Proposed modular demountable isolation mini-en-suites for protecting patients and health care workers against infectious diseases in hospitals

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ABSTRACT

Severe Acute Respiratory Syndrome (SARS) has induced the need of rationalization of how pathogens can be spread by coughed aerosols which may deposit on object surfaces or evaporated into droplet nuclei floating as particulates in the air, and body fluid substance such as human excretion to be discharge into a sewage pipework system. Both pathogen-contaminated liquids and air have to be treated right at the source as far as possible. And the best way is to capture or kill the pathogens nearest to where they are emitted from the human body.

This paper reports on proposed modular demountable isolation en-suites each comprising an ante-chamber, a bed and sitting chamber, a toilet and shower chamber connected in an ascending order of negative pressures, for protecting patients and health care workers against airborne pathogens and aerosol-borne pathogens in existing hospitals, based on the pathogen isolation concepts stated above, yet not compromising the isolation functions needed (CDC, 1997).

INDEX TERMS

Isolation ward; Airborne infection diseases; SARS; Hospital drainage

INTRODUCTION

In an existing isolation room of six beds (Figure 1), means of pathogen isolation include mouth masks to be worn by patients, the physical distance separation between the patients, and the control of airflow patterns and rates in the various locations inside the room. Pathogen isolation is most difficult to achieve when patients vomit, sneeze or cough. When a person sneezes, hundreds and thousands of droplet nuclei bearing virus/bacteria will quickly form and then float in the air, dispersing around the room (Deacon, 2003). Also, patients may move around the room to go to toilets. Bacteria counts are high when bed sheets are changed. All these add to the difficulty of pathogen isolation among the patients. Health care workers are immersed in an atmosphere of airborne pathogens. They are also exposed to liquid-borne pathogens in cases of patient vomiting and soiled beds.

One obvious drawback in the layout of the isolation ward shown in Figure 1 is that when the patient passed through the ante-room (designed at +10 Pa of air pressure, NHS, 1994) from the ward area (designed at –15 Pa, NHS, 1994) into the toiler/bath area (designed at less than +10 Pa), the ante-room will be filled with airborne pathogens somehow. Since the corridor next to the ante-room is designed at 0 Pa (NHS, 1994) airborne pathogens in the ante-room (designed at +10 Pa) will flow together with the air to the corridor via the door gaps.

A single isolation room, or semi-suite isolation room, i.e. two single rooms sharing one toilet/bathroom (Figure 2), provide airborne pathogen isolation among patients, and prevents pathogen migration from the single room (designed at –15 Pa) to the corridor (designed at 0

Pa) via the ante-room (designed at +15 Pa). However liquid-borne pathogens can pass to another patient who uses the same toilet/bath, particularly for the semi-suite case.

MINI-EN-SUITE DESIGN AND OPERATION PRINCIPLES

The proposed modular demountable isolation mini-en-suite comprises an ante-chamber, a bed-and-sitting chamber, a toilet-and-shower chamber connected in an ascending order of negative air pressures (Figure 3). The ward (designed at –5 Pa) is at higher pressure than the ante-chamber (designed at –15 Pa), which is connected to the bed-and-sitting chamber (designed at –25 Pa), and finally the toilet-and-shower chamber (designed at –35 Pa). Furthermore, the ante-room, which is located between the corridor and the ward, has the highest air pressure. The nurses' station is located inside the ward area. Health care workers (HCW) have to enter the ante-chamber through door 'A', and close it behind before going into the bed and sitting chamber through door 'B'. Afterwards, the HCW has to close door 'B' behind to maintain the proper air pressure balance.

For maintaining the proper pressure balance, so as to ensure that proper airflow direction for pathogen control is achieved, the doors 'A', 'B', and 'C' linking the constituting chambers and the ward have to be kept closed all the time except at moments when people have to pass through them, and normally only one such consecutive door is allowed to be opened at one time. Better control of airborne pathogens can be achieved if the HCW and patient can stay for a short while in the ante-chamber with doors 'A' and 'B' closed before going out into the ward. This is because air flowing from the ward into the en-suite via the ante-chamber will dilute the pathogen content in the chamber. Since the volume of this ante-chamber is 1/8 of the volume of the bed-and-sitting chamber, the air change rate in the ante-chamber is almost eight times higher than the bed-and-sitting chamber. A short stay in this ante-chamber will be sufficient to let the high airflow rate to dilute the airborne pathogens that were taken into the ante-chamber from the bed-and-sitting chamber when door 'B' was opened. Also the HCW and patients going through the ante-chamber are to have their footwear soaked up with suitable disinfectants for killing pathogens. These arrangements will substantially minimize the possible transmission of airborne pathogens from their emitting sources into the ward.

A clearance space of about 400 mm wide around the bed is for the HCW to carry out health care service, as well as for the patient to move around the bed, sit down or do simple exercise inside the bed-and-sitting chamber. This space, for work and circulation, is also for placing medical instrument, trays and other devices. In case the HCW has to offer health care service from the bed head, the bed can be pushed away from the wall, so that the HCW can position himself/herself between the bed head and the wall.

When bed transportation out of the ward is required, such as in the case of emergency, a part of the front surface of the chamber can be hinged open, to make way for speedy transportation of the bed (Figure 4). In this case, the entire ward is exposed to receiving pathogens originally contained in the contaminated air of the bed-and-sitting chamber which is now opened. However such contamination is minimized because the contaminated air in the opened up bed-and-sitting chamber primarily flows into the toilet-and-shower chamber.

The provision of drainage system in hospital is different from those in other buildings. In infection control zones, the sewage from laboratory and treatment areas is to undergo special treatment processes before discharging. A special independent pipework system is installed to isolate this sewage in order to avoid cross-contamination with the general sewage of the hospital.

In our proposed design, liquid-borne pathogens are killed with suitable chemicals inside the toilet-and-shower chamber (Figure 5). The chemically treated liquid content inside the foul water container, which is now free of pathogens, is taken out once or twice a day by carts for disposal elsewhere, such as the existing toilet provided next to the existing ante-room.

Samples from human excrement for biochemical and pathogenic tests are collected and taken inside the en-suite. In this way, liquid-borne pathogens do not normally exist outside the en-suite.

The chamber surfaces are made of transparent materials such as polycarbonate, which has a suitable resistance to disinfectants like diluted bleaching water. They can be easily cleaned.

The en-suite and the related equipment can be prefabricated, offering quick assembly. The ward can be equipped with isolation en-suites in a couple of hours, provided that suitable modifications have been made on the existing bed head panels as well as the air conditioning systems. The assembled en-suites can be demounted after suitable disinfecting cleaning has been made and the contaminated HEPA air filtering machines are carefully removed out of the ward. Such removal can be easily handled because the HEPA filtering machines are mobile on wheels. Thus the original ward appearance can be quickly reinstated.

CONTROL OF AIRBORNE PATHOGENS BY HEPA FILTERING MACHINES AND UPGRADING OF EXISTING AIR CONDITIONING SYSTEMS

High Efficiency Particulate Air (HEPA) filters are the basic devices to arrest airborne pathogens (CDC, 1997) such as *Mycobacterium* that cause *Mycobacterium tuberculosis* (CDC, 1994). To deal with SARS, mobile HEPA filtering machines are proposed, using stationary type HEPA filters of high quality as recommended by CDC (CDC, 1994, 1997), but assembled with fans and pre-filters as portable units. They are in fact of quality as good as fixed HEPA filtering machines. This allows the convenient changing of virus-trapping HEPA filters, cleaning and maintenance of the machines including disinfection by suitable agents, like ozone. All these can be carried out with suitable tools at a place away from the isolation rooms and the patient accessible areas.

Because of the pressure gradient, air in the ante-room will first flow into the ward, then into the ante-chamber of the isolation en-suite, then the bed-and-sitting chamber, and finally the toilet-and-shower chamber. From this last chamber, the contaminated air is drawn through the HEPA filter machine A before it is exhausted to the outdoor space either fully or partially (with recirculation) (Figure 6). The recirculating air stream of the air-conditioning system, which is a mix of the return air from the ward and from the HEPA filter machine A, is to go through another HEPA filtering machine B, which then acts as the general ward filtering machine. It is because a portion of the air drawn from the isolation en-suite via the toilet-and-shower chamber is exhausted, that an equal amount of replenishing air has to be supplied by the air conditioning system. If the capacity of the existing system is not adequate to handle this, it has to be upgraded. Furthermore, since the general ward area is to be pressurized with clean air, another HEPA filtering machine C is proposed to be added to the existing system for handling this air stream.

In parallel to the above, a spreader is proposed to supply filtered air to the patient as an additional protecting device. By this, a small HEPA filtering machine D is provided to draw air inside the en-suite, filter it and then suitably spread the filtered air of high quality to the face of the patient via a proprietarily designed spreader. This is to protect the patient from the pathogens that are taken into the en-suite from the ward.

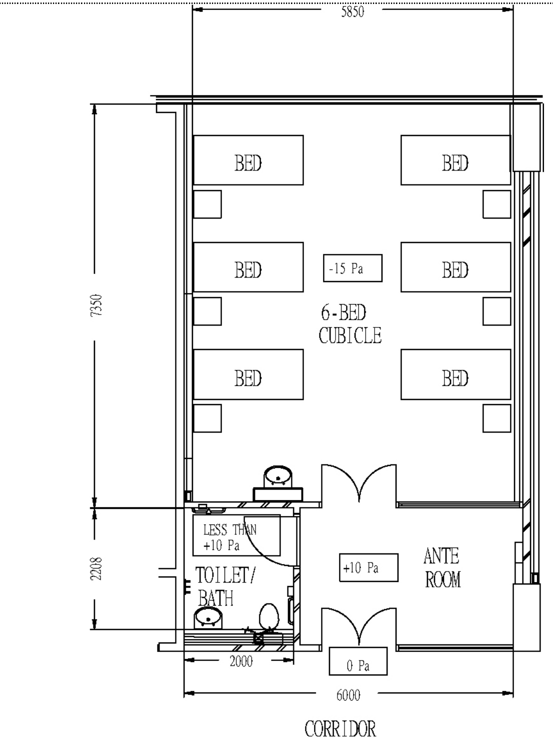

Fig. 1 LAYOUT OF AN EXISTING ISOLATION ROOM OF 6 BEDS

(WITH DESIGN AIR PRESSURE INDICATED IN PASCAL, Pa)

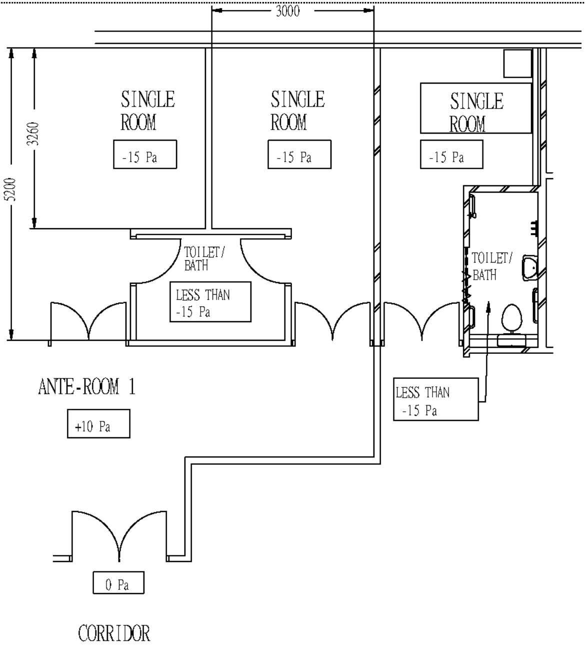

Fig. 2 AN EXISTING LAYOUT OF SEMI-SUITE ISOLATION ROOM (i.e. 2 SINGLE ROOMS SHARING ONE BATH / TOILET)

(WITH DESIGN AIR PRESSURE INDICATED IN PASCAL, Pa)

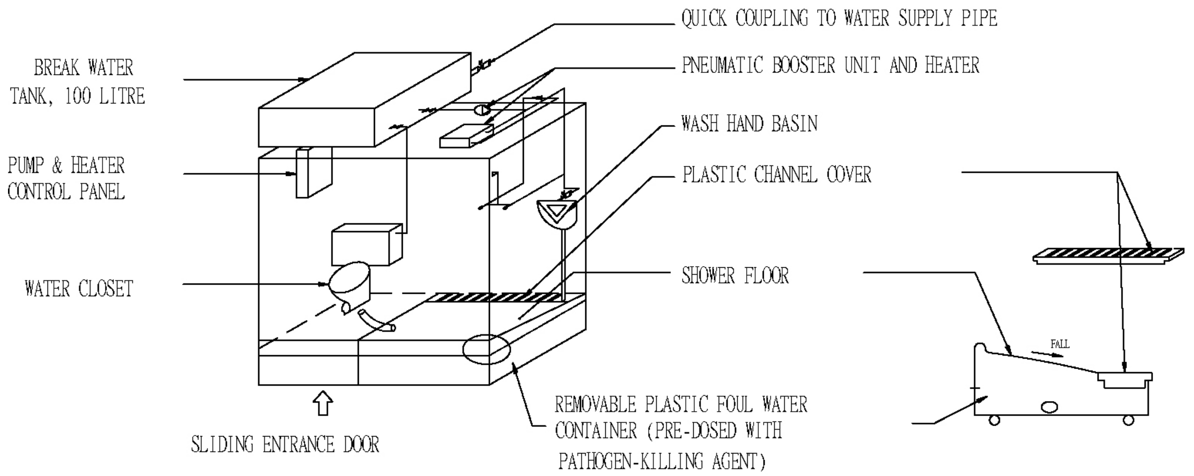

Fig.5 THE TOILET AND SHOWER UNIT OF THE PROPOSED ISOLATION MINI-EN-SUITE

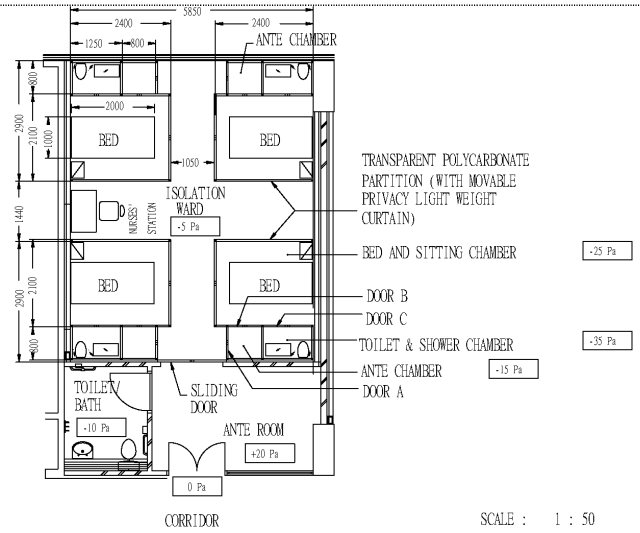

Fig.3 LAYOUT OF 4 PROPOSED MINI-EN-SUITES HOUSED INSIDE AN EXISTING WARD (WITH DESIGNED AIR PRESSURES INDICATED IN PASCAL FOR EACH COMPARTMENT)

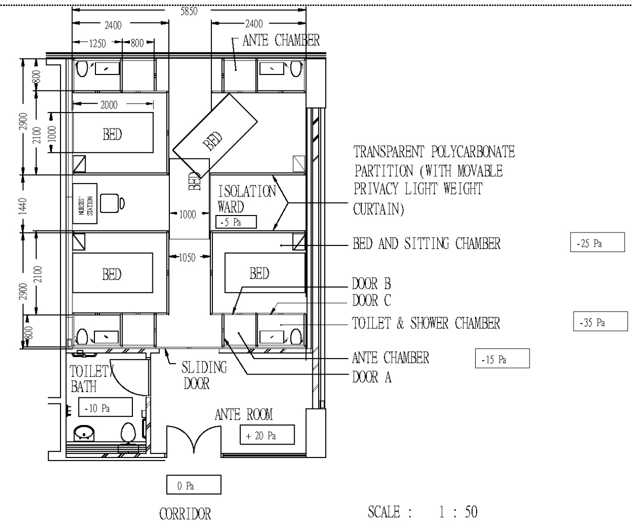

Fig.4 LAYOUT OF 4 PROPOSED MINI-EN-SUITES HOUSED INSIDE AN EXISTING WARD, WITH END OF PORTION OF BED AND SITTING CHAMBER OPENED UP FOR SPEEDY BED TRANSPORTATION

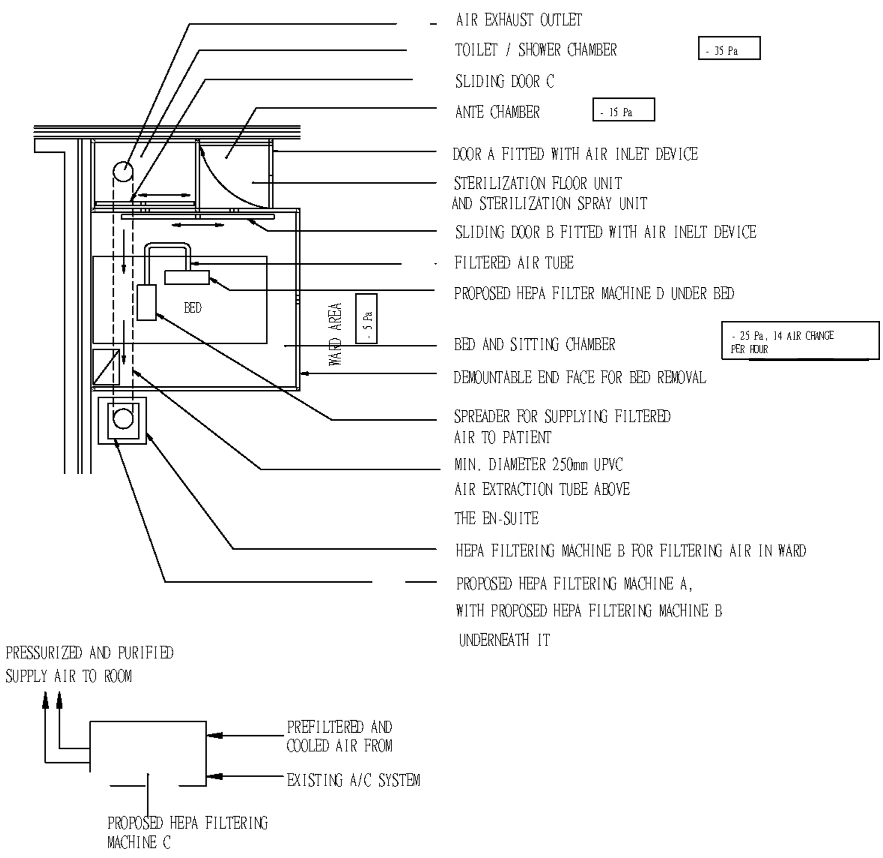

Fig.6 PROPOSED ISOLATION MINI-EN-SUITE, SHOWING CONTROL OF AIR-BORNE PATHOGENS BY HEPA FILTERING MACHINES

CONCLUSION

A scheme of modular demountable isolation en-suites has been introduced for protecting patients and health care workers against airborne pathogens and aerosol-borne pathogens in existing hospitals. With en-suite toilet/shower facilities, patients need not go around the ward to access washing and drainage facilities and they can use these facilities right next to them. This, together with the suggested chamber separation and spreader protection, are the intended design for minimizing cross transmission of airborne pathogens by: (i) the physical barriers, (ii) the air pressure differentials, and (iii) the airflow quantities and directions. Such provisions of the en-suite systems are called WIN Protection provision for the patient. This offers a possible alternative of providing cost-effective isolation pathogens in isolation wards, allowing conversion of the existing wards into some stringent isolation conditions within a couple of hours.

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