SCOTTISH HOSPITALS INQUIRY

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Scottish Hospitals Inquiry

Expert Report

Hilary Humphreys, DSc, MD, BCh, BAO, Dip HIC,

FRCPI, FRCPE, FRCPath, FFPathRCPI, FESCMID

Irish Medical Council Registration No: 05460

Emeritus Professor of Clinical Microbiology, Royal College of Surgeons in Ireland, University of Medicine & Health Sciences

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1. Career history and professional background

Following postgraduate training in internal medicine, I completed basic and higher specialist training in clinical microbiology in St. James's Hospital, Dublin and Bristol, UK in the 1980s. In 1991, I was appointed Senior Lecturer and Consultant Microbiologist at the University Hospital, Queen's Medical Centre, and the University of Nottingham. I became Professor of Clinical Microbiology at the Royal College of Surgeons in Ireland University of Medicine and Health Sciences (RCSI) in 1998 and Consultant Microbiologist in Beaumont Hospital, Dublin. Although I stepped down from my consultant microbiologist position in August 2021, I remain active in research and teaching, and I am emeritus Professor of Clinical Microbiology and Senior Clinical Educator in the RCSI. I am also active in a number of professional activities as outlined below.

I have been interested in healthcare-associated infection (HCAI) and infection prevention and control (IPC) for over 30 years, both in my clinical roles and academic positions. I have been chair of hospital infection prevention and control committees in both Nottingham and Dublin and I have taught on the topic at both undergraduate and postgraduate level, as well as being asked to give lectures at scientific meetings in Ireland, the UK, and beyond. I have held a number of positions in a variety of professional bodies, including Dean of the Faculty of Pathology at the Royal College of Physicians in Ireland from 2016 to 2019, and I am an examiner for the Royal College of Pathologists in the UK. Currently, I am President of the Healthcare Infection Society (HIS), a UK-based charity that includes clinical microbiologists, infectious diseases physicians, scientists, infection prevention and control nurses and others dedicated to advocacy, research and education in HCAI and IPC. I am also on the Executive Committee and am Honorary Treasurer of the European Study Group of Nosocomial Infections (ESGNI), which is under the auspices of the European Society of Clinical Microbiology and Infectious Diseases. Furthermore, I have been involved in and led guideline groups on methicillin-resistant *Staphylococcus aureus* (MRSA) and aspects of operating theatres in the UK and Ireland over the last 20 years. Currently, I chair a joint HIS and ESGNI Working Group looking at rituals and behaviour in operating theatres, which is due to finalise its report in 2023.

Much, if not most, of my research has been applied/translational, i.e. bed to bench-side, in efforts to try to improve patient care and to learn from the science. That research has covered

laboratory aspects, clinical, epidemiological surveys, interventions to improve IPC and components of professional behaviour in the whole area of HCAI. While my publications range over a broad range of topics, many do include components that are relevant to the Scottish Hospitals Inquiry, in terms of IPC and infections transmitted by air. These publications include research or descriptions of outbreaks on aspergillus, a fungal infection in a general intensive care unit due to spores being spread from a false ceiling, and airborne dissemination of *Burkholderia cepacia* to patients with cystic fibrosis such as during physiotherapy. Other publications include the value of positive pressure isolation in preventing invasive aspergillus infection, air and surface contamination with MRSA and a variety of publications on operating theatres, practices there as well as air systems, including the recent controversy over the value of ultraclean ventilation theatres in reducing surgical site infection in patients undergoing prosthetic joint surgery. Even more recent publications in the last two years include ventilation in hospitals and air quality generally, and the role of airborne transmission in the spread of COVID-19. I have provided an input with some general feedback to HTM-03-01 (2021) as a microbiologist with an interest in infection prevention and control, including on aspects of ventilation. Full citations for a selection of these papers that may be relevant are to be found in Appendix 1.

2. Executive summary

Healthcare-associated infections (HCAI) are a well-recognised adverse event that can occur when patients are admitted to healthcare facilities, especially acute hospitals. The virulence and transmissibility of microbes, the vulnerability of patients, compliance with optimal professional practice, such as with hand hygiene, and the design and specifications of the physical inanimate environment are all factors that are involved.

Ventilation, whether it be natural (open doors and windows) or artificial/controlled in single rooms, critical care areas and operating theatres, is important in preventing infection. However, appropriate ventilation is just one of a series of measures that are in place to prevent HCAI. While there is evidence that inadequate air filtration in clinical areas housing patients with haematological malignancy may result in aspergillosis (a fungal infection that does not infect patients without immunosuppression) and that sub-standard operating theatre ventilation can result in an increase in surgical infections, it is challenging to quantify that risk, and to make an estimate as to the risk when there are deviations from recommendations. Furthermore, appropriate ventilation is part of a suite of infection prevention and control measures that contribute to preventing infection such as prophylaxis antibiotics (antibiotics used to prevent as opposed to treating infections).

Finally, while the importance of appropriate ventilation in preventing HCAI is well recognised by some, e.g. microbiologists, hospital engineers and haematologists that may not be the case amongst many other healthcare professionals. However, the recent pandemic has probably increased awareness of infections spread in hospitals by droplet and the airborne, route even amongst the general population and amongst most if not all healthcare workers. Hence, the importance of optimal ventilation, be it natural for general clinical areas or controlled/artificial for specialised areas with vulnerable patients, has probably increased in importance.

3. The importance of infection, prevention and control in the healthcare setting

3.1 Infection prevention and control and patient safety

3.1.1 Amongst the adverse events or safety issues that can arise after a patient is admitted to hospital or healthcare facility, HCAI are amongst the most important (1). While side-effects to drugs were the commonest, HCAI were amongst the top three in a recent Irish study, and the greatest recent decrease in preventable adverse events occurred with HCAI, which fell by 22%. (2) Similar findings might be expected in Scotland, given many similarities such as healthcare provision and demography. It is generally considered that many HCAI are preventable, especially those arising from the insertion of medical devices such as intravascular catheters ('drips) and some outbreaks. Furthermore, prevention strategies can enhance patient safety and improve the quality of patient care. Hence, there are a number of key performance indicators (KPI) in many health services related to HCAI as a measure of quality and IPC (e.g. rates of *Clostridioides difficile* infection or CDI) that are important in many accreditation processes.

3.2 How pathogens spread and risk factors

3.2.1 Microbes, may spread by a number of well recognised means, such as by **contact** between patients and surfaces or between patients and patients, by **faecal-oral** or by ingestion, e.g. leading to food poisoning, by the **blood-borne** route, such as hepatitis and HIV as in intravenous drug users, and via the **air** such as COVID-19 and measles, whether by **droplets** or by the **airborne** route. Particles spread by the droplet route are generally considered to be larger and hence do not travel as far (up to 1-2 meters) as those spread by the airborne route, which may travel greater than 2 meters from the source. Finally, pathogens or microbes may also spread from the mother to the child via the placenta, often referred to as **vertical** spread.

3.2.2 The factors influencing whether or not a hospital patient acquires a pathogen can be described or categorised at its simplest by focussing on three components, i.e. **the host or patient**, the **actual pathogen** itself and its virulence, and the **environment**.

3.2.3 Patients vary in their susceptibility to HCAI with those at the extremes of life in terms of age being most vulnerable, i.e. neonates and the elderly. However, modern medical care has resulted in an increasing number of more susceptible patients arising from surgical and medical interventions, who are at risk from opportunist pathogens (microbes that would

not be a risk in a normal healthy individual but would in somebody who is more vulnerable). Examples of opportunist pathogens or microbes include the fungus aspergillus and skin bacteria such as *Staphylococcus epidermidis*. Pathogens vary in their virulence, i.e. the capacity to cause disease and the severity of the subsequent illness. An example of that is the recent Omicron variant of SARS COV2, which is felt to be less virulent than the Delta variant. Some very transmissible pathogens, however, such as the 'common cold' caused by rhinoviruses are relatively mild for most patients.

3.2.4 The interplay between the virulence of the microbial pathogen (bacterium, virus or fungus) and the patient, particularly the patient's immune response, governs whether or not the individual gets an infection, and if so, how severe. While many microbial virulence factors have been described in the laboratory, linking one or more of these to a particular infection and its severity in an individual patient is often not easy. An exception would be staphylococcal toxic shock syndrome and the production of a specific TSST-1 toxin, by the causative strain of *Staphylococcus aureus*, as not all strains produce TSST-1. For SARS-CoV-2, the cause of COVID-19, the severity and the outcome are as much determined by the immune response, especially the degree of inflammation, as by anything else.

3.2.5 Environmental factors include the physical environment such as inadequately decontaminated instruments used during surgery and overcrowding in hospitals but also the human environment particularly professional practice, e.g. poor compliance with hand hygiene. There is an understandable focus on optimising the inanimate and human environment, i.e. ensuring the physical conditions are as safe as possible, and mandating compliance with professional practice, as the patient's vulnerability to infection may be unmodifiable and it is part of evolution that microbes mutate and change. This includes making sure the physical environment is safe and ensuring that healthcare professionals comply with best practice, e.g. hand hygiene.

3.3 Preventing and controlling the spread of infections

3.3.l Most HCAI are multi-factorial in origin, that is many factors contribute to why one individual gets an infection and another may not. While it may be somewhat simplistic, it is perhaps easiest to look at dividing these factors in to **intrinsic** and **extrinsic** risk factors.

3.3.2 Intrinsic risk factors refer to those that relate to the patient or vulnerable host, i.e. the patient's age, drugs the patient may be on that weaken the immune system (e.g. high dose corticosteroids), underlying diseases such as cancer and diabetes mellitus, and their general state of health. Examples of optimising these to reduce the risk of infection would be ensuring

that a patient with diabetes mellitus has their blood sugars well controlled before surgery. Another example would be reducing weight before a major operative procedure. However, there is a limit to the scope of action for reducing many intrinsic risk factors, especially in advance of urgent hospital admission or before emergency procedures.

3.3.4 Extrinsic risk factors refer to those outside or beyond the patient and include aspects of the environment, professional practice and the use of interventional drugs such as prophylactic antibiotics. Hence, any IPC programme or strategy should be multi-modal and include improving professional practice such as better compliance with hand hygiene, addressing hospital hygiene, instrument sterilization, etc. In so far as it is possible, any IPC strategy should ensure that the setting or building in which care is provided are appropriate for the category of patients that will be treated there with due attention given to air-controlled ventilation systems for patients at higher risk of infection such as patients with haematological malignancies.

3.3.5 In recent decades, all patients seen either in the community or in hospitals are considered to be potentially at-risk of infection. Hence, what are called **standard precautions** are instituted, i.e. basic measures of IPC for all patients at all times, even before a patient is suspected of or identified as having a transmissible infection. This includes such measures as hand hygiene, disposal of waste, environmental decontamination, etc. Additional **transmission-based precautions** are added to these, when and if a patient is suspected or confirmed as having an infection that is transmitted by a particular means. For example, if a patient has a pathogen known to be spread by contact, e.g. MRSA, additional **contact-based precautions** are added to standard precautions, and this often includes patient isolation, i.e. in a single room or cohorting (patients with a suspected or similar infection housed together in a separate part of the ward). Similarly, a patient admitted with suspected tuberculosis would/should be isolated on admission to hospital because of the known risk of spread by aerosols with the use of both standard and **aerosol -based precautions**.

3.3.6 Additional IPC measures include the use of antimicrobial agents to prevent infection, i.e. antibiotic prophylaxis administered just before surgery, or antibiotics administered in an asymptomatic contact (e.g. family member) to prevent the onward spread of meningococcal meningitis. Realistically and in practice, a suite of measures are required rather than only one measure for a particular infection. The requirement for multiple prevention measures cannot be over-emphasised. Hence, the importance of a multi-disciplinary and multi-modal approach. Recent years have seen the publication of local, national and international data on HCAI, which have engaged the public and patients. This has

resulted in greater pressure on politicians and healthcare delivery services but with the consequences of an increased focus on improving care (3). This has been done through the development and implementation of guidelines at local and national level, and standards, usually at national and sometimes international level.

4. Ventilation and HCAI

4.1 Infection prevention and control

4.1.1 Ventilation, whether natural or introduced by mechanical means, has three functions, i.e. the removal of odours or noxious smells, the maintenance of a comfortable temperature for patients and staff, and assisting in the prevention and control of infection. Up to now, and especially before the COVID-19 pandemic, most clinical areas of a hospital have been naturally ventilated, i.e. through the use of open doors and open windows. Areas where there is controlled and mechanically delivered ventilation include the operating theatre, pharmacy where drugs are made up, certain areas within the laboratory to optimise the safety of staff there, and those areas of the hospital where there are particularly vulnerable patients, e.g. patients on cancer chemotherapy or where patients with transmissible infections are housed, such as those patients with tuberculosis (4). Ventilation is specifically required in the operating theatre to prevent bacteria shed from the operative team falling on the wound, leading to surgical site infection (SSI). This is achieved by trying to ensure that the cleanest air is that closest to the wound and bacteria from the surgical team are carried away from the wound. In areas with very vulnerable patients such as those with severe neutropenia (i.e. low or absent neutrophils which are a category of white cells in the blood), natural ventilation might include opportunist pathogens such as the fungus aspergillus, and therefore mechanical air filtration ventilation in this setting provides cleaner or purer air. Hence, specifically in these two areas non-mechanically ventilated air would be inappropriate.

4.2 Utilisation

4.2.1 The background and supporting technological and scientific literature is probably greatest for that relating to the operating theatre. This requirement originally arose due to the need in operating theatres to protect staff from noxious gases as part of early anaesthesia (5). More recently, there has been some controversy over the need for the very expensive specialised ventilation required for prosthetic joint surgery (6). The original studies in the

1980s strongly suggested that this specialised ventilation for prosthetic joint surgery, usually called ultraclean ventilation (UCV), reduced infection rates, and hence UCV was adopted in many centres and countries. However, in the last decade or so, data from national registries such as in New Zealand and a review of recent research data, has suggested to some that UCV provides no additional benefit to the ventilation in conventional operating theatres when used with prophylactic antibiotics, given just before surgery. Furthermore, UCV is more expensive to install and has higher maintenance and energy costs. Nonetheless, the additional purity of air provided by UCV suggests that there is biological plausibility in having UCV in this setting, and many orthopaedic surgeons would probably require it for their patients. They and others might argue that the additional expense is justified given the considerable costs of treatment and the significant pain and disability that follow infection of a prosthetic joint.

4.2.2 In terms of preventing infection outside the operating theatre and specifically regarding isolation rooms for risk patients, negative pressure ventilation is used where the patient has a transmissible infection (**source isolation**) and you do not want the air from that patient spreading to other patients in the ward, i.e. air does not spread from the isolation room as the air pressure is negative there compared to other clinical areas nearby. Patients in this category would include those with COVID-19 infection. In contrast, positive pressure ventilation is used for protecting very vulnerable patients (**protective isolation**) such as those on cancer chemotherapy or a patient following organ transplantation where air from their room moves to other areas as the pressure there is higher than in surrounding clinical areas. This prevents the ingress of air from other parts of the ward where there may be pathogens such as methicillin-resistant *Staphylococcus aureus* (MRSA) and therefore protects the vulnerable patient from pathogens spread by air.

4.2.3 In addition to ensuring that the air is of sufficient quality, the air is filtered and the correct direction of airflow is achieved through differential air pressures expressed in Pasqual's (Pa), air changes per hour (ACH) and airflow rates (AFR). Therefore, a patient who is in a room with positive pressure ventilation, will have air pressures higher in that room, e.g. by 5 or 10 Pa compared to the surrounding area.

4.3 Relative importance of ventilation

4.3.1 Controlled ventilation such as in isolation facilities is one component of preventing infection being spread or being acquired by patients via air. This is especially important for patients who have highly transmissible infections such as measles or where patients are especially vulnerable to infection such as patients on cancer chemotherapy or

following bone marrow transplantation. However, in addition to ventilation itself, other measures are required such as standard and transmission-based precautions, including hospital hygiene, prophylactic antibiotics, etc. There is often much discussion over how many air-controlled rooms are necessary in acute hospitals, tertiary referral and specialist units both now and in to the future. However, an important starting point in deciding that is to consider how many at-risk patients are likely to be admitted under the categories described above.

4.3.2 It is challenging to identify specially the exact contribution a controlled ventilated area may have in either preventing a patient acquiring infection or in general preventing infections being transmitted within a hospital, because ventilation is not used alone, but is part of a suite of preventative measures. However, recent experience with COVID-19 highlights the importance of isolation and cohorting in reducing healthcare-associated SARS- Co-V2. The experience in Hong Kong during the SARS outbreak in the 2000s prompted the authorities there to build additional isolation rooms, which may partially explain the better preparedness of countries such as Hong Kong, Singapore and China for initially dealing with COVID-19, having experienced major problems with SARS (7). This lesson was not learned in most European countries, hence the experience of open and often over-crowded hospitals during some of the early phases or waves of the COVID-19 pandemic.

4.4 Differing standards between countries and in different clinical areas

4.4.1 Although I have had general input into the most recent version of HTM03-01, I am not an expert in the detailed technical specifications for a ventilation system. However, my assumption and understanding is that these are aimed at optimising the ventilation system to address the risk to patients and indeed staff. Hence, while there may be minor differences between Scottish and other standards in the UK, these are probably not significant in terms of their clinical implications. However, standards often have to balance logistics, cost, common sense/plausibility and feasibility with risk, while following any scientific evidence where it exists. Hence, the highest specifications in terms of air changes or provision of a lobby are especially important in those patients most at risk such as patients with neutropenia.

4.4.2. The specifications and literature relating to the operating theatre are somewhat more extensive in many ways for historical reasons, e.g. the need to remove potentially toxic gases, even though the evidence-base is far from definitive. There is acknowledgement that the critical care area, including high dependency units, should have controlled ventilation with single rooms and in HBN-04-02, published in 2013, it is recommended that at least 20% of beds should have controlled ventilation but that that would increase to 50% if many patients

with neutropenia are likely to be admitted there (8,9). This is because of the wide range of infections that may be admitted to critical care units, e.g. measles during childhood and influenza or COVID-19, and the rooms would therefore need to be able to cater for patients requiring protective (very vulnerable) and source (infectious) isolation. The increasing complexity of patient care in recent years makes a case for near universal single room accommodation or at least double rooms in new hospitals or units, while acknowledging that this presents challenges in terms of facilitating the continuous observation of patients by nursing and other staff. Advances in haematology and oncology mean there is a greater requirement for controlled ventilation in single rooms, given the aggressive regimens for many cancers, and the greater use of stem cell transplantation (10).

4.4.3 Scottish guidelines (Appendix 2) on ventilation, published in 2014, cover many of these areas, including air filtration and HEPA, air intake and extract, specialist ventilation systems, and the specifications for conventional operating theatres, ultraclean ventilated theatres and isolation rooms (11). In general, the specifications are what might be expected and are largely similar to other guidelines in the UK. For example, they recommend 10 ACH for a unit/ward with neutropenic patients with an air pressure of +10 Pa, and 25 ACH for a general operating theatre with a higher ACH in the preparation room when this is used to lay up surgical instruments before being used by the surgeon (Table A1- reproduced in Appendix 2). There is no precise science that I am aware of that sets the ACH for a critical care unit at 10 and whether this is significantly better than 12 or even 15 ACH, but the important principle is that the ACH are higher than a normally ventilated room (about 6 ACH) and the air pressures, air flows and filters are also designed to achieve the purpose of the ventilated facility. These guidelines, when implemented in terms of construction, commissioning and monitoring would help minimise infections acquired in operating theatres and in units with vulnerable patients, when combined with other measures such as good professional practice. Minor variations in parameters can occur over time, and especially as plant ages. Hence, while it is difficult to be definitive, ACH of 7, 8, and 9 might still give significant protection, but those at 5 or less would probably not as they would be similar to what you would see in a non-mechanically ventilated area. Nonetheless, failing to implement guidelines is likely to increase the risk of adverse events occurring, such as infection, even if quantifying this increased risk would be challenging generally and especially in the case of an individual patient.

4.5 Source and protective isolation

4.5.1. This has already been alluded to above in terms of the principles and definitions when discussing positive and negative pressure rooms. However, English guidelines from 2013 (9), recommend avoiding the construction of rooms that can be switched from negative to positive pressure ventilation or *vice versa* because of the risk of an incorrect setting, i.e. having a patient with a transmissible infection such as COVID-19 in a room, inadvertently switched to positive when it should be at negative pressure. More recently designed rooms, have high efficiency particulate air (HEPA) filters fitted with a positive-pressure ventilation lobby (PPVL), with neutral pressure actually in the patient room (12). HEPA helps purify air by trapping quite small particles that may carry microbes, including aspergillus spores. These are used in UCV theatres and in units caring for high-risk patients such as those with leukaemia to prevent aspergillus infections. This therefore, both protects the patient in the room and the rest of the patients outside that single room. However, such facilities must be appropriately constructed, maintained and monitored to ensure that they function in the way that they are intended to, e.g. the air pressures are correct and hence the flow of air (12). Nonetheless, where there are rooms of the previous specifications, i.e. can be switched from positive to negative and *vice versa* depending on the requirement, it is imperative that procedures are in place to ensure that the patient is in the room with the correct setting. For example, when a patient at high risk of infection who should be in a positive pressure ventilated room is admitted, there should be documentation that the ventilation setting for the particular needs of that patient are correct, i.e. positive pressure, and that this is maintained until the patient is discharged and or until the patient is deemed to be no longer at a high risk of infection.

4.6 Room configuration and design

4.6.1. Much of this relates to good building practice in terms of adequate size or space and finish. Rooms should be large enough to include the patient bed, likely equipment and adequate space for healthcare staff to deliver care. Increasingly, there is discussion and a view in many quarters that we should move to all single room accommodation in acute hospitals (i.e. those hospitals that admit unwell patients 24-hours a day as emergencies in medicine, surgery, paediatrics, etc.), both to prevent infection and to provide greater privacy and dignity for patients (13). However, this presents challenges in ensuring that patients continue to be monitored adequately in single *versus* multi-bed rooms, and that patients do not feel isolated when on their own in a room. This would mean that any patient on admission with an undiagnosed infection would have minimal contact if any with other patients before or after the diagnosis of infection, by virtue of being in a single room. While Nightingale wards, where

you can house a large number of patients in one large room with the same condition, have proven useful recently in the management of COVID-19, these are no longer appropriate for acute hospitals with complex case mix and where different infections may easily spread between contiguous patients. When a patient in a multi-bed area is diagnosed with a transmissible infection sometime after hospital admission, by the time that IPC precautions are started, the infection may have spread to the other patients in that multi-bed area. In contrast, where the patient has been in a single room since admission, the risk of onward spread of that infection has been minimised. Where there are multi-bed rooms, the number of beds should probably be reduced to, in my opinion, at most three and where possible patients with similar infections or patients at risk of similar infections, should be housed in the same three-bedded unit or bay.

4.7 Consequences of ventilation failures

4.7.1 Measures to protect and prevent HCAI are multi-faceted including standard precautions, adequate space, good professional practice, etc. Hence, when infections occur, unless there is an obvious clear breach in a specific standard, it can be difficult to ascertain definitely, what factor was most important and where the failure or failures were. For example, in a patient developing a SSI after major surgery, the lapse or failing might be in preparing the patient for surgery, not giving the patient prophylactic antibiotics, especially if the procedure is a contaminated/dirty procedure (i.e. on a viscus such as the bowel which is breached/perforated with spillage of bacteria in to the abdomen), sub-optimal surgical technique or inadequate ventilation in the operating theatre, and the failure to use aseptic (sterile) technique when assessing/examining the wound post-operatively. Deficiencies in operating theatre ventilation may be compensated for by the use of prophylactic antibiotics and therefore not become clinically apparent. However, having a patient at high risk of infection, e.g. leukaemia with a low neutrophil count (a risk for aspergillus infection) in a negatively ventilated room would represent a clear risk of that patient acquiring infections borne by air from nearby patients as the air from those patients would be flowing to the single room, as it is at negative pressure.

4.7.2. In the scientific literature, many reports or papers are outbreak reports or equivalent and are not rigorous trials. Hence interpreting what happened and the role of any deficiencies in ventilation can be challenging, but adverse consequences are more likely to occur the more vulnerable the patient and the greater the number of gaps in IPC. However, where neutropenic patients are housed in rooms where HEPA filtration is inadequate, there is

a greater risk of aspergillosis, and outbreaks have occurred (14). In the operating theatre setting, air filtration, antibiotic prophylaxis, good clear protocols probably often compensate for sub-optimal ventilation specifications (e.g. reduced ACH) when and if these occur. However, inadequate or temporary operating theatre facilities have been associated with increased infection rates (15). Finally, the recent use of sophisticated molecular typing systems to characterise strains has indicated that microbes, not normally associated with airborne spread, may be transmitted by air and contribute to infection which might not otherwise be apparent in non-ventilated clinical areas. An example of this is MRSA, which can be carried by both patients and staff, be present on surfaces and which can be detected in the air and possible transmitted by that route (16). This probably occurs because all of us continuously shed skin scales as part of skin regeneration. These can contain bacteria such as MRSA, which can be carried in the nose and on the skin. Hence, MRSA shed on skin scales in one area of a ward might be transported to another area with the prevailing air direction. Therefore, while sometimes there is either a clear link or an assumed link between the occurrence of infection and a breach in preventative measures, in many instances it can be difficult to identify any breach in measures and that may be because of unknown factors that we have yet to identify, i.e. there is often some degree of scientific uncertainty. However, sometimes without obvious clear evidence, we can make some conclusions based on previous experience and biological plausibility.

4.7.3. It can be difficult to assess the possible impact of failure to comply fully with ventilation guidance, if the deviation is small. For example, if it is recommended that a conventional operating theatre should have 25 ACH when built, and if monitoring suggests that it is 18-22, that may have arisen due to the age of the plant and may not result in an increase in infection, in contrast to the risk if the ACH were as low as 8-12. However, it seems reasonable to assume that the greater the deviation in, or the number of deviations from, what is recommended in guidelines or standards, the greater the risk of preventable infection occurring.

4.8 Temperature and patient safety

4.8.1 An appropriate ambient temperature ensures the comfort of patients and staff. However, it is not clear what direct impact variations in the ambient temperature have on the risk of HCAI. It is possible that in circumstances where temperatures are too cold or too hot, staff discomfort may lead to sub-optimal practice and in the case of patients; it is well known that patient hypothermia is associated with an increased risk of post-operative surgical infection (17). Hence, the working environment should be comfortable for staff with minimal

opportunities to prevent this being the case. Therefore, areas with controlled ventilation should not have openable windows that might prevent this being the case.

4.8.2 A serial rise in surgical site infection, associated with increases in ambient temperatures, has recently been reported but it is not clear whether this was also related to seasonal factors, changes in medical staff during the summer or differences in patient throughput or case mix (18). Nonetheless, it is logical and rational to provide a suitable temperature in which to care for patients, and this is also of benefit to staff.

5. Perspectives on the role of ventilation and preventing HCAI

5.1 Up to the recent pandemic, interest in ventilation facilities in hospitals was confined to engineers and technical services, infection prevention and control personnel and some surgeons. However, the onset of the COVID-19 pandemic has heightened an interest in both droplet and airborne infection amongst the public and the healthcare community and the implications, not only for hospitals but also for community facilities such as schools where some have advocated HEPA filtration.

5.2 There is a need for a review of ventilation quality in healthcare facilities, particularly for vulnerable patients even if risks are complex and there are a number of factors, which affect the development of infection (19, 20). I certainly now believe more strongly than in the past on the need to improve the spacing of patients in hospitals, consider air flows and critically appraise ventilation facilities for all patients, and not just those in high-risk areas. I think that realisation is increasing, and is being reflected by other healthcare professionals.

6. Future proofing

6.1 Hitherto, there has been some interest in looking at hospital design, particularly from the perspective of preventing infection, but this has been quite generic and not specific to ventilation standards (21, 22). Certainly, we are likely to see greater attention on this when building new hospitals or building new units on existing hospital sites. However, the challenge is how to address existing buildings and to optimise these, given what we now know and the increasingly vulnerable hospital population. This will require expertise but also additional resources and the will to improve facilities. This will have to be balanced by other demands in healthcare and also after considering environmental issues. Ventilated rooms are more expensive to build and have significant ongoing energy costs, but new technologies, including the greater use of mobile HEPA filtration systems may assist in the future.

6.2 Certainly, more space between patients and preferably all patients being housed in single rooms, and greater attention to airflow in the absence of controlled ventilation or patients not being in single rooms, are required. This will ensure that airflow generally goes from patients to the outside, and the provision of more controlled ventilation facilities for vulnerable patients with systems in place to ensure that they are fit for purpose. Disadvantages to housing patients in single rooms include a feeling by the patient of being 'unclean' or being 'shunned', potentially more falls amongst patients, less visits by healthcare staff, e.g. doctors' ward rounds not entering the room, and the need for more nursing staff as multiple patients in a single space such as a patient bay, can be visually observed more easily.

7. Conclusions

7.1 The role of ventilation in the prevention and control of HCAI is recognised amongst those directly involved, e.g. microbiologists, engineers and those caring for severely immunosuppressed patients, if perhaps not so much amongst most staff working in healthcare facilities. This may have changed somewhat arising from the pandemic with healthcare-acquired COVID-19 being a regular feature, and contributed to by droplet, and possibly aerosol spread. However, it is complex in terms of assessing its precise role in preventing HCAI, even for those microbes that spread by the droplet and airborne route, but it is part of a larger picture of infection prevention and control measures. While its importance is recognised in key parts of the hospital, such as the operating theatre, infectious diseases units and haematology/oncology units, heretofore, there has been little emphasis on it for general patients including those who might be at risk such as those on high dose corticosteroids or on biological agents. However, other measures such as standard and transmission-based precautions, optimal professional practice, routine hospital maintenance and hygiene, and prophylactic antibiotics prevent many infections that might otherwise have occurred and may mask the consequences of sub-optimal ventilation.

7.2 As with road safety, a triad of interventions are important, i.e. optimal human behaviour, e.g. staying within the speed limit, a safe environment, e.g. motorways for busy routes with heavy traffic and good lighting, and using technology, e.g. air bags, have all contributed to reducing road traffic deaths. Nonetheless, accidents still happen but it is not always clear what specific failure or failures resulted in their causation. Nonetheless, increasing attention to these three domains are likely to reduce the number of road fatalities

further. Similarly, in preventing HCAI, a multi-modal IPC approach is required and ventilation in the light of what we have learned from COVID-19 will be increasingly considered as of greater importance than in the past.

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Appendix 1. Some publications on healthcare-associated infection and spread by air from Hilary Humphreys

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Appendix 2. Comments on SHTM 03-01 Part A- Ventilation for Healthcare Premises

Overall comments

This is a well laid out document with technical terms explained and practical advice on implementation. It has a number of very helpful Tables and Figures that assist in explaining concepts and these are also useful from an educational perspective. A key table is Table 1A spread over two pages as part of Appendix1. It is reproduced below with the two pages in sequence. It outlines what is required for various parts of a healthcare facility, e.g. critical care or general ward in terms of air changes per hour (ACH), air pressures in Pascals (Pa), the level of air filtration, as well as the noise and temperature range that should be aimed for.

This table is a very helpful summary, especially for those not expert in engineering and aerodynamics. For example, a room to house a patient with neutropenia should have 10 air changes per hour, be at an air pressure of +10 to the surrounding area to avoid the ingress of contaminated air to the room with the vulnerable patient, and have a supply filter of grade H12, i.e. HEPA. Therefore, it is clear that for these patients specialised, purpose-built facilities are required to protect this vulnerable group of patients. For patients in an 'Infectious disease isolation room', the air pressure should be negative to the surrounding area (-5 Pa) to prevent the microbe causing the patient's infection, e.g. TB, spreading to other patients and staff. Hence, here, the ingress of air from the surrounding area is not a concern; the arrangements here are to prevent the spread of air in the patient's room beyond that room.

As with the requirements for specific categories of rooms referred to above, the details for operating theatres, both general and ultraclean ventilation (UCV) theatres are clear and appropriate. Here, the filter designation is F7 for a general theatre (80-90% efficiency) but H12 to provide greater cleanliness, equivalent to HEPA, in a UCV theatre. This is to optimise the purity of air which is re-circulated and hence to prevent airborne bacteria shed from the skin of the orthopaedic surgical team landing on the operative site, and in particular on the prosthetic or artificial joint when being implanted.

Often the challenge is for healthcare providers to provide these in existing premises that were designed and built to previous guidelines or standards, especially when the plant is aging and 20 or more years old. How does one adapt or upgrade existing units, when should it be done, how to fund it, and if it is better to build a new facility than re-furbish an existing unit? Appendix 3 of SHTM 03-01on page 145 (Operating Design Logic) provides an algorithm on how one might approach this conundrum regarding an operating theatre suite, i.e. the complete unit or complex and not just the individual operating theatre. As all this has major logistical,

strategic and financial implications, and it requires the involvement of many disciplines and groups with senior management and probably beyond, depending on the capital investment involved.

Implications and deviations from standards

As an IPC practitioner, it can be difficult to extrapolate the implications of any deviations in terms of an increased risk of infection, especially when the variations are relatively small. In any facility with controlled ventilation whether it be for operating theatres or for air-controlled single rooms, regular maintenance and assessment of airflows, air pressures and filtration efficacy are essential, and may minimise any deviations as the plant ages. Over time if there are gaps in maintenance, the variations between what is recommended and what is found in practice, may diverge to a greater extent than what might have been expected, assuming that the plant was appropriately built and commissioned.

Ventilation standards for operating theatres are usually specified as those when just built and commissioned. Hence, a theatre that was built with 25 ACH may after 10 years no longer have that, but perhaps reach 21/22. These are probably adequate ACHs for most procedures.

Even where air changes or air pressures are sub-optimal in an isolation room used for a vulnerable patient such as one with neutropenia, the risk will also depend on how severe the neutropenia is. Nonetheless, if there is a significant variation from the standard, the risk of infection is likely to increase, even if quantifying that risk would be challenging. Deviations in ACH in general areas are less clinically significant as the patient categories there are at lower risk of infection and for some areas such as patient waiting areas or outpatient areas, patients do not spend long periods in these areas.

Application	Ventilation	ach/Hour	Pressure (Pascals)	Supply Filter	Noise (NR)	Temp (°C)	Comments For further information see Sections 6
General ward	S / N	6	-	G4	30	18-28	
Communal ward toilet	E	10	-ve	-	40	-	
Single room	S / E / N	6	0 or –ve	G4	30	18-28	
Single room WC	E	3	-ve	-	40	-	
Clean utility	S	6	+ve	G4	40	18-28	
Dirty utility	E	6	-ve	-	40	-	
Ward isolation room	-	-	-	-	-	-	See SHPN 4, Supplement 1
Infectious disease iso room	E	10	-5	G4	30	18-28	Extract filtration may be required
Neutropenic patient ward	S	10	+10	H12	30	18-28	
Critical Care Areas	S	10	+10	F7	30	18-25	Isolation room may be –ve press
Birthing Room	S & E	15	-ve	G4	40	18-25	Provide clean air-flow path
SCBU	S	6	+ve	F7	30	18-25	Isolation room may be –ve press
Preparation room (Lay-up)	S	>25	35	F7*	40	18-25	*H12 if a lay-up for a UCV Theatre
Preparation room / bay sterile pack store	S	10	25	F7	40	18-25	*50NR if a bay in a UCV Theatre
Operating theatre	S	25	25	F7	40	18-25	
UCV Operating theatre	S	25*	25	H12	40	18-25	Fresh air rate; excludes re-circulation
Anaesthetic room	S & E	15	>10	F7	40	18-25	Provide clean air-flow path
Theatre Sluice/dirty utility	E	>20	-5	-	40	-	
Recovery room	S & E	15	0	F7	35	18-25	Provide clean air-flow path

Application	Ventilation	ach/hour	Pressure (Pascals)	Supply Filter	Noise (NR)	Temp (°C)	Comments For further information see Section 6
Recovery room	S & E	15	0	F7	35	18-25	Provide clean air-flow path
Cardiac catheterisation lab	S	15	+ve	F7	40	18-22	
Endoscopy room	S	15	+ve	F7	40	18-25	
Endoscopy cleaning	E	>10	-ve	-	40	-	
Day case theatre	S	15	+ve	F7	40	18-25	
Treatment room	S	10	+ve	F7	35	18-25	
Pharmacy aseptic suite	S	20	#	H14	-	18-22	# See EG3MP (Orange guide) a
Cat 3 or 4 containment room	#	>20	#	H14*	-	18-22	# See ACDP guide; *Filter in extract
Post mortem room	S & E	S = 10 E = 12	-ve	G4	35	18–22	Provide clean air-flow path
Specimen store	E	-	-ve	-	-	-	Fan accessible from outside of store

Table A1 continued

1st April 2022

SCOTTISH HOSPITALS INQUIRY

Hearings Commencing
9 May 2022

Day 4
Thursday 12 May
Professor Hilary Humphreys

C O N T E N T S

14:30

THE CHAIR: Good afternoon, Professor Humphreys. Can you see us, see at least me?

PROFESSOR HUMPHREYS: Yes, I can and I can hear you.

THE CHAIR: Right. You certainly sound very clear to me. As you appreciate, you are about to be asked some questions by Mr MacGregor QC. Before that, will you take the oath?

PROFESSOR HUMPHREYS: Yes, I will.

Professor Hilary Humphreys

(Sworn)

THE CHAIR: Thank you very much, Professor. I should just say that, if for any reason, you want to take a break during your evidence, just please indicate that and we can do that. Now, Mr MacGregor.

Questioned by Mr John MacGregor

Q Thank you, my Lord. You are Professor James Francis Hilary Humphreys. Is that correct?

A That's correct.

Q You have provided a report to the Inquiry dated the 1 April 2022?

A That's correct.

Q Just for the benefit of Lord Brodie and the core participants, that is in bundle 6 at pages 3 to 28 and Professor Humphreys' CV is available in bundle 8 at pages 51 to 62. Professor Humphreys, the content of your report will form part of your evidence to the Inquiry. You are also going to be asked some questions today and if you do want to refer to your report at any point, please do just let me know.

I want to begin by asking you questions about your qualifications and experience. Am I correct that you are currently Emeritus Professor of Clinical Microbiology at the Royal College of Surgeons in Ireland, University of Medicine and Health Sciences?

A That's correct.

Q What does that role involve?

A Well, I retired from clinical practice in 2021, so I remain actively involved in research and education and various other professional activities.

Q Within your report and your CV, you have set out a number of your degrees and diplomas. Do those include a Doctor of Medicine----

A Correct.

Q -- a Bachelor of Surgery----

A Correct.

Q -- and you also have a diploma in hospital infection control?

A That's correct.

Q What is the diploma in hospital infection control?

A That was a diploma awarded by the London School of Hygiene and Tropical Medicine. Based upon reflections over many years, it was part of a training course that was instituted in the UK for people with a particular interest in healthcare infection prevention and control.

Q Okay. If I could begin by looking at your report, which is firstly at page 6 in the bundle, which covers your career history and professional background. If we could begin back in the 1980s, did you qualify as a doctor in the early 1980s?

A Correct. I qualified in 1981 from University College Dublin.

Q You then held registrar positions in Dublin and Bristol from 1985 until 1991?

A That's correct.

Q You completed postgraduate training in internal medicine and then specialist training in microbiology?

A That's correct. After I qualified, I did a few years in general medicine in areas such as cardiology, nephrology and general medicine including on call and then decided to go into a career in clinical microbiology.

Q In 1991, you were appointed senior lecturer and consultant microbiologist at University Hospital at the University of Nottingham. Is that correct?

A That's correct.

Q What did that role involve?

A It involved a combination of contributing to the service in University Hospital Queen's Medical Centre in Nottingham in terms of diagnosis, prevention, control and advice on treatment, as well as teaching medical students and others and engaging in the research activities of the department, which especially functioned on interest in staphylococcus aureus, a common bacteria causing healthcare associated infection.

Q So, just so I am understanding, you were involved in infection prevention and control, is that correct?

A That's correct. I was.

Q Then in research into clinical microbiology?

A That's correct, yes.

Q Did you stay in that role

until 1998, whenever you were appointed professor of microbiology at the Royal College of Surgeons in Ireland?

A That's correct, yes. I did spend a year in another hospital in Dublin, but it was really a very temporary appointment. The essence of what I've been doing has been since 1998 in the RCSI and Beaumont Hospital.

Q Again, as you say, you were also consultant microbiologist at Beaumont Hospital in Dublin.

A Correct.

Q What did that role involve?

A Well, again, a bit analogous to the role in University Hospital in Nottingham: providing a clinical service in terms of diagnosis, treatment, prevention of infection; a combination of laboratory work; clinical work on wards, such as the critical care areas; then general education in terms of improved use of antibiotics and infection prevention measures.

Q You mentioned that you stepped down as consultant microbiologist in August 2021.

A That's correct, yes.

Q Have you remained active in research and teaching since retiring?

A Yes. I'm still involved in a couple of research projects and there's still work outstanding from the time that I was head of department in the RCSI.

Q Do you have specific areas of interest in terms of your research?

A Well, I suppose generally as a microbiologist you can be engaged in research in different kinds of molecular research or virulence. I suppose my particular areas have been in the epidemiology patterns of infection in hospitals; preventative measures, including, for example, enhanced decontamination or cleaning; and then looking at trends over time. Those would be the general areas, although I have conducted and been involved in research in other areas such as basic pneumococcal disease – pneumococcus causes bloodstream infection and meningitis.

Q Would the general public understand your research to be in areas including hospital-acquired infections?

A I think they would, yes.

Q In relation to that area, hospital-acquired infections, and more generally in infection prevention and control, have you written in peer-reviewed journals?

A Yes. Over, I suppose, nearly 30 years or more, yes.

Q In terms of that area, infection prevention and control, approximately how many peer-reviewed journal articles have you written?

A In total, over 300. I suppose if you were to look and categorise them as infection prevention and control, probably two thirds or more would be in that particular area.

Q So, would it be fair to say, in terms of the summary of your career history and professional background that you have set out, that for approximately 30 years, you have been involved, both working in and researching into healthcare-associated infection and more generally infection prevention and control?

A Yes, I think that's a fair summary.

Q Now, you mention within your report at page 6 that you chaired a hospital infection prevention and control committee both in Nottingham and in Dublin, a post that you held. Can you explain to the Inquiry, what do you mean by “an infection prevention and control committee”?

A Okay. So apologies if you see me looking to the left. I have the document up on my left, so I'll be referring to it as you make reference to it, so I hope you don't think I'm not paying attention to you. So, that would have been a multi-disciplinary committee which would have met frequently, such as maybe monthly. It would look at data, would make recommendations about measures that should be taken to improve prevention and control and then would liaise with senior management. It had become more formalised, I think, in the UK in terms of more formal recognition of, for example, a doctor who would head up on infection and prevention control, but it certainly was, and continues to be in some countries, a format in which, if you like, a microbiologist has input into hospital strategy and measures to minimise hospital infections.

Q So, effectively a committee – you said multi-disciplinary – that would meet to discuss and try and mitigate hospital-acquired infection and infection prevention and control issues more generally?

A Correct, yes.

Q You mentioned being president of the Health Care Infection Society.

What is the Health Care Infection Society?

A So that's a society that was established about 40 years ago, initially driven by microbiologists like myself to heighten awareness, research and education in hospital infection, and subsequently more widely healthcare-associated infection, which includes things like residential institutions, nursing homes. It includes microbiologists, both medically trained and scientifically trained, infection prevention and control nurses, epidemiologists, scientists and others. It publishes a journal, the Journal of Hospital Infection, which would be regarded as one of the international leaders in the field and it awards research grants, organises educational meetings and engages in advocacy. Although primarily it's based in the UK and would have largely a UK membership, it has membership from outside the UK in Europe, North America and beyond.

Q Thank you. Now you mention at the bottom of page 6 of your report, or the bundle with your report in it, you describe your research as being "applied/translational". What do you mean by that term?

A Well, microbiology is both a clinical specialty, but it's also a science. So, at the scientific level, the kind of research that might be undertaken would be at a very detailed level about virulence factors and genetic components in the laboratory, but it might not necessarily relate to medicine or to healthcare generally. So my research has largely been looking at, "What can we learn in microbiology that we can apply to the care of patients in hospitals or elsewhere that will mitigate some of the consequences of being admitted in hospital?"

Q You are familiar with a document called the Health Technical Memorandum 03-01 from 2021?

A Correct.

Q What is that document?

A It basically, I think, lays out a lot of very useful and interesting information on ventilation and the requirements required for this and they are documents that are used, not just in the UK but beyond, because of the expertise that's collated together within them.

Q Did you provide input in relation to the latest version, the Health Technical Memorandum 03-01 of 2021?

A I did, but I would say it was nowhere near as great as the input of many others. My input was largely one as a clinical microbiologist to give a sense of whether or not the

measures and recommendations were both comprehensible and relevant to clinical care.

Q Who asked you to become involved?

A I think it was the chair, or the lead, of that particular group that was devising that guideline, or that document, rather.

Q In terms of the guidance which the Inquiry has already looked at, that would be an individual called Malcolm Thomas. Is that correct?

A Correct, yes. Yes, I know Malcolm.

Q Now, you mentioned that you reviewed the document and I think you said that you had a relatively limited input, but you are recognised as a contributor, is that correct?

A That's correct, yes, I'm listed in the contributors. I was a bit surprised to be listed as a contributor because although I suppose I technically did contribute, I didn't feel my contribution was as much as many others who were involved in it on a more continuous basis.

Q Again, whenever you reviewed that document, could you just explain to the Inquiry the type of input that you had?

A Well, I'm a medically trained clinical microbiologist. I'm not an engineer, an architect or a technical services person so I suppose I was looking at the document to see, number one, did it make general sense in terms of what it was recommending, in terms of aspects of infection prevention and control? Number two, was it sort of understandable and comprehensible? Now, any document like that has a lot of technical information and that technical information is very valuable and I need some guidance through certain sections of it, but the sense that it would be relevant, would be important and would be largely comprehensible in terms of its general principles and advice to people like me working in hospitals and beyond.

Q Okay. So, in terms of the review that you undertook of that document, did you have any significant concerns in relation to its content from an infection prevention and control perspective?

A No, I don't recall that I did.

Q So, we will come on to look at this in slightly more detail, but you will be familiar that there is a table within that guidance which sets out a whole range of parameters within a hospital, table A2. For example, pressure regimes and air changes per

hour?

A Yeah, correct. Yes.

Q So would you have reviewed that in terms of reviewing the draft Health Technical Memorandum?

A I would have looked through it. I wouldn't necessarily have provided detailed feedback as to whether the precise mathematical specifics of the air changes or whatever were correct. It was more whether the overall tenor of it, the general recommendations, were what I felt was reasonable or not.

Q What was your view on the overall tenor of the document?

A I felt that it was fairly logical and was plausible in terms of what we're trying to do in these circumstances.

Q Just to be clear, what do you mean by that, “What we were trying to do in these circumstances”?

A Well, that the recommendations were based upon either evidence or what was known to be appropriate and that they were reasonable in terms of what could be implemented. So, for example, obviously the more air changes you have in a facility, in theory, the greater the dilution of any contamination in the air, but you may not require huge air changes where the risk is relatively low. So, that sort of balance between making sure we have preventative measures in place, but that they are, I suppose, balanced by other aspects such as expense, space and so on.

Q So the values that we see within that document, should they be understood as being a compromise following discussions between multi-disciplinary parties, engineers, infection prevention and control clinicians and the like?

A In the general area of research in this area, there are certain principles that have been shown to be the case, which is that the more air changes you have, the more dilution of contamination you have, the better the quality of filters you have, the less likely you are to get contamination coming through, but, for example, if you're asking me “Is there a strong evidence that, for example, six air changes per hour is better than five or not as good as seven?” I don't think you can be as precise as that. In fact, internationally, there are some variations into what people would recommend in terms of air changes per hour, in some of the parameters that are laid out in this document.

Q Thank you, Professor. If I could ask you to move on within your report in the top right-hand corner of

page 8, we are at section 2, the Executive Summary. Now, you begin by dealing with the whole concept of "healthcare-associated infections." Can we just be clear, what do you mean by that term?

A Okay. So, if you go back about 20 years or more, people talked almost exclusively about hospital-acquired infections. In other words, it was just about infections acquired in hospital. So the term "healthcare-associated infections" is a broader term. It takes into consideration infections not only acquired in the hospital that – be it the outpatients, the emergency department, or the ward – but it also includes infections acquired in GP surgeries, in nursing homes, in residential units. So it's a broader term than simply "hospital-acquired infections".

Q You state a range of factors that would be relevant to a patient acquiring a healthcare-associated infection. So those include "virulence and transmissibility of microbes." What do you mean by that?

A So, virulence would be how dangerous a bug is or a microbe is. If you take, for example, something like rabies, which has an almost 100 per cent mortality, as opposed to a virus that might cause a common cold like rhinovirus. Again, anthrax would be regarded as a very virulent bacterium, whereas a staphylococcus found on the skin of all of us would be regarded as of low virulence. Then transmissibility refers to the capacity of that microbe, whether it be virus or bacteria, to spread from one person to another. So, for example, the current Omicron variant of SARS-CoV-2, the cause of COVID 19, is more transmissible, it's easier spread than, for example, earlier variants.

Q You also mention a relevant factor would be the vulnerability of the patient. Again, can you just explain what you mean by "the vulnerability of a patient"?

A How prone they are to get infections. So if we take, for example, the very young – by that I would mean, say, premature neonates – or the very elderly people who are maybe in their eighth or ninth or beyond decade, perhaps more specifically, patients who, by virtue of an underlying disease, such as a cancer or leukaemia are patients who are on treatment that reduce the body's defenses in terms of coping with infection, such as high dose steroids. So that's what I mean by the vulnerability. So, a healthy 40-year-old

male coming in for a hernia repair is not as vulnerable as maybe a 70-year-old patient with leukaemia and underlying diabetes mellitus and I would say, just to finish on this particular point, I would say the cohort of patients who are vulnerable to infection has probably increased over the last number of decades, largely because we have been better at treating many of their underlying diseases, such as cancer.

Q Thank you. Now, just in terms of a couple of terms that have cropped up in the Inquiry so far, there has been references to "immunocompromised patients." What would you understand that term to mean?

A I suppose immunocompromised, and I would admit that there's a certain amount of maybe looseness in the use of terminology here – I suppose immunocompromised patients would be maybe a subcategory of vulnerable patients where specifically their immune system is compromised. Now, that can be compromised because they were born with a defect – although that's relatively rare – but more likely it might be because they've got an underlying disease such as cancer or they're on treatments, such as chemotherapy for cancer, which affects the immune system in its efforts to, if you like, kill the cancer cells. So "immunosuppressed" would be patients with cancer on chemotherapy, patients with leukaemia, patients who have had organ transplantation, patients with HIV disease would be examples of this kind of patient.

Q Thank you. Another term that has cropped up in the work of the Inquiry is the term "neutropaenic patients". What does that mean?

A So neutrophils are cells found in the peripheral blood – that's blood that you might, for example, take from an arm giving blood for a test – and it's a white blood cell and it's important in the immune system. One of the things it's particularly good at is partially digesting or altering the surfaces of bacteria or viruses so that other parts of the immune system can kick in. So a patient who is neutropaenic means that they have virtually no neutrophils, sometimes no detectable neutrophils, and so those patients would be particularly regarded as highly vulnerable to infection, and particularly to opportunist infection. The term opportunist means, if you like, microbes that would not normally affect a normal individual with a normal immune system, but would do so

somebody who is immunosuppressed, particularly severely immunosuppressed. So an example of that would be aspergillus fumigatus or aspergillosis, which is a fungus which is all around us, doesn't normally affect individuals who are well and healthy, but if you were severely neutropaenic, and particularly for a prolonged period of time, would be at high risk of invasive aspergillosis affecting the lungs and possibly the brain and spleen as well.

Q Within your report, still dealing with risks of healthcare-associated infections, you also mention “compliance with optimal professional practice” being relevant. What do you mean by that?

A So that refers to healthcare staff, be they doctors, nurses, allied healthcare professionals, and their approach to the management of patients or clients. So I suppose, if you think about it in general terms, how fastidious are they, how conscientious are they, how careful are they that, for example, they ensure that they washed or decontaminated their hands before approaching the patient or in the care of an IV, intravascular, line or drip? That's what I mean by “professional practice”. Do they wear personal protective equipment when they should do so? Do they take it off appropriately? So all of those kind of activities, human behaviors are very important in preventing and controlling infection.

Q Then the final factor that you list is specifications of the physical environment. Again, in layman's terms, what do you mean by that?

A I suppose the facility or the building in which the patient or the client is being cared for, in terms of is it clean, is it bright, is it spacious, is it airy? Does it have additional measures when the particular patient is at very high risk of infection, such as controlled ventilation? I think it's probably fair to say that as the cohort of patients in hospital have become more complex and older with more vulnerable and immunosuppressed patients, I think those aspects perhaps have become more important in terms of our understanding of the risks that those patients face.

Q Okay. So, if I understand your position, having run through all those issues, there is really a range of factors that are in play in relation to risks associated with healthcare-associated infections, is that correct?

A Correct.

Q In terms of the physical environment specifications and the

physical environment, is that one factor among many or is it more important than others?

A I think it's one factor amongst many, but it is more important in certain categories of patients than it would be in others. So, again, go back to my example of the male in their forties coming in for a hernia repair, it's not so critical in that sort of patient. But, clearly, in the patient with leukaemia who's neutropaenic, it is much more important.

Q So could there be scenarios within a hospital where there is adequate ventilation and a patient nonetheless still contracts a healthcare-acquired infection?

A Yes, yes. So some infections are spread by contact. So if, for example, a healthcare member of staff hadn't adequately washed his or her hands and were carrying a bug on their hands, they might pass that on directly to the patient and the physical infrastructure might not be that relevant in that particular situation where there was a breach in infection prevention and control measures.

Q Now, am I correct, in terms of the ultimate analysis in your report, that your ultimate conclusion is that inadequate ventilation would create a risk to patient safety and care in a hospital environment?

A Yes, it would. I think it would vary depending on the part of the hospital and in the categories of patients being managed there. But, yes, that's correct, and I think that's probably increasingly recognised as a result of what we've learned during the pandemic.

Q So are there specific patients that are at higher risk if there is inadequate ventilation in a hospital?

A I think those-- Well, there's, first of all, the patients who are at risk because the patient has a transmissible infection. So, for example, if you have a child or an adult with measles, that's quite transmissible, and so if that individual patient is not managed appropriately in an appropriately ventilated facility, then that patient can transmit the measles to other patients in the hospital. Then there's the patient who's very vulnerable to infection, severely immunocompromised. Again, if we use the example of the neutropaenic patient, if he or she is exposed to air that is not filtered adequately, then they may be exposed to those opportunist microbes that I told you about, including aspergillus.

Q Within page 8 of the bundle, so still within the executive

summary of your report, you refer to a body of evidence in relation to risks associated with immunocompromised patients. Can you just explain what you mean by that body of evidence?

A I suppose it's partially good research studies that have been done over the years and partially experiential, which is, you know, our experiences and how we report on them and how we share our information. I think increasingly – as you and others, I'm sure, will know – over the last 20 or 30 years, we emphasise evidence-based medicine. So where we have good scientific evidence, we apply that in the care of patients. Now, there isn't necessarily strong evidence for some of the things we do in healthcare, including in infection prevention and control, but there is common sense and intuition and what I call biological plausibility. In other words, that-- if you, for example-- By that I mean-- If you think about this from a logical point of view, that the more bugs you have in a particular area, the more likely you are to get infection. So if you reduce the number of bugs, then you're less likely to get infection, even if you haven't shown that in some sort of scientific or experimental setup.

Q So just to make sure that I am understanding: there might not be actual scientific experiments that you can point to, but in terms of your experience, you are talking about a plausibility drawing upon experience in the field of microbiology?

A Yeah, yes. I mean, I think it's fair to say, and most people would recognise, that unlike, for example, in the treatment of cancer or, for example, the use of vaccines, the rigour of the evidence for some of the things we do in the prevention of healthcare-associated infection would not be of the same standard. One of the reasons for that is that often what we do is multipronged. We do a number of things at the same time. So to separate each individual component of that and to say, “Well, this particular part, reduce it by 20 per cent, and this part, reduce it by 30 per cent,” is not possible, I'm afraid.

Q Is that why, in fairness, in your report, you talk about risk as a general concept, but very fairly say, for example, in the executive summary, “it is challenging to quantify that risk, and to make an estimate as to the risk when there are deviations from recommendations”? Do you see that?

A Yes, I-- Yes, that's something that I think is-- It would be, obviously, ideal if we were able to say

that if a certain factor is not in place, it increases the risk by twice or three times. But we're not in a position to be as precise as that in terms of many of the interventions we take in the prevention and control of healthcare-associated infections.

Q So, at this stage, really talking at a level of generality, we are talking about risk associated with inadequate ventilation in a hospital as opposed to you as an expert being able to talk to an absolute causation to a specific outcome for an individual patient. Is that correct?

A Yes, I think that's a fair summary of the position as I would see it.

Q Can you explain, please, Professor Humphreys, what role do clinical microbiologists have in infection prevention and control, specifically in the identification, management and mitigation of risk?

A So the clinical microbiologist or infection specialist, as the role may be undertaken by an infectious disease physician in parts of the UK and elsewhere, would essentially be involved in surveillance, in other words, the overseeing of the collection of data to see trends over time and to see, for example, whether or not there has been an increase in number of infections on a particular ward. He or she would liaise with the laboratory in terms of the laboratory results that might confirm those infections. He or she would be involved in both ongoing strategies in terms of infection prevention, such as increased cleaning or decontamination, or in response to outbreaks, and would review information over time to see what needs to be done in the future to improve things or what needs to be done in terms of how to react to something new, whether it be a new multidrug-resistant superbug or, as we've seen over the last two years, COVID-19.

Q How would a microbiologist or an infection prevention and control committee link into a hospital management board?

A Increasingly now, the leadership, if you like, and the direction of infection prevention and control in hospitals and other healthcare institutions is more at senior management level than it would be, say, 20 years ago. It's now, in the UK and in Ireland certainly, very clearly within the remit of the chief executive officer or his or her delegate as would be seen fit, and it certainly would be something that would be looked at by

trustees or by boards in terms of the safety of the hospital as part of patient safety.

Q Would some form of risk register be maintained?

A That's been my experience over recent years, yes.

Q Can you explain what you mean by a risk register?

A I think a list of issues either that need to be addressed or, in some instances, may not be addressed, and then a judgment as to whether or not the risk is low, medium or high. When I've seen risk registers, it's usually a red-- something that's in red indicates something that needs to be addressed urgently, something that's in amber is maybe something that is a priority but wouldn't be as high a priority, and then either yellow or green is something that needs to be done at some stage or other but is-- represents a relatively low risk.

Q Thinking again about microbiologists and infection prevention and control officers, are there key performance indicators in this space?

A I think most people would accept that there are and indeed there should be, otherwise how do you know how well you're doing or how poorly you're doing? So I think in the UK and Ireland, key performance indicators would be the number or the rate of acquisition of clostridium difficile or C. diff infections in hospital or the number of hospital-acquired bloodstream infections due to MRSA or, for example, the number of new cases of, say, multidrug-resistant bacteria like CPE, which stands for carbapenem-resistant Enterobacterales. So that's a more recent, if you like, multidrug resistant bacterium.

Q So would they effectively be looking at standard issues or standard pathogens that might be encountered?

A Correct, and you'd also be looking at, if you like, either a target that you should be below or looking at a range in which you should fall depending on the category of hospital you are and the risk. So, for example, if you're a tertiary referral centre, it might be expected to have more complex patients and therefore your rates might be higher than if you were a fairly uncomplicated district general hospital.

Q What about the converse? What about rare pathogens? Would there be any key performance indicators in relation to those?

A Yeah, so, I mean, a good

example of that would be, for example, legionella. So legionella is usually acquired in in the community or perhaps travel associated. But if you had, say, a legionella being diagnosed in a patient who's been in hospital for two or three weeks, you would know that because the incubation period is up to two weeks at most that that was almost certainly acquired in hospital. That would ring alarm bells in terms of looking to see what the source was and whether measures were in place that should be in place to prevent hospital-acquired legionella.

Q How should those responsible for the management of a hospital respond to the identification of rare pathogens?

A Well, first of all, I think very quickly, and certainly would need to convene a group to address the issues, to, first of all, decide what nature of investigation would be required, what measures need to be taken, if you like, to prevent any further cases and then look at why it might have happened and to learn from it in the future, as well as obviously dealing with ongoing cases if they occur in terms of making sure those patients are adequately managed.

Q So, within a hospital setting, if concerns were raised by microbiologists, how would you consider those should be dealt with by hospital managers?

A Well, if you're talking about a case of hospital-acquired legionella, then I would think it should be-- it should ring alarm bells and should be dealt with immediately and should be overseen by the CEO or his or her delegate, and normally they would regard that as a very serious occurrence, and rightly so.

Q Thank you. Moving on, within paragraph 3.2 of your report, so that's on page 9, you use the terms----

THE CHAIR: Sorry. Sorry, Mr MacGregor, I wonder if you quite got an answer to your question. The question, as I have noted, “If concerns were raised by microbiologists,” and the answer is, “If legionella, alarm bells.” Now, the two things may connect, but I just wonder if the-- Sorry, Professor Humphreys, but I am just trying to make sure I have absolutely got your evidence.

MR MACGREGOR: Professor Humphreys, I asked you the question in terms of if concerns were raised by microbiologists, how those should be dealt with. Certainly my understanding was you would go to say that, certainly for particular issues, that it should be really raised at the highest levels

within management. But again, if you could just explain what your evidence is, please.

A Yeah, sorry, I went perhaps on a side issue with legionella. But I suppose in other areas, on an ongoing basis, I think there's an increasingly recognised relationship between senior management and infection prevention control team, as it were, including the clinical microbiologist if he or she is the lead of that, and he or she would be liaising regularly with senior management on ongoing measures and in terms of strategy, but also in terms of any unexpected occurrence that might take place, including outbreaks from time to time. So, yes, there needs to be very clear governance on the relationship between those who are the infection prevention control team and senior management. I'm not sure if that's answered the question more comprehensively.

Q Thank you.

THE CHAIR: Thank you.

MR MACGREGOR: I was moving on to look at paragraph 3.2 of your report, which is on page 9 of the bundle. At that section in your report, you use the terms “pathogens” and “microbes”. Can you explain what you mean by those?

A Yes, so a microbe is a microbe such as a bacterium, a virus or a fungus, but it mightn’t necessarily cause disease. So there are lots of bacteria, for example, in the environment that we never come across in terms of human health. A pathogen implies that, in some or all circumstances, it will cause disease, whether that is symptomatic or asymptomatic. So, for example, if we take a bacterium called staph aureus, the resistant version of which is MRSA, you may see that in the environment, you may carry it in your nose, but it can cause significant illness, including bloodstream infections.

Q You mention at paragraph 3.2.2 of your report:

> “The factors influencing whether or not a hospital patient acquires a pathogen can be described or categorised into three areas: host, actual pathogen and environment.”

If we take each in turn, what do you mean by host?

A So the host, I mean the patient and his or her vulnerability. So, going back to what I said earlier on, if the patient is very elderly, a lot of

underlying diseases, malignancy, on drugs that affect the immune system, then they are especially vulnerable. The pathogen will depend upon, I suppose, its virulence and its propensity to cause disease in different circumstances. So perhaps if I can give you an example of that: if you take a bacterium called staphylococcus epidermidis, this is a bacterium we all have on our skin, as the name epidermidis may suggest. On the skin, it causes no problems. However, if it gets into the bloodstream and you have an artificial heart, then you may get a condition called endocarditis, which is an infection of the heart, whereas, if you look at a pathogen like staph aureus, we would generally say that that's more virulent, more pathogenic, and you may get an infection even in the absence of something unusual, like having a heart valve. Then the environment is really some of the things we've touched upon, the infrastructure, the space, the cleanliness, the decontamination of instruments; but also, I include in that the human environment, and going back to, again, what we said was, if you like, the personal professional practice in human behaviour.

Q Again, can you just explain what your position would be in terms of the interplay between those three factors, in terms of the risk of a healthcare acquired infection?

A I think that, obviously, in a situation where you have a very vulnerable or immunosuppressed host or immunocompromised host, where you've got a very severe pathogen, and where you've either inadequate environment or poor professional practice, then you've a cumulative effect in terms of the risk to the patient. As I said, you might have a very vulnerable patient and you might have, you know, a pathogen that could cause infection in that patient, but because they're in maybe a-- good circumstances and there's good professional practice and a variety of other factors, they might not get infection. I'm not sure if that explains what you had in mind.

Q Yes. Thank you, Professor Humphreys. If we look within-- at page 10 of the bundle, paragraph 3.24, I think fairly you state there:

> "The interplay between the virulence of the microbial pathogen… and the patient, particularly the patient's immune response, governs whether or not the individual gets an infection, and if so, how severe."

Then you go on to say that:

"While many microbial virulence factors have been described in the laboratory, linking one or more of these to a particular infection and its severity in an individual patient is often not easy."

Is that correct?

A That's correct, yeah.

Q Within page 10 of the bundle, you talk about intrinsic factors and extrinsic factors. Again, what do you mean by those terms?

A So, by intrinsic factors, I mean those, if you like, internal to the patient, so for example, their age, whether they've got underlying disease like diabetes mellitus, maybe whether they smoke, maybe whether they're obese or overweight, and so on. Some of those are modifiable, but some of them are not. Then extrinsic risk factors in terms of what happens to the patient in hospital or in healthcare, what drugs we give them, what kind of procedures, what measures we might do that, while important – such as an operation – might render them more vulnerable to an infection.

Q Again, am I correct in saying, as you summarise in paragraph-- at page 10, that really there is a limit sometimes to what you can do in terms of intrinsic factors in relation to a patient?

A Correct, so particularly if the patient is admitted as an emergency. So, if a patient is admitted electively or it's a planned procedure, you can ask them perhaps to try and lose weight, to reduce smoking, you can try and optimise the control of their diabetes mellitus and so on; but if they come in as an emergency with a perforated appendix or a perforated colon and they need urgent emergency surgery, well, in that situation, you don't really have time.

Q For those patients, can extrinsic factors such as the environment be particularly important?

A Well, in those circumstances, what would be particularly important would be that the-- obviously, if we take that example of the emergency surgery, that the surgery is done quickly, that it's done in an appropriate operating theatre, that the surgical team take all due precautions necessary so that, even though this patient has not been prepared for surgery optimally, then the risk is mitigated to some extent.

Q Are you familiar with the terms natural ventilation and mechanical ventilation?

A Yes.

Q Can you have natural ventilation within a hospital setting?

A Yes, many parts of the hospital are naturally ventilated or traditionally have been naturally ventilated.

Q Are there certain sections of a hospital that should only have mechanical ventilation?

A Well, the operating theatre-- for most surgical procedures, it should be carried out in a controlled, ventilated facility. In other words, an operating theatre or an operating room. There are other areas of the hospital, pharmacy, laboratories, central sterile units where, for procedure reasons, they need ventilation. Then also you need controlled or artificial ventilation where you have either patients who are vulnerable to infections, such as the patient neutropaenia, or where you have patients who pose a risk to other patients, such as the patient with measles, patients with infectious tuberculosis. There are other areas as well, but those are some examples.

Q Now, within your report, you mention at times prophylactic antibiotics. What are they?

A So most individuals think about antibiotics as drugs that are given to treat infections; so you have a urinary tract infection or cystitis, and you go to your general practitioner and he or she gives you an antibiotic to take for that. In prophylaxis, we're either talking-- we're usually talking about prevention, either primary or secondary prevention. So primary prevention would be the patient goes, for example, for an elective procedure – let's say for an artificial knee joint replacement – and the surgical team, or maybe the anaesthetist gives one or two doses of antibiotics starting just before the procedure. Why does that happen? Because as the surgeon goes through the skin, into the joint, he or she – despite best procedures – may introduce bacteria into that area, whereas by giving a dose of antibiotic before the procedure, you're getting blood and tissue levels of an antibiotic that can kill immediately that bacterium before it may lodge on the new joint. So that's an example of, if you like, primary prophylaxis or surgical prophylaxis.

Secondary prophylaxis would refer to maybe more so in the community where, for example, if you've a case of meningococcal meningitis, you would give prophylaxis to their close contacts, such as people living in the same household.

Q Would you need patient

consent to administer such antibiotics?

A Yes, you would. That would almost always be-- For example, in the case of the surgical patient, it would be included in the surgical consent.

Q Within your report, at page 13 of the bundle, you introduce the concepts of source isolation and protective isolation. If we could take each and in turn, what do you mean by "source isolation"?

A Source is basically where you have a source of infection, so you have a patient with a transmissible infection and you're trying to prevent that infection spreading to other patients in the immediate area. So, you know, it might be-- we talked about measles earlier on, which is highly transmissible; you want to prevent the measles in the patient who is admitted to hospital spreading to other parts of the hospital. Another category of infection would be influenza and indeed COVID-19.

Whereas protective isolation, you're basically using the isolation to protect a patient or a group of patients. So, again, go back to the examples we've used already, the patient with neutropaenia. We agree, I think, that patient is highly susceptible to infection. We want to protect him or her, so we put that patient in isolation to protect him or her getting microbes from other patients in the ward or indeed members of staff.

Q So again, if we could go back, for source isolation, what pressure regime would be required?

A Well, in that situation, you want to make sure that the air in that patient-- because the patient is the source of the infection, you want to make sure that the air surrounding that patient doesn't go out to the rest of the room. So you want it, basically, to be negative. You want the air to be coming into that patient rather than going out from that patient because, if the air goes from the patient to the rest of the area, it will bring whatever pathogen they have, such as measles.

Q Then the converse of that, if you wanted to achieve protective isolation, what pressure regime would you require?

A You want the air, in other words, to be positive. You want the air to be going from that patient. So that patient is-- doesn't have an infection, but he or she is at risk of infection. So you want to protect that patient from the air outside the isolation room, so you want positive pressure, so the air going from the patient's area, the patient who is vulnerable or

immunosuppressed, to the rest of the ward rather than the other way around.

Q If we just think for a moment, Professor, about the consequences of potentially getting the pressure regimes wrong. So take, for example, neutropaenic patients, what would be the potential impact on a neutropaenic patient if you got the pressure regime wrong?

A Well, they would then become vulnerable to any microbes, including pathogens, that would be outside their isolation room in the ward, whether it be multidrug resistant bacteria such as MRSA or, if there wasn't adequate filtration, fungi – including aspergillosis.

Q Potentially, how serious could that be for a neutropaenic patient?

A Well, aspergillosis, for example, is a very serious infection, and even with appropriate treatment, antifungal treatment, it can be difficult to treat, particularly if the neutropaenic state is prolonged. So, yes, it could be very consequential.

Q If a neutropaenic patient was in the wrong pressure environment, would you expect that risk to be identified?

A I would hope it would be. It should be if measures are in place to make sure that that patient is in the right air-controlled facility. Now, you know, some isolation rooms have the facility for them to be switched to protective or source isolation, and it's absolutely really important that the correct category is provided for the right category of patient.

Q Just at a practical level, how would it be ensured that such a patient was in the correct pressure regime?

A By checking that the ventilation was switched to the right category and documenting it.

Q Now, in relation to ventilation systems themselves, I think you very fairly say at page 14 of the bundle that you're not an expert in the detailed technical specifications for a ventilation system. Is that correct?

A That's correct, yes.

Q But you offer some observations in terms of how one might go about setting regimes within hospitals. Is this really a balance amongst a whole range of factors?

A Do you mean between different ventilation facilities or between the ventilated facilities and the rest of the hospital?

Q I think amongst a whole host of factors, are we talking about balancing logistics, common sense,

plausibility; are all of those issues in the mix?

A Yes. So we've identified some areas in the hospital where I think it's-- and it's in the various official documents, both English and Scottish documents, where we recognise that we need ventilation. The question really is, for example, how many operating theatres you need will depend upon what your throughput is and what your planned throughput is likely to be over the next ten years or more. The number of air-controlled rooms, whether they be for patients – excuse me – who are highly vulnerable to infection or whether they be for patients with infection, again, will depend upon your case mix. I suppose the more of these, obviously, you have, the better, but you've got to balance that against, you know, the cost of both building those facilities, the cost of maintaining them – increasingly we're aware of the energy issues – and then obviously, you know, there may be space.

So, for example, I recall a particular situation in my own experience where we were modifying an existing facility, and we had a guideline which said "You need X amount of square metres for a particular unit for each room" but on the other hand, if we went to that, we would have significantly less room so we would have less, if you like, access to the service that we were providing. So there was a compromise made that we would slightly reduce the size of the room in that facility to make sure we had enough rooms to provide the service that we were that we were trying to provide.

So that's an example where sometimes, particularly in existing facilities, it can be difficult, if you like, to get all the parameters right because there are some constrictions in place; and of course there's often also a budget in place which may or may not allow what you might ideally like as opposed to-- And indeed you're often trying to not only decide what you need for now, but also decide for what you think you will need over the next 30 years, but it can be more difficult to justify what you think you're going to need over 30 years as opposed to what people will say, "Well, we clearly need X number now. Do we really need X number plus Y in 30 years' time because we're spending money now, the benefit of which we may not see for some time."

Q So a range of factors to be considered, including cost.

A Correct.

Q Would you consider that overprovision or overengineering would equally be undesirable in relation to healthcare ventilation?

A Well, as a kind of microbiologist in infection prevention and control person, I probably would be arguing on the overengineering aspect of it. I would say they need, perhaps-- you know, I've been looking into the future and saying we need to-- as I said to you earlier on, I think the cohort of hospitalised patients is becoming more complex, so I would be anticipating what our needs would be. I think particularly that's been, I think, well seen with COVID-19, but on the other hand, there are there are mechanical and physical restrictions on what you can provide. So there has to be, I suppose, sometimes a certain amount of compromise in terms of what's likely – even allowing for what you hope you would be able to provide now and into the future.

Q Just moving on. In page 15 of the bundle, you return to look at the two tables that we have touched upon before. So, firstly, appendix 1 from the Scottish Health Technical Memorandum, and then secondly appendix 2 from the Health Technical Memorandum in England. Am I right in thinking that you say, at page 15, that there is no particular science that you are aware of that justifies really any particular of those air change regimes?

A Well, what I would say perhaps maybe more correctly with more precise science: I think that, if you look at what's recommended, it's-- it makes a lot of sense, it's plausible because you're basically, for example, increasing the air changes according to where you think there is risk, and you're applying what we know biological-- So, I mean, there is, I suppose, intrinsic biological plausibility – call that evidence, if you like. What I suppose what I'm trying to get across and perhaps I haven't explained it adequately, is that there isn't a sort of a randomised control trial which says that, for example, 10 air changes per hour is as good as 12 or 13 air changes per hour but, in that ballpark, you're in the right place to, if you like, optimise the facilities that you provide.

Q So, for example, if we took critical care areas that have 10 air changes an hour, in your professional opinion, would you be able to say whether 11 was better than 10, or 9 was equally as good as 10, or is that simply impossible?

A I'm not sure I could. I mean, I think if you look at the

mathematics of this and, again, this is technical areas that-- you get dilution-- you get more rapid dilution the more air changes you have, but you still get fairly good dilution of contaminated air in a relatively short space of time even with 10 air changes per hour.

Q In your opinion, is there though a risk associated with reducing air changes?

A There is a risk, but I wouldn't be able to give you a judgment as to how significant that risk would be. I mean, if you go from, for example, looking at that page you're referring to. If, for example, you've got-- you talk about 25 air changes for a general operating theatre and you go down to 15/16, then I think you're into territory where there may be a significant risk. On the other hand, if you're going from 25 to 20, the risk may not be so great. In any event, over time, over-- with age, air changes within an operating theatre may decline due to, if you like, the longevity of the plant, as it were.

Q So if we look at page 15 of bundle 6, approximately six lines up from the bottom of the page, is that why you reach the ultimate conclusion by saying:

> "Hence, while it is difficult to be definitive, ACH of 7, 8, and 9 might still give significant protection, but those at 5 or less would probably not as they would be similar to what you would see in a non-mechanically ventilated area. Nonetheless, failing to implement guidelines is likely to increase the risk of adverse events occurring, such as infection, even if quantifying this increased risk would be challenging generally and especially in the case of an individual patient."

Yeah, I mean, that would be my view, and it's my opinion and it's my judgement but I'm not saying that there might not be others who might take a contrary view. But my understanding of the whole role and value of ventilation and the impact it has, with other measures to prevent and control infection, that would be summarised there.

Q In terms of the importance of flowrate within a hospital ward or room once comfort levels have been achieved, does that really depend upon the clinical context you are dealing with?

A Yes, I think so. So, again, if you look at the situation-- Well, let me just give you an example.

So let's say you have a general ward, and you have a-- the patients are stable, there's no infection. You might have, for example-- generally people say you have about six air changes per hour in a normally ventilated room. Now, if you have a situation where you're trying to reduce infection being transmitted by, for example, SARS-CoV-2, we try to increase those air changes by opening windows and opening doors, even though obviously there's a comfort issue there. So there's both the air changes per hour, there's the direction of the air and then there's the filters that you were using, as I understand it, are what's important there. So, the greater the air change is, the greater dilution you have, reducing the number of contaminants in the air and therefore the safer it is. That's generally the principle upon which we work.

Q If I could ask you, please, Professor Humphreys, to look within bundle 1 to page 837 and to paragraph 5.6, please.

A Still in my document, is it?

Q No, in the top right-hand corner it should say "page 837". It should be from SHTM 03-01 Part A.

A I've got 756, let me just see.

Q It would be page 837.

A Sorry, no.

Q Top of the page would have "5. Ventilation Strategies".

A Excuse me. What page is it again, Mr MacGregor?

Q So, in the top right-hand corner, it should have "page 837".

A I've got 756. I wonder if it is just further down the pages. Let me just see. 970. 837. Sorry, I have it now, apologies.

Q Thank you. Do you see at the bottom there, there is a paragraph 5.6?

A Yes.

Q That states:

"With natural ventilation, it is almost impossible to maintain consistent flow rates and ensure that minimum ventilation rates will be achieved all times. However, this variability is normally acceptable in non-clinical spaces such as office accommodation, staff areas, library/seminar rooms and dining rooms, and some clinical areas such as level 0 and 1 care spaces and waiting and consulting rooms where risk of airborne infections is likely to be low."

Do you see that?

A Correct, yes.

Q Would you agree with that statement?

A I would, yes.

Q So, is it fair to say that if a purpose of a particular room or ward is neither control of infection from an infectious patient or protection of a particularly vulnerable patient from infection, the flow rate is not clinically important?

A No, and if you look at, even in-- we talked earlier, I think, in terms of naturally ventilated areas in hospitals. Often, in general medical and surgical wards where we believe that we have low-risk patients for infection, often they would be naturally ventilated, even though patients would be there for a period of time.

I think the difficulty we're now facing is that within that category are a cohort of what we call “general medical or surgical patients.” We often have patients who are at some risk of infection because of advances in medical care, including the use of drugs that affect the immune system – biological agents, which are used to dampen down the inflammation in patients, like, for example, patients with rheumatoid arthritis or patients with multiple sclerosis. So, I think we're seeing changes in that and obviously, if you've patients in hospital who are in those areas for whatever reason – so, for example, they have to move through the hospital to radiology or whatever – then if they're highly immunosuppressed, then it does represent a risk.

Q Thank you. So, is the principal purpose of flow rate in general wards, or non-isolation rooms, to ensure the comfort of patients?

A I think that's a fair comment, yes.

Q Would you agree that the need for a particular relative pressure environment depends upon the individual clinical context?

A Correct.

Q Is the principal situations in which it is required, to prevent the spread of infection from a room containing an infectious person, or to protect a particularly vulnerable patient from airborne infection?

A Yes. Those are two very clear categories in which you need dual ventilation in a single room.

Q Would it ultimately be a matter for clinicians to decide on the particular requirements of any ward or room?

A Yes and it also would be a situation where – and this often happens – you have to prioritise

maybe one patient over another because you may not have sufficient numbers of rooms in which to, ideally, cater for patients. So you might have to look at an individual patient and say, “Well, patient A is at greater risk than patient B”, even though you would also like patient B in a similar facility.

Q Are you familiar with the work of Dr Lidwell and what has been referred to as “The Lidwell Report”?

A Correct, yes.

Q Can you explain to the Inquiry, what is The Lidwell Report?

A The Lidwell Report – and a lot of the work that he and others did – was looking at, basically, the quality of air, in terms of the numbers of bacteria and air changes. It was done a number of years ago and I think has informed, especially in operating theatres, the design and specifications of operating theatres, not just in the UK and Ireland, but indeed beyond that. Of course, Lidwell was also involved in a seminal trial, a clinical trial, looking at the role of ultra-clean, ventilated theatres – or sometimes they are referred to as “orthopaedic theatres” – to reduce infection further in prosthetic joint, or artificial joint, surgery.

Q In terms of the work that Dr Lidwell did in terms of air changes per hour, do you know what conclusions his research reached?

A I think, obviously, the more air changes per hour, the more rapidly you dilute the contamination in the air and, indeed, render very little, if any, of the residual air that's present. This comes up often in a context which I find where sometimes surgical colleagues want to have what we call a “septic patient” at the end of the list. So they're operating on a number of patients who are what we call “clean surgery” which is that they have no infections. They're going in to do a particular procedure. Then they have a patient who, for example, has an abdomen and pus needs to be drained from the abdomen. They want to put that patient at the end of the list believing that it's safer to do so, because he or she will not contaminate subsequent patients.

Now, if you actually look at the mathematics of it, once you get a very rapid dilution of existing microbes in the air in a very short period of time – for example, if you've got six air changes per hour in a room – after half an hour, with three air changes, you'll only have removed 95 per cent, so you're removing the residual contamination in that area very quickly over a relatively short period of time,

but obviously it depends on how long you can wait before you bring another patient into that operating theatre. Obviously, in other areas of the hospital, it will depend upon the air changes and how quickly you will get to that situation where more than 99 per cent of the residual contamination has been removed.

Q So, applying the principles developed by Dr Lidwell, after four air changes would approximately 98 per cent of contaminants in a space be removed?

A Correct, yes.

Q Does his research indicate that each successive change will remove a smaller and smaller number of contaminants?

A Yes, you're getting closer and closer, but never quite mathematically reaching 100 per cent removal of the existing contaminants. I don't know whether it's relevant, but interestingly enough, I came across a research paper a while back and again, this was not confirmed in clinical practice, but it was looking at the mathematics of all of this, looking at the risk in outpatient and emergency department, according to the number of air changes and the potential risk to healthcare professionals. I thought this was an interesting statistic, that the risk of a healthcare professional acquiring TB from an infectious TB patient was 2 per cent or 1 in 50 if there were five to six air changes per hour and they stayed in that area for 15 minutes. So again, it's obviously related to how infectious the patient is, but it's also related to how long you stay in that area with that patient and how many air changes you are and the higher the number of air changes, obviously you can either stay in longer for the same risk or you reduce the risk.

Q Would you agree that whether there is any increase in risk or, if so, the extent of any increase depends upon the particular individual circumstances?

A Yes, I think it would, yes.

Q Just to return to the issue of natural ventilation, are you aware of whether higher summer temperatures impact on whether natural ventilation can still be relied upon?

A I know that over the course of my career I've often had queries from medical and nursing colleagues in the height of a summer when we've had a rare heatwave to say that "It's very hot in here and we believe that there's an increased risk of infection arising from the heat." Now, I think there's two factors there. I

think, first of all, there's the discomfort for patients and staff, and the fact that, if people are uncomfortable, they may not perform to the best of their ability. In terms of the risk of temperature *per se*, I've only seen one study, which was an epidemiological study in the United States, which showed a correlation or a relationship between increasing seasonal temperatures over the summer and post-operative surgical site or wound infection rates.

Now, they did try to control for other variables, things like the changeover of doctors, usually during the summer, a case makes different types of surgery and so on; but again, going back to that term I used earlier on, it's kind of biologically plausible because, if you have a humid environment and a warm environment, bacteria will replicate more commonly. Therefore, the skin on the bacteria, which will often be those skin that cause surgical site infection, may be higher in numbers when you've got a humid or hot condition.

Now, obviously, throughout Britain and Ireland, most of the year, we don't have such high temperatures, for example, into the 30s or beyond, but certainly it's potentially possible that, in those circumstances, you might get higher infection rates due to that biological issue, but I think also because of the fact that staff will be uncomfortable and they may not be working at their optimal, if you like, capacity.

Q Would you regard four air changes per hour with mechanical ventilation supplemented by natural ventilation in a room to be a significant departure from a standard that required six air changes per hour?

A Yes, I'd find it difficult to make the judgement on that because it would depend upon what the nature of the natural ventilation was and whether it was continuous. So, for example, with natural ventilation, it's said that if you have the ventilation coming in on one side and going out at the other side, and if it comes in-- if it goes out at the top, it goes out quicker, so there are the various ways in which you can design natural ventilation to maximise the airflow through that area. So I think I would be cautious about making assumptions about that; that may be within the limitations of my technical expertise in these areas.

Q Thank you. I would just like to ask you a couple of questions about single rooms in hospitals. Is there a general trend towards near 100 per cent single rooms in modern hospitals?

A Yes. I think that's the view, that we should move towards that. Although, for the reasons-- some of the reasons we've discussed and for other reasons such as privacy and dignity, but I think there's also a recognition that there are challenges in doing so, and they're not just in terms of resources. There are downsides to single-- I mean, as a microbiologist, I would love to see 100 per cent single rooms because I think that would certainly contribute to preventing infection or could significantly contribute, but there are other issues to consider apart from expense. There's the issue of it's more difficult for nursing staff to observe patients if every patient is in a single room; there's a sense that some patients, when they're in a single room, feel stigmatised or isolated or cut off from other people; there's the issue of-- there's been some reports that, for example, falls are more common in single rooms because nobody sees that the elderly patient is about to fall and can reach out and help them falling. So there are sort of-- there's an argument going on, but I think in any new build, new hospital, I think serious consideration would be given to trying to provide 100 per cent single rooms.

Q Okay, but would you accept that there could well be a clinical justification for a departure from 100 per cent single bedrooms?

A Yes, and to go back to a sort of quasi-parallel situation was that if you-- if, for example, you had the option of 100 per cent single rooms or a mixture of single rooms and maybe double or three bedrooms, but you had more beds, then what that would mean is you would have-- you would be able to provide a greater range of services or you would be able to provide the same range of services in a shorter time with shorter waiting times. Particularly if you felt that some of the patients you would be admitting to that hospital were not very high risk and therefore they could go into a two or three bedroom, then that would be the trade off, if you see what I mean.

Q Within your report in relation to multibed wards, you indicate that you think there should be a maximum of three beds. Why do you reach that opinion?

A Well, I mean, that's a judgement and opinion. I think the hospital that I've worked in for the last 20/25 years or so has had six-bay rooms. Now, of course, it also does depend upon the size of those multibed rooms, but I do think six

complete strangers in a room together is far from optimum. So, if you have to make a compromise and you can't have 100 per cent single room, I would have thought two to three, at most four, with adequate space is a compromise that you might live with – but that's a matter of opinion, and it's just my opinion.

Q In fairness, is that an area where views amongst clinicians may differ?

A I think it is, yes. Indeed, some clinicians – particularly, for example, clinicians in the areas of oncology and haematology would-- even though some of their patients would not be high risk – they would be at risk, but they might not be at high risk – but they would be very keen on 100 per cent single rooms, and I can understand that. My impression also is that a lot of our critical care colleagues would also like to see 100 per cent single rooms in ICUs, for example.

Q Am I correct in thinking-- That's obviously your opinion, but is there any guidance that supports the view that it should simply be a maximum of three beds?

A In terms of general areas within the hospital or ICU?

Q Well, perhaps if we take both, if we take general wards first.

A In general wards, that would be my view. As I said, some might say that that's too liberal and it should be only two; others might say it should be four or it could be six as long as they're low risk. In terms of critical care, I think-- somewhere I think I've referred to the number of rooms that should be single rooms, and it increases to 50 per cent if you're going to be admitting a lot of patients with neutropaenia.

My experience over the last five to ten years is that we're seeing increasing numbers of high-risk patients in critical care – such as, for example, ICU – as we have more aggressive treatment for these patients and as they live longer. So I think-- 50 per cent I think is-- it would probably be required, if not more, in most tertiary referral centres; again, that would be opinion.

Q Are you familiar with the term "high efficiency particulate filtration"?

A Correct, yes.

Q Is that something that is called HEPA filtration?

A HEPA filters, yes, that is correct.

Q What is a HEPA filter?

A Again, my understanding

as a non-technical expert is that it's a very sophisticated filter which filters out almost all the particles that you are likely to see spreading from one area to another. It's a much more sophisticated and effective filter than what you might have, for example, even in a general operating theatre or in a general clinical area. HEPA filtration is particularly important in areas where you're going to have neutropaenic patients because it will screen out the fungal spores that cause aspergillosis. HEPA filtration is also used in ultra clean ventilated theatres or orthopaedic theatres used for prosthetic joint implantation because you really need very pure air there to reduce the likelihood of bacteria from skin contaminating the artificial joint.

Q Are you familiar with the term "patient pathway"?

A In a very general sense, yes.

Q What does that mean?

A It conveys to me a patient is admitted to hospital and has a number of, if you like, either geographical areas in which they might be but also either procedures or checks in terms of investigations, documentation and so on.

Q For a patient that was deemed to require HEPA filtration, would you expect to see that across the patient pathway?

A Ideally, yes, but obviously the patient who requires HEPA filtration may need, for very good, legitimate reasons, go to other parts of the hospital which may not, in the course of that travel, have HEPA filtration. Normally, what we would do in that situation is we would ask the patient to wear a mask that would mitigate that risk or the patient might be on prophylaxis-- prophylactic antifungal agents, again, like we discussed earlier, to prevent aspergillus.

Q So you would expect some form of management to be taking place of that situation.

A Yes, I think so. I mean, again, sometimes in an emergency situation, the emergency might necessitate very urgent action taken before those measures could be instituted.

Q Would you expect that to be recorded anywhere?

A I certainly would like it to be recorded, but whether or not, particularly in an emergency situation, it would or would not, I can't honestly say that it would. The priority would be to provide urgent care to that patient in

wherever it was required. For example, if the patient who was severely immunosuppressed needed to go to the operating theatre or needed organ support in the critical care area that would be the priority, and the documentation of aspects of that might not be there.

Q Would you expect that to be communicated to the patient?

A I'm not sure that it would be. Again, it might be the sort of thing that might get overlooked in the emergency of the circumstances in which the priority was to provide urgent life-saving treatment for that patient.

Q With the absence of HEPA filtration across the patient pathway, would it potentially expose the patient to increased risk?

A It would, but that risk and the measure of that risk would be dependent on obviously the vulnerability of the patient, but it also would be where they were going on that patient journey and whether there were other mitigating factors such as, for example, on antifungal prophylaxis.

Q Professor Humphreys, are you familiar with the term "chilled beam technology"?

A Not really, except that I know it's a function or it's a technical aspect of ventilation, but I would rather not comment on details of it.

Q Again, do you have any knowledge or expertise in the term "comfort modules"?

A Not really, no.

Q Are you familiar with the term "thermal wheels"?

A I have a vague understanding of the concept in terms of energy conservation, but I wouldn't-- it would be outside my area of expertise.

Q Are you aware of any risks associated with thermal wheels in relation to the treatment of immunocompromised patients?

A Well, I know that wherever you're in a situation where you have heat you may get condensation, and where you've got condensation, you've got to be very careful you don't have stagnant water because of the risk of Aspergillosis. But, other than that, I would defer to those with more expert engineering knowledge.

Q Okay. If I could just take you to page 25 of the bundle and to Appendix 2 and to the second paragraph, you state, in relation to the table:

"This table is a very helpful summary, especially for

those not expert in engineering and aerodynamics."

In relation to aerodynamics, can I just be clear, do you mean air movement?

A Yes. The movement of air to and fro, yes.

Q In relation to the guidance that we have looked at, both the Health Technical Manual and the Scottish Health Technical Manual, are you aware of whether they have tolerances built into them?

A I'm not aware that they are. They are recommendations, guidelines as to what should be the case, particularly, I think, in new builds. Obviously, where you have an existing facility, it may or may not be possible to refurbish to provide those guidelines-- provide those specifications.

Q If I could ask you to look back, please, to page 19 of the bundle and to paragraph 5.2 of your report, so this is a section of your report called "5. Perspectives on the role of ventilation and preventing HCAI". Do you see that on page 19?

A Yes. I see 5.2, yes.

Q At 5.2, you state:

"There is a need for a review of ventilation quality in healthcare facilities, particularly for vulnerable patients even if risks are complex and there are a number of factors, which affect the development of infection."

Can you just explain why you put that statement in your report?

A I suppose for two reasons: number one, I think – going back to something I think I've already alluded to – I think that over the last 10 or 15 years, the complexity of care has increased in hospitals and particularly in in critical care areas, and we're now seeing a much greater, I think, number of vulnerable patients who are immunocompromised and a more heterogeneous group of patients, some of which may not be recognised as vulnerable.

So, again, I go back to an example I gave earlier, there's lots of medical and surgical conditions that are now being treated with very powerful but very effective what are called "biological agents", which affect the immune system and dampen down inflammation, such as in the treatment of multiple sclerosis, such as in the treatment of inflammatory bowel disease, such as Crohn's disease. These patients often come under the radar. They're not necessarily flagged as immunosuppressed or vulnerable

because they're-- they have kind of common medical conditions. But what's changed is not the condition, but the treatment of condition. It improves the outcome, improves the quality of life, but it renders the patient more vulnerable to infection than would be the case if they were not on those.

The second reason I state that is I think, in the context of the COVID-19 pandemic, we have realised that we-- our hospitals were under huge pressure because of the transmissibility of COVID and because we had very, very defined and, in many instances, very limited facilities in which to care for these patients because most of our areas within hospital were naturally ventilated and we had no control over where the airflows were going. So we often had to come up with innovative ideas in terms of, for example, putting fans on windows to extract the air from a core area where there might be COVID patients to make sure the air from those COVID patients was not going back into the rest of the ward.

So, for those two reasons, I think we need to review and I think probably either increase the number of air control ventilated facilities or avail of alternative technologies such as portable HEPA filtration systems, or there are various air purification systems that are marketed out there commercially that may be worth looking at.

Q If I could maybe just take you through that in a little more detail, could you just be clear of what you think this review should involve?

A Well, I think we need to look at the categories of patients we now have in hospital compared to 10 or 15 years ago because most of the facilities that many of us work in are not only 10 or 15 years old, but would be older, much older than that, and we need to look at the proportion of those patients that are low risk, medium risk, high risk, and maybe very high risk, such as our neutropaenic patients. We need to look at what current facilities we have for those patients and whether we believe that those are adequate or not. Then I think we need to incorporate into that some sort of future planning not only for increased numbers of some of those patients that I talked about, but perhaps a bit more flexibility such that if we have another pandemic, we can perhaps react better. So those would be, in very broad general terms, the kind of things I'm talking about.

Q In terms of that review,

what disciplines do you think should be involved?

A I think it would be-- it would need to be multidisciplinary; it would need to be-- involve, obviously, management and healthcare planners, it would need to involve infection prevention and control and infection specialists, it would need to involve clinicians looking after these patients, engineers, architects and probably health economists as well amongst others. I mean, that's not an exhaustive list.

Q Again, just so I am absolutely clear, what would you be seeking to achieve through such a review?

A I think more to marry, if you like, the facilities that we have and will have in the future with, if you like, the patient demographics in terms of the numbers of patients at various levels of risk so that we can try and match better the facilities we have according to the patients and the vulnerability that they have.

Q Professor Humphreys, the final question that I have for you is in section 7, your conclusion section, at pages 20 and 21 of the bundle, you try to tie your report together by giving the example of road safety and trying to use that as an analogy in relation to risk in relation to healthcare ventilation. Can you just explain to the Inquiry through that road safety analogy how you have tried to draw things together?

A Well, I've always taken some inspiration and indeed knowledge from my understanding of the approach to road safety in Ireland, and I'm sure it's the same in the UK, in terms of the emphasis on basically the physical structure in which we drive, so making roads safer, removing bends, using motorways rather than single lane roads which are safer than single-lane roads, providing better lighting, using technology, for example, in the case of the car, the seatbelt and the airbag and various other measures in the car now which can tell us when we're too close to car in front. Then the most difficult one of all, I suppose, is the human behaviour, what we do as drivers in terms of, “Do we do what we should do when we're in the car?”, in terms of not go into a car with alcohol, put on our seatbelt and drive within the speed limit and so on and so forth. I think there's a kind of parallel there in healthcare-associated infections. So we have, if you like, the infrastructure, which we focused on in terms of space, ventilation, we have the technology, which we have in some instances in terms of more rapid

diagnostics, we have it in terms of, for example, various devices that are now maybe more safer than others, and then we have, if you like, trying to improve human behaviour, which in some ways is the most challenging of all, but that's through education, through motivation and obviously having people accountable for their behaviour.

Q Thank you, Professor Humphreys. I do not have any further questions, but Lord Brodie may have some questions for you and there may be applications from core participants but thank you.

THE CHAIR: Thank you, Mr MacGregor. Does anything arise from Professor Humphreys' evidence? Right, I have got an indication that something does. Mr Ellis, do you want to speak to Mr MacGregor? (After a pause) Mr MacGregor.

MR MACGREGOR: Thank you. Just a couple of questions, Professor Humphreys: in paragraph 6.1 of your report, you mention HEPA filtration systems. Are filtration systems an acceptable method of reducing contaminants in air where necessary, either in place of or together with air changes per hour?

A My understanding in my-- is that HEPA filtration are usually used in conjunction with controlled air changes in hospitals. So what you want is-- For example, if you look at the example we gave earlier on, so you've got a neutropaenic patient in a single room, you want to make sure that the quality of the air coming into that room where the patient is is of the highest quality. But then you also need the air changes and the air pressures to make sure that there are no-- there's no contamination coming into that room where the patient is from other parts of the hospital, if you see what I mean.

Q Thank you.

A I don't know whether that answers the question.

Q Where necessary, could mobile filtration systems meet patients' requirements for clean air?

A They may do so. I think we need to look at that a bit more. I know in the past, before COVID, we looked at-- in its situation, we looked at mobile HEPA filtration units. But the problem was that if you don't have a seal system the HEPA filtration may actually draw in air excessively. So you need to look at the specification of the mobile HEPA filter and whether it can actually filter the air volume in that particular space, and you need to look at where the air is coming into that

room or that clinical area to make sure that you're not overburdening the HEPA filtration unit. So those would be the issues that I think we need to look at. Now, I wouldn't-- I would need to take advice from engineers and so on as to the details of that, but that would be my-- the issues I would raise about that.

Q Thank you, Professor Humphreys.

THE CHAIR: Mr Ellis, are you content?

MR ELLIS: (No audible reply)

THE CHAIR: Thank you very much, Professor Humphreys. That is the end of your evidence. Thank you very much for that. If you were here, I would say you are free to go, but you are free to do whatever you wish. Thank you very much for your evidence.

A Thank you very much.

THE CHAIR: Now, if I remember correctly, our timetabling for tomorrow is a 9.30 start.

MR MACGREGOR: 9.30, my Lord.

THE CHAIR: Well, we will see each other tomorrow at 9.30.

(End of Day 3)

SCOTTISH HOSPITALS INQUIRY

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