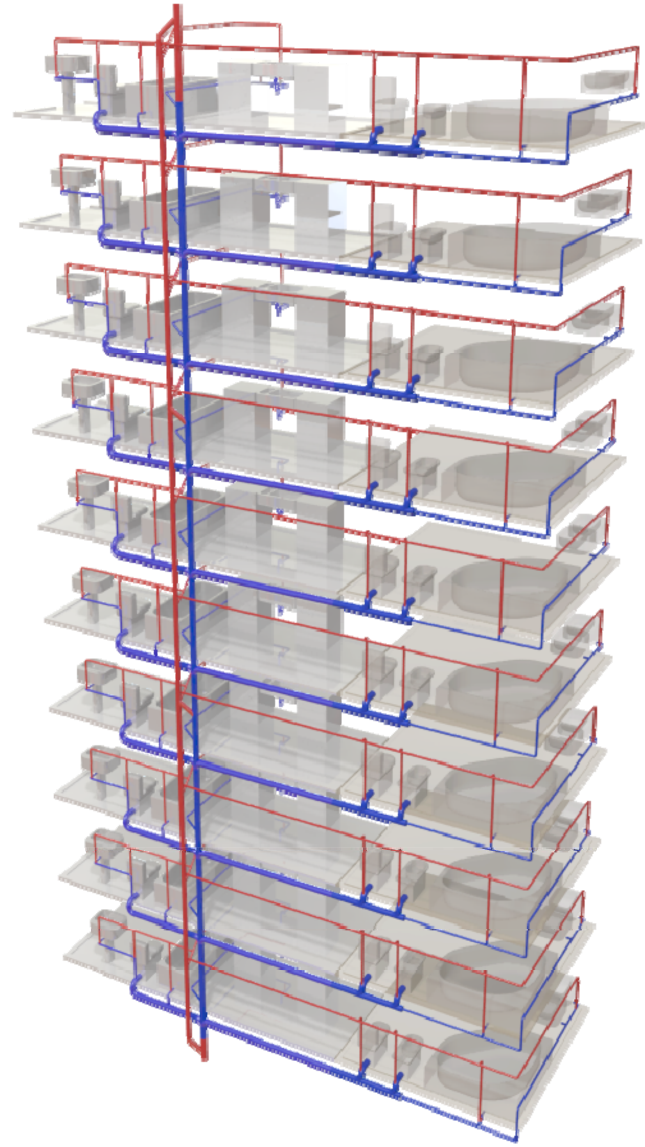
- The building drainage system interconnects all parts of a building

- 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.

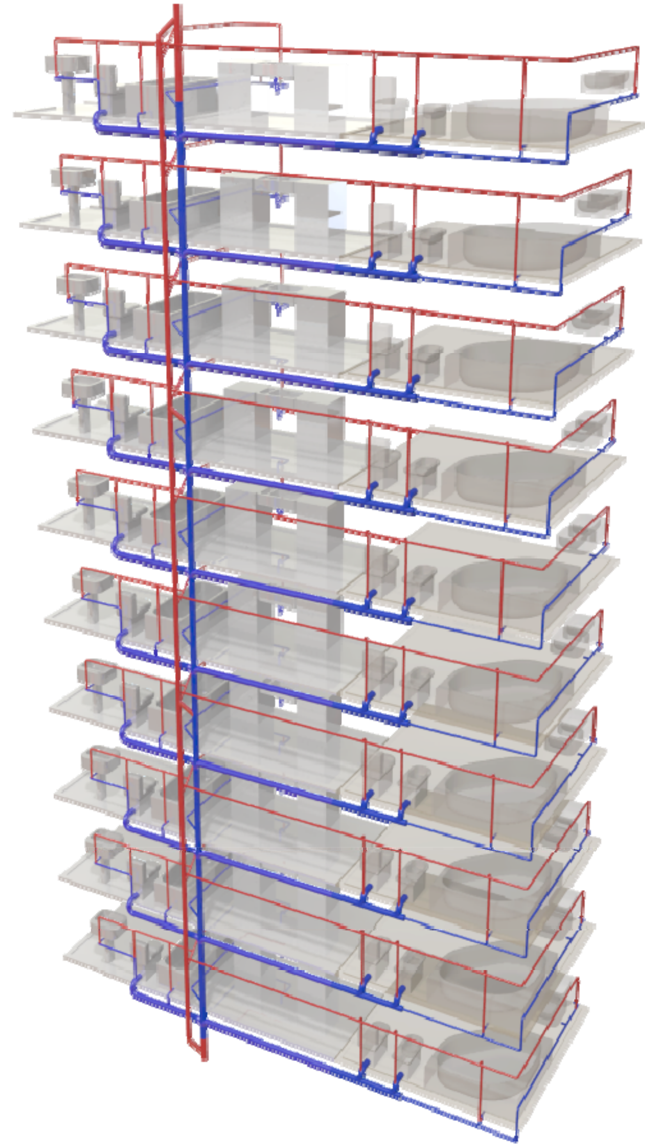
- Norovirus GII isolated from wastewater sampled from main drain of a hospital building, confirming contamination during an outbreak.



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 *psuedomonas spp.* Can be carried on airstreams inside a building drainage system.



Thank you for listening