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HVAC Systems for Inpatient Rooms

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ABSTRACT

Different types of air-conditioning systems, including constant-air-volume air systems, variable-air-volume air systems, fan coil systems, other terminal unit systems, induction units, etc., are described in this paper. Different types of rooms are described. The advantages, disadvantages, and different maintenance needs of a variety of air-conditioning systems, including constant-air-volume air systems, variable-air-volume air systems, fan coil systems, terminal unit systems, dual-duct systems, and induction unit systems are reviewed. It concludes that air systems probably are the most advantageous systems for inpatient care spaces.

INTRODUCTION

Inpatient spaces are defined in a companion paper by Gallivan et al. (2000). This paper describes HVAC issues and factors that should be considered before establishing HVAC design criteria. As patient length of stay (LOS) becomes shorter, patients are sicker and require more intervention, technology, and staff support as well as local HVAC system control capability. The air quality and filtration of conditioned air supplied to patients also need to be carefully reviewed.

HVAC SYSTEM DESIGN REQUIREMENTS

The HVAC system in a patient room is one of the more critical features as it provides him or her with a feeling of comfort and aids in recovery and treatment. Tables 1, 2, 3, and 4 provides a general description of HVAC system requirements collected from different standards. The very differences illustrate the difficulty of finding a common ground for design. The following sections provide certain guiding principles that can be used for HVAC system design for specific room types and also for other rooms not discussed here. The major components are described below.

Ventilation

Ventilation standards and guidelines for indoor air quality have been published by ASHRAE (1999a), the Federal Health Resources and Services Administration, and AIA (1996). Meeting these standards should reduce the probability of infection transmission in clinical settings; however, some highly infectious patients may transmit infection even if these ventilation standards and guidelines are met. The ventilation mechanism can be described as follows:

Dilution and Removal of Airborne Contaminants. Dilution reduces the concentration of contaminants in a space by introducing air that does not contain those contaminants into the space. Air is then exhausted directly to the outside or returned to the ventilation system of the building. Continuously recirculating air back to the HVAC system in a space without introducing proper rates of exchange of outdoor air may result in a concentration of contaminants. Air exhausted to the outside should be away from intake vents, people, and animals ASHRAE (1999a).

Air Mixing. Proper ventilation requires that mixing of air (ventilation efficiency) within a space must be adequate (see discussion of *K* factor later in this paper). Air mixing can be enhanced by locating air supply outlets at the ceiling level and exhaust outlets near the floor, thus providing downward movement of clean air through the breathing area to the floor area for exhaust.

Direction of Air Flow. For control of infection transmission, the direction of air flow is also critical. The direction of air flow is determined by the differences in air pressure

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between adjacent spaces, with air flowing from higher pressure space to lower pressure space.

Proper air flow and pressure differentials between areas of a health care facility are difficult to control because of open doors, movement of patients and staff, temperature, and the effect of vertical openings (e.g., stairwells and elevator shafts). An open door between two areas may reduce any existing pressure differential. Air pressure differentials can best be maintained in completely closed rooms. Therefore, doors should remain closed.

For critical areas where air flow direction must be maintained while allowing for patient or staff movement between adjacent areas, an appropriately pressurized anteroom must be provided.

The ventilation rate is usually expressed as room volume air changes per hour (ACH). It is calculated by dividing the larger of exhaust or supply air volume (in cubic feet per hour) by the volume of the room (in cubic feet). As DiBerardinis et al. (1993) points out, this is the *theoretical* air changes per hour. The actual number of ACH depends upon how well the mixing occurs, and this is critically dependent on the design and location of supply and exhaust air outlets. The ratio of the actual to the theoretical ACH is called the *K factor*, and it describes the efficiency of air mixing. The most accurate way to determine air mixing (and K factor) is to measure the decay rate of a tracer gas such as sulfur hexaflouride (SF_6). In the absence of such test data, K factors can be estimated (see ACGIH's [1998] *Industrial Ventilation*).

Unfortunately, most hospital HVAC system designers tend to ignore this fact of mixing. The result is several improperly ventilated patient rooms.

Another criterion for ventilation rate is cubic feet of air per minute (cfm) supplied per occupant of the room space. ASHRAE Standard 62 (ASHRAE 1999a) has become the governing standard in most jurisdictions.

Load Calculations

Cooling Load. The cooling load is made up of external loads or skin loads, internal heat gain, ventilation load, and humidification and dehumidification loads. Figure 1shows the measured internal load for various patient rooms in a major teaching hospital. Figure 1 shows the difference between outpatient and inpatient buildings between older and newer more intensive facilities. The external load is dependent on type of construction, size of windows, external exposure, climatic conditions, and location. The ventilation rate should be sufficient for the patient and one visitor in the room and should take care of the nursing visits and doctor visits, etc., and provide enough capability for adequate ventilation. *ASHRAE Fundamentals* (1997) should be used for this calculation.

Heating Load. The heating load is made up of external loads or skin loads, ventilation load, and humidification loads. *ASHRAE Fundamentals* (1997) should be used for this calculation.

Temperature Control Concept

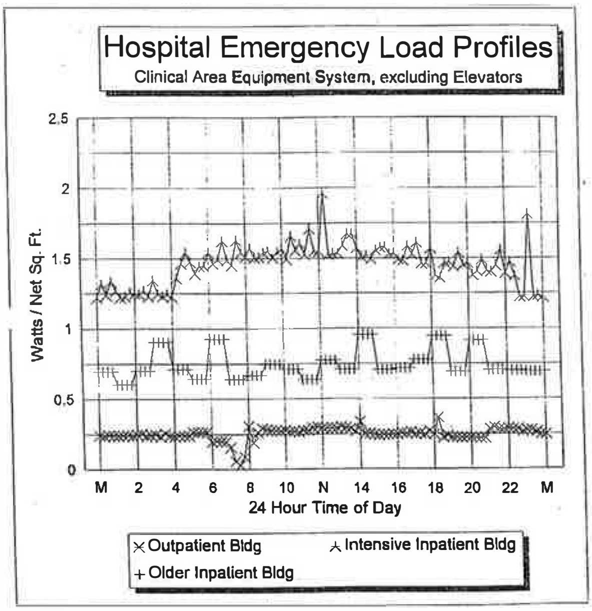
It is recommended that each patient room have individual temperature control. Zoning large areas of patient rooms with a single thermostat creates problems. Different patients may require different temperatures in different rooms depending upon their age, sex, condition, and type of treatment. In addition, visitors sometimes have more vocal statements concerning their loved one's room conditions than the patient, and individual controls help mitigate this problem. Each occupant of a patient room should be allowed to modify the temperature.

This concept, when used, also limits the types of HVAC systems installed in the facility. For example, in a northern climate, a two-pipe fan coil system would be limited in its ability to provide required cooling on a warm spring or fall day.

Humidity Control Concept

Many have advocated local humidifiers for patient rooms and local humidity control. In the writers' opinion, this is not recommended. Central humidifiers that provide reasonable central humidity will work best. Of course, that is only possible with an all-air system. Maintaining a good central humidity system provides an adequate range of humidity in each patient room.

The type of humidification needs to be carefully reviewed. The contamination danger to patients via air or droplet nuclei with bacteria in the air is quite high if humidification is not done appropriately. Several methods of humidification are available:



Source: Stymiest, D., Electrical Load Profiles of Hospital Systems, APEx Program SASHE Paper, American Society for Healthcare Engineering, Chicago, IL, January 15, 1996.

Figure 1 *Measured internal load for patient rooms.*

- Direct steam injection
- Water spray
- Evaporative cooling system

The direct water spray method is not recommended, as its control of Legionella bacteria and other airborne pathogens is almost impossible. Direct steam injection is the most common method. However, the source of steam needs to be carefully reviewed. Many steam boiler systems have water treatments that allow possible contamination of the steam introduced into the supply air, with IAQ problems later on. Evaporative cooling may be used in special conditions. Local humidifiers in general are not recommended. Most patient rooms, with the exception of critical and intensive care areas, do not require very close humidity control, and local humidifiers are usually not well designed, controlled, or installed. In many cases, improperly designed and installed units cause water droplets and/or steam vapor to enter patient rooms, and operating personnel end up securing these humidifiers as inoperable. The monies spent for installation of these units is then wasted. Where very close humidity tolerance is required, local humidifiers will need to be installed. In such cases, very careful design to ensure proper air to steam vapor mixing is vital.

Dehumidification

The most common form of dehumidification is subcooling the air to the saturation point. This is sufficient, as the typical patient room does not have a large latent load.

DDC vs. Traditional Controls

The most common traditional control system is pneumatic, which has the advantage of being well known and simple. However, it fails to meet the need of many new requirements in patient rooms. To confirm that IAQ requirements are being met, it may be necessary to have the ability to monitor patient rooms remotely for temperature, humidity, air change rates, and pressure differential with adjacent areas if required. Alarms may be required to inform clinical caregivers and/or HVAC system operations if conditions deviate from the derived norm. Direct digital control (DDC) systems provide an excellent alternative.

Filtration

The minimum filtration required for inpatient care spaces is defined in Tables 1, 2, 3, and 4, which summarize various industry recommendations and standards from AIA (1996), ASHRAE (1996), and BOCA (1993). However, there is a thought in the health care industry that such minimum filtration may not be adequate. Some health care providers suggest that in certain types of care all patients should receive 100% HEPA-filtered air. In the writers' opinion, this suggestion should be carefully reviewed and its implications understood. For example, this requirement usually limits the HVAC design to an all-air system and it increases operating cost both in filter replacement and ongoing energy cost. Patients are visited by friends and family in street clothes and shoes. This outer apparel may be a source of more contamination.

In certain transplant rooms, ULPA filtration (filtration efficiencies 99.99995% with 0.12 micron particles) may be used. HEPA filters, which remove at least 99.97% of particles 0.3 microns in diameter, have been shown to be effective in clearing the air of *Aspergilus* spores, which are in the size range of 1.5 to 6 microns. The ability of HEPA filters to remove tuberculous bacilli from the air has not been studied, but tuberculosis-containing droplet nuclei are approximately 1 to 5 microns in diameter, about the same size as *Aspergilus* spores; therefore, HEPA filters theoretically should remove infectious droplet nuclei. HEPA filters may be used in general-use areas and TB isolation rooms. Using HEPA filters

TABLE 1
Environmental Requirement for General Patient Care

		Guidelines for Construction and Equipment of Hospital Medical Facilities				ASHRAE Standards	BOCA
		1996-1997	1992-1993	1987	1983	1995	1993
1	Air movement relationship to adjacent area	-	-	-	-	-	-
2	Minimum air changes of outside air per hour	2	1	-	-	2	-
3	Minimum total air changes per hour	2	2	2	2	4	-
4	All air exhausted directly to outdoors	-	-	-	-	-	-
5	Recirculated by mean of room units	-	-	-	-	-	-
6	Relative Humidity (%)	-	-	-	-	30-50	30
7	Design temperature (F)	70-75	70-75	70-75	70-75	75	70-78
8	Minimum CFM of outside air/person/hour	-	-	-	-	-	25
10	Final filter efficiencies(%)	90	90	90	90	90	-

TABLE 2
Environmental Requirement for Infections Isolation Patient Care

		Guidelines for Construction and Equipment of Hospital Medical Facilities				ASHRAE Standards	BOCA
		1996-1997	1992-1993	1987	1983	1995	1993
1	Air movement relationship to adjacent area	NEG	NEG	NEG	NEG	NEG	-
2	Minimum air changes of outside air per hour	2	1	-	-	2	-
3	Minimum total air changes per hour	12	6	6	2	4	-
4	All air exhausted directly to outdoors	-	YES	YES	YES	YES	-
5	Recirculated by mean of room units	NO	NO	NO	NO	NO	-
6	Relative Humidity (%)	-	-	-	-	30-60	30
7	Design temperature (F)	70-75	70-75	70-75	70-75	75	70-78
8	Minimum CFM of outside air/person/hour	-	-	-	-	-	25
9	Prefilter efficiencies (%)	25	25	25	25	25	-
10	Final filter efficiencies(%)	90	90	90	90	90	-

TABLE 3
Environmental Requirement for Protection Isolation Patient Care

		Guidelines for Construction and Equipment of Hospital Medical Facilities				ASHRAE Standards	BOCA
		1996-1997	1992-1993	1987	1983	1995	1993
1	Air movement relationship to adjacent area	OUT	OUT	-	-	OUT	-
2	Minimum air changes of outside air per hour	2	1	-	-	2	-
3	Minimum total air changes per hour	12	6	-	-	15	-
4	All air exhausted directly to outdoors	-	-	-	-	yes	-
5	Recirculated by mean of room units	NO	NO	-	-	-	-
6	Relative Humidity (%)	-	-	-	-	30-60	30
7	Design temperature (F)	70-75	70-75	-	-	72	70-78
8	Minimum CFM of outside air/person/hour	-	-	-	-	-	15
9	Prefilter efficiencies (%)	25	25	-	-	25	-
10	Final filter efficiencies(%)	90	90	-	-	90	-

TABLE 4
Environmental Requirement for Critical and Intensive Care

		Guidelines for Construction and Equipment of Hospital Medical Facilities				ASHRAE Standards	BOCA
		1996-1997	1992-1993	1987	1983	1995	1993
1	Air movement relationship to adjacent area	-	-	-	-	-	-
2	Minimum air changes of outside air per hour	2	2	2	2	2	-
3	Minimum total air changes per hour	6	6	6	6	6	-
4	All air exhausted directly to outdoors	-	-	-	-	-	-
5	Recirculated by mean of room units	NO	NO	NO	NO	NO	-
6	Relative Humidity (%)	30-60	30-60	30-60	30-60	30-60	30
7	Design temperature (F)	70-75	70-75	70-75	70-75	75-80	70-78
8	Minimum CFM of outside air/person/hour	-	-	-	-	-	25
9	Prefilter efficiencies (%)	25	25	25	25	25	-
10	Final filter efficiencies(%)	90	90	90	90	90	-

to recirculate air from an isolation room back into the general circulation is acceptable in renovated spaces. For new construction, it should be avoided.

Filter efficiencies are defined in ASHRAE (1999b). To provide a quick reference, HEPA filters are aerosol filters capable of minimum efficiency of 99.97% when challenged with a thermally generated dioctylphthalate (DOP) aerosol whose particle size is 0.3 microns and that is homogeneous monodispersed. ULPA filters are similarly defined with an efficiency of 99.99%.

When HEPA filters are used, the air-handling system must be designed to ensure adequate supply and exhaust capacity. Proper installation, testing, and meticulous maintenance are critical if a HEPA filter system is used. Poor design, installation, or maintenance could permit infectious particles to circumvent filtration and contaminate the ventilation air. The filters should be installed to prevent leakage between filter segments and between the filter bed and its frame. Every new and replacement installation should be challenged and certified by qualified personnel. A regular maintenance program is required to monitor HEPA filters for possible leakage and for filter loading. An air pressure drop monitor should be installed in the filter system to provide an accurate means of objectively determining the need for filter replacement. Installation should allow for maintenance without contaminating the delivery system or the area served.

In certain cases HEPA filters can be used for recirculated air. However HEPA-filtered, recirculated air should **not** be used if the contaminants contain carcinogenic agents.

If air from potentially contaminated general-use areas (e.g., emergency rooms or clinic waiting areas) cannot be exhausted directly to the outside, HEPA filters may be useful for removing infectious organisms from air before its recirculation in a room or before its return to common supply ducts. In new construction, HEPA filters should not be used to recirculate air from a tuberculosis isolation room back into general circulation. In renovations, when direct exhaust to the outside is not possible, recirculation is acceptable.

HEPA filtration is used for general areas (e.g., emergency rooms and waiting areas) of health care facilities. Recirculating the air is an alternative to using large percentages of outside air for general ventilation. If air is recirculated, care must be taken to ensure that infection is not transmitted in the process.

Perimeter Heat

In northern climates patient room heating is required in winter. This can be achieved by either installing baseboard radiation along the exterior wall or a heating element in the unitary system or supplying heating air along the length of the exterior window. The control of these heating elements must be coordinated with the overall room control to prevent wide variations of the temperature in the room as well as prevent simultaneous heating and cooling.

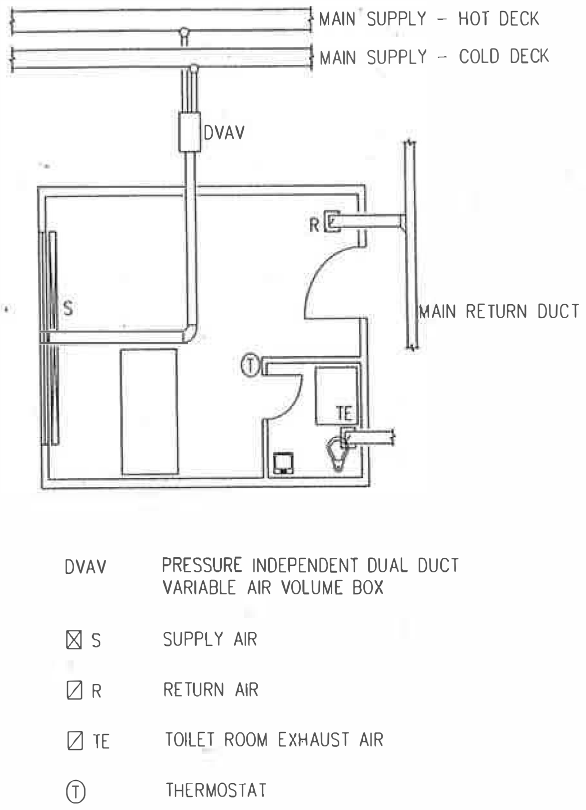


Figure 2 *General patient room dual-duct variable air volume box.*

The decontamination needs of baseboard radiation must be taken into consideration. In most patient rooms this is not a problem. In certain cases, open fin baseboard units can accumulate dust and may be problematic.

Reheat

Usually hot water reheat coils are connected to a hot water piping system. Some times dual-duct systems as described below can also provide heating.

Dual-Duct Systems

Two sets of ducts are needed, one carrying cold air, the other hot air, to terminal boxes that mix hot and cold air to satisfy a room temperature controller. The two airstreams are used for temperature control and are referred to as the hot deck and the cold deck. DD systems may be constant volume or variable volume. In variable-volume systems, there is a minimum turndown level at the terminal box to maintain temperature at all times. A dual-duct system is illustrated in Figure 2.

TYPICAL PATIENT ROOM HVAC SYSTEM OPTIONS

The following is a short description of various common types of patient room HVAC design options, their advantages

TABLE 5
Constant Volume Systems

Advantages	Disadvantages	Remarks
No moving parts.		Less maintenance.
	Requires year-round reheat system availability.	High energy usage. Requires constant reheat of supply air to maintain space temperature.
Can be very quiet.		
Central primary air system can provide excellent filtration.		
Requires primary air risers at any location. Requires limited shafts. Usually many units are served with one primary air riser.		Less expensive. Only limited numbers of shafts need to be rated. Fire dampers may be needed at wall penetration.
Local humidification is possible.		Central air system can provide better humidity control. Local humidification is not recommended.
Does not require schedule maintenance.		

and disadvantages. The list is by no means exhaustive. There may be some hybrid systems in use. However, the reader can use the general principles behind this discussion to evaluate systems not discussed here. It should be noted that, although patient room layouts will vary, the HVAC system elements are usually the same.

Constant Air Volume with Reheat

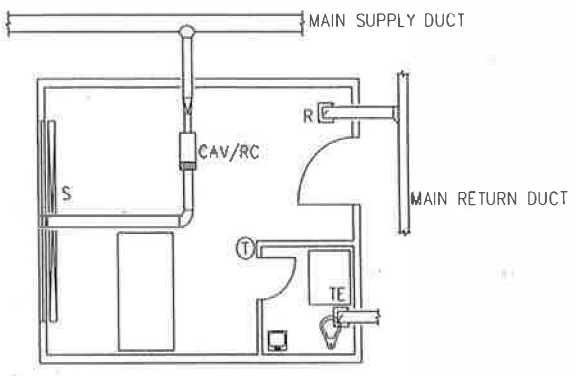
A constant volume of conditioned air is supplied to the patient care space through a terminal unit from the central air-conditioning system at dew-point and dry-bulb temperatures low enough to balance the maximum expected cooling and humidity load, and sensible heat is added as required to maintain space temperature through reheat coils. The reheat coil is located in the room air terminal unit (see Figure 3). Table 5 lists advantages and disadvantages of constant-volume systems.

Fan Coil Unit with Central Ventilation

Chilled water and or warm water is supplied to the coil(s) of the room fan coil unit. The ventilation air volume should be the larger of what is required by codes and recommended by engineering standards. It can be separately supplied to the patient care space or directly ducted to the fan coil unit (see Figure 4). The flow of chilled water and/or hot water through the coils automatically modulates to balance the room cooling/heat load and maintain space temperature. Table 6 lists advantages and disadvantages of fan coil systems.

Fan-Powered Box with Central Ventilation

The ventilation air volume should be the larger of what is required by codes and recommended by engineering standards. It can be separately supplied to the patient care space or directly ducted to the fan-powered box (see Figure 5). The system is very similar to either a constant-volume or variable-volume system, with one major exception—a local fan in the terminal box supplies more air than the primary air supplied. The flow of hot water through the reheat coil, if provided, can further automatically modulate to balance room cooling/heat load and maintain space temperature. This system can be used for certain types of isolation room as well for transplant rooms.



CAV/RC — PRESSURE INDEPENDENT CONSTANT AIR VOLUME BOX WITH REHEAT COIL

S — SUPPLY AIR

R — RETURN AIR

TE — TOILET ROOM EXHAUST AIR

Ⓣ — THERMOSTAT

Figure 3 *General patient room constant air volume box with reheat.*

TABLE 6
Fan Coil System

Advantages	Disadvantages	Remarks
	Moving parts.	More maintenance.
	Not quiet.	Noise problems may occur.
Local control.		May lose temperature control during changing seasons if two-pipe fan coil system is installed.
	Requires local filtration.	More maintenance.
	Patient room is out of commission during routine maintenance.	Most fan coil units are located inside patient rooms. Requires primary air risers at any location. Requires limited shafts. Usually many units are served with one primary air riser.
Local humidification is possible.		Central air system can provide better humidity control. Local humidification is not recommended.

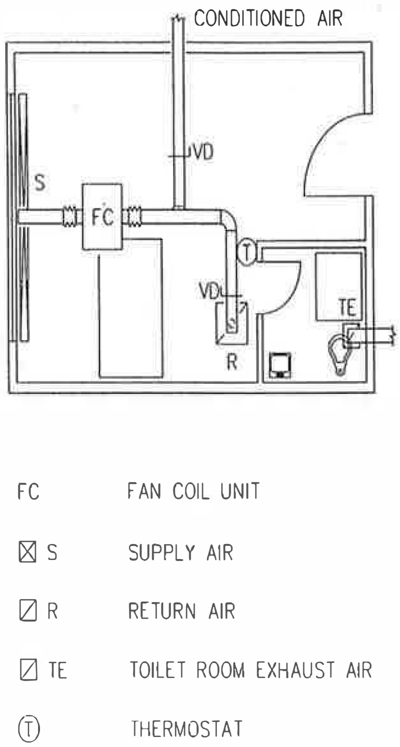


Figure 4 *General patient room fan coil unit with central ventilation.*

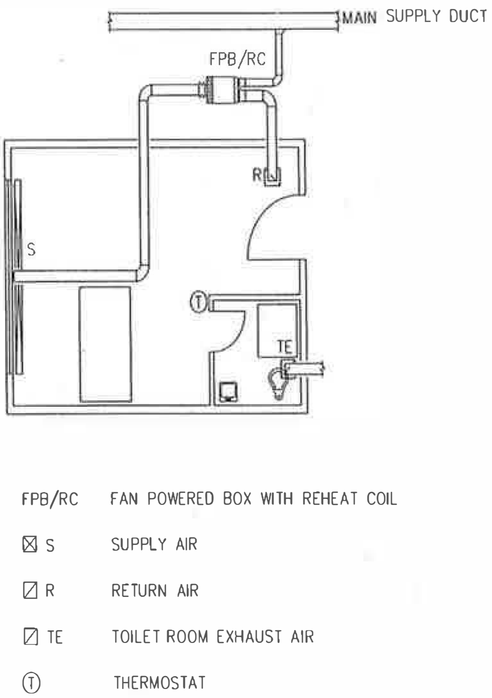


Figure 5 *General patient room fan-powered box with reheat.*

In some cases, instead of a fan-powered box, a small separate fan, sized just to overcome the pressure drop of the final filter, can be provided. Table 7 lists advantages and disadvantages of a fan-powered box system.

Induction Units/Systems

The induction system consists of an air supply from a central air handler that can be either a high-pressure or low-pressure system connected to a terminal unit (see Figure 6). The main air is called primary air and is released via nozzles. This change of pressure "induces some of the room air to also flow," hence, the name "induction." The space temperature control is maintained from reheat coils, and the control valve is controlled from the room thermostat. Variations of the system are listed below.

TABLE 7
Fan-Powered Box System

Advantages	Disadvantages	Remarks
	Moving parts.	More maintenance.
	Not quiet.	Noise problems may occur.
Local control.		
	Requires local filtration.	More maintenance.
Central primary air system can provide filtration as well as local filters.Certain patient rooms require HEPA local filtration and can be accommodated with this option.		
	Patient room is out of commission during routine maintenance.	Host fan-powered boxes are located inside patient rooms.
Requires primary air risers at any location. Requires limited shafts. Usually many units are served with one primary air riser.	Less expensive. Only limited number of shafts need to be rated. Fire dampers may be needed at wall penetration. Local humidification is possible.	Central air system can provide better humidity control. Local humidification is not recommended.

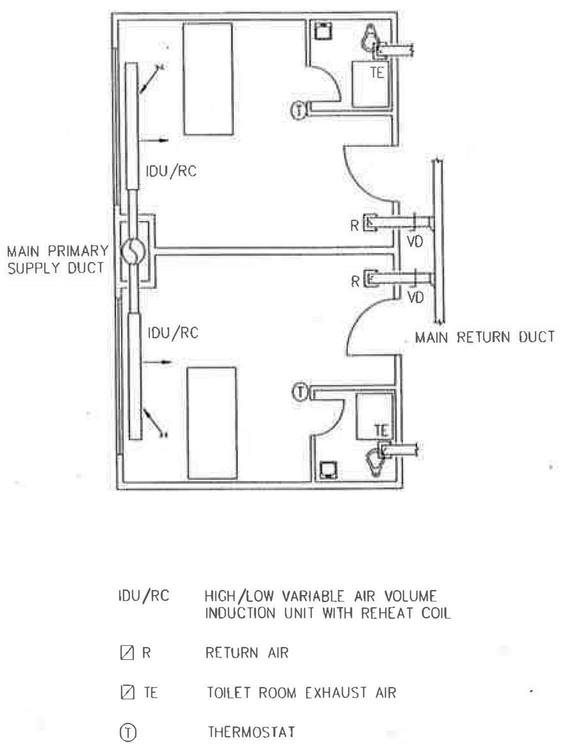


Figure 6 *General patient room induction unit with reheat.*

Low-Pressure Induction Unit. The conditioned air from a central air-handling system is delivered at 0.2 to 0.5 in. w.g. pressure to a room induction unit.

High-Pressure Induction Unit. The conditioned air from a central air-handling system is delivered at more than 0.5 in. w.g. pressure to a room induction unit.

Variable-Air-Volume Induction Unit. Variable-air-volume induction units modulate the amount of primary air to a minimum acceptable value. The induction ratio of one primary air to three volumes of room air provides satisfactory room air motion and distribution. When required, the reheat coil in the induction unit modulates hot water flow to maintain space temperature. Table 8 lists advantages and disadvantages common to all induction systems.

Self-Contained Air-Conditioning Unit with Central Ventilation or Incremental Systems

This system consists of local units installed in each patient room. These could be window units through the wall heating and cooling units, heat pumps, or a combination (see Figure 7).

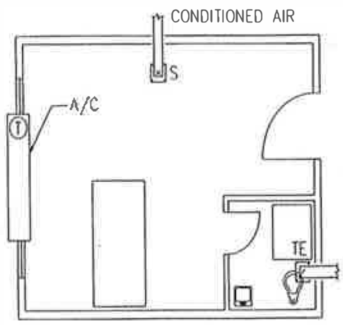
A self-contained air-conditioning unit or room air conditioner cooling capacity is provided to the space by direct-expansion (DX) systems. Heat from the space is rejected through condenser air that is discharged outdoors, or, in the case of an air-to-water heat pump, the heat could be rejected by a central cooling tower or condenser. Space temperature is controlled by a room unit thermostat. The ventilation air required by code is separately supplied to the space. The advantages and disadvantages of such a system are listed in Table 9.

Variable Air Volume with Reheat

Conditioned air at designed dry-bulb and wet-bulb temperature is supplied from the central air-handling system and distributed to the patient care space through variable-air-volume terminal units (see Figure 8). Air in to the room(s) is modulated according to the load to maintain space temperature. When the amount of conditioned air is throttled or reduced to a predetermined minimum quantity required by code and standards, the supply air volume is no longer

TABLE 8
Variable Air Volume Induction Unit

Advantages	Disadvantages	Remarks
No moving parts.		Less maintenance.
Quiet.		No noise problems.
Local control.		
	Picks return air at floor level.	Might pick up unwanted contaminants from floor.
	No local filtration is possible. Manufacturers only offer lint screen as option.	Certain patient rooms require local filtration option. Lint screen does not meet hospital filtration standard.
	Requires primary air risers at outside wall. Requires multiple shafts. Usually two units are served from one primary air riser at each level.	Expensive. Each shaft needs to be rated. Fire dampers may be needed at wall penetration
	No local humidification is possible.Central air system can have humidity control.	
	Requires year-round reheat system availability.	
	Patient room is out of commission during routine maintenance.	Unit requires schedule maintenance—deposit of partial from return air.



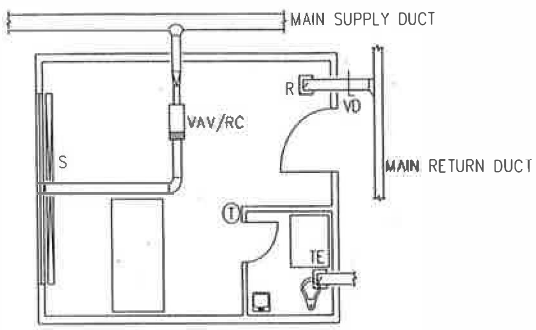
A/C INCREMENTAL UNIT

⊠ S SUPPLY/VENTILATION AIR FROM CENTRAL AIR CONDITIONING UNIT

◪ TE TOILET ROOM EXHAUST AIR

Ⓣ THERMOSTAT

Figure 7 *General patient room self-contained air conditioning/incremental unit with central ventilation.*



VAV/RC PRESSURE INDEPENDENT VARIABLE AIR VOLUME BOX WITH REHEAT COIL

⊠ S SUPPLY AIR

◪ R RETURN AIR

◪ TE TOILET ROOM EXHAUST AIR

Ⓣ THERMOSTAT

Figure 8 *General patient room variable air volume box with reheat.*

reduced. Sensible reheat is provided by reheat coil to provide comfort and maintain space temperature. Reheat can also be provided by a hot deck duct system in a dual-duct system (see description of dual-duct system for details). Table 10 lists advantages and disadvantages of variable-volume systems.

Isolation Room HVAC System Design Criterion

A generic isolation room would have the following features:

- High air change rate per hour (ACH)
- Appropriate filtration (regular hospital grade or HEPA filters)
- Air flow and/or loss of appropriate pressure alarms

TABLE 9
Self-Contained Air-Conditioning Unit with Central Ventilation or Incremental System

Advantages	Disadvantages	Remarks
	Moving parts.	More maintenance.
	Not quiet.	Noise problems may occur. Noise may interfere with clinical care.
Local control.		May loose temperature control in different seasons.
	Requires central air ventilation system.	Certain patient rooms that require HEPA local filtration cannot be served by this option.
For maintenance, only a single room is down. Scheduling problems are limited.		
	No local humidification is possible.	
	Taking ventilation air locally is not possible.	AIA (1996) requires that noncentral air-handling systems, e.g., through-the-wall coil units, be equipped with filters rated at 80% air resistant or more.
	Patient room is out of commission during routine maintenance.	Units located inside patient room.

TABLE 10
Variable-Volume System

Advantages	Disadvantages	Remarks
No moving parts.		Less maintenance.
Can be very quiet.		
Excellent local heating/ cooling control.	Requires year round reheat system availability.	Can be very energy efficient only reheat minimum conditioned air required by code.
Central Primary air system can provide excellent filtration.		
Supply air risers can be at any location. Requires limited shafts. Usually many are served with one primary air riser.		Less expensive. Only limited numbers shaft needs to be rated. Fire dampers may be needed at wall penetration.
Local humidification is possible.		Central air system can provide better humidity control. Local humidification is not recommended.
Do not requires local routine maintenance.		

Care must be taken to consider the HVAC system failure and maintenance requirements. For example, how a contaminated filter is removed is critical and should be thought through. Training of caregivers is important so they may know what to expect once an alarm is annunciated.

Tables 2 and 3 describe specific requirements for different isolation rooms compiled from various standards. The most stringent conditions should become the design standard.

ASHRAE recommends that ventilation in isolation rooms be at least 6 total air changes per hour (ACH), including at least 2 outside air changes per hour. If air is recirculated in the isolation room, it should be passed through properly designed, installed, and maintained HEPA filters before being recirculated.

Air from the room should be exhausted directly to the outside of the building and away from intake vents, people, and animals, in accordance with federal, state, and local regulations concerning environmental discharges.

Isolation-room doors must be kept closed to maintain control over the direction of air flow.

A separate anteroom serves as an excellent airlock to minimize the potential for infection to spread from the patient's area to adjacent areas. To work effectively, the anteroom must have directional airflow. For example, in an area occupied by a patient with infectious tuberculosis, air should flow into the potentially contaminated area (the patient's room) from adjacent areas. The patient's room is said to be under lower, or negative, pressure.

In the case of TB isolation rooms, germicidal UV lamps may be considered as a supplement to ventilation to further decrease the number of infectious droplet nuclei in the air.

Transplant Room HVAC System Design Criterion

There are several similarities between transplant room HVAC systems and protective isolation room HVAC systems. For example, a generic transplant room would also have the following features:

- High air change rate per hour (ACH)
- Appropriate filtration (HEPA filters only)
- Air flow and/or loss of appropriate pressure alarms

Care must be taken to consider the HVAC system failure and maintenance requirements. For example, how a contaminated filter is removed is critical and should be thought through. Training of caregivers is important so they may know what to expect once an alarm is annunciated.

In many cases, laminar flow or modified laminar flow systems are provided (see Figure 9). In many other cases, a local ceiling-mounted HEPA filter air outlet may be more than sufficient. As indicated in Tables 5 and 10, an all-air (either constant volume or variable volume) system is highly recommended as it provides the most flexibility.

HVAC SYSTEM DESIGN RECOMMENDATIONS

In the writers' opinion, an all-air system provides the most flexibility and easily meets patients' requirements. Advantages of all-air systems are as follows:

1. Central filtration, humidification, and cooling, which make the system more efficient.
2. Quiet, no fans running in the room.
3. Can easily pressurize room as long as the door is kept shut.
4. If designed properly, air terminal boxes and reheat coils can be outside the room, negating the need for maintenance personnel to enter the room for routine maintenance.
5. DDC controls can be easily implemented. This provides more precise control and remote monitoring.

MAINTENANCE, CORRECTIVE/PREVENTIVE

There is a definite maintenance need to ensure that the patient rooms are available and also that the patient rooms remain comfortable. Toward this end, we have the following critical items that need to be reviewed:

1. Temperature control
2. Air balance (room air changes)
3. Critical equipment serving the room.

Critical equipment could be anything from a drain pan for a local cooling unit to the monitoring and adjustment of a variable-volume system. It may also be a control valve leaking on a reheat system. Duct cleaning (exhaust particularly) is critical because of linens, filter changing, and maintenance of economizers.

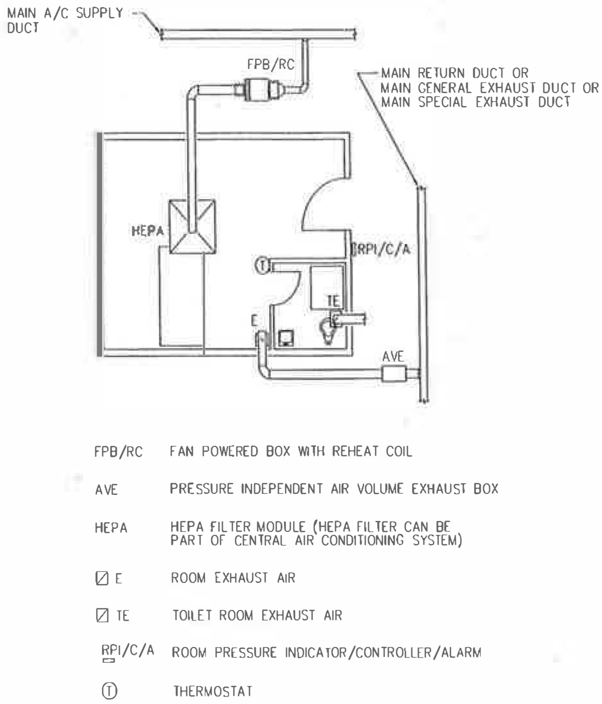


Figure 9 *ICU bone marrow transplant room without vestibule.*

Examples of factors that can change the direction of air flow include the following:

- Dust in exhaust fans, filters, or ducts
- Malfunctioning fans
- Adjustments made to the ventilation system elsewhere in the building
- Various damper positions on an economizer system.

In areas where the direction of air flow is important, trained personnel should monitor air flow frequently to ensure that appropriate conditions are maintained (CDC 1992) The close fit of all doors should be maintained. In protective isolation rooms, the direction of air flow should be monitored while the room is being used. The use of flutter strips provides a means of constantly observing the direction of air flow; smoke tubes or smoke sticks are also a quick, simple means of determining the direction of the air flow.

COMMISSIONING

As one can see from the above descriptions, patient rooms are complex in design as well as operation. The HVAC system plays a most crucial part. Without a well-designed and commissioned system, a good patient comfort level cannot be guaranteed. Maintenance needs have been discussed elsewhere. Regarding commissioning needs, Lawson (1993) describes a detailed process that does not originate at the end of the construction but starts at the very conception of the project.

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