MANAGEMENT OF AIRBORNE INFECTION ISOLATION ROOMS

Greg Powell and Francis W. H. Yik
BSE Department, Hong Kong Polytechnic University, Hong Kong S.A.R., China
begreg@polyu.edu.hk

ABSTRACT

Airborne infection isolation (AII) rooms are essential facilities for controlling spread of airborne infectious diseases in healthcare settings. Their proper operation, which is paramount to protecting the wellbeing of healthcare staff, visitors and patients, requires proper planning and management. Although the traditional management role may be thought of as being responsible for the daily operation and maintenance (O&M) of the facilities, many maintenance tasks, which are essentially re-commissioning procedures, are dependent on provisions made for testing and commissioning (T&C) at the design stage. Furthermore, the reliability of the engineering systems and the ability to maintain and repair them without interrupting normal operation of the systems also depend heavily on design decisions. Facility managers should therefore also be aware of design recommendations in addition to actual specifications since any shortcomings will impact on how they can manage and operate the AII facilities. Targeting at managers involved with the design, procurement, and operation of AII facilities, the paper presents the findings of a literature review and observations from practical experience, in respect of the current ventilation design recommendations for AII facilities including design features that would allow maintenance tasks to be performed safely without interrupting the operation of the AII rooms. Some of the procedures a facility management team can perform to verify if AII rooms are functioning correctly are then described, together with the identification and causes of potential problems.

KEYWORDS: AII Room, ventilation, management, O&M.

INTRODUCTION

Airborne infection isolation (AII) rooms are essential provisions in healthcare settings to safeguard healthcare workers (HCWs), maintenance staff, patients, and visitors from potential cross-infection. To achieve this, the mechanical ventilation systems of AII rooms must be properly designed, operated and maintained to ensure achievement of the required isolation performance, and be able to function reliably and continuously, except when necessary maintenance works are carried out. In this paper, the operation principles of AII rooms and the ventilation design guidelines are summarised. Some of the procedures that a facility management team can perform to verify correct functioning of AII rooms, and to identify causes of potential problems are described.

PRINCIPLE OF OPERATION OF AII ROOM

A patient who has contracted an airborne infectious disease, such as tuberculosis (TB) or severe acute respiratory syndrome (SARS), should be placed in a negatively pressurised AII room. The room exhaust is greater than the supply so that make up air is drawn from adjacent spaces, thus preventing leakage of any potentially contaminated air. The pressure difference achieved is dependent on the air tightness of the construction, which may be quantified by the equivalent leakage area (ELA), as shown in Equation 1 (Hayden et al., 1996).

$$A_E = 0.01138\left(\frac{\Delta Q^{1.170}}{\Delta P^{0.602}}\right) \qquad \text{Equation 1}$$

Where A_E = is the ELA (square inches), ΔQ the differential airflow rate (cfm) and ΔP the differential pressure (inches water gauge).

The Centers for Disease Control (CDC, 2003) recommends a supply-exhaust imbalance of 100 cfm (≈ 50 l/s) to give a differential pressure of -2.5Pa. Using the SI equivalent of equation 1 yields an ELA ≈ 400 cm^2, which we found in previous measurements to be representative of an average standard of construction of isolation rooms in Hong Kong. More stringent differential pressures are specified elsewhere, for example -15Pa in the UK (RACCDC, 2004) to -30Pa in Australia (SCIC, 1999). Lower differential pressures, in the range of -0.25Pa (AIA 1996) to -0.5Pa (Decker, 1995), may be sufficient to prevent leakage of contaminated air under door closed conditions, but such small pressure differentials may be disturbed by climate effects (temperature differences and wind pressure), or operation of nearby ventilation systems. Decker (1995) also showed that for an isolation room that achieved a differential pressure of -0.5Pa when the door was closed, leakage of air out of the room became detectable within 3 minutes once its door was opened.

Ingress and egress of HCWs will entrain contaminated air into clean areas. Alevantis et al. (1996) showed that a pressure difference of around -7Pa (with closed door) could ensure that only 1% of the room air could be found in adjacent spaces. Our walk through measurements using CO_2 as a tracer gas showed that concentrations in adjacent spaces were of the order of 5% – 8% of room concentration for differential pressures of -3Pa to less than 1% at -8Pa. In Norway, 4 isolation rooms were tested using sulphur hexafluoride (SF_6), where the corridor-anteroom and corridor-patient room pressure differences were -15Pa and -30Pa respectively (Rydock and Eian, 2004). In each case SF_6 was detected in the corridor, although at much lower concentrations than in the ante room.

Increasing the pressure difference would cause greater air movement on opening the door which helps reduce the amount of contaminated air entrained with the person. This can be achieved by increasing the supply-exhaust flow rates differential. A differential pressure in the range 8–10Pa can be readily achieved provided attention is paid to the air tightness of the construction. Air transfer grilles with automatic dampers between the corridor and anteroom and between the ante room and the AII room are needed as pressure stabilisers.

Achieving the required level of air tightness requires, among other things, all windows to be well sealed; walls to be extended from floor to structural ceiling and be applied with impervious surface finishes; doors to be well sealed except for purposely provided door undercuts in the range 3 – 12 mm (CDC, 2004), or be fitted with door louvers; and ceilings to be air tight with any openings for services well sealed around the edges. This includes pipe work, light fixtures, electrical light switches, fire services and any access doors. Ceiling mounted furniture such as curtain rails should not obstruct access to ceiling mounted air terminals to permit measurement of flow rates using flow hoods or similar devices.

The previous discussion points to the need for an ante room to act as a buffer between the AII room and the corridor with the pressure from the corridor through the anteroom to the AII room being increasingly negative. A potentially hazardous situation will emerge when the relative pressure between an isolation room and any one of the surrounding spaces is reversed. Therefore, differential pressures sensors are installed such that whenever abnormality is detected, an alarm will be signalled. For providing an effective air lock, the two ante room doors should be interlocked to prevent them from being opened at the same time (SCIC, 1999). Care should be taken to avoid the interlock from being inadvertently overridden. Sliding doors are preferred to swing doors for minimization of undesirable air movements (Tang et al., 2006).

Ventilating the ante room at the rate of 12ach will achieve 99% and 99.9% removal efficiencies in 23 and 35 minutes respectively CDC (2005). Similarly it can be shown that at a ventilation rate of 10ach, a removal efficiency of 50% can be achieved after 4 minutes. HCWs should therefore stay in the anteroom for a few minutes to allow significant dilution of any entrained contaminated air. This time can be used effectively if a hand wash basin is provided and if PPE is stored in the anteroom, to allow changing. Higher contamination dilution efficiency would be achieved by increasing the air change rate.

Each isolation room must be provided with a dedicated washroom (or ensuite) to minimise the need for taking the patient outside. The washroom and the isolation room are to be ventilated by the same mechanical ventilation system. Any foul air extracted from the washroom will be replenished by air induced to flow from the isolation room into the washroom through the door gap or a transfer grille in the washroom door. The washroom exhaust rate should be 10ach at minimum, which should be capable of maintaining a 2.5Pa pressure difference between the washroom and the patient room when the door is closed.

Ideally, each isolation room should accommodate only one patient at any one time. At times of serious epidemics, however, shared use of isolation rooms may become a necessity. This is acceptable provided that patients staying in the same room are all confirmed to have contracted the same infectious disease, and the same strain of multi-strain infections; there should be 1-2m separation between beds (WHO, 2004) and curtains should be drawn around a patient to limit the travel of droplets emitted when a patient coughs or sneezes. Until diagnosis is confirmed, each *suspected* patient must be lodged in a single room.

When an AII room is idle, it may be used for accommodating non-infectious patients and be operated under neutral pressure, provided the room has been cleansed and has remained unoccupied with the mechanical ventilation kept running to purge away any residual infectious diseases in the room. Dual purpose rooms, which can operate in either negative or positive pressure, are no longer acceptable, due to the risk of incorrect mode selection.

Two or more AII rooms may be positioned side-by-side. In this case, the adjacent anteroom and AII room pressures must be closely balanced, otherwise, cross infection may arise if air leakage paths exist between adjacent spaces. It may be thought cost-effective to have adjacent AII rooms sharing an ante room. This, however, is undesirable, because shared anterooms could lead to incorrect air flow direction (Pavelchak et al., 2000). In addition, contaminated air from one AII room could be entrained into the anteroom, which could be induced to flow into the adjacent AII room by the anteroom-AII room pressure difference.

In order to maintain sufficient distance between beds, allow easy access for bed making or cleaning and to permit the use of wheelchairs and patient hoists, a single bed isolation room should have, at minimum, a floor area of $16m^2$ (SCIC, 1999) and a 4-bed room $58m^2$, excluding the clinical support and ensuite area (NHS Estates 2005).

Supply and exhaust arrangement

For new facilities, the supply air should be 100% outdoor air (SCIC, 1999); for other cases, an absolute minimum of 2ach of outdoor air should be provided (CDC 2003). Whilst ventilation rates are commonly expressed in number of air changes per hour (ach) referenced to the room volume, the figures should be interpreted with caution. For a given contaminant source strength (e.g. one infectious patient), a ventilation rate of 12ach will yield a lower contamination concentration in a large room than in a smaller room. Attention, therefore, should also be paid to the absolute ventilation rates (e.g. in l/s), particularly for small rooms (less than $43m^3$ volume).

The recommended minimum supply flow rate for a single person AII room is the greater of 12ach or 145*l*/s (SCIC, 1999). For a multiple patient AII room, the supply air flow rate should be increased pro-rata; otherwise the contaminant concentration will be higher thus exposing HCWs to a higher risk of infection. This is important for AII rooms that would normally house one patient but would be used to house more under surge conditions. The supply air flow rate for an AII room should be determined based on the design sensible cooling load of the room without reheat under the design condition. The exhaust flow rate should be equal to the sum of the supply and the leakage flow rate. As the leakage characteristics of a room will remain uncertain until the room has been built and testing and adjustments are done, allowances should be made in determining the exhaust system capacity and use of adjustable supply and exhaust fans is desirable. Our measurements suggest that fans are typically 20% oversized.

The design indoor air condition should be 21–24°C and 40–70% RH (ASHRAE, 2003). Each patient room should be fitted with its own thermostat control (ASHRAE, 1999). The supply air system must be all air, constant air volume (CAV) system (SCIC, 1999). Ideally, each AII room should be served by a dedicated system with its own air-handling unit (AHU) although a common AHU may be used to serve multiple rooms located together, provided design provisions are made to prevent one room's pressure characteristics from affecting another's. Similarly, each AII room should have a dedicated exhaust and when an exhaust system is used to serve multiple rooms, provisions must be made to prevent one room's pressure characteristics from affecting another's (Standards Australia, 2003). Exhaust fans should be located as near to the discharge point as possible such that all exhaust ductwork inside the building is maintained under negative pressure (Standards Australia, 2003).

Both supply and exhaust fan systems should be backed-up by stand-by units with automatic changeover, so that either fan can be shut down for maintenance or filter changing (SCIC, 1999). The supply fan(s) should be fitted with automatic cut-outs in case of exhaust fan failure or in the event that negative pressure is not achieved in the room (Standards Australia, 2003). The exhaust system should be designed so that filters can be changed without compromising the safety of maintenance staff (SCIC, 1999). Supply and exhaust fans should be provided with essential power supply (RACCDC, 2004).

Although a high level of mixing and contaminant dilution is desirable, a general flow pattern where the clean air from the supply air terminal passes over the HCW, then over the patient and is finally exhausted will help lower the exposure of health care workers to infectious diseases (Standards Australia, 2003). The supply air grilles are typically ceiling mounted with low level exhaust grilles located either at each side of the patient's head (Streifel, 1996) or 150mm above the floor (SCIC, 1999). Ceiling mounted supply terminals should be of the perforated plate type (CDC, 1994), located near the door but the supply airflow should not disturb the differential air pressure relationship with the ante room (Pavelchak et al., 2000). Supply and exhaust terminals should be located to prevent short circuiting (CDC, 2005). Room furniture and other fittings should not obstruct the airflow paths.

The air inside an isolation room should contain as few as possible contaminants, especially bacteria and viruses, which requires a high standard of supply air filtration. Although UVGI disinfection systems can reduce the number of airborne bacteria and micro-organisms, there is a lack of documented evidence to quantify their effectiveness and to provide detailed guidance on the placement, lamp intensity and air flow rate through these devices.

HEPA filters must be fitted in renovated facilities where air is recirculated from the AII room. The use of terminal HEPA filters should be considered in situations where supply and exhausts to/from AII rooms are shared in order to prevent back draughts (SCIC, 1999). HEPA filters should be housed in metal frames, with the filter and frame sealed with well fitting rubber gaskets (DoHS, 1996). To maintain continuous operation, duct mounted HEPA filters should be fitted in a parallel duct arrangement. HEPA front access filters should be fitted at each room exhaust point; a duct damper with edge and blade seals should be provided immediately downstream of each HEPA filter to allow for duct isolation prior to HEPA filter removal and room cleaning (Standards Australia, 2003). The life of HEPA filters can be prolonged if pre-filters are used (CDC, 2003). All filters should be fitted with manometers or pressure gauges (DoHS, 1996).

COMMISSIONING

An Infection Control Risk Assessment (ICRA), following the American Institute of Architects' (AIA) requirements, should be prepared by a multi-disciplinary body of experts from the fields of infection control, risk management, facility design, construction, ventilation, safety and epidemiology (AIA, 2001). AII rooms should be commissioned by an independent third party commissioning authority (CA) (AIA, 2001). The CA should be appointed early so that necessary provisions such as variable flow fans, volume control dampers (VCDs) are specified correctly and actually installed.

The AII room should be inspected to ensure that all the recommended arrangements stated in the preceding section are adequately provided. Consideration should be given to carry out containment testing using tracer gas and verification of airflow patterns. The ventilation system should be tested and balanced according to recognised commissioning codes or standards e.g. ASHRAE, (1996 & 2005) to ensure specified design differential pressures are achieved while satisfying minimum ventilation flow rate criteria. All alarms and gauges should be commissioned to verify the airflow direction and pressure readings. In particular, checks should be made to ensure that there is no bi-directional airflow over the door.

The client should ensure that the commissioning team are in possession of the most up to date design information. After handover, the owner shall keep documentation and records as specified by ASHRAE (2007). Training should also be provided to the owner's O&M staff in conformity with, but are not limited to, the requirements of ASHRAE (2007). Furthermore, sufficient training and instruction should be given to HCWs so that they are able to read and interpret the monitoring instruments and also carry out the required action plan in the event of an AII room being found to be performing incorrectly.

MAINTENANCE

Maintaining proper air flows (in both magnitude and direction) in an AII room is crucial to its proper functioning. However, the performance of any complex system will degrade over time. For a mechanical ventilation system, continuous use will result in increasingly loaded air filters and loosened fan belts (Pavelchak et al., 2000), lint build up on fan blades and in low level exhaust grilles (Streifel, 1996), and worn motor bearings; all of which will reduce the airflow and compromise the effectiveness of the AII facility. Only qualified engineering staff should carry out maintenance tasks or make changes to the ventilation system. All replacement parts should conform to the original design specification.

Regular maintenance tasks on the ventilation system should include checks or measurements on the air change rate, supply air and exhaust flow rates, supply air diffuser or registers, return/exhaust grilles and ductwork, supply and exhaust fans and dampers, room pressure gauges and alarms (Standards Australia, 2003). The maintenance interval should be 13 weeks, or some other interval determined by condition based monitoring procedures such as filter pressure drops, daily records of room pressures etc (SCIC, 1999). Appropriate re-commissioning checks should be performed after completion of maintenance tasks to ensure that the correct flow rates and pressure relationships are re-established.

HEPA filter replacement intervals should be determined by the filter pressure drop readings or, if a prescribed time interval is preferred, once every 4 months (13 weeks) (SCIC, 1999). HEPA filters should only be removed after a minimum of 7 days of being isolated from the duct air stream (Wang et al., 2003). In some cases this period may need to be longer – WHO guidance states that the SARS virus remained viable at 4°C for 3 weeks. HEPA filter replacement should be performed when the room is vacant. The time period should be a minimum of 10 minutes to allow droplets to settle (DoHA, 2004), however a longer interval is likely to be required based on CDC (2005) data for ventilation rate and required removal efficiency. Where HEPA filters are not designed on a duty and stand by basis, the filter should be changed before admitting an infected patient to the room if it has less than 2 weeks operational life left (Wang et al., 2003). This would interrupt the operation of the room. HEPA filters may be sterilised with a 10% bleach solution before removal (CDC, 2005). Maintenance staff should wear a respirator (CDC, 2005) and disposable gloves and follow safe maintenance practice such as given in USEPA's air-quality guidelines (Striefel, 1996).

With some diseases, e.g. SARS, HEPA filters should be disposed of as clinical waste (DoHA, 2004). If pre-filters are used they should be treated in the same way as HEPA filters (CDC, 2005). Maintenance personnel should thoroughly disinfect themselves upon completion of replacement. Carts and trolleys should be disinfected before leaving the isolation room. Waste bags and containers should be completely sealed to prevent any virus becoming airborne due to air movement from the ventilation system.

OPERATION

Daily testing of air flow movement using smoke tubes should be carried out by releasing smoke around all four door edges to confirm that two directional airflows are not present over the door (CDC, 2005). If manual gauges are fitted they should be read daily with the reading recorded. It must be ensured that doors and windows are kept closed to maintain pressure relationships. Filter pressure drop readings should be made weekly and the results recorded. If the AII room has been in use as a general treatment room during non-outbreak conditions, consideration of the HEPA filter loading is still of importance (Rydock, 2002). When returning the room to AII use the filter pressure drop should be compared with historical records to determine whether the HEPA filter should be replaced.

An intercom, CCTV, or similar communications system should be provided which will allow staff to communicate directly with the patient and vice-versa, without the need to enter the room and also allows staff present in the room to communicate with people outside the room without leaving the room (Standards Australia, 2003). Appropriate warning signs should be placed on the entry doors to the anteroom and patient room warning of semi-contaminated and contaminated areas respectively. A biohazard logo on the door to the AII room can raise HCW awareness and assist in ensuring additional precautions. If it is not feasible to have signage then suitable markings should be made on the floor.

Room cleaning should be carried out after an AII room has been vacated by a patient. The room should be ventilated for an appropriate period as determined for HEPA filter replacement. Cleaning personnel should wear rubber gloves, a disposable gown, goggles/visor/shield and a P2 (N95) mask/respirator (DoHA, 2004). Surfaces should then be cleaned with detergent and water, and disinfected with a broad-spectrum disinfectant with proven antiviral activity (e.g. sodium hypochlorite 500 ppm, (1 in 100 dilution of household bleach) or 60-70% alcohol). All reusable equipment should be reprocessed in accordance with manufacturer's instructions.

CONCLUSIONS

AII rooms depend on their mechanical ventilation systems for effective control of airborne infection transmission. The systems' performance can be degraded over time through normal continuous use, resulting in potentially increased risk of infection transmission. Appropriate design decisions and facility management procedures coupled with appropriate training can result in a facility which can be maintained and operated safely without compromising the safety of healthcare & maintenance staff, patients and visitors.

ACKNOWLEDGEMENTS

The work reported here was performed for the Electrical and Mechanical Services Department and the Hospital Authority of the Hong Kong Government.

REFERENCES

AIA, (1996), Guidelines for design and construction of hospital and health care facilities, The American Institute of Architects, Washington D.C.

AIA, (2001), Guidelines for design and construction of hospital and health care facilities, The American Institute of Architects, Washington D.C.

Alevantis, L. E., Offermann, F. J., Loisselle, S. and Macher, J. M., (1996), "Pressure and ventilation requirements of hospital isolation rooms for tuberculosis (TB) patients: Existing guidelines in the United States and a method for measuring room leakage" in Maroni, M. (Ed.), Ventilation and Indoor air Quality in Hospitals, Kluwer Academic Publishers, Netherlands.

ASHRAE (1996), Guideline 1 -1996. Commissioning of HVAC Systems., ASHRAE Handbook HVAC Applications, American Society of Heating, Refrigerating and Air-conditioning Engineers, Atlanta GA.

ASHRAE (1999), Chapter 7. Health Care Facilities. ASHRAE Handbook HVAC Applications, American Society of Heating, Refrigerating and Air-conditioning Engineers, Atlanta GA.

ASHRAE (2003), Special Project 91. HVAC design manual for hospitals and clinics, Ed. Geshwiler, M., American Society of Heating, Refrigerating and Air-conditioning Engineers, Atlanta GA.

ASHRAE (2005), Guideline 0 -2005. The Commissioning Process, American Society of Heating, Refrigerating and Air-conditioning Engineers, Atlanta GA.

ASHRAE (2007), Proposed New Standard 170P. Ventilation of health care facilities. Third Public Review, American Society of Heating, Refrigerating and Air-conditioning Engineers, Atlanta GA.

CDC, (2003), Guidelines for environmental infection control in healthcare facilities. Recommendations of CDC and the Healthcare Infection Control Practices Advisory Committee (HICPAC), Centers for Disease Control and Prevention and Healthcare Infection Practices Advisory Committee, U.S. Department of Health and Human Services, Atlanta, GA.

CDC, (1994), Guidelines for preventing the transmission of Mycobacterium tuberculosis in health care facilities, MMWR 43 No. RR13. Centers for Disease Control and Prevention, Atlanta, GA.

CDC, (2005), Guidelines for preventing the transmission of Mycobacterium tuberculosis in health care settings, MMWR 54 No. RR17. Centers for Disease Control and Prevention, Atlanta, GA.

Decker, J. (1995), "Evaluation of isolation rooms in health care settings using tracer gas analysis", Applied Occupational & Environmental Hygiene, Vol. 10 No. 11, pp 887-891.

DoHA, (2004), Interim Australian infection control guidelines for Severe Acute Respiratory Syndrome (SARS). Section 2. Healthcare Facilities, Department of Health and Aging & Communicable Disease Network Australia .

DoHS, (1996), "Capital works guidelines. 6.3. Air conditioning in health care buildings", Department of Human Services, Victoria, available at: http://www.health.vic.gov.au/infcon/ic/acon.pdf

Hayden II, C. S., Fischbach, T. J., Johnston, O. E., Hughes, R.T., and Jensen, P. A., (1996), A model for calculating leakage areas into negative pressure isolation rooms, CDC, U. S. Department of Health, Cincinnati.

NHS Estates, (2005), "Ward layouts with single rooms and space for flexibility", available from: 195.92.246.148/knowledge_network/documents/Ward_layouts_20050517165909.pdf

Pavelchak, N., Depersis, R. P., London, M., Stricof, R., Oxtoby, M., Diferdinando, G. Jr., and Marshall, E., (2000), "Identification of factors that disrupt negative air pressurization of respiratory isolation rooms", Infection Control and Hospital Epidemiology, Vol. 21 No. 3, p191.

RACCDC, (2004), Isolation rooms (including mechanically ventilated rooms): Best practice standards for capital planning, Regional Advisory Committee on Communicable Disease Control, Belfast.

Rydock, J. P. (2002), "A simple method for tracer containment testing of hospital isolation rooms", Applied Occupational & Environmental Hygiene, Vol. 17 No. 7, pp 486-90.

Rydock, J. P. and Eian, P. K., (2004), "Containment testing of isolation rooms", Journal of Hospital Infection, Vol. 57 pp 228-32.

SCIC, (1999), Guidelines for the classification and design of isolation rooms in health care facilities, Standing Committee on Infection Control, Department of Human Services, Victoria, Australia. Melbourne.

Standards Australia, (2003), HB260-2003. Hospital acquired infections – engineering down the risk, Sydney.

Tang, J. W., Li, Y., Eames, I., Chan, P. K. S., and Ridgway, G. L., (2006), "Factors involved in the aerosol transmission of infection and control of ventilation in healthcare premises", Journal of Hospital Infection, Vol. 64 No. 2 pp 100-114.

Wang, S. C., Wallingford, K. M., Burr, G. A., and Lee, C. H., (2003), "Recommended guidelines for inspection of isolation wards for SARS patients", available from: www.isoh.gov.tw/eversion/sarse.htm

WHO, (2004), "Practical guidelines for infection control in health care facilities" available at: http://www.wpro.who.int/publications/pub_p290222387.htm