HVAC Design for Healthcare Facilities

Course No: M06-011
Credit: 6 PDH

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SECTION # 1

HVAC FOR HEALTHCARE FACILITIES – AN OVERVIEW

HVAC design for health care facilities is all about providing a safer environment for patients and staff. The basic difference between air conditioning for healthcare facility and that of other building types stem from:

1. The need to restrict air movement in and between the various departments (no cross movement).

2. The specific requirements for ventilation and filtration to dilute and reduce contamination in the form of odor, airborne micro organisms and viruses, and hazardous chemical and radioactive substances. Ventilation effectiveness is very important to maintain appropriate indoor air quality.

3. The different temperature and humidity requirements for various areas and the accurate control of environmental conditions.

4. The design sophistication to minimize the risk of transmission of airborne pathogens and preserve a sterile and healing environment for patients and staff.

These requirements demand very high quantities of outside air along with significant treatment of this ventilation air, including cooling, dehumidifying, reheating, humidifying and filtration.

Infection Control

In a hospital environment, there tend to be high concentrations of harmful micro-organisms. From an infection control perspective, the primary objective of hospital design is to place the patient at no risk for infection while hospitalized. The special technical demands include hygiene, reliability, safety and energy-related issues.

Infections, which may result from activities and procedures taking place within the facility, are a cause for great concern. Three main routes responsible for infections are contact, droplet, and airborne transmission, which are quite affected by room design and construction factors.

Contact Transmission

Contact transmission is the most important and frequent mode of transmission of infections (nosocomial). It can be subdivided into direct-contact transmission and indirect-contact transmission.

a) Direct-contact transmission involves direct body to body contact for the transfer of micro-organisms from an infected person to a susceptible host.

b) Indirect-contact transmission involves the contamination of an inanimate object (such as instruments or dressings) by an infected person.

Droplet Transmission

Droplet transmission occurs when an infected person generates droplets containing microorganisms which are propelled at a short distance through the air and deposited on the conjunctivae, nasal mucosa or mouth of a host. Droplets do not remain suspended in the air, so special air handling and ventilation are not required to prevent droplet transmission. (Do not confuse droplet transmission with airborne transmission.) A person's coughing, sneezing and talking generate droplets. Other procedures such as suctioning and bronchoscopy are also a source of droplets.

Airborne Transmission

Airborne transmission occurs when either airborne droplet nuclei or dust particles disseminate infectious agents.

a) Droplet nuclei - The high velocity with which coughing and sneezing expel droplets from the respiratory tract results in large numbers of bacteria or viruses entering the air in smaller droplets. These droplets rapidly evaporate in the air leaving a residue of typically 5 μm or smaller in size. These droplet nuclei settle so slowly that they remain airborne in occupied spaces and circulate on air currents until mechanically removed by the ventilation system. Control of environmental factors (such as special air handling and ventilation) is necessary to prevent nosocomial airborne transmission of microorganisms.

b) **Dust -** Dust contaminated by viable infectious agents may build up as a reservoir

capable of causing an outbreak of infection, even after the departure of the infectious patient from whom the pathogens originated. Dust may become contaminated when dried sputum and other infectious secretions suspended in the air as dust particles mix with environmental dust.

ISOLATION ROOMS

The infected patient can contaminate the environment. A single room with appropriate air handling and ventilation is particularly important to prevent direct or indirect contact transmission and also for reducing the risk of airborne transmission of microorganisms from a source patient to susceptible patients and other persons in hospitals. This is often termed “Isolation Room” in medical terminology.

There are two types of isolation rooms: 1) airborne infection isolation (AII) rooms and 2) protective environment (PE) rooms.

1. **Airborne infection isolation (AII)** refers to the isolation of patients infected with organisms spread via airborne droplet nuclei <5 μm in diameter. These include patients suffering form measles, chicken pox and tuberculosis. Other areas include: the emergency department, intensive care units (adult, paediatric, newborn) and procedure areas such as bronchoscopy suites or sputum induction rooms.

2. **Protective environment (PE)** is a specialized area for patients who have undergone allogeneic hematopoietic stem cell transplant (HSCT). The patients whose immune mechanisms are deficient because of immunologic disorders (e.g., human immunodeficiency virus [HIV] infection or congenital immune deficiency syndrome), chronic diseases (e.g., diabetes, cancer, chemotherapy, emphysema, or cardiac failure), or immunosuppressive therapy (e.g., radiation, organ transplant, cytotoxic chemotherapy, anti-rejection medication, or steroids) are also placed in protective environment.

How does above classification affect HVAC designer?

The differentiating factor between “AII” and “PE” rooms is the pressure relationships.

- The protective environments (PE) are set at POSITIVE air pressure relative to adjoining spaces. These areas require frequent air exchanges ($\geq$12 per hour) and

require all supply air passing through high efficiency particulate air (HEPA) filters.

- The isolation rooms housing infectious patients (AII) must be maintained at NEGATIVE pressure. These areas require frequent air exchanges (≥12 per hour) and require all supply air to be exhausted without recirculation.

Both these areas require inline monitoring to ensure that they remain under set pressure. Doors to the rooms should be self-closing, and the walls, windows, ceiling, floor, and penetrations well sealed.

We will discuss details in Section – 2 of this course.

SECTION # 2

HVAC CONTROL PARAMETERS FOR ISOLATION ROOMS

An airborne infectious isolation room is constructed to minimize the migration of air from an isolation room to other areas of health care facilities. The risk of being infected through the airborne route is a function of particle concentration. The chance of a particle that is carrying an organism falling into an open wound increases with particle concentration. By reducing the concentration we reduce the chance of infection and, hence, the number of patients infected.

Four main factors affect the local concentration around a person in a room:

1. Firstly, the concentration of particles would tend to increase with rate of production of particles in the room.

2. Secondly, the proportion of supply and exhaust air quantity in relation to the size of the room.

3. Thirdly, the level of filtration of the supplied air will affect the ability of the ventilation system to dilute the room air particle concentration and

4. Fourthly, air turbulence and air movement in the room can transport particles so the method of air distribution will affect local concentrations.

The last three of these are attributes of the ventilation system that can be engineered to limit the effect of the first. Recommendations for engineering controls to contain or prevent the spread of airborne contaminants center on:

1. General ventilation

2. Air cleaning (primary and secondary filtration)

3. Local exhaust ventilation (source control)

GENERAL VENTILATION

The most effective means of controlling contaminants, odor and indoor air pollution is through ventilation, which requires simultaneous control of number of conditions:

1. Air change rates
2. Pressure gradient appropriate with class of isolation
3. Appropriate air distribution in the compartments being air conditioned.
4. High quality air filtration including absolute filtration
5. Precise temperature and humidity control ensuring maintenance of the intended microclimate

AIR CHANGE RATES

Ventilation supply rates for health care facilities require large expenditure of fresh air to dilute and remove the contaminants generated in the space. The ventilation rates for healthcare facilities is expresses as air changes air per hour (ACH), which is a measure of how quickly the air in an interior space is replaced by outside (or conditioned) air. For example, if the amount of air that enters and exits in one hour equals the total volume of the space, the space is said to undergo one air change per hour. Air flow rate is measured in appropriate units such as cubic feet per minute (CFM) and is given by

$$Q = \frac{(ACH) \times (room\ volume)}{60\ \text{min}/h} = cu\ ft/\text{min}$$

In this equation,

Q is the volume flow rate of air being calculated, and ACH is the number of air changes per hour

To determine the airflow required to adequately ventilate an area,

1) Calculate the room volume to be ventilated Width x Length x Height = ft^3 (cubic feet).
2) Calculate the air volume requirement by multiplying the room volume by the air change rate per hour = ft^3/h.

Studies carried out be AIA, indicate that just one air-change with fresh air can remove 63% of suspended particles from the room air. If a ventilation system can perform 10 air changes per hour (ACH), 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 (>20 ACH) may cause turbulence and the cost for ventilation itself will be too high. Therefore, a recommended compromise of 12 ACH is proposed which should be achievable when the filters have reached their maximum pressure drop. Higher ACR also equates to higher energy use.

The selection of 12 air changes per hour is largely a matter of convention. Ventilation rates are voluntary unless a state or local government specifies a standard in healthcare licensing requirements. These standards typically apply to only the design of a facility, rather than its operation. Based on the scientific knowledge and professional judgment reflected in the AIA guidelines, ASHRAE and the American National Standards Institute (ANSI) have developed design recommendations for ventilation and pressure relationships for various patient-care areas. Healthcare facilities without specific ventilation standards should follow ANSI/ASHRAE Standard 62, *Ventilation for Acceptable Indoor Air Quality* or otherwise in the absence of any specified supply air change/hour following guidelines may be used:

- For the space to be maintained under negative pressure exhaust 10 to 15 percent more air than the supply.
- For the space to be maintained under positive pressure, exhaust 10 to 15 percent less air than the supply air.

ROOM PRESSURE CONTROL

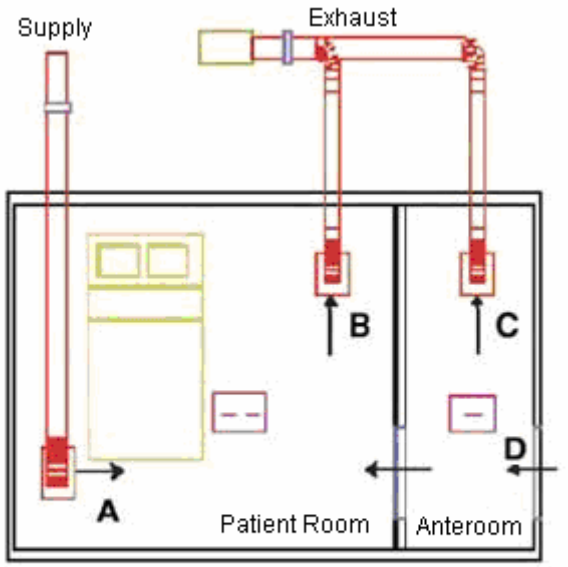
Building room pressurization is a critical factor to monitor in a hospital as it can greatly affect the controllability of the environment. If the building pressure is allowed to become negative due to supply filters being loaded, supply fans running too slow, or return fans running too fast, humid and dirty air can be drawn into the building through cracks and openings. This air is completely unconditioned and can provide several of the necessary ingredients to promote mold growth (e.g., moisture, more spores, and nutrients.)

Building room pressure gradient is achieved by controlling the quality and quantity of intake and exhaust air, maintaining differential air pressures between adjacent areas, and designing patterns of airflow for particular clinical purposes.

CLASS N – NEGATIVE PRESSURE ISOLATION ROOMS

The basic principle of pressurization for microbial contaminant control is to ensure that air flows from less contaminated to more contaminated areas. Air in an open Class N room, for example, should flow from corridors **INTO** the isolation room to prevent the spread of airborne contaminants from the isolation room to other areas. The purpose of this design is to eliminate the spread of infectious contaminants and pathogens into the surrounding environment via the airborne route.

Class N is applicable to all infection isolation rooms where the patients known to or suspected to have infections are placed.



NEGATIVE PRESSURE ISOLATION ROOM

The schematic above shows HVAC air flow arrangement for class N rooms. An anteroom designed to provide an “air-lock” (no mix of air) between the infectious patient and the common space is placed adjacent to the patient room. The air would flow from the ante room to the isolation room. Pressure control is maintained by modulating the main supply and exhaust dampers based on a signal from a pressure transducer located inside the isolation room.

Infection-Control and Ventilation Requirements for “All” Rooms

Use AIA guidelines as minimum standards where state or local regulations are not in place for design and construction of ventilation systems in new or renovated health-care facilities.

Recommended elements include:

1. Ensure that the airborne infectious isolation rooms are designed to maintain negative pressure.

2. Maintain continuous negative air pressure no less than (2.5 Pa [0.01 inch water gauge]) in relation to the air pressure in the corridor. This is accomplished via a separate exhaust system sized to remove at least 15% more air than that of the supply system.

3. Monitor air pressure periodically, preferably daily, with audible manometers or smoke tubes at the door (for existing AII rooms), or with a permanently installed visual monitoring mechanism.

4. Provide ventilation to ensure ≥12 ACH for renovated rooms and new rooms, and ≥6 ACH for existing AII rooms, when supply or exhaust air filters are at their maximum pressure drop.

5. The recommended air filtration for the class N, airborne infectious isolation rooms is MERV 14 rating air filters (90% dust spot test filters) on the supply side and HEPA (99.97% @ 0.3μm DOP) on the exhaust side.

6. Recirculation of exhausted air is discouraged, from class N rooms. The exhaust air should be directed to outside, away from air-intakes and populated areas. However, where recirculation may be deemed acceptable in some circumstances, HEPA filters (99.97% @ 0.3μm DOP) capable of removing airborne contaminants on the supply side must be incorporated.

7. The disposal of effluents should not create a hazard to persons outside or the staff maintaining these systems. Where supplemental engineering controls for air cleaning are indicated from a risk assessment of the “AII” area, also install Ultraviolet Germicidal Irradiation (UVGI) units in the exhaust air ducts of the HVAC system to supplement HEPA filtration. For example in TB clinics, the air is often HEPA filtered

and sometimes given UVGI exposure before exhausting to the outside, though the reasons for this are primarily because of litigation concerns and not based on any known realities.

8. Consider UVGI fixtures on or near the ceiling to irradiate upper room air. Note that UVGI, may be used to augment HEPA filters, but cannot be used in place of HEPA filters, as their effectiveness on airstreams is limited.

9. The supply air should be located such that clean air is first passed over the staff/other occupants and then to the patient. Air distribution should reduce the staff's exposure to potential airborne droplet nuclei from infectious patients, accounting for the positions of the staff and the patient, and the procedures undertaken in the isolation room.

10. Insider patient room, the supply air should be from the ceiling diffuser located at the perimeter near to the entry and the exhaust air should be drawn at lower levels approximately 6 inches above the floor in the room.

11. Exhaust air ducts should be independent of the building's common exhaust air system to reduce the risk of contamination from back draught.

12. Locate the exhaust fan at a point in the duct system that will ensure the duct is under negative pressure throughout its run within the building.

13. The makeup air intakes should be located so that no contaminated air from nearby exhaust stacks or any sources of air contaminants is drawn into the makeup air system.

14. Ensure supply air ducts are independent of the building's common supply air system. If sharing of supply ducts with other isolation rooms is unavoidable, provide the ducts with terminal HEPA filters (or other failsafe back draught prevention system). Install a high efficiency bag filter as a pre-filter to protect the HEPA filter.

15. Design the supply air and exhaust systems to be of a constant volume system. Variable air volume (VAV) systems are NOT recommended.

16. A monitoring system should be provided to signal any malfunction of the

supply/exhaust air system. Consider differential low -pressure instrumentation in a prominent location outside the room along with a local audible alarm in case of supply/exhaust failure.

17. Ensure that rooms are well-sealed for better maintenance of pressure gradients that will also eventually reduce load on the air handling plant. Ensure air tightness by

    - Properly constructing windows, doors, and intake and exhaust ports
    - Maintain plasterboard ceilings that are smooth and free of fissures, open joints, and crevices
    - Sealing all penetrations on the walls above and below the ceiling
    - Monitoring for leakage and making any necessary repairs

18. Install self-closing devices on all 'AII' room exit doors considering the direction of door swing in relation to room pressure.

19. Provide a staff hand-wash basin in the anteroom and include personal respiratory protection for persons entering these rooms and for staff who lack immunity to airborne viral diseases (e.g., measles or varicella zoster virus [VZV] infection).

20. Do not use a room with a through-the-wall ventilation unit unless it can be demonstrated that all required 'AII' engineering controls are met.

21. Maintain backup ventilation equipment (e.g. portable units for fans or filters) for emergency provision of ventilation requirements for AII rooms, and take immediate steps to restore the fixed ventilation system.

22. Label the area as being a negative pressure isolation room.

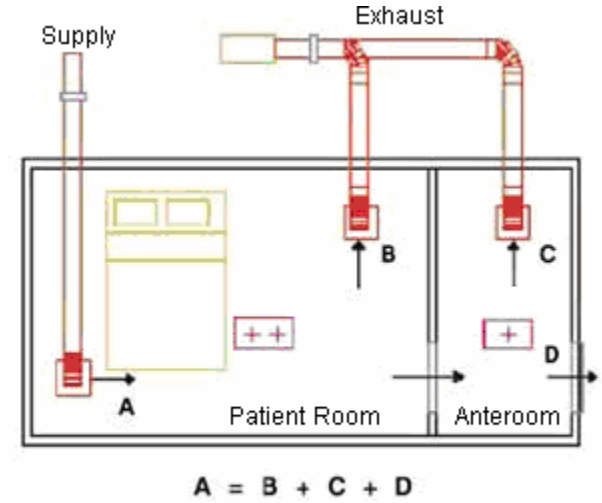
Emergency Rooms and Reception Areas

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. The likelihood of airborne contaminants leaving these rooms is reduced by keeping these rooms under NEGATIVE

pressure, relative to surrounding areas. Air is exhausted from these rooms either directly to the outside or through high efficiency particulate air (HEPA) filters.

CLASS P – POSITIVE PRESSURE ISOLATION ROOMS

Class P - positive pressure isolation rooms are set at positive pressure relative to ambient pressure, meaning that air flow must be from the "cleaner" area towards the adjoining space (through doors or other openings). This is achieved by the HVAC system providing more air into the "cleaner" space than is mechanically removed from that same space. Class P is applicable to all protective environments housing severely neutropenic and immuno-suppressed patients.



POSITIVE PRESSURE ISOLATION ROOM

In the schematic diagram above an airlock or anteroom is provided adjacent to the patient room. For a positive pressure room, air would flow from the isolation room to the anteroom and than to the corridor. Pressure control is maintained by modulating the main supply and exhaust dampers based on a signal from a pressure transducer located inside the isolation room.

Infection Control and Ventilation Requirements for PE rooms

Use AIA guidelines as minimum standards where state or local regulations are not in place for design and construction of ventilation systems in new or renovated health-care facilities. Recommended elements include:

1. Ensure that the protective environment room is designed to maintain positive pressure.

2. Maintain positive room air pressure (≥2.5 Pa [0.01-inch water gauge]) in relation to the corridor. Ideally it should be >8 Pa (0.03 inch-water gauge).

3. Ventilate the room to maintain ≥ 12 ACH or 145 liters per second per patient (whichever results in the greatest air quantity), when the supply air filter is at the maximum pressure drop.

4. Class P rooms can be either 100% fresh air or can use recirculated air usually a 60/40 mix of outdoor air/recirculated air. As rule of thumb, air pressure should be maintained positive with respect to any adjoining rooms by supplying 10 to 15% excess air.

5. The recommended air filtration for the class P, protective rooms is HEPA (99.97% @ 0.3µm DOP) on the supply side and NO filtration is needed on the exhaust side. The HEPA filter could be centrally located at the air handling unit or point-to-use HEPA filters may be used. A terminal HEPA filter at the point of use is recommended.

6. UVGI systems are sometimes used in conjunction with HEPA filters. When ultraviolet germicidal irradiation (UVGI) is used as a supplemental engineering control, install fixtures 1) on the wall near the ceiling or suspended from the ceiling as an upper air unit; 2) in the air-return duct of an 'AII' area; or 3) in designated enclosed areas or booths for sputum induction.

7. The supply air should be located such that clean air is first flows across the patient bed and exits from the opposite side of the room. Air distribution should reduce the patient's exposure to potential airborne droplet nuclei from occupants.

8. Positive pressure rooms may share common supply air systems.

9. Differential pressure indication device should be installed to permit air pressure readings in the rooms and provide a local audible alarm in case of fan failure.

10. Ensure that rooms are well-sealed for better maintenance of pressure gradients that will also eventually reduce load on the air handling plant. Ensure air tightness by

- Properly constructing windows, doors, and intake and exhaust ports
- Maintain plasterboard ceilings that are smooth and free of fissures, open joints, and crevices
- Sealing all penetrations on the walls above and below the ceiling
- Monitoring for leakage and making any necessary repairs

11. Maintain airflow patterns and monitor these on a daily basis by using permanently installed visual means of detecting airflow in new or renovated construction, or by using other visual methods (e.g., flutter strips or smoke tubes) in existing PE units. Plan for automatic documentation of the monitored results.
12. Install self-closing devices on all room exit doors in PE rooms. All emergency exits (e.g., fire escapes, emergency doors) in PE wards should be kept closed (except during emergencies) and equipped with alarms.
13. Do not use laminar air flow systems in newly constructed PE rooms.
14. Do not use a room with a through-the-wall ventilation unit as PE room.
15. Install an ensuite bathroom along with a staff hand-wash basin in the anteroom.
16. Label as a positive pressure isolation room.

Infection-Control and Ventilation Requirements for Operating Rooms

The room pressure requirement for operating rooms is similar to PE rooms with following exceptions:

1. Maintain positive-pressure ventilation with respect to corridors and adjacent areas; maintain $\geq$15 ACH, of which $\geq$3 ACH should be fresh air.
2. Filter all recirculated and fresh air through the appropriate filters, providing 90% efficiency (dust-spot testing) at a minimum.
3. In rooms not engineered for horizontal laminar airflow, introduce air at the ceiling and exhaust air near the floor.

4. Do not use ultraviolet (UV) lights to prevent surgical-site infections.

Special Challenges

A unique challenge occurs when a patient needs both the positive and negative room isolation. For example when there is an immune compromised patient who also has a communicable infectious disease such as TB. Studies indicate that approximately 15% of HIV patients also suffer from TB, and this presents a unique design problem. This patient needs to be in a protective environment for his own health but also needs to be isolated to protect others from his communicable disease.

The solution is to house such patients in a positive pressure protective environment room with an anteroom that is under negative pressure relative to the corridor and protective environment.

Caution: Avoid designing systems to switch between positive and negative pressure.

ANTE ROOMS

An ante room is always recommended for both positive and negative isolation rooms for three main reasons:

1. To provide a barrier against loss of pressurization, and against entry / exit of contaminated air into / out of the isolation room when the door to the airlock is opened.

2. To provide a controlled environment in which protective garments can be donned without contamination before entry into the isolation room.

3. To provide a controlled environment in which equipment and supplies can be transferred from the isolation room without contaminating the surrounding areas.

There are three possible airflow / control designs which differ in pressure relationship of anteroom to the isolation room and the corridor.

Design # 1:

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:

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.

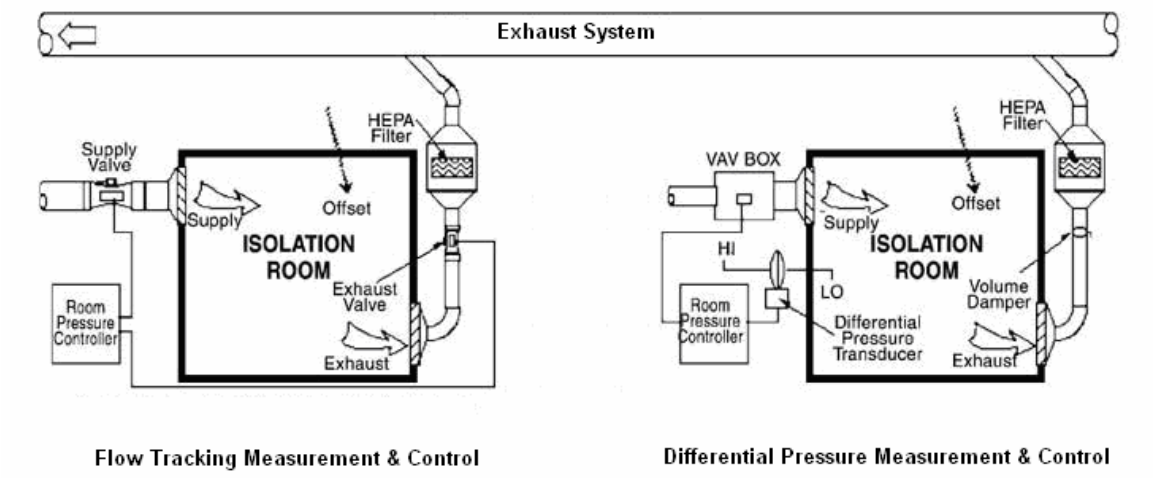
Design # 3:

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.

MONITORING OF ROOM PRESSURE

Dynamic pressure differential monitoring must take place in order to ensure the room is at appropriate pressure. The two common methods of differential pressure control are 1) flow tracking measurement & control and 2) differential pressure measurement & control.



Flow Tracking Measurement & Control

Differential Pressure Measurement & Control

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.

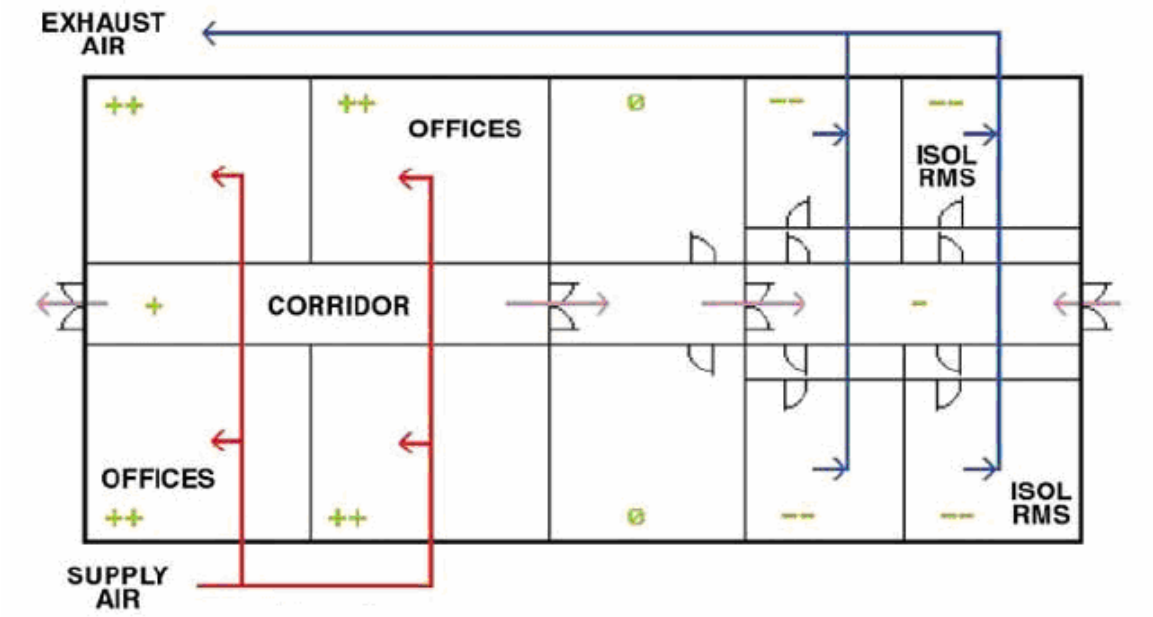
In differential pressure system, the actual differential pressure between the isolation room and the corridor is taken by measuring the velocity of air induced through a hole in the envelope between the isolation room and corridor created by the differential pressure. However, the magnitude of this differential 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 requires the use of room differential pressure monitors but both agencies accept their use, provided that they measure down to 0.001” wg.

Codes require that as 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.

Proper room pressurization can be checked using a smoke stick or smoldering match at doors held open approximately 1/4 inch to visually see which direction air is moving. Care must be taken when checking this to make sure that the door is not moving during the test since a door swinging can move more air than the design ventilation differential in the room. It should be an obvious rule of thumb that if you can't detect air movement via this method then no significant, practical pressurization of the room exists.

DIRECTIONAL CONTROL OF AIRFLOW

The design principle of pressurization control is to exhaust air from those areas which have the greatest contamination potential, and allow air to be staged, or cascaded, from progressively cleaner areas. Figure below illustrates the basic principle of cascading airflows from clean areas to relatively contaminated areas.



Directional airflow for isolation rooms

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 blue 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.

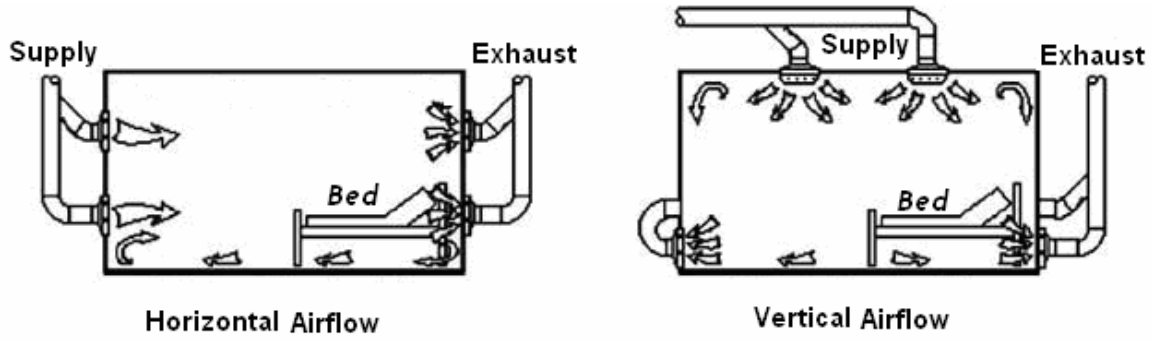
AIR DISTRIBUTION

In conventional air conditioning, filtered air is typically distributed from the ceiling, with

return air is collected from the ceiling on the other side of the room.

In special situations in health care facility (e.g., operating rooms, delivery rooms, catheterization laboratories, angiography rooms, HEPA-filtered rooms for immune-suppressed patients) the direction of air movement needs to be controlled. The air is introduced from ceiling registers on the perimeter and is returned or exhausted through registers located at least 6 inches above the floor. This arrangement provides a downward movement of clean air through the breathing and working zones to the contaminated floor area for exhaust.

Figure below shows the 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.



Room Air Distribution in Isolation Rooms

Non-aspirating diffusers (typically perforated face) are recommended. These diffusers entrain large amounts of air, achieve good mixing, prevent updrafts and provide a laminar flow of air that 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.

Do not place diffuser immediately over the patient bed as it would result in

uncomfortable drafts projected directly at the patient.

Laminar Flow

Other mechanism of air distribution in ultra-clean areas of hospitals is the laminar or **uni**directional airflow distribution. Laminar airflow ventilation systems are designed to move air in a single pass with parallel streamlines, usually through a bank of HEPA filters either along a wall or in the ceiling.

Laminar flow systems use perforated ventilation grills across the entire ceiling or side wall at air flow rates significantly greater than normal to force a steady constant stream of air across the entire room, similar to a smooth steady flow out of an open water faucet versus one that splashes as the water comes out of the faucet.

Laminar flow distribution requires a very high volume of air flow and is designed for an air velocity of 90 + 20 ft/min. This unidirectional approach optimizes airflow and minimizes air turbulence and ensures that any contamination that is generated within the area is quickly and effectively removed. Laminar airflow systems are often used in operating rooms to help reduce the risk for healthcare-associated airborne infections.

Note: The data that demonstrate a bona-fide application and support of laminar airflow in PE rooms is lacking. Given the high cost of installation and operation, the value of laminar airflow is questionable and shall be ascertained through life cycle analysis.

AIR FILTRATION

All of the air that is drawn into an air handling system is "contaminated" to some degree. It is commonly accepted that airborne particles (solid particles, liquids, fumes, smoke, or bacteria) that are larger than 5 microns in size tend to settle quickly out of the air onto horizontal surfaces. Airborne particles that are less than 5 microns in size (especially those less than 2 microns in size) tend to settle slowly out of the air and remain suspended (airborne) for larger period of time.

Concerns over hospital-acquired infections have propelled filtration solutions into the forefront as a primary tool for infection control. There are five methods of filtration.

1. Straining - Particles in the air are larger than the openings between the filter fibers.

This technique is suitable for gross removal of large particles. Filtration efficiency is low.

2. Impingement – Particles collide with filter fibers and remain attached to the filter. The fibers may be coated with adhesive. Filtration efficiency is low.

3. Interception – Particles enter into the filter and become entrapped and attached to the filter fibers. Filtration efficiency is medium.

4. Diffusion – Small particles, moving in erratic motion, collide with filter fibers and remain attached. Filtration efficiency is high.

5. Electrostatic – Particles bearing negative electrostatic charge are attracted to filter with positively charged fibers. Filtration efficiency is high.

All public areas of health care facilities are required to have two banks of filters — a 30% (ASHRAE 52.1) prefilter and 90% final filter. Provided that the final filter is properly installed and maintained and provided that there is little or no bypass around the filter, the combined efficiency of two bank filters is nearly 100% in removing particles of 1µm - 5 µm in diameter. This filtration system is adequate for most patient-care areas in ambulatory care facilities, and the operating room environment.

A common metric for filter performance is the minimum efficiency reporting value (MERV), a rating derived from a test method developed by ASHRAE. The MERV rating indicates a filter's ability to capture particles between 0.3 and 10.0 microns in diameter. A higher MERV value translates to better filtration, so a MERV-13 filter works better than a MERV-8 filter. In health care facilities a final filter of MERV-14 is satisfactory.

High Efficiency Particulate Air (HEPA) Filters

HEPA filters have a minimum initial efficiency of 99.97% for removing particles 0.3 microns in size. This is a critical point as these filters are being used to remove mold and bacteria, typically 1 to 5 microns in size when airborne, as well as viral particles which are submicron in size (as a reference, *Aspergillus* spores are 2.5 - 3 µm in diameter).

Each HEPA filter is individually tested at the factory in order to confirm their conformance to this standard. They may also be field-tested in order to confirm their

ongoing adherence to efficiency requirements.

Where to use HEPA Filters

HEPA filters should be used:-

1. On the supply air distribution of the protective rooms.

2. On the return air of the infectious isolation rooms when the air is recirculated within the space in order to increase ACH while reducing the total exhaust requirements. Ideally the infectious isolation rooms should be designed for 100% fresh air and exhaust.

3. On the exhaust of the infectious isolation rooms and local exhaust hoods when exhausting air to the outside is not practical or when the exhaust is located near a potential air intake. (Refer note below)

4. When the HVAC system configuration dictates recirculation of air from the isolation room to other parts of the facility.

Note - 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 Maintenance

Efficiency of the filtration system is dependent on the density of the filters that may create a pressure drop unless compensated by stronger and more efficient fans so that flow of air is maintained. When HEPA filters are used in infection control applications it is imperative to have a meticulous maintenance program in place. For optimal performance, it is critical that:

1. HEPA filters to be installed in equipment which seals the filter in place in order to prevent contaminated air from bypassing the filter.

2. HEPA filters to be tested on site when they are first installed and every six months

thereafter to confirm that they are operating at their design efficiency.

3. HEPA filters to be monitored (with manometers or other pressure indicating devices) on regular basis and replaced in accordance with the manufacturer's recommendations and standard preventive maintenance practices. Gaps in and around filter banks and heavy soil and debris upstream of poorly-maintained filters have been implicated in healthcare-associated outbreaks of aspergillosis, especially during times of nearby construction.

HEPA filters are a costly budget item. In order to extend the life of a HEPA filter and reduce ongoing replacement costs, it is strongly recommended to provide a roughing prefilter prior to the HEPA. Studies indicate that a low-efficiency prefilter may extend the life of a HEPA filter by 25%, while adding higher efficiency intermediate filters such as a MERV 14 (95% by ASHRAE 52.1 dust spot test) filter can extend the life of the HEPA filter by as much as 900%. This concept, called "progressive filtration," allows HEPA filters in special care areas to be used for 10 years or more. HEPA filter efficiency is monitored with the dioctylphthalate (DOP) particle test using particles that are 0.3 μm in diameter.

Caution: HEPA filters replacements require bag-in / bag-out procedures to minimize risk of exposure of the maintenance personnel to the infectious material.

Portable HEPA Filters

Portable, industrial grade HEPA units are recommended for use during construction and renovation. These industrial grade portable HEPA filters are capable of filtration rates in the range of 300--800 CFM and are used to:

1. Temporarily recirculate air in rooms with no general ventilation;

2. Augment systems that cannot provide adequate airflow; or

3. Provide increased effectiveness in airflow

The effectiveness of the portable unit for particle removal depends on: 1) the configuration of the room; 2) the furniture and persons in the room; 3) the placement of the units relative to the contents and layout of the room; and 4) the location of the supply

and exhaust registers or grilles.

If portable, industrial-grade units are used, they should be capable of recirculating all or nearly all of the room air through the HEPA filter, and the unit should be designed to achieve the equivalent of >12 air changes per hour (ACH). (An average room has approximately 1600 cu-ft of airspace).

Portable HEPA units are useful engineering controls when the central HVAC system is undergoing repairs, but these units do not satisfy fresh air requirements. Portable HEPA filter units placed in construction zones can be used later in patient-care areas, provided all internal and external surfaces are cleaned, and the filter replaced or its performance verified by appropriate particle testing.

Odor Control

There are several areas within a health care facility where odors or gaseous contaminants are common. Some of these contaminants may only be nuisance or comfort related, while others may represent a threat to personal health.

Fumes and smells can be removed from air by chemical processes such as “gas sorption” which control compounds that behave as gases rather than as particles (e.g., gaseous contaminants such as formaldehyde, sulfur dioxide, ozone, and oxides of nitrogen). Gas sorption involves one or more of the following processes with the sorption material (e.g., activated carbon, activated alumina or chemically treated active clays):

- A chemical reaction between the pollutant and the sorbent,
- A binding of the pollutant and the sorbent, or
- Diffusion of the contaminant from areas of higher concentration to areas of lower concentration

Gas sorption units are available in variety of chemical treated clays, each performing differently for different gases. A prefilter is recommended upstream of the gas sorption unit to ensure that filter pores are not blocked with particulates. There are currently no standards for rating the performance of gaseous air cleaners, making the design and evaluation of such systems problematic.

Air Filtration to Protect HVAC Equipment

Accumulation of dust and moisture within HVAC systems increases the risk of spread of healthcare-associated environmental fungi and bacteria. The components of air handling units such as cooling coil, filters, and ductwork can be the ideal environments for breeding bacteria, fungus and mold. It not properly maintained, these will become reservoirs for infection causing molds. Common practices for protecting HVAC coils include locating the filter upstream of the coil and having a filter rating of at least MERV 8. The filters should fit snugly into the holding frames; be of rigid, moisture resistant construction; and be constructed from materials that will not support microbial growth. Care should be taken to ensure that no air bypasses around the filters. Bypass can be reduced by gasketing the filters to seal them in place and by installing filter blanks in spaces were the filter track does not contain filters.

Ultraviolet Germicidal Irradiation (UVGI)

As a supplemental air-cleaning measure, UVGI is effective in reducing the transmission of airborne bacterial and viral infections in hospitals, but it has only a minimal inactivating effect on fungal spores. UVGI is also recommended in air handling units to prevent or limit the growth of vegetative bacteria and fungi.

Most commercially available UV lamps used for germicidal purposes are low-pressure mercury vapor lamps that emit radiant energy predominantly at a wave-length of 253.7 nm. Two systems of UVGI have been used in healthcare settings -- duct irradiation and upper-room air irradiation. In duct irradiation systems, UV lamps are placed inside ducts whereas in upper-room air irradiation, UV lamps are either suspended from the ceiling or mounted on the wall.

Bacterial inactivation studies using BCG mycobacteria and *Serratia marcescens* have estimated the effect of UVGI as equivalent to 10 ACH - 39 ACH. Another study, however, suggests that UVGI may result in fewer equivalent ACH in the patient-care zone, especially if the mixing of air between zones is insufficient.

Because the clinical effectiveness of UV systems may vary, UVGI is not recommended for air management prior to air recirculation from airborne isolation rooms and also in

operating rooms.

Regular maintenance of UVGI systems is crucial and usually consists of keeping the bulbs free of dust and replacing old bulbs as necessary. Understand the safety issues associated with the use of UVGI systems from suppliers and manufacturer's.

LOCAL EXHAUST VENTILATION

Local exhaust ventilation is designed to capture toxic gases, vapors, dusts, fumes and mists near its source, before the contaminant has a chance to disperse into the workplace air. A proper design of an exhaust ventilation system is necessary for effective removal of airborne contaminants that would otherwise pollute the work environment resulting in health hazards.

A local exhaust ventilation system usually consists of number of separate exhaust hoods applied to several different operations and connected by system of branch and main ducts to a central air cleaning device and exhaust fan and discharge stack to the outside. A local exhaust system is most effective for laboratories and special procedure rooms. It has following benefits:

1) It minimizes employee exposure to contaminants.

2) It uses much less airflow than the dilution ventilation.

3) The contaminant can be collected for disposal or recovery.

Laboratories and Special Procedure Rooms

Laboratories and special procedure rooms that are known to contain toxic and hazardous contaminants are typically designed under negative pressure to prevent these gases from spreading throughout the facility. Examples of these areas include cytology labs where xylene and toluene may be part of the process, autopsy exhaust, ethylene oxide (ETO) sterilizer exhaust, X-ray film processing areas, infectious materials in waste (including regulated medical waste), steam sterilizers, areas using high-level disinfectants or morgues, where formalin may be used. These chemicals are both irritants and carcinogenic. Such areas typically employ 100% pass-through ventilation where no air is recirculated within the facility.

Conditions do occur, however, where it is possible for these chemicals to be re-entrained into the facility due to the close proximity of exhaust to potential air intakes. In applications like this, gas phase or multi-stage filtration equipment may also be considered. In a morgue where formalin is used, we must not only be concerned with gas phase filters to deal with the formalin, but we must also be concerned with the removal of potentially infectious airborne bacteria. There have been documented cases of transmission of m. tuberculosis from viable TB bacteria which may become airborne during the autopsy procedure. In situations where air from a morgue must be filtered at the exhaust point, it is important to utilize a system with both HEPA and gas phase filtration.

Kitchen Ventilation

Extract systems from kitchen equipment (cooking stove, ovens, dishwasher etc) should be separate from any other and the extracted air should not be recirculated. The following design guidelines should be noted:

Hoods and Ducts

1) Duct velocity should be between 1500 and 4000 fpm
2) Hood velocities (not less than 50 fpm over face area between hood and cooking surface)
3) Extend hood beyond cook surface 0.4 x distance between hood and cooking surface
4) Canopy, ducting and lagging should be made from non-combustible material.

Filters

1) Recommended filter velocity: 100 - 400 fpm
2) Recommend filter quantity: Typically 2 CFM exhaust for each sq. in. of filter area maximum
3) Recommended installation: Install at 45 - 60° to horizontal, never horizontal
4) Shield filters from direct radiant heat. Recommended elements:

- No exposed cooking flame—1-1/2’ minimum to filter
- Charcoal and similar fires— 4’ minimum to filter

Locker Room, Toilet, and Shower Space Ventilation

The ventilation of locker rooms, toilets, and shower spaces is important in removing odor and humidity. Legal minimum requirements should be consulted when designing these facilities. In toilets recommended rates of exhaust ventilation are 10 ACH or 2cfm /sq-ft whichever is higher. Supply air may be introduced through door grilles and/or undercuts. Do not transfer more than 4.2 Cu M/Min (150 CFM) of air per door undercut.

Public toilets and congregate baths do require ducted supply air up to 8.5 air changes per hour maximum. The balance air should be drawn from the corridors to maintain negative pressure and to ensure exhaust of 10 air changes per hour.

TEMPERAURE & HUMIDITY CONTROL

Two essential components of conditioned air are temperature and humidity. After outside air passes through a low - or medium-efficiency filter, the air undergoes conditioning for temperature and humidity control.

Temperature Control

Control of temperature includes the operation of both heating and cooling systems to maintain temperature setpoints in the different areas of the building. Cool temperatures (68°F - 73°F) are usually associated with operating rooms, clean workrooms, and endoscopies suites. A warmer temperature (75°F) is needed in areas requiring greater degrees of patient comfort. Most other zones use a temperature range of 70°F - 75°F. Temperatures outside of these ranges may be needed on limited occasions in limited areas depending on individual circumstances during patient care.

HVAC systems in healthcare facilities have either single-duct or dual-duct systems. A single-duct system distributes cooled air (55°F) throughout the building, and uses thermostatically controlled reheat boxes located in the terminal ductwork to warm the air for individual or multiple rooms.

The more common dual-duct system consists of parallel ducts, one with a cold air

stream and the other providing a hot air stream. A mixing box in each room or group of rooms mixes the two air streams to achieve the desired temperature. Temperature standards are given as either a single temperature or a range, depending on the specific healthcare zone.

Humidity Control

Efforts to limit excess humidity and moisture in the infrastructure and on air stream surfaces in the HVAC system can minimize the proliferation and dispersion of fungal spores and waterborne bacteria throughout the indoor air. Control of humidity includes the operation of both humidification and dehumidification systems to maintain a minimum and maximum humidity level in the facility.

Four measures of humidity are used to quantify different physical properties of the mixture of water vapor and air. These are relative humidity, specific humidity, dew point and vapor pressure. The most common of these is "relative humidity," which is the ratio of the amount of water vapor in the air to the amount of water vapor air can hold at that temperature. At 100% relative humidity, the air is saturated. For most areas within healthcare facilities, the designated comfort range is 30% - 60% relative humidity. Relative humidity levels >60%, in addition to being perceived as uncomfortable, promote fungal growth.

Dehumidification

If the moisture is not controlled sufficiently by the HVAC system, this could spell disaster with regard to trying to keep significant mold growth out of the facility. Dehumidification is typically accomplished by cooling air below the dew point.

For a facility only trying to maintain the space at 75° DB and 50% RH (i.e., 55° dew-point), the coils must still be capable of delivering air with a dew-point less than 55° in order to absorb the space latent gain. Where humidity control is solely by cooling, consider cooling coils with higher rows (more surface area, although this will increase the air pressure drop and the fan power) and restrict the face velocity to 400 feet per minute or lower.

If the process operation requires a higher level of dehumidification (typically RH levels less than 40%) that cannot be attained with cooling coil dehumidification alone, then a

desiccant based dehumidifier could also be considered. For example, if the operating space is to be maintained with a condition of 60° DB and 50% RH (i.e., 38.5 grains/#, or 41.3° dew-point), then a chilled water coil only capable of delivering air off the cooling coils at 50° to 52° (saturated) will not satisfy the need. The supply air would have to be delivered at an absolute humidity level of less than 41.3° dew-point. This would require a low temperature chiller or a desiccant-based dehumidification/cooling system.

Humidification

Humidification can be achieved by means of steam humidifiers. The humidifiers used shall be made of materials preventing the development of microbes and which are resistant to corrosion. For monitoring and cleaning purposes, easy, permanent access to the locations where water may accumulate shall be ensured. The air handling units shall be suitable for air drying by means of the cooling system or by application of absorptive rotors.

Recommended elements:

a. Locate duct humidifiers upstream from the final filters.

b. Incorporate a water-removal mechanism into the system.

c. Locate all duct takeoffs sufficiently downstream from the humidifier so that moisture is completely absorbed.

d. Incorporate steam humidifiers, if possible, to reduce potential for microbial proliferation within the system, and avoid use of cool-mist humidifiers.

e. Do not use normal water spray humidifiers.

Temperature and Humidity Controls

Serious consideration must then be given to the controllability of the systems. As is far too often the case, most HVAC systems are installed with the primary function of either cooling or heating, with the humidity control simply as a secondary function of the system. This is evidenced by the fact that most HVAC systems are installed only with a thermostat installed to operate the system. Including humidity control devices in the controls package for the HVAC system is almost non-existent. Logic says that you can

not control something which is not measured. Always install a humidistat to measure the humidity levels. Many design issues can lead to a lack of moisture control within the hospital that can potentially lead to mold problems and infections.

REFERENCE STANDARDS

Designing HVAC systems for hospitals is a specialist skill and it requires knowledge of specific regulations.

The American Institute of Architects (AIA) has published guidelines for the design, construction, and renovation of healthcare facilities that include indoor air-quality standards (e.g., ventilation rates, temperature levels, humidity levels, pressure relationships, minimum air changes per hour [ACH]) specific to each zone or area in healthcare facilities (e.g., operating rooms, laboratories, diagnostic areas, patient-care areas, support departments). These guidelines represent a consensus document among authorities having jurisdiction (AHJ), governmental regulatory agencies (i.e., Department of Health and Human Services [DHHS], Occupational Safety and Health Administration [OSHA]), healthcare professionals, professional organizations (e.g., American Society of Heating, Refrigeration, and Air-conditioning Engineers [ASHRAE], American Society of Healthcare Engineers [ASHE]), and accrediting organizations (i.e., Joint Commission on Accreditation of Healthcare Organizations [JCAHO]).

Many state or local agencies that license healthcare facilities have either incorporated or adopted by reference these guidelines into their state standards. The JCAHO, through its surveys, assures that facilities are in compliance with the space and square footage requirements of this standard for new construction.

The American Society of Heating, Refrigeration and Air-conditioning Engineers, Inc. (ASHRAE) has recently published the 2003 *HVAC Design Manual for Hospitals and Clinics* ("the Design Manual") to address these challenging design requirements for healthcare facilities. This Design Manual was developed by a group of members of ASHRAE's Special Projects Committee SP-91. The members included design professionals, health specialists, researchers, code officials and representatives of the revision task-force for the American Institute of Architects (AIA) Guidelines for the Design and Construction of Hospitals and Healthcare Facilities, the American Society of Hospital Engineers (ASHE) and the American College of Surgeons (ACS).

SECTION # 3

HVAC SYSTEM & EQUIPMENT DESIGN

There are a number of issues that must be resolved before the proper HVAC system can be designed, whether it is intended for the isolation rooms, surgical suite, the patient rooms, or the administration offices.

Initially, the proper ambient design conditions must be selected. Too often, only the peak cooling design conditions are considered for sizing the capacity requirements of the system. These ambient conditions are listed in the *ASHRAE Handbook – Fundamentals* as the dry-bulb temperatures with mean coincident wet-bulb temperatures, representing conditions on hot, mostly sunny days. These conditions are used in sizing cooling equipment such as chillers or package equipment for cooling control. In some climates, this might be satisfactory; however, in geographic areas known for higher humidity levels, considering only this cooling condition might not be sufficient. Extreme dew-point temperature conditions may occur on days with moderate dry-bulb temperatures, resulting in high relative humidity's and peak absolute moisture loads from the weather.

These values from tables found in the Fundamentals Handbook are useful for humidity control applications, such as desiccant cooling and dehumidification, cooling-based dehumidification, and fresh air ventilation systems. These values can also be used as a checkpoint when analyzing the behavior of cooling systems at part load conditions, particularly when such systems are used for humidity control as a byproduct of temperature control.

Type of HVAC System - Isolation Rooms and Critical Examination Rooms

For the critical areas such as isolation rooms, intensive care units and operating rooms, critical diagnostic and examination rooms, consider only the centralized HVAC system encompassing "all air systems".

In all air systems, the outdoor air enters the system via a low - efficiency or "roughing" filters, which removes the large particulate matter. It is mixed with the return air and is made to pass the fine filters, which removes small size particles and many microorganisms. The air is than conditioned and delivered to each zone of the building. After the conditioned air is distributed to the designated space, it is withdrawn through a

return duct system and delivered back to the HVAC unit. A portion of this "return air" is exhausted to the outside while the remainder is mixed with outdoor air and filtered for dilution and removal of contaminants. In some critical areas the air again filtered through HEPA filters located downstream the cooling/heating coil or at the terminal end of the duct.

All air systems can be classified as single-zone, multi-zone, dual-duct and reheat systems.

Single-zone systems: Single-zone systems serve just one zone having unique requirement of temperature, humidity and pressure. This is the simplest of all air systems. For this type of system to work properly, the load must be uniform all through the space, or else there may be a large temperature variation.

Multi-zone systems: Multi-zone systems are used to serve a small number of zones with just one central air handling unit. The air handling unit for multi-zone systems is made up of heating and cooling coils in parallel to get a hot deck and a cold deck. For the lowest energy use, hot and cold deck temperatures are, as a rule, automatically changed to meet the maximum zone heating (hot deck) and cooling (cold deck) needs. Zone thermostats control mixing dampers to give each zone the right supply temperature.

Dual-duct systems: Dual-duct systems are much like multi-zone systems, but instead of mixing the hot and cold air at the air handling unit, the hot and cold air are both brought by ducts to each zone where they are then mixed to meet the needs of the zone. It is common for dual-duct systems to use high-pressure air distribution systems with the pressure reduced in the mixing box at each zone.

Reheat systems: Reheat systems supply cool air from a central air handler as required to meet the maximum cooling load in each zone. Each zone has a heater in its duct that reheats the supply air as needed to maintain space temperatures. Reheat systems are quite energy-inefficient and have been prohibited by various codes. Energy may though be saved through the recovery of the refrigeration system's rejected heat and the use of this heat to reheat the air.

Caution

Air from infectious patient rooms is normally NOT recirculated and is exhausted directly

to the outside via a HEPA filter.

Use of terminal heating and cooling units such as fan coil units is NOT acceptable in isolation rooms, surgical suites and other critical areas where maintaining the room pressure relationships is important.

Type of HVAC System - Normal Patient Care Rooms, Administrative and Non-critical Areas

For the patient bedrooms and other non-critical areas, any one of the following HVAC systems can be used.

1. All air systems as discussed above.

2. Terminal heating and cooling units, such as fan coil units or radiant ceiling panels.

3. Radiant heating and cooling system

The amount of outdoor air and how it is supplied to the occupied spaces would depend upon the type of HVAC system used. When the fan coil units or radiant ceiling panels are used, a central ventilation unit supplies conditioned air to the spaces. With this arrangement, the source of outdoor air being external to the principle cooling and heating equipment, it is possible to ensure the predetermined amount of outdoor air distribution to all the spaces.

CHILLERS

The chiller is the heart of an air conditioning plant. In a typical water-cooled chiller plant, it accounts for as much as 60% of the total HVAC power requirement. It is even higher (at 80%) in an air-cooled chiller plant. Chillers are specified by their design capacity in tons (1 ton = 12,000 Btu/hr) and their design efficiency in kW/ton.

Today chillers are available to operate at as low as 0.470 kW per ton. Given that annual energy costs for a chiller may amount to as much as one-third of their purchase price, even a modest improvement in efficiency can yield substantial energy savings and attractive paybacks. ASHRAE Standard 90.1 establishes minimum energy efficiency levels.

Four types of electrical chillers dominate the market:

1. Reciprocating compressors

   Reciprocating compressors are driven by a motor and use pistons, cylinders and valves to compress the refrigerant. These compressors are available in hermetic, semi-hermetic or externally driven versions.

   - In a hermetic unit, the motor and compressor are enclosed in a common housing, which is sealed. Because the components are not accessible for repair, the entire compressor unit must be replaced if it fails.
   - In the semi-hermetic unit the motor is also part of the unit, however it is not sealed so it is serviceable.
   - In a direct drive unit the motor and compressor are separated by a flexible coupling. These types of units utilize older technology and are not commonly used today.

2. Scroll compressors

   Scroll compressors perform at higher efficiency levels than reciprocating compressors. The compressors operate without cylinders, pistons or valves so it offers:

   - Low maintenance and high reliability
   - Low noise and vibration levels
   - Low space requirements
   - Relatively low weight

   Inside the scroll compressor, two spiral-shaped members fit together forming crescent shaped gas pockets. One member remains stationary while the other orbits relative to first. This movement draws gas into the outer pocket and seals off an open passage. As the spiral movement continues, gas is forced toward the center of the scroll design, creating a nearly continuous compression cycle.

3. Screw compressors

   A screw compressor's moving parts include a main and secondary rotor. It also has significant benefits:

   - Dramatic reduction of compressor parts
   - Low maintenance and high reliability
   - Low noise and vibration levels
   - Low space requirements
   - Relatively low weight

   The screw compressor's suction, compression and discharge all occur in one direction. Suction gas is pressed into one grooved rotor by the second similar rotor. The screw-like rotor motion continues toward the end of the compressor's working space. In this way, refrigerant volume steadily reduces or compresses until it reaches the stationary end of the compressor. These chillers are common in high capacity ranges up to 1000 tons and are available in both air-cooled and water cooled options.

4. Centrifugal compressors

   Centrifugal compressors are used in chillers with typical capacities of 150 to 2,000 tons. Centrifugal chillers are the most efficient of the large-capacity chillers but are ONLY used in water cooled configurations.

The most effective chiller is primarily a function of chiller size and in general the following guidelines apply:

<=100 tons 1st Choice – Reciprocating

2nd Choice – Scroll

3rd Choice - Screw

100 -300 tons	1st Choice – Screw
	2nd Choice – Scroll
	3rd Choice - Centrifugal
> 300 tons	1st Choice – Centrifugal
	2nd Choice – Screw

Chillers operate more efficiently when they are loaded close to their full rating than when they are only lightly loaded. It is imperative to determine which portion of the total load required 24 hours operations.

Recommended Elements:

- Peak load demand determines the overall capacity of the system. The total chiller capacity in tons of refrigeration shall match or exceed the peak building load or in other words, shall be the sum of the total cooling requirements of all connected air handling units.
- Part load requirements determine the number and size of chillers required. Cooling load profile will help to determine the type of chiller to use and if single or multiple chillers should be installed. Multiple chiller installations allow facilities professionals to stage their operation to match building loads while keeping the chillers operating at energy efficient loading.
- Adopt standby or (N+ 1) strategy. For health care facilities continuity of supply is critical, therefore the provision of cooling cannot be relied on a single chiller. One back up unit would be required.

AIR HANDLING SYSTEM

An air handling systems is a means of providing conditioned air to the space in order to maintain the environmental requirements. Often termed as the heart and lungs of the

health care facility, these must be selected and sized properly for its very important task. And that task is to control the environment to promote the healthiest conditions possible for the patients and other occupants.

Air Handling Equipment Sizing Criteria

Air must be delivered at design volume to maintain pressure balances. The air handling equipment must be sized in accordance with the following guidelines:

1. Load Calculations: Heat gain calculations must be done in accordance with the procedure outlined in the latest ASHRAE Handbook of Fundamentals. The calculations performed either manually or with a computer program.

2. The calculated supply air shall be the sum of all individual peak room air quantities without any diversity.

3. Safety Margin: A safety factor of 5 percent shall be applied to the calculated room air quantity to allow for any future increase in the room internal load.

4. The adjusted supply air shall be, thus, 5 percent in excess of the calculated supply air.

5. Air leakage: The air leakage through the supply air distribution ductwork shall be computed on the basis of the method described in the SMACNA Air Duct Leakage Test Manual. The maximum leakage amount shall not exceed 4 percent of the adjusted supply air.

6. Supply Air Fan Capacity: The capacity of the supply air fan shall be calculated per the following example:

    a. Calculated Supply Air Volume = 20,000 CFM

    b. Safety Margin = 5 percent of item (a) = 1,000 CFM

    c. Adjusted Supply Air Volume = 21,000 CFM

    d. Duct Air Leakage = 4 percent of item (a) = 840 CFM

    e. Supply Air Fan Capacity = 21,840 CFM

7. Equipment Selection: selection of the supply air fan, cooling coil, preheat coil, energy recovery coil (if any), filters, louvers, dampers, etc., shall be based on the supply fan capacity, 21,840 CFM calculated in the example above. A psychrometric chart shall be prepared for each air-handling unit. Make sure heat gains due to the fan motor and duct friction losses are taken into account for sizing cooling coils.

8. Air Distribution:

   - The main supply air ductwork shall be sized to deliver the supply air fan capacity, 21,840 CFM as calculated in the example above.

   - The individual room air distribution system including supply, return, exhaust air ductwork, air terminal units, reheat coils and air outlets/inlets shall be sized and selected on the basis of the adjusted supply air volume, 21,000 CFM.

   - The fan and motor selection shall be based on the supply air fan capacity and static pressure adjusted, as necessary, for the altitude, temperature, fan inlet and discharge conditions, and the AMCA 201 System Effect Factors. The fan selection shall be made within a stable range of operation at an optimum static efficiency. The fan motor W (BHP), required at the operating point on the fan curves, shall be increased by 10 percent for drive losses and field conditions to determine the fan motor horsepower. The fan motor shall be selected within the rated nameplate capacity and without relying upon NEMA Standard Service Factor.

9. Motor Voltages: Motor Voltages shall conform to NEMA/ANSI standard as follows:

System/Motor Voltages

System Voltage (Transformers)		**Utilization Voltage (Motors)**
Nominal	With 4 Percent Drop	Standard (For Schedule)
120	115.2	115

System Voltage (Transformers)		Utilization Voltage (Motors)
Nominal	With 4 Percent Drop	Standard (For Schedule)
208	199.7	200
240	230.4	230
480	460.8	460
600	576.0	575
2400	--	2300
4160	--	4000

Air Handling Units Specifications

The air handling equipment requires special attention to disinfection, and cleanliness; clusters of infections due to *Aspergillus* spp., *Pseudomonas aeruginosa, Staphylococcus aureus,* and *Acinetobacter* spp. have been linked to poorly maintained and/or malfunctioning air conditioning systems.

The failure or malfunction of any component of the HVAC system may subject patients and staff to discomfort and exposure to airborne contaminants. AIA guidelines prohibit United States hospitals and surgical centers from shutting down their HVAC systems for purposes other than required maintenance, filter changes, and construction. Often the routine maintenance and troubleshooting functions need to be addressed without necessarily disabling the units.

The following key elements need to be addressed when procuring these units.

1. Specify the cabinet construction with stainless steel or galvanized steel sheets polyester-coated both from the inside and outside. Ensure cabinet framework is

constructed from aluminum profiles for increased rigidity.

2. Specify a layer of non-flammable mineral wool between the inside and outside sheets for the cabinet casing.

3. Specify oblique floors for the air handling unit, tubs for the cooling units and drip channels made of stainless steel construction. Specify vacuum seal P-trap on the drain pan.

4. Specify all edges and offsets to be filled with fungicidal silicon certified for hygienic applications in health care facilities which precludes formation of the microbe expansion centers.

5. Specify provision for pressure gauges on the filter section casing of AHU along with audible alarm. This is to confirm that NO air stream will elude filtration, if openings are present because of filter damage or poor fit.

6. Specify access and inspection openings with the lighting elements installed in covers of the sections for humidification, filtration, heat exchangers and fans.

7. Specify modular construction with all the subunits to be assembled in a manner enabling their washing from all sides. All subunits and materials shall be resistant to commonly used disinfecting agents.

8. Specify a drum fan with an inspection flap and an outflow pipe which enables the drum cleaning OR a centrifugal and axial-flow fan with an open rotor.

9. Specify driving motor manufactured in the IP class, enabling washing and disinfection.

10. Specify multistage filtration with minimum of MERV 14 final filtration installed in plastic frames and mounted in frameworks made of resistant materials. The filters shall be provided with differential pressure gauge and pollution level indicators.

11. Specify UV bactericidal lamp ensuring disinfection of the recirculated air.

12. Specify cable glands providing connection of motors and the lighting system, ensuring the appropriate tightness and cleanliness class.

Exhaust Fans

Exhaust fan must be selected to produce the rate of airflow required by the exhaust system. The flow must be developed against the total system resistance, including pressure losses through the air distribution network including air cleaning devices. A fan of proper size and operating speed should than be selected from the ratings published by the fan manufacturer.

The exhaust fan should be located downstream of the air cleaning filter and as close to the discharge point as possible. The preferred location for an exhaust fan is outdoors, normally on the roof. A straight duct section of at least 6 equivalent duct diameters and 3 equivalent duct diameters should be used when connecting to the fan inlet and outlet respectively before any bend or fittings. When this is impractical due to space constraints, corrective devices such as turning vanes or flow dividers should be used, or the associated loss must be accounted for.

Fan selection should consider long term contaminant effects on the fan and the fan wheel. Where severe conditions of abrasion or corrosion are present, special lining or metals could be used in fan construction. Safe means should be provided to allow the wheel of an exhaust fan to be examined without removing the connecting ducts.

A flexible sleeve or band should be incorporated onto the fan inlet and outlet ducts to minimize vibration of the ductwork.

Air Distribution Ductwork

Recommended Elements:

1. In an effort to save installation dollars, the return duct is often deleted from the plans and the interstitial space between the suspended ceiling and the roof assembly, or the floor assembly above, is used as a return plenum. Open return air path directly over the false ceiling is NOT recommended for isolation rooms or elsewhere in health care facilities.

2. Any air leakage through duct joints will disrupt the pressure balance raising possibility of infectious material entraining into the air supply. The supply and return air ducts should be properly sealed and insulated during construction. On the return

side of the equipment, leaky ducts will draw in far more moisture than the cooling coils were designed to remove. The result is a higher than designed and desired humidity level in the space.

3. 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.

4. The ductwork of a negative pressure isolation room must not communicate with the ductwork of the rest of the hospital. Ductwork 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.

5. 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.

6. Position the exhaust discharge duct to prevent the contamination of intake air. In acute cases, the discharge plume may need to be modeled to prevent entrainment.

7. Round duct should be used for the construction of the exhaust system. Rectangular ducts, if used, should be as square as possible.

8. All branches should enter the main duct at gradual expansions at an angle not exceeding 45 and preferably 30 or less. Connections should be to the top or side of the main and directly opposite each other. Elbows and bends should be at a minimum of 2 gauges heavier than straight length ducts of equal diameter and have a centerline radius of at least 2 and preferably 2.5 times the duct diameter. The smaller branches should enter the main near the high suction end, closer to the fan inlet.

9. Exhaust stacks should be vertical and terminated at a point where height or air velocity would preclude re-entry of the contaminated air into the work environment.

10. Duct velocities should be sufficient to prevent the settling of dry aerosols. The recommended minimum duct velocity for most areas of the healthcare facility is 2500 fpm.

11. Ductwork should be located so that it is readily accessible for inspection, cleaning and repairs; Keep provisions for routine test ports for appropriate airflow and pressure balance.

12. Labeling the ductwork helps prevent unnecessary exposure to maintenance personnel who may unknowingly cut into the ductwork for the purpose of testing airflow or repairing equipment. Using a HEPA filter at the point of exhaust in the room allows you to use non-sealed ductwork (after the HEPA), which may be on a shared exhaust run. The ductwork located after the HEPA filter does not need to be labeled as potentially contaminated.

Insulation

The dew-point temperature of the air surrounding the cooler ducts and pipes could easily be higher than the surface temperature of the ducts and pipes. Condensation will occur when this happens. If the ducts and piping happen to be in the ceiling space, the condensate can drip onto a surface that is loaded with mold food (ceiling tiles, dry wall boards, insulation, plywood, etc.) and all of the necessary elements are there for mold growth.

Care must be taken to ensure that the supply air ducts, the chilled water lines (supply and return) and the refrigerant lines are well insulated with non-flammable mineral wool.

Noise Criteria

1. The noise level should be restricted to 35 NC level for all patient rooms, operating rooms (major or minor), diagnostic rooms, audio suites, examination rooms, conference rooms, large offices, lobbies and waiting areas.

2. The noise level should be restricted to 40 NC level for all small private offices, nursing stations, auditoriums, treatment areas, corridors, pharmacy and general work rooms.

3. The noise level should be restricted to 45 NC level for all laboratories, Dining, Food Service/Serving , Therapeutic Pools

4. The noise level should be restricted to 50 NC level for all gymnasiums, recreation

rooms, laundries and HVAC plant rooms.

Duct Sizing Criteria

Duct systems should be designed in accordance with the general rules outlined in the latest ASHRAE Guide and Data Books, SMACNA Manuals and Design Guide Section of the Associated Air Balance Council Manual.

1. Supply duct system, with total external static pressure 2 inches – w.g and larger, shall be designed for a maximum duct velocity of 2500 fpm for duct mains and a maximum static pressure of 0.25 inch-w.g. per 100 ft duct length. Static pressure loss and regain shall be considered in calculating the duct sizes. Size supply branch ducts for a maximum duct velocity of 1500 fpm.

2. All other duct systems such as return and exhaust, including branch ducts, shall be designed for a maximum velocity of 1500 fpm for the duct mains and a maximum static pressure of 0.10 inch- w.g. per 100 ft duct length, with the minimum duct area of 48 sq in (or 8 in x 6 in) size.

3. Indicate Duct Static Pressure Construction Classification according to SMACNA (1/2", 1", 2", 3" and 4") on drawings.

Pipe Sizing Criteria

All piping required for HVAC systems shall be sized based on the following criteria:

Water losses, pressure loss, etc., for sizing piping shall be based on "Cameron Hydraulic Data": With C = 100 for open (cooling tower) systems and C = 150 for closed systems. For closed systems, the maximum friction loss shall be 4 ft of water per 100 ft of pipe with maximum velocity of 14 fps for systems in occupied areas, and up to 8 fps for mains and large branches. For open systems, the maximum friction loss shall be 4 ft of water per 100 ft of pipe and a maximum velocity of 8 to 10 fps. The minimum pipe size shall be 3/4-inch.

HVAC EQUIPMENT LOCATION AND INSTALLATION

Equipment shall be located to be accessible for installation, operation and repair. Mechanical spaces shall be of suitable size to permit inspection and access for

maintenance, and to provide space for future equipment when required.

The effect that equipment noise or vibration might have on areas adjacent to, above, and below equipment shall be considered. Design shall comply with specified room sound ratings.

Location of equipment remote from sound sensitive areas should be emphasized.

Make provisions for all necessary stairs, cat walks, platforms, steps over roof mounted piping and ducts, etc., that will be required for access, operation and maintenance. Access to roofs by portable ladder is not acceptable.

Air Handling Equipment

Air handling units and similar equipment shall be housed in a mechanical equipment room or in a mechanical penthouse enclosure. Penthouse type of fully weatherized roof top units constructed in standard sections of modules would be acceptable in lieu of the mechanical equipment rooms or mechanical penthouses. These units shall provide excess sections for walk through servicing, maintenance, and shall ensure that the piping connections and electrical conduits are fully enclosed within the units.

Cooling Towers

Select and locate cooling towers to avoid problems with aesthetics, noise, vibrations, air recirculation or drift. Include a noise analysis of the proposed cooling tower relative to adjacent occupancies and consider alternative cooling tower selections, if necessary, to meet noise level of 60 dB(A) at 15 m (50 feet) which may be lowered for critical locations. Consider provisions for security and maintenance lights and receptacles. Provide a permanent service platform and ladders for access to cooling tower basin access doors.

Water treatment of cooling tower water is very important because the cooling tower operation is associated with Legionella disease and lower respiratory tract infections. Effective methods for disinfecting the hospital water supply include chlorination, thermal eradication, UV light, ozone treatment and metal (copper –silver) ionization system.

Air Intakes and Outlets

1. Ensure that air intakes and exhaust outlets are located properly in construction of new facilities and renovation of existing facilities.

    a. Locate exhaust outlets >25 ft from air-intake systems.

    b. Locate outdoor air intakes ≥6 ft above ground or ≥3 ft above roof level… (The air intake shall be located as high as practical or not less than stated).

    c. Locate exhaust outlets from contaminated areas above roof level to minimize recirculation of exhausted air.

2. Operating Room system air intakes shall be at least 30 ft above the ground.

3. Laboratory and Research exhaust shall be terminated at the highest point of the building (NFPA 99, 5-3.3.4).

4. Outside air intake shall not be near hot exhaust discharging horizontally or deflected down, nor be near plumbing vents, animal room exhausts, generator exhausts, loading docks, automobile entrances, driveways, passenger drop-offs, cooling towers, incinerator and boiler stacks.

5. Louvers shall be designed for a maximum velocity of 750 fpm through the free area of 35 percent. Drainable louvers may be designed for a maximum velocity of 1000 fpm and 45 percent free area.

6. Ensure that the intakes are kept free from bird droppings, especially those from pigeons.

SECTION # 4

CONTINGENCIES FOR HVAC DESIGN

Hospital shall be fully functional under any circumstance, regardless of the unpredictability or severity of the situation. Understanding code requirements, performing a hazard vulnerability analysis, and understanding what role the medical facility has in the community during an emergency are all essential to designing a safe and reliable HVAC system for a hospital.

Loss of Power

The loss of normal power at a medical facility whether the result of a natural disaster (thunderstorm, earthquake, hurricane….) or system failure (due to any eventuality such as short circuiting, inappropriate maintenance, maintenance crew digging in the wrong place, a squirrel/rat causing electrical disruptions…) , is a situation that an HVAC engineer must anticipate.

It is critical that the continuity of HVAC services is maintained. Developing a contingency plan for uninterruptible HVAC services and backup capacity in the event of a general power failure should be established as early in the design phase as possible.

Code required systems

The National Electric Code (NEC) and National Fire Protection Association Standard for Healthcare Facilities (NFPA 99) require certain HVAC systems to be connected to the emergency power system in a hospital.

<u>Generator-related equipment</u>

- Fuel pumps
- Damper operators and controls
- Ventilation and combustion air fans and
- Remote radiator fans

<u>Fire safety systems</u>

- Smoke control systems including exhaust fans, air-handling equipment, and controls
- Stair pressurization equipment and controls
- Kitchen hoods

Heating equipment to maintain inside design temperature where the outside design temperature is lower than +20°F

- Operating rooms and associated support spaces
- Labor and delivery rooms and associated support spaces
- Recovery areas
- Intensive care and coronary care units
- Nurseries
- Protective and infectious isolation rooms
- Emergency treatment spaces
- General patient rooms

Supply, return, and exhaust air systems serving the following areas

- Surgical and obstetrical delivery suites and associated support spaces
- Intensive care and coronary care units
- Protective and infectious isolation rooms
- Emergency treatment spaces
- Bone marrow treatment areas
- Clinical laboratories
- All diagnostic and treatment areas.

- Exhaust fans for fume hoods and radio-isotope hoods
- Autopsy room exhaust air systems
- Ethylene oxide evacuation and anesthesia evacuation systems

HVAC Equipment serving above areas

- Water chillers, pumps, and air handling units
- Building automation and control system serving systems on emergency power
- Refrigeration system and controls for food storage and clinical laboratory refrigerators and freezers.
- HVAC systems serving critical areas, telecommunication rooms and computer rooms.
- Electric heat tape for exposed piping, absorption chillers to prevent crystallization, oil sump heaters on electric centrifugal chillers.

The HVAC systems and equipment listed above are considered to be the minimum requirements in an acute care hospital. Additional state and local requirements as addressed by authority having jurisdiction (AHJ) will add to the minimum requirements. These requirements should be understood prior to the start of any design.

Performing a hazard vulnerability analysis as outlined by the Joint Commission on Accreditation of Healthcare Organizations (JCAHO) is the best way to begin to establish the extent of the HVAC emergency power requirements that are above the minimum required by code or otherwise mandated. Whenever feasible, design and install fixed backup ventilation systems for new or renovated construction of PE rooms, AII rooms, operating rooms, and other critical-care areas.

HVAC system impact on generator size

HVAC systems have a significant impact on the emergency power system of a hospital. The connected load of the HVAC equipment can range from 3 to 6 W/sq ft in an acute care facility. This is generally 50% to 60% of the entire load on the emergency generator

plant. With the typical cost of an emergency generator plant ranging from $800 to $1,200/kW of generator capacity, the cost of adding 100 hp of motor load could be as high as $90,000.

It goes without saying that care must be taken when determining what HVAC equipment is required to be connected to the emergency power system. Establishing an appropriate balance between the cost of adding equipment to the emergency generator and the risk of not having HVAC service during a loss of power is a difficult task. Major system decisions are dependent on an early understanding of these issues. As an example, the number of air-handling units (AHU) and what departments they will serve can have an impact on the size of the mechanical rooms, as well as the size of the emergency generator.

SECTION # 5

ENERGY CONSERVATION

Depending on the climate, between 35% and 60% of the annual energy costs of the typical healthcare facility are related to the operation of the HVAC systems.

Recommended Elements:

Room Pressurization

The significant airflow requirements and high air changes per hour that are necessary to maintain sterile and healthy environments are also the major contributor to the significant energy usage of healthcare facilities. As a result, the HVAC systems not only use higher fan energy to move the air from the air-handling system, but these also use significant energy to cool and dehumidify outdoor air to maintain space temperature and humidity requirements. It is important to build the spaces tight and avoid over pressurization. Let's see one example to show the energy loss due to over pressurization.

One-inch water gauge pressure is equivalent to wind velocity of 4005 feet per minute (~45 miles/hr).

High pressurization will result in higher leakage rates. The amount of expected leakage can be calculated from the following equation:

Leakage Velocity (fpm) = (Room pressure in inch-w.g) $^{1/2}$ x 4005

Leakage rate = Opening Area (sq-ft) x leakage velocity (fpm)

Case-1: Assuming 0.05" w.g. positive pressurization

Leakage Velocity = $(0.05)^{1/2}$ x 4005

= 0.223 x 4005

= 895 fpm

With a total of 2 square feet opening

Leakage Rate = 2 x 895 = say 1800 CFM

Case-2: Assume 0.1" w.g. positive pressurization

Leakage Velocity = $(0.1)^{1/2}$ x 4005

= 0.316 x 4005

= 1265 fpm

With a total of 2 square feet opening

Leakage Rate = 2 x 1265 = 2530 CFM [This is 40% increase in leakage rate.]

Now let's see the impact on energy costs.

For the same example above, assume the outside makeup air is at 95°F DB/72°F WB which needs to be conditioned to 72°F DB/60°F WB. From the psychrometric charts, the enthalpy difference (heat to be removed to bring outside air to clean room conditions) is 9.5 BTU/lb of air.

The heat load is given by equation:

Q (Btu/hr) = 4.5 x airflow in CFM x enthalpy difference

For case-1: 1800 CFM leakage

Q = 1800 x 9.5 x 4.5 = 76950 BTU's/hr

This is equivalent to 6.4 TR* [*Note 1 ton of refrigeration (1 TR) is equivalent to heat removal rate of 12000 BTU's/hr]

For case-2: 2530 CFM leakage

Q = 2530 x 9.5 x 4.5 = 108234 BTU's/hr or

This is equivalent to 9.0 TR

Therefore the client will incur an extra capital cost equivalent to 9- 6.4 = 2.6 TR. Not only the capital cost, higher pressurization (case-2) will incur recurring higher energy costs of

nearly 4 kWh [@ 1.5 kWh per TR of cooling load], which translates to 35000kWh per annum on 24/7 operations.

The room pressure should be limited to 0.01 inch-w.g for PE and operating rooms. Positive pressurization can be maintained only if the sealing integrity of the building is maintained. The building should be air tight for low air leakage performance. Uncontrolled leakages areas in the building are door undercuts; pass through, walls, ceilings and duct joints etc; that should be restricted as far as possible.

Use of Variable Air Volume Supply and Return Systems

Fan power is proportional to the cube of airflow rate or fan speed. The fan laws state:

1. Airflow α fan speed
2. Pressure α (fan speed)^2
3. Horsepower (HP) α (fan speed)^3

A reduction in the supply air volume by 10% will result in a power reduction of approximately 27% [1 – (0.9)^3]. Significant energy savings can be achieved by designing the air handling systems as variable air volume (VAV) tracking systems with variable frequency drive fan motor. Except in spaces where constant air change rate and/or critical pressure differential relationship are essential, variable air volume terminal units with or without reheat coils shall be used.

The VAV system is applicable to all non-critical care spaces such as dining areas, out-patient administrative offices, maintenance areas, many out-patient therapy areas and many common areas, which do not have continuous pressurization control requirements.

Caution

VAV system is NOT recommended for critical care spaces where continuous directional pressurization control is required (either positive or negative) and significant minimum airflow rates are required constantly irrespective of the occupancy. These include spaces such as isolation rooms, surgical suites, laboratories or pharmacy areas, intensive-care units and patient rooms, etc

Although AIA and ASHRAE allow ventilation rates to be reduced to 25% of the occupied period rates, as long as continuous directional control and space pressurization is maintained at all times and the full (occupied) ventilation air change rates can be re-established at any time, VAV is NOT advisable due to safety concerns.

Optimal Equipment Sizing

a. Most engineers size air handlers with a "rule of thumb" of 500 fpm. This saves time, but increases cost of ownership. Pressure drop in a duct or air handler is approximately proportional to the face velocity squared. Fan power requirement decreases approximately as the velocity decrease. To reduce the pressure drop, specify a low face velocity unit in the 250 to 450 fpm range.

b. Utilizing variable frequency drives (VFDs) to realize operational savings from oversized fans, pumps, cooling towers and some types of chillers. Variable-speed drives use 15-30% less energy than constant-speed drives.

c. Size the equipment to avoid efficiency penalties at part load conditions. Often this will involve unequal unit sizing and/or modular approach.

Optimizing Air distribution and Reducing Pressure Drop

Fan energy use is directly proportional to the pressure drop that the fan is pushing air through. Thus, the more restrictive the supply system, the higher the pressure drop, and the higher the fan energy use. Carefully evaluate the air distribution system. The major energy savings can accrue from the air distribution. Strategies for lower pressure drop include:

a. Minimize obstructions to air flow, run straight duct lengths and avoid arbitrary zigzags. Pressure drop in ductwork *is inversely proportional to the fifth power* of duct diameter for e.g. substituting a 16 inch duct for a 12 inch duct reduces pressure drop by about 75%.

b. Select cooling coils, sound attenuators and filters with low air pressure drop

c. Keep low face velocity

d. Select high efficiency filters. Higher-performance air filters clean supply air more

efficiently, resulting in a reduction of energy consumption.

e. Avoid excessive safety margins

Efficient Filtration

Filtration also has a substantial impact on energy efficiency. With static pressure drops of up to 0.072 pounds per square inch (psi), filters can consume an enormous amount of fan power. As with other air-handling components, the key to efficient filtration is to consider the details, especially face velocity (airflow per unit area of filter media). The *efficiency* of a filter refers not to energy efficiency, but to how well it removes particles from the airstream. *Pressure drop* is the measure that determines how much fan power is required to move air through the filter, and it varies by the square of the air speed through it. For typical HVAC-duty filters (30 percent ASHRAE dust-spot efficiency) a reasonable target pressure drop is 0.0036 psi. Dirty, thick, or poorly designed filters can have pressure drops as high as 0.072 psi—as much as the entire frictional drag of the duct system.

Heat Recovery Devices

Use economizer cycle for free cooling. Air conditioning systems shall be designed to operate without refrigeration whenever the ambient temperature drops below 48°F.

For all locations where the outdoor winter design temperatures are below –1°C (30°F) and the winter degree days are in excess of 3000, heat recovery devices, comprising of either heat recovery wheels, air to air plate heat exchangers or glycol run around loop heat recovery coils, shall be installed. This applicable to all 100 percent outdoor air systems and exhaust air systems whenever the capacity is in excess of 3000 CFM and are of continuous duty.

Caution

Do not provide heat recovery systems in the following special exhausts (where mixing is a concern):

a. All Fume Hood Exhaust

b. Kitchen Exhaust (Range Hood and Wet Exhaust)

c. Autopsy Exhaust

d. Isolation Room Exhaust

e. Wet Exhaust from Cage and Cart Washers

f. ETO - Ethylene Oxide Sterilizers Exhaust

Selecting High Efficiency Equipment

a. Specify high efficiency components, including high efficiency motors and fans, chillers and other equipment

b. Screw and centrifugal compressors enhance chiller reliability. Modern centrifugal chillers consume as little as 0.50 kW per ton of refrigeration and the centrifugal chillers equipped with the variable-speed technology yield greater energy savings even during part load operation.

Don't Overcool the Spaces

Chiller work is proportional to the vapor pressure work of the compressor – this work is lowered if chilled water temperatures are raised and/or condenser water temperatures are lowered. The majority of health care chilled water requirements are best served by medium chilled water temperature at 44 to 52°F chilled water.

Caution

Oftentimes in an effort to conserve energy, the chiller is allowed to operate with a slightly elevated leaving water temperature (e.g., elevating from 44° to 46°, possibly). While this will indeed save on the energy bill, and it might be sufficient for keeping the space temperature under control, it could fail miserably at controlling the moisture within the space (especially within the operating rooms). If the humidity within the space should exceed the desired maximum acceptable level (e.g. 55% to 60% RH), then there should be a humidity sensor and transmitter within the space that could override the temperature controls and then lower the chilled water temperature in order to keep the humidity under control.

Challenge the room volume

Seek opportunities to evaluate whether conditions permit to minimize room size. Doing this reduces re-circulation airflow requirements and the associated energy usage. Capture savings by creating mini enclosure environments within large areas.

Consider Alternate Cooling Strategies

The cooling can be provided with electric chiller, gas engine driven chiller or alternatively through vapor absorption machines using natural gas/fuel oil firing or steam. Other strategies include thermal storage systems using chilled water reservoirs or ice banks.

A carefully thought-out energy strategy that does not rely on any single energy source for all heating or cooling needs can have many benefits. The ability to switch to the least expensive fuel to produce chilled water during times of peak demand will lead to lower utility costs than the competing hospital who has decided to take the lowest first cost approach to chilled water and steam production. A secondary benefit to the diversification of energy usage is the ability to produce chilled water for the critical areas of the hospital with minimal investment when compared to the cost of electrically driven chillers or direct-expansion equipment connected to the emergency power system.

CONCLUSION

Engineering guidelines for ventilation control for 'Protective Environment' and 'Airborne Infection Isolation Areas' are given as follows:

	Class – P: Positive Pressure Areas (e.g. Protective Environment)	**Class – N: Negative Pressure Areas (e.g. Airborne Infection Isolation)**
Pressure differentials	> 2.5 Pa (0.01 in-water gauge)	> 2.5 Pa (0.01 in-water gauge)
Air changes per hour (ACH)	>12	≥ 12 (for renovation or new construction)

Filtration efficiency	Supply 99.97% @ 0.3µm DOP Exhaust – None required	Supply 90% dust spot test Exhaust – 99.97% @ 0.3µm DOP
Room airflow direction	Out to the adjacent area	In to the room
Clean-to-dirty airflow in room	Away from the patient (high risk patient or immune-suppressed patient)	Towards the patient (airborne disease patient)
Ideal pressure differential	>8 Pa	> 2.5 Pa

Notes

- Pa = Pascal, a metric unit of measurement for pressure based on air velocity; 250 Pa equals 1.0 inch water gauge.
- DOP = Dioctylphthalate particles of 0.3 µm diameter.

Understanding the role of a hospital in the community during an emergency situation where normal power is not available and determining what functions within the hospital must remain operational in that emergency are the basis for many of the HVAC design decisions on a project. The right decisions will ultimately provide the hospital with a safe and reliable HVAC system.

Involve infection control professionals with a clinical background from the inception of the project. This allows for identifying potential infection control issues early and provides an opportunity to design solutions prospectively. Infection control professionals set forth the design criteria, policies and procedures for efficient design and regularly conduct assessment of facilities. They play an important role in educating architects, engineers, and construction workers about potential infection control risks and appropriate methods for reducing them. The optimum Indoor Air Quality (IAQ) level is the responsibility of the architects and mechanical engineers.