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HVAC Design Criteria for Isolation Rooms

By Pranab K. Chowdhury
General Manager – Engineering
Blue Star Ltd., Gurgaon
and
Samta Bajaj
Consulting Engineer, New Delhi

Pranab K. Chowdhury *is a mechanical engineer from the University of Pantnagar with 23 years experience in HVAC design. He is a member of ASHRAE, ISHRAE and The Institution of Engineers.*

Samta Bajaj *is a mechanical engineer from Delhi College of Engineering with 13 years of HVAC experience, of which 11 years were in Blue Star Ltd. She now works as an independent consultant and has been involved in the design of eight different hospital projects. She is a member of ISHRAE.*

Airborne transmission of respiratory diseases in indoor environments remains a problem of indoor air quality. Microbial predators have existed since time immemorial, but transmission had always required direct contact, because they could not tolerate the sunlight and temperature extremes outdoors. Man's cozy new habitats made it possible for these ancient parasites to survive short airborne trips between hosts.

All hospitals knowingly or unknowingly admit patients with communicable diseases. In recent years, the transmission of nosocomial infection has become a serious threat for health care facilities. Technically, nosocomial infections relate to those who are hospitalized, but health care professionals may themselves be at risk. OSHA* states that, "The most effective way to prevent or lessen transmission of nosocomial infection (hospital

acquired) is to isolate the airborne contaminant and to provide an environment that will promote reduced exposure to contaminant".

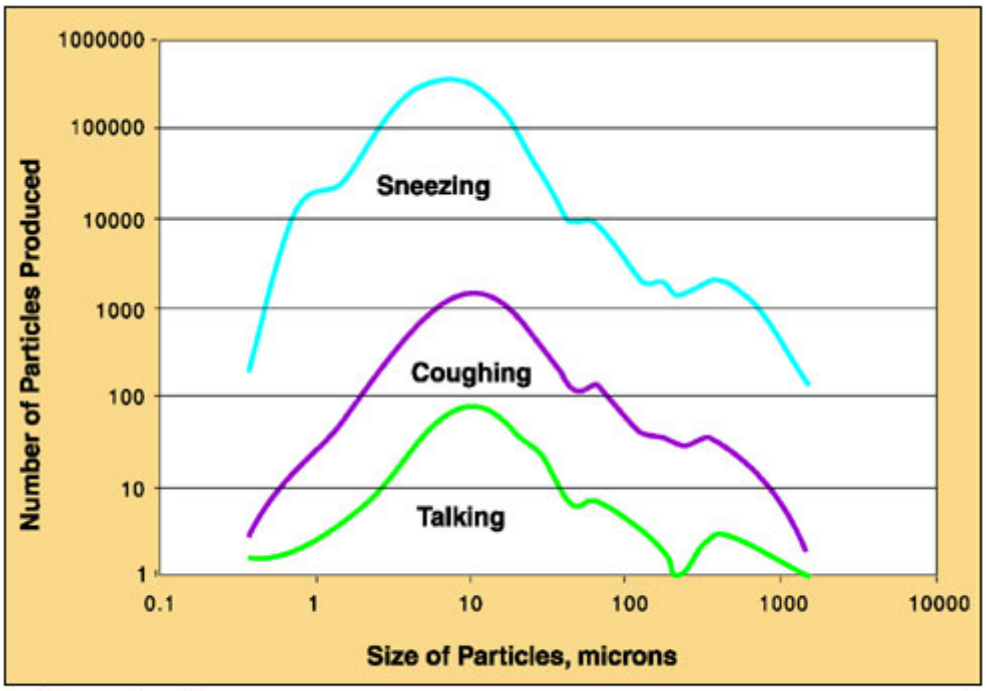

Figure 1 : Profile of particle sizes produced by an infectious person
infectious person

Infectious or protective 'Isolation rooms' in hospitals prevent nosocomial transmission and provide safety and protection for patients, staff and visitors. An airborne infectious isolation room is constructed to minimize the migration of air from an isolation room to other areas of health care facilities. Where possible, a patient known or suspected to harbour transmissible microorganisms should be placed in a single room. This prevents direct or indirect contact transmission or droplet transmission. A single isolation room with appropriate air handling and ventilation is particularly important for reducing the risk of airborne transmission of microorganisms from a source patient to susceptible patients and other persons in hospital.

Infection and disease can be contained by maintaining a pressure differential between the isolation room and the surrounding areas. Rooms held at negative pressure are used for patients with highly infectious diseases such as tuberculosis (TB). Similarly, immuno-suppressed patients who are vulnerable to disease and infection, such as burn victims, bone marrow and organ transplant recipients, patients with leukemia etc. are put into isolation rooms held at positive pressure to keep contamination out.

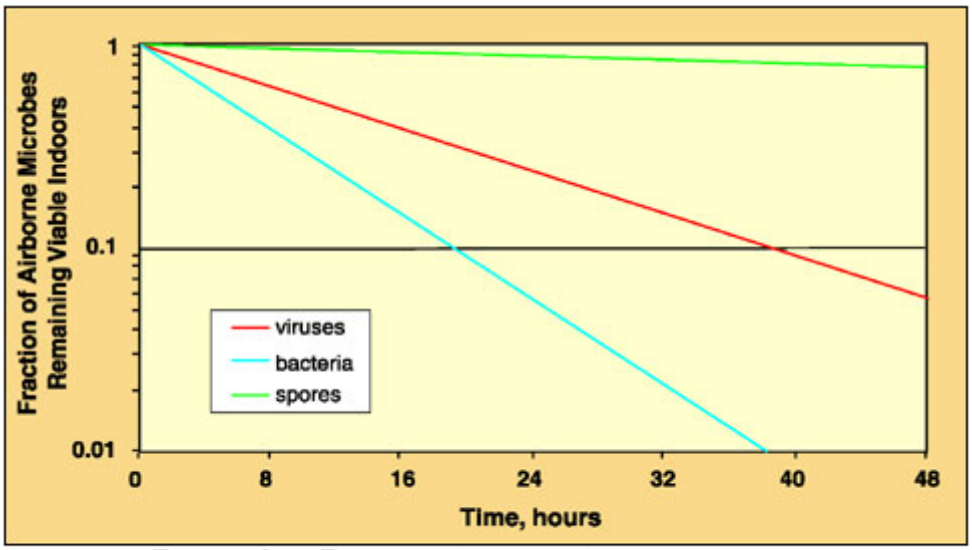

Figure 2 : Disappearance of airborne sneeze droplets from room air by size

Modes of Infection Transmission

Transmission-based infection control practices are central to preventing the transmission of microorganisms within health care settings. Microorganisms are transmitted in hospitals by three main routes : Direct or indirect contact with patient and patient care items; droplets (particles larger than 5µm) that are generated from a source person during talking, coughing, sneezing or during medical procedures like bronchoscopy and autopsy (**Figure 1**); and the airborne droplet nuclei (particles 5 µm or smaller) that are generated as the airborne droplets lose their weight through evaporation. While transmission through contact or via large particle droplets requires close contact between source and recipient persons, the airborne contaminants can remain suspended for hours and spread by diffusion or air currents.

These airborne microbes lose viability over time with air decay rates depending on size. (**Figure 2**).

The control of airflow through special provisions made in HVAC systems designed for isolation rooms can help to prevent the spread of these infectious contaminants to surrounding areas. This is achieved by controlling the quality and quantity of intake and exhaust air, diluting infectious particles in large volumes of air, maintaining differential air pressure between adjacent areas and designing air flow patterns for specific usage of areas.

This article is intended to touch upon the engineering practices and technology required for effective HVAC design for isolation rooms meant to prevent airborne transmission route.

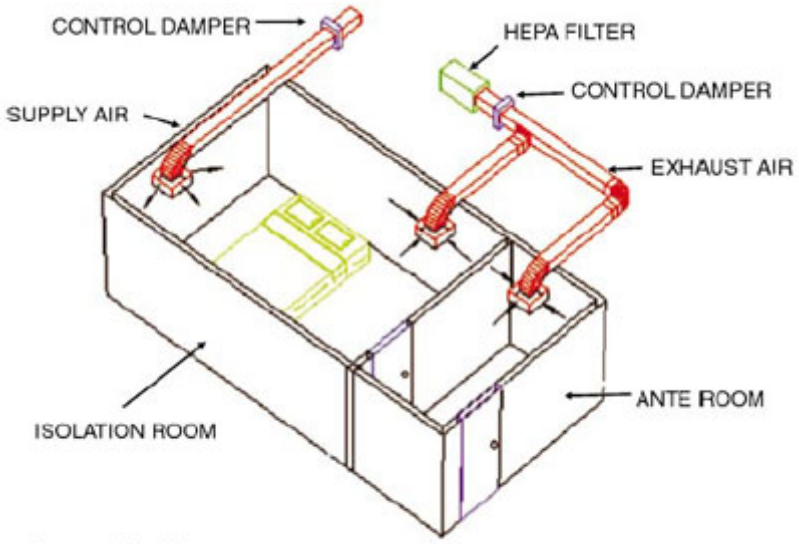

Figure 3: Illustration of airflow pattern & pressure control in isolation rooms

Where are Isolation Rooms Required?

The Centers for Disease Control and Prevention (CDC) TB Guidelines (1994), OSHA TB Enforcement Policy (1996) and proposed TB rule (1997) provide the federal guidelines and regulations for isolation rooms. In April of 2001, the American Institute of Architects (AIA) have called for more stringent practices in the new revision to their 'Guidelines for Design and Construction of Hospital & Health - Care Facilities'. These guidelines require isolation rooms for a number of areas in the health care facility if determined by an infection control risk assessment. These areas include medical and surgical nursing units, critical care units, pediatric care units, newborn intensive care units, emergency service areas, nurseries and also other areas such as renal dialysis, if they require isolation rooms.

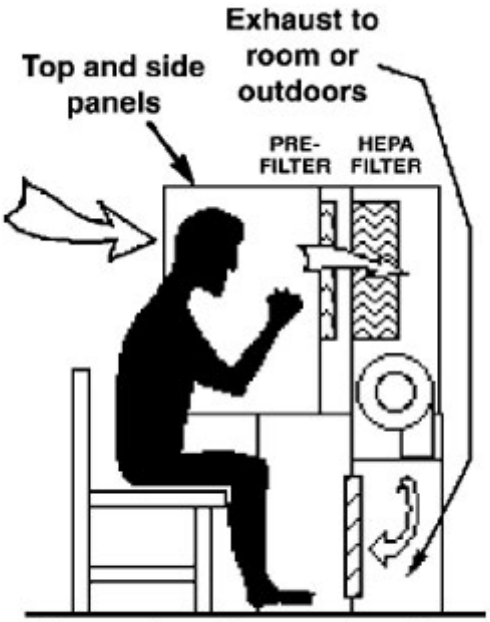

Figure 4 a : Capture hood for source control

Table 1 : Functional classification of isolation rooms

	Class S (Standard)	Class N (Negative)	Class P (Positive)	Class A (Alternating)
Key Ventilation Criteria	No air pressure difference between the room and the adjacent corridor	Lower air pressure in the room than in adjacent corridor	Greater air pressure in the room than in the adjacent corridor	Ventilation controlled to achieve either positive or negative pressure in the room
Transmission based precautions	To prevent contact or droplet transmission	To prevent airborne transmission	To prevent transmission of pathogens from outside environment to immunosupressed patients	Not recommended
Examples	Hepatitis A, meningococcal infection	Measles, chicken pox, tuberculosis	Prevention of infection in bone marrow or organ transplant recipients	Not recommeded

Classification of Isolation Rooms

Table 1 gives a functional classification of isolation rooms. The classification is based on the basic design principle for pressure control of isolation room as illustrated in the isometric view shown in **Figure 3**.

It includes an anteroom or airlock which has three functions:

- To provide a barrier against loss of pressurisation, and against entry / exit of contaminated air into / out of the isolation room when the door to the airlock is opened.
- To provide a controlled environment in which protective garments can be donned without contamination before entry into the isolation room.
- To provide a controlled environment in which equipment and supplies can be transferred from the isolation room without contaminating the surrounding areas.

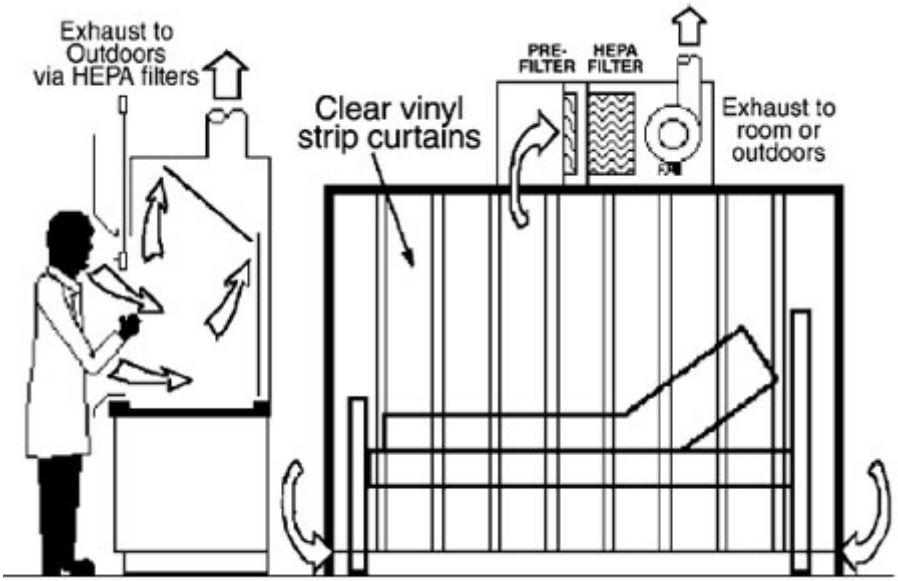

Figure 4b : Fume hood Figure 4c : Isolation tent

In this diagram, air is supplied to the isolation room and exhausted from both the isolation room and the anteroom. The balance of airflow, or the difference exhausted will dictate whether the room experiences positive or negative pressure with respect to ambient. There are different possible airflow configurations for pressure control which are discussed later in this article.

Table 2 : Air change rates and removal efficiencies of airborne contaminants

Minutes Required for :			
Air Changes Per Hour	**90% Removal**	**99% Removal**	**99.9% Removal**
1	138	276	414
2	69	138	207
3	46	92	138
4	35	69	104
5	28	55	83
6	23	46	69
7	20	39	59
8	17	35	52
9	15	31	46
10	14	28	41
12	12	23	35
14	10	20	30
16	9	17	26
18	8	15	23
25	6	11	17

30	5	9	14
40	3	7	10
50	3	6	8

Design Guidelines

The CDC* acknowledges as the second level of importance, the use of engineering controls to prevent the spread and reduce the concentration of infectious droplet nuclei. This includes source control, directional airflow, general ventilation for dilution, removal of contaminated room air and air cleaning through HEPA filteration. The engineering controls also refer to the ultraviolet germicidal irradiation (UVGI) and personal respirators which are not covered in this article.

Source Control

The use of local exhaust ventilation to remove airborne contaminants at or near their source is an effective infection control measure. There are two types of source control ventilation devices that are commonly used. These are capture type and enclosing type.

Figure 4a shows a capture type enclosure that is designed to capture infectious nuclei expelled from an infected person in procedure and treatment rooms. **Figure 4b** shows a hood device used in clinical laboratories when working with highly infectious materials such as *Mycobacterium tuberculosis*. **Figure 4c** shows an isolation tent that is used around the patient's bed or other areas during high risk procedures.

Figure 5a : Sputum induction chamber : Upflow design

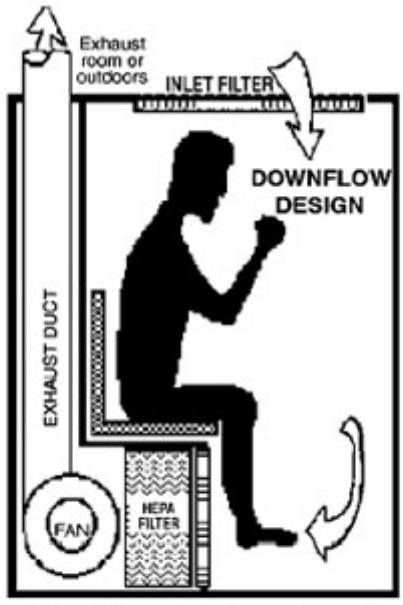

Figure 5b : Sputum induction chamber : Downflow design

Additionally enclosing type devices such as sputum induction chambers (**Figure 5a & 5b**) are available. These enclosures are maintained at a negative pressure with respect to surrounding areas at all times. The exhaust air is passed through HEPA filters and thereafter can be discharged into the room or outside the building. The CDC and OSHA standards recommend 99.9% removal efficiency of the airborne particle during the interval between the departure of one patient and the arrival of the next without respiratory protection.

Air Change Rates

Just one airchange with fresh air can remove 63% of suspended particles from the room air. If a ventilation system can perform 10 airchanges per hour (ACHs), it takes 14 minutes to remove 90% of airborne contaminants in a room and 28 minutes to remove 99%. Thus increased number of fresh air changes per hour is effective for cleaning airborne contaminants. However, the higher air change rate may cause turbulence and the cost for ventilation itself will be too high. Therefore, a recommended compromise of 12 ACHs or more is proposed which should be achievable when the filters have reached their maximum pressure drop.

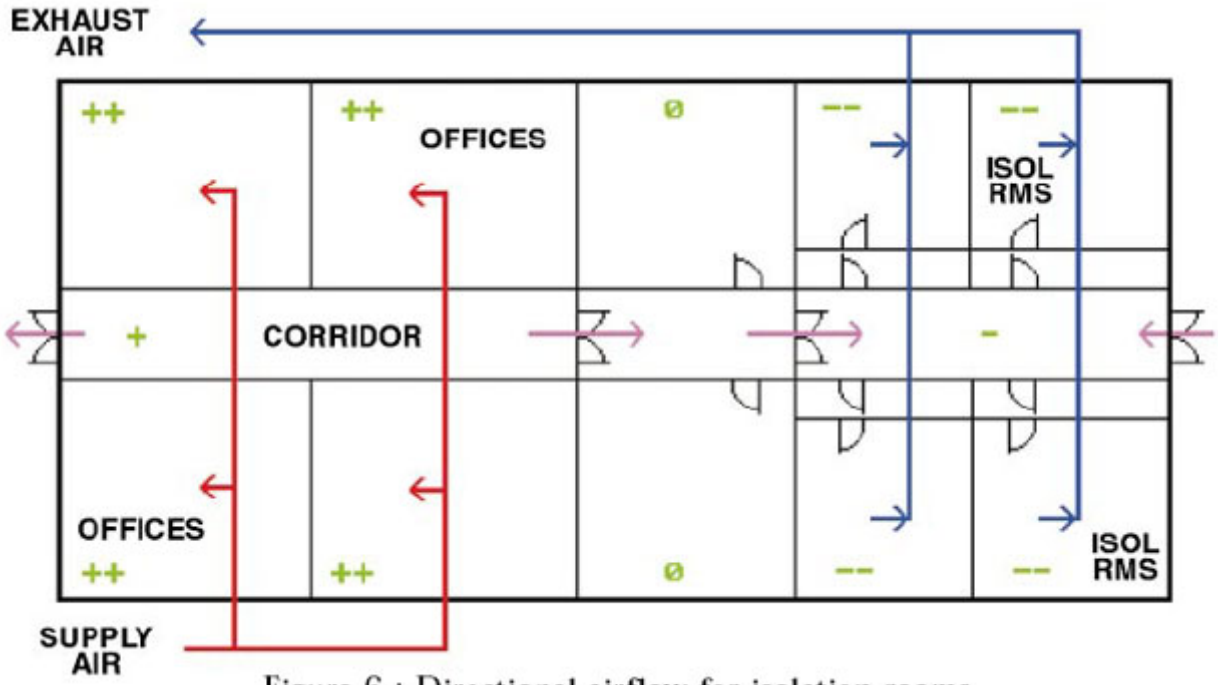

Figure 6 : Directional airflow for isolation rooms

Table 3 : Ventilation air change rates for isolation rooms

CDC Guidelines	Pressure Relationship	Minimum Air Changes or Outdoor	Minimum Total Air	All Air Exhausted	Recirculation of Air Within

	to Adjacent Spaces	Air Per Hour	Changes Per Hour	Directly to Outdoors?	Rooms Allowed?
Infectious Isolation Room (in existing facilities)		-	6	Yes	OPT[A]
Infectious Isolation Room (in new facilities)		-	12	Yes	OPT[A]
ASHRAE '99 Appl. Hbk					
Infectious Isolation Room		2	6[B]	Yes	No
Protective Isolation Room		2	15	Yes	OPT[A]
Isolation Room Anteroom		2	10	Yes	No
AIA Guidelines 1996-97					
Infectious Isolation Room[A]		2	12	-	No
Protective Isolation Room[A]		2	12	-	No
Isolation Room Anteroom[A]		-	10	Yes	No

General Ventilation

The purpose of general ventilation is to dilute and remove contaminants generated in the space. Recommended ventilation rates and pressure relationships for hospital isolation rooms as available in various guidelines is shown in **Table-3**

Directional Airflow

This technique is used to isolate an entire area that can be a group of isolation rooms or a ward for infectious patients. The directional airflow is achieved by pressurisation control by supplying air to areas of least contamination (greatest cleanliness) and stage this air to areas of progressively greater contamination potential. **Figure 6** illustrates the basic principle of cascading airflows from clean areas to relatively contaminated areas.

In the above diagram, a facility is depicted which has offices and isolation rooms, separated by corridors and other areas (storage rooms, labs). Air is supplied to the areas, usually offices, maintained at the greatest positive pressure (marked with a '++'), and

exhausted from the areas maintained at the greatest negative pressure (marked with a '– –'). Transfer air (exfiltration/infiltration) is identified with purple arrows. The unlabeled rooms in the diagram above could be laboratories, which usually have independently operating exhaust hoods or separate ventilation systems. If not, they would be generally designed as double negative pressurization areas.

Air Filtration

For infectious isolation rooms, where recirculation of room air is allowed, the return air should be HEPA filtered. For protective isolation, the supply air should also be HEPA filtered. HEPA filtration can be used as a method of air cleaning that supplements other recommended ventilation measures. HEPA filters should be used:-

- When the HVAC system configuration dictates recirculation of air from the isolation room to other parts of the facility.
- when it is impossible for air from an infectious isolation room and /or local exhaust devices to be exhausted directly outdoors.
- when air is being recirculated into the same infectious isolation room.

The guidelines do not mandate the exhaust air from an infectious isolation room to be HEPA filtered before being discharged outdoors unless there is any chance that the exhaust air could reenter the system. However, there is always a possibility of exhaust re-entry under certain wind and climatological conditions. It is, therefore, preferable to filter all exhaust air.

HEPA filters have an efficiency to capture at least 99.9% particles of all sizes greater than or equal to 0.3 mm. For droplet nuclei, which are considerably larger, the capture efficiency is virtually 100%. HEPA filters should be prefiltered to increase their life and reduce costs. While designing airflow rates, special attention should be given for volume control to compensate for increasing pressure drop over the life of the filters. Filter replacements require bag-in / bag-out procedures to minimise risk of exposure of the maintenance personnel to the infectious material.

Measurement of filter pressure drop and regular monitoring is also recommended.

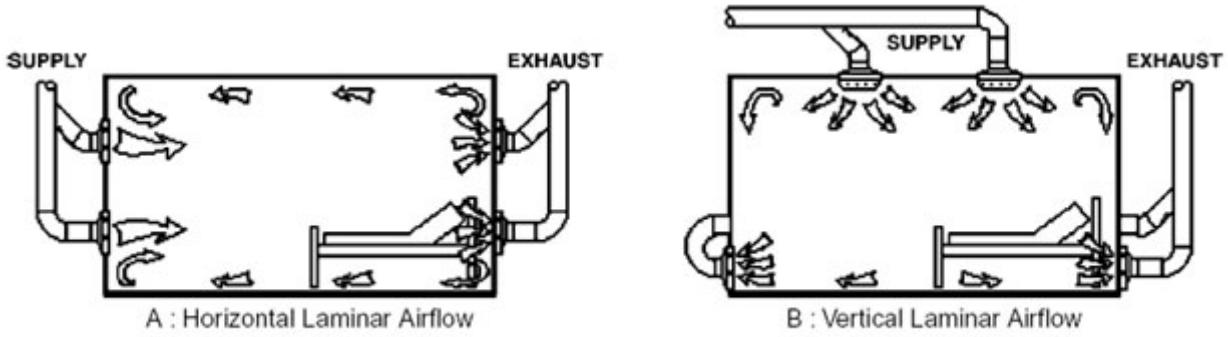

Figure 7 : Room air distribution in isolation rooms

Room Air Distribution

Figure 7 shows two possible room air distribution methods as stated in the CDC guidelines. Laminar (horizontal or vertical) flow distribution is preferable. Introduction of low velocity air near the ceiling at the entrance of the room, flowing past the patient, and exhausted or returned close to the floor at the head of the patient bed. An airflow pattern is thus established which helps to move microorganisms from the point of patient's expulsion to the exhaust / return air terminal to prevent health care workers or visitors from inhaling the bacteria. Air should be supplied through non-aspirating diffusers (typically perforated face) to prevent updrafts and to provide a laminar flow of air which will flush the isolation room of unwanted airborne particles. The diffuser should be placed away from patient bed, preferably near the point where a health care worker or visitor would enter the room. The placement of the diffuser immediately over the patient bed would result in uncomfortable drafts being projected directly at the patient. Room air temperature should be 24°C and humidity should be designed in the range of 30-60 percent.

Supply and Exhaust Air Duct Design

The duct work of a negative pressure isolation room must not communicate with the duct work of the rest of the hospital. Duct work should be designed to reduce the possibility of cross-contamination in the event of fan failure. This can be accomplished by ducting each negative pressure isolation room separately from the air-handling unit. Separate long duct work runs from the air-handling unit increase static pressure and reduce the contaminated airflow in the event of a failure.

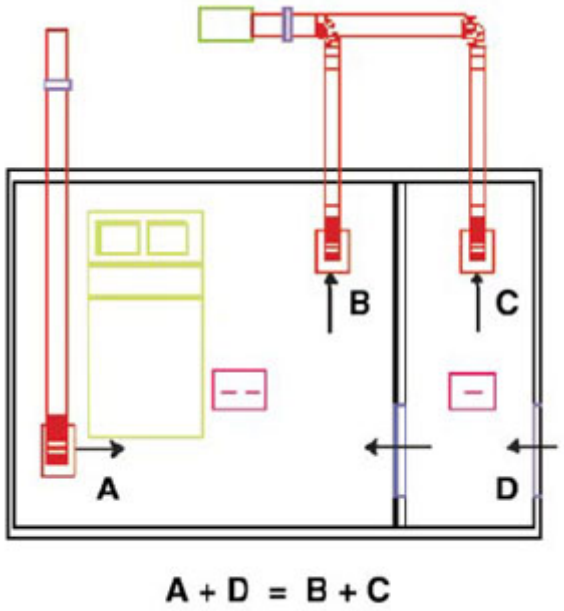

Figure 8 : Negative pressure isolation room

Supply and exhaust systems should be designed as failsafe (for example, using duplex fans) to prevent contamination of any area within the facility in the event of fan failure. The exhaust fan should be located at a point in the duct system that will ensure that the entire duct is under negative pressure within the building.

Negative Pressure Isolation Rooms

Negative pressure isolation rooms (**Figure 8**) maintain a flow of air into the room, thus preventing contaminants and pathogens from reaching surrounding areas.

The air pressure differential which is required to be maintained is 0.001" wg. This is generally accomplished by maintaining an inward velocity of 100 fpm, or exhausting 10% of the airflow, or exhausting 50 cfm more than the supply. There are three possible airflow / control designs which differ in pressure relationship of anteroom to isolation room and the corridor. Refer **Table 4**.

Table 4 : Alternate designs for infectious isolation room airflow

	Design #1I	**Design #2I**	**Design #3I**
RELATIVE PRESSURE RELATION-SHIPS	**Anteroom Negative to Isolation Room and Corridor**	**Anteroom Positive to Isolation Room and Corridor**	**Anteroom Net Neutral; Negative to Room, Positive to Corridor**
Isolation Room to Corridor	⊖	⊖	⊖
Anteroom to Corridor	⊖ ⊖	⊖	⊕
Toilet Room to			

Corridor

Design # 1 I : Anteroom negative to isolation room and corridor

This design has two advantages: There is no need to supply air to and delicately balance the anteroom, and if the anteroom becomes contaminated there is still a pressure buffer between the anteroom and the corridor. The disadvantage is; since the anteroom is negative with respect to the isolation room, the chance of contaminating the anteroom is higher.

Design # 2 I : Anteroom positive to isolation room and corridor

This design also has two advantages. There is no need to exhaust air from and delicately balance the anteroom, and since the anteroom is positive with respect to the isolation room, the change of contaminating the anteroom is lower. The disadvantage is: If the anteroom does become contaminated, it is likely that the corridor will become contaminated as well. So, this design is not recommended.

Design # 3 I : Anteroom net neutral; positive to isolation room and negative to corridor

This design incorporates the best features of the other two designs. The advantages are: Since the anteroom is positive with respect to the isolation room, the chance of contaminating the anteroom is lower, and if the anteroom becomes contaminated, there is still a pressure buffer between the anteroom and the corridor. The disadvantage is increased cost and complexity of the controls and balancing.

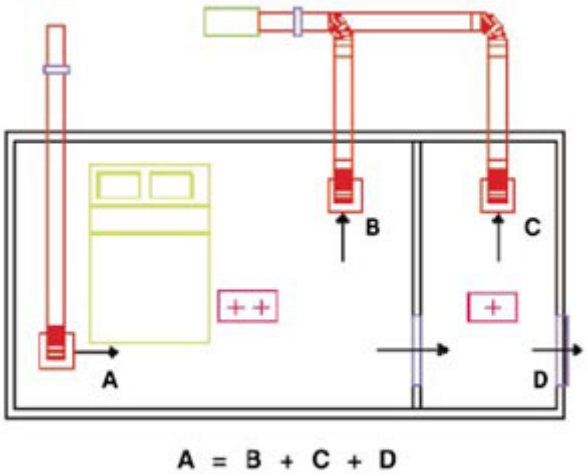

Figure 9 : Positive pressure isolation room

Positive Pressure Isolation Rooms

Positive pressure isolation rooms (**Figure 9**) maintain a flow of air out of the room thus protecting the patient from possible contaminants and pathogens which may otherwise enter. The application of these rooms is for immuno-suppressed patients. The design criteria for positive pressure isolation rooms are similar to the negative pressure isolation rooms with the only difference that the supply air is filtered through HEPA filters. There are three possible airflow / control designs for positive pressure isolation rooms which differ in pressure relationship of anteroom to the isolation room and the corridor. Refer **Table 5**.

Table 5: Alternate designs for positive isolation room airflow

	Design #1P	Design #2P	Design #3P
RELATIVE PRESSURE RELATION-SHIPS	**Anteroom Negative to Isolation Room and Corridor**	**Anteroom Positive to Isolation Room and Corridor**	**Anteroom Net Neutral; Negative to Room, Positive to Corridor**
Isolation Room to Corridor	+	+ +	+
Anteroom to Corridor	−	+	+
Toilet Room to Corridor	−	−	−

Design # 1 P : Anteroom negative to both isolation room and corridor

This design has two advantages: There is no need to supply air to and delicately balance the anteroom, and if the anteroom becomes contaminated there is still a pressure buffer between the anteroom and the corridor. The disadvantage is: Since the anteroom is negative with respect to the corridor, the chance of contaminating the anteroom is higher.

Design # 2 P : Anteroom positive to both isolation room and corridor

This design also has two advantages. There is no need to exhaust air from and delicately balance the anteroom, and since the anteroom is positive with respect to the corridor, the change of contaminating the anteroom is lower. The disadvantage is: If the anteroom does become contaminated, it is likely that the isolation room will become contaminated as well. So, this design is not recommended.

Design # 3 P : Anteroom net neutral; negative to isolation room and positive to corridor

This design incorporates the best features of the other two designs. The advantages are: Since the anteroom is positive with respect to the corridor, the chance of contaminating the anteroom is lower, and if the anteroom becomes contaminated, there is still a pressure buffer between the anteroom and the isolation room. The disadvantage is increased cost and complexity of the controls and balancing

Energy Conservation

The use of 100% outside air in Class N isolation room is relatively energy-intensive. However, the use of heat recovery wheels is not recommended (unless incoming air is also HEPA filtered) due to possible cross-contamination of incoming clean side air. Devices such as run around coils are more appropriate.

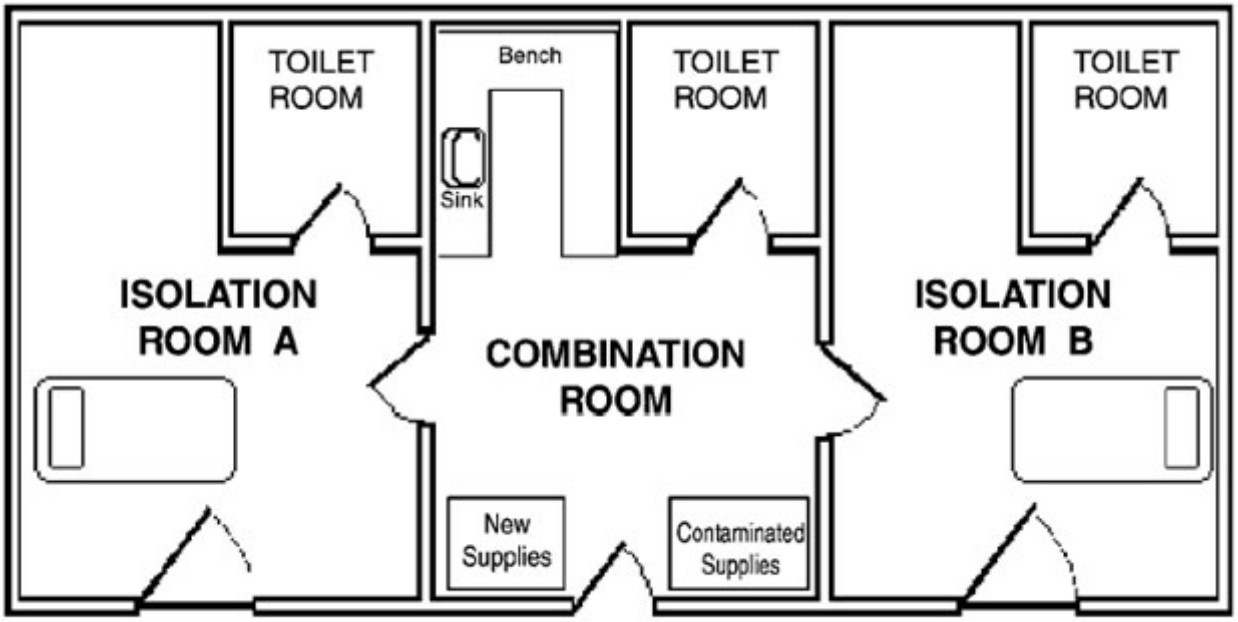

Figure 10 : Creating isolation rooms from existing patients rooms

Renovations

During renovations of existing patient rooms, there may not be enough space available to create an anteroom. A possible solution is to create two isolation rooms and a common anteroom from three existing patient rooms. **Figure 10** shows a possible layout for such conversion.

The isolation rooms should be airtight and well-sealed from the surroundings to help maintain the pressure differential. All utility penetrations through walls / ceilings must be properly sealed.

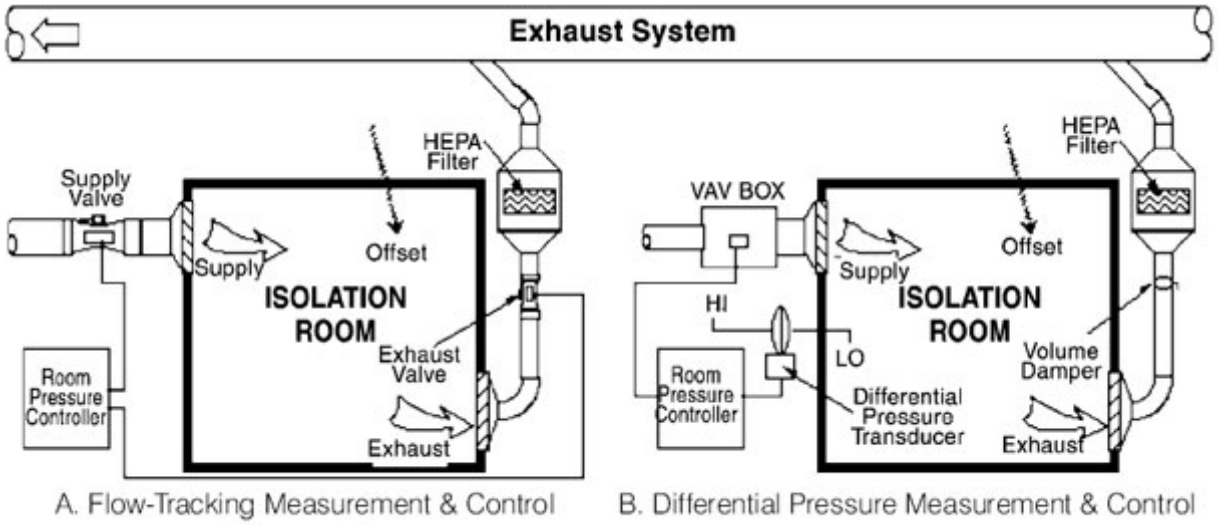

Figure 11 : Isolation room differential pressure control measurements

Room Pressure Controls

The two common methods of isolation rooms differential pressure control are Flow Tracking measurement & control and Differential Pressure measurement & control (**Figure 11**). In flow tracking system, the exhaust and supply flow rates from and to space are measured and controlled to produce a desired infiltration or exfiltration.

In differential pressure system, the actual differential pressure between the isolation room and the corridor is taken by measuring the velocity of air induced through a hole in the envelope between the isolation rooms and corridor created by the differential pressure.

However, the magnitude of this differential pressure being too small, it is affected by other factors like building stack effects, elevator effects, wind etc., and as such it is difficult to measure. There are accurate ultra-low-differential pressure transducers available, but their cost is very high.

Neither OSHA, nor CDC require the use of room differential pressure monitors but both agencies accept their use, provided that they measure down to 0.001" wg.

As a minimum, air pressure relationships from the isolation room to the adjacent anteroom or corridor should be indicated with a mechanical gauge. Air pressure drop across filters should be indicated with a mechanical gauge or manometer.

Programmable microprocessors with features like temperature and humidity control, system status, continuous data logging, malfunction display, visual alarms, air changes per hour, display and monitoring, pressure indication and remote monitoring and alarm are also available nowadays.

Emergency Rooms & Reception Areas

In public areas of a health care facility such as an emergency room, reception and waiting areas, persons with undiagnosed active infection can come in contact with and infect others prior to examination and treatments. As such, these areas should be maintained at negative pressure to prevent contaminated air from reaching sensitive areas. Return air from these areas should be either HEPA filtered or to a minimum 95% filtered. This will remove all or most of the infectious droplet nuclei.

TB is posing an ever-increasing threat in health care facilities. Patients get admitted in hospitals for getting healthy but can contract TB infection during their stay for treatment in the hospitals. Preventing the transmission of TB and other infectious diseases, requires the use of both old proven methods as well as new technology in HVAC system design.

This article touched upon new guidelines, practices, techniques and technologies in HVAC system design for isolation rooms, addressing the need to upgrade infection control. When these are applied prudently and correctly, the risk of infection transmission can be significantly controlled.

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