SCOTTISH HOSPITALS INQUIRY

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Hearing Commencing 9 May 2022

Bundle 6 – Expert Reports and Statement

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Scottish Hospitals Inquiry

Expert Report

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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 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	ac/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

Report on Ventilation Principles

Author: Shaun D Fitzgerald OBE FREng FCIBSE FEI MA PhD

22 March 2022

Table of Contents

1 Context

I have been asked to contribute to the Public Inquiry investigating the construction of the Queen Elizabeth University Hospital Campus, Glasgow, and the Royal Hospital for Children and Young People, and Department of Clinical Neurosciences, Edinburgh. In particular, I have been asked to provide some background as to the principles behind ventilation design, some background behind these governing principles, and how these relate to healthcare settings. I have general experience in academic research on ventilation in buildings, and practical building design and implementation and associated guidance. However, I am not an expert on the statutory requirements for building design nor their origins.

I have been provided with the HTM03-01 Part A (2021) and SHTM03-01 Part A (2014).

2 Professional Background

I am an engineer who has spent significant time in both academic research as well as in industry. I am a Chartered Engineer (since 1997), a Fellow of the Royal Academy of Engineering (since 2014), a Fellow of the Energy Institute (since 2004), a Fellow of the Chartered Institution of Building Services Engineers (CIBSE) (since 2005), and have spent around 20 years in the field of ventilation in buildings.

I studied engineering at the University of Cambridge and then after a year in the geothermal industry undertook a PhD in fluid mechanics and heat transfer in geothermal reservoirs. After a post-doctoral research position following the PhD, I joined the Faculty of Stanford University to be the Geothermal Program Manager.

On leaving Stanford I joined Bain & Company, one of the leading strategy consulting firms. In 2001 I left Bain to return to the field of fluid mechanics and heat transfer and led the industrial interface part of a research programme at Cambridge University on natural ventilation in buildings. During this 4 year research programme I published numerous papers on ventilation in buildings and also undertook ventilation design consulting work for a wide range of projects, the vast majority of which were non-domestic. The research papers were mainly focused on natural ventilation within buildings, but the ventilation design consulting work also included the interaction of natural ventilation systems with mechanical ventilation and cooling systems within buildings.

In 2006 I left full-time employment at Cambridge University to set up a spin-out company Breathing Buildings, which acquired the rights to intellectual property that had been created as a result of the research. The company was initially funded by BP and I then took this through multiple rounds of venture capital funding before selling the company to Volution Holdings in December 2016.

During my time at Breathing Buildings I led all of the major ventilation design projects, as well as the largest contracts for supply of controlled ventilation equipment. I oversaw the design of the ventilation strategy for Houghton le Spring Primary Care Centre, which received various awards for the innovative but robust ventilation scheme. This project was an NHS project commissioned by Sunderland Teaching Primary Care Trust. The building was constructed by Willmott Dixon and was designed by P+HS Architects supported by Mott MacDonald engineers. Breathing Buildings was engaged by the Primary Care Trust to support the overall ventilation design.

The project was the first healthcare facility to achieve a BREEAM 'outstanding' rating at the design phase, received the highest award for best practice in sustainable design and environmental performance, meeting a score of 85% against strict criteria. BREEAM is the Building Research Establishment's Environmental Assessment Method. It is the world's first sustainability rating scheme for the built environment and has contributed much to the strong focus in the UK on sustainability in building design, construction and use. BREEAM is now an international standard that is locally adapted, operated and applied through a network of international operators, assessors and industry professionals. Through its application and use BREEAM helps clients measure and reduce the environmental impacts of their buildings and in doing so create higher value, lower risk assets. To date, BREEAM has been used to certify over 260,000 building assessments across the building life cycle.

The project involved reviewing the design criteria set out by the Primary Care Trust, undertaking modelling of temperatures and airflow in the building with both natural ventilation and mechanical supplementation of the natural ventilation scheme; specifically, although the building was designed to operate mainly with natural ventilation, the strategy included fans within the ventilation shafts at certain points of air inlet and outlet in order to help ensure the flow rates and thereby help meet the design criteria.

Treatment rooms were part of the design and importantly these rooms were designed to be served by their own ventilation shafts – these were not connected to other rooms. This principle of separating certain areas is similar to that for hospital settings.

The major innovation for the building was the inclusion of a thermal wall and a means to provide natural cooling but where some of the cooling was provided higher up the building. This feature enabled the building to ventilate even when it was overall cooler inside than outside; one of the challenges of other (previous) designs involving cooling in a basement is that although the cooling occurs, one then requires the cool and relatively dense air to rise which is not possible under buoyancy alone. In these previous designs either fans or else much hotter temperatures (and less dense air) at the top of the building are needed.

I also oversaw the natural ventilation design work we undertook for Foster and Partners on the Apple Headquarters building in Cupertino, California as well as the Bloomberg European Headquarters building in London which won the RIBA Stirling Prize in 2018. Both of these buildings were based on a hybrid ventilation concept which involved both natural and mechanical ventilation.

I was heavily involved with the Education and Skills Funding Agency in the revision of Building Bulletin 101 (BB101), which is the document that lays out the ventilation requirements for educational buildings. This is relevant because HTMs, SHTMs and BB101 involve consideration of ventilation flow rates. In particular, the revision of BB101 included general teaching spaces as well as laboratories and laboratory storage areas where timescales for removal of contaminants (as might arise from a spillage) were considered. I also had input to Building Bulletin 93 which is the guide to acoustics, since the noise caused by the use of a ventilation system is related to the rate of supply of air; a higher flow rate in a given ventilation system results in higher noise levels.

Whilst Breathing Buildings was originally established as a natural ventilation company, we evolved into hybrid ventilation – the combination of mechanical and natural ventilation. A number of our products had mechanical ventilation incorporated into them, and we therefore had to comply with

mechanical ventilation regulations and testing in our facilities in order to take these to market and work with customers to establish the most appropriate equipment for their needs.

One of the interesting and relevant projects which I oversaw as CEO of Breathing Buildings was an investigation into an acoustics problem with a very tall skyscraper in London. The lift lobby adjacent to the restaurants half-way up the building had started to suffer from a very annoying whistling noise emanating from airflow up the lift shaft and through the narrow gap in the lift doors. We spent significant time on site investigating the potential causes and ultimately identified the problem following a series of separate tests in the middle of the night when the restaurants were closed. The problem was caused by more extract ventilation equipment being installed, but without compensating air supply, and hence negative pressure being created in area. This is an example of the types of problem which can arise when mechanical ventilation systems are installed or changed without appropriate consideration of the impact on adjacent spaces.

I left Breathing Buildings in 2018 in order to take up the position as Director of the Royal Institution in London. In 2020 I then returned to Cambridge University as Director of the Centre for Climate Repair in the Department of Engineering. This period has been beset with the challenges of Covid-19 and I have served and am serving on numerous bodies to support governments with my expertise in ventilation of buildings. I am a Member of the SAGE Environmental Modelling Group, the expert group of the World Health Organisation, am one of the primary authors for the Chartered Institution of Building Services Engineers 'Emerging from Lockdown' series of guides. I was also a Member of the Royal Society Rapid Assistance for Modelling the Pandemic (RAMP) team, a Member of the Independent High-Risk Aerosol Generating Procedures Panel, the DCMS Events Research Programme Science Board & DCMS Venues Steering Group.

I have published in various leading and relevant journals in my career, and a publication list is given in the Appendix as part of my CV.

3 An introduction to building ventilation

The primary purpose of ventilating a building is generally to help provide a space which is pleasant and safe in terms of air quality. However, ventilation can also be used to help regulate the temperature within the space. The term air-conditioning is different from the term ventilation. Ventilation is the term used referring to the provision of air to a room which is, at least for some of the time, comprised of fresh air. Sometimes ventilation systems can be turned to full-recirculation mode, for example when the building is not occupied but needs pre-heating prior to occupation and where the heating of the building is provided by a heater within the ventilation system. However, when the building is occupied then the ventilation system will operate with a percentage of fresh air being provided to the room. Air-conditioning refers to the conditioning of air in a room. In some cases, this can be a unit within the ceiling void which simply takes in room air via a grille, heats or cools this as required together with removal of moisture, and then returns the air to the room via a different grille. However, air-conditioning can also be provided as part of the ventilation system.

3.1 Natural, mechanical, hybrid.

Some buildings or rooms within buildings are naturally ventilated, by which we mean that the rate of supply of fresh air to the space is governed by the forces of nature, i.e. wind and/or buoyancy. Buoyancy is the force which is created by differences in density of vertical columns of air. For example, if air in a room is hotter than outside then it will be less dense than the exterior air. If there

are openings at the bottom and top of the room of comparable size then in the absence of any wind force the hot air will rise in the room and leave through the upper opening, whilst colder fresh air will enter the room via the lower opening.

A natural ventilation strategy includes single sided ventilation, cross ventilation, or stack ventilation systems. Single-sided ventilation refers to the case where a room has openings just on one side of the room. Cross-ventilation refers to the case where a room has openings on multiple sides, so that when the wind is blowing fresh air can enter through the upwind openings and room air can leave through the downwind openings. Stack ventilation refers to the case where a shaft provides a pathway linking the room to the roof or other higher external part of the building. A shaft can provide both inflow of fresh air and outflow of room air; the exact pathways depend upon whether there are other openings in the room, the temperature in the room relative to the outside, and the wind.

Some buildings or rooms within buildings are mechanically ventilated, by which we mean that the rate of supply of fresh air to the space is governed by one or more fans. A full mechanical ventilation strategy includes fans to both supply air and extract air.

A hybrid or mixed mode strategy involves a combination of mechanical and natural ventilation. The combination can be in parallel, whereby for example opening windows are used for all the supply and some of the extract and where some extract fans are also operating. Conversely the combination can be in series; that is where different systems are in use at different times of the day or year.

3.2 Components of a ventilation system

The components of a natural ventilation system can involve:

- opening windows (can be manual, automated, or a combination of both)
- opening dampers (can be manual, automated, or a combination of both); dampers are usually insulated panels that can be rotated a certain amount to provide an opening for air into or out of a space, but which can be closed too when the ventilation system is turned off
- roof stacks (these can be manual or automated, but automated ones are more common); roof stacks are often comprised of a louvre arrangement (such as are often used on weather stations) to allow air flow through the blades but prevent driving rain from passing through, with opening dampers behind the louvres

The potential components of a mechanical ventilation system are much more varied, are usually automated, and can involve:

- Supply fans – these provide the driving force for air to flow into a room
- Extract fans – these provide the driving force for air to be removed from a room
- Heat recovery devices (rotary heat exchangers/thermal wheels, plate heat exchangers, run around coils) – these are used to help reduce the heating requirements of a building by passing some of the heat of the air extracted from rooms to the fresh air being supplied. They can also provide a similar function in hot weather to reduce the cooling/dehumidification requirements if the air being extracted is cooler and/or drier than the outside air

    - A rotary heat exchanger, also known as a thermal wheel, is a device that moves plates which have been exposed to the outflowing air into the incoming air stream. The plates are often coated with a material which enables moisture and heat energy to be transferred from one stream to another
    - A plate heat exchanger is a device which enables heat from one airstream to be conducted through a thin sheet of material and transferred to a different air stream
    - A run around coil is a device which passes heat energy from one air stream into a liquid, with the liquid then being pumped through a pipe to somewhere else in the building, where it then releases its heat energy into a different air stream
- Filters – these filter out particulates from exterior air. They are needed for rooms such as various laboratories or operating theatres, but can also be used to help reduce the build-up of dirt on other pieces of equipment in a ventilation system such as heating / cooling elements
- Humidifiers – these can be included in order to add moisture to an air stream so that the relative humidity in the room is not too low. In winter, the cold exterior air can be quite dry since cold air cannot contain as much moisture as warm air. When it is heated in a building the relative humidity drops and if people are exposed for long periods of time to dry air, then they can develop sore eyes or cracked skin, so hence systems are often installed to maintain relative humidity levels of at least 30% (100% is the maximum that the air can hold)
- Chillers – chillers are used to reduce the temperature of the air in the room. They are particularly helpful when the exterior temperature is higher than the target interior temperature and there is no natural means of cooling, such as use of thermally massive structures and night-cooling of the building
- Dehumidifiers – these are used to remove moisture from a room and particularly helpful when the exterior temperature is higher than the target interior temperature and where the moisture content of the exterior air is too high for the interior to be comfortable
- Heaters – these are used to add heat to an airstream and to provide warming to an occupied space
- Chilled beams – these are devices located in the room and are used to help regulate the temperature of the air in the space
    - Active chilled beams are part of a mechanical ventilation system. The air being supplied to the room can be heated or cooled by the chilled beam just before the air enters the occupied space
    - Passive chilled beams are not part of a ventilation system and rely on convection in the room. They cool the air at high level, the air then becomes dense and falls, and is replaced by warmer air rising in the room.

In general, more centralized systems tend to have more components. For example, ventilation systems which are standalone products and just serve a single room on their own may have a plate heat exchanger and a filter, and possibly a heater. However, they are less likely to have a cooling coil and will not usually have a scheme by which moisture can be reclaimed. These products are more complicated, require more space to operate than just a ceiling void, and hence will often be located in a plant room or on the roof where multiple rooms can use the same facility (i.e. a centralised system).

3.3 Thermal comfort in ventilation systems

The maintenance of thermal comfort in a ventilation system is very important because if there are discomfort issues arising from the ventilation system itself then this can lead to not just complaints but intervention/interference from occupants. For example, if air is introduced to a space and causes cold draughts in winter then users may block off vents or find ways of turning the equipment off. Similarly, if the space overheats in summer due to insufficient air flow, then occupants will not be happy, and they may elect to install energy-inefficient space coolers.

4 Ventilation in a Healthcare Setting

4.1 Purpose of ventilation system in a healthcare setting

As in other building types one of the purposes of ventilation in a healthcare setting is to provide good air quality and to help regulate the temperature in the space. However, its primary function is to control closely the environment and air movement of the space that it serves in order to contain, control and reduce hazards to patients and staff from airborne contaminants, dust and harmful micro-organisms.

4.2 The role of ventilation in securing the safety and care of patients in hospitals

Controlled ventilation is a very important part of the overall environmental strategy to keep patients, staff and visitors safe. The areas of greatest concern for high levels of ventilation control are where there are patients who are particularly vulnerable to respiratory illnesses or where there are patients who are infectious or potentially infectious. When designed, installed and operated correctly ventilation systems can really help reduce risk of infection. However, when not designed, installed or operated correctly then ventilation systems can not only fail to protect people but can increase the risk of infection and transmission.

5 Critical parameters to be controlled by ventilation systems in hospitals

The parameters which can be controlled by ventilation systems are pressure, flow rate, temperature and humidity.

- Pressure is important because fluid (liquid or a gas) moves from areas of high pressure to areas of low pressure. So, the direction of flow is governed by whether the pressure in one area is higher or lower than an adjacent area. The SHTM 03-01 Part A refers to pressure and nominal pressure in Tables A1 and A2 for different room types. Where there is a reference to a positive or negative pressure rather than a specific value, the intent is to help air move out of the positive rooms to either neutral pressure areas or negative pressure areas when there are openings linking spaces. Where there are specific values in Table A2 for rooms of different levels of cleanliness, the pressures suggested are ‘nominal pressure’ values. As explained in the note to Table A2, “nominal room pressures are given to facilitate setting up of the ventilation equipment, the calculation process, and the sizing of transfer devices. In practice, the resultant pressures are not critical, provided the desired airflow rates and movement are achieved.” The last part of the last sentence is important – it is the airflow rate and direction of air flow which matters most.

- Flow rate is important because the rate of removal of a contaminant is directly proportional to the rate of supply of fresh air and rate of extraction of room air. Note that the rate of extraction is equal to the rate of supply for the purpose of ventilation design
- Temperature is important because this is a parameter which influences comfort of occupants
- Humidity is important because this is a further parameter which influences comfort of occupants; there are research papers investigating the lifetime of viruses as a function of different humidity levels and hence humidity might be an important factor in this regard too

The complexity of a ventilation system is such that these parameters are related. Temperature and humidity are related through the psychrometric chart.

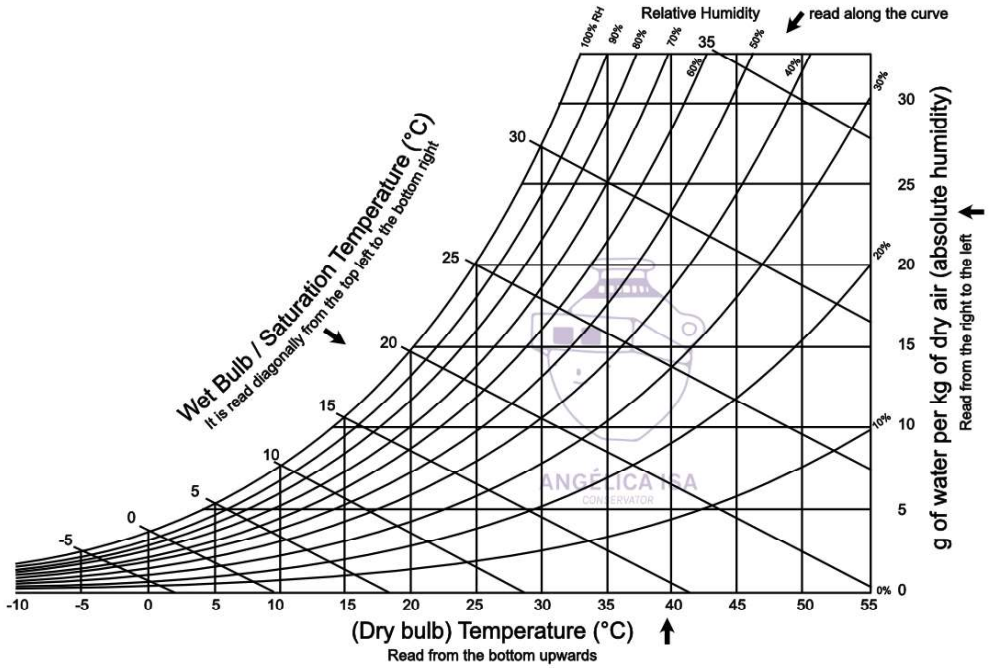


Figure 1 Psychrometric chart relating absolute humidity (grams of water per kg of dry air), relative humidity (effectively the amount of water vapour held by the air as a proportion of the maximum amount it could hold at a given temperature), and temperature. Dry bulb temperature is the air temperature. Wet bulb temperature is the temperature read by a thermometer with a wet material wrapped around the sensor; if some of the moisture in the wet material can evaporate into the air then the temperature of the wet material will decrease. Note the wet bulb and dry bulb temperatures are the same at a relative humidity of 100% because moisture cannot evaporate from the wet material.

Pressure and flow rate are related through the resistance characteristics of ventilation system components and fan curves. A larger diameter duct provides less resistance than a smaller diameter one and will permit a higher flow rate for the same pressure difference along the duct. Fan curves relate the flow rate and pressure differential across the fan which different fan products provide.

The two variables which underpin the flow of air within a mechanical system and within a mechanically ventilated building overall are pressure (Pascals) and flow rate (litres/second). In a naturally ventilated space pressure differences are much weaker, and buoyancy can be an important

driver. This relatively weak force (which is ultimately a result of pressure differences) is driven by differences in temperature within a building, and between the building and the exterior.

For most healthcare settings involving patients who are vulnerable and/or potentially infectious, mechanical ventilation systems will be used. This is because natural ventilation systems are more variable; the performance depends on the wind speed, wind direction and temperature differences between the interior and exterior. If a space is used to house a patient where a given air flow rate and/or a given pressure is required at all times whilst that patient is present, then it is normal for a mechanical system to be used.

The ventilation rate is sometimes expressed in terms of air changes per hour (ACH) rather than in litres/second (or cubic metres per hour). Whilst it is relatively straightforward to relate one to the other by dividing the flow rate in cubic metres per hour by the volume of the room, the metrics in fact reveal different features pertinent to the management of a space.

If there is a steady release of an airborne contaminant into a space at say X particles per second, then the steady state concentration of the contaminant in the room (in terms of particles per litre) will be dependent on the ventilation rate of say Y litres/second; the volume of the space V is irrelevant as far as the steady state concentration level is concerned. This can be shown since X particles/second divided by Y litres/second yields X/Y particles per litre.

The implications of this scientific fact are important if rooms in a building are designed based on a given air change rate. For example, let us compare two rooms each with an infectious person present and generating the same amount of airborne contaminant (e.g. virus) per unit time. If one room is twice the volume of the other, then if the air change rates are the same the larger room will be supplied with twice as much air per unit time. Therefore, the steady state concentration level of contaminant will be half that observed in the smaller room.

However, if instead of a steady release of a contaminant we are interested in the effects of a change in release rate, such as an instantaneous chemical spillage, then the assessment of the time for the decay of the contaminant to occur is a function of the air change rate.

In summary, ventilation rates expressed in litres/second and ACH are both helpful in the context of designing a healthcare setting, but the parameters have different qualities, the value of which depends on the issue being considered.

5.1 Setting of parameters in hospital settings

Flow rates in hospital settings are important because they help manage the build-up and decay of contaminants in a space. The pressure in a given space and the linkages between spaces need to be carefully managed so as to manage the risk of transmission of airborne contaminants. In general, spaces which are designed to house infectious persons need to be maintained at a sufficiently negative pressure relative to adjacent spaces in order to reduce the risk of contaminants which the infectious persons generate from entering other spaces.

Guidance on the setting of parameters for hospital ventilation systems is included in Health Technical Memorandums for England and Scottish Health Technical Memorandums for Scotland. These address requirements for particular spaces in health care settings such as hospitals and I understand that these provide industry standard guidance for ventilation requirements in these settings.

For example, an Infectious Diseases Isolation Room should be designed to maintain a pressure of -5Pa (Appendix 2, HTM; Appendix 1, SHTM). In contrast, spaces which are designed to house patients where exposure to contaminants presents an elevated risk need to be maintained at a sufficiently high pressure relative to adjacent areas which could be the source of contaminants. For example, an Operating Theatre should be designed to maintain a pressure of 25Pa (Appendix 3, HTM; Appendix A, SHTM).

It is important to note that both the pressures, and in particular how they relate to adjacent spaces (i.e. pressure differentials), and flow rates as specified in the HTMs and SHTMs should be followed. They help in different but complementary ways. Compliance with pressure metrics helps ensure contaminants from one zone do not flow easily to another; i.e. designed so that flow moves from rooms with higher pressure to those with lower pressure values when there is a linkage (such as an open door movement).

Compliance with flow rate metrics in ACH helps ensure the build-up and decay of contaminants in space are controlled. Compliance with flow rate metrics in litres/second (if specified) help regulate the steady state value of a contaminant for a given release rate of contaminant. (Note that if flow rate metrics in litres/second are not specified then for a given room volume the metric of ACH will help regulate the steady state value of a contaminant for a given release rate of contaminant.)

The design parameters for other hospital rooms are given in the Appendices of the HTM and SHTM, examples of which are given below.

Application	Ventilation	Air-change rate (ac/h)	Pressure (Pascal – Pa)	Supply filter grade (BS EN 16798)	Noise (dB(A))	Temp (°C)	Comments (for further information see Chapter 8)
General ward (level 0 and 1 care)	S/N	6	–	SUP2	35	18–28	
Communal ward toilet	E	6	–ve	–	45	–	
Single room	S/E/N	6	0 or –ve	SUP2	35	18–28	
Single room WC	E	3	–ve	–	45	–	
Clean utility	S	6	+ve	SUP3	45	18–22	
Dirty utility	E	6	–ve	–	45	–	
Ward isolation room (PPVL)	S	10	Lobby +10 Room 0	SUP2	35	–	See Health Building Note 04-01 (Supplement 1)
Infectious diseases isolation room	E	10	–5	SUP2	35	–	See Table 4
Neutropaenic patient ward	S	10	+10	H12	35	–	See Table 3
Critical care areas (Level 2 and 3 care)	S	10	+10	SUP1	35	–	Isolation room may be –ve pressure or PPVL. See Table 3
Birthing room	S & E	10	0	SUP2	45	*20–25*	See Table 5
NICU/SCBU	S & E	10	+ve	SUP1	35	*20–28*	Isolation room may be –ve pressure
For general and UCV operating suites and associated rooms, see specific guidance in Chapter 8 and typical design solutions in Appendix 7							
Operating department recovery room	S & E	15	0	SUP2	45	*18–25*	Provide clean airflow path
Catheterisation room	S & E	10	+ve	SUP2	45	*18–22*	

Application	Ventilation	Air-change rate (ac/h)	Pressure (Pascal – Pa)	Supply filter grade (BS EN 16798)	Noise (dB(A))	Temp (°C)	Comments (for further information see Chapter 8)
Interventional or non-interventional Imaging room of any type	S & E	10	+ve	SUP2	48	–	Stable conditions as specified for the imaging equipment
Sedation recovery room as in paragraph 8.16	S & E	10	S/E	SUP2	45	**18–28**	
Endoscopic procedure room	S & E	10	-5	SUP2	40	*20–25*	See Table 2
Endoscope reprocessing wash room	E	10	–ve	–	45	–	
General treatment room	S & E	10	Neutral	SUP2	45	*20–25*	See Table 2
Emergency department waiting area	S & E	6	–	SUP2	–	*18–25*	See Table 2
Containment level 3 laboratory	#	>20	#	H14*	–	*18–22*	# See ACDP guide; *Filter in extract See Table 4
Post-mortem room	S & E	S = 10 E = 12	–ve	SUP2	45	**18–22**	Provide clean airflow path
Specimen store	E	–	–ve	–	–	–	Fan accessible from outside of store

Notes:

Waiting and circulation areas should be directly or indirectly ventilated to provide a comfortable environment and control airborne contamination and odours.

18–22°C indicates the range over which the temperature may float.

18-22°C indicates the range over which the temperature should be capable of being controlled.

S = Suppy

E = Extract

N = Natural ventilation where possible

Class	Room	Nominal pressure (Pa)[a]	Airflow rate for bacterial contaminant dilution: Flow in or supply (m^3/s)	Airflow rate for bacterial contaminant dilution: Flow out or extract (m^3/s)
Sterile	Preparation room		See standard schemes in Appendix 7 for recommended design values	
	(a) lay-up	35		
	(b) sterile pack store	25		
	Operating theatre	25		
	Scrub bay[b]	25		
Clean	Sterile pack store	+ve	6 ac/h	–
	Anaesthetic room[c]	15[c]	The greater of 15 ac/h or 0.15	The greater of 15 ac/h or 0.15
	Scrub room	15	–	0.10 min[d]
Transitional	Recovery room	0	15 ac/h[e]	15 ac/h[e]
	Clean corridor	0	(See note f)	7 ac/h
	General access corridor	0	(See note f)	7 ac/h
	Changing rooms	3	7 ac/h	7 ac/h
Dirty	Service corridor	0	–	(See note g)
	Utility room	–5 or 0	–	0.40 or 0.10

Notes:

a. Nominal room pressures are given to facilitate setting up of pressure-relief dampers, the calculation process, and the sizing of transfer devices. In practice, the resultant pressures are not immutable provided the desired airflow rates and movement directions are achieved.

b. An open or semi-open bay is considered to be part of the operating theatre; a low-level extract under the scrub trough is required. (See Chapter 8 paragraph 8.45 onwards and "Note" for more information.)

c. For design purposes, anaesthetic should be assumed to be at 15 Pa. When commissioning, equal to or greater than 10 Pa is considered suitable.

d. May need to be increased if scrub is large to promote scouring.

e. 15 ac/h is considered necessary for the control of anaesthetic gas (see Appendix 9).

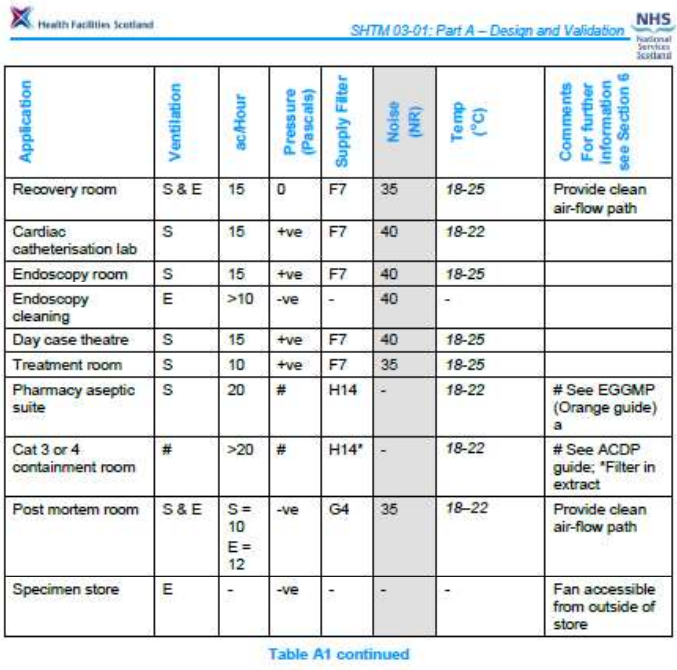
f. Supply airflow rate necessary to make up 7 ac/h after taking into account secondary air from cleaner areas.

g. No dilution requirement. Temperature control requirements only.

Figures 2-4. HTM Tables of design parameters for different room types in hospitals.

Application	Ventilation	ac/Hour	Pressure (Pascals)	Supply Filter	Noise (NR)	Temp (°C)	Comments For further information see Section 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

Table A1



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Application	Ventilation	ac/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 EGGMP (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

Figures 5-6. SHTM Table A1 of design parameters for different room types in Scottish hospitals.

6 Significance of room design and configuration

All rooms need to be designed with their end-use in mind, so that user interaction and use of the room is appropriately considered. For example, a mechanical ventilation system with careful management of pressures in different rooms can be disrupted if windows are opened. Therefore, it is important that if tight control of pressure and pressure differentials is required in certain zones that either opening windows are not included or else this effect has been carefully accounted for in the design.

Conversely, it is important that due consideration and use of natural ventilation is used in appropriate spaces so that patients, staff and visitors can derive benefit from these schemes through factors such as improved connectiveness to the outdoors especially in temperate weather – this can help improve the overall well-being of people and, as a result of the relative ease of provision of high rates of fresh air, can also lead to improvements in average air quality.

7 Guidance and accepted industry standards

The construction industry has a number of guides and standards to help with the design, construction, and commissioning of ventilation systems. These include building regulations such as Part F (which lay out the flow rates in various building types) through to industry guides such as those published by CIBSE; CIBSE provide guidance for ventilation rates in different settings, with CIBSE Guide A giving suggested flow rates in litres per second per person. Importantly guides also include the HTMs and SHTMs which lay out the requirements specific to the healthcare setting.

In order for engineers to sign off the ventilation system the system needs to be operating and measured. It is typical for ventilation hoods to be used to measure the flow rates from ventilation grilles especially in centralised ducted systems, since balancing of a system is usually required. Ventilation hoods are devices which can be temporarily attached to a ventilation supply grille and which measure the flow rate. Balancing of a system is required because if there is a central supply fan, the amount of air provided to one room further away from the fan and along a longer duct will be less than the amount of air provided via the same duct with an identically sized opening nearer the supply fan. Although one can calculate likely pressure drops throughout a ventilation system it is difficult to account for every bend in the duct work provided on site for example. It is therefore fairly common for the flow rates to be checked after installation and for necessary adjustments to resistances within the system to be made; these adjustments can be provided by introducing additional restrictions to grilles which are providing too much flow to thereby enable flow through other grilles to be increased.

7.1 Potential consequences of not complying with guidance and industry standards

First and foremost, the correct design, installation, commissioning and operation of a ventilation system in a healthcare setting is required in order to help with the safety of people; patients, staff, and visitors. If flow rates are not achieved in line with the guidelines, then there will be increased risks of infection due to higher steady state levels of contaminants when infectious persons are present for extended periods of time. In addition, the time scale for decay of contaminants which could be introduced to a space will be extended, and therefore the total exposure to others for a given amount of time will be increased.

If the recommended pressure differences between spaces are not achieved, then there is an increased risk of contamination through airborne transmission. In the case of vulnerable patients or particularly virulent contaminants such as some viruses then this is very concerning.

8 Requirements imposed by British Standards BS EN 15780

The requirements of BS EN 15780 are with regards to the cleaning regimes for ventilation systems and associated ductwork. Specifically, the Standard applies to both new and existing ventilation and air conditioning systems and specifies the assessment criteria of cleanliness, cleaning procedures of these systems. The validation of the effectiveness of cleaning applies also to products, which conform to EN 1505, EN 1506, EN 13053, EN 13180 and EN 13403, used in air conditioning and ventilation systems for human occupancy defined in the scope of CEN/TC 156. Notably this European Standard does not apply to installations for industrial processes.

The reason for this standard is that cleanliness of ventilation systems is considered important for human comfort and health, energy consumption, system service life, and for cleanliness of operations or processes carried out in the ventilated area.

10 Basis of statements made

The points made in the above paragraphs addressing questions which have been posed to me, to my knowledge, reflect a broad consensus in the scientific and engineering community regarding the role of ventilation, and the requirements of ventilation systems, in a healthcare setting.

I am aware of occasions in meetings where the specific numbers in the HTMs have been discussed, but once at the design stage, the numbers of the parameters are taken as being those which must be met by the project. The only occasions where debate about the numbers has arisen in my experience has been in the context of research where flow patterns are being investigated, but my experience of research has been in a general context rather than specific to healthcare.

There is ongoing research in the field of ventilation, and this is informing design principles. For example, the research with which I was involved in the early 2000s regarding mixing versus displacement ventilation has helped inform the changes to the design guide for ventilation in educational buildings. Specifically, the recommended winter ventilation strategy has been changed to stress the importance of mixing air for management of cold draughts as a starting point in natural ventilation schemes rather than just electing to use displacement ventilation and a heater. CIBSE AM10 which is an industry guide for natural ventilation in non-domestic buildings is also under review at present.

11 Summary of general principles

The provision of a ventilation system which operates in accordance with the HTMs and SHTMs is important as part of a strategy to provide an environment which reduces risk of infection and transmission to an acceptable level. Ventilation in a healthcare setting is to help control the environment and air movement in a space in order to contain, control and reduce hazards to patients, staff and visitors from airborne contaminants, dust and harmful micro-organisms.

It is not possible to eliminate risks completely, but the design principles which are laid out in the guides and the values of the parameters which have been used will have been chosen because they are deliverable. Design guides are typically written in collaboration with not just academic scientific and engineering experts in the field, but practicing design engineers, manufacturers, installers/contractors, and facilities management teams. This was certainly my experience in the 2018 revision of Building Bulletin 101 which the Education Skills Funding Agency oversaw on behalf of the Department for Education.

Appendix

DR SHAUN DAVID FITZGERALD OBE FRENG

[redacted]

PROFESSIONAL EXPERIENCE

2020-present **UNIVERSITY OF CAMBRIDGE** Cambridge, England
Director of Centre for Climate Repair, Department of Engineering

- Establishing research priorities for Centre
  - Reducing emissions - undertaking research on ventilation, energy efficient buildings and COVID-19 on EPSRC funded programme
  - Removing greenhouse gases
    - supporting Boies lab in Engineering Department to develop programme on methane oxidation in collaboration with UCL
    - coordinating funding proposals with academics in DAMTP and Earth Sciences, on ocean-based carbon dioxide removal in collaboration with National Oceanography Centre
  - Refreezing the Arctic – supervising MEng project on ice thickening and supporting Hugh Hunt in Engineering in supervision of PhD student and two MEng students on Marine Cloud Brightening
- Management of Centre
  - Coordinating partners and associates of the Centre both within Cambridge and externally
  - Launched and developed the Centre for Climate Repair with Sir David King, operating as a new entity and supporting Cambridge Zero
  - Developing governance for the centre especially regarding some of the sensitive climate repair options
  - Coordinating partners and associates of the Centre both within Cambridge and externally
  - Working with Chair of the Centre raising funding from High Net Worth alumni
- Chair of Management Board of Laing O'Rourke Centre for Construction Engineering and Technology
  - Following retirement of Lord Robert Mair, appointed as chair of the management board
- Impact Assessor for REF2021. UKRI appointment to support the research evaluation framework for engineering
- Covid-19 scientific advisor
  - Member of Scientific Advisory Group for Emergencies (SAGE) Env. Modelling Group for SARS-CoV-2
  - One of the primary authors for CIBSE guidance on emerging from lockdown, regular national media interviews
  - Member of the Royal Society Rapid Assistance for Modelling the Pandemic (RAMP) team
  - Member of Independent High-Risk Aerosol Generating Procedures Panel, DCMS Events Research Programme Science Board & DCMS Venues Steering Group
  - Member of the WHO High-Level Expert Group on COVID-19
- Lecturer for Building Physics Course, supervision MEng projects

2002-present **GIRTON COLLEGE** Cambridge, England
Fellow in Engineering and Tutor

- Member of College Council 2020 to present
- Tutor for undergraduates for >10 years and supervisor for first year and fourth year undergraduates.
- Involved in Admissions, including supporter of widening participation
- Initiated review and change in privacy and safeguarding policies
- Dean for Covid 2020-2021
- Financial Planning Committee from 2020

2018-2020 **THE ROYAL INSTITUTION OF GREAT BRITAIN** London, England
Director

- Leader of the UK's best-known science engagement charity with core team of ~70 persons and volunteer base of >100, membership base of 4,500
  - Overall responsibility for strategic direction and viability of the charity
  - At request of Trustees oversaw major changes in senior team and implemented new structure
  - Oversaw launch of new 5 year strategy and complete restructuring of trust funds for the charity
  - Responsible for liaising with Trustees, key donors and strategic partners
  - Host for Discourses and Hospitality for Speakers, Donors, Royal Patrons and esteemed visitors
  - Charity Commission ceased its special oversight of the charity in October 2019 following significant changes in the charity (leadership, financial, controls) ending 9 years of intense scrutiny

2015-2020 **ROYAL ACADEMY OF ENGINEERING VISITING PROFESSOR** Cambridge, England
Dept of Engineering, University of Cambridge

- Responsible for development and delivery of building physics course lectures for 3rd year undergraduate engineering
- Lecturing for CISL, LOR Masters course on fluid mechanics of natural ventilation and innovation in business

2006-2018 **BREATHING BUILDINGS LTD** Cambridge, England
Chief Executive Officer

- Founder and leader of technology company pioneering low energy hybrid ventilation systems (Cambridge University spin-out)
  - Overall responsibility for success of company. Developed all aspects of the business plan, led all financing rounds including venture capital funding and successful sale of business to Volution plc
  - Led all major building projects and relationships with multiple stakeholders: Ventilation strategy for Apple HQ (Cupertino, USA) and RIBA Stirling 2018 winner Bloomberg HQ (London) with Foster & Partners; review and remediation of critical ventilation issue at The Shard (London)
  - Initiated and led restructuring of the business in 2011, successfully managed redundancy process, and sensitive changes at Board level
  - Led all major communication with media (journals, television, press, online)
  - Oversaw all technical innovations, patents and provided expert advice to attorneys in legal cases
  - Led negotiations with contractors for major supply and installation contracts, responsible for health and safety
  - Undertook market evaluation, due diligence and selection for US & Canadian business partner and EU suppliers
- Key Advisory Board Member of Education and Skills Funding Agency (ESFA) for re-writing government policy on ventilation in schools (BB101), the document referred to in Part F of Building Regulations for Educational Buildings published in 2018. Worked closely with ESFA on drafts and led the stakeholder engagement discussions
- Key Advisory Board Member of CIBSE Natural Ventilation Group responsible for revising industry guidelines for ventilation of all non-domestic buildings
- Member of Individual Candidate Panel for Energy Institute assessing candidates for Chartered Engineer

2002-2006 **UNIVERSITY OF CAMBRIDGE** Cambridge, England
Research Associate

- Conducted research as part of Cambridge – Massachusetts Institute of Technology (CMI) project
  - Directed industry engagement programme and coordinated research with MIT
  - Author of numerous papers and filed patent in 2005 which led to start-up company

1997-2001 **BAIN & COMPANY** London, England
Senior Consultant

- Worked with one of the leading global strategic management consultancy firms with a view to setting up my company

- Practice areas: Strategy, mergers and acquisition, organisational restructuring
- Industries: Nuclear waste, engineering/manufacturing, retail
- Clients: FTSE 100, smaller FTSE companies, large private companies and venture capital firms. Examples:
    - Led review of liabilities for major UK nuclear industry client; resulted in total restructuring of group
        - Directed European team due diligence of a US/Europe nuclear company; $500m deal in 4 weeks

1995-1997 **STANFORD UNIVERSITY** Stanford, California
Geothermal Program Manager, Acting Assistant Professor

- Managed university geothermal program, including:
    - Supervising and conducting research in fluid flow and heat transfer, examining problems of boiling in porous media and fractures, and ground water clean-up from industrial disasters
    - Liaising with California Energy Commission and US DoE regarding policy on injection into geothermal reservoirs and strategies for waste-water disposal. Pipelines from Lake County and Santa Rosa constructed taking 20m gallons of treated waste-water/day to the Geysers reservoir
    - Providing expert technical advice for legal disputes in clean-up projects
    - Establishing links with and advising international geothermal companies, and managing the Stanford-hosted international geothermal conference
    - Lecturing Masters' course on geothermal systems including engineering and finance of geothermal projects, and providing teaching in Indonesia on geothermal reservoir engineering
    - Consultancy in feasibility studies of 10-200 MW geothermal projects, resulting in > $300m investments

1994-1995 **UNIVERSITY OF CAMBRIDGE** Cambridge, England
Research Associate, Institute of Theoretical Geophysics, Department of Earth Sciences

- As post-doctoral researcher:
    - Investigated effects of gravity on the injection of liquid into vapour-filled rock. This work, together with the PhD work, resulted in publications in *Nature* and other journals, and interviews on BBC Radio 4 Science Now and BBC World Service

1993-1994 **CAITHNESS CORPORATION** Ridgecrest, California
Independent Reservoir Engineering Consultant

- Analysed the 260MW Coso geothermal project in Nevada to optimise reservoir performance

1990-1993 **UNIVERSITY OF CAMBRIDGE** Cambridge, England
PhD Student, Institute of Theoretical Geophysics, Department of Earth Sciences

- Conducted doctoral research in the optimisation of geothermal power projects.

1989-1990 **GEOSCIENCE LTD.** Falmouth, England
Mechanical Engineer

- Reservoir, power systems and financial modelling for clients

AWARDS

2011 Fellow Chartered Institution of Building Services Engineers

2014 Fellow Royal Academy of Engineering

2021 Chartered Institute of Building Services Engineers President's Commendation

2021 OBE for services to Covid-19

EDUCATION/QUALIFICATIONS

2005	Fellow Chartered Institution of Building Services Engineers	London, England
1998	**GRADUATE SCHOOL OF BUSINESS, UNIV OF MICHIGAN** Corporate Financial Management Executive Program	Ann Arbor, Michigan
1997	Fellow of the Energy Institute, Chartered Engineer (Member from 1997, Fellow from 2004) London, England	
1990-1993	**DARWIN COLLEGE, UNIVERSITY OF CAMBRIDGE** Doctor of Philosophy, Fluid Flow in Geothermal Reservoirs	Cambridge, England
1986-1989	**GIRTON COLLEGE, UNIVERSITY OF CAMBRIDGE** Master of Arts in Engineering, Alice Violet Jenkinson Scholarship	Cambridge, England

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Scottish Hospitals Inquiry

Healthcare Ventilation Principles and Practice

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Principal author

Signed by: Stephen Maddocks

Executive Summary

Cundall (Stephen Maddocks) have been asked to provide a report outlining the specific principles and practicalities of Healthcare Ventilation. The report addresses the process for the development of a ventilation system in a hospital from concept design through to commissioning and validation. The report also addresses the standards and guidance that are relevant to ventilation systems in hospitals.

It is noted that NHS specific guidance is available for Scottish and English applications, but the differences are minor and in many cases the wording identical and comparisons are identified in the report.

The requirement for standardised documents and in particular ventilation design, is to ensure that the funding envelopes set by Governments for Health buildings are not exceeded and there is neither an over or under provision of engineering systems whilst maintaining patient and staff comfort and safety

As with many design standards these have evolved as more operational experience and data becomes available from live hospitals.

Contents

1.0 Biography

I am a chartered building services engineer with over 40 years industry experience having started as an apprentice in the industry in 1981 based in a Building Services Design Consultancy (DSSR).

Academically I undertook a technician's certificate on day release whilst undertaking my Apprenticeship as I had left school at 16. I then undertook a Polytechnic Diploma at Newcastle Upon Tyne Polytechnic. In 1988, I started a one day a week degree course at University of Central Lancashire which allowed me to gain my charted status. All three of my key academic qualifications were specifically in Building Services Engineering.

I became a member of the Chartered Institute of Building Service Engineers (MCIBSE) in January 1995, a Chartered Engineer (C.Eng.) in April 1996 and a Fellow of the Institute of Healthcare Engineering and Estate Management (FIHEEM) in December 2005.

As noted above I started as an apprentice in the industry with DSSR who specialised in the design of Mechanical and Electrical (Building Services) services particularly in Hospitals and Healthcare projects. My first recollection of Hospital Design was collation and managing the documents for what was known as the Department of Health (England) (DoH-E) Exemplar Nucleus Hospital design pack. DSSR were engaged in writing the Building Services aspects of the exemplar design. I was also involved in learning the detailed design of hospital ventilation systems, manually calculating the pressure resistances through systems as we had no computer systems then.

I moved on to another consultancy (Hoare Lea) after nine years again specialising in hospitals, examples include major developments at Blackpool Victoria Hospital, Royal Lancaster Infirmary and Hope Hospital (Salford). In 1992 I joined the NHS as a Capital Projects Officer at Trafford General Hospital where I was responsible for new and refurbishment of the building services capital developments looking at building services aspects specifically. Schemes included replacement of an existing operating theatre suite with a new Ultra Clean Operating Theatre to increase Orthopaedic Surgery operations, Clinic refurbishments, Day Surgery unit and management of the replacement of the electrical infrastructure whilst keeping the hospital operational. I stayed at Trafford General for two years before re-joining my previous consultancy picking up on further healthcare work at many sites including Wigan Royal Albert Edward Infirmary, Royal Manchester Children's Hospital, Blackburn Queen Park Hospital, Evelina Children Hospital, Bishop Auckland Hospital, Wharfedale Hospital, North Wales Cancer Treatment Centre, to name a few staying there until 2002. Schemes were both Trust financed, and Private Finance Initiative (PFI) developer led schemes.

In 2002 I joined a multidisciplinary design consultancy (BDP) as Associate Director to lead on healthcare for the northwest Building Services team and I was responsible for leading the engineering design team for PFI schemes at Burnley General Hospital and Hexham General Hospital. I stayed there until 2006 when I joined the PFI division of a major contractor/developer (Lend Lease). This position only lasted just short of two years due to the company pulling out of the whole PFI market.

In 2008 I joined Cundall as a Partner and Health Sector leader. I have worked on a number of healthcare projects including delivering the Ulster Hospital redevelopment. This was a capital funded project in Northern Ireland with a value of approximately £200 million. The hospital was approximately 60,000 square metres. It was completed in 2 phases and delivered over 500 beds and supports full District General Hospital accommodations including Aseptic Pharmacy, MRI Suites, A&E, Restaurant and kitchen, Mortuary etc. I also assist with early design advice on projects across the globe.

I have been invited to give lectures at the University of Sheffield on the master's degree in architectural engineering on the principles of ventilation and air conditioning. I have mentored Architectural Students at Manchester Metropolitan University on the low energy design principles of their final year designs.

I've also been called in as a technical expert to look at a range of engineering issues including energy consumption in hospital, life expectancy of steam boiler systems, and nurse call systems.

I currently sit on the CIBSE Healthcare Committee and am one of a team of industry authors writing a Healthcare Design Guide to pass knowledge and lessons learnt to fellow designers due to the specialised nature of healthcare design.

2.0 Project Design Process and Drivers

2.1 Project Design Process

Any new hospital project moves through various design and approval stages and there are various titles for the stages depending on which Project Management route is followed. This could be following the NHS Scotland Capital Investment Manual process, NHS Business Case route of Project Initiation Document, Strategic Outline Case, Outline Business Case, Full Business case, or the or the RIBA Designs stages 1-7. However, they all revolve around 4 key stages:

a) Pre-Design,
b) Design,
c) Construction, and
d) Handover

Some key considerations at each stage specifically in relation to ventilation design are as follows, although this list Is not exhaustive:

Stage	Factors to be reviewed
Pre-Design (this could also encompass Strategic Definition, Preparation and Briefing stages)	Site location – are there local issues such as noisy or odorous industrial processes that may impact the building design and services strategies Building Orientation – to maximise/minimise solar impact Schedule of Proposed Departments and preferred Clinical Relationship and impact on Engineering Infrastructure (incoming gas, electricity, water) Cost estimates impacted by the above to assist when developing the scheme budget for funding approval A simple building diagram Reference Design may be developed to support the funding application
Design	Building Form and Construction, thermal performance standards, windows sizes, structural floor to floor heights. Etc. Consider if any areas can be naturally ventilated or require mechanical ventilation Plantroom Locations to optimise ductwork distribution routes Vertical and horizontal distribution systems between plantrooms and departments Fresh Air intake and exhaust air discharge locations to prevent cross contamination. Fire Strategy (so departments may continue running if others go into a fire alarm condition)
Construction	How can systems be installed How much can be manufactured off site to speed installation How can the systems be tested, commissioned and set to work?
Handover	Commissioning and setting to work systems

	Validation of commissioning Collation of testing results Collation of Record information – what was installed Demonstration of systems to users and maintenance personnel

Figure 1-Design and Procurement Stages

Note: - Commissioning is the setting to work of all engineering systems that move air and water around a building and is vital to ensure the systems perform as intended by the designer. Air and water-based systems need to be set-up to ensure correct flow rates are delivered to ensure air change rates are achieved or heating is available to various areas around a building and without which, the systems would not operate as designed. Validation is the demonstration of the commissioning results to third parties or retesting to prove the original testing and is an important aspect of bringing any new hospital into operation.

Throughout the above stages there are many competing interests that have to be resolved that can only be resolved by dialogue with all parties. Some key ones include:

- Architects - Engineering services impact on spaces planning, impact on ceiling heights and floor and wall finishes, noise of plant and equipment on spaces,
- Structural engineer - Engineering services impact and weight of systems to be supported by the super structure, where are holes located and impact on the column layout to support the superstructure,
- Infection Control – review of core principles, note- Infection Control Nurses/Officers exist in all NHS organisations and hold policies to limit Infection related issues that can influence design matters,
- Maintenance Staff (either NHS or Private Sector) agreement to servicing strategies and system resilience and back-up systems.

2.2 NHS Scotland Capital Investment Manual

There is significantly more detail regarding the procurement of a hospital that is detailed in the NHS Scotland - Scottish Capital Investment Manual - Commissioning Process. The diagram below is taken from the 2017 edition, but the manual was first created as far back as 2009 with similar processes in place.

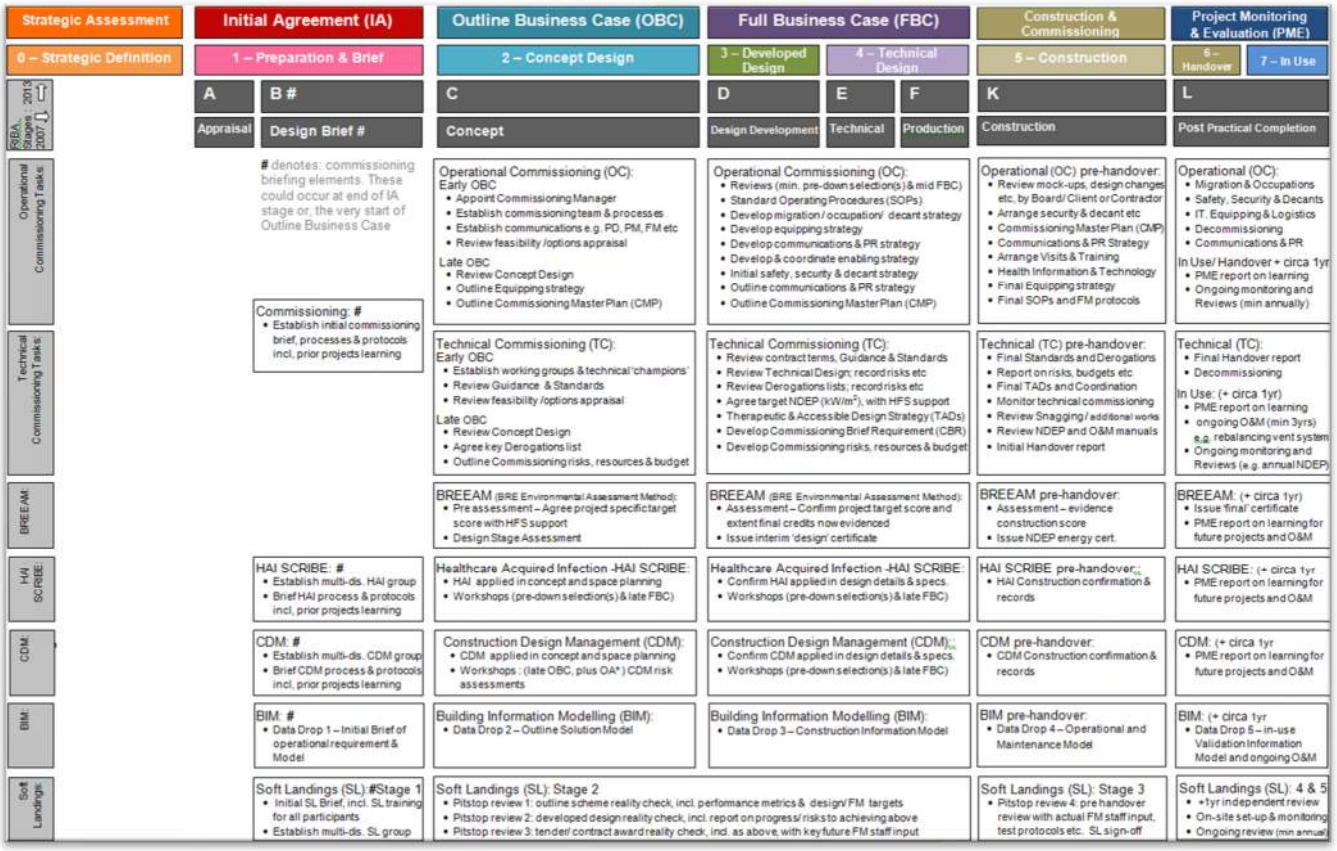


Figure 2- Schedule of Activities - NHS Scotland Scottish Capital Investment Manual Commissioning Process Pub Feb 2017

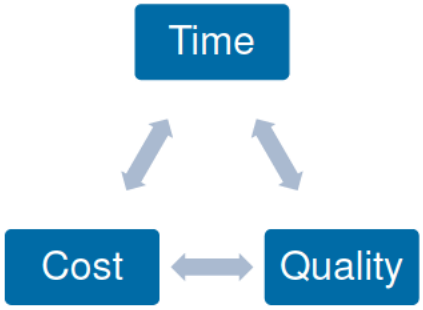
2.3 Whole Project Drivers

2.3.1 Time - Cost - Quality

In this section I discuss the key design factors that impact the planning, design, installation, commissioning, (including validation) and operation of a hospital ventilation system including a review of the challenges that often arise. Validation of a system is often an independent assessment of a system that may be undertaken after the contractor has commissioned a building but is also an ongoing obligation on the hospital operation to ensure continued performance of systems.

Developing a robust workable programme for all key project stages is essential to ensure smooth running of a project with time to complete all tasks. Commissioning being the last main task of a Contractors work programme is often reduced to absorb construction delays, resulting in poor setting to work and testing. Validation is often carried out by an independent person or company and completed after the contractor has tested and commissioned the systems, validation may be undertaken on a random sample basis and on the more critical the systems. All commissioning and validation tests should be recorded for future checking.

Any Capital Development project has 3 main driving forces, over and above Patient, Staff and Public Safety: -



All of these need to be balanced based on the clinical/medical brief and including consultation with the Estates team and Infection Control to gauge any local policies and procedures that may inform the design solution.

Time – Needs to address the need for how soon the completed project is required. This needs to take into consideration issues such as:

a) political commitments,
b) funding arrangement. PFI funded schemes have a higher degree of urgency from a cost viewpoint as financial investors will want a faster return on investment,
c) build speed is influenced by resource, plant and material availability,

Cost – The functional clinical brief will dictate the departments and numbers of beds. The NHS publish a predefined Hospital Premises Cost Guide which is reference source for cost allowances based on costs per square metre or number of beds etc. based on the clinical brief. The Cost guides are based on the HBN/HTM standard minimum requirements and represent the benchmark standards for all NHS properties. These set the budget for a project that meets the clinical requirement and build standard. The cost allowances are then adjusted based on aspects such as:

a) site location,
b) land purchase costs,
c) inflation,
d) ground conditions,
e) Engineering Plant Requirements,
f) Refurbishment works,
g) Enabling requirements,
h) Utility infrastructure reinforcement,
i) Abnormal ground or other project risk,
j) Optimism Bias or project contingency,
k) Desire for expandability.

Quality – Is the building design impacted by requiring to meet:

a) a specific aesthetic or architectural need because of the locality,
b) are there any specific Environmental ratings required such as Building Research Establishment's Environmental Assessment Method ("BREEAM"), which is a sustainability rating for the built environment. Note there are competing / conflicting priorities and objectives in healthcare, that of reduced energy consumption versus the clinical need to dilute potential pathogens / produce air pressure cascades,
c) are there any specific environmental performance standards to be met over and above statutory requirements to meet local Planning Policy requirements. An example on new commissions includes requirements for Net Zero Carbon solutions.

2.4 Other Impacts on Engineering Design Strategies

The Patient (and Staff) environment is a key element of any hospital design, and the building services engineer has to strike a balance on many design decisions to design a space that is:

a) Correctly lit to aid visual tasks,
b) At the correct temperature for comfort,

c) Quiet enough to allow tasks to be performed,
d) Correctly ventilated to deal with odours emissions and potential pathogens,

Design is heavily influenced by the drivers that emerge from an analysis and review of all the items listed in section 2.1 and 2.2 above to a greater or lesser degree with some specific examples noted below:

Building Location significantly impacts the patient environment. The location could be a quiet suburb or inner city. The location influences,

a) opportunity for effective natural ventilation in some areas,
b) air quality – is extra filtration required,
c) ambient noise - noise attenuation required,
d) heat island effect – is more cooling required,
e) daylight - impacted by surrounding buildings.

Hospital Functional departments and their relationships

a) Operating theatres generally require plant located very close to the department so are on upper levels of a hospital,
b) Magnetic Resonance Imaging scanners are best located at ground floor due to weight of the scanner and away from other services to minimise electromagnetic interference,
c) Pathology and Mortuary – away from public zones for privacy and dignity.

Plant and System Resilience (back-up in case of failure for example Generator & UPS (Battery back) essential for certain areas i.e., operating theatres regardless of infrastructure)

a) Site location may have weak infrastructure requiring greater reinforcement or back-up systems,
b) Department complexities require different levels of standby e.g., Intensive Care Units with patients on life support have different requirements for plant and equipment as it is harder to disrupt such areas,
c) Acceptable downtime of plant for maintenance may impact on plant selection.

Maintenance practices and Resource (manpower)

a) Local practice can dictate equipment selection and provision e.g., availability of spares or specialist maintenance companies may dictate that a hospital has established procedures for certain plant and equipment, The Contract may stipulate response times in case of plant failure.

2.5 Capital Expenditure -v- Operational Expenditure

There is always a balance between the capital purchase price of any item in a building be it architectural element (say flooring) or a piece engineering equipment, and the operational cost (both energy and maintenance requirements) of that item.

Most items used in the construction of a building have a Residual Service Life (often referred to as Design Life or Life Cycle) that, providing the product is maintained in accordance with the manufacturer's instructions, the product is expected to last for a defined number of years.

The Chartered Institute of Building Services Engineers publish Guide M Maintenance Engineering and Management 2014 which indicates anticipated life expectancy of plant. It is important to reference this standard in any project to ensure good quality products are supplied but also to allow life expectancy and life cycle replacement to be factored into any project, an example extract is below: -

Item	Equipment: maintainable components	Reference service life (RSL) (years)	Remarks	RICS NRM3 code	BESA SFG20 schedule code
Water installations (WI) (*continued*)				5.4	
Cold water distribution (CWD) (*continued*)				5.4.2	
Storage tanks				5.4.2.2	56-09
8	Cold water storage tanks and cisterns:			5.4.2.2.8	56-01 and 56-02
	— cast iron	35	Depends on the material type		
	— steel (galvanised)	15			
	— mild steel, treated	25	Not for domestic or drinking water use		
	— plastic or non-metallic	20	High-quality structural support is needed		

Figure 3 – Part Extract CIBSE Guide M Appendix 12.A1 Indicative Economic Life Expectancy

In the construction industry there is a quoted ratio or Rule of Thumb called the 1:5:200 model which means:

- Cost to Build = £1
- Cost to Maintain = £5
- Cost Operate = £200

Traditionally procured projects often don't address the funds required to carry out preventative maintenance and plant replacement requirements of engineering systems, hence the focus is on specifying "gold standard plant and equipment" rather than an alternative of buy cheap - buy twice approach. There is also an understanding that in some critical facilities in a hospital, it is often difficult to close departments down to undertake routine preventative maintenance. Statutory compliance maintenance should always take priority.

The cheapest capital cost is often however the one that has the main focus when evaluating tender returns however on a PFI style contract the maintenance of the equipment and its replacement is often wrapped up into the project overall cost and life of the contract.

An understanding of the above is another driver in the design process.

3.0 Hospital Design Standards and Briefing

3.1 Background to Modern Hospital Design

3.1.1 Defining Hospitals

In designing hospitals, a broad understanding of the different types of healthcare facility that may exist is required these are often referred to as:-

a) Primary Care – contact between a patient and a GP typically at a GP surgery or local clinic and often the first point of entry into the care system
b) Secondary or Acute Care, - a typical hospital known in England as a District General Hospital, deals with general issues and often the first point for investigation into a medical condition
c) Tertiary or Specialist Care, - typically for Cancer treatment, Neuro surgical (brain) or Orthopaedic surgery (joints)

Furthermore, patient treatments fall into four basic categories

a) surgical procedures – physical interventions to diagnose, repair, remove or rebuild damaged or infected tissue.
b) medical care – the administering of drugs or various forms of practical, non-invasive treatment to diagnose, cure or reduce the severity of an infection or condition.
c) mental health – the use of counselling, often in conjunction with drugs, to control or alleviate abnormal behavioural or false perception issues in patients.
d) palliative care – treatment to temporarily or partially relieve or mitigate long-term conditions.

In all cases a patient may require treatment in one or more of the categories as either an in-patient (overnight or longer stays) or an out-patient (day visits).

The degree and complexity of the engineering infrastructure decreases for all clinical categories from surgical down to palliative care, but the engineering infrastructure is vital for patient safety and infection control. This is the case regardless of whether this is a project in England or Scotland

3.1.2 Nucleus Design

The Department of Health England (DoH-E) set about the development of a standardised approach to Hospital Design in 1975 referred to as Nucleus Design.

The Nucleus Design provides standard designs for a footprint of approximately 1,000 square metres with different design packs developed for the various departments of District General Hospitals such as ward layouts, operating theatre layouts, accident and emergency, intensive care units etc. The concept gave design standards for the architectural elements and design principles for the building services aspects. The system was developed before computers and electronic data storage, so each department was contained in a lever arch file with concepts layout and room data sheets being pre-defined. The concept also developed a standardised approach to developing the capital costing of Hospitals based on Department use referred to as Departmental Cost Allowances Guide (DCAG), as noted in 2.2.1

Figure 4-Typical Nucleus layout

The control of hospital design was managed by Regional Health Authorities (Health Boards in Scotland) who generally had their own design division that developed the design concept and controlled capital developments across a region. This was to ensure an equitable spread of general ward provision and specialisms across a region. The design team were employed on a full duties design basis.

There were other ward layout design pre-Nucleus namely Nightingale (1871) early 20th Century Sub Divided wards, Post War Racetrack (1950's and 1960's), Nuffield Wards (1950's), and Falkirk Wards (1960's).

Nucleus design fell out of favour as it was largely aimed at out-of-town sites which had Greenfield sites, and buildings were restricted generally to two storeys in height. They were also felt to be not very inspiring from an architectural view and nursing methods changed and evolved along with a drive for improved Patient Experience.[1]

An example of the change in design of a ward is as follows

- Nightingale Wards - 16 beds either side of a long ward with a Nurse Station in the middle allowing nurses to observe all patients, virtually no patient privacy or dignity and if an infection occurred it could be transmitted to others,
- Nucleus - 7 bed wards in a single space (with some single bedrooms) improved Patient Dignity but issues still exist around infection spread,
- 4 bed wards, some new hospital still have 4 bed wards with improvements in Patient Dignity,
- Single bed wards – Privacy and dignity highest but harder to manage and observe patients.

There were variances to the concept referred to as Nucleus Related which often went to 3 storeys with a slightly expanded footprint, but the core principles were the same. The desire for higher quality architecture, connectivity to public transport networks and nursing practices all led to a rethink of hospital design and has led to higher rise inner city hospitals and a divergence from the nucleus design layouts principles. However, the fundamental design criteria and principles remained and have largely remained unchanged.

3.2 Construction Reforms[2]

The drive for more efficiency in the construction industry was driven by reforms proposed by Sir John Egan's report Rethinking Construction 1998 and Sir Michael Latham's report Constructing the Team 1994. These reports led to a restructuring of the traditional approach of fully designed scheme by a design team, and a contractor building the design.

[1] The Patient Experience describes an individual's experience of illness/injury and how the healthcare system treats them. Increasing focus on the Patient Experience is part of a move towards patient centred care and influences the architectural and engineering design of a facility.
[2] Text adapted from Design Buildings - The Construction wiki

The new model was built around a Contractor undertaking elements of design under a Design and Build procurement model which in itself has presented challenges and opportunities when designing new hospitals namely the speed with which they were designed and built. Construction often starts much earlier than normal meaning up front design decisions being made ahead of where they would have been made with a more traditional construction approach.

Latham report Constructing the Team

Sir Michael Latham noted that the construction industry in the UK had consistently performed in a way that was thought to be wasteful compared to other industries. There was a general impression that it did not deliver good value for its customers. In part it was felt this was due to the unusual nature of the industry, where, unlike a production line, each building is a one off. But in addition, the nature of contracting arrangements means that it can be an adversarial industry with significant potential for disputes.

Latham proposed that the client should be at the core of the construction process and that the industry should move away from its adversarial structure, adopting a more integrated approach with greater partnering and teamwork.

There were a great number of detailed recommendations within the report, some of which are set out below:

- As the largest single procurer of construction, the government should commit itself to becoming a best practice client,
- The New Engineering Contract (NEC) should be adopted more widely as a less adversarial form of contract,
- Partnering should be used to encourage the establishment of long-term contracting arrangements,
- Public sector registers should be established for approved contractors, sub-contractors and consultants,
- There should be greater standardisation and better integration of contract documents,
- There should be compulsory latent defects insurance,
- There should be publication of a number of codes of practice and guidance documents to clarify, co-ordinate and standardise practices across the industry,
- A specified duty to deal fairly with each other, and the supply chain in an atmosphere of mutual trust and co-operation,
- Interrelated documentation, clearly defining roles,
- Risk allocation to the party best able to manage, estimate and carry it,
- The avoidance of conflict, speedy dispute resolution and adjudication,
- Firm duties of teamwork with shared financial motivation.

The Latham report refers to 'partnering' and includes the concept of teamwork between supplier and client, in a process of total continuous improvement. It required openness between the parties, ready acceptance of new ideas, trust and perceived mutual benefit.

Egan Report Rethinking Construction

Sir John Egan started from a similar premise to the Sir Michael Latham report on the historic poor performance of the construction industry.

In the report, Sir John Egan suggested that ‘the industry as a whole is under-achieving’ and called for ‘dramatic improvements’. He proposed that this would be possible ‘…if we focus all our efforts on delivering the value that our customers need, and if we are prepared to challenge the waste and poor quality arising from our existing structures and working practices’.

Egan stated that ‘…we are not inviting UK construction to look at what it does already and do it better; we are asking the industry and Government to join with major clients to do it entirely differently’.

The report identified five drivers of change:

- committed leadership,
- a focus on the customer,
- integrated processes and teams,

- a quality driven agenda,
- commitment to people,

It proposed:

- integrated project processes,
- decent and safe working conditions,
- improved management and supervisory skills,
- replacing competitive tendering with long term relationships,
- that leading public sector bodies should become best practice clients.

There were many spin-off strategies and organisations that came out of the reports, but the approach kick started the change in procurement from the client separately employing the designers and contractors to single design and build appointments with contracting organisations taking on board key design appointments and having greater control and input into the design process with varying degrees of success.

3.3 Key Briefing Requirements for Designers

The following are key aspects to enable clients to fully brief designers in the requirement of any hospital development programme

3.3.1 Schedule of Accommodation and Brief

This is the client generated brief that should clearly set out the clinical requirements of the hospital, bed numbers, number of operating theatres special departments etc. This should also include any specific engineering requirements including compliance with the relevant Scottish Health Building Notes (SHBN's) and Scottish Health Technical Memorandum's (SHTM's) This is often generated by the client (HFS Scotland or Health Board) in conjunction with a Clinical Health Planner (either an NHS person or independent private practice) with support from Architects and Engineers. The use of Independent Clinical Health Planners became more prevalent under the governments PFI initiative when the approach to "standard solutions" was varied. A brief should still contain the core clinical requirements such as bed numbers (surgical or medical), number of operating theatres, specialist departments. Etc and the corresponding Room Data Sheets that provide the level of detail for departments and spaces, see next section.

A simple flow chart to explain the process is as follows: with the development of detailed Room Data Sheets occurring at the Briefing Stage. The RDS can be generated by the Client (NHS/HFS) if they have personnel with correct experience or the clients design team/clinical planner.

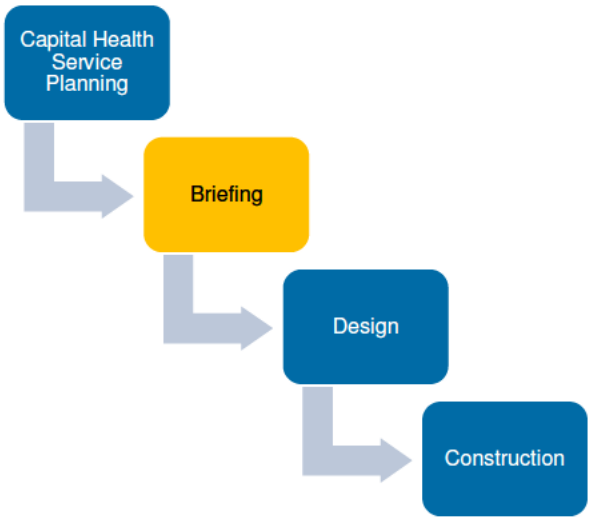


Figure 5-Simplified Building Process

3.3.2 Room Data Sheets (RDS)

This Nucleus Design Pack was the original briefing tool for many new Hospitals and contained the Room Data Sheet (RDS) which was and is the **most critical design document** for a designer, regardless of procurement route. Whilst Nucleus Design packs no longer exist, the Room Data Sheet system is still retained as it provides important specification requirements. It details the specific detailed performance requirements of a clinical or non-clinical space and should be generated specifically for each project early in the briefing and design process. Examples of spaces are:

Clinical	Non-Clinical
Wards	Medical Secretary accommodation
Operating Theatres	Estate's offices, workshops, storerooms
Critical Care Units	Finance Department
Maternity Ward	

The RDS system was developed by the DoH-E, under the name of Activity Data Base (ADB) based on standard departments, each standard department had a list of standard rooms as per the nucleus concept with pre-defined information (which also sets the level of specification and hence the cost models). As an example, a local hospital (NHS Trust/Health Board) would identify that they needed a new hospital with the accommodation listed in the table above. The client project team (comprising nursing staff and department managers) would be handed a pack of information that would include the standard/normal rooms which could then be reviewed. This pack could be generated either by the NHS/HFS team, the clinical planner or the design team. If there is any customization needed for local practices, then this could be manually amended in the database. The system works on a series of menus which starts with a department, then a room, then surfaces then performance requirement. Details become greater as you drill down into the RDS system.

The ADB system is currently owned by Talon Solutions who state that:

- Activity Database (ADB) is a computerised package to assist healthcare planners, architects, and teams involved in the briefing, design and equipping of healthcare environments,
- It is the only data and software package endorsed by NHS England and NHS Improvement,
- It is the only package that contains accurate and detailed data drawn directly from the Health Building Notes (HBNs), which support the NHSI Frameworks identifying the way care will be delivered in the future, as well as Health Technical Memoranda (HTM) publications,
- The system is based on the DoH England HBN's HTM's. any localisation would have to be undertaken by the Project Team.

A key benefit is that all components have a unique coding system that has been in place for over 30 years that is recognised by the NHS Purchasing Authorities and supply agreements and specification standards exist for many components.

This system started out in a pre-computer era before database packages became easier to manage, so they generally could not be altered. The system then became computer based in the 1990's as the use and availability of databases became more common. The software database systems allow greater customisation of the database although the core requirements listed includes the benchmark requirements of the HBN's or HTM's. If there is any local adjustment required (for example for a Scottish Hospital to accommodate a standard in the SHTMs which was different to the HTMs) such changes would have to be made by manually updating the room data sheet.

The RDS includes the performance of the fabric, (wall and floor coverings) the finishes (paint specifications), the lighting (lux), noise levels (dBA rating), temperature (deg C), humidity (Relative humidity or range), ventilation rates (air changes

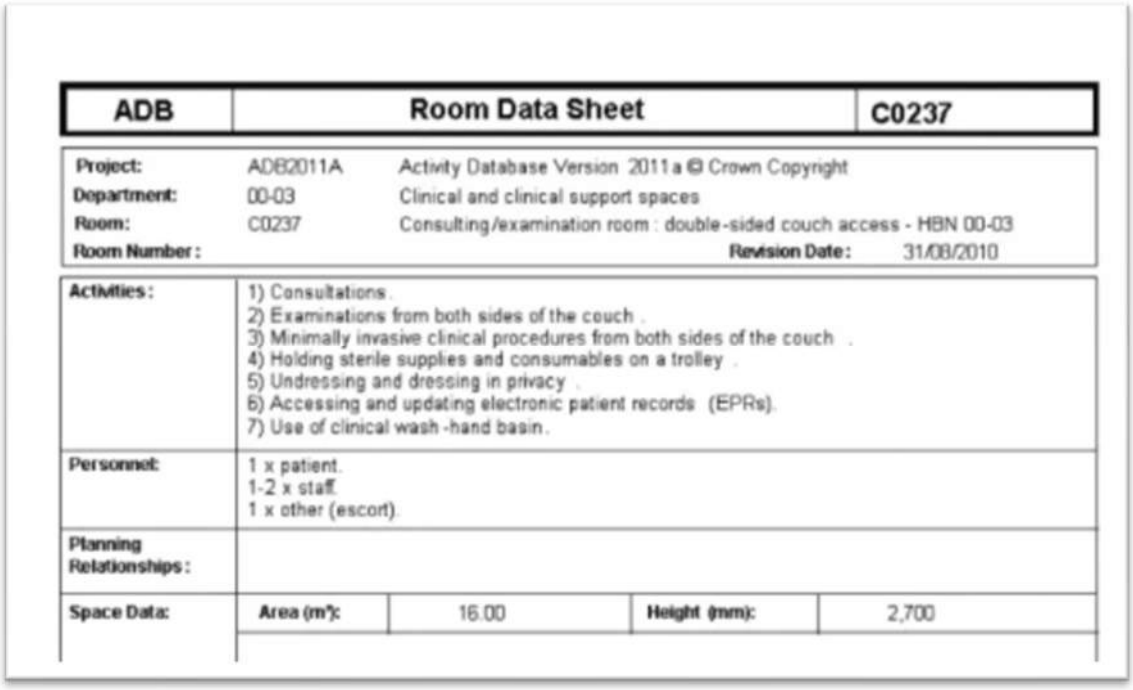
per hour), pressure (pascals and whether negative or positive to surrounding spaces) and in general is often the starting point for any designer when embarking on a detailed design of a hospital.

Experienced hospital Designers (Architects and Engineers) should review the RDS when they are initially created for anomalies and raise queries with the client body. If rooms or components in the proposed design did not exist in the ADB-RDS system, then unique sheets can be generated from a blank template. The standard data base is updated within a few months of a new guidance issued by the NHS

Examples of department lists and details for a specific department to explain the above are contained in Appendix A.

The Room Data Sheet consists of 4 key components

A. Room Data Sheet – what is the size, how many people, what is the use etc,
B. Room Design Character – wall, floor and ceiling finishes etc,
C. Room Environmental Data – engineering performance requirements e.g., temperatures, air change rate, air pressure cascades, filtration standards, lighting levels) etc,
D. Schedule of Components – number of sockets, medical gases, furniture and fixings etc.



ADB	Room Data Sheet			C0237
Project:	ADB2011A	Activity Database Version 2011a © Crown Copyright		
Department:	00-03	Clinical and clinical support spaces		
Room:	C0237	Consulting/examination room : double-sided couch access - HBN 00-03		
Room Number :		Revision Date:	31/08/2010	
Activities :	1) Consultations . 2) Examinations from both sides of the couch . 3) Minimally invasive clinical procedures from both sides of the couch . 4) Holding sterile supplies and consumables on a trolley . 5) Undressing and dressing in privacy . 6) Accessing and updating electronic patient records (EPRs). 7) Use of clinical wash-hand basin .			
Personnel:	1 x patient. 1-2 x staff. 1 x other (escort).			
Planning Relationships :				
Space Data:	Area (m²):	16.00	Height (mm):	2,700

Figure 6-Snapshot typical example of an ADB RS - refer to Appendix A for more details

The above example is taken from the NHS Activity Data Base product, but other suppliers provide comparable database systems that are commercially available. Some projects rely on spreadsheet-based systems.

The RDS are best described as an informed “starter for 10” based on best practice design, operational experience and functionality. The advent of the data base systems also allow for a computer aided design layout to be generated.

Any deviation from the pre-defined data should be recorded in a derogation schedule for validation and audit purposes.

3.3.3 Hospital Building Notes

The DoH-E/NHS have produced what are referred to as Health Building Notes (HBN’s) for various departments throughout a hospital these are published in the form of a book that typically details issues such as:

a) description of a typical department,
b) how it functions,
c) typical arrangements,
d) staffing requirements,

e) relationships to other departments,
f) key design principles and features
g) engineering principles.

Scotland has adopted the HBN's with local adaptations and are referred to as Scottish Health Building Notes (SHBN's). which would typically be referred to in any project brief from the very inception of a project.

3.3.4 Health Technical Memoranda

Alongside the HBN's there are a series of Health Technical Memoranda (HTM's). The HTM's cover the core design principles of systems such as

a) Electrical systems,
b) Water Services,
c) Ventilation Systems,
d) Medical Gases.

Scotland has adopted the HTM's with some local variances and these are referred to as Scottish Health Technical Memoranda (SHTM's).

A client body procuring a hospital (for example an NHS Trust) must develop a Project Brief for a new hospital that should ordinarily specify that the design and build is in compliance with HBN's and HTM's (SHBN's/SHTM's) (unless a list of derogations was agreed at the time a contract is agreed). If there was only reference to Statutory Compliance, then in terms of ventilation only The Building (Scotland) Regulations 2004 (the "2004 Regulations") and the Scottish Technical Handbook (Scottish equivalent of the "Approved Documents" issued in England in terms of The Building Regulations 2010) would apply. Regulation 9 and schedule 5, part 3, paragraph 3.14 of the 2004 Regulations make provision in relation ventilation. Schedule 5, part 3, paragraph 3.14 provides that:

"Every building must be designed and constructed in such a way that ventilation is provided so that the air quality inside the building is not a threat to the building or the health of the occupants"

The Scottish Technical handbook covers general construction standards across all sectors and contains a general section on ventilation. However, it has no specific provisions relevant to healthcare.

If no reference to the SHBN's and SHTM's is made in a brief, then the default compliance documents would be the Building Regulations in England or 2004 Regulations/ Technical Handbook in Scotland. It is worth noting that the English Building Regulations 2010 contain similar general provisions on ventilation (The Building Regulations 2010, regulations 39, 44 and schedule 1, section F1). However, the Approved Document F, Volume 2: Buildings and other dwellings make reference to the need for compliance with HTM's, CIBSE Guidance documents and British Standards (see table 1.1 and Appendix E).

In my view the requirements of the SHTMS and SHBN's are the fundamental starting block for any hospital design. They are often used by Private Healthcare providers in the UK and overseas as the most appropriate standards based on years of development and operational experience of hospitals.

4.0 Statutory Compliance

4.1 HTM's and Compliance

In England the Building Regulations 2010[3] are the primary legislation for Building Construction standards. A series of Approved Documents covering different aspects of Building Construction have also been issued to provide more detail. The Health Technical Memorandum are referenced in Part F- Ventilation Requirements. The example below is from Part F – Volume 2: Buildings other than dwellings Requirement F1 Means of Ventilation. Regulations 39 and 44

Table 1.1 Ventilation for buildings other than offices and car parks

Building/space/activity	Regulations and guidance (also see CIBSE's Guide A and Appendices D and E)
Animal rooms	CIBSE Guide B2 *Ventilation and Ductwork* (2016) *Code of Practice for the Housing and Care of Animals Bred, Supplied or Used for Scientific Purposes* (Home Office, 2014)
Building services plant rooms	Dangerous Substances and Explosive Atmospheres Regulations 2002 Provision for emergency ventilation to control dispersal of contaminating gas releases (e.g. refrigerant leak) is given in paragraphs 23 to 25 of HSE Guidance Note HSG 202 *General Ventilation in the Workplace – Guidance for Employers.* **BS EN 378-3** *Refrigerating systems and heat pumps. Safety and environmental requirements – Installation site and personal protection* Follow manufacturers' guidance for adequate provision of air for service equipment.
Catering and commercial kitchens	HSE Catering Information Sheet No. 10: *Ventilation in catering kitchens* (2017) BESA DW 172 *Specification for Kitchen Ventilation Systems* (2018) CIBSE Guide B2 *Ventilation and Ductwork* (2016)
Cleanrooms	CIBSE Guide B2 *Ventilation and Ductwork* (2016)
Common spaces[1]	Either: a. natural ventilation by appropriately located ventilation opening(s) with a total opening area of at least 1/50 of the floor area of the common space b. mechanical ventilation installed to provide a supply of fresh air of 0.5 litres per second per m² of floor area.
Data centres	CIBSE Guide B2 *Ventilation and Ductwork* (2016)
Dealing rooms	CIBSE Guide B2 *Ventilation and Ductwork* (2016)
Factories and workshops	Control of Substances Hazardous to Health (COSHH) Regulations 2002 Factories Act 1961 Health and Safety at Work etc. Act 1974 BESA TR 40 *Guide to Good Practice for Local Exhaust Ventilation* (2020) CIBSE Guide B2 *Ventilation and Ductwork* (2016) **NOTE:** Requirements are often exceeded by other criteria, such as the ventilation requirements of the particular manufacturing process.
Farms	Welfare of Farmed Animals (England) Regulations 2007 **BS 5502** *Buildings and structures for agriculture*
Gymnasiums	Sport England Design Guidance Note: *Fitness and Exercise Spaces* (2008)
Healthcare buildings: non-surgical	CIBSE Guide B2 *Ventilation and Ductwork* (2016) NHS Activity DataBase Health Technical Memorandum (HTM) 03-01 (Department of Health) Health Building Notes (HBN) – various (Department of Health)
Hospitals	CIBSE Guide B2 *Ventilation and Ductwork* (2016) NHS Activity DataBase Health Technical Memorandum (HTM) 03-01 (Department of Health) Health Building Notes (HBN) – various (Department of Health)
Hotels	CIBSE Guide B2 *Ventilation and Ductwork* (2016)

Figure 7-Part Extract Bldg Regs Part F1 Section F1(1) Page 13

[3] HM Government – The Building Regulations 2010- 2013 Ed. Approved Document F Ventilation

The equivalent of the English Building Regulations in Scotland is The Building (Scotland) Regulations 2004. The Building Standards Technical Handbook 2020 (online version) is issued to supplement the regulations. The Building Standards Technical Handbook does not appear to contain reference to the SHBN or SHTM standards. However, the established SHTM's have been in existence for many years and, although they are not specifically mentioned in the Technical Handbook, in my opinion, they are a key starting point for any designer tasked with designing a hospital ventilation system.

There could-be situations however, whereby workplace related standards would apply such as Health and Safety Executive standards by default for specific ventilation practices such as fume cupboards or Local Exhaust Ventilation.

4.2 Status of HTM's/SHTM's

The precise legal status of HBN's/HTM's/SHTM's is not in my area of expertise however they are regarded by many as the Best Practice guidance for Hospital Design and should be considered as the starting point for any new design. Chartered Engineers are obliged under the Ethical Code of Practice of the Engineering Council to propose Best Practice guidance of which the HTM's/HBN's fall under. The SHTMS' and SHBN's provide the benchmark and design principles that inform the cost allowances used when setting a project budget, for new hospitals and ensure a similar/standardised approach to design principles.

5.0 Hospital Ventilation Design Principles

5.1 The need for Hospital Ventilation

The principles and importance of ventilation in hospitals is recorded as far back as 1859 with Florence Nightingale's papers for the National Association of the Promotion of Social Science on Sanitary Condition of Hospitals and Hospital Construction. In these papers, she makes reference to the deficiency of ventilation in spaces and goes on to state:

> *Natural ventilation or that by open windows and open fireplaces is the only efficient means of procuring the lifespring of the sick - fresh air.*[4]

The papers she prepared were incredibly detailed on aspects such the layout, access (and importance) of daylight, the location of a central fire for radiant heating are all fully detailed, hence the development of the term a Nightingale Hospital many of which are still providing healthcare in operational hospitals.

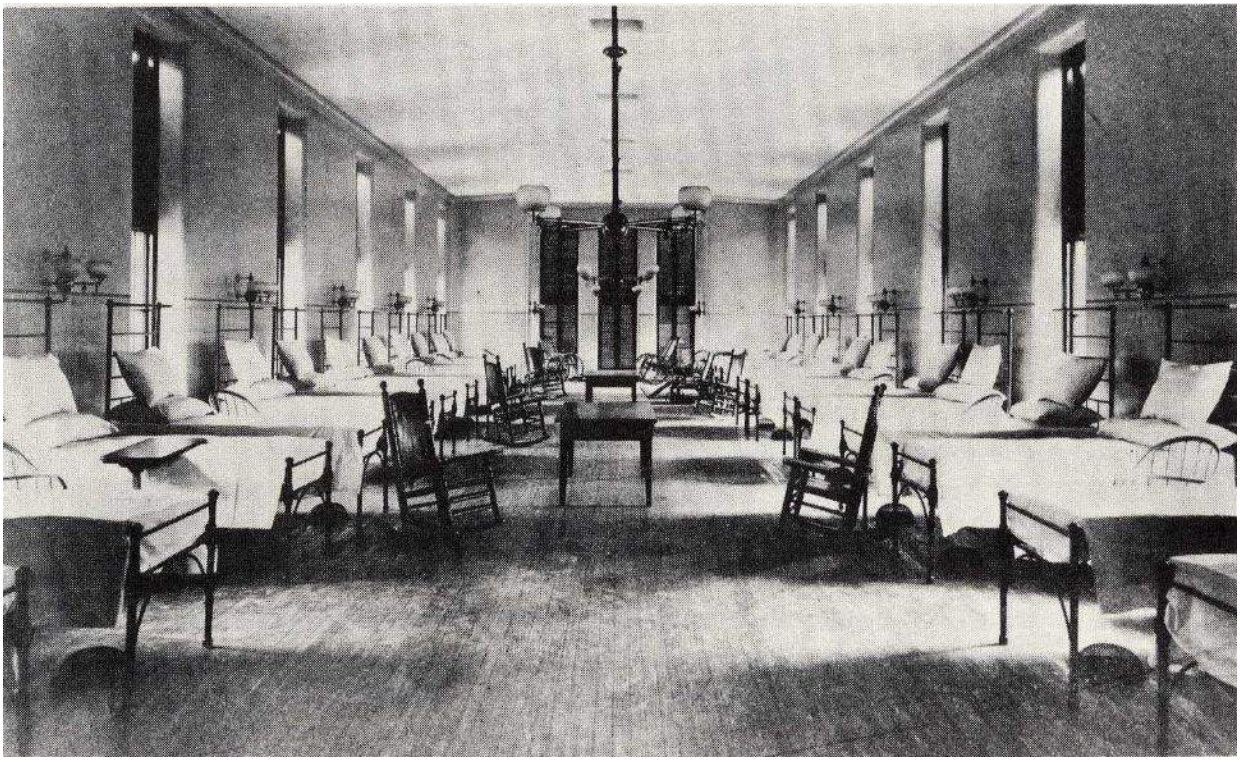


Figure 8- Traditional Nightingale Ward

[4] Notes On Hospitals being two papers read before the National Association for the Promotion of Social Science at Liverpool in October 1858 with Evidence Given to the Royal Commissioners on the state of the Army in 1857 by Florence Nightingale

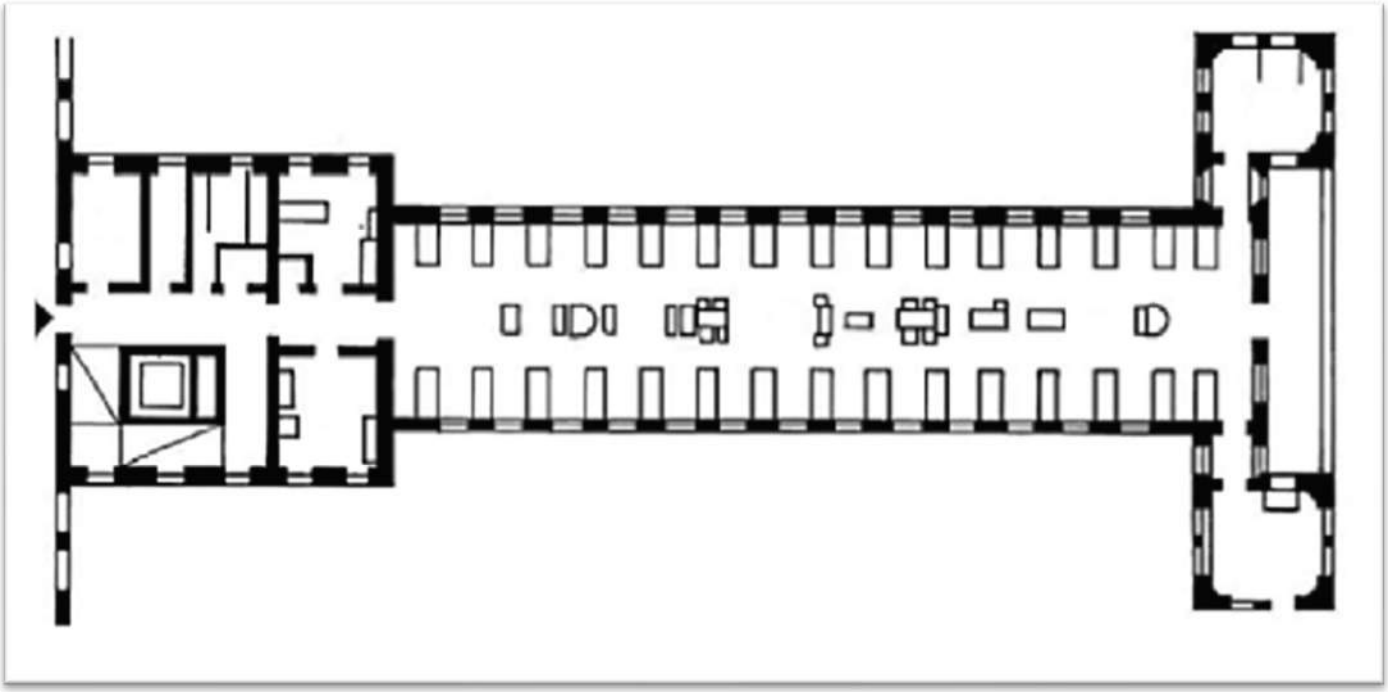


Figure 9-Traditional Nightingale Ward layout

5.2 Setting of Hospital Ventilation Standards

In the UK the principles of design standards for hospitals falls around four major pieces of work that have been issued on a cycle of 1983, 1994, 2007 and 2021.

5.2.1 DV4 – February 1983

In England in 1983 the Department of Health and Social Services (DHSS) published DHSS Engineering Data referenced "DV4" which is an 86-page design manual for the Design Commissioning, Testing Maintenance and Operation of ventilation systems in Operating Theatre Departments. - the document was specifically written for Operating Departments. The document provided exemplar layouts air changes requirements, plant configurations and calculation methodology and based on studies in the 1970 some were understood to be undertaken by Dr.O.Lidwell who published some 130 technical papers on ventilation principles.

This document describes the ventilation of an operating room as having three main functions:

- control temperature and humidity of the space
- dilute airborne bacterial contamination
- control the air movement within the suite such that transport of airborne infections or bacteria from less clean to clean areas is minimised (sometimes referred to as cascade air pressure control)

The document listed the required nominal air pressures between spaces to ensure the cascade principle of clean air to dirty air was maintained along with recommended air flow rates of both supply and extract in air changes per hour and in litres per second. The fundamental principles in terms of room nominal design pressures, air change rates and airflows haven't changed although in the years following DV4 being created and issued, the main theatre room air change has increased from a fixed volume of 0.65m3/sec to an air change rate of 25 air changes per hour that caters for various changes in theatre dimensions.

An interesting point to note is that some spaces are designed to have a specific air change rate per hour which is considered necessary for the control of anaesthetic gas - gases administered to patients to sedate them prior to and during surgical procedures. Dealing with anaesthetic gases is an unusual aspect of healthcare facilities.

Early anaesthetic gases had flammable properties, so air change rates were prescribed to minimise the explosion risk via dilution means, also as medical gases are denser than air, they tend to drop to floor level so requiring air movement systems (supply and extract air grilles) to be correctly located in a space. In an anaesthetic room the air should push down from the ceiling and out at low level. In the operating theatre recovery bays where patients exhale anaesthesia then dilution is required to protect the nursing staff so again air should be delivered in a specific manner as described within design guidance.

5.2.2 HTM2025 - 1994

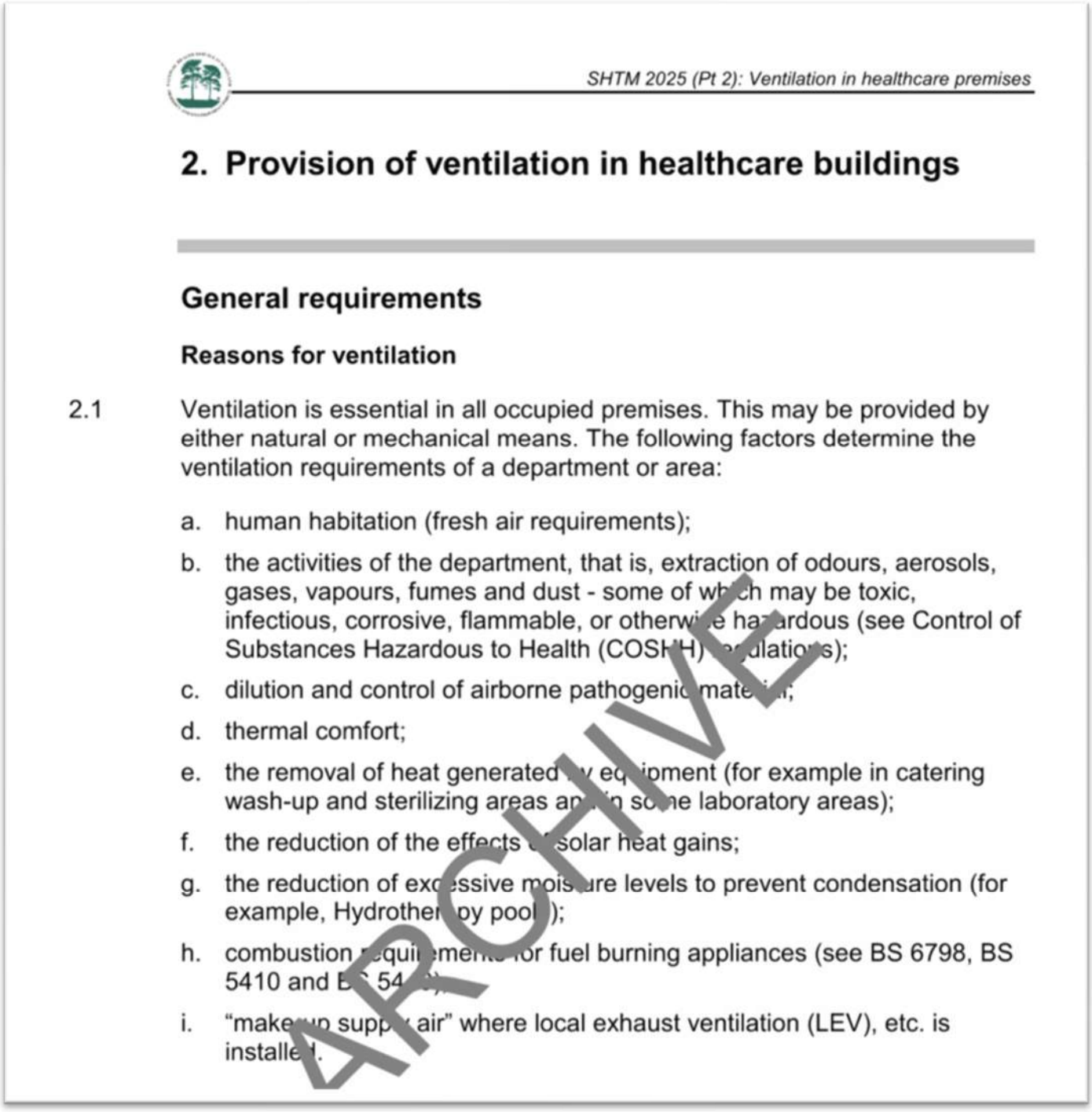
Ventilation in Healthcare Premises Design considerations was published in 1994 (reprinted 1998) and was split into 4 volumes

- Management Policy
- Design Considerations
- Validation and Verification
- Operational Management

The document built on the work detailed in DV4 and the description of the purpose of ventilation is noted as follows:

> *Clause 2.1 Ventilation is essential in all occupied premises. This may be provided by either natural or mechanical means. The following factors determine the ventilation requirements of a department or area:*
>
> *a) human habitation (fresh air requirements);*
> *b) the activities of the department, that is, extraction of odours, aerosols, gases, vapours, fumes and dust – some of which may be toxic, infectious, corrosive, flammable, or otherwise hazardous (see Control of Substances Hazardous to Health (COSHH) regulations).*
> *c) dilute and control airborne pathogenic material.*
> *d) thermal comfort.*
> *e) the removal of heat generated by equipment (for example in catering, wash-up and sterilizing areas and in some laboratory areas).*
> *f) the reduction of the effects of solar heat gains.*
> *g) the reduction of excessive moisture levels to prevent condensation (for example Hydrotherapy pools).*
> *h) combustion requirements for fuel burning appliances (see BS5376, BS5410 and BS5440).*
> *i) "make-up supply air" where local exhaust ventilation (LEV) etc is installed*

SHTM 2025 (June 2001) equivalent of the above is shown below and the wording is identical



SHTM 2025 (Pt 2): Ventilation in healthcare premises

2. Provision of ventilation in healthcare buildings

General requirements

Reasons for ventilation

2.1 Ventilation is essential in all occupied premises. This may be provided by either natural or mechanical means. The following factors determine the ventilation requirements of a department or area:

a. human habitation (fresh air requirements);

b. the activities of the department, that is, extraction of odours, aerosols, gases, vapours, fumes and dust - some of which may be toxic, infectious, corrosive, flammable, or otherwise hazardous (see Control of Substances Hazardous to Health (COSHH) Regulations);

c. dilution and control of airborne pathogenic material;

d. thermal comfort;

e. the removal of heat generated by equipment (for example in catering wash-up and sterilizing areas and in some laboratory areas);

f. the reduction of the effects of solar heat gains;

g. the reduction of excessive moisture levels to prevent condensation (for example, Hydrotherapy pools);

h. combustion requirements for fuel burning appliances (see BS 6798, BS 5410 and BS 54[illegible]);

i. "make-up supply air" where local exhaust ventilation (LEV), etc. is installed.

The document still largely dealt with the design of Operating theatres and but also mentions natural ventilation:

> *Clause 2.5 As the motivating influences of natural ventilation are variable, it is almost impossible to maintain consistent flow rates and thereby ensure that minimum ventilation rates will be achieved at all times. This variability normally is acceptable for general areas including office accommodation, general wards, staff rooms, library/seminar rooms, dining rooms and similar areas, which should be naturally ventilated, that is, provided with opening windows.*
>
> *Clause 2.6 In all cases, however, heat gain or external noise may preclude natural ventilation*

The SHTM 2025 (June 2001) is shown below again wording is identical

Natural ventilation

2.4 Natural ventilation is usually created by the effects of wind pressure. It will also occur to some extent if there is a temperature difference between the inside and the outside of the building. The thermo-convective effect frequently predominates when the wind speed is low and will be enhanced if there is a difference in height between inlet and outlet openings. Ventilation induced by wind pressures can induce high air change rates through a building, provided air is allowed to move freely within the space from the windward to the leeward side.

2.5 As the motivating influences of natural ventilation are variable, it is almost impossible to maintain consistent flow rates and thereby ensure that minimum ventilation rates will be achieved at all times. This variability normally is acceptable for general areas including office accommodation, general wards, staff rooms, library/seminar rooms, dining rooms and similar areas, which should be naturally ventilated, that is, provided with opening windows.

2.6 In some cases, however, heat gain or external noise may preclude natural ventilation.

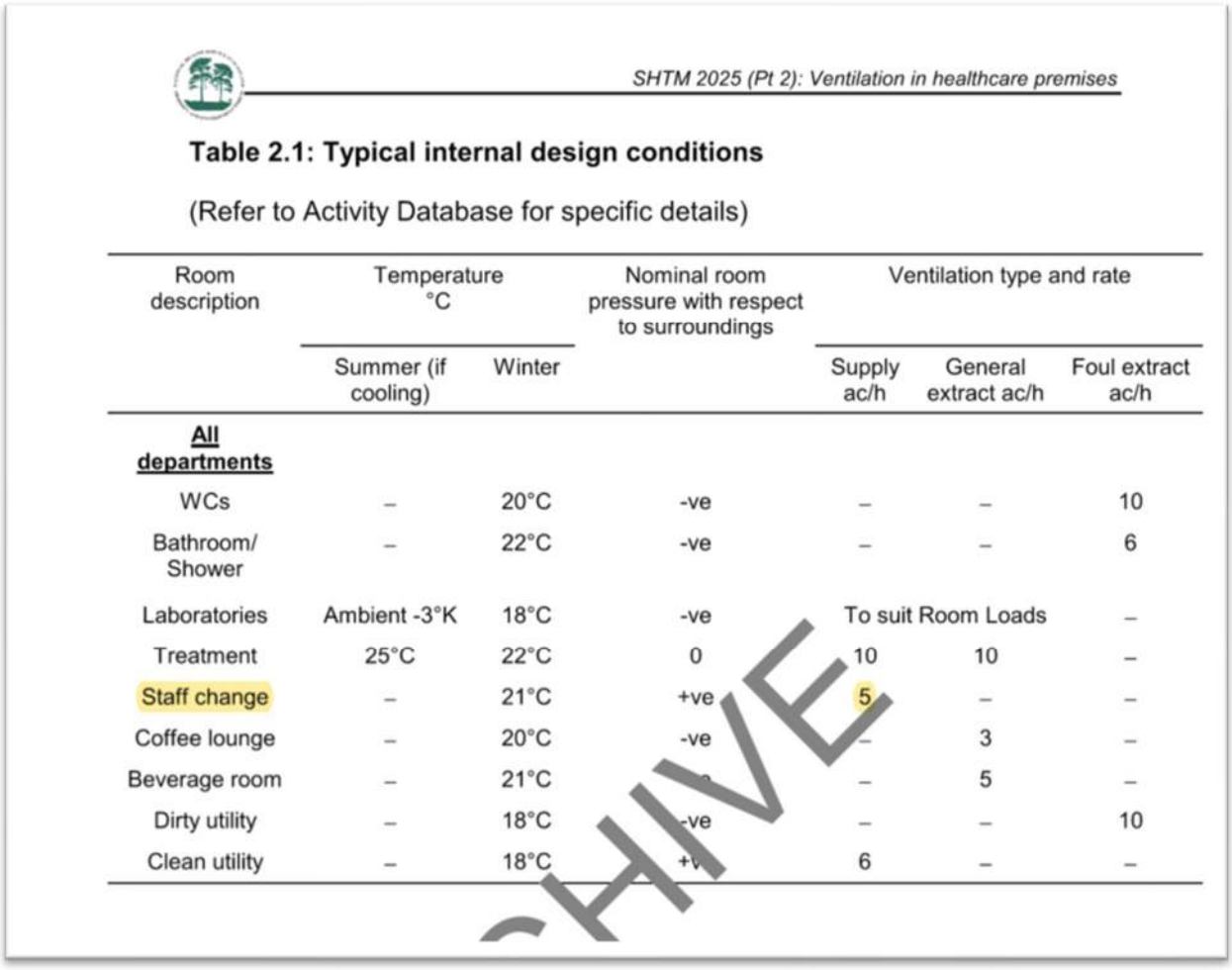
The document did however introduce minimum air change rates for spaces outside Operating Theatres Departments as shown in the extract below:

ROOM DESCRIPTION	TEMPERATURE (°C) SUMMER (IF COOLING)	TEMPERATURE (°C) WINTER	NOMINAL ROOM PRESSURE WITH RESPECT TO SURROUNDINGS	VENTILATION TYPES & RATE SUPPLY AC/h	VENTILATION TYPES & RATE GENERAL EXTRACT AC/h	VENTILATION TYPES & RATE FOUL EXTRACT AC/h
ALL DEPARTMENTS						
WCs	–	18°C	–ve	–	–	10
BATHROOM/SHOWER	–	21°C	–ve	–	–	6
LABORATORIES	Ambient +3°C	18°C	–ve	TO SUIT	ROOM LOADS	–
TREATMENT	25°C	21°C	0	10	10	–
STAFF CHANGE	–	21°C	+ve	3	–	–
COFFEE LOUNGE	–	18°C	–ve	–	3	–
BEVERAGE ROOM	–	18°C	–ve	–	5	–
DIRTY UTILITY	–	18°C	–ve	–	–	10
CLEAN UTILITY	–	18°C	+ve	6	–	–

Table 2.1 Typical internal design conditions
(Refer to Activity DataBase for specific details)

Figure 10- Table 2.1 HTM 2025 1994 Reprinted 1999-page 9

The above table is also replicated in SHTM 2025, with some local variations but clear reference is made to Room Data Sheets (Activity Database) thereby informing the designer to check if there are any Project specific requirements. Please note the highlight is made in the digital copy and cannot be removed but serves no intent in this report.



SHTM 2025 (Pt 2): Ventilation in healthcare premises

Table 2.1: Typical internal design conditions

(Refer to Activity Database for specific details)

Room description	Temperature °C		Nominal room pressure with respect to surroundings	Ventilation type and rate		
	Summer (if cooling)	Winter		Supply ac/h	General extract ac/h	Foul extract ac/h
All departments						
WCs	–	20°C	-ve	–	–	10
Bathroom/ Shower	–	22°C	-ve	–	–	6
Laboratories	Ambient -3°K	18°C	-ve	To suit Room Loads		–
Treatment	25°C	22°C	0	10	10	–
Staff change	–	21°C	+ve	5	–	–
Coffee lounge	–	20°C	-ve	–	3	–
Beverage room	–	21°C		–	5	–
Dirty utility	–	18°C	-ve	–	–	10
Clean utility	–	18°C	+v	6	–	–

Figure 11- Table 2.1 SHTM2025 (Pt2) Ventilation Healthcare Premises Design Considerations

5.2.3 HTM 03-01 Part A- 2007

Specialised Ventilation for Healthcare Premises Part A Design and Validation was first published in 2007 and comprehensively update in 2021.

Key variations from HTM2025 are noted in the Executive Summary of the document as being

This Health Technical Memorandum has been revised to reflect the current guidance on theatre suite layout and room sizes given in Health Building Note 26, Volume 1 – 'Facilities for surgical procedures', including the recommended air-change rates.

Other key issues

- *it addresses the issues relating to patient comforts and prevention and control of healthcare associated infections. Specialised ventilation systems play a central role in these important areas.,*
- *it looks at the methods of controlling the casual exposure of staff to anaesthetic substances,*
- *it outlines the design and acceptance testing of general and ultra clean ventilation systems (UCV) systems,*

- *it sets out the minimum requirements for the design of air-handling units with regard to the control of Legionella and safe access for routine inspection and maintenance.*

As the design documents evolved so has the extent of guidance and applicable air change rates for more areas expanded as noted below:

Appendix 2 – Recommended air-change rates

Application	Ventilation	AC/hr	Pressure (Pascals)	Supply filter	Noise (NR)	Temp (°C)	Comments (for further information see Chapter 6)
General ward	S/N	6	–	G4	30	**18–28**	
Communal ward toilet	E	6	–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 Health Building Note 04-01 (Supplement 1)
Infectious diseases isolation room	E	10	–5	G4	30	**18–28**	Extract filtration may be required
Neutropeanic patient ward	S	10	+10	H12	30	**18–28**	
Critical care areas	S	10	+10	F7	30	*18–25*	Isolation room may be –ve pressure
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 pressure
Preparation room (lay-up)	S	>25	35	F7	40	*18–25*	
Preparation room/bay (sterile pack store)	S	10	25	F7	40*	*18–25*	*50 NR if a bay in a UCV theatre
Operating theatre	S	25	25	F7	40	*18–25*	
UCV operating theatre	S	25*	25	H10 or greater	50	*18–25*	*Fresh-air rate; excludes recirculation
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
Catheterisation room	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 EGGMP (Orange guide) [a]
Category 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

Notes: **18–22**°C indicates the range over which the temperature may float.
18–22°C indicates the range over which the temperature should be capable of being controlled.

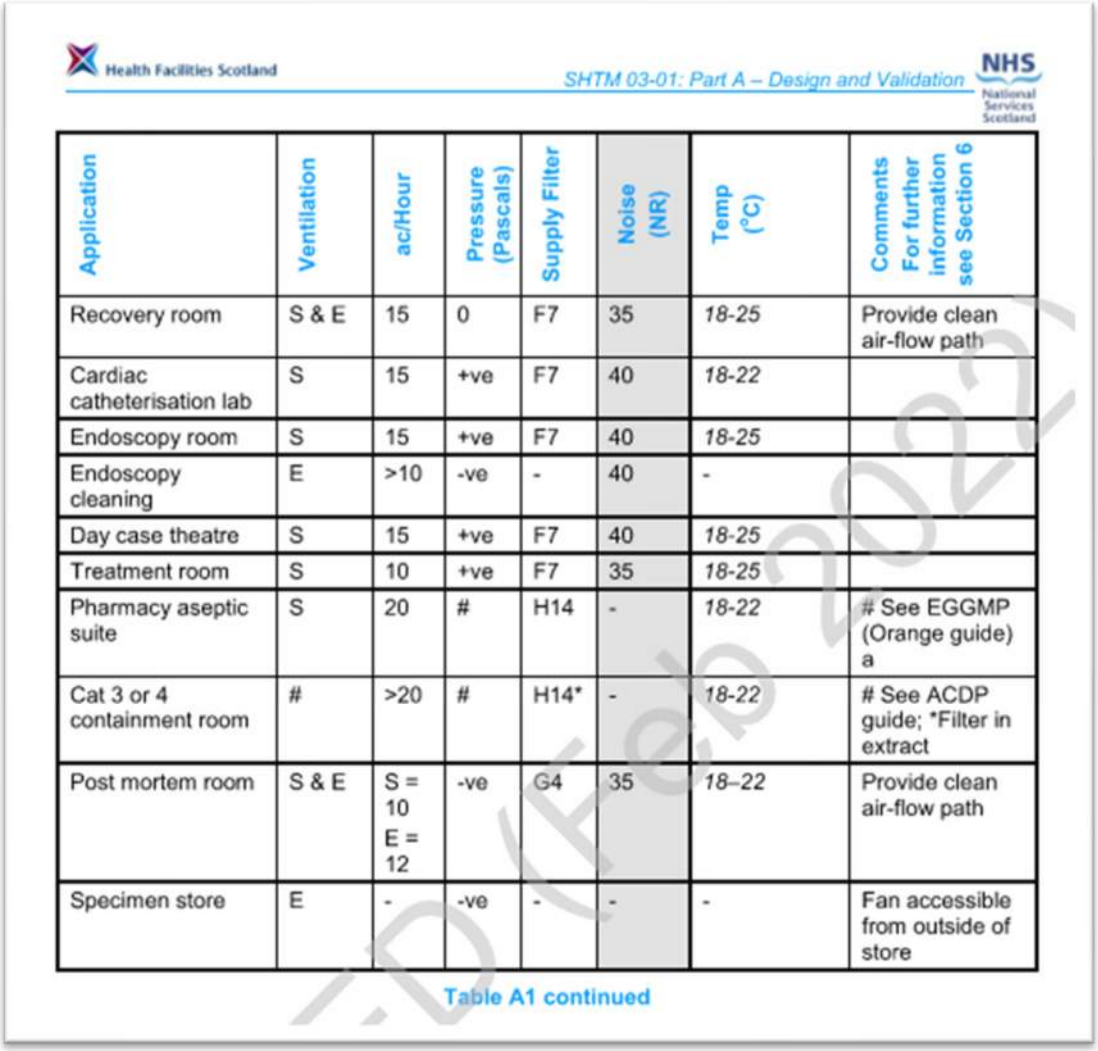
Figure 12-HTM 03-01 Part A 2007 Appendix 2 Page 83

There is an equivalent table in SHTM 03-01 Part A Design and Validation Version 2 February 2014

Appendix 1: Recommended air-change rates

Application	Ventilation	ac/Hour	Pressure (Pascals)	Supply Filter	Noise (NR)	Temp (°C)	Comments For further information see Section 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

Table A1



Health Facilities Scotland — SHTM 03-01: Part A – Design and Validation — NHS National Services Scotland

Application	Ventilation	ac/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 EGGMP (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

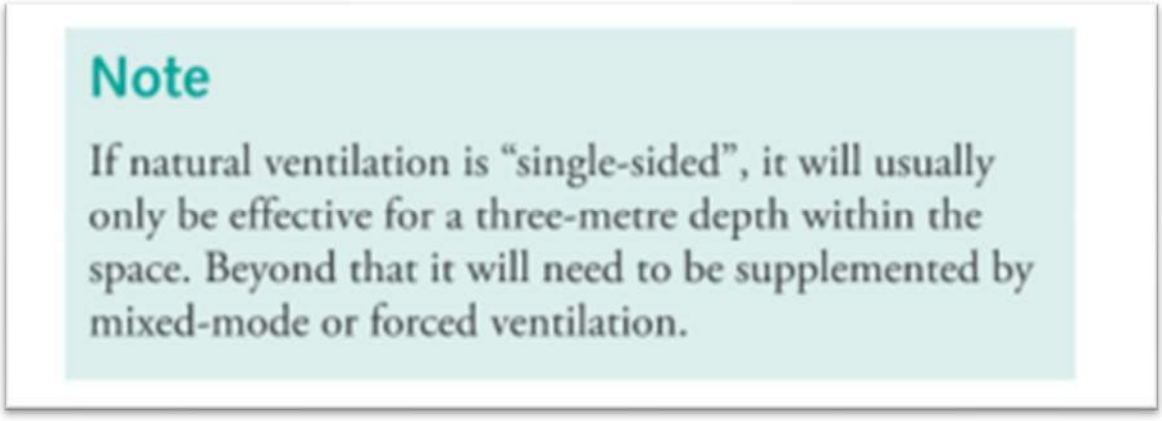
Figure 13-SHTM 03-01- Part A Feb 2014 Table A1 Pages 139 and 140

The only air change rate difference between the 2 documents relate to the Communal Ward Toilet which is 10 air changes per hour in SHTM-03-01 and 6 in HTM 03-01

This issue did however introduce the requirement for mechanical supply and extract ventilation in general wards There is no explanation as to how the design air change rate of 6 air changes has been determined. Experienced designers often check the following parameters in a room and design the ventilation plant and distribution systems on the highest flow rates:

- Fresh air requirement for dilution/contamination control,
- Fresh air for people or process air replacement (such as fume cupboard),
- Cooling benefit to cope with room heat gain.

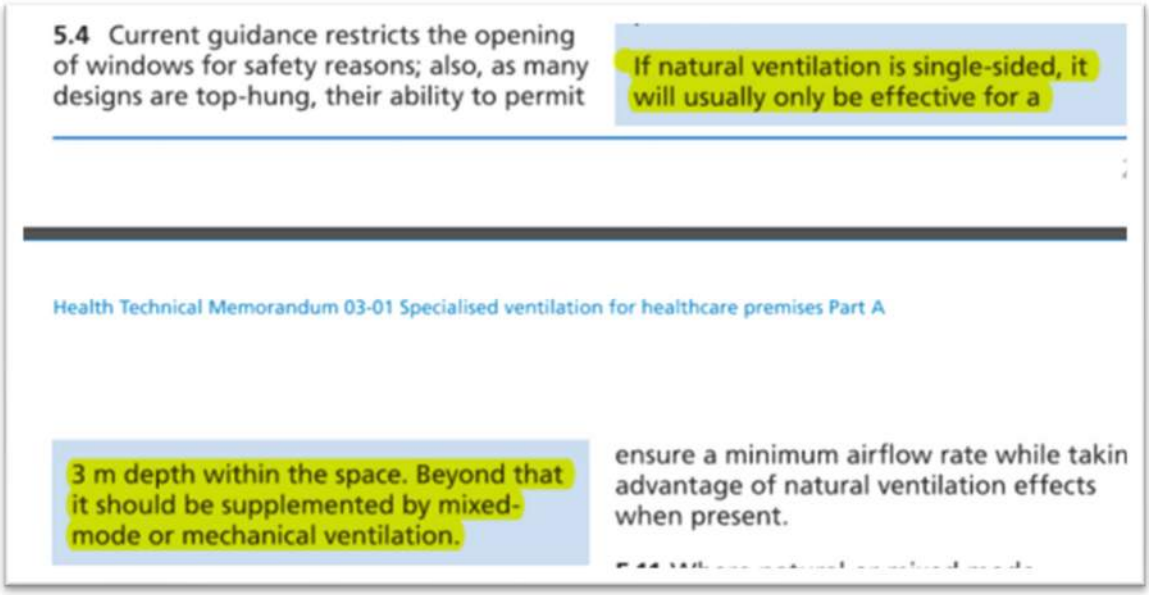
HTM 03-01 expends on the efficacy of natural ventilation as follows in both the 2007 and 2021 versions.



Note

If natural ventilation is "single-sided", it will usually only be effective for a three-metre depth within the space. Beyond that it will need to be supplemented by mixed-mode or forced ventilation.

Figure 14-HTM03-01-2007 Section 2 clause 2.6 Page 8



5.4 Current guidance restricts the opening of windows for safety reasons; also, as many designs are top-hung, their ability to permit

If natural ventilation is single-sided, it will usually only be effective for a

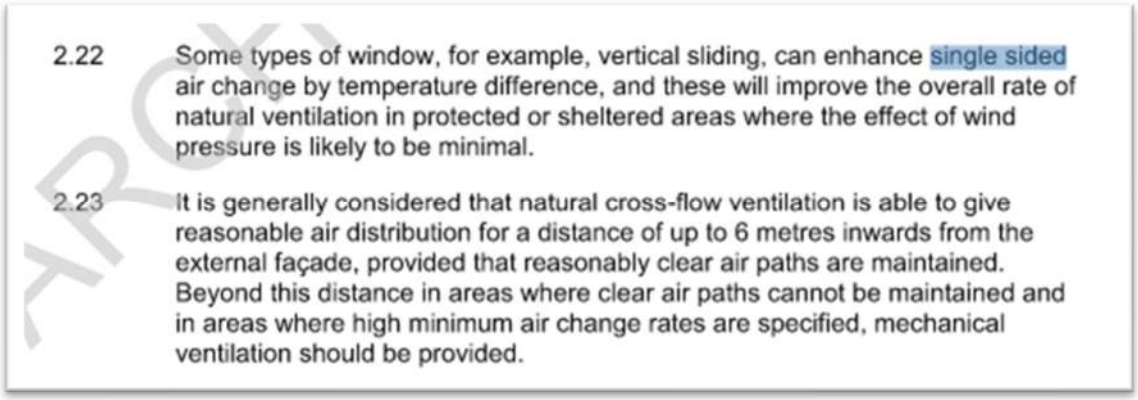
Health Technical Memorandum 03-01 Specialised ventilation for healthcare premises Part A

3 m depth within the space. Beyond that it should be supplemented by mixed-mode or mechanical ventilation.

ensure a minimum airflow rate while takin advantage of natural ventilation effects when present.

Figure 15-HTM03-01 Part A Design 2021 pages 23-24

The SHTM's also quote similar guidance

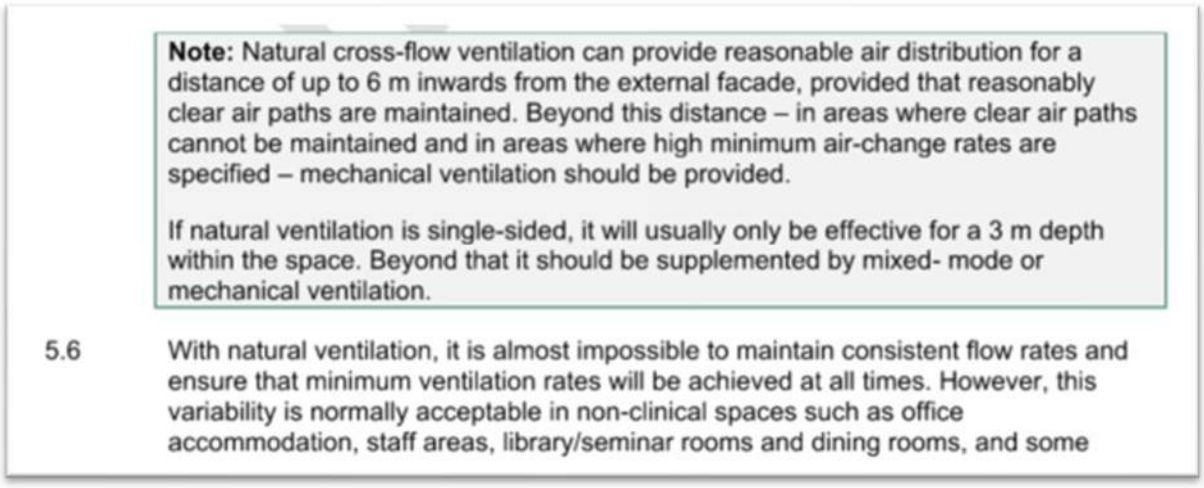


2.22 Some types of window, for example, vertical sliding, can enhance single sided air change by temperature difference, and these will improve the overall rate of natural ventilation in protected or sheltered areas where the effect of wind pressure is likely to be minimal.

2.23 It is generally considered that natural cross-flow ventilation is able to give reasonable air distribution for a distance of up to 6 metres inwards from the external façade, provided that reasonably clear air paths are maintained. Beyond this distance in areas where clear air paths cannot be maintained and in areas where high minimum air change rates are specified, mechanical ventilation should be provided.

Figure 16-SHTM03-01 Part A February 2014 Page 24

In SHTM 03-01 Part A 2022



Note: Natural cross-flow ventilation can provide reasonable air distribution for a distance of up to 6 m inwards from the external facade, provided that reasonably clear air paths are maintained. Beyond this distance – in areas where clear air paths cannot be maintained and in areas where high minimum air-change rates are specified – mechanical ventilation should be provided.

If natural ventilation is single-sided, it will usually only be effective for a 3 m depth within the space. Beyond that it should be supplemented by mixed- mode or mechanical ventilation.

5.6 With natural ventilation, it is almost impossible to maintain consistent flow rates and ensure that minimum ventilation rates will be achieved at 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

Figure 17-SHTM03-01 2022 Section 5 Page 36

5.3 Authorship of HBN's and HTM's

It is worth noting that the writing of guidance documents is undertaken collaboratively often on a volunteer basis by specialists in the specific guidance documents field including

a) Operational Estates Staff, (maintenance and management personnel)
b) Medical Staff, (microbiologists, infection control staff etc)
c) Academics
d) Experienced designers, (Architects and Engineers)
e) Independent specialists
f) Manufacturers

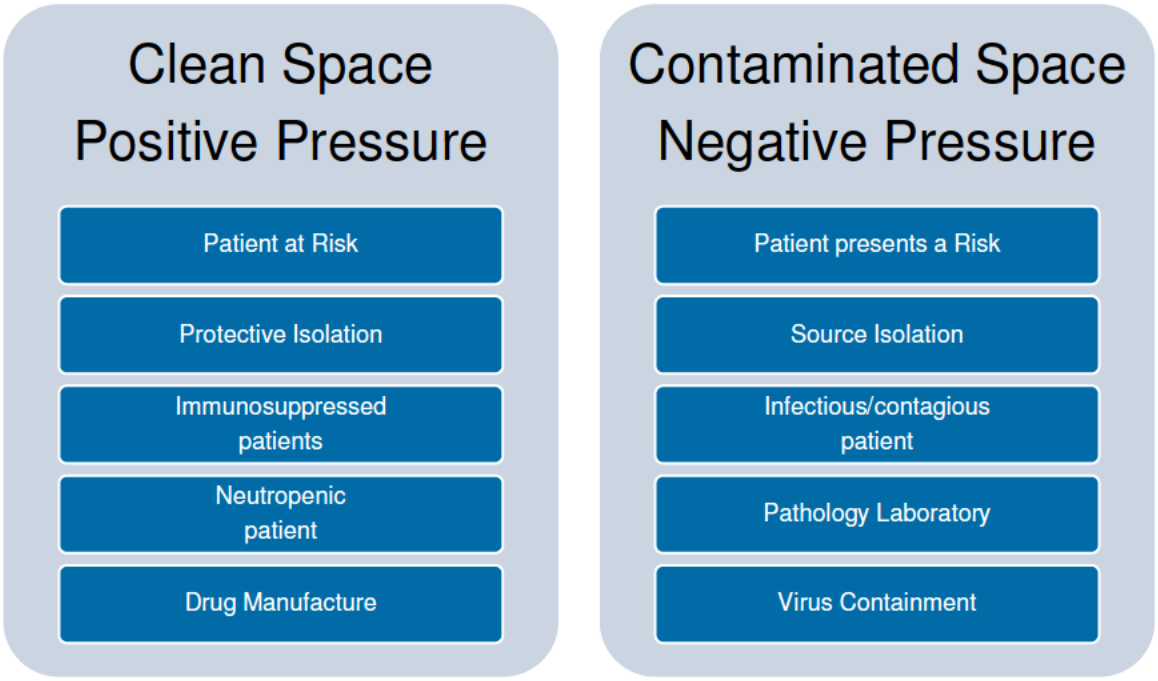
6.0 Clean or Contaminated Spaces

6.1 Clean or Contaminated Spaces

The guidance noted in section 5 has evolved over time and specific issues have arisen as clinical practices have changed.

Ventilation is fundamentally about controlling temperature and pressure of a space. Humidity control used to be a key factor but is no longer controlled in most areas due to the cost of controlling humidity levels and legionellae risk associated with generating humidity.

There are two distinct types of spaces that often have different titles and it is hoped the following will help define the key titles and purpose of a space.



Two of the more specialised departments in a hospital include Pharmacy and Pathology and each are governed by a different set of core design parameters. Which is noted in the HTM's, briefly summarised as follows to indicate the complexity of Hospital Ventilation design.

Pharmacy and Drug Manufacturer

A pharmacy will store and dispense drugs to wards and so to patients. In larger Pharmacies there may also be drug manufacture undertaken in what are known as Aseptic Suites or highly sterile areas. As drugs are manufactured for administration, they fall under a different set of regulatory documents issued by the Medicines and Healthcare Products Regulatory Agency. The design of an Aseptic Pharmacy must follow the design principles and then be validated during the design, installation, commissioning and operation in order to be granted a licence to operate. The drugs manufactured in an Aseptic Pharmacy may consist of Chemotherapy drugs to treat cancer patients as the cancers are often unique and require specific drugs to be created, and Total Parenteral Nutrition TPN treatments. This is the provision of nutrition to be delivered to patients who cannot consume normal food as their condition prohibits this and they must be fed via an intravenous method.

Pathology Laboratory

This is where pathogens and illnesses are detected and analysed and depending on the laboratory classification, fall under the Health and Safety Executive Advisory Committee on Dangerous Pathogens remit.

6.2 Patient Accommodation

For several years there was no defined standard for the type of space a patient should be located in, and many hospital wards comprised of multi-bed, rooms. A typical ward may have had say three 7-bed bays in a single space with say 6 single bedrooms. Any patient who was ***a risk*** or ***at risk*** to others could be safely located in a single bedroom.

The drive for patient dignity and privacy through initiatives such as NHS Patient Experience (2011) has increased the provision of single bedrooms such that many general wards in new hospitals are all single bed wards with a room per patient often with their own ensuite toilet/shower.

Some rooms were designated as being able to house patients who were ***a risk*** or ***at risk*** and there may have been a ventilation arrangement that was switchable between a positive pressure space and a negative pressure space.

In its simplest form this could have been enabled via a switch that adjusted a control damper or extract fan, but the key issue would be a member of the nursing staff had to assess the nature of the patient in the room and it was felt that mistakes could easily happen on a busy ward or switches could be forgotten to be reset. This scenario also presented a problem with say a person undergoing chemotherapy, so they were immunosuppressed but also had say chicken pox and were infectious.

The NHS England published a new Health Building Notes for Wards in 2009 entitled HBN 04-01 Adult Inpatient Facilities this replaced a previous guidance document HBN 4 from 1997 that covered general inpatient Wards.

HBN 04-01 2009 notes the following:

Isolation facilities

2.18 Single-bed rooms provide an effective facility for isolating patients with a variety of infections, such as MRSA. However, in some circumstances it may be necessary to provide a higher level of isolation, particularly for those patients with airborne diseases or for immuno-suppressed patients who may be at risk of infection from others. In these cases, an isolation suite – which includes an entrance lobby, bedroom and en-suite sanitary facilities – will be required. This is listed as optional in the schedule of accommodation for this Health Building Note. The need for and number of isolation suites should be decided locally and in consultation with local Health Protection Agency staff.

2.19 Isolation suites are described in paragraph 3.29.

Isolation suite (Optional accommodation)

3.29 An isolation suite comprises a single-bed room, en-suite shower room and a ventilated lobby.

3.30 For detailed guidance on isolation suites and example layouts see Health Building Note 4 Supplement 1 – 'Isolation facilities in acute settings'.

3.31 If it is proposed to install a ceiling hoist track system between an isolation room and en-suite shower room, the design should not compromise the airflow pattern between the two rooms. ***The design of the isolation suite works on the principle of supplying air from the lobby at high level to the bedroom and removing it at low level via a transfer grille in the en-suite door.*** *This ensures good mixing of the air in the bedroom, with a consequent dilution of possible contaminants. The wall area above the outward-opening door that is penetrated by the track and suspension system should not therefore allow unrestricted airflow between the bedroom and en-suite at high level. Suitably profiled filler boards and the use of brush seals will ensure an adequate resistance to flow and prevent short-circuiting.*

The bold underlined text has been added in this report to indicate the ventilation aspects of the HBN were addressed in a general description section, but this ventilation aspect was not referred to in the General Engineering Section of the HBN meaning guidance may be missed if someone was searching for detailed engineering principles.

6.3 Positive Pressure Ventilated Lobby (PPVL) rooms

HBN04-01 was supplemented in 2013 with the document, HBN 04-01-Supplement 1 - Isolation Facilities for Infectious Patients in acute settings.

HBN 04-01- Supplement No 1 2013 introduced the principle of the Positive Pressure Ventilated Lobby (PPVL) as it was recognised that the provision of isolation rooms that are switchable from positive to negative air pressure was no longer recommended because of the risk to people inside and outside the room in the event of the setting being incorrect.

The guidance on PPVL and negative pressure isolation suites in the document was based on a model that was validated by the Building Services Research and Information Association (BSRIA) and the University of Leeds.

It should be noted that the introduction stated that "*This Health Building Note does not describe the specialist facilities required in high security infectious disease units, isolation wards for cohorting groups of infectious patients, protective isolation for severely immuno-compromised patients, critical care areas and special care baby units. It focuses on single occupancy isolation rooms only.*"

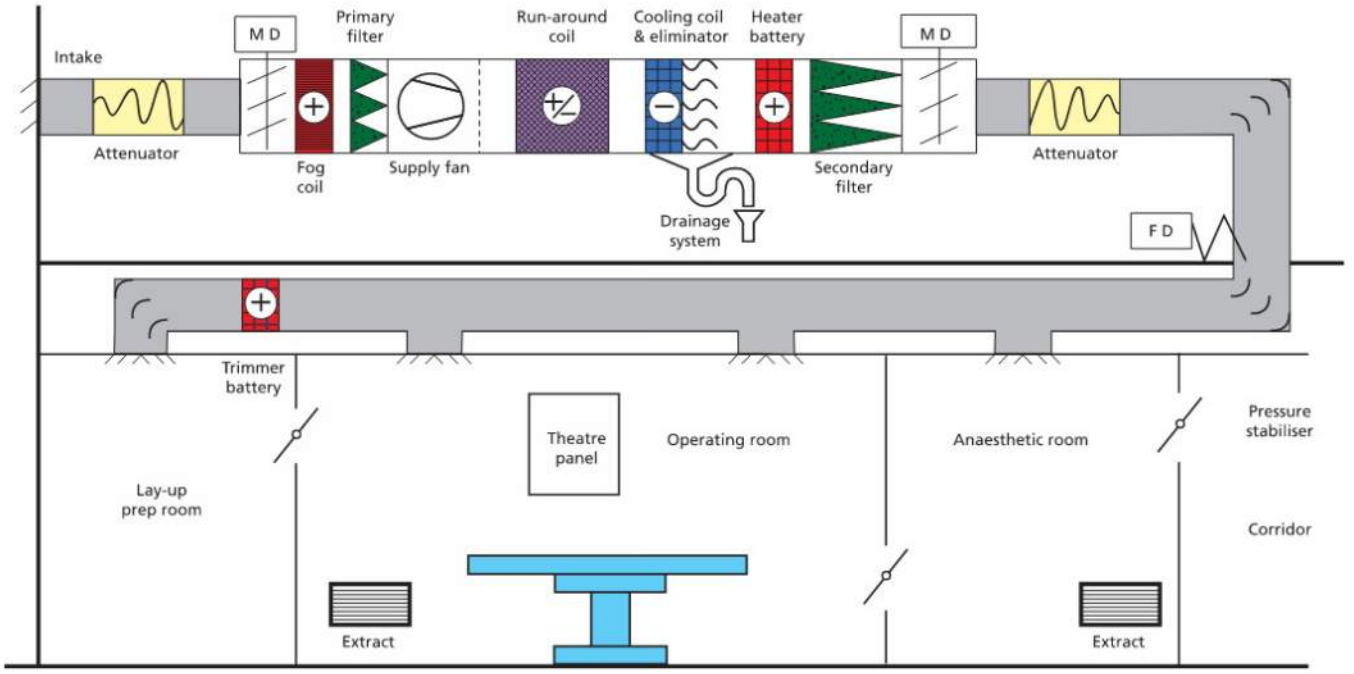
The latest HTM-03-01 has very specific details guidance that encompasses the requirements of the supplementary document.

7.0 Ventilation System Components

The key components in any Hospital mechanical ventilation systems are plant (air handling unit-AHU) and distribution ductwork delivering conditioned air to/from spaces via a series of sheet metal ducts and terminal devices to deliver the air in a draught free manner.

7.1 AHU layout

The below diagram is taken from HTM 03-01-Part A 2021 and whilst it shows an operating theatre the arrangement is no different in principle for a ward or administration facility.



The plant components are not dissimilar to air handling units in use in other sectors such as commercial offices, however in HTM, Compliant AHU's are generally significantly longer as each device that influences the air stream (filter, heater, cooler) has specific access sections to allow maintenance personnel to get inside the AHU and thoroughly clean and disinfect the inside of the units and undertake routine maintenance. The construction requirements (materials) and detailed performance requirements are much more enhanced than commercial units. An example being light fittings are located inside sections with a control switch outside so that a maintenance operative can inspect the unit without isolating it and thereby stopping air flow to a department.

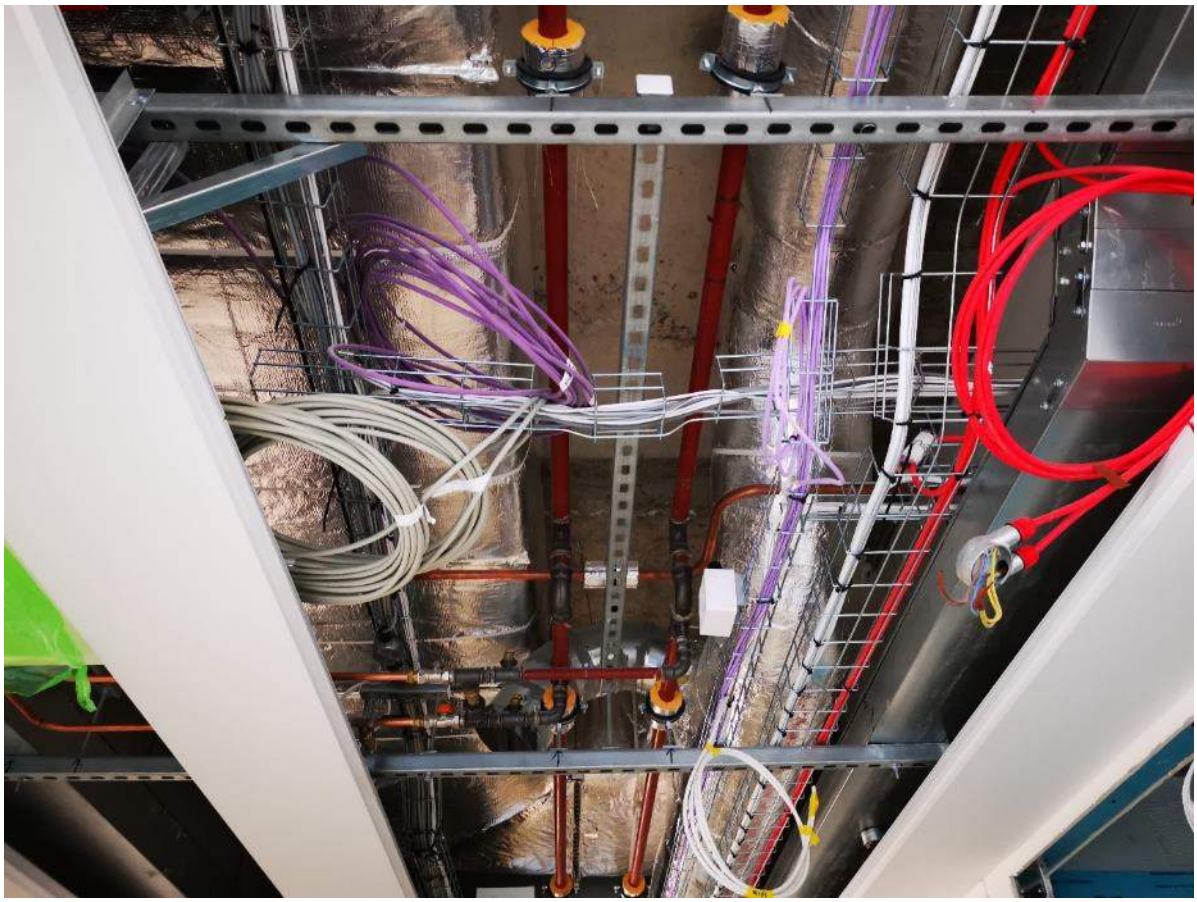
The routine maintenance of AHU's is very difficult to programme with many areas of a hospital operating on a 24 hour basis and in some critical areas duty/standby AHU's are often considered but seldom instigated due to the prohibitive costs. Ductwork should be routinely inspected internally and cleaned if deemed necessary which would entail a greater degree of department closure.

Chilled beams have been used to provide additional cooling in spaces. They can be active (i.e. have air pushed through them which is then delivered to the space) or passive where no air passed through the beam. In both types of beam chilled water is passed through them to provided source of cooling, rather like hot water is passed through a conventional heating radiator. Active beams do require regular cleaning from within the space they serve via use of vacuum cleaning.

8.0 Design Challenges

In section 2 a number of key design drivers were noted. These all represent challenges to the building services design engineer at the initial briefing on a project to understand the scope of the project but as the design develops further issues come into play including co-ordination with architecture and structure which is essential.

Mechanical ventilation systems are by far the largest component of any building services system on the floor plate of a hospital. The location of vertical and horizontal distribution strategies requires careful consideration with other mechanical an electrical distribution system, heating pipework, plumbing pipework, cable tray and medical gas pipework. The photograph below shows a typical ward corridor during installation of the services. Ventilation ductwork is closest to the slab, pipework is in between ventilation ductwork, cable tray is below the ductwork.



All the engineering systems in the ceiling void of a hospital will require routine access and maintenance and ultimately replacement. Typically engineering services will need replacing at least twice if not three times during the life span of a building so a well-considered layout with good access arrangements is vital from the beginning of a project.

A typical Hospital has a design life of 60 years based on the correct selection of robust fabric (walls, floors structure etc). Engineering Services have a range in life expectancy of between 15 and 30 years depending on the robustness of product.

The design of corridors, location of vertical risers to distribute services to/from plant rooms, plant compounds that allow routine maintenance and plant replacement via temporary cranes or permanent staircase all have to be considered during the design development process.

Appendix A

9.0 Appendix A- Example Room Data Sheets

ADB	List of Departments	28/3/2022

Project: ADB2020 Activity Database version 2020 © Copyright
Filter:

Code	Description	Date
00-02	Sanitary spaces	01-Oct-2017
01-01	Cardiac facilities	20-Mar-2013
01-01-01	Example 1: Cardiac operating theatre suite: 4 theatres	20-Mar-2013
01-01-02	Optional Accommodation: Cardiac operating theatre suite : 4 theatres	20-Mar-2013
01-01-03	Example 2: Catheter laboratory suite: 4 rooms	20-Mar-2013
01-01-04	Optional Accommodation: Catheter laboratory suite: 4 rooms	20-Mar-2013
02-01	Cancer treatment facilities	20-Mar-2013
02-01-01	Example 1: Chemotherapy service in an acute hospital	20-Mar-2013
02-01-02	Optional Accommodation: Chemotherapy service in an acute hospital	20-Mar-2013
02-01-03	Example 2: Radiotherapy service in an acute hospital: two linear acceleators	20-Mar-2013
02-01-04	Example 3: Radiotherapy service in an acute hospital: four linear accelerators (main centre)	20-Mar-2013
02-01-05	Optional Accommodation: Radiotherapy service in an acute hospital: four linear accelerators (main centre)	20-Mar-2013
03-01	Adult acute mental health units	01-Oct-2017
04-01	Adult in-patient facilities - list of spaces	11-Dec-2009
04-01A	Adult in-patient facilities - 24-bed ward, 50% single-bed rooms	11-Dec-2009
04-01B	Adult in-patient facilities - 24-bed ward, 83% single-bed rooms	11-Dec-2009
04-01C	Adult in-patient facilities - 24-bed ward, 100% single-bed rooms	11-Dec-2009
04-01D	Shared Accommodation: Adult in-patient facilities	11-Dec-2009
04-01E	Optional Accommodation: Adult in-patient facilities	11-Dec-2009
04-02	Critical care units	20-Mar-2013
04-02-01	Example 1: 8-bed critical care unit	20-Mar-2013
04-02-02	Example 2: 16-bed critical care unit	20-Mar-2013
04-02-03	Optional Accommodation: 16-bed critical care unit	20-Mar-2013
04-02-04	Example 3: 32-bed critical care unit	20-Mar-2013
04-02-05	Optional Accommodation: 32-bed critical care unit	20-Mar-2013
07-01	Satellite dialysis unit - list of spaces	31-Mar-2013
09	Maternity care facilities	20-Mar-2013
09-02-01	Example 1: Consultant-led birthing unit (5000 births/annum)	20-Mar-2013
09-02-02	Example 2: Midwife-led birthing unit (1000 births/annum co-located with consultant-led unit)	20-Mar-2013
09-02-03	Example 3: Midwife-led birthing unit (1000 births/annum, standalone)	20-Mar-2013
09-02-04	Optional Accommodation: Midwife-led birthing unit (1000 births/annum, standalone)	20-Mar-2013
09-03-01	Example 4: Neonatal intensive care unit – serving 5,000 local births, but also including 11 intensive care/high dependency cots	20-Mar-2013
09-03-02	Optional Accommodation: Neonatal intensive care unit – serving 5,000 local births, but also including 11 intensive care/high dependency cots	20-Mar-2013
09-03-03	Example 5: Special care unit – serving 2,500 local births	20-Mar-2013
09-03-04	Optional Accommodation: Special care unit – serving 2,500 local births	20-Mar-2013
10-02	Day surgery facilities	01-May-2007
11-01	Facilities for primary and community care services	20-Mar-2013
11-01-01	Example 1: Primary care centre	20-Mar-2013
11-01-02	Example 2: Extended primary care centre	20-Mar-2013
11-01-03	Example 3: Community Hospital	20-Mar-2013
BARIATRIC	Bariatric Exemplar spaces	09-Jul-2020
HBN06	Facilities for diagnostic imaging and interventional radiology V1 and V2 - list of spaces	01-Jan-2001

ADB	List of Departments	28/3/2022

Project: ADB2020 Activity Database version 2020 © Copyright
Filter:

Code	Description	Date
HBN08	Rehabilitation services facilities	01-Jan-2004
HBN12	Out-Patients department	01-Jan-2004
HBN13	Sterile Services Department	02-Jan-2004
HBN15	Facilities for pathology services - list of spaces	28-Apr-2005
HBN20	Mortuary and post-mortem room facilities - list of spaces	01-Jan-2005
HBN22	Accident & emergency facilities for adults and children	01-Jan-2005
HBN23	Hospital accommodation for children and young people	01-Jan-2004
HBN26V1	Facilities for surgical procedures	02-Jan-2004
HBN37	In-patient facilities for older people - list of spaces	01-Jan-2005
HBN52V3	Accommodation for Day Care: Medical Investigation facilities - list of spaces	29-Mar-1995
ISOLATION	Isolation Unit Exemplars	20-Apr-2020

ADB	List of Rooms	28/3/2022

Project:	ADB2020	Activity Database version 2020 © Copyright
Department:	03-01	Adult acute mental health units

Code	Description	Area (m²)
B0507A	Seclusion room	15.00
B0512	Single Bedroom: mental health	12.00
B0514	Single-bed room: accessible; mental health.	14.50
B2407	Recovery room: 2 trolleys	24.00
B2511-01	Recover room: with mini kitchen; 8 places	15.50
D0434-01A	Rest room with beverages & snack preparation bay: 10 places	20.50
D0611	Dining room: 16 places (including wheelchair place)	25.00
D1101	Sitting quiet room: 6 places (including wheelchair place)	15.00
D1111	Sitting room: 16 places (including wheelchair place)	30.00
F0312	Kitchen servery	22.00
F0416	Cafe seating area: 10 places (including 1 wheelchair place)	20.00
G0503	Lobby: seclusion room	5.50
G0712A	Telephone booth: wheelchair accessible	2.00
H1313-01A	Meeting room: 15 places (including 1 wheelchair place)	32.50
H1335-01	Group room: 9 places (including 1 wheelchair place)	16.00
H1335-02	Meeting room: multi-functional	16.00
J0232A	Reception: 2 person	11.00
J1255-01A	Waiting area: 10 places (including 1 wheelchair place)	15.00
J1255A	Waiting area: 5 places (including 1 wheelchair place)	9.00
J1414	Play area: 3 children	4.50
M0251-02	Office: 1 person	8.00
M0252-03	Office: 2 person	12.00
M0268-03	Administration area: continuous use: 6 workstations	30.00
M0278-03	Administration area: shared use: 6 workstations	31.50
M0330-02	Office: with informal meeting space; 1 workstation.	12.00
M0410-01	Photocoping/printing room	6.00
M0724-01	Interview room: 5 places (including 1 wheelchair place)	8.00
M0727-01	Interview room: 7 places (including 1 wheelchair place)	12.00
M1028	Office : with patient bank provision; 2 workstations	16.00
P0625A	Pantry/refreshment area	8.00
P0627A	Ward Pantry	12.00
P0711A	Mini kitchen	5.00
P0808A	Vending machine area	3.00
Q0129	Therapy kitchen	20.00
Q0512	Activity room	25.00
Q0526	Therapy room: wet activities; (arts and crafts)	16.00
Q0526-01	Therapy room: wet activities; (arts and crafts)	30.00
Q0617	Gymnasium	30.00
Q0619	Sports Hall	162.00
S0012A	Infant feeding room	6.00
S0015	Private room for drugs dispensing	8.00
S0045-01	Faith / Contemplation room	16.00
S0051	Family Visiting Room	16.00
T0151A	Touchdown base	2.00
T0155	Computer Bay	2.50
T0211A	Staff communications base: 2 places	11.00
T0540-01	Medicine store/preparation room	8.00
V0922-02	WC: Independent wheelchair user.	4.50
V1318	Shower room: single bed room en suite; mental health	3.00
V1320A	Shower room: independent wheelchair	7.50
V1325	Shower room: seclusion bedroom en-suite	4.50
V1736-01	Bathroom: assisted; with hoist storage	16.00
W0812-01	Store: records	13.00
W1226-01	Store: exercise equipment, activity area	24.00
W1405-01	Store: patients clothing and personal effects	15.00

ADB	List of Rooms	28/3/2022

Project:	ADB2020	Activity Database version 2020 © Copyright
Department:	03-01	Adult acute mental health units

Code	Description	Area (m²)
W1407A	Store: patients restricted property	2.00
W1585A	Store: general	12.00
W1594-02	Store: linen	3.00
W1594-03	Store: linen	6.00
X0104A	Treatment room; Elecrtoconvulsive therapy - ECT	16.50
X0145-07	Treatment room: double sided couch access	16.00
X0714-01	Sensory room	12.00
X0718	De-escalation room	12.00
Y0331A	Dirty utility room: bedpan processing	12.00
Y0523	Patient utility/laundry	10.00
Y0642A	Disposal hold: 1700 litres	8.00
Y1510A	Cleaners room	8.00

ADB	Room Data Sheet	B0512

Project:	ADB2020	Activity Database version 2020 © Copyright	
Department:	03-01	Adult acute mental health units	
Room:	B0512	Single Bedroom: mental health	
Room Number:		**Revision Date:**	30/09/2017

Activities:	1) Patient may undress/dress in vicinity of bed, with/without assistance. 2) Patient will receive therapeutic and clinical attention from healthcare staff. 3) Patient to sit in bed area for therapeutic, social, recreational purposes. 4) Displaying cards and pictures. 5) Controlled observation of bedroom and patient. 6) Personal belongings and clothing are stored.			
Personnel:	1 x Patient. Up to 2 x Staff.			
Planning Relationships:	En-suite sanitary facilities.			
Space Data:	**Area (m²):**	12.00	**Height (mm):**	2700

Notes:

Design notes:

Patient may be ambulant or semi ambulant.

Design solution notes:

Component list notes:

Mental Health patient use of space:

Where there is a significant risk of assault or self harm all furniture and fittings are required to be robust, anti ligature, prevent opportunities for concealment and meet infection control requirement while being therapeutic and dome tic in tyle The ri k management advisor should determine the level of requirements for each room to ensure that appropriate safe access is provided for service users and staff.

ADB	Room Environmental Data	B0512

Project:	ADB2020	Activity Database version 2020 © Copyright
Department:	03-01	Adult acute mental health units
Room:	B0512	Single Bedroom: mental health
Room Number:		**Revision Date:** 30/09/2017

TEMPERATURE AND VENTILATION	**Requirements**	**Notes**
Permissible Space Temperature Range(dry bulb) (degC):	18 – 28	
Heating Design Temperature (dry bulb)(degC):	22	
Minimum Air Changes (AC/hr):	6	
Ventilation Type:	S/E/N	
Pressure Relative to Adjoining Space:	-ve	
Supply Air: Final Filter Class	G4	
Permissible Relative Humidity Range (%):	Uncontrolled	
General Notes:		

LIGHTING		
Type Of Control:	S	
Daytime General Service Illuminance (Lux):	100	
Daytime Specific Service Illuminance (Lux):	200	Bedhead
Nighttime General Service Illuminance (Lux):	5	
Nighttime Specific Service Illuminance (Lux):	5	
Local Task Illuminance (Lux):	1000	Fixed examination Lamp
Colour Rendering Required:	Y	
Colour Rendering Required Characteristics (Ra):	80	
Unified Glare Rating Limit (UGRL):	19	
Emergency Escape Route Lighting Required:	Y	In accordance with BS 5266 and Health Technical Memorandums
Standby Lighting Grade - General Lighting:	B	
Standby Lighting Grade - Local Lighting:	A	
General Notes:		

RISK		
Clinical Risk Category:		
Non-clinical Business Continuity Risk Category:		
General Notes:		

NOISE		
Noise Intrusion (dB) 1hr day:	40	The LAmax,f dB noise limit applies only at night 23:00 to 07:00 hours.
Noise Intrusion (dB) 1hr night:	35	
Noise Intrusion (dB) f night:	45	
Maximum Internal Noise from M&E Services (NR):	30	Total noise of MEP services under normal operation across the range 63Hz to 4kHz inclusive.
Room Sound-insulation Parameters - Privacy:	Confidential	Reference to Table 3 of the Department of Health 'Acoustics: Technical design manual 4032:0.6:England'.
Room Sound-insulation Parameters - Noise Generation:	Typical	
Noise Sensitiviy:	Medium	
Sound-insulation Rating (dB D nT,w):		
General Notes:		

SAFETY/FIRE		
Maximum Surface Temperature (DegC):	43	
Domestic Hot Water Discharge Temperature (DegC):	41	
Maximum Cold Water Discharge Temperature (DegC):	<20	
General Notes:		
Type of Automatic Fire Detection:	Smoke	L1 in accordance with HTM
General Notes: L1		

ADB	Room Design Character	B0512

Project:	ADB2020	Activity Database version 2020 © Copyright
Department:	03-01	Adult acute mental health units
Room:	B0512	Single Bedroom: mental health
Room Number:		**Revision Date:** 30/09/2017

Walls:	Wall finishes to comply with Performance Requirements in HBN 00-10 Part B:Walls and Ceilings (2013) Wall finishes to be selected using the "Selection process for finishes" and "Types of finish by room space" included in HBN 00-10 Part B:Walls and Ceilings.
Floor:	Floor finishes to comply with Performance Requirements in HBN 00-10 Part A:Flooring (2013) Floor finishes to be selected using the "Selection process for finishes" and "Types of finish by room space" included in HBN 00-10 Part A:Flooring.
Ceiling:	Ceiling finishes to comply with Performance Requirements in HBN 00-10 Part B:Walls and Ceilings (2013) Ceiling finishes to be selected using the "Selection process for finishes" and "Types of finish by room space" included in HBN 00-10 Part B:Walls and Ceilings.
Doorsets:	Configuration, glazing, fire rating, security, etc. to be determined by Project Team. Refer to HBN 00 04 (2013) for effective clear door widths. 2 sets of doors: 1 x personnel, wheelchair & equipment access (1000mm); 1 x personnel access (1000mm) In Mental Health accommodation doorsets, including ironmongery, should comply with the requirements set out in HBN 03 01.
Windows:	Essential Clear glass with solar and privacy control. Designation to be validated against current documentation (HBN 00-10 Part D: Windows and associated hardware (2013)) In Mental Health accommodation windows and glazing should comply with the requirements set out in HBN 03-01.
Internal Glazing:	Desirable Project Option Clear with privacy control In Mental Health accommodation glazing should comply with the requirements set out in HBN 03 01
Hatch:	Not required
Notes:	All finishes selected must have an appropriate risk assessment to accompany the design decision. Infection Control must be consulted as described in HBN 00-10.

ADB	Schedule of Components by Room	B0512

Project: ADB2020 Activity Database version 2020 © Copyright
Department: 03-01 Adult acute mental health units
Room: B0512 Single Bedroom: mental health
Room Number: **Revision Date:** 30/09/2017

Quantity			Code	Description	Alt. Code	Grp
New	Trans	Total				
1		1	MIR032	MIRROR, wall mounted, hall stand with 2 no. anti-ligature coat hooks 1250H 600W 150D Mirror 900H 300W		1
2		2	OUT005	SOCKET outlet, switched, 13 amp, single		1
3		3	OUT010	SOCKET outlet, switched, 13 amp, twin		1
1		1	OUT121	SOCKET outlet, computer data, single		1
1		1	OUT131	SOCKET outlet data/voice, double.		1
1		1	OUT206	SOCKET outlet television aerial, single.		1
2		2	SWC082	SWITCH 5amp ac single pole, 2 way, wall mounted		1
1		1	THE010	THERMOSTAT, wall mounted		1
1		1	BOA082	BOARD, marker, whiteboard, dry-wipe, with pen holder, wall mounted, 900H 450W		2
1		1	CAB172	CABINET, bedside locker/table, size 450W 450H 450L		2
1		1	TVM003	TELEVISION monitor, colour, flat panel, large, wall mounted		2
1		1	BED051	BED, divan, size 900W 450H 1950L		3
1		1	CHA306	CHAIR, easy, low back, with open arms, upholstered, wipeable		3
1		1	DES031	DESK unit/dressing table, rectangular, 1200L 600D		3
1		1	WAR059	WARDROBE shelving unit, 500W 250D 740H		3
1		1	WAR060	WARDROBE unit and safe, 600W 500D		3

Written Statement

Andrew Peter Seymour Poplett

Introduction

1. My name is Andrew Peter Seymour Poplett and I am an Authorising Engineer (AE) and currently employed as an independent healthcare consultant, where my role is to provide input/expertise to health facilities in relation to ventilation and water. An AE acts as an independent professional adviser to the healthcare organisation. The AE should be appointed by the organisation with a brief to provide services in accordance with the relevant Health Technical Memorandum (HTM). The professional status and role required may vary in accordance with the specialist service being supported. The AE acts as assessor and makes recommendations for the appointment of Authorised Persons (APs), monitors the performance of the service, and provides an annual audit to the Designated Person (DP). To effectively carry out this role, particularly with regard to audit, the AE should remain independent of the operational structure of the healthcare organisation.

Experience and Expertise

2. I started my career as an apprentice engineer in 1985, working for an installation building services company. During my six years with the company I undertook various aspects of design, contract supervision and installation work across a range of industrial and healthcare building services projects. I was later made redundant from this role, however was successful in gaining employment within the NHS as an operational estates officer working at an acute district general hospital.

3. Within this role I began to specialise in ventilation within some of the critical units within that hospital as well as general estate management. Due to my role I moved between a number of NHS trusts, often as a result of trusts mergers. This led to me taking up the role of head of estates for a learning disabilities trust in Northumberland, which later merged to form the then largest mental health trust in England and I took up the role of head of property and planning. In 2010 an opportunity arose for me leave the NHS, which I chose to do and set myself up as an independent healthcare consultant. I now provide independent, impartial and bespoke consultancy services such as system auditing, personnel assessments and awareness training, compliance reviews and action planning to assist and guide clients through the maze of NHS, HSE guidelines, legislation and compliance. I act as an Authorising Engineer, and present my knowledge on subjects such as healthcare ventilation and water system management, service improvements and incident investigations.

4. During the last 12 years as a healthcare consultant, I have undertaken various support consultancy roles for a number of both private and NHS healthcare providers. Following the Health Technical Memoranda (HTM) 00 recognising the role of Authorising Engineer (AE) I began to practise as an AE for specialist ventilation and water, formally registering through IHEEM, which is the Institute of Healthcare Estates and Engineering Management. An Authorised Engineer is independent and appointed (normally by an NHS Trust or PFI Principle Service Provider) to take responsibility for effective management of safety guidance recommended by the Department of Health. Part of the AE role is to undertake an

annual audit of the operation of facilities. The role and remit of an AE is the same in both the HTM and SHTM.

5. I have been peer-reviewed and operate now as a registered AE for both specialist ventilation and for water separately. The peer review process (by the Institute of Healthcare Engineering & Estate Management (IHEEM)) provides a level of assurance that the AE has been assessed by their peers to work and act in a manner and standard which meets the institutes code of practice and conforms to the requirements of the HTM. This role keeps me busy and I currently practice as an independent AE for around 35 to 40 healthcare organisations, principally NHS trusts, but I also act on behalf of trusts for a number of private healthcare providers through Private Finance Inititive (PFI) or Local Improvement Finance Trust (LIFT) arrangements.

6. I'm an incorporated engineer registered with the Engineering Council and a full member of IHEEM. I'm an associate member of the Chartered Institute of Building Services Engineers, (CIBSE) and an affiliate member of the Institute of Fire Engineering. I am currently a committee member of the Northeast Regional IHEEM Committee and Chair of the national IHEEM ventilation technical platform. I am also a founder member of the Specialist Ventilation in Healthcare Society (SVH), which is an independent society that was set up by Malcolm Thomas, the President, who is the lead author of the previous and current ventilation Health Technical Memoranda (HTM), such as HTM 2025, HTM 03-01 2007, and lead author on HTM 03-01 2021. The SVH Society was formed in November 2014 with the aim of bringing together those who were practicing or wished to become Authorising Engineers (Ventilation) (AE(V)) or who have a more general interest in Ventilation in the Healthcare setting. At this time I am only a member of the SVH and have no details on the membership

but know it holds a register of practicing AEs and draws up competencies for prospective AEs. Those interested in ventilation for healthcare can also subscribe to association membership. A significant portion of the Society meetings is given over to discussing and clarifying interpretation of HTM 03-01 and other healthcare ventilation standards.

7. As a member of the SVH Society, I have been lead author and published various guidance or supplementary guidance documents on aspects of ventilation within a healthcare setting. I have also lead authored a couple of guidance notes and supplementary briefing notes for IHEEM's ventilation technical platform, and written numerous articles on ventilation-related issues and the management of ventilation for the Health Estates Journal, which is the magazine of IHEEM and healthcare engineering. Attached at Appendix 1is a summary overview of my work history and involvement with articles and guidance for the institutes and Societies to which I belong;

8. I have been asked to provide a written statement to the Scottish Hospitals Inquiry (SHI) with regards my knowledge and familiarity with the English guidance of the Health Technical Memoranda (HTM) 03-01, on which the Scottish guidance, Scottish Health Technical Memoranda (SHTM) 03-01, is based. I have also been asked to provide my knowledge and experience in design, installation, commissioning and validation of ventilation systems in hospitals. I have been provided with a list of questions from the SHI along with copies of SHTM 03-01. This statement seeks to answer the questions.

<u>General Principles of Hospital Ventilation</u>

9. I have been asked what scientific/professional disciplines underpin the knowledge relevant to healthcare ventilation. All of the principal engineering disciplines within hospitals are covered by a Health Technical Memoranda (HTM), of one variety or another. Generally speaking, there is an over arching HTM 00 standard which provides the framework for all other HTM's and then the engineering disciplines are divided into seven principal areas and an eighth that covers anything that the first seven do not. These areas would be decontamination of reusable medical equipment; medical gas pipeline systems; heating and ventilation; water; fire; electrical engineering; environmental and waste management issues, and then HTM 08 series covering anything that the previous ones don't, for example acoustic treatments, lifts and vertical/horizontal transportation systems and pneumatic tube systems. So ventilation in terms of its importance within healthcare has been covered by various HTMs or Health Building Notes (HBN) in various guises for well over 60 years. Guidance was developed as follows:

- Nuffield - Functions and Designs of Hospitals – 1955
- Operating Department - HBN26 – 1964
- Ventilation in Operating Suites - Lidwell – 1972
- Ventilation in Operating Departments, DV4 - 1983
- Ventilation in Healthcare Premises - HTM 2025 – 1994
- Specialised Ventilation for Healthcare premises – HTM 03-01 2007
- Specialised Ventilation for Healthcare premises – HTM 03-01 2021

The HBN's provide guidance under various clinical and non-specific engineering topics including infection prevention and control.

10. The majority of the evidence-based research specifically for ventilation is based on Dr Owen Lidwell's research paper dating back to 1972, which predominantly looked at the impact and effects of ventilation into hospital-acquired infections in operating theatres. This is where ventilation was identified as a contributing factor in reducing the risk of hospital-acquired infection during surgery. The Lidwell Report in June 1972 was the first published research and guidance into "Ventilation in Operation Suites" was issued by a joint working party from the Medical Research Council and DHSS. This report (frequently known as the Lidwell Report after the chairman of the joint working party), concluded that ventilation in theatres was required to ensure three key principles namely; bacteriological safety, the removal of anaesthetic gases, and comfort. The report still represents the principle research evidence for the current ventilation standards for theatre ventilation in the UK, although the recommendations and standards have been subject to development over time. Key elements of the research established the following standards;

- Bacteriological contamination concentrations (during surgical procedures) should not exceed 180 Colony Forming Units (CFU) per M^3 over any 5 minute period (clause 3.4). A CFU is a unit commonly used in microbiology to estimate the concentration of microorganisms/bacteria in a test sample.

- Airflow Must be maintained from clean to less clean areas even when a door is open (clause 4.3)

- The air change rate should not be less than 20 changes per hour (clause 4.4.4).

- Relative humidity should be controlled between 40 – 60% (clause 6.3.4).

These basic standards were further developed and refined into the first DHSS design guide for ventilation of operating departments issued in February 1983 and cross referenced in both HBN 26 and HTM 2025.

11. The primary driver for ventilating healthcare spaces, particularly within operating theatres, is the dilution of airborne contamination that is generated within the space because of surgical procedures or the people who are present. As well as dilution, you can use ventilation to isolate or control one area from another, so for an infectious patient, the aim is to try and ensure that the air which is being contaminated or potentially contaminated by that infection does not leak into surrounding areas.

12. The use of ventilation will also protect vulnerable immunocompromised or those patients who have virtually no immune system as a result of illness or treatment, so they are not exposed to potential airborne pathogen either from surrounding areas or indeed outside air. This patient group would include those receiving organ transplant, bone marrow transplant as part of their medical treatment. These patients have a reduced immune response so they do not reject the transplanted organ or material, but that makes them susceptible and vulnerable to pathogens that they otherwise might not be vulnerable to.

Role of Ventilation in hospital setting

13. I have been asked if I can explain what is the role and purpose of ventilation in a hospital setting. Ventilation is the provision of air which should be filtered where it needs to be filtered, and tempered into a space either to achieve minimum building regulation compliance for the dilution of contamination and an appropriate indoor air quality or, where certain clinical activities are being undertaken, to provide an

appropriate level of dilution for contamination that is potentially generated within the space to keep it at appropriate levels. The filtering of natural ventilation can be something as simple as a fly screen to prevent insects entering and landing on sterile instruments/areas. Any filtration however does add a degree of resistance to the airflow.

14. In providing an explanation of ventilation within healthcare setting I believe an understanding of contaminants will also assist in understanding why ventilation is important. Contaminants basically fall into three broad categories of airborne risk, these are viruses, bacteria and fungal spores. Each have their own unique properties but can be considered harmful to patients in some circumstances.

15. Viruses are generally very small, generally short-lived outside of the body, but not always, with COVID being an example. They transport or travel within a medium, such as water droplets or droplet nuclei expelled from a person.

16. Bacteria, of which there are many, some harmful, some not, can live for longer periods outside of the body, but they generally travel on something so the most typical example within healthcare is bacteria travelling on skin scales. With every human being constantly shedding skin scales they can carry bacteria on them and travel through an airborne route from one patient to another or from a member of staff to a patient.

17. The third contaminant is fungal spores, probably the longest-lived outside of the body. Anecdotal evidence has shown that aspergillus spores were found in the Egyptian tombs, which were sealed for 3,000 years and were successfully cultured having spent 3,000 years in a sealed chamber. Fungal spores can travel within the air and compared to bacteria and viruses they tend to be larger, but you are still

talking about particles that are between two and five microns typically in size. To put that in context, a human hair diameter is approximately 70 to 100 microns, so these are very small particles. Fungal spores can infect directly and travel for considerable distances in air with evidence suggesting spores can travel at least two miles from point of production.

18. If you have a particularly vulnerable patient who is neutropenic then it's not just about protecting them from the immediate environment of the hospital. For example if there is construction work ongoing around the hospital environment and the wind is in the wrong direction then a concentration of particles could be introduced to that patient environment. Many fungal spores and indeed many bacteria are ubiquitous in nature, they are found commonly all over the place. We probably breathe in aspergillus spores on a daily basis, and they have no impact on us whatsoever. However for certain clinical groups they can be a greater problem, from asthma attacks or respiratory disorder and for a very small minority of severely neutropenic or immunosuppressed patients, they can evolve into invasive aspergillus which can be fatal.

19. Ventilation is used to extract, and preferably at the point of production or generation, any contamination that is done as a result of clinical activity or indeed non-clinical activity. So, from the basics of a cooker hood extracting cooking fumes over the cooker it is extracted at the point of production rather than released into the general atmosphere, or within an operating theatre where point-of-use extraction is not practical or achievable, it provides a general dilution effect to the air from any contamination that's generated in the space.

20. My reminder for this is the phrase “the solution to pollution is dilution”, with the aim to make sure that there is dilution of any contaminant that’s developed within the space to a safe level, so it will not cause health issues for either the patient or indeed staff, visitors, or anybody else within the premises.

21. Ventilation can also be used to separate one area from another and generate clean air paths, so again linked to removing the contamination at the point of production or at least at a point where the contamination does not or is limited to travel through another person’s breathing zone. For example, if it is an endoscopic procedure and you have a patient with potential tuberculosis, part of the endoscopic procedure is to pass the camera down into the lung area and the patient has to cough to pass the camera into there. You don’t want the staff breathing in particles which that person expels as part of the cough if they have, or could have, TB. In this instance the recommendation and advice would be low-level extraction immediately behind the area where the patient is being treated. Any particulate that is expelled gets drawn away to low-level and extracted from the room, rather than passing through the staff breathing zone on its way to an extract grill in the ceiling.

22. Ventilation can also provide appropriate environmental room conditions, so temperatures and in some cases humidity control, which is where ventilation can become air conditioning. Air conditioning is the control of the environmental air within a space by temperature and humidity. So you can get recirculating air conditioning units because the units that you see mounted on the walls or in the ceilings, they don’t provide external fresh air but draw air from the room, heat it and cool it, and can adjust the humidity and put it back into the room. That can be necessary and essential for some clinical areas of activity, burns patients for example.

23. Humidity control is critically important because if you have a large wound site you would not want it to dry out or heal too quickly as it could cause subdermal scarring. So humidity control can be vital within certain clinical areas. In some previous versions of HTM humidity control was also critically important because of some of the anaesthetic agents that were used in sedation or anaesthesiology. These agents had the potential to be explosive or highly flammable and static electricity was a concern where electrical discharge through static discharge could act as an igniter for an explosive anaesthetic agent. Those anaesthetic agents are no longer used, and therefore humidity control, generally, for the control of static electricity, is less of an issue now than it used to be. So ventilation requirements change and evolve as clinical practice changes and evolves and indeed some of the medicines, some of the agents that are used within that clinical practice also change. Ventilation technologies and engineering solutions also change and develop over time.

Parameters of a ventilation system

24. I have been asked to explain what parameters a ventilation system can control, how they interact and their relation to patient safety and care. There are a number of parameters for healthcare ventilation systems. A system can have supply-only, extract-only, supply and extract ventilation and you can have natural ventilation, so it doesn't have to be forced. Opening a window does provide natural ventilation to a space and you can engineer natural ventilation to achieve air-change rates and effective dilution within a space. However, natural ventilation is influenced by the size of opening, the facing of the opening and any prevailing wind direction and most critically outside influencing factors such as temperature differential. If it is very cold outside and very warm inside then you will get more natural infiltration of

air through natural ventilation. If it is very warm outside and warm inside, you will tend to get less natural ventilation because of the thermodynamics of air but you will get natural ventilation.

25. I have been asked that given unpredictability of natural ventilation would there be areas of a hospital that it would not be appropriate. In certain circumstances natural ventilation may be the best option. I would not imagine anyone being comfortable with natural ventilation within a theatre setup but it has been done in the past. It could be used but it would depend on certain climatic conditions for it to work well. If using natural ventilation you would have to have a detailed understanding and assessment of the limitations and the factors that can influence it.

26. You can also get what's called "mixed-mode" ventilation, which is a combination of natural ventilation and some forced ventilation, or you can have full forced mechanical ventilation supply and extract via fans, which is normally ducted. All three groups can be appropriate in some settings within healthcare.

27. When we look at air change rate this is used to describe the volume of air that goes into the room or is extracted from a room to give a number of times that the volume of air within that space is changed per hour. This is a tailored measurement that is governed by the room size or dimensions. Within previous versions of HTM the ventilation rates were specified as litres per second. The problem is that litres per second into a very small room will give a very high air-change rate. If you measure the velocity of the air and you know the cross-sectional area that that velocity is achieving, that will give you a volume of air. That can be defined in a litres per second or metres cubed per hour. An air change rate is derived directly from the litres per second or metres cubed per hour divided by the room volume, because you

are getting air changes per hour. You cannot measure an air-change rate without measuring the volume-flow rate and the volume of the room. Air changes are used as a simplified method to identify the required dilution rate within a given space irrespective of its size.

28. There is a formula which I believe was established as part of Lidwell's original research, which is that one air change, provided that it is distributed evenly across the whole room, is likely or will remove 63 percent of any airborne contamination. Any subsequent air change will remove 63 percent of any residual air contamination. If you had a room with 100 particles of contamination the first air change would clear 63 percent, leaving 37 percent within the space, the second air change would clear 63 percent of that remaining 37, provided no additional contamination was released into the room and provided that the air distribution covered the whole room volume. This formula that is widely used and accepted nationally and subject to the proviso that no additional contaminants are introduced into the room. If it was introduced in the right-hand corner of the ceiling and extracted in the right-hand corner at low level, it is unlikely to achieve full-room air change because the air will short circuit and take the path of least resistance. Air-change rates are a shorthand method for summarising ventilation rates, but they have to be governed or looked at to make sure that they relate to whole-room distribution or dilution/scrubbing. I have been asked if Lidwell's formula and research on air change contamination is still used today and it is.

29. When we look at air pressure this is used to denote air movement from one space to another. So, if something is at a positive pressure, the air provided into the room is greater than the air extracted or leaking from the room and therefore you get a positive pressure. If you have more extract than supply you suck the air out of the

room, you don't necessarily provide air into the room so there's no supply air but air is drawn in through natural leakage, cracks under the doors and creates a negative pressure. Negative pressure is used to contain any airborne contaminant, that could be gaseous, that could be odour, or it could be particulate. Positive air pressure means that you provide that air into that space, and the air is pushed from clean to less clean spaces. And it's a phrase that is used on numerous occasions throughout the HTM, and it's part of this desired airflow path, making sure that air moves from clean to less clean areas to control any potential contaminant risk.

30. When you are seeking to maintain within a space either a positive, neutral or negative pressure it is a specified level of pressure cascade or pascal (a pascal is a standard unit of measurement for pressure) that is used to determine a degree of positivity or negativity. Neutral pressure is intended that if there are no openings and the room is in a normal state, it will not share air to the surrounding area or from the surrounding area into the room. However, that can be impacted and will be impacted when doors are opened because you will get temperature differential and in exactly the same way as natural ventilation can occur, you will get potential air either coming into or out of the space.

31. The pressure that you maintain within a space is governed not only by the ventilation rate but also the air permeability of that structure. For example you will never be able to pressurise a colander as it's full of holes, so it doesn't matter how much air you put in it, you are unlikely to ever achieve a pressure because it will balance naturally through all of the openings. The air permeability also ensures the desired clean air path. The air is drawn out from the area where you want it drawn out from and it doesn't leak out of other surrounding areas. It can be linked to areas such as fire strategy and smoke strategy as well to ensure that areas stay isolated

from another area in the event of smoke transmission. So air permeability is the test method that we use to ensure that spaces can achieve a desired pressure cascade, be that positive or negative.

32. As you introduce air to a space or extract from a space you generate a pressure profile, either positive or negative. If there was no ventilation in a room it would be considered at neutral pressure. If you introduce supply air and don't have forced extract air you will generate a positive pressure within that room provided that room doesn't have too many leaks. If the door is open then it won't create a positive pressure because the air will stabilise between the point where it was introduced and the surrounding area. That's the interaction between pressure and air change, the amount of air that you put in and the amount of air you extract out, linked to the integrity of the construction of the room, the air permeability, will determine the pressure cascade that can be achieved.

33. On looking at air filtration rate this is generally considered to be based upon a desired internal air quality, driven by the surrounding external air quality of the specific geographic area of the hospital. If the location of a hospital is inner city centre with large volumes of traffic, the external air quality is likely to be poorer than if you have a hospital out in the countryside. If you have a hospital sited by a coast or subject to high salt levels, coastal environment, then that again can impact the level and quality of filtration that you have in your system to provide the required indoor air quality of a space.

34. There are times where the filtration is there to protect the equipment, including the air handling equipment. So the initial filter that is fitted, the pre-filter as it is normally called or the return-air filter on an extract system, is generally there to

protect the mechanical engineering device from contamination and blockage. The final filters are then used to provide a finer grade of filteration to a desired air quality that the patient requires. In cases where a patient is neutropenic and susceptible to ubiquitous fungal spores in the air, you would filter to a higher grade standard. If you are manufacturing pharmaceuticals within an aseptic pharmacy suite then your concerns would be that the drugs are not contaminated by any air within the area, and that is where the use of High Efficiency Particulate Air (HEPA) filters or ultra-filters are brought into effect. They filter down to a far finer degree to keep particles out as much as practically possible and can be used in any setting where particulate size or concentration is critical.

35. The ventilation parameters are co-dependent and interlinked and within a healthcare setting they are fundamental in infection prevention control, fire strategy and smoke transmission. The dilution effect of air reduces the concentration of contaminants within the space, depending upon the patient, whether they are infectious or at risk of infection. The pressure cascade is used to provide assurance that there is a positive pressured space so airborne contamination can't enter, or it's a negative pressure space so contamination can't leave through uncontrolled means.

36. If you changed one of the supply or extract air-change rates without adjusting the other proportionally, you would almost certainly have an impact on the pressure cascade because if you put less air in but drew more air out, you could turn an area from positive pressure to negative pressure.

37. When looking at a room that has both supply and extract ventilation and you adjust one and not the other, then you will definitely impact the pressure cascade of that room. It won't necessarily reverse it as it depends upon the scale of the change,

but it will have a more definitive impact. The air-change rate is derived from either the supply or the extract. So if a room has 10 air changes and you wanted positive pressure, and you had both supply and extract within the room, you could put in 10 supply air changes and extract out 8 air changes. That would give you a net positive pressure compared to adjacent areas. However, if you had 10 extract air changes and 8 supply air changes, you would still only have 10 air changes, but you would extract 10 air changes, 8 of them from the supply air that you'd introduced and two air change equivalents through natural leakage into the room. An air-change rate isn't supply plus extract, it's whichever one is the greater that gives you the air change for the room.

Setting Parameters for rooms

38. I have been asked to explain what ventilation parameters are set for specific areas or rooms within a hospital. The HTM 03-01 2021 specifies some areas with recommended ventilation rates within chapter 8 and there is a table listed in Appendix 2 of the document to be used as a guidance for typical spaces. This table shows the air change rate, pressure cascade, filtration grade that's needed, temperature is specified and then there are some additional comments and advisory notes where supplementary guidance may need to be sought. All of these have a fundamental role in patient care and safety., as highlighted in Chapter 2 of Part A HTM 03-01. They were selected because they reflect the typical rooms that are detailed in Chapter 8 of Part A HTM 03-01 and are typical to what you will find in a vast majority of acute hospital settings. The whole of HTM 03-01 is written specifically for acute care medicine but it doesn't require an A&E department to be an acute care facility. If it's a surgical centre it would need to comply to 03-01 because of the operating theatres, critical care, and ward areas. For places like a

dental practice, or GP, or mental health facility, or a care home, or one of the other myriad of healthcare providers, you need to assess the appropriateness of applying HTM 03-01 to the clinical risk profile. Some of them will be similar, some of them will be markedly different.

39. For example an operating theatre will typically require at least 22 air changes per hour, however the final air change rate is derived from the design and what is within the room. If you have a lot of equipment in that room that generates an awful lot of heat, such as robotics, CT scanners, imaging devices then it may be that the air-change rate needs to be considerably higher. It is driven by the minimum air-change rate for infection control, which according to HTM 03-01 is at 22, but it may be that it requires 35 because of the heat gains from within the space.

40. If you have a clinical activity which is not defined within the HTM, what it should be possible to do is for the clinical team to look at similar patient environments and determine the correct minimum level of ventilation requirements. So, for example, there is no renal dialysis unit listed within chapter 8 of HTM, however, there is a listing for invasive treatment rooms. The hospitals will have rooms whereby, clinically, a comparison should be able to be made that if it is an invasive procedure that would typically be done in a treatment room then it would 10 air changes and 10 pascal positive air pressure for the right environment for a renal dialysis room. Ultimately that would be an infection prevention discussion between IPC, Clinicians, and Microbiologists with advice sought from engineers in a collaborative process, discussing what was going to be done in the room, any chemical a:gents or anaesthetising being used. All of these play a factor into the right level of ventilation for that space.

41. The decisions taken on setting these parameters would be driven by the clinical activity within that space. If you have a critical care area then you will have more vulnerable patients than those on a typical medical ward or a daycase ward or another type of patient environment. It's also about the length of time and duration that a patient, or indeed a member of staff, would be exposed to a potential risk. Within an Outpatient department the patient exposure is very limited due to the short duration in which patients are seen and treated. However an in-patient may be in for at least 24 hours, if not longer, so their potential exposure is over a much more extended period and therefore potentially requires different ventilation rates. It's also about the staff exposure, for example those working within dentistry probably see a different patient every 20 minutes but the dentist and nurse are likely to be in the same room for 8 hours, exposed to a number of patients. If these patients all have COVID, then the level of risk to the individual staff working in there is that much higher. The levels of contamination are potentially more concentrated depending upon the air-change rate, but also it's the duration of exposure. That's where legislation such as Control of Substances Hazardous to Health (COSHH) regulations and the work exposure limits, either instantaneous or over an eight-hour shift period, will determine what level of concentration you are trying to manage and that will derive any ventilation rates.

Key Components in Hospital ventilation system (mechanical or forced)

42. I have been asked to describe the key components of a hospital ventilation system and how they operate/control the parameters of air pressure, air changes, temperature, filtration, humidity and others relevant to patient safety and care. When people talk about air-handling unit or a fan, it's actually made up of a lot of separate components, all of which have a role to play. The order in which those components

are positioned is critical to the efficiency of the unit and the condition of the air that you're trying to achieve.

43. The ventilation system starts with the outside air and from where you draw the air in from. It needs to be identified that the air being drawn in from outside isn't providing a source of potential contamination. Therefore even before you get to the air intake louvre, you don't want it drawing in air that's been exhausted immediately from another area. If you have an infectious disease unit and that's exhausting the air then you don't want a theatre air intake immediately beside it as this will draw in anything that's been removed from a potentially infectious area into a theatre air intake.

44. You also don't want vegetation, wildlife or anything else in the immediate area of an air intake because that will host fungal spores and bacteria and will act as a potential source of contamination. The air intake, which is normally a weather-proofed louvre preventing ingress of water, is fitted with a vermin screen to prevent large contamination entering in, such as feathers, vermin, rodents, birds. That then delivers the outside air into an intake plenum or ductwork section prior to the AHU which normally has an automatic shut-off damper, which ensures that if the air handling unit is shut down for any reason the damper will automatically close to make sure that external air pressure or wind does not blow through the unit.

45. Following on from this you have what is described as a fog or frost coil, which is an un-finned heating element designed to ensure that the air entering the air-handling unit does not carry an unnecessary level of moisture which could adversely affect the pre or primary filter. You then have a coarse-grade filter, which filters out large contaminant that's made it through the initial vermin screen but prevents and

protect the equipment of the air-handling plant. This can also be fitted with an acoustic attenuator to cut down noise transmission from the air-handling unit back out into the atmosphere.

46. The next component is a fan unit, which traditionally would been belt and pulley, however under the new HTM, a direct-drive fan is fitted which draws the air into the air intake and directs it to the rest of the handling plant. Following this is a heat-recovery device whereby you recover the energy (either heating or cooling) that was taken from the exhaust air and you put it into to preheat or to precool the air. This facilitates the transfer of energy so you are not wasting all of the energy from the clinical treatment space, throwing it outside and treating raw outside air from external conditions. This is now governed by the European standards and international law, a requirement that air-handling units can't be provided without certain energy efficiency being achieved within the heat-recovery device (EU 1253 (ERP regulations) and EN 1886 (January 2008).

47. Once you've gone through the heat recovery element, you then go through a cooling coil. This will chill the air, but also, as a result of this it will naturally also increase the relative humidity of the air and condense moisture out from it. You will normally have an eliminator plate to stop moisture being carried in the air current beyond the drip tray, which is there to collect the moisture and safely drain it out of the air-handling unit. You then have a re-heater coil which reheats the air. So, if you've cooled it and you've increased the relative humidity and to control this you reheat and dry the air out. If you have to control the relative humidity, you can have a humidifier steam lance where you inject steam in to re-humidify the air without adjusting its temperature. It then goes through a final filter, which is the final finer-grade filter, another automatic shut off damper so it doesn't get backdrafts from the

distribution ductwork, and you can close it off to work on the unit safely. You will then have a distribution attenuator which reduces noise transmission from the unit onto a ductwork distribution system, which delivers it to the area where you are providing air to.

48. If you want separate temperature controls within given areas you can also have trimmer batteries, which can heat or cool to further condition the air if there is a requirement for separate environmental control temperatures within one specific space. The air will then get delivered through grilles into the room. If it's an Ultra Clean Ventilation (UCV) operating theatre, this would have a secondary ventilation recirculation HEPA, with current HTM guidelines stipulating that this should achieve 22 air changes per hour of outside 'fresh' air.

49. From the air being introduced to the room through the supply grilles, you would then have extract grilles, sometimes within the space or sometimes in adjacent spaces depending upon the pressure profile that you're trying to achieve. Those extract grilles go through ductwork back up to the air-handling plant and a coarse filter to take out any coarse particulate contamination that's been generated within the space, such as clothing, skin scales, etc. It will then go through an extract fan and another heat-recovery device, where the energy is transferred from the extract into the supply. Finally it goes through a further attenuator to an exhaust grille, which will be protected with a vermin screen to make sure rats, mice, foxes, birds cannot access into it against the flow of air, from where it is then discharged.

Challenges / Constraints / Compromises

50. Through any large healthcare project there will be challenges and compromises, however it is possible to achieve a known state of ventilation within a

hospital, which should be verified or subject to annual verification of performance, so there is a means to make sure that that performance is maintained. One of the greatest challenges within healthcare from a personal opinion is that hospitals are built to last 50 to 100 years, yet clinical practice and procedures evolve and change every five to seven years. Due to the intensity or nature of the clinical activity they move around within the current space or the nature of the clinical activity is changed and therefore it potentially impacts on ventilation. We rarely reassess on every clinical change the implications to ventilation. For example if a ward was designed as a geriatric ward and its then changed to a respiratory ward, the patient vulnerability profile changes and therefore the ventilation strategy for that area is, in my experience, rarely fully reassessed.

51. One of the silver linings of the Covid pandemic was that it highlighted the requirement for ventilation strategy when moving patients to other wards. Its unlikely to happen now but historically it did. Modifying ventilation within a healthcare setting can be extremely expensive and invasive with ceilings being taken down, moving duct work, it's a huge undertaking. However in the last two years I have noticed through the NHS trusts that I have worked with they look at and consider ventilation far more closely than they did in 2018. In my experience if you are dealing with a particular vulnerable patient group then ventilation is looked at. However if the patient group is non-vulnerable then historically it has been put in the too difficult or too expensive column and possibly overlooked or not given right level of priority.

52. Ventilation is also the largest building service that's installed physically. Ducts are very big and bulky, they take up a lot of space and normally concealed within ceiling voids or loft spaces. They are extremely disruptive to change, modify and adapt. If you suddenly need three extra electrical sockets then it's relatively cheap

and not too disruptive to install on an electrical circuit as long as that it doesn't exceed its maximum working capacity. To change a ventilation system is considerably more challenging and costly.

53. I believe that the pandemic over the last two years highlighted these issues very well. We suddenly had three patient streams where we had patients who we knew had COVID, patients who we knew didn't have COVID and those patients that we didn't know the status of on the point of admission. From a clinical point of view you would want to isolate known COVID positive patients from non-COVID positive patients. This can be achieved through pressure differential and making sure those positive with infection were under a negative pressure cascade, in the same way as someone who was infection free would be under a positive pressure so they wouldn't become infected. If you had three people, positive with COVID, you still wouldn't want them exposed to one another, certainly in the early days, as we were unclear as to whether the severity of illness was directly linked to the level of exposure to the virus.

54. This is where the working exposure limit and viral load came into play. Normally you would want to know what you're trying to achieve and know whether you are protecting the patient from the environment and other patients and staff, or whether you are protecting the environment, staff and other patients from that patient. Frequently wards move around, ICUs expand and contract and they all have different ventilation requirements and this makes it extremely challenging to sometimes practically change in an operational hospital environment.

55. One of the most common areas where compromise or derogation to the standards can be required is if you are modifying or adjusting an existing healthcare

environment. Unlike a new project you are not starting with a blank sheet of paper, you're starting with the confines and restrictions of an existing building envelope or an existing plan brief. Working in this area can be challenging but in my experience I have not had a time when patient safety has been compromised because that is sacrosanct. What can be compromised at times is the location that you would fit an air-handling unit or the type of air-handling unit that you would fit. You cannot compromise on energy recovery because that is now a statutory obligation, but you could compromise on air conditioning or humidification. There are times where you can compromise on location and the practical aspects and configuration of some plant, but in my experience you do not compromise performance which could have an impact on patient care.

Development of Ventilation System

56. I have been asked if I have knowledge or experience in the key stages in the development of a hospital ventilation system. This something that I have been involved with throughout my career in different roles and stages, however as an AE(V) it is a central element of the service which I support and advise on. The ventilation strategy for a healthcare installation starts with the clinical brief or pre-design stage for what the hospital or healthcare facility is intended to do. This would normally be developed by the design team with direct involvement from the clinical and IPC teams with the support of the AE(V) if considered appropriate. Once you have that information, you have an idea of the floorplan or a design output specification that the commissioning body, normally in England an NHS trust, have got as the basis of a business case. This output or performance specification is then used by the design team to undertake the design process.

57. From an early stage ventilation is typically identified as being important, base conformance to building regulation requirements and supplementary guidance up to HTM compliance. The guidance within the HTM and the HBNs recommend which areas need dedicated ventilation and which areas can be fed from general ventilation areas, such as noncritical systems. It should also identify, as the design develops, areas where there might be specific requirements for isolation facilities, local exhaust ventilation systems (LEV), or other elements of critical ventilation. This will assist in creating the ventilation strategy, which should be provided to the design team who develop it based on the requirements from the clinical output specifications. This is then used as a basis of the design moving forwards and should be referred back to at critical points of the design development process, up to final sign off, ensuring it's fully compliant to HTMs, HBNs, and all of the other guidance as stated.

58. The standards are set when agreeing the ventilation strategy and are used as the basis for design. The ventilation strategy and subsequent detailed design are then used to commission the system against the design and its then validated back against the original strategy and agreed design performances to ensure that the design has achieved the standards that they were based upon. That way the NHS trust know what it's getting, how much it's going to cost, and that is the basis that the project is then delivered against.

59. The project will then be commissioned to make sure that all of the individual engineering elements work as they have been designed. The commissioning process is covered in HTM 03-01 2021 under clause 11.1: **"**Commissioning is the process of advancing a system from physical completion to an operating condition. It will normally be carried out by specialist commissioning contractors working in conjunction with equipment installers. Commissioning of the ventilation system will

normally be the responsibility of the main or mechanical contractor who should coordinate the process". This is supplemented in clause 11.2: **"**Commissioning is often subdivided into sections (for example, air handling unit, automatic controls, air side balance, building fabric and fittings). Each section may be commissioned by its specialist installer, and they are often accepted in isolation". It will then be independently validated against the original ventilation strategy, acknowledging any accepted derogation, ensuring that all of the building engineering services interact with one another as they should. This is outlined in HTM 03-01 2021 in chapter 12 under the following clauses:

12.1 All new and refurbished ventilation systems should be independently validated prior to acceptance by the client.

12.2 Validation differs from commissioning in that its purpose is to look at the complete installation from air intake to extract discharge and assess its "fitness for purpose as a whole". This involves examining the fabric of the building being served by the system and inspecting the ventilation equipment fitted as well as measuring the actual ventilation performance, checking against the HTMs. Validation is not a snagging exercise; see the Note after paragraph 12.30.

12.3 Validation is a process of proving that the system in its entirety is fit for purpose and achieves the operating performance originally specified. It will normally be a condition of contract that "The system will be acceptable to the client if at the time of validation, it is considered fit for purpose and will only require routine maintenance in order to remain so for its projected life."

and it can be handed over and put into clinical use.

60. Following on from the commission it would be subject to annual verification for critical ventilation systems to make sure that it continues to operate to an agreed performance level all the way up to when it gets decommissioned. Annual verification is within part B of the HTM, and it is effectively an MOT to ensure that any plant is still performing as it should, and the rooms are performing as they should, to agreed levels as specified within the HTM.

61. For example, an operating theatre should achieve 22 air changes within that clinical space. Every year it will be checked to ensure that it is still providing 22 air changes or an acceptable percentage thereof which, in operating theatres in 03-01 2021, is 80 percent or a minimum of 18 air changes per hour within that space.

62. These levels date back to the original research that Owen Lidwell did which identified the hospital-acquired infection risk increases with air changes during surgery of below 16 to 17 air changes. Depending upon the nature of the operation, depending upon the nature of the clinical activity, and, critically, depending upon the number of people within that space, governs the amount of potential contamination that could be released into that space and therefore that has a direct correlation and impact to the required ventilation rates.

63. At every stage of the process, particularly at the design stage there are frequent discussions about where savings could be made or to duplicate areas served by a single AHU plant, rather than having one area by one AHU plant, value engineering as it's commonly termed. The consequences to resilience and patient safety are considered fundamental at those stages. Some derogations can be driven by economic consideration, but generally, in my experience, they are never put ahead of patient safety.

64. I have been asked if there were an error and a multi-bed room within a critical care area was incorrectly listed as requiring four air changes per hour, would it be expected that it would be identified and addressed through the life of the project. I would like to think so, but it's very difficult to judge on that as it depends on how it's recorded, how often it's referred back to, if it has been signed off and then never looked at again until it comes around to validation. It is possible that it could reach the validation stage with the error not picked up, however I would not expect it to get through validation though as the validator should be sufficiently competent to recognise that's a major deviation and ask why it deviates significantly from the standard. That is one of the reasons why we validate, as it's that final check before we admit a patient in there. There are certain things that need to be checked and double checked. The design of hospitals should be one of those things that are checked and double checked.

Technical Guidance and HTM

65. Throughout England and Wales there are a number of technical guidance documents produced by NHS England and NHS Improvement (NHSEI). These documents include the following:

> Health Technical Memoranda 03-01 (HTM), which provides guidance for anyone involved in the design, installation or operation of healthcare ventilation. It is primarily written by engineers for engineers however it is increasingly contributed to with each production involving infection prevention control specialists. Manufacturers are involved within it and contractors who are used to maintain and verify and validate systems. It's primary focus is an

engineering technical document, however it encompasses a far broader church and a far broader church is involved in its production.

Health Facilities Notes (HFN) and Health Building Notes (HBN), which provides guidance on infection prevention and control, cleaning services frameworks, security, and health and safety and provides a best practice guidance on the design and planning of new healthcare buildings and on the adaptation or extension of existing facilities.

Health Planning Notes (HPN), which provides a comprehensive guidance on planning for in-patient facilities for both adults and children, accident and emergency facilities, and isolation facilities.

Health Technical Notes (HTN), which provides a comprehensive guidance on a range of healthcare specific standards, policies and current best practice. Many of these documents can provide guidance on aspects which impact ventilation.

66. In regards updates of these publications I believe that typically it would be around a ten-year cycle, so what's written is likely to be current for ten years. If a major change happened then an addendum would be issued. For example HTM 04-01 was originally published in two parts and covers use of water. There was an issue with Pseudomonas in Belfast and supplementary guidance was produced, resulting in HTM 04-01 addendum for Pseudomonas being published. When HTM 04-01 was later reviewed and rewritten it became a three-part document, not a two part with an addendum. Now it is possible, and I do not know this for certain but it is possible that as a result of COVID there may be supplementary guidance issued relating to

ventilation. If that is the case then it is likely to be issued as a supplement to HTM 03-01 2021. So part A and part B will be retained but supplement issued for a specific area such as, for example, COVID. The next time that 03-01 would be reviewed and rewritten, then it would be incorporated into the main body of the guidance, if appropriate at that time.

67. There are a number of reasons why the guidance is replaced or updated. This could be due to changing technology and different equipment being available and different clinical approaches. The other major element for change is the need to address energy usage and the environmental impact, given the statutory obligations of climate crisis and to reflect lessons learned over the preceding 10/12 years of HTM 03-01 2007. When you look at the documentation in HTM 2025, it was more prescriptive in its installation standards and so forth. Performance issues and some issues within health care ventilation encouraged a refocus on being more prescriptive on minimum installation standards. Links to climate change issues such as the need to leak test ventilation systems to a higher standard than industry would typically use.

68. The guide does not cover every aspect of clinical activity but the document has adopted and acknowledged new clinical changes in clinical practice such as hybrid and robotic theatres. There has been no change to the minimum standards because it's not yet universal, so the standards have to be written for the typical usage. But as emerging technologies come through they may have an impact on ventilation strategy.

69. Further guidance on ventilation has also been published by Specialist Ventilation in Healthcare Society (SVH), IHEEM and CIBSE. A number of these

documents are highlighted in my CV at Appendix 1. There are other guidance documents relating to ventilation but the healthcare specific guidance is, as far as I'm aware, limited to a relatively small group of individuals who are either generally involved in the drafting of HTM or are members of societies or institutes that help support it.

70. I have been asked which groups and individuals the HTMs are aimed and it is primarily used by designers and healthcare organisations who have responsibility for provision of and maintenance of healthcare ventilation, specifically, HTM 03-01. All HTMs are aimed at designers and operators, which is why you'll find that in the majority of the HTMs they're divided into two parts, part A and part B. Part A is about the concept, the design, the installation, the commissioning and the validation. It is not retrospective and applies to all new or refurbishment projects from the date of publication. In my experience if a project has reached a point of contract signing (i.e an approved business case, fully designed, tendered and contract awarded), then the standard at the time of signing would be used as the basis for the project. However it may be considered appropriate to review the changes to see if they can be adopted after this time, although it will genrally be a contractural issue. There is no hard and fast rule to the best of my knowledge and it is normal that any revision is widely consulted on prior to publication and the impacts can be assessed on this basis if considered appropriate by the contracting authority/client. Part B of the HTM is about the operational, maintenance and the ongoing testing and that is written and designed to apply to all ventilation systems, irrespective of the standard to which they were designed.

71. There are still contracts particularly within legacy PFI contracts where the design has been done according to HTM 2025 and they will work to the criteria of

HTM 2025. If they had read HTM 03-01 2007, and the latest version in 2021, it is in many respects more relaxed than the original HTM 2025. The design standard isn't retrospective anyway. When HTM 03-01 2021 was published, if a system had been designed to 2025, it would still comply. To give you an example, within HTM 2025, theatres were designed to deliver 20 air changes per hour. They had to be tested each year and verified each year and still had to achieve 20 air changes. However, under HTM 03-01 2007 the design of a theatre air change rate was increased from 20 to 25, but under verification and in use, there was a 25 per cent tolerance allowed on that where the theatre was still considered to be compliant and safe to use. So, you could have fewer air changes and still be compliant under 2007 than you would've been under 2025 as there was no tolerance applied then. Under HTM 03-01 2021, the air change rate in theatres has been lowered to 22 air changes with an 80 per cent tolerance, with a minimum performance of 18 air changes.

72. The acceptable performance threshold has been lowered but it's still above what Lidwell's research demonstrated in 1972, that 17 air changes was the cut-off point and that there would be an increase in infection if it was below that. There is still a safety margin, it's just a smaller safety margin, however this is as a result of trying to conserve energy and not over-engineer.

73. I have been asked if compliance with HTM guidance is mandatory. This depends upon the interpretation of the word mandatory and is also dependent on an element of interpretation of the guidance and standards. They can be derogated from provided you record why and the reasons and this can be evidenced and supported. As I understand it the Health and Social Care Act, which is legislative, requires health care providers to conform to various guidance documents and one of those guidance documents, which is I believe expressly stated, are HTMs and

HBNs. So to comply with the Health and Social Care Act you are required to comply to HTMs and HBNs. HTM03-01 - 2021 refers to the “Health and Social Care Act” as placing a duty of care on healthcare providers (para 1.2). It also refers to more particularised duties set out in the Health and Social Care Act 2008 (Regulated Activities) Regulations 2014 (para 3.8 ff)).

74. In all practical sense my belief and interpretation is that the HTMs should be viewed as an approved code of practice and as such should be deemed in elements as minimum standards. In other elements which could be derogated subject to sound recording and reasoning it could also be seen as best practice. It's not black and white and I believe that organisations who choose to derogate from the HTMs have an increased risk of potentially compromising patient outcomes, staff/visitor safety in addition to increased risk of legal, civil and reputational damage/harm.

Derogations

75. I have been asked if its ever acceptable to depart from the terms of the HTMs. From my own point of view I wouldn't depart from any element that had a direct impact on patient, visitor or staff safety, which I would consider to be an absolute red line. If it was a compromise on resilience or quality of installation or engineering, then it would have to be fully documented as to why the derogation was necessary and what justification could be provided for that. I generally as a rule do not accept pure financial reasoning as an acceptable basis for derogation. If it were very time limited or a crisis then there may be acceptable pressures where the risks associated with not providing the service is greater than the risks associated with providing a derogated service. However it should never impact on patient or staff safety and is a judgement call that needs to be taken by a multidisciplinary informed

group, it's not down to an individual. An engineer can't decide to derogate on an engineering topic in isolation, they must consider what potential implications that engineering derogation may have from a clinical perspective or an Infection Prevention Control perspective.

76. The new HTM 03-01 2021 is explicit on this and no derogation should be made by an individual. It must be made as a collective discussion, collective responsibility through the Ventilation Safety Group. The HTM 03-01 2007 version did not include a requirement for a Ventilation Safety Group, so it was silent on derogation in terms of approval. The implication, if you read the whole document, is that you would have to seek the approval of all interested parties, you cannot derogate in isolation and it would need to have Clinical Director or Director of Infection Prevention Control to sign off on it. As an Authorising Engineer one of my remits is to steer people in making sure that all aspects are considered when considering a derogation.

77. This would also apply to the parameters within ventilation, such as air change rates, air pressure and open and closed door protection. There needs to be a minimum volume of air applied to a room if it's got a single door and more air if it has a double door. This ensures that when that door is opened, if the airflow is designed to be from this room to the next room, i.e. positive pressure, it will remain that way when the door is opened and someone passes through it and then closes the door behind them. For example you could have a room with 20 air changes, but only 100 litres a second going into it. If that had double doors then there wouldn't be sufficient airflow to make sure when you open the double doors air didn't travel from the surrounding area into that room.

78. If you choose to derogate or not comply with an HTM and it can be demonstrated that as a result it has compromised patient safety, then I believe you would be in breach of the Health and Social Care Act, which is the umbrella the Regulations come under, so if you breach the regulations then you breach the Act. The directors of an organisation would potentially face corporate manslaughter charges and the associated penalties of that. If you have breached the Health and Safety at Work Act or any of the subsequent regulations, COSHH regulations, workplace regulations, then that would also be a breach and would carry the penalties associated with a material breach of the Health and Safety at Work Act.

79. If you had not complied with one of the more subtle areas of HTM, for example the new HTM 2021 stipulates that within a multi storey building, the lift should go all the way up to the plant room level. If that was derogated, so the lift stopped at the top occupied level and didn't go up to the plant room level, then it would be a breach of HTM. However, if it was adequately recorded and derogated and an adequate explanation as to why it was done, such as planning restrictions, or costs and you could demonstrate that safe access for maintenance staff, plant and equipment replacement could be achieved by another route, I don't believe that would be a breach of law. It would technically be a derogation against the HTM however ay future validation would note the agreed derogation and if it did not affect patient safety then it could be potentially accepted.

80. There are still a number of older hospitals, Victorian buildings which are often described as Nightingale wards, with windows that open on both sides of the ward, which normally didn’t have any forced mechanical ventilation. When it comes to natural ventilation, it is pretty much an ideal design because you can open the upper windows on one side, the lower windows at the other and you will get a good cross

flow of air across the ward, which is the most efficient natural ventilation through that design. However with that layout what you don't have is any privacy and dignity, there is no separation of patients other than by curtains and social distancing of bed spacing. The sources of infection can be far higher, but the opportunity to naturally ventilate, if you ignore patient dignity and privacy and all of the other infection risk, is probably better in the Nightingale Hospitals in some respects.

81. As we move towards a more modern approach and layout of wards you will see individual bedrooms with private en-suites. This significantly improves the patient experience and many aspects of healthcare, but because you now have multiple smaller areas you make ventilating the space far more challenging to achieve.

82. There are always difficulties whenever you are working within an older existing building envelope as you've gone from a potentially naturally ventilated solution to requiring a forced ventilation. The services are constrained by the physical space that you have available and unless you turn the hospital into something like the Pompidou Centre, running all the services on the outside, you are limited by the space available and ceiling heights of an existing healthcare facility.

83. Another significant issue with older hospitals is maintenance access to plant areas. We don't want plant, particularly mechanical plant, that requires inspection and maintenance in the patient area, because any maintenance team would then be working within a clinical area, which could cause clinical disruption and potential infection risk. I wouldn’t want those services above the ceilings either because that would equally involve taking out ceiling tiles to gain access to do maintenance. The ideal solution would be to maintain the plant in a plant room environment on the floor

above the area that it serves. No matter the age of the building you cannot derogate the minimum legal standards.

84. The difficulty you face is space, particularly within urban areas, as you can't have a hospital that's only two stories tall, the ground floor being the patient space and the first floor all being plant. It would be an ideal layout but expensive and a hospital like that could require a very large say 100-acre site. So due to existing healthcare facilities, which are often of a vertical design, you end up with lots of floors of clinical practice, service ducts and distribution infrastructure throughout the building. All of the plant, whether that's the boilers at low-level or the air handling plant at roof level are usually contained within an area that can be accessed by maintenance staff, without needing to enter the clinical environment.

85. What tends to happen is that the clinical areas are limited by the number of bays or beds they can accommodate, because the amount of space that has to be taken up by plant. Anything is possible, but it can take extremely complex engineering solutions and it may be that instead of having an eight-bedded ICU, you end up having a four-bedded ICU. At which point you either need twice the area to accommodate the same number of beds, or it financially doesn't economically make sense. It is possible to do but in my experience I have never been asked to compromise patient safety issues on the basis of achieving a bed capacity.

86. Working within an existing envelope of a building significantly increases the challenges. Starting with a blank sheet of paper and a green field site you can design as much as anything, with departmental interactions, because one of the biggest issues with healthcare isn't just having the right spaces, but it's having the right adjacencies. So ideally your recovery area needs to be beside your theatres

that need to lead on to ICU, which in turn goes to HDU and then to general wards, with the patient journey dictating the interactions. All the diagnostic and imaging equipment needs to be beside accident and emergency to diagnose patients and know which part of the health stream to put them into. That's when the strategic planning of hospitals comes into play and why it becomes a significantly greater challenge when you have an existing site.

87. To summarise, you cannot derogate from minimum standards. If a ward or room is designed to do ten air changes and you have an eighty per cent tolerance within the current HTM, and it falls below eight air changes, it's non-compliant and should be shut. The recommended air-change rates are the required standards to minimise the risk of adverse health impact patients and staff.

88. The HTM also states that hospitals should not have any ventilation plant that hasn't been subject to a major refurbishment every 10 years and replaced every 20 years (HTM 03-01 Part A - Expected service life (13.32) & HTM 03-01 Part B Lifecycle of ventilation systems (1.53/1.54)). However, if that was enforced to the letter then you would shut almost every single hospital in the country overnight. That's when you have to take a sensible approach and risk assess. If the performance is safe and appropriate then you can schedule and plan capital investment when it can be afforded and achieved, but you wouldn't instantly take it out of operation if it was old but still functionally suitable.

89. I believe what is required and in my own personal opinion, is that the process for managing, recording and monitoring derogations should be formalised. When a derogation is made it should be kept as a live document and kept under constant review. A decision to derogate taken at the time of a capital project may have been

justified at that time but could have consequences for how the building is then later developed as clinical activity changes. So a decision to derogate needs to be recorded accurately at the time and kept under review to ensure that that decision remains appropriate throughout the life of that installation. So while some aspects of the guidance may reflect a legal obligation which cannot be departed from without breaking the law the guidance itself does not have any inherent legal status.

90. There are circumstances where just complying with the HTM wouldn't automatically mean that you'd also comply with minimum legal standards. For example a post-mortem room has to have ten supply air changes and twelve extract. If you suddenly had to do a post-mortem on a patient who died from viral haemorrhagic fever, you wouldn't carry this out in a normal mortuary because of the potential risk of a release of a Category 4 pathogen. So the HTM is right, however it's set for normal usage. For a given circumstance that the HTM is defined for then it should achieve legal compliance but could not necessarily be deemed to cover every circumstances, which a hospital may be engaged in. The guidance only makes recommendations, albeit ones which are informed by a wide range of appropriate technical knowledge.

91. It follows that appropriate professional judgement will still be required when designing, installing and operating ventilation in hospitals. It should not therefore be assumed that following the letter of the guidance will be sufficient in all circumstances to produce an acceptable ventilation installation which is compliant with the law, and that in any event, such judgement will be needed when ventilation is needed in circumstances for which the guidance does not provide. This is one of the drivers between the 2007 guidance and the 2021 guidance and why the new HTM draft includes a requirement for a multidisciplinary ventilation safety group.

HTM 03-01

92. I have been asked if I have had any involvement in the latest iteration of HTM 03-01 2021, which is intended to ensure that those responsible for commissioning and operating hospitals, such as health boards, meet their various legal obligations relating to ventilation. I was approached by Malcolm Thomas, who was the lead author for 2007 version of HTM 03-01 and the current 2021 version. He had been brought on-board by a company called Archus, healthcare consultancy, who had secured the bid to draft HTM 03-01. He was looking for me to contribute to HTM 03-01 (2021) and sit on a panel of specialists who contributed, debated and discussed the content and update of the revision of HTM, which commenced in 2017. This group included Microbiologists, infection prevention control professionals and clinicians. I believe the draft was finished and ready for publication in early 2019 but was delayed as a result of the global pandemic, until June 2021.

93. My contribution to this document saw me authoring draft text for some sections, such as the function and role of a ventilation safety group. I was also part of the group collective where we discussed and reviewed all of the various iterations and all of the contributions that everyone made until Malcolm Thomas pulled together the final version. It was a lengthy process, however I think the process was driven by the scope of the technical topic. There was a large group who contributed to the draft of HTM 03-01 2021 and Malcolm Thomas kept notes and comments received from the last date of publication, with suggestions or areas where people feel that something was missed, areas of potential error. These areas would be revisited and covered in any future draft. The scope of the review would also have to meet the parameters set by the Department of Health.

94. Once we were approaching what we hoped would be the finalised document it was circulated out to wider institutes for comment. I believe that several thousand comments were received by Malcolm. He then sifted through all of those comments where they were consolidated and it was then reviewed by the wider group, discussing their relevance and if it needed to be included in final draft. This gave Malcolm sufficient information to produce the final document. The final document was then sent to proofing and to the Department of Health for approval and ratification because there was, as I understand it, a financial cost benefit analysis required. So if changes had been suggested that would have a financial impact, the Department of Health had to be satisfied that the financial consequence was sufficient or the benefit outweighed the cost. The draft was subsequently agreed and published.

95. The document is written in language that a layperson should be able to comprehend, but it boils down to the definition of competence and my definition of competence is to know when you're not. So, if you read something and you fully understand it and you understand the principle and you understand what it's saying, then you can act on that and take it as the right answer. If you read something and you are unsure then you shouldn't plough on regardless, you should stop and consult with others to make sure that you are right in your interpretation.

96. I have been made aware that I am acknowledged as a contributor to the interim SHTM 03-01 2021, which is being published. I had no communication or discussion with anybody prior to that document being published. Now, it is pretty much identical to HTM 03-01, which I did contribute to and I'm perfectly happy having my name attached to it as is Malcolm Thomas, however he also has had no discussion with anyone from National Services Scotland.

97. It has been issued as interim guidance and I do not know what NHS Scotland's intention is as to whether they will issue a completely revised SHTM at a future date. It may revolve around COVID, or other influencing factors. I was a little surprised when it came out as I would expect to be contacted if I'm named in the document as a contributor before releasing the document. I'm aware that the devolved administrations were party to the drafting of the HTM and I suppose it depends upon the nature of the HTM as to whether it gets a Scottish equivalent or whether it gets completely rewritten. My understanding from others I have spoken to is that there are less than a dozen words that have been changed unless they relate directly to legislation which, because there's different legal structures, was necessary. But generally, the content is near identical.

STATEMENT OF TRUTH [to be signed by witness once statement is finalised]

I, Andrew Poplett, confirm that:

(i) The contents of this statement is the truth to the best of my knowledge and recollection;
(ii) I am willing for this statement to form part of the evidence before the Scottish Hospitals Inquiry.
(iii) I am willing for this statement to be published on the Scottish Hospitals Inquiry website.

Signature: Andrew Peter Seymour Poplett

Date*:* 13.04.2022

Appendix 1

Resume of Andrew Poplett – IEng, MIHEEM, MSVHSoc, ACIBSE, AffIFE

Summary Employment History

Trained and qualified as a mechanical building services engineer (BTec HNC) (1985-89)

September 1985 to September 1991 : Haden Young Limited Newcastle upon Tyne

Worked as a specialist project engineer (commissioning & snagging) 1992 started work for the NHS as an operational Engineer

January 1992 to April 2000 – Newcastle General Hospital / Newcastle City Health NHS Trust

Following the completion and implementation of the Newcastle Services Review (NSR) became an Operational Engineer (Specialist Services) Newcastle General Hospital within the newly formed Newcastle City Health NHS Trust, where through internal promotion became Acting Estates Manager.

Lead engineer on Aspergillus “outbreak” in Newcastle (1998) helped develop containment precautions for Aspergillus control standards (NDSC Ireland)

April 2000 to March 2006 - Northgate & Prudhoe (NHS) Trust

In 2000 became Head of Estates for Northgate & Prudhoe NHS Trust

April 2006 to May 2009 - Northumberland Tyne & Wear (NHS) Trust

Due to a merger of three existing NHS Trust’s became Head of Property & Planning for Northumberland Tyne & Wear (NHS) Trust

May 2009 to present - Andrew Poplett Enterprises Ltd

Left NHS in 2009 to become an independent healthcare estates consultant and AE for specialist healthcare ventilation and water.

Over 35 years of experience in healthcare engineering

Chair of the IHEEM Ventilation Technical Platform, Member of IHEEM Regional Committee, & Member of the Water Technical Platform AE(W) Peer Review Panel.

Founder Member of the SVHSoc, Associate member of CIBSE, and Affiliate member of IFE

Lead Author of the following Supplementary Guidance Notes

IHEEM Ventilation Technical Platform (VTP)- Briefing Note - VTP/BN/001 - Potential Increased Risk of Aspergillus Infection due to COVID-19 & the Associated Essential Precautions & Control Measures to Consider

IHEEM Ventilation Technical Platform (VTP)- Guidance Note - VTP/GN/001/V1.0 March 2021 - Design Output and Performance Specification Guidance for the Ventilation Strategy / Systems for Dental Care Facilities

SVH Society - Updated Briefing & Guidance on Considerations for the Ventilation Aspects of Healthcare Facilities for Coronavirus – Revision Number 03-V5 8th June 2020

SVH Society – Guidance Note - Air Handling Unit Condition and Risk Based Monitoring Briefing Document

SVH Society - Guidance on Critical Ventilation System Risk Assessment Process and Factors

SVH Society - Fire Damper Briefing Document

SVH Society - Cryptococcus Briefing for AE(V)’s, AP(V)’s & Estates Professionals

Contributing Author of the following Supplementary Guidance Notes

Health Technical Memorandum (2021) 03-01 Specialised ventilation for healthcare premises;

Part A: The concept, design, specification, installation and acceptance testing of healthcare ventilation systems

Part B: The management, operation, maintenance and routine testing of existing healthcare ventilation systems

National Guidelines for the Prevention of Nosocomial Invasive Aspergillosis During Construction/Renovation Activities via production of the Newcastle-upon-Tyne City Health Trust Estates Department – Operational Policy for Aspergillus Management EOP53 (Version 1 updated 2nd February 2000)

Author of the following Health Estate Journal (HEJ) Articles & IHEEM Presentations

Aspergillus fumigatus – a ubiquitous foe – October 2014

L8 – Consider the ventilation aspects – November 2014

Fire Safety – Importance of Regular Inspection stressed – January 2015

Who should appoint AE's & AP's – April 2019

The Estates Manager's Guide to Cryptococcus in Healthcare Ventilation - June 2019

When to seek derogation, and the best approach – September 2021

AE's & AP's – Jack of all trades but masters of none? March 2022

SCOTTISH HOSPITALS INQUIRY

Hearing commencing 9 May 2022

Bundle 6 – Expert Reports and Statement