VENTILATION AND AIR CONDITIONING OF STERILE SPACES IN HOSPITALS

By
Twana Smko Fathullah
Mech. Engineer

INTRODUCTION

Ventilation is used extensively in all types of healthcare premises to provide a safe and comfortable environment for patients and staff. More specialized ventilation is provided in primary patient treatment areas such as operating departments, critical care areas and isolation units.

It is also installed to ensure compliance with quality assurance of processed items in pharmacy and sterile services departments, and to protect staff from harmful organisms and toxic substances (for example in laboratories).

The sophistication of ventilation in healthcare premises is increasing. Patients and staff have a right to expect that it will be designed, installed, operated and maintained to standards that will enable it to fulfill its desired functions reliably and safely.

There are various sterile spaces in hospitals which are highly at risk in terms of infection. HVAC systems for comfort applications focus on three parameters which are temperature, relative humidity and fresh air rate. However; additional parameters as number of particles, number and types of microorganisms, pressure difference between the sterile and its neighboring spaces, supply air velocity and air distribution have to be considered in the HVAC system of sterile spaces. Therefore, the design of HVAC systems for sterile space applications is more difficult and complicated compared to the comfort applications. The aim for using sterile air in hospital spaces is creating a germ-free environment and keeping this sterile environment conditions steady for all patients and hospital staff. This sterile environment reduces the risk of infection transmission from patient to patient or from patient to hospital staff. Also, the risk of surgical site infection is reduced by this approach. HVAC system of sterile spaces must satisfy various design conditions such as thermal comfort and sterilized indoor air. The air of sterile spaces must be aseptic and it should be with low velocity and at constant temperature and relative humidity.

STERILE SPACES IN HOSPITALS

There are many different spaces used for various activities in a hospital. Some of these spaces require higher hygienic needs than the others. DIN 1946-4 classifies these spaces into two groups as Class I and Class II as high or very high need of hygiene and normal levels of hygiene, respectively. The list of most common Class I spaces is given below.

1. *Operating suites,*
2. *• Delivery rooms,*
3. *Intensive care rooms,*
4. *Isolation rooms,*
5. *Central sterile services (Deutsches Institut für Normung 1999 March, American Institute of Architects 2006, American Society of Heating Refrigerating and Air-Conditioning Engineers 2003)*

1. OPERATING SUITE

An operating suite is a space, complete with its required sub-facilities, that is designed to perform required surgical operations. The components of an operating suite are;

- *Operating rooms,*
- *Pre-operation (pre-op) rooms,*
- *Anesthesia equipment rooms,*
- *Post-operation (post-op, recovery) rooms,*
- *Sterile equipment rooms,*
- *Soiled equipment rooms,*
- *Staff supports areas,*
- *Interconnecting corridors and halls (American Society of Heating Refrigerating and Air-Conditioning Engineers 2003).*

1.1. OPERATING ROOM

An operating room is the space where the surgical procedures take place and this space requires high levels of hygiene since the infection risk is high. Because of this reason, operating room personnel wear protective garments such as gloves, shoe covers, masks, caps etc. Since operating rooms is one of the most important rooms in operating suite in terms of patient health. (Figure 1.1)

Figure 1.1 Operation Room

1.2. PRE-OP ROOM

Pre-op room is the room where the patients are prepared for surgery. The patient is transferred to operating suite on wheelchair or stretcher and introduced to pre-op room first. In this room, the sedation is applied if it is needed according to the type of surgery, the heart beat and blood pressure of the patient are checked, the procedure that is going to be followed during surgery is reviewed and the patient is readied to be transferred to the operating room.

Figure 1.2 Pre-op room

1.3. ANESTHESIA EQUIPMENT ROOM

Anesthesia equipment room is the space where the anesthetic equipments are cleaned, tested and stored. When needed, the required equipments are transferred to the related space to be used.

1.4. POST-OP ROOM

Post-op room is similar to pre-op rooms. Patient is transferred to this room from the operating room for post-operative treatment. The patient is held in this room until the effects of anesthesia are removed and first medications are given. Patient is held under post operative treatment until it is been decided by the nurses that the patient is ready for transferring to intensive care or patient room.

Figure 1.4. Post-op Room

1.5. STERILE AND SOILED EQUIPMENT ROOMS

Sterile equipment room holds the sterile instruments and medical supplies that are used during surgical procedures. The level of hygiene in sterile equipment rooms must be equal or higher than the operating room. These spaces must be positively pressurized with respect to the neighboring spaces. The direction of airflow must be outwards even it is adjacent to an operating room. By this way it is ensured to minimize the contamination level in the room and the risk of contamination of sterile equipment is reduced. Used equipments are collected and stored in soiled equipment rooms. Disposable and reusable equipments are separated and reusable equipments are sent for cleaning and sterilization. This room must be kept under negative pressure with respect to the adjacent spaces in order to keep the airborne contaminants in the room.

2. DELIVERY ROOM

Delivery room is the space where the birth takes place. Two kinds of delivery rooms are found in hospitals as traditional and alternative delivery rooms. In traditional delivery room design, expectant mothers are moved to delivery rooms for delivery following the labour phase. After the delivery, mothers are moved to recovery room and for the final stage, they moved to the post partum unit, where the mother and her baby rest. The alternative delivery room design (Labour/Delivery/Recovery [LDR]) is a specialized type of patient room. In this delivery room design the mother is not moved but all the required functions are supplied in the same room according to the phase of delivery. Some designs of modern delivery rooms may include the post partum phase in which the mother and her baby are treated for the duration of their stay in hospital in the single LDR unit which is called LDRP (Labour/Delivery/Recovery/Post Partum) unit. These types of delivery rooms are used for normal deliveries. If surgical intervention is required, the mother is moved to cesarean operating rooms (named also as delivery operating rooms). The delivery operating room is almost identical with general operating rooms. Following the cesarean section operation, the mother is moved back to her room for recovery and post partum (American Society of Heating Refrigerating and Air-Conditioning Engineers 2003).

3. INTENSIVE CARE UNITS

Intensive care units are spaces where extremely ill patients are continuously monitored and assisted by life-support units in necessary situations. There are special types of intensive care units each serving for different purposes. The most common types of intensive care units are surgical intensive care, medical intensive care, cardiac care, post-anesthesia care, neurological intensive care, burn/wound intensive care and neonatal intensive care. Whether specialized or generalized, the design considerations for the intensive care units are similar, except for the neonatal intensive care units. Newborn nursing operations for infant care are much more focused on the patient's bedside than other types and this reason obligates considering different design conditions.

According to the different aims of intensive care units, the expectations from the HVAC systems may differ. For instance, the burn intensive care units need high level of hygiene while normal intensive care units do not. In addition, higher relative humidity level is required for burn intensive care units, compared to the others (American Society of Heating Refrigerating and Air-Conditioning Engineers 2003).

Figure 3. Intensive Care Unit

4. ISOLATION ROOMS

The purpose of an isolation rooms is to protect health care workers, other patients and visitors from exposure to any airborne infectious agents. To control the transfer of microorganisms via air, isolation rooms must be implemented. Two types of isolation rooms exist; negative pressure room (or airborne infection isolation room) and positive pressure room (or protective environment room) (American Society of Heating Refrigerating and Air-Conditioning Engineers 2003). Both types of rooms aim to control air flow and reduce the number of airborne infectious agents to a level that ensures infection of other person is unlikely.

4.1. POSITIVE PRESSURE ROOMS

Patients with suppressed immunity due to some reasons such as surgical operation, drug use and illness are kept in these rooms. The aim is to reduce the risk of transmission of infection from the environmental sources to the susceptible host via air. This room is a specialized patient room that has proven to have outward air flow through all its six surfaces and sustained positive air pressure with respect to all six surfaces, including the outside wall. High or very high levels of hygiene are required for protective environment rooms. For this purpose, this room has specific ventilation design features such as HEPA filtering and specialized air distribution profile, where the air is supplied near the patient bed and exhausted towards the door of the room (American Society of Heating Refrigerating and Air-Conditioning Engineers 2003). Another key factor for ventilation design is the diluting the contaminants in the room air, and this is provided by adequate fresh air change rates.

4.2. NEGATIVE PRESSURE ROOMS

Patients are placed in negative pressure rooms to reduce the risk of transmission of infection via air from the patient to the other patients and hospital staff. This kind of room is also known as airborne infection isolation rooms. This room is especially used for airborne infectious patients in order to be kept, examined and treated. In this patient room, on contrary with the protective environment room, inward air flow through all six surfaces is provided and negative air pressure with respect to all adjacent rooms is maintained. High level of hygiene is not needed for airborne infection isolation rooms. The recommended practice is to transfer the exhaust air by an independent ductwork system, which is maintained in negative pressure, and to filter the exhaust air by high efficiency air filters before releasing it to outdoor. It is not a necessity for the room to have an electronic pressure monitoring and control system; but a mechanical means of measuring the pressure relationship is required (American Society of Heating Refrigerating and Air-Conditioning Engineers 2003).

5. CENTRAL STERILE SERVICES

Central sterile services department cleans and prepares instruments and equipment for use in surgical procedures, delivery, emergency care and related areas. This department in the hospital is responsible from various duties. These responsibilities can be listed as follows. • Cleanup of surgical case carts; separation of trash, linens and instruments. • Decontamination of instruments and washing of carts. • Cleaning of instruments including ultrasonic cleaning, soaking and processing through a washer/sterilizer. • Assembly of instrument sets and supplies for surgical packs and packaging. • Sterilization of packs, labeling and storage. • Preparation of case carts or sets of packs for scheduled and emergency procedures • Delivery of case carts or sets of packs to the served departments. • Receipt and stocking of supplies and linens to be used in packs. • Inventory control and administration (American Society of Heating Refrigerating and Air-Conditioning Engineers 2003). Central sterile services department is responsible in some cases for the delivery of sterile equipment to the served departments. The level of hygiene in sterile equipment storages in central sterile services department must be equal or higher than the operating room. These spaces must be positively pressurized with respect to the neighboring spaces. The soiled equipment work areas in this department must be kept under negative pressurization.

Figure 5 Sterile storage area

HVAC DESIGN PARAMETERS FOR STERILE SPACES

Criteria for HVAC design of sterile rooms involve indoor and outdoor temperature and humidity, room pressure, filtration stages, total and fresh air change rates. In addition, economical factors for maintenance and operation, heating and cooling loads, glazing characteristics etc. must be taken into account. The effects of the mentioned design parameters on thermal comfort and infection control are discussed in this chapter.

1. TEMPERATURE

Room temperature directly affects the thermal comfort of both hospital staff and patients. Especially, the staff wearing protective garments working under highly radiant lighting can be affected easily in terms of thermal comfort. This uncomfortable feeling affects the concentration; consequently the result of the activity being held in the room can be affected negatively. The thermal comfort feelings of surgeons working under lighting and in protective garments are different from other operating room personnel. Surgeons generally feel more comfortable at lower temperatures while nurses and anesthesia specialists feel comfortable at higher temperatures. Generally, temperatures between 24- 26°C are suitable for the thermal comfort of patient while temperatures below 21°C increase the risk of hypothermia. However, the thermal comfort of surgical staff is greatly reduced with the room temperatures higher than 23°C (Melhado, Hensen and Loomans, Literature Review of Staff Thermal Comfort and Patient "Thermal Risks" in Operating Rooms 2006). Not only the thermal comfort is taken into account to determine design temperature, but the activity being held in the room must also be considered. Especially in operating rooms, the type of operation must be defined since different types of operations require different room temperatures. Some examples are (American Society of Heating Refrigerating and Air-Conditioning Engineers 2003);

- *32°C with a low relative humidity level found beneficial for treating certain kinds of arthritis.*
- *High relative humidity with 32°C is used for burn patients.*
- *Room temperature around 30°C is used for pediatric surgery.*
- *For cardiac surgery, room temperature is set about 15-16°C and raised up to temperatures around 25°C*
- *Room temperature around 15-16°C is used for transplant operations. Since the room temperature depends on the type of operation, the temperature must be individually controlled for each operating and delivery room (American Institute of Architects 2006). In spaces where the health of the patients is more important than the thermal comfort, room temperature must be specified in a range in which the growth of the microorganisms are affected and/or the immunity system of the patients are not affected, negatively (American Society of Heating Refrigerating and Air-Conditioning Engineers 2003).*

2. RELATIVE HUMIDITY

Like the room temperature, the relative humidity ratio is a factor affecting the thermal comfort of both patients and hospital staff. A high level of relative humidity is a common thermal disturbance, especially when combined with low room temperature. Consequently, the concentration of staff may be adversely affected by this disturbance. Humidity control during cooling of the air is very important to prevent this adverse effect. As in temperature, relative humidity level of the room must not act as a potent risk for the patient's health. Previous studies have shown that average values for relative humidity between 40% and 70% are not suitable for microbial growth. In addition to this fact, low levels of relative humidity results with the drying or the mucous coating on special tissues in the upper and lower respiratory tracts which causes the particles in the air to be breathed deeply into the lungs (American Society of Heating Refrigerating and Air-Conditioning Engineers 2003).

Other effect of relative humidity ratio of room air is on the patient's wounds. Low relative humidity ratio results with excessive drying of the wound, especially in surgeries. High relative humidity ratio is needed during eye surgeries or tissue transplant operations for burn wounds where the drying of the wound is not desired. For example, up to 95% relative humidity is used for burn patients. In some cases, low relative humidity levels may be required, such conditions can be experienced in treatment of arthiritis, where the relative humidity level are maintained at around 35% (American Society of Heating Refrigerating and Air-Conditioning Engineers 2003).

3. FILTRATION

A sterile space in a hospital is generally closed environments. The fresh air need of this space is provided by mechanical ventilation system. In order to prevent the increment of particle concentration in a space, the supply air must be filtered appropriately. It is reported that the microorganisms are transported by the particles suspended in the air; therefore, an increase in the particle concentration would result with an increase in the microorganism concentration. The particles present in the supply air is not the only source of particle concentration. Along with the particles transported into a sterile space by supply air, particles are also generated in space by the activities. These particles may also carry microorganisms. The microorganisms that are present in the air may be bacteria, viruses or originate from molds. The bacteria which are highly infectious and transported via air or air-water mixture are Mycobacterium tuberculosis and Legionella pneumophila (Legionnaire's disease). Varicella (chicken pox/shingles), Rubella (German measles), and Rubeola (regular measles) are the examples or viral infections that are transported by air. It is proved that some molds like Aspergillis can be fatal to advanced leukemia, bone marrow transplant and other seriously immunosuppressed patients. Previous studies have shown that 99.9% of all bacteria present in a hospital are removed by 90-95% efficient filters. The main reason of this is that the bacteria exist in colony-forming units that are larger than 1 mm. The use of high efficiency particulate air (HEPA) filters having filtering efficiencies of 99.97% in certain areas is recommended. It is proved that many of the airborne viruses are in sub-micron size,

Thus, there is no exact method to eliminate 100% of the viable viruses from air even HEPA and/or ultra low penetration (ULPA) filters offers the greatest efficiency. Implementing ultraviolet (UV) lights or chemicals to inactivate the viable viruses are not proven effective (American Society of Heating Refrigerating and Air-Conditioning Engineers 2003). And Table 6 shows the Filter types

4. AIR VELOCITY AND AIR DISTRIBUTION

The velocity of air in a sterile space is important due to its influence on the comfort feeling along with the other effects such as drying of the wounds, especially in surgical site. There are two types of air distribution profiles for a sterile space which are laminar and turbulent flow. The velocity of air is a significant factor for air distribution. Turbulent air distribution is generally used in older operating rooms and in other sterile spaces in an operating suite such as post-operation or sterile equipment rooms. The particles that are present in the operating room are considered to be distributed homogeneously for this kind of air distribution profile (Figure 4.1). Conventionally ventilated operating rooms are generally used for general surgeries which do not require high level of hygiene. It is recommended to use laminar flow operation rooms for surgeries requiring high level of hygiene (American Society of Heating Refrigerating and Air-Conditioning Engineers 2003).

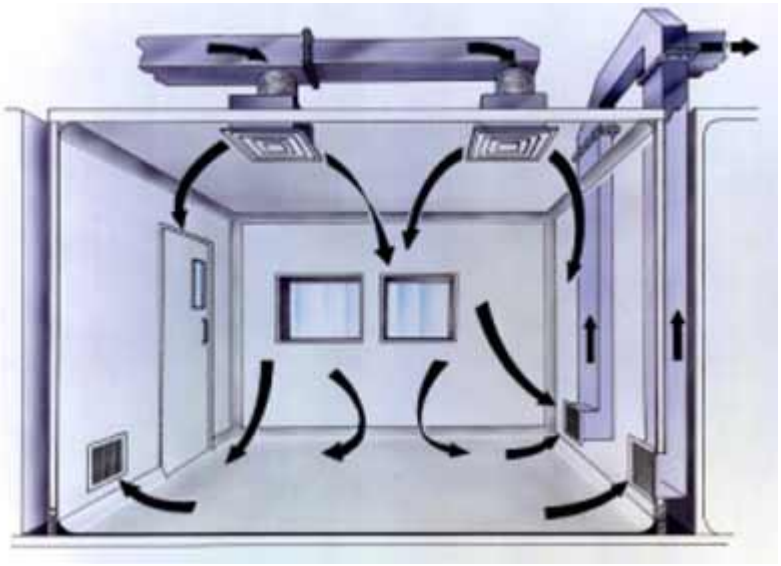

Figure 4.1 Turbulent air flow distribution

In laminar flow rooms, a clean space is created in the room and the flow profile prevents the contaminant from entering this clean space from outside. In this kind of room, the filtered air with low particle concentration is supplied above the patient and/or the personnel, and the air flows down to floor level and is exhausted by low level registers (Figure 4.2). Since the velocity of the air is low, the supply air temperature must always be 1-2°K lower than the room temperature in order to provide the flow of the air down to floor. Supplying cold air above the personnel may reduce the thermal comfort. Also it is shown that if the operating room staff lacks in required precautions for infection control, the air moving from the staff to the patient transfers skin squames and particles from the head of the staff (Owers, James and Bannister 2004). Horizontal laminar flow rooms are recommended to overcome these problems of vertical laminar flows but it is almost impossible to protect the horizontal laminar flow of the air because of the medical equipments, movement of staff etc (Melhado, Hensen and Loomans, Review of Ventilation Systems in Operating Rooms in View of Infection Control 2006).

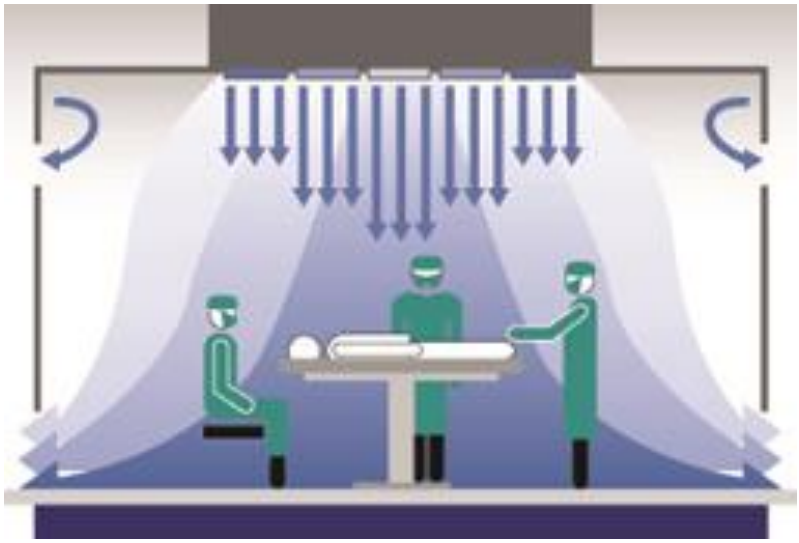

Figure 4.2. Laminar air flow distribution

For completing the sweep by the air supplied by the laminar flow unit, only supplying colder air is not enough. Most of the time, air distribution profile is not complete without proper exhaust grille arrangements. To complete the distribution profile, it is recommended to arrange low level exhaust grilles. Another example for complete air distribution is the recommended profile for airborne infection isolation and protective environment rooms. It is recommended to supply the filtered air in the region near the door of the room and exhaust in the region near patient bed for airborne infection isolation room and supply the air from above the patient bed and exhaust from the region near the door (American Society of Heating Refrigerating and Air- Conditioning Engineers 2003). Using low level exhaust is beneficial in operating rooms because of the precipitation of waste anesthetic gases. It is more effective by low level exhaust to remove these waste gases (Melhado, et al. 2005).

5. PRESSURIZATION

The aim of the pressurization is to protect the cleanliness of room air from the contaminants that may enter from the neighboring spaces. Since most of the airborne viruses are in sub-micron size, filtration is not a perfect method to effectively eliminate the viable particles. Therefore, the best practice to prevent airborne viable particles to spread is achieved by pressurization. The air can flow from a space to the neighboring spaces through the openings of the room. The pressure difference between these spaces is the main factor to specify the flow between them. Positive pressurization means an outwards flow from the room while negative pressurization refers to an inwards flow. The flow direction of air between the spaces must be determined by comparing the cleanliness levels of neighboring rooms. Air must flow from a space with high level of hygienic need to a lower one. This required air flow can be maintained by the openings of the room like door perimeters. Furthermore, the transfer grilles with preset spring loaded dampers can be employed to maintain required pressure difference. Thus, the excess of supply or exhaust air can flow from/to the space and the rooms are maintained under a constant pressure even the doors are kept closed for a long period.

5.1. VOLUMETRIC FLOW RATE

The pressure difference between the room and the adjacent spaces is maintained by providing differentials in volumetric flow rates of supplied and extracted air. For example, supply air flow rate of 150 m3/h and exhaust flow rate of 100 m3/h would result with the positive pressurization of the room while the inverse flow rates would result with negative pressurization. The disadvantage of this method is when the doors of the room are kept close for a long period; the pressure of the room would become too high/low which would make high amount of air flow between the rooms at high velocities when the doors are opened. When the doors are closed, a noise may be generated due to high velocity of air flow through door perimeter.

5.2. ROOM DIFFERENTIAL PRESSURE

Volumetric flow rate method can be used for most hospital rooms. Room differential pressure method is generally used for high-risk areas (American Society of Heating Refrigerating and Air-Conditioning Engineers 2003). This method involves maintaining the pressure difference between the sealed room and its neighbours steady. The required pressure difference which will be kept constant is determined by the standards and guidelines. The pressure of the room and its neighbours is monitored continuously.

6. TOTAL AND FRESH AIR CHANGES

Total and fresh air change rates are important to maintain the required air quality of the spaces. The supply of fresh air improves the air quality in terms of increasing the oxygen amount and diluting the chemical gases and particles that exist in the room air. The mechanically supplied air can be 100% fresh air or the fresh air can be mixed with filtrated return air. The decision about supplying 100% fresh air or mixture of fresh and returned air depends on various factors such as the activity being held in the room, required hygiene level, energy conservation, operation costs etc.

COMPARISON OF STANDARDS ON STERILE SPACES

Standards and guidelines on HVAC design of sterile environments in hospitals have been developed by institutions and organizations around the world. Each country develops its own standard and despite well known effects of HVAC systems on infection, no union standard exists. Some of these standards and guidelines are :

- *German standard for heating, ventilation and air conditioning systems of hospitals, DIN 1946-4 (Deutsches Institut für Normung 1999 March)*

- *ASHRAE's HVAC Design Manual for Hospitals and Clinics (American Society of Heating Refrigerating and Air-Conditioning Engineers 2003)*

- *AIA's Guidelines for Design and Construction of Health Care Facilities book which approaches to hospital design in terms of architectural, mechanical and electrical engineering points of views (American Institute of Architects 2006)*

- *Guidelines of CDC (Melhado, et al. 2005)*

- *Brazilian standard for air quality of hospital spaces, NBR 7256 (Melhado, et al. 2005)*

- *Spanish ventilation standard, UNE100713:2003 (Melhado, et al. 2005)*

- *Design guidelines for hospitals that belongs to the Netherlands, CBZ (Melhado, et al. 2005)*

- *Guidelines of HICPAC (Melhado, et al. 2005)*

- *French ventilation standard, NF S90:351 (Melhado, et al. 2005 and Dorchies 2005)*

- *German guidelines for hospital ventilation and air conditioning, VDI 2167 (Verein Deutscher Ingenieure 2004 December)*

- *Australian Queensland Government Private Hospital Guidelines (PHG) (Health Department of Western Australia Facilities & Assets Branch 1999)*

- *Queensland Government Infection Control Guidelines (ICG) (Queensland Health Communicable Diseases Unit & Capital Works Branch 2002)*

The comparison of the design parameters is performed via tables. The discussion is performed for each sterile space of hospital.

1. OPERATING SUITE

The operating suite is the special department of the hospital for surgical procedures. The operating suite consists of several different components which are;

- *Operating rooms*
- *Pre-op rooms*
- *Anesthesia equipment storage*
- *Post-op rooms*
- *Sterilization rooms*
- *Clean and dirty storage areas*
- *And interconnecting corridors and halls.*

1.1. OPERATING ROOM

The operating rooms are classified into groups according to their hygiene need and the types of surgical procedures that are executed in the room. As can be seen from the Table 1.1 most of the references classify the operating rooms according to the type of the surgical procedure. ASHRAE and AIA divide the operating rooms into three groups as Class A, B and C. Class A operating room serves for minor operations that are performed under local, topical or regional anesthesia without preoperative sedation. Intravenous, spinal and epidural operations are excluded and these methods are appropriate for Class B and C rooms. Class B room provides minor or major surgical procedures performed in conjunction with oral, parenteral or intravenous sedation or under analgesic or dissociative drugs. Class C rooms are suitable for major surgical procedures that require general anesthesia or regional block anesthesia and support of vital bodily functions (American Institute of Architects 2006 and American Society of Heating Refrigerating and Air-Conditioning Engineers 2003). In opposition to this classification, DIN 1946-4 groups operating rooms under two classes according to the hygiene need of the rooms. Class I holds the rooms that need high or very high levels of hygiene and Class II is for normal levels of hygiene. Class I is divided into two, again with respect to the hygienic needs and thus, the air distribution profile. Rooms with very high hygiene need and laminar air flow unit forms Class Ia and rooms with relatively lower need for hygiene forms Class Ib. Class Ib rooms are permitted to have turbulent air flow profiles (Deutsches Institut für Normung 1999 March). Brazilian standard NBR specifies the operating rooms as general purpose and cesarean operating rooms (Melhado, et al. 2005) while Australian Private Hospital Guidelines specifies as for general purpose and orthopedic procedures (Health Department of Western Australia Facilities & Assets Branch 1999). The classification of Australian Infection Control Guidelines is similar to the classification of DIN 1946-4 where Option 1 is the equivalent of Class Ia and Option 2 is the equivalent of Class Ib (Queensland Health Communicable Diseases Unit & Capital Works Branch 2002). A temperature range between 18 and 24°C is recommended by most of the publications but PHG recommends a lower temperature as 16°C. As can be seen from NBR, the recommended temperature for delivery is higher than other surgical procedures. Generally a wide range of relative humidity is recommended as from 30% to 60%, however, ICG proposes a narrower range as 50-55%.

For filtration, most of the standards specify the filtration stages and filter types that must be used for removing the particles. For example DIN 1946-4 forces designers to clean the supply air by at least three stages of filtration as F5, F7 and H13 types of filters according to DIN EN 779 and DIN EN 1822. PHG requires HEPA filter installations with adequate pre-filtration and the HEPA filters must have a minimum of 99% hot DOP arrestance efficiency. The pre-filtering must be completed by extended surface filters of minimum 80% arrestance efficiency to No.4 dust and 95% to No.2 Dust as specified in related Australian Standard AS1132 Methods of Test for Air Filters for Use in Air Conditioning and General Ventilation. In opposition to this definite description of filtration, AIA lacks the information about filtration. Laminar flow air supply profile is recommended by all references, especially where very high levels of hygiene is needed. In addition to this, DIN 1946-4 and ICG permit the use of turbulent systems for Class Ib (or Option 2) operating rooms. The air velocity parameter depends greatly on the air distribution profile and the velocity of air is an important factor. Generally low velocities for air are preferred in operating rooms to prevent the settled dust to become airborne again. Also the disturbance created by the airflow must be minimized. Because of these reasons the range of air velocity in an operating room is specified around 0.20 m/s. For the supply velocity ASHRAE recommends a range of 0.25-0.45 m/s while VDI 2167 recommends 0.20 m/s (Verein Deutscher Ingenieure 2004 December). The velocity limit is set as 0.3 m/s for CDC. (Melhado, et al. 2005) The velocity values are defines in a range of 0.1-0.25 m/s for PHG at the operating room table and 0.2 m/s for ICG as VDI. All of the investigated references agree about the pressurization of the operating room and a positive pressurization of the room is recommended. Since the operating room is one of the cleanest spaces in an operating suite, only permitted airflow is from sterile equipment stores to operating rooms. The air must flow from the operating room to other adjacent spaces. The method for providing this positive pressure in an operating room is the other issue that is handled by the standards. ASHRAE and AIA give a constant pressure difference value between the operating room and neighbouring spaces. In addition to this, ASHRAE and ICG define both the pressure difference and a difference of flow rates between the supply and the exhaust air. This is useful when an active control of the pressure difference between the rooms is not wanted. The designer can easily be informed about how to create sufficient pressure difference. While these abovementioned references give constant values for maintaining required pressure difference, DIN 1946-4 follows a different path. The required fresh and total air flow rates are specified in the investigated references. DIN 1946-4 advises 1200 m3/h flow rate for fresh air and 2400 m3/h for the total supply air flow rate as minimum rates. The recommendation of ICG for total air supply rate is defined as 1700 l/s (6120 m3/h) for general surgery and 2000 l/s (7200 m3/h) for orthopedic surgeries. When compared to the rest of the recommended values, except for the recommendation of PHG for orthopedic surgeries, which is 55 air changes per hour (ACH). The rest of the references define the required air flow rates in terms of air changes per hour, which depends on the volume of the operating room, meaning how many times the room air is changed in an hour. General suggestion is 3 ACH for fresh air and 15 ACH for total air supply. This means that the room air must be changed 15 times in an hour, and 3 of this 15 change must be fresh air. As an example; if the flow rates are calculated for a 6m x 6m room with a 3.5m clear height, meaning a room having a volume of 126 m3, the room must be supplied with at least 1890 m3/hr air, and at least 378 m3/hr of this 1890 m3/hr must be fresh outdoor air. An

important point to emphasize is the note given for defined fresh air rate by ASHRAE, which is the minimum amount of fresh air must not be lower than 15 l/s per person occupying the room. Another point is that this reference suggests two different values for ventilation rates, according to the system used. It is recommended to change the air of the room for 25 times when return air systems are used while 15 ACH is suggested for 100% fresh air systems. Also, one can see from the air change rates suggested by the references, most of the investigated publications permit the use of return air. As seen from Table 1.1, there is no criterion about the limit of the particle contaminations in an operating room. However, the levels for microbiological contamination are reported in some studies in literature. Chow and Yang specified a criterion as 35 cfu/m3 for an operating room at rest and they stated that the microbiological count should not exceed 180 cfu/m3 in operation state for United Kingdom. In the same study, it is declared that in an ultra clean operating room with laminar flow unit, the microbiological count limit is set as <10 cfu/m3 within the region 30 cm of the wound for conventional clothing. Furthermore, this level should be <1 cfu/m3 when total body gowns are implemented. The maximum accepted level under these conditions is defined as 10 cfu/m3. For the rest of the operating room outside the clean area, the maximum allowed limit is set as 20 cfu/m3 (Dharan and Pittet 2002 and Chow and Yang 2005). The same limit is set as 25 cfu/m3 for the hospitals in Geneva, Switzerland and 5 cfu/m3 in the French Guidelines (Landrin, Bissery and Kac 2005). In the study of Balaras the level of the particles in an operating room is limited according to ISO 14644-1 which is a standard named as "Cleanrooms and associated controlled environments Part 1: Classification of air cleanliness". It is mentioned that the cleanliness class of an operating room should not be greater than Class 7 (Balaras, Dascalaki and Gaglia 2007). In the study of Dharan and Pittet, it is declared that few countries have set bacterial threshold limits for conventionally ventilated operating rooms, although most recommend 20 ACH to obtain 50-150 cfu/m3 of air. In their study, a table related to the classification of operating theatre zones according to their risk categories is given and the limits of airborne particles and bacterial concentrations in the University of Geneva Hospitals in Switzerland are presented (Dharan and Pittet 2002).

1.2. PRE-OP AND POST-OP ROOMS

Additional information on some of the design parameters for pre and post-op rooms were found during the investigation of the listed publications. This information is given in Table 1.2 The recommended ambient temperature for these spaces is 21 - 24°C by ASHRAE and AIA. DIN 1946-4 suggests an ambient temperature of 22 - 26°C. For the relative humidity ratio of the room air, a range of 30-60% is suggested by ASHRAE and DIN 1946-4. Turbulent air flow is strongly suggested by ASHRAE but no other comment about the air distribution within the room is found in the rest of the references. DIN 1946-4 and ASHRAE's design manual both agree on the pressurization issue of these spaces. In both references, positive pressurization of pre and post operation rooms is suggested. It can

be added that airflow from the sterile equipment store rooms and operating rooms can be permitted. ASHRAE and AIA guidelines both recommend the same air changes for fresh and total air supplies while DIN standard suggests a certain amount of fresh air per unit area of the room and Australian PHG suggests supplying fresh air according to the number of people occupying the room. Only AIA guideline lacks the information about filtration. ASHRAE and DIN standards suggest filtration stages same as operating rooms. PHG recommends filtering supply the air for post-op rooms with filters having minimum dust arrestance efficiencies of 80% for dust No.4 and 95% to dust No.2. When invasive procedures take place, this filtering system must be used as a pre-filter for HEPA filtering.

2. DELIVERY ROOM

Only brief information about temperature, relative humidity, air changes and pressurization in delivery rooms are given in some of the reviewed standards and guidelines, no clear statement about the hygiene level of delivery rooms is found. DIN 1946-4 is the only standard in which the hygienic condition of delivery rooms is specified. According to DIN standard, the delivery rooms are defined as Class II spaces; however the hygiene need for the delivery operating rooms is stated as Class I. Not only German standard DIN 1946-4 declares that the delivery rooms are Class II spaces, but the Australian Private Hospital Guidelines also specifies the delivery rooms as spaces where relative low levels of hygiene is needed than the operating rooms unless invasive procedures takes place. Under these circumstances, delivery room is classified as having need of high hygiene and HEPA filtering is applied using the previously defined pre- filter set. The recommended values for the HVAC design parameters of the delivery rooms are given in Table 2. The comparison of Table 1.1 and 2 reveals that higher room temperatures are required for delivery rooms. It is declared in reviewed references that the dilution ventilation is an important factor in ventilation of the delivery rooms. The waste anesthetic gases must be properly removed from the room air. For providing successful dilution of chemicals and particles in the air the rate of fresh air change and air distribution becomes important.

3. INTENSIVE CARE UNIT

There are different types of intensive care units all serving to different purposes. The expectations from the HVAC system may differ according to the different aims of the intensive care units. For instance, according to ASHRAE, burn intensive care units need high level of hygiene while normal intensive care units do not (American Society of Heating Refrigerating and Air-Conditioning Engineers 2003). In studied standards and guidelines, there is no clear information about the hygiene level of the intensive care units, except the German standard DIN 1946-4 in which intensive care units are divided into two types as intensive care units for regular patients and the units for patients having high infection risk. Table 3 shows the available data in literature relating to HVAC design parameters of intensive care units. As seen from the table, ASHRAE and DIN standards are only references that provide the most specific information for special intensive care units. As in the Table 3, higher room temperatures are suggested for newborn intensive care units, when compared to the other types. Generally 30-60% or relative humidity ratio is suggested to be maintained in the units. In

addition, higher relative humidity ratios are needed in burn intensive care units to prevent the excessive drying of the tissues (American Society of Heating Refrigerating and Air-Conditioning Engineers 2003). Another point that needs to be emphasized is the requirement that is suggested by ASHRAE's design manual is that, according to this reference, laminar air flow must be maintained in burn intensive care units.

4. POSITIVE PRESSURE ROOM

The implementation aim of these rooms is to protect the immunosuppressed patients from the environmental infectious sources. High or very high levels of hygiene are required for protective environment rooms. Recommended conditions to be fulfilled are given in Table 4 The investigated references that suggest values for both fresh and total supply air rates accept using return air systems. On the contrary, Australian Infection Control Guidelines obliges the design of 100% fresh air systems. All references recommend filtration of air by implementing H13 class HEPA filters. For the air distribution in the room, only ASHRAE recommends supplying of air above the patient bed by laminar flow units and low level exhaust near the door of the room.

5. CENTRAL STERILE SERVICES DEPARTMENT

The level of hygiene in sterilization area and sterile equipment stores in central sterile services department is equal of higher than the operating room. In opposition to this assumption, German standard DIN 1946-4 accepts sterile equipment stores in operation suites as Class I spaces but any sterilization or sterile equipment store area outside the operating suite is declared as Class II. In accordance with DIN 1946-4, PHG declares that the central sterile services department or the sterile equipment supply unit in the operating theatre that are not attached to an operating room, do not need hygiene levels as the operating rooms need. If the sterile equipment area is attached to an operating room, high efficiency particulate air filtering is required with adequate pre- filters. The recommended HVAC design parameters by studied standards and guidelines for both soiled and sterilized equipment areas are shown in Table 5. Not all of the studied references have commented on the filtration stages for supply air except VDI, DIN and ASHRAE standards. Although there is not a concrete comment about the filtration stages in most of the references, the same level of filtration that is used for the operating rooms can be implemented since the same level of hygiene is needed. For the case of the differential pressure of the room, all reviewed references agree on the positive pressurization of sterilized equipment areas. The soiled equipment room should be maintained under negative pressure. The suggested ambient temperatures of the sterilized or soiled equipment areas vary between 20 and 25°C and the minimum room temperature for soiled equipment areas is recommended by AIA guidelines, which is defined as 20°C. It can also be seen from Table 5 that the recirculation of return air is permitted in sterile equipment areas.

Table 1.1 Recommended values for HVAC design parameters for operating rooms

Reference	Operation of Room Type	Temp.	Relative Humidity	Filtration	Air Velocity	Air Distribution	Pressure	Pressure Difference	Outdoor ACH	Total ACH
ASHRAE	Class A	18-26 °C	30-60%	MERV 7/8-14/15-17	0,25-0,45 m/s	Laminar	P	2,5-7,5 Pa / 35-47 L/s excess supply	5*/15** / 15(lt/sn)/ person	25* / 15**
	Class B			MERV 7/8-14/15-17						
	Class C			MERV 7/8-14/15-17						
AIA	Class A	20-23 °C	30-60%	N/D	N/D	Laminar	P	2,5 Pa	3	15
	Class B									
	Class C									
DIN	Class Ia	19-26 °C	30-60%	F5-F7-H13	N/D	Laminar / Turbulent	P	20 m^3/m excess supply	1200 m^3/h	2400 m^3/h
	Class Ib			F5-F7-H13						
CBZ	N/A	18-24 °C	N/A	F5-F7-F9-H13	N/A	Laminar	P	N/A	N/A	N/A
VDI	N/A	18-24 °C	30-50%	F5/F6/F7-F9-H13	0,20 m/s	Laminar	P	N/D	N/D	N/D
NBR	General	19-24 °C	45-60%	G2-F2-A3	N/A	N/A	P	N/A	N/A	N/A
	Cesarean	22-26 °C		N/A						

Table 1.1 (Cont.) Recommended values for HVAC design parameters for operating rooms

Reference	Operation of Room Type	Temp.	Relative Humidity	Filtration	Air Velocity	Air Distribution	Pressure	Pressure Difference	Outdoor ACH	Total ACH
CDC	N/A	N/A	30-60%	%30-%90-%99,97	0,3-0,5 m/s	N/A	P	N/A	3 / %20	15
NF S90	N/A	N/A	40-60%	F6-F7-H13	N/A	Laminar	P	N/A	N/A	N/A
UNE 100713	N/A	N/A	N/A	F6-F9-H13/H14	N/A	Laminar	P	N/A	N/A	N/A
PHG	General	16-24 °C	40-70%	See Text	N/D	Laminar	P	N/D	30%	20
	Orthopaedic			See Text	0,1-0,25m/s				6	55
ICG	Option 1	18-24 °C	50-55%	Two Stage (AHU & Terminal)	0,2 m/s	Laminar	P	15 Pa / 150-200 lt less exhaust	350 l/s or 8	1700l/s - 2000 l/s if orthopaedic
	Option 2	18-24 °C	50-55%	Two Stage (AHU & Terminal)	0,2 m/s	Laminar / Turbulent	P	15 Pa / 150-200 lt less exhaust	350 l/s or 8	20

* Recommended outdoor and total ACH values for return air systems

** Recommended total ACH for 100% fresh air systems

Table 1.2 Recommended HVAC design parameters for pre- and post-operative rooms

Reference	Temp.	Relative Humidity	Filtration	Air Velocity	Air Distribution	Pressure	Pressure Difference	Outdoor ACH	Total ACH
ASHRAE	21-24 °C	%30-60	Same with OR	N/D	Turbulent	P	N/D	2	6
AIA	21-24 °C	%30-60	N/D	N/D	N/D	N/D	N/D	2	6
DIN	22-26 °C	N/D	F5-F7-H13	N/D	N/D	N/D	N/D	30 $m^3/m^2.h$	N/D
PHG	N/D	N/D	See Text	N/D	N/D	N/D	N/D	(20 l/s)/person or 2	10

Table 2 . Suggested HVAC Design parameter values for delivery operating rooms

Reference	Temp.	Relative Humidity	Filtration	Air Velocity	Air Distribution	Pressure	Pressure Difference	Outdoor ACH	Total ACH
ASHRAE	20-24 °C	30-60%	N/D	N/D	N/D	P	N/D	5*/15**	25*/15**
AIA	20-23 °C	30-60%	N/D	N/D	N/D	P	N/D	3	15
DIN	min 24 °C	N/D	F5-F7-H13	N/D	N/D	N/D	N/D	15 $m^3/m^2.h$	N/D
PHG	N/D	N/D	See Text	N/D	N/D	N/D	N/D	20 (l/s)/person or 2	10
NBR	22-26 °C	45-60%	N/A	N/A	N/A	P	N/A	N/A	N/A

* Recommended outdoor and total ACH values for return air systems

** Recommended total ACH for 100% fresh air systems

N/A – Not Available

N/D - Not Defined

Table 3 . Recommended minimum design values for HVAC systems of intensive care units

Reference	Room Type	Temp.	Relative Humidity	Filtration	Air Velocity	Air Distribution	Press.	Press. Diff.	Outdoor ACH	Total ACH
ASHRAE	General	21-24 °C	30-60%	N/D	N/D	N/D	N/D	N/D	2	6
	Newborn	22-26 °C	30-60%	N/D	<0,25m/s@isolet level	N/D	N/D	N/D	2	6
	Burn	N/D	40-60%	HEPA	0,25m/s@bed level	Laminar	P	N/D	2	6
AIA	General	21-24 °C	30-60%	N/D	N/D	N/D	N/D	N/D	2	6
	Newborn	22-26 °C	30-60%	N/D	N/D	N/D	N/D	N/D	2	6
DIN	Infectious	24-26 °C	N/D	F5-F7-H13	N/D	N/D	P	N/D	30 $m^3/m^2.h$	N/D
VDI	General	N/D	N/D	F9	N/D	N/D	P	N/D	100 $m^3/h.person$	N/D

N/D - Not Defined

Table 4 Recommended design parameters of HVAC systems for isolation rooms

Reference	Temp.	RH	Filtration	Air Velocity	Air Distribution	Press.	Pressure Difference	Outdoor ACH	Total ACH
ASHRAE	21-24 °C	N/D	MERV 8-17	<0,5m/s throw	Laminar	P	2,5 Pa	2	12
AIA	24 °C	N/D	N/D	N/D	N/D	P	2,5 Pa	2	12
DIN	24-26 °C	N/D	F5-F7-H13	N/D	N/D	P	N/D	30 $m^3/m^2.h$	N/D
VDI	N/D	N/D	H13 filter on supply	N/D	N/D	P	N/D	100 $m^3/h.person$	N/D
PHG	N/D	N/D	%99 DOP efficiency	N/D	N/D	P	N/D	2	12 or 9 $l/s/m^2$
ICG	N/D	N/D	H13 filter on supply	N/D	N/D	P	%10 less exhaust	12 or 145 l/s.patient	N/D

N/D - Not Defined

Table 5 . Recommended HVAC design parameters for central sterile services and sterile equipment stores

Reference	Room Type	Temp.	Relative Humidity	Filtration	Air Velocity	Air Distribution	Press.	Pressure Diff	Outdoor ACH	Total ACH
ASHRAE	Soiled Eqpt Room	22-25 °C	30-60%	N/D	N/D	N/D	N	N/D	2	6
	Sterile Eqpt Room			MERV 8 - 15			P		2	4
	Sterile Work Room			MERV 8 - 15			P		2	4
AIA	Soiled Eqpt Room	20-23 °C	N/D	N/D	N/D	N/D	N	N/D	N/D	6
	Sterile Eqpt Room	24 °C	30-60%				P			4
	Sterile Work Room	N/D	max. 70%				P			4
DIN	Sterile Eqpt Room	22-26 °C	N/D	F5-F7-H13	N/D	N/D	P	N/D	15 $m^3/m^2.h$	N/D
PHG	N/D	N/D	N/D	See Text	N/D	N/D	P	N/D	N/D	10
VDI	N/D	N/D	N/D	F7-F9-H10/H11	N/D	N/D	P	N/D	N/D	N/D

N/D - Not Defined

TABLE 8 for AIR FILTERS and EFFICIENCY

CLASSIFICATION	Arrestance or Dust Spot Efficiency	US ASHRAE 52.2	European Union EN779 Class		Typical Controlled Contaminant	Application
PRE Filter (G Class)	AFI <65 %	MERV 1	G1	Am< 65%	Particle bigger than 10.0μm (Pollen) (Spanish moss) (Dust mites) (Sanding dust) (Spray paint dust) (Textile fibers)	Gross filter, domestic and commercial
	AFI 65%-70%	MERV 2	G2	65%≦Am< 80%		
	AFI 70%-75%	MERV 3				
	AFI 75%-80%	MERV 4				
	AFI 80%-85%	MERV 5	G3	80%≦Am<90%	Particle size within 3.0μm-10.0μm (Mold) (Spores) (Hair spray) (Cement dust) (Snuff) (Powdered milk)	Commercial, industrial, paint shop
	AFI 85%-90%	MERV 6				
	NBS 25%-30%	MERV 7	G4	90%≦Am		
	NBS 30%-35%	MERV 8				
MEDIUM Filter (F Class)	NBS 40%-45%	MERV 9	F5	40%≦Em< 60%	Particle Size within 1.0μm-3.0μm (Lead dust) (Milled flour) (Coal dust) (Auto emissions) (Nebulizer drop) (Welding fumes)	IAQ concerned commercial & industrial, medical
	NBS 50%-55%	MERV 10				
	NBS 60%-65%	MERV 11	F6	60%≦Em< 80%		
	NBS 70%-75%	MERV 12				
	NBS 80%-85%	MERV 13	F7	80%≦Em< 90%	Particle size within 0.3μm-1.0μm (All bacteria) (cooking oil) (Most smoke) (Copier toner) (Most face powder) (Most paint pigments)	IAQ concerned commercial, industrial, medical, food etc
	NBS 90%-95%	MERV 14	F8	90%≦Em< 95%		
	NBS>95%	MERV 15	F9	95%≦Em		
		MERV 16				

CLASSIFICATION	Mean Fractional Efficiency	IEST RP-CC001.3	European Union EN1822 Class		Typical Controlled Contaminant	Application
HEPA Filter (H Class)	≧95% at 0.3μm	n/a	H10	≧85% at MPPS	Particle size bigger than 0.3μm (Virus [unattached]) (Carbon dust) (Sea salt) (All combustion smoke) (Radon progeny)	All types of cleanrooms
	≧98% at 0.3μm		H11	≧95% at MPPS		
	≧99.97% at 0.3μm	TYPE A				
	≧99.99% at 0.3μm	TYPE C	H12	≧99.5% at MPPS		
	≧99.995% at 0.3μm		H13	≧99.95% at MPPS		
	≧99.999% at 0.3μm	TYPE D	H14	≧99.995% at MPPS		
ULPA Filter (U Class)	≧99.9995% at 0.12μm	TYPE F	U15	≧99.9995% at MPPS	Particle size bigger than 0.12μm	super cleanroom
	≧99.99995% at 0.12μm		U16	≧99.99995% at MPPS		
	≧99.999995% at 0.12μm		U17	≧99.999995% at MPPS		

Note :

1. AFI : American Filter Institute
2. NBS : National Bureau of Standards
3. ASHRAE : American Society of Heating Refrigerating & Air-conditioning Engineers
4. MERV : Minimum Efficiency Reporting Value
5. MPPS : Most Penetrating Particle Size
6. HEPA : High Efficiency Particulate Air Filter
7. ULPA : Ultra Low Penetration Air Filter
8. Am : Average Arrestance Efficiency for Coarse Filters
9. Em : Average Efficiency for Fine Filters
10. IEST : Institute of Environmental Sciences and Technol

Target

My purpose of this research is to brought the mechanical engineer designers consider the use of international standards for design the ventilation and air-condition for any section and department of the hospital exactly in operation rooms because of more important this department in the hospital.

Unfortunately through my information collecting about many governmental and private hospitals in Sulaimanyah city, most of them don't use any international standard for designing especially in private hospitals

References

American Institute of Architects. 2006. Guidelines for Design and Construction of Heath Care Facilities. Washington: American Institute of Architects.

American Society of Heating Refrigerating and Air-Conditioning Engineers. 2003. HVAC Design Manual for Hospitals and Clinics. Atlanta: American Society of Heating Refrigerating and Air-Conditioning Engineers, Inc.

Balaras, Constantinos A, Elena Dascalaki, and Athina Gaglia. 2007. "HVAC and Indoor Thermal Conditions in Hospital Operating Rooms." Energy and Buildings 39:454- 470

Chow, T T, and X Y Yang. 2005. "Ventilation Performance in the Operating Theatre Against Airborne Infection: Numerical Study on an Ultra-clean System." Journal of Hospital Infection 59:138-147.

Deutsches Institut für Normung. 1999. DIN 1946-4 Ventilation and Air Conditioning - Part 4: Ventilation in Hospitals. Berlin: Deutsches Institut für Normung e.V.

Dorchies, Fabrice. 2005. "Nosocomial Infections and Air Filtration in Operating Theatre Suites - Application of French Standard NFS90-351:2003." Business Briefing: Hospital Engineering & Facilities Management:1-3.

Humphreys, H, and E W Taylor. 2002. "Operating Theatre Ventilation Standards and the Risk of Postoperative Infection." Journal of Hospital Infection 50:85-90.