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Excising Infection in the Surgical Environment (ExISE)

A new AHRC initiative is exploring the architecture and design of operating theatres and what it could mean for AMR research.

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Excising Infection in the Surgical Environment (ExISE) is a newly funded Arts and Humanities Research Council research project within the major cross-UK Research Council initiative Tackling Antimicrobial Resistance (AMR). A perhaps unusually interdisciplinary team of academics in infectious diseases, pathogen transmission, architecture, history and philosophy of science, fluid mechanics, and history of art will introduce a design perspective to AMR research by investigating the physical environments for surgery. Project partners include RCS Research Fellows, the NHS Sustainable Development Unit, the Institute of Hospital Engineering and Estate Management, NHS Improvement, leading engineering and design practices Happold and Gensler, and the international hospital contractor Skanska.

It builds on the scoping work of the Principal Investigator's NHS-funded 'Bloody Rooms' project, which enabled a basic understanding of the behaviour of pathogens within airflows in a hospital room. The aim of the research is to eliminate aerosol-related Surgical Site Infections (SSIs) in operating theatres (OTs) through re-examining the evidence. The work may lead to the reinvention of the physical surgical environment to a greater or lesser degree. Designing out transmission routes for SSIs could ultimately reduce the reactive use of antibiotics post-surgery and hence their contribution to AMR.

The importance of airborne transmission in OTs appears to have dominated design throughout the past 60 years or so, but the position on a favoured solution taken since the late 1950s is not wholly proven and has not kept pace with modern surgery. Sadly SSIs are

not eliminated in contemporary OTs and so the research team asks: 'Is there another way?'

According to our medical school colleagues, more recent studies suggest that current surveillance may have underestimated SSIs by up to 50%. Costs of SSIs in readmissions, increased length of stay, and additional procedures and treatment may be as much as £700 million per year in the UK. A 2016 meta-analysis on all surgical wounds by Hyldig *et al* showed an infection rate of 9%. In 2015 Inui *et al* reported on vascular wound infections presenting after 10–20% of operations. The primary mechanisms of airborne-related transmission are thought to be due to pathogens already within the room – normally bacteria or fungi – being released into the air. This may be from a surgical procedure that aerosolises droplets containing microorganisms from the patient's own body or released on skin squame from the surgical team. Rather than being inhaled, as in classical airborne infection, these pathogens deposit out – either directly into woundsites or indirectly by contaminating instruments. These microorganisms pose a major problem when they enter a woundsite. The mid-20th-century redesign of the OT was driven by the idea that SSIs could be dramatically reduced by the mechanical induction of prodigious flows of cool air through the OT, over all occupants and contents.

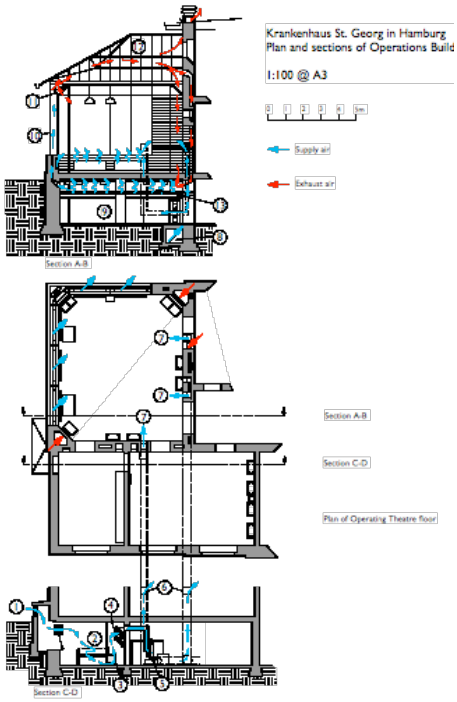
Operating theatres in the UK currently conform to one of two configurations prescribed in HTM03-01 Part A *Specialised Ventilation for Healthcare Premises*: the Ultra Clean downflow Ventilated (UCV) or the 'Mixed' Ventilation (MV) theatre. Both cases deliver high ventilation rates. In the UCV, there are up to 40 full room air changes per hour (ie every 90 seconds), making what appears to us to be a bizarre working environment. The guidance has become enshrined contractually by a liability-conscious construction industry, yet has not kept pace with surgical developments. The same rooms and ventilation are now used for complex surgery using robotic techniques, where equipment and the heat load disrupt airflow patterns, as well as keyhole surgery with the smallest of incisions in the body.

'Bloody Rooms' started to assemble an outline history of OT design and its drivers. ExISE will go on to develop a detailed history so that we can understand how we have got to where we are. Modern OTs are described as heavily controlled environments. Early surgical amphitheatres accommodated the public spectacle of surgery, but operating theatres built after 1890 set surgery apart. Coupled with strict aseptic routines, the gleaming, light-filled, standalone operating theatres of the period were constructed to thwart germs from infiltrating surgical sites.

The sophisticated *Operationshaus* at Hamburg's General Hospital in St Georg (built 1897) was cocooned in a double glass envelope through which warm air was drawn naturally and recirculated, constantly ascending to prevent downdraughts and condensation forming. However, the actual theatre was mildly pressurised with air pumped by a centrifugal fan, which was then filtered through charcoal and gravel and drawn over ice in hot weather or heater batteries in winter. Figure 1 shows our reconstruction of the Aseptic theatre at St Georg from contemporary publications celebrating its opening. The intention in Hamburg was to deliver an environment equivalent to a hospital in the countryside. Its near contemporary in Nuremburg pursued a similar highly glazed sealed envelope with interstitial heating. These approaches were subsequently denounced as technology progressed but might have invented a fundamental configuration of lasting value.

Subsequent 20th-century efforts to standardise surgical procedures and spatial configurations alike were in part a response to airborne infection worries. In a series of papers, Bourdillon and his co-authors proposed to displace airborne particles as if by a 'piston' of air at up to 60 air changes per hour. By 1955, the Nuffield Trust reported that mechanical air conditioning was required for human comfort, better asepsis, and safety. It suggested that mechanical air conditioning was pragmatic to enable lower ceiling heights so that OTs could be absorbed into new multistorey-framed hospitals, losing the separate *Operationshaus*. Theatres typically enjoyed 10–12 air changes an hour, which is a rate still deemed acceptable by Bourdillon – but already a 10-fold increase from the 1890s values. Planning documents from the 1960s specified ventilation standards that required most theatre spaces to be pressurised and ventilated at significantly

Figure 1 The aseptic operating theatre in the *Operationshaus* at Hamburg's St Georg General Hospital in 1897 (reconstructed by Slaine Campbell from archival research by Kathryn Schoefert at King's College London).



Key 1. Air intake for direct operating space ventilation; 2. First filter charcoal; 3. Pre-tempering chamber cooling over ice in summer; or 4. Heating over hot water batteries in winter; 5. Electric air pump; 6. Supply air outlets into the operating theatre beyond; 7. Location of supply outlets on plan; 8. Fresh air supply to cavity glazing on two sides of the theatre; 9. Space for tempering direct supply air to the theatre; 10. Wide cavity between outer clear and inner translucent glass; 11. Opening lights within the glazed cornice; 12. Glazed roof void collects exhaust air from cavities and it appears from the theatre before returning it through natural circulation 13. Heating plenum below the theatre floor.

higher rates (at least 1,000 cu.ft/min in the theatre). They defined 'clean' and 'dirty' zones and formalised room sizes and functions.

Modular operating theatres and the observed reduction in SSIs under the Charnley-Howorth canopy system supported these design decisions. Conceptual reliance on high-volume air exchanges in theatre to reduce airborne infection risk became firmly established. Yet researchers have periodically questioned the evidence base for current theatre ventilation regimes and spatial configurations.[6,7] ExISE fluids scientists will assemble laboratory models from the reconstructions of historical OTs of particular promise, alongside a contemporary 'Ultraclean' OT. Water-bath modelling for 'Bloody Rooms' indicates inconsistencies between theory and practice in the top-down and bottom-up forced ventilation of spaces with airborne pathogens, which are simulated here by silicon carbide particles at 13 microns (Figure 2). These are standard hospital ventilation strategies. ExISE will model the effects of a sustained downflow in a space in which contaminants are being discharged at a credible rate, as in the Ultraclean canopy configuration.

In parallel with its search for useful historical precedent, and modelling of the behaviour of pathogens within common airflow patterns, Exise will explore the human dimension. This will hopefully achieve greater understanding of the physical and psychological experience of being in and working in a contemporary OT for surgical teams and support staff, and the effect of behaviours on SSIs and ultimately AMR. Researchers will be visiting surgical teams and interviewing them *in situ* and at the Royal College of Surgeons. The research team is extremely interested to hear about surviving or well-documented historical operating theatres.

Figure 2 Series of images illustrating the time evolution of the particle concentration in a top-down ventilation system in which there is a source of cooling at high level in the space. The colour represents the concentration of the particles in the flow. The particles are supplied at high level with the stream of cooled air (here modelled as relatively dense saline water in this water-bath analogue). This descends to the floor of the space, mixes across the floor and generates a lower layer of particle-rich fluid, with the continuing supply of fluid causing the concentration to gradually build up. A steady state is reached when the supply of particles matches the outflow plus the rate of sedimentation on the floor of the space. In summary, the downflow system does not clear the space. Source: BP Institute University of Cambridge.

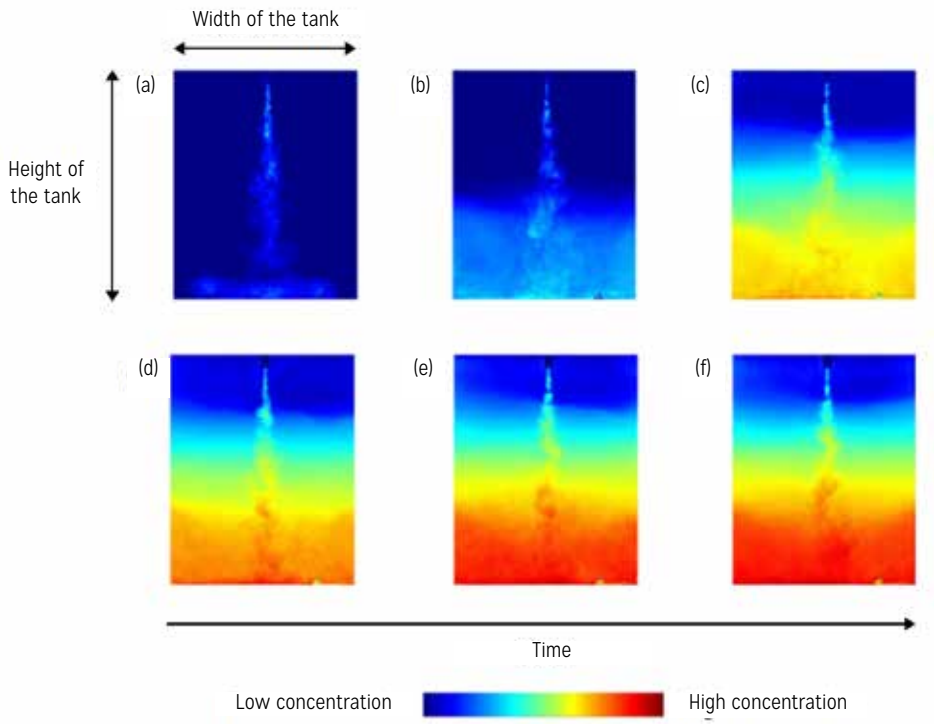
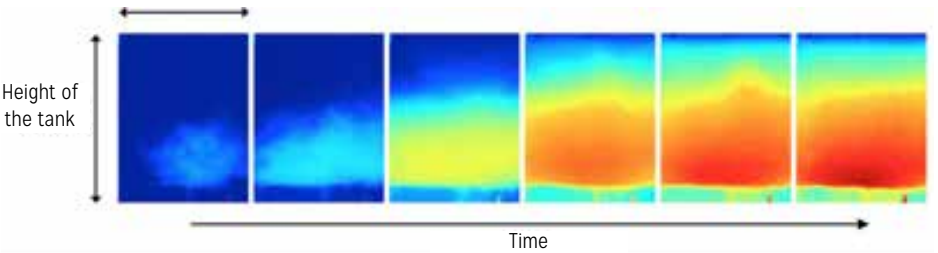


Figure 3 A false colour time series showing the developing pattern of particle transport generated by a source of warm air at low level in a heated space, which is a common bottom-up ventilation strategy. The warm air rises as a plume from the heat source, carrying particles to the upper part of the space. Here the particles spread laterally, forming a region of high concentration, and the particles gradually accumulate in this part of the space. Eventually the flow exits from high level in the space, transporting some particles from the space, while other particles settle to the floor. Red denotes high concentration and blue denotes low concentration. Source: BP Institute Cambridge.



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