Saturday, 11 May 2019

Surgical Operating Theaters: Three Decades of CFD Analyses

Thessaloniki, Greece ,May 2019

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HOSPITAL DEPARTMENTS

Specific Design Concept of Hospital Facilities

There are seven principal divisions of an acute care hospital:

- ***surgery and critical care,***
- ***nursing,***
- ***ancillary,***
- ***administration,***
- ***diagnostic and treatment,***
- ***sterilizing and supply,***
- ***service.***

The environmental requirements of each of the departments/spaces within these divisions differ to some degree according to their function and the procedures carried out in them. Close coordination with health care planners and medical equipment specialists in the mechanical design and construction of health facilities is essential to achieve the desired conditions.

Critical Care and Isolation Rooms

In the isolation rooms for infectious patients, the patient bed should be located closing to the extraction ports. The streams of the air will defend for the HCW and visitors and will extract the infected air from the room. The infectious isolation rooms should be maintained in negative pressure, and located closing to positive pressure areas even in the part load of these areas. In the isolation rooms for immunosuppressed patients, whose have high susceptibility to infection, the air should be their guard from the infection. The creation of air curtain near the immunosuppressed patient is recommended here to be an additional defence. The immunosuppressed patient's bed should be located in the side of supplied air, or closing to the supply outlets, figure 5.

Surgical Operating Rooms

1. No area of the hospital requires more careful control of the aseptic condition of the environment than does the surgical suite. The systems serving the operating rooms, including cystoscopic and fracture rooms, require careful construction to reduce to a minimum the concentration of airborne organisms.
2. Operating room air distribution systems that deliver air from the ceiling, with a downward movement to several exhaust inlets located on opposite walls, is probably the most effective air movement pattern for maintaining the concentration of contamination at an acceptable level.
3. Generally, operating rooms are in use no more than 8 to 12 h per day (excepting emergencies). For this reason and for energy conservation, the air-conditioning system should allow a reduction in the air supplied to some or all of the operating rooms. However, positive space pressure must be maintained at reduced air volumes to ensure sterile conditions.
4. A separate air exhaust system or special vacuum system should be provided for the removal of anaesthetic trace gases. One or more outlets may be located in each operating room to permit connection of the anaesthetic machine scavenger hose, if any.

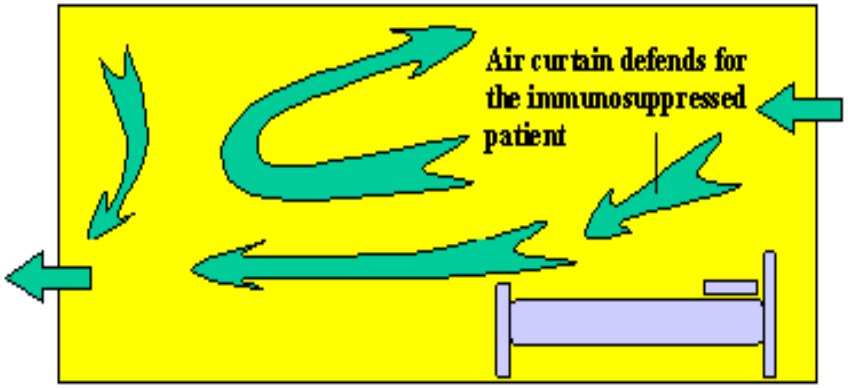
The following conditions are recommended for operating, catheterization, cystoscopic, and fracture rooms:

1. There should be a variable range temperature capability of 20 °C to 24°C.
2.
3.

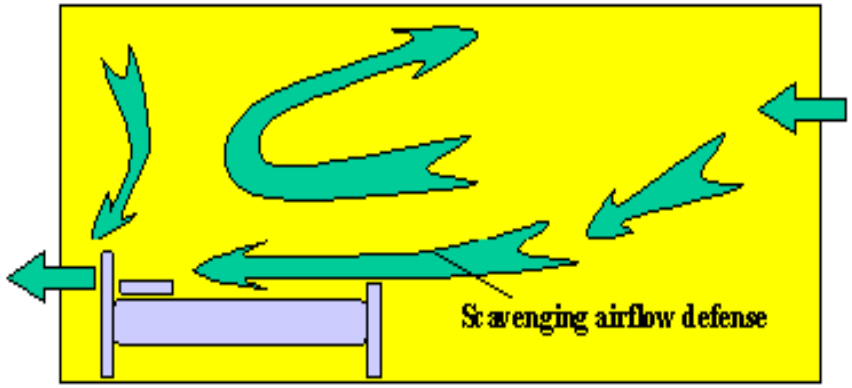
4. Differential pressure indicating device should be installed to permit air pressure readings in the rooms. Thorough sealing of all wall, ceiling, and floor penetrations and tight-fitting doors are essential to maintaining readable pressure.
5. Humidity indicator and thermometers should be located for easy observation.
6. Filter efficiencies should be in accordance with table 2 (mentioned before).
7. Entire installation should conform to the requirements of NFPA Standard 99, Health Care facilities.
8. All air should be supplied at the ceiling and exhausted or returned from at least two locations near the floor (see Table 1 for minimum ventilating rates). Bottom of exhaust outlets should be at 3 in. above the floor. Supply diffusers should be of the unidirectional type. High-induction ceiling or sidewall diffusers should be avoided.
9. Acoustical materials should not be used as duct linings unless 90% efficient minimum terminal filters are installed downstream of the linings. Internal insulation of terminal units may be encapsulated with approved materials. Duct-mounted sound traps should be of the backless type or have polyester film linings over acoustical fill.
10. Any spray-applied insulation and fireproofing should be treated with fungi growth inhibitor.
11. Sufficient lengths of watertight, drained stainless steel duct should be installed downstream of humidification equipment to assure complete evaporation of water vapour before air is discharged into the room.
12. Control centres that monitor and permit adjustment of temperature, humidity, and air pressure may be located at the surgical supervisor's desk.
13. Conform to the fully vertical flow displacement (the present new hypothesis), or at least use one supply plenum in the center of the ceiling. The sidewall supplying is completely refused.
14. Use two opposite sidewalls as location of the extract grilles, it is more accurate to use the wide-distance opposite sidewalls as the extract walls. The supply plenum in this direction of the two opposite sidewalls can have the shorter side, figure 6. The architectural designer should aid the mechanical designer to perform that, figure 7.

more valuable to increase supply area in the increasing direction, which doesn't contain any extract grilles than the other directions.

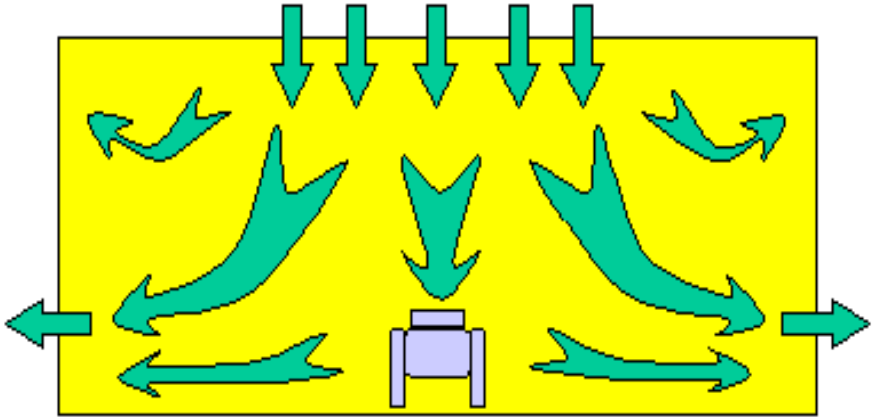
16. Keep the air extracting at two levels, one near the floor at level less than 1 m from the floor, and the other above the occupied zone and comfort level, i.e. 2 m from the floor.
17. It is essential to use partial walls in the upstream of the supplied air.
18. It is preferable to use a separate airside system to serve the surgical operating suites in the hospitals. It is recommended to replace the Variable Air Volumes system in the surgical operating suit by another system is capable to ensure continues airflow supplying.
19. Leave two opposite sidewalls suitable for vertical extract duct shafts. This will allow the airside system designer to follow the recommendations of positioning of the extract grilles in the suitable places.
20. Define the bad distributed airflow areas (according to the present or suggested Airside system design) in the operating theatres to being free from any possible source of the airborne contamination.
21. Follow the recommended positioning of the operating table to let a one-bed length to the extract grilles. That will aid to yield good airflow pattern around t



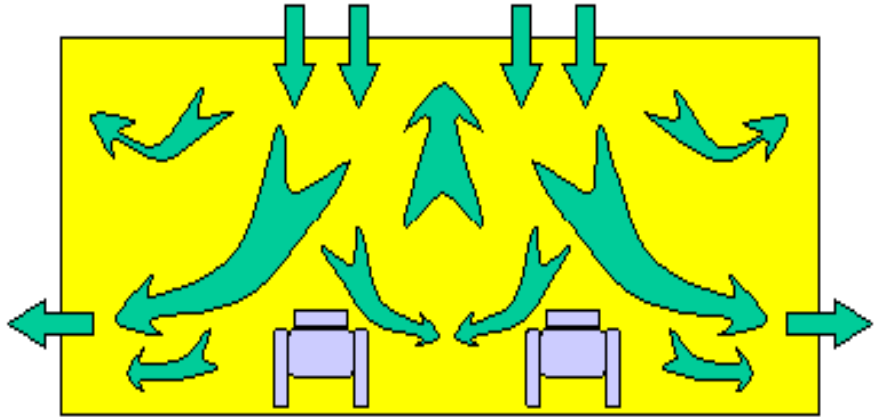
Isolation Room
Immunosuppressed Patients



Isolation Room
Infectious Patients



Surgery Room



Surgery or Critical Room

Obstetrical

- The pressure in the obstetrical department should be positive or equal to that in other areas.

Delivery Rooms

- The design for the delivery room should conform to the requirements of operating rooms.

Recovery Rooms

- Postoperative recovery rooms used in conjunction with the operating rooms should be maintained at temperature of 75°F and a relative humidity between 50% and 60%. Because residual anaesthesia odour sometimes creates an odour problem in recovery rooms, ventilation is important, and a balanced air pressure relative to the air pressure of adjoining areas should be provided.

Nursery Suite

- Air conditioning in nurseries provides the constant temperature and humidity conditions essential to care of the newborn in a hospital environment. Air movement patterns in nurseries should be carefully designed to reduce the possibility of drafts.
- All air supplied to nurseries should enter at or near the ceiling and be removed near the floor with the bottom of exhaust openings located at least 3 in. above floor. Air system filter efficiencies should conform to Table 2.

Full-Term Nursery

- A temperature of 23°Cand relative humidity from 30% to 60% are recommended for the full-term nursery, examination room, and work space. The maternity nursing section should be controlled similarly to protect the infant during visits with the mother. The nursery should have a positive air pressure relative to the workspace and examination room, and any rooms interposed between the nurseries and the corridor should be similarly pressurized relative to the corridor. This prevents the infiltration of contaminated air from outside areas.

Special Care Nursery

- The design conditions for this nursery require a variable range temperature capability of 23°C to 26°C and relative humidity from 30% to 60%. It is desirable to maintain these same conditions within the nursery proper to accommodate both infants removed from the incubators and those not placed in incubators. The pressurization of this nursery should correspond to that of the regular nurseries.

Observation Nursery

- Temperature and humidity requirements for this nursery are similar to those for the full-term nursery. Because infants in these nurseries have unusual clinical symptoms, the air from this area should not enter other nurseries. A negative air pressure relative to the air pressure of the workroom should be maintained in the nursery. The workroom, usually interposed between the nursery and the corridor, should be pressurized relative to the corridor.

Emergency

- This department, in most instances, is the most highly contaminated area in the hospital as a result of the soiled condition of many arriving patients

Trauma Rooms

- Trauma rooms should be ventilated in accordance with requirements in Table 1. Emergency operating rooms located near the emergency department should have the same temperature, humidity, and ventilation requirements as those of an operating room.

Anaesthesia Storage Room

- The anaesthesia storage room must be ventilated in conformance with NFPA Standard 99. However, mechanical ventilation only is recommended.

Nursing

- Patient Rooms: Central systems should be used to air condition patients' rooms, the recommendations in Tables 2 and 3 for air filtration and air change rates should be followed to reduce cross-infection and to control odour. Rooms used for isolation of infected patients should have all air exhausted directly outdoors. A winter design temperature of 75°F with 30% RH is recommended; 75°F with 50% RH is recommended for summer. Each patient's room should have individual temperature control. Air pressure in patient suites should be neutral in relation to other areas.
- Egyptian governmental agency design criteria and international codes require that all air from toilet rooms be exhausted directly outdoors. The requirement appears to be based on odour control.
- Where room unit systems are used, it is important to exhaust through the adjoining toilet room an amount of air equal to the amount of outdoor air brought in the room for ventilation. The ventilation of toilets, bedpan closets, bathrooms, and all interior rooms should conform to applicable codes.

Intensive Care Unit

- This unit serves seriously ill patients, from the postoperative to the coronary patient. A variable range temperature capability of 23°C to 26°C, a relative humidity of 30% minimum and 60% maximum, and positive air pressure are recommended.

Protective Isolation Units

- Immunosuppressed patients are highly susceptible to diseases. An air distribution of 15 air changes per hour supplied through a nonaspirating diffuser is recommended. The sterile air is drawn across the patient and returned near the floor, at or near the door to the room.
- When the patient is immunosuppressed but not contagious, a positive pressure should be maintained between the patient room and adjacent area. Exam and treatment rooms should be controlled in the same manner. A positive pressure should also be maintained between the entire unit and the adjacent areas to preserve sterile conditions.
- When a patient is both immunosuppressed and contagious, isolation rooms within the unit may be designed and balanced to provide a permanent equal or negative pressure relationship with respect to the adjacent area or anteroom. So alternatively, such isolation rooms may be equipped with controls that enable the room to be positive, equal, or negative in relation to the adjacent area. However, in such instances, controls in the adjacent area or anteroom must maintain the correct pressure relationship with respect to the other adjacent room(s).

Infectious Isolation Unit

- The infection isolation room is used to protect the remainder of the hospital from the patients' infectious diseases. Recent multidrug-resistant strains of tuberculosis have increased the importance of pressurization, air change rates, filtration, and air distribution design in these rooms. Temperatures and relative humidity should correspond to those

- ***Diagnostic and Treatment***
- *Magnetic Resonance Imaging (MRI):* These rooms should be treated as exam rooms in terms of temperature, humidity, and ventilation. However, special attention is required in the control room due to the cryogen's used to cool the magnet. The manufacturer of the magnet should be consulted.
- *Treatment Rooms:* Patients are brought to these rooms for special treatment that cannot be conveniently performed in the patient rooms. To accommodate the patient, who may be brought from bed, the rooms, should have individual temperature and humidity control. Temperatures and relative humidity should correspond to those specified for patients' rooms.
- *Physical Therapy Department:* The cooling load of the electrotherapy section is affected by the short-wave diathermy, infrared, and ultraviolet equipment used in this area.
- *Hydrotherapy Section:* This section, with its various water treatment baths, is generally maintained at temperatures up to 80°F. The potential latent heat buildup in this area should not be overlooked. Temperatures and relative humidity should be within the comfort zone. The air may be recirculated within the areas.
- *Occupational Therapy Department:* In this department, spaces for activities such as weaving, braiding, artwork, and sewing require no special ventilation treatment. Recirculation of the air in these areas using medium-grade filters in the system is permissible.
- *Workrooms:* The clean workroom serves as storage and distribution center for clean supplies and should be maintained at a positive air pressure relative to the corridor.
- The soiled workroom serves primarily as a collection point for soiled utensils and materials. It is considered a contaminated room and should have a negative air pressure relative to adjoining areas. Temperatures and relative humidity should be within the comfort range.
- *Sterilizing and Supply:*
- The unit usually consists of a cleaning area, a sterilizing area, and a storage area where supplies are kept until requisitioned. If these areas are in one large room, air should flow from the clean storage and sterilizing areas toward the contaminated cleaning area. The air pressure relationships should conform to those indicated in Table 1. Temperature and humidity should be within the comfort range.
- The following guidelines are important in the central sterilizing and supply unit:
- Insulate sterilizers to reduce heat load.
- Amply ventilate Sterilizer equipment closets to remove excess heat.
- Where ethylene oxide gas sterilizers are used, provide a separate exhaust system with terminal fan. Provide adequate exhaust capture velocity in the vicinity of sources of leakage. Install an exhaust Sterilizer doors and over the Sterilizer drain. Exhaust aerator and service rooms. Gas concentration sensors, exhaust flow sensors, and alarms should also be provided. Sterilizers should be located in dedicated unoccupied rooms that have a highly negative pressure relationship to adjacent spaces and 10 air changes per hour.
- Maintain storage areas for sterile supplies at a relative

Hospital

- **SPACE PROVIDING PREVENTIVE DIAGNOSTIC, CURATIVE AND REHABILITATIVE HEALTH SERVICES TO THE ACUTELY ILL AS WELL AS AMBULATORY PATIENTS.**

Categorization of hospitals depending upon services :

- General.
- Specialized.

Categorization of hospitals depending level of patient they serve

- **Primary level**
- **Secondary**
- **Tertiary**
- **Super specialty**

Categorization of hospitals depending upon no. of beds

- **Category A (25-50)**
- **Category B (51-100)**
- **Category C (101-300)**
- **Category D (301-500)**
- **Category E (501-750)**

Draft standards | 2 sections | 10 chapters

The national hospital standards are first divided into two major sections:

1. Patient-Focused Standards [5 chapters]
2. Hospital-Focused Standards [5 chapters]

The patient-focused standards:

1. Patient Safety Goals [PSG]
2. Total Patient Management [TPM]
3. Critical Care Management [CCM]
4. Total Medication Management [TMM]
5. Patient and Family, Rights and Education [PFRE]

Then Hospital-focused standards:

1. Quality and Risk Management [QRM]
2. Infections Control and Prevention [ICP]
3. Facility Safety and Equipment Management [FSEM]
4. Governance and HR Management [GHM]
5. Information and Communication [IAC]

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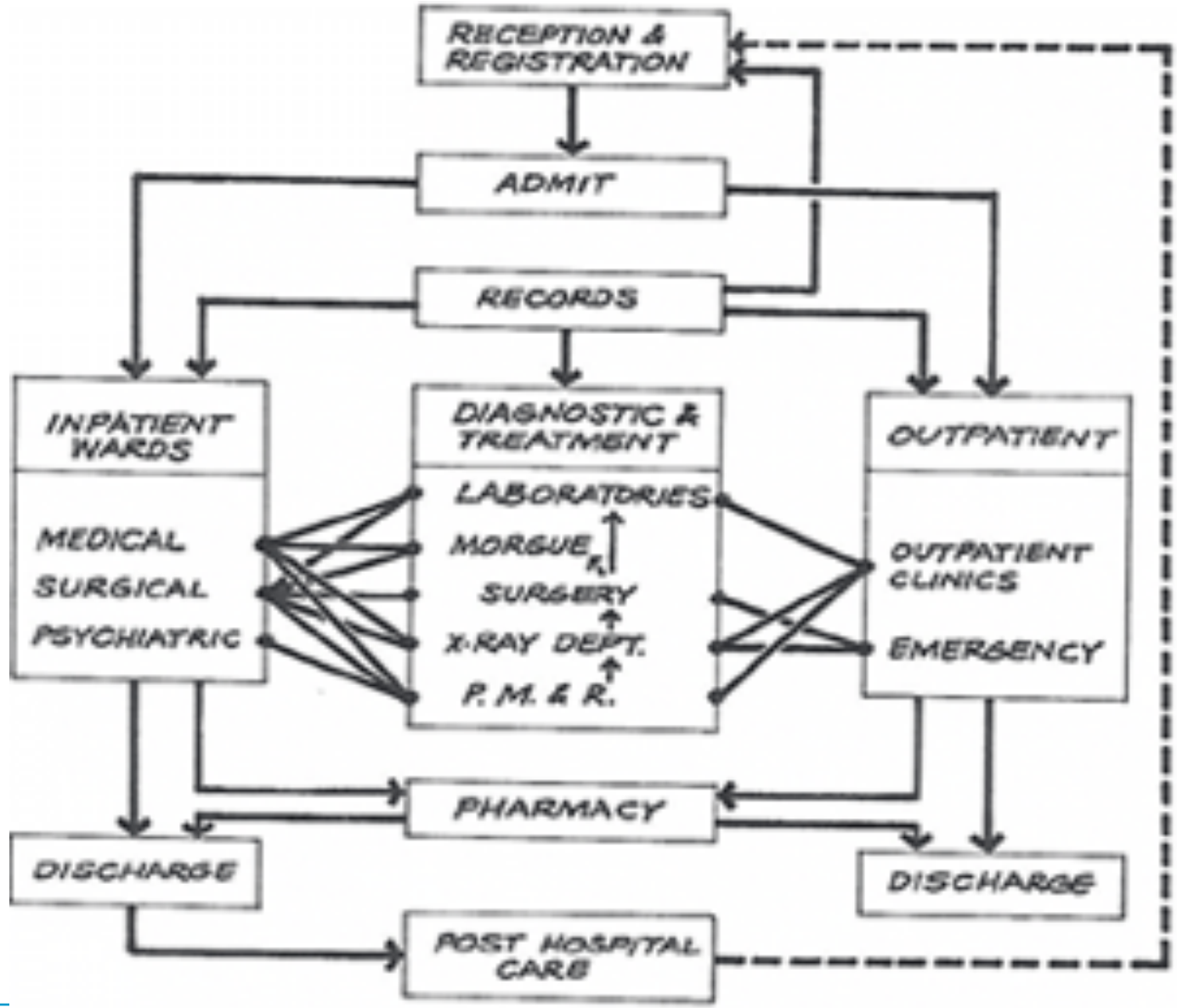
Government of the People's Republic of Bangladesh
Directorate General of Health Services (DGHS)

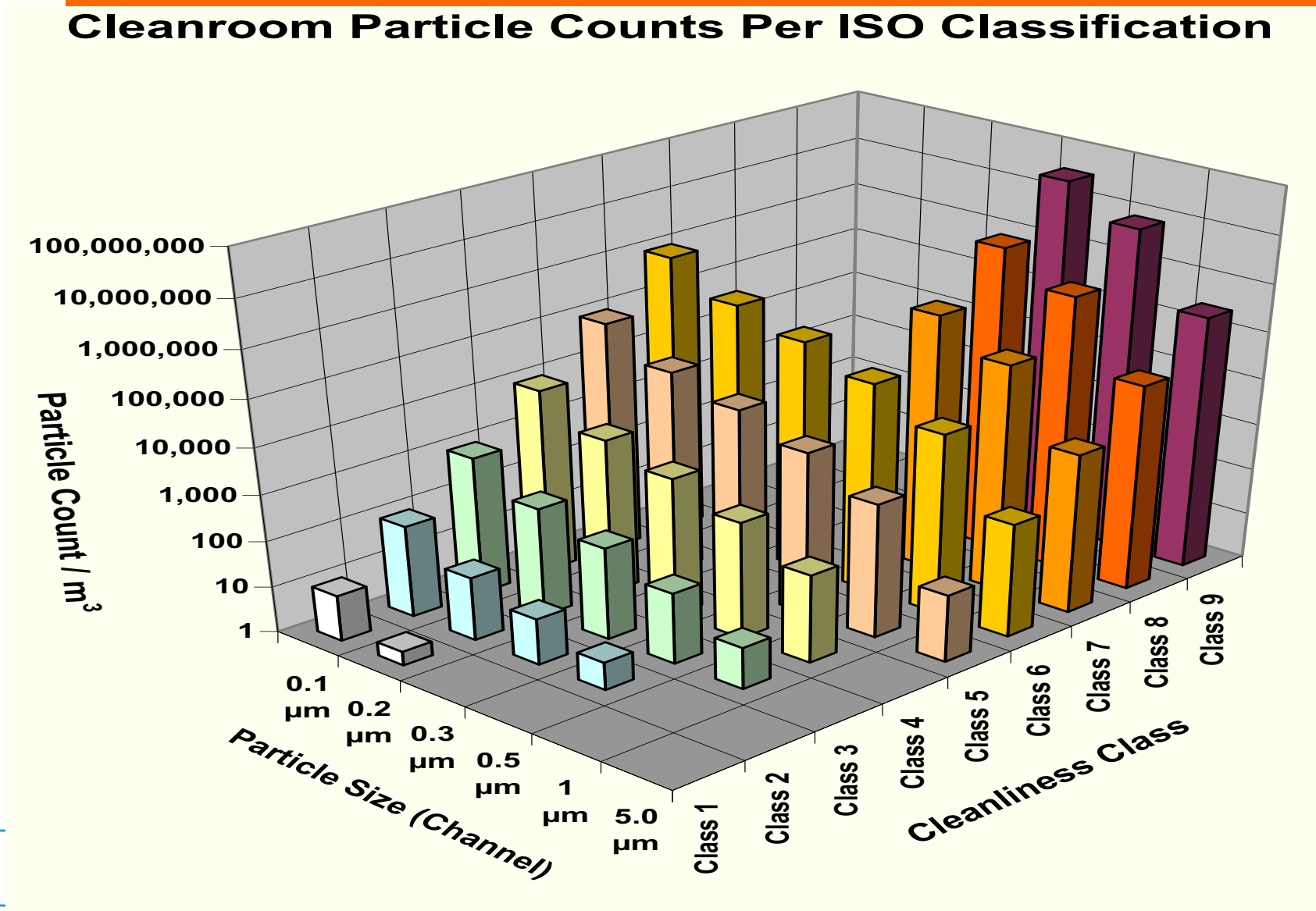
THE ROCKEFELLER FOUNDATION



MAJOR CLINICAL RELATIONSHIPS

ISO 14644 Classification

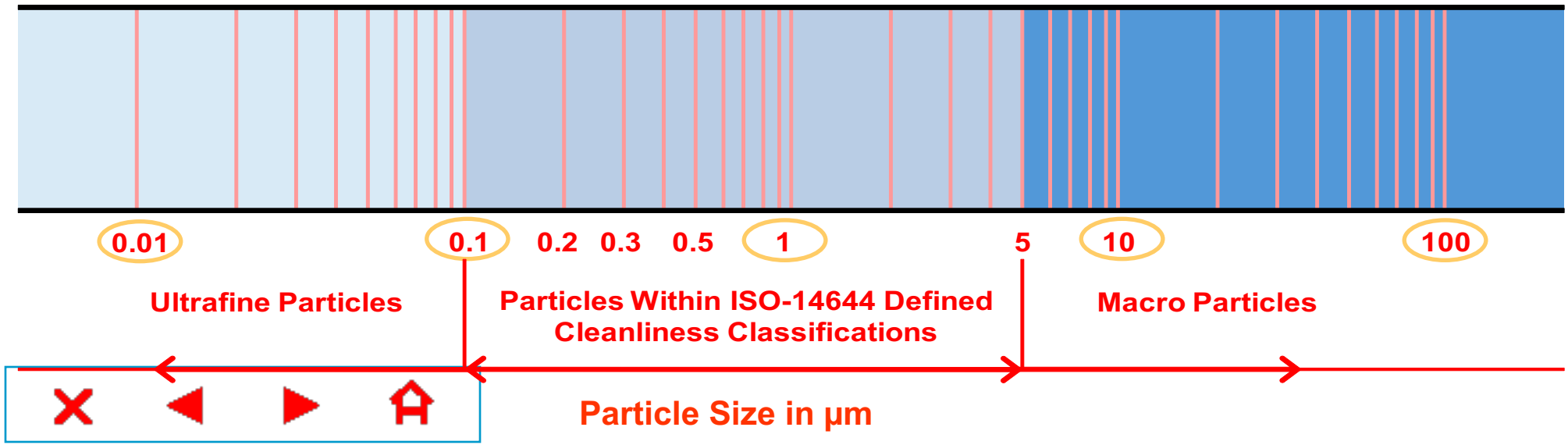
(Airborne Particle Sizes, Counts and Classifications)

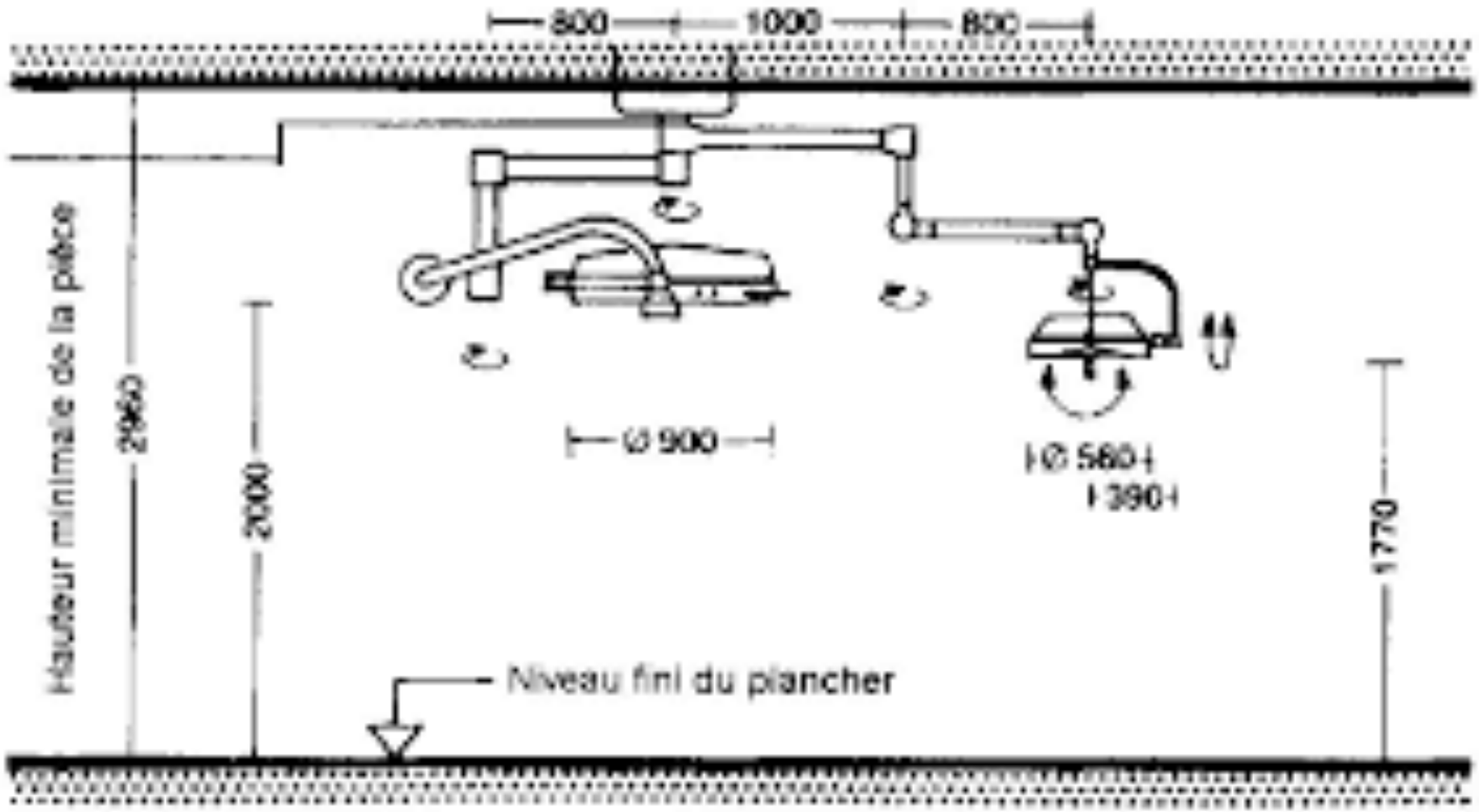


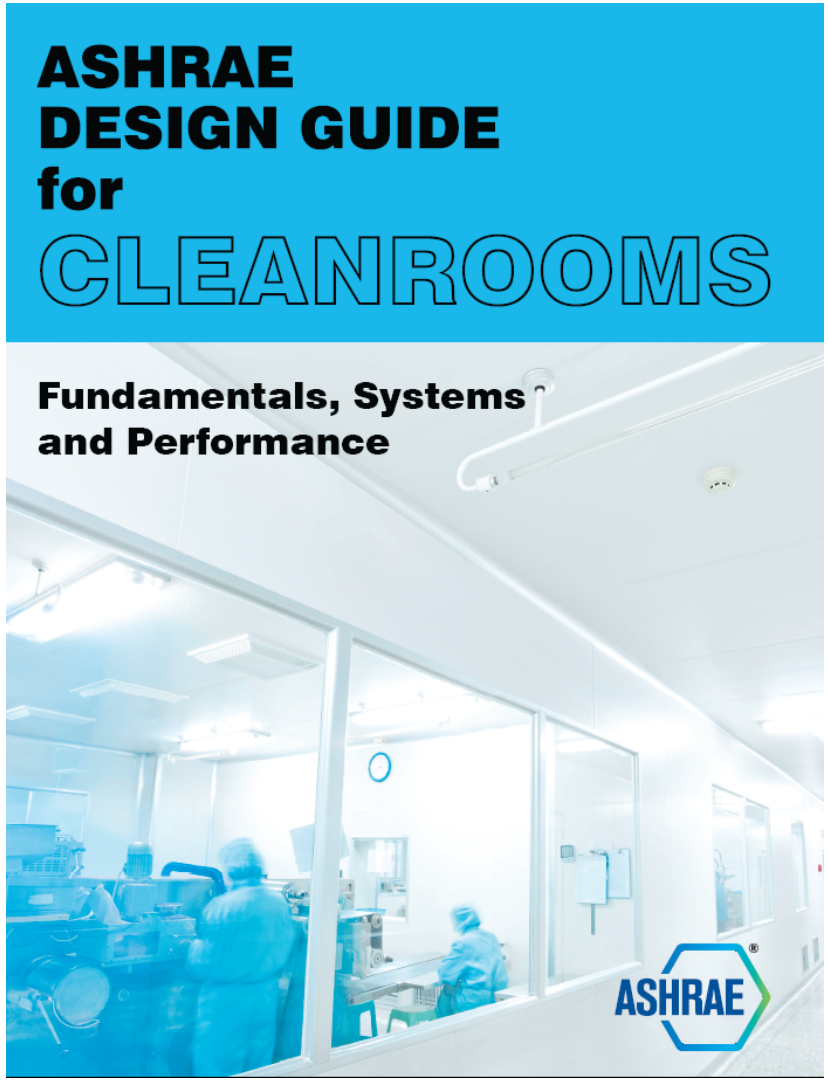
Airborne Particulates

(Airborne Particle Sizes, Counts and Classifications)

1. Particles larger than 100 microns can be seen with naked eyes.
2. Next step particles ranging from 0.01 to 100 microns are main interest of contamination for years.
3. Atoms and molecules used to be considered too small as industrial contamination, but not any more after introduction of the concern of Airborne Molecular Contamination (Non-solid, in gas or vapor phase).




800
1000
800
Hauteur minimale de la pièce
2960
2000
Ø 900
Ø 560
390
1770
Niveau fini du plancher


ASHRAE
DESIGN GUIDE
for
CLEANROOMS
Fundamentals, Systems
and Performance
ASHRAE


STANDARD
ANSI/ASHRAE/ASHE Standard 170-2008
Ventilation of
Health Care Facilities
ASHRAE
ASHE
ANSI

Cleanroom Standards in US

(Previous US Federal Standard and Current ISO Standards)

U.S. Federal Standard 209E	Airborne particulate cleanliness classes in cleanrooms and clean zones (former US standard, canceled in November 2001)

ISO Document	ISO-14644: Cleanrooms and Associated Controlled Environments
ISO-14644-1	Classification of Air Cleanliness
ISO-14644-2	Cleanroom Testing for Compliance
ISO-14644-3	Methods for Evaluating & Measuring Cleanrooms & Associated Controlled Environments
ISO-14644-4	Cleanroom Design & Construction
ISO-14644-5	Cleanroom Operations
ISO-14644-6	Terms, Definitions & Units
ISO-14644-7	Enhanced Clean Devices
ISO-14644-8	Molecular Contamination
ISO-14698-1	Biocontamination: Control General Principles
ISO-14698-2	Biocontamination: Evaluation & Interpretation of Data
ISO-14698-3	Biocontamination: Methodology for Measuring Efficiency of Cleaning Inert Surfaces

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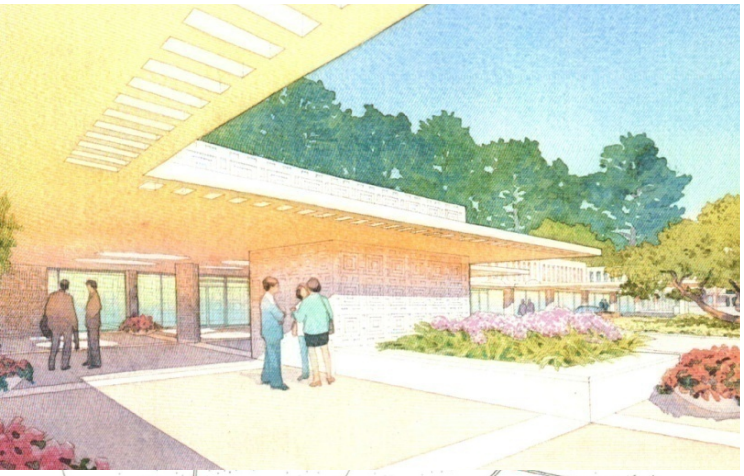
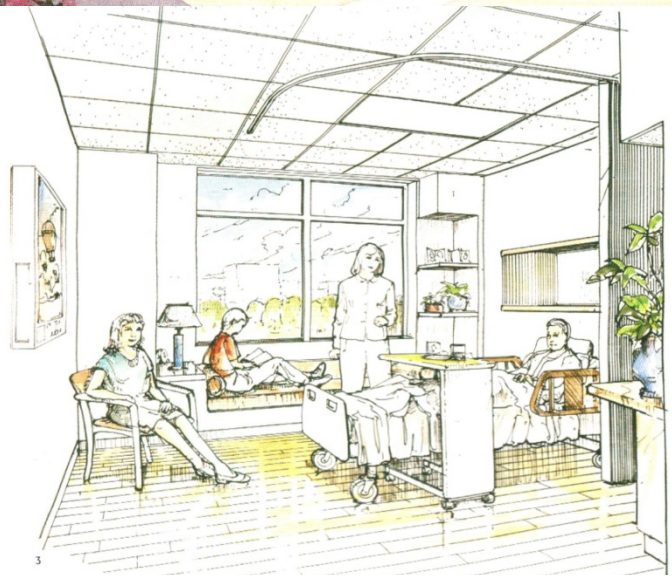




- Rule 1:

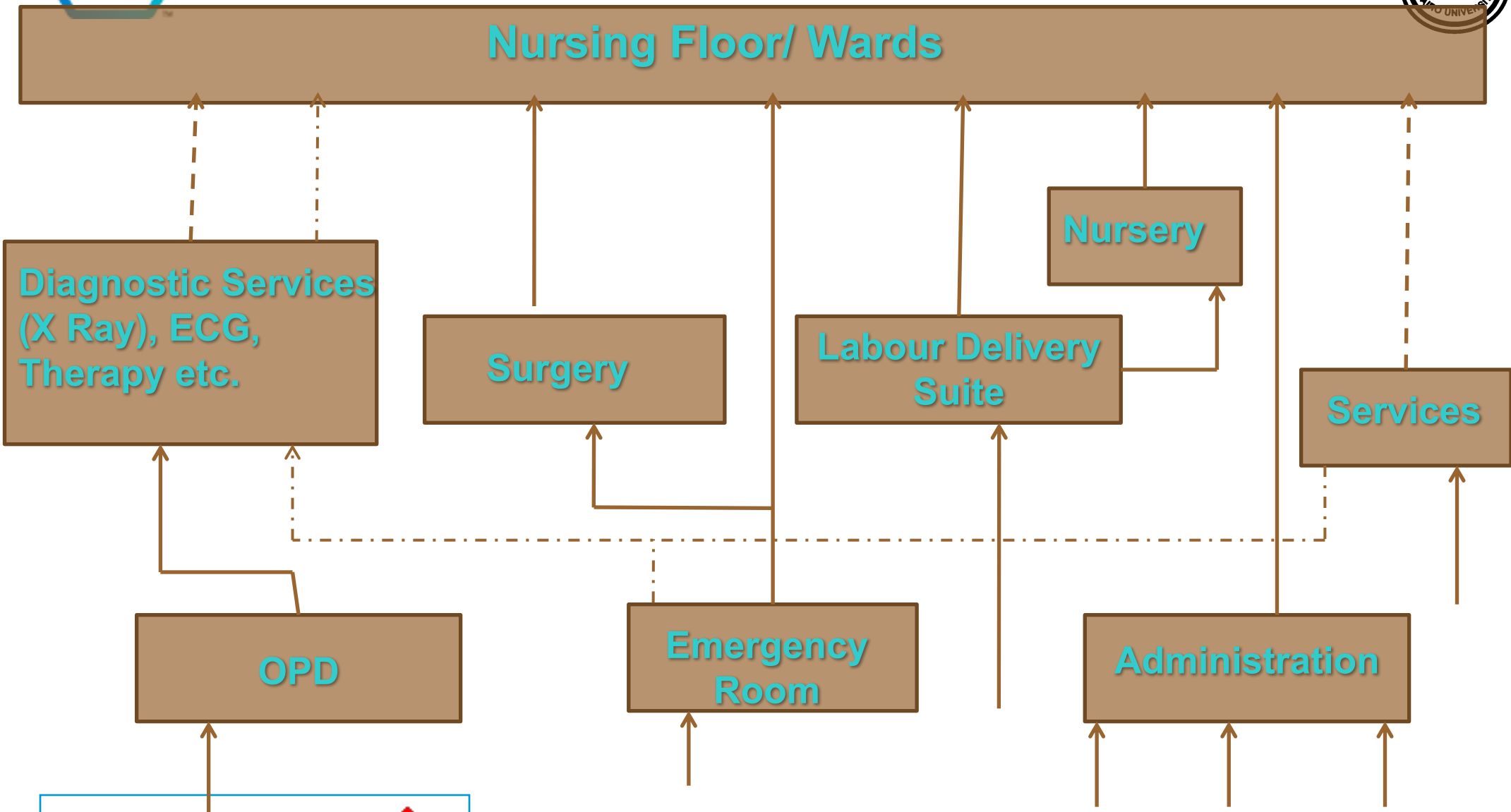
  Protection of patients
- Rule 2:

  Plan shortest possible traffic rules.
- Rule 3:

  Separation of dissimilar activities
- Rule 4:

  Control

Flow Chart of A General Hospital



Space Requirements of A General Hospital

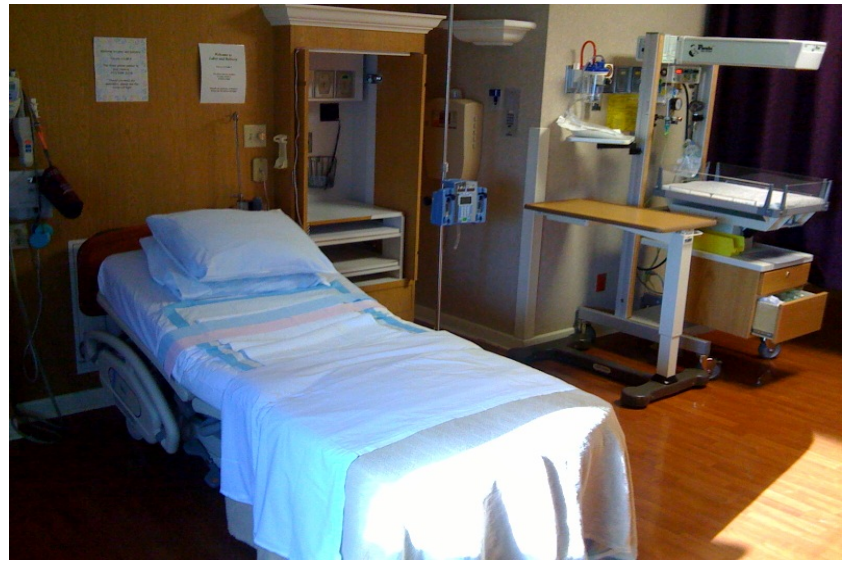
Services	Areas	Services	Areas
Emergency	10-15	Administration	30-35
Outpatient	10-15	Housekeeping	4-5
Social Service	1	Materials management	4-5
Admissions And Discharge	2	Central stores	25-35
Clinical Laboratory And Pathology	25-30	Laundry	10-15
Delivery suite	12-15	Medical records	5-8
Diagnostic radiology	30-40	Medical staff facilities	2-3
Dietary and food service	25-30	Engineering and maintenance	50-60

Space Requirements Of A General Hospital

Services	Areas	Services	Areas
Nuclear medicine	4-5	Education, auditorium	5-10
Personnel	3-4	Nursery	4-3
Public spaces	10-15	Pharmacy	4-6
Pulmonary function	1-2	Nursing Units	250-300
Occupational therapy	3-5	Purchasing	2
Physical therapy	10-12	Radiation Therapy	8-10
Surgery	35-50		
Circulation	100-150		

Building Norms CSSD

- **General**
  - Admin office : nil
  - Store room (new and unsterile) : 240 m2
- **Sterlisation unit**
  - Wash up area: 120 m2
  - Check up and assembly: 180 m2
  - Autoclave room: 80 m2
  - Storage and issue: 120 m2
- **Solution preparation unit**
  - Glass washing: 120 m2
  - Solution preparation : 120 m2
  - Solution storage : 120 m2
- Total: 1100 m2



Building Norms Cubicle and ward sizes

Sno.	Cubicle/ward	Size(sq.ft.)	Area /bed
1	Single bedded	120	120
2	Double bedded	180	90
3	Three bedded	240	80
4	Four bedded	320	80
5	Six bedded	480	80
6	Eight bedded	640	80
7	Twelve bedded	960	80
8	Sixteen bedded	1280	80

Table (2) General Pressure Relationships and Ventilation of Hospital Areas

Function Space	Pressure Relationship to Adjacent Areas	Minimum Air Changes of Outdoor Air per Hour(a)	Minimum Total Air Changes per Hour(b)	All Air Exhausted Directly to Outdoors	Air Recirculated Within Room Units
SURGERY CRITICAL CARE					
Operating room (all outdoor air system)	P	15(c)	15	Yes	No
(recirculating air system)	P	5	25	Optional	No
Delivery room (all outdoor air system)	P	15	15	Optional	No
(recirculating air system)	P	5	25	Optional	No
Recovery room	E	2	6	Optional	No
Nursery suite	P	5	12	Optional	No
Trauma room(d)	P	5	12	Optional	No
Anesthesia storage (see code requirements)	±	Optional	8	Yes	No
NURSING					
Patient room(e)	±	2	4	Optional	Optional
Toilet room(f)	N	Optional	10	Yes	No
Intensive are care	P	2	6	Optional	No
Protective isolation(g)	P	2	15	Yes	Optional(h)
Infections Isolation(g)	±	2	6	Yes	No
Isolation alcove or anteroom	±	2	10	Yes	No
Labor/delivery/recovery/postpartum (LDRP)	E	2	4	Optional	Optional
Patient corridor(e)	E	2	4	Optional	Optional

Function Area	Pressure Relationship to Adjacent Areas	Minimum Air Changes of Outdoor Air per Hour Supplied to Room	Minimum Total Air Changes per Hour Supplied to Room	All Air Exhausted Directly to Outdoors	Air Recirculated Within Room Unit
PATIENT CARE					
Patient room	±	2	2	Optional	Optional
Patient area corridor	±	Optional	2	Optional	Optional
Toilet room	N	Optional	10	Yes	No
Diagnostic and Treatment					
Examination room	±	2	6	Optional	Optional
Physical therapy	N	2	6	Optional	Optional
Occupational therapy	N	2	6	Optional	Optional
Soiled workroom or soiled holding	N	2	10	Yes	No
Clean workroom clean holding	P	2	4	Optional	Optional
Sterilizing and supply					
Sterilizer exhaust room	N	Optional	10	Yes	No
Linen and trash chute room	N	Optional	10	Yes	No
Laundry, general	±	2	10	Yes	No
Soiled linen and storage	N	Optional	10	Yes	No
Clean linen storage	P	Optional	2	Yes	No
Service					
Food preparation center	±	2	10	Yes	yes
Warewashing room	N	Optional	10	yes	Yes
Dietary day storage	±	Optional	2	Yes	No
Janitor closet	N	Optional	10	Yes	No
Bathroom	N	Optional	10	Yes	No

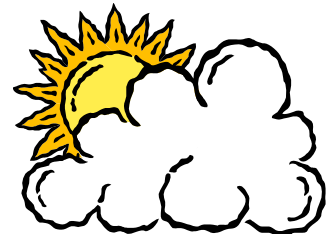
Saturday, 11 May 2019

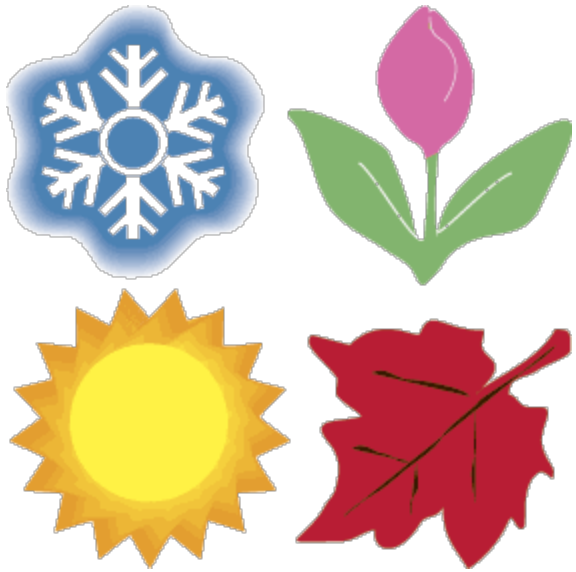
Climatic Design Conditions

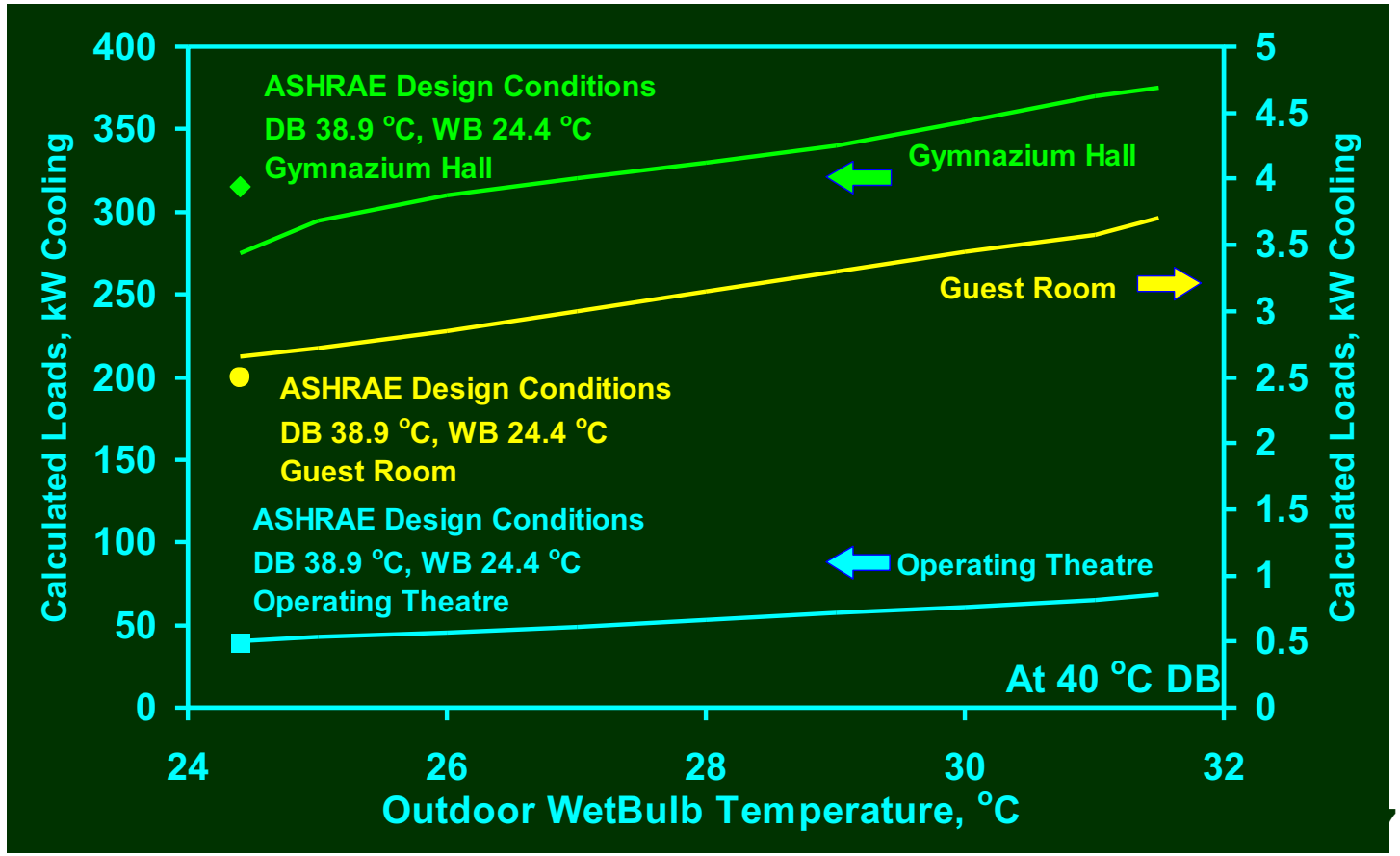
The correct specifications of outdoor ambient conditions affect thermal loads, as shown in Figure, and consequently the comfort level. Some researches recommend changing the focus on the effect of building envelope to reduce the thermal load to enhance the thermal comfort.

Outdoor Design Conditions

Summer dry bulb temperature	40 C
Summer wet bulb temperature	30.5 C







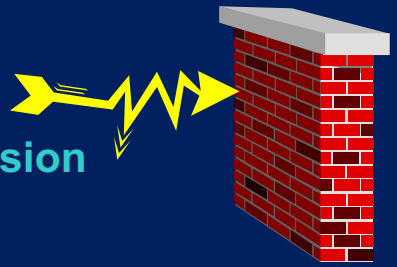
Load Estimation

A cooling load calculation determines total sensible cooling load due to heat gain (1) through structural components (walls, floors, and ceilings); (2) through windows; (3) caused by infiltration and ventilation; and (4) due to occupancy. The latent portion of the cooling load is evaluated separately. While the entire structure may be considered a single zone, equipment selection and system design should be based on a room-by-room calculation.

Solar Gain

Glass transmission through windows

Wall transmission



Roof transmission

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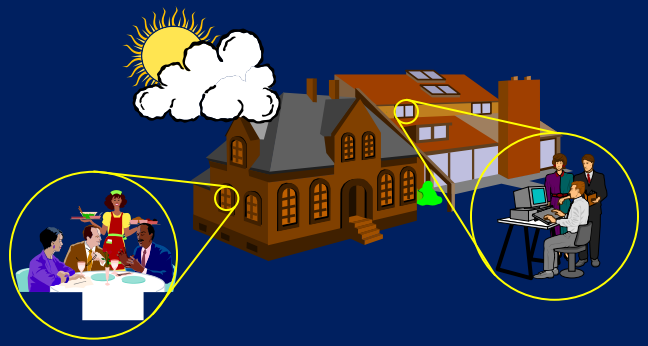
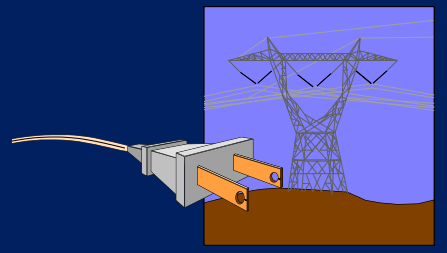


Lighting loads

Other electric loads

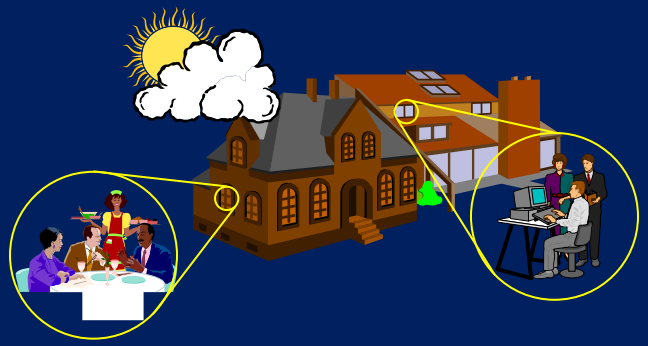


Load Estimation

The load estimation is important factor in the HVAC design of the air-conditioned spaces. For proper design of the distribution system, the amount of conditioned air required by each room must be known.

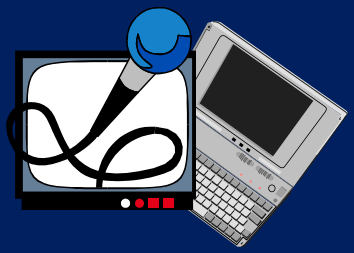
The under estimation of the load leads to discomfort design of the enclosure.

The over estimation of the load leads to inefficient energy utilization.



People activity loads

Miscellaneous loads



Net ventilation load

Cooling infiltration

Supply fan load

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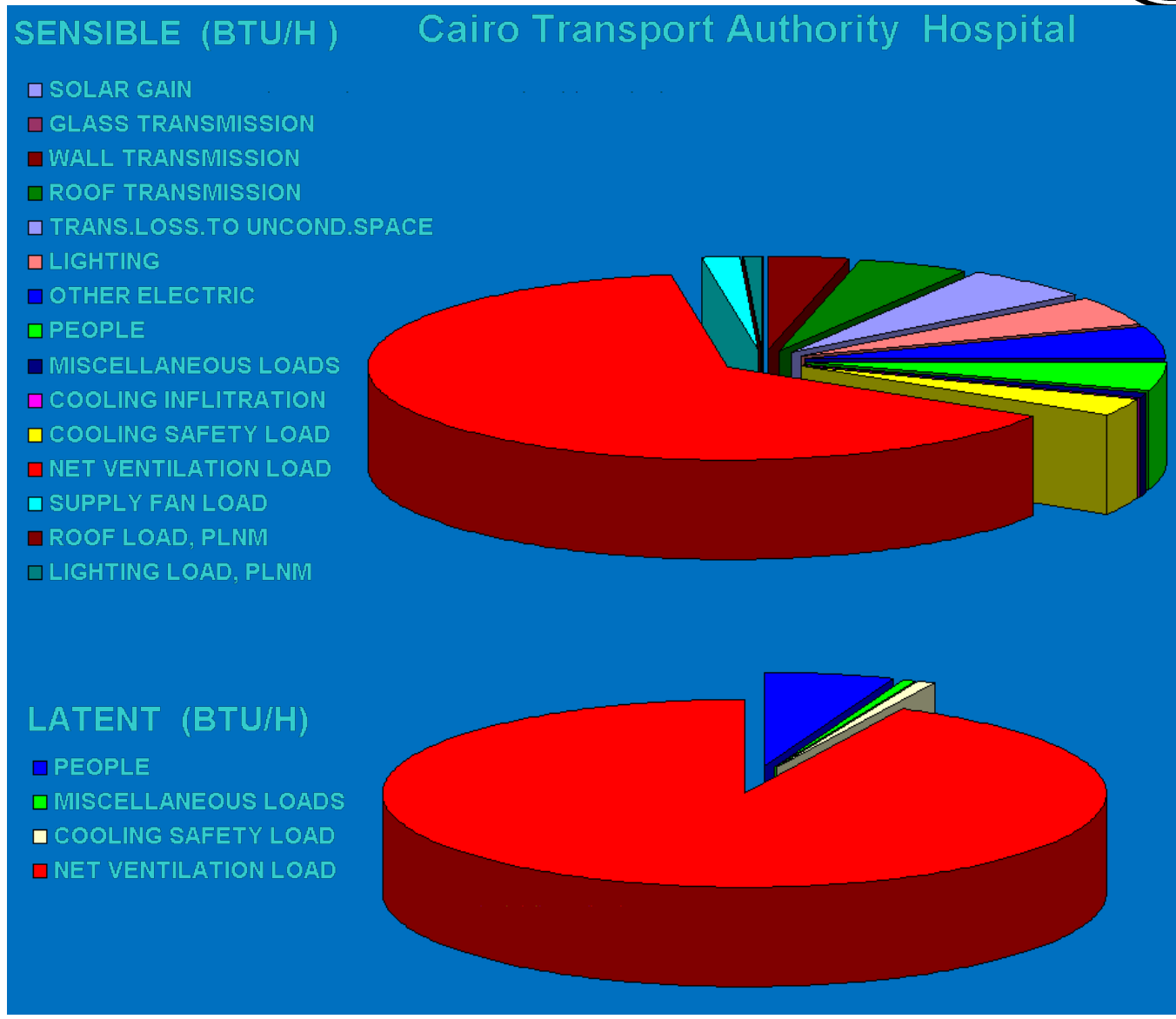
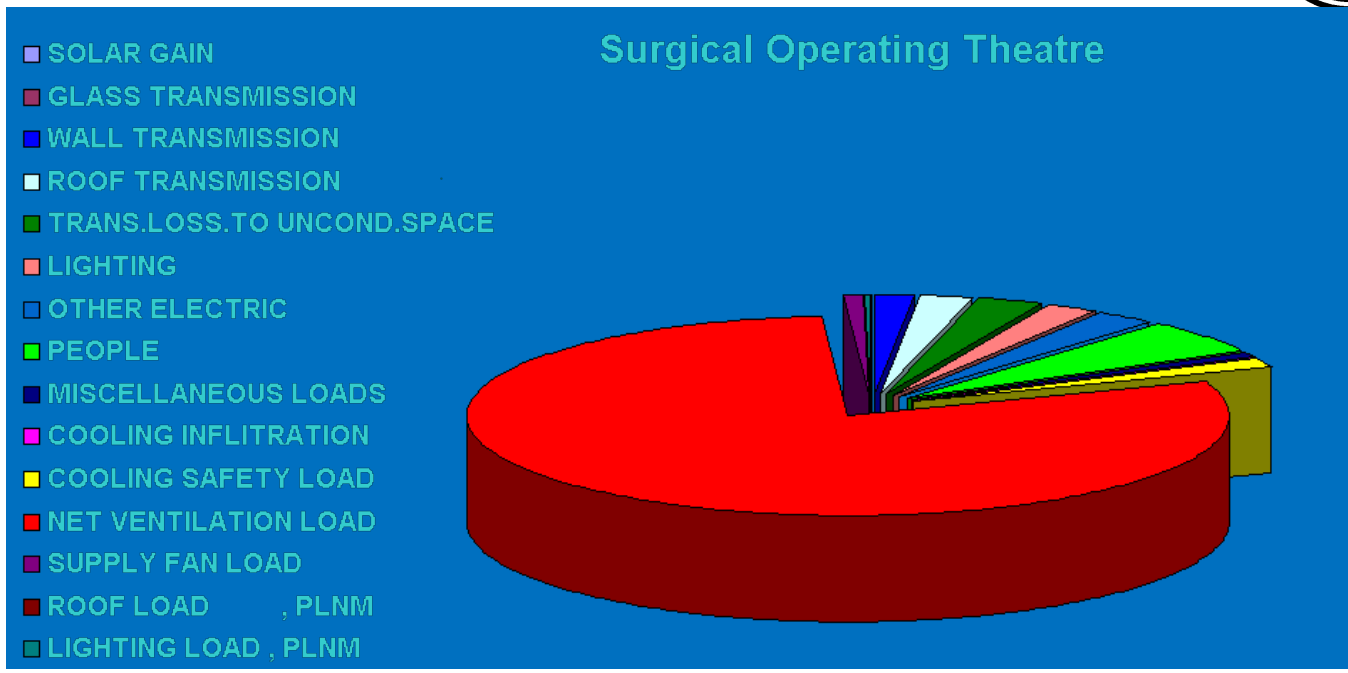
Typical Cooling Load In Hospitals



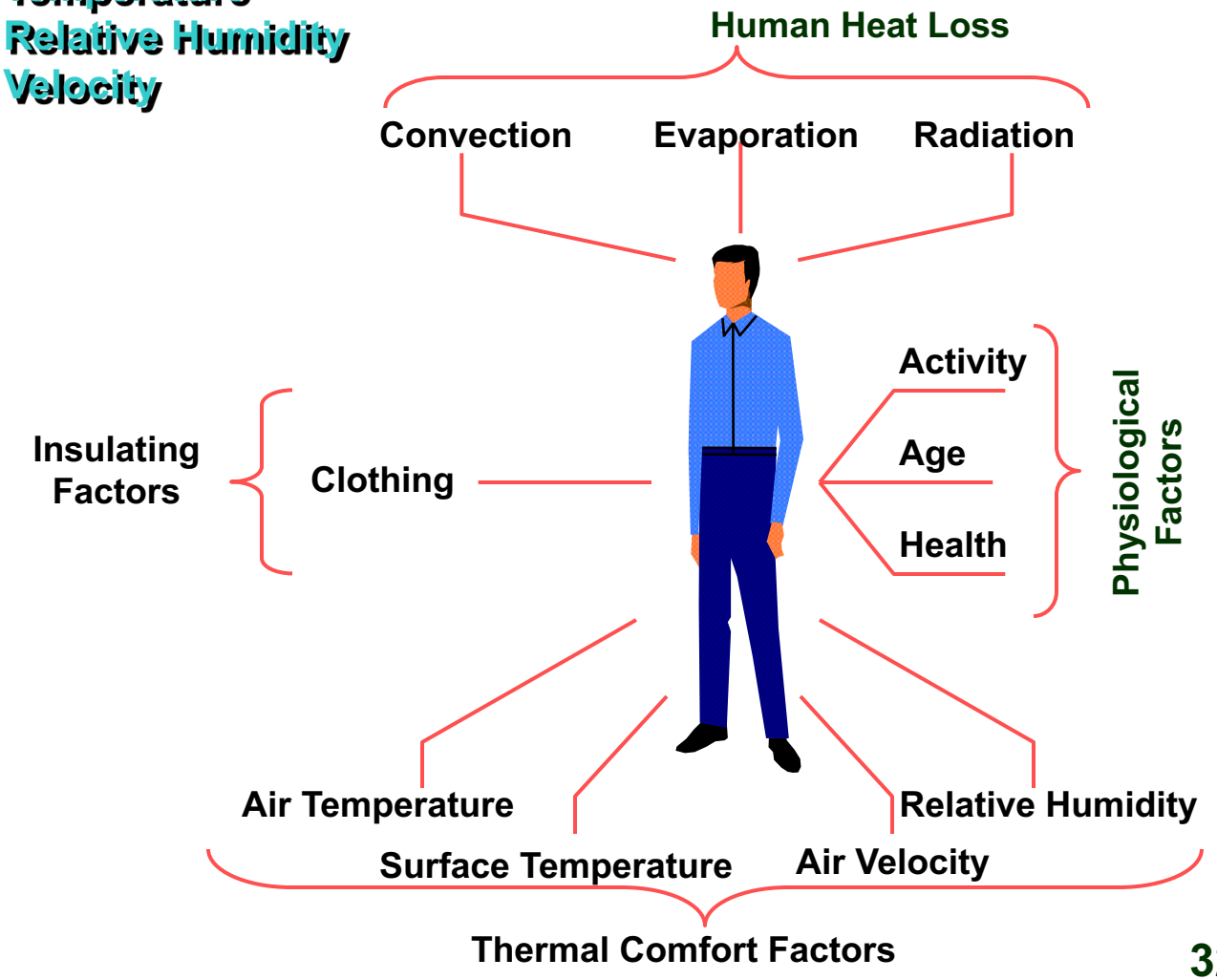
Typical Cooling Load In SOT



Comfort Principles and Factors

Factors influencing thermal comfort

- Air Temperature
- Air Relative Humidity
- Air Velocity



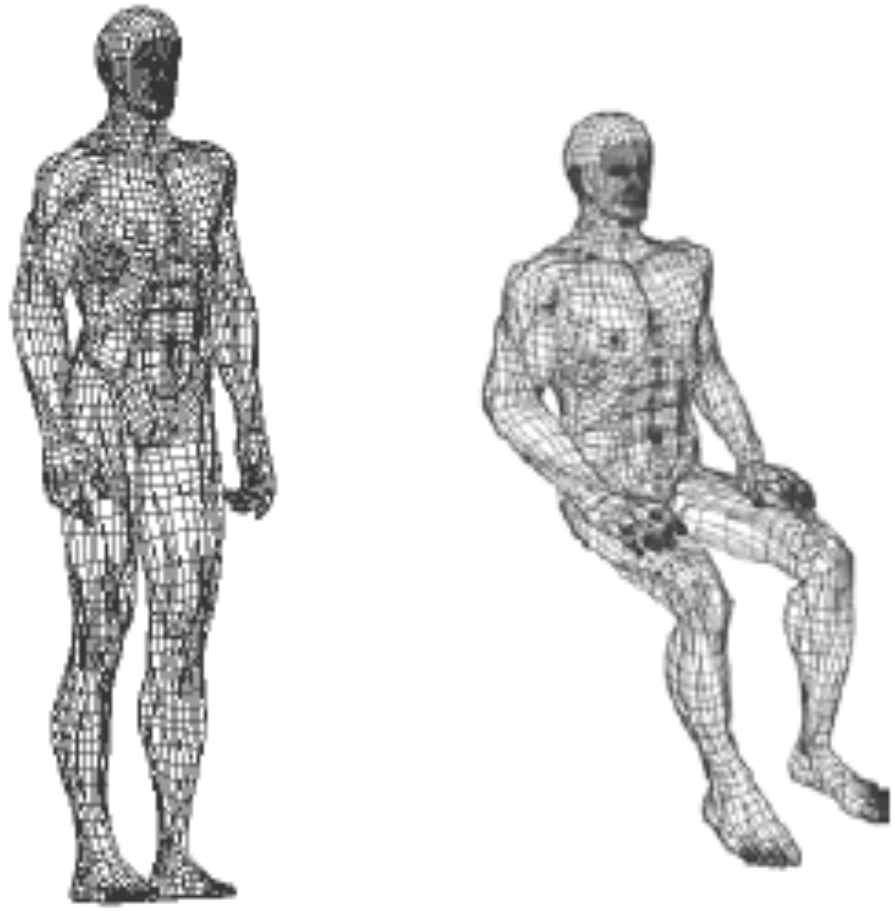
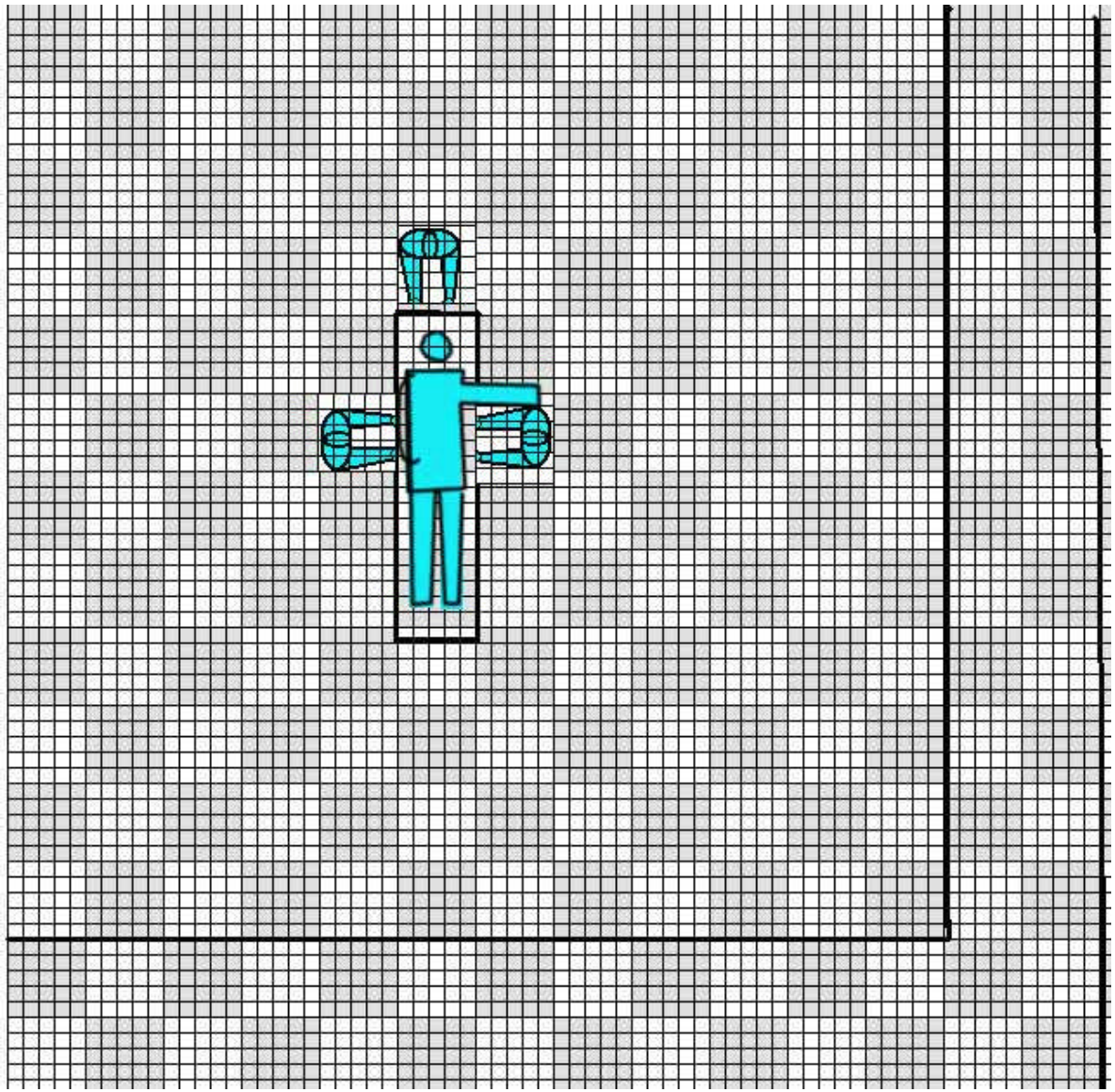


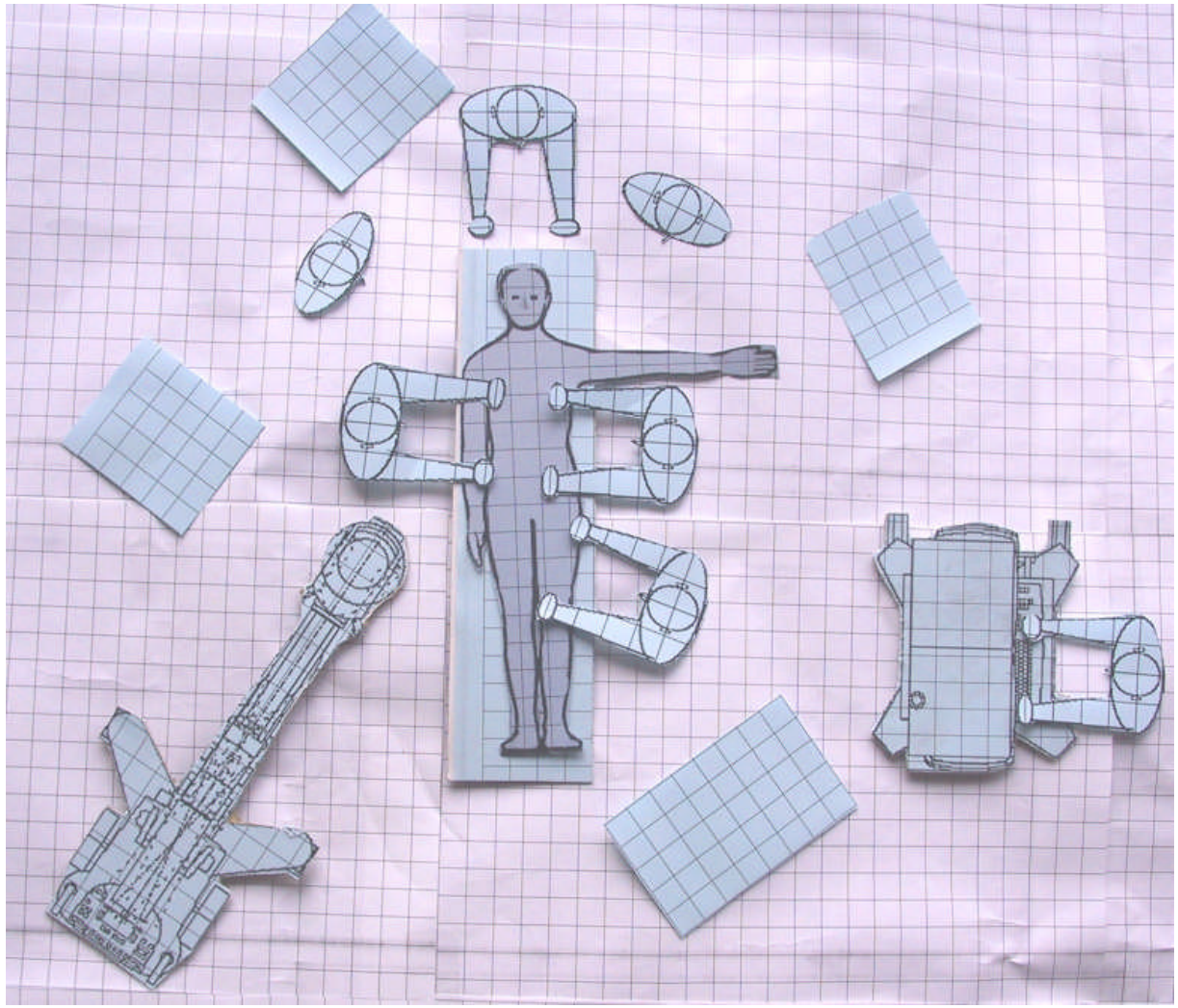
Figure 1. *The human body geometry models used in the study.*

Design of Modern Healthcare Facilities

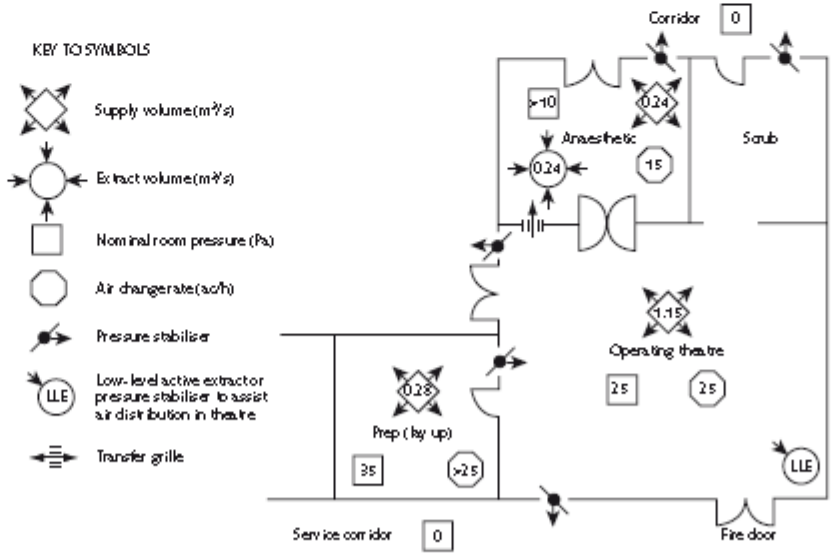
Operating Bed to Room Relation

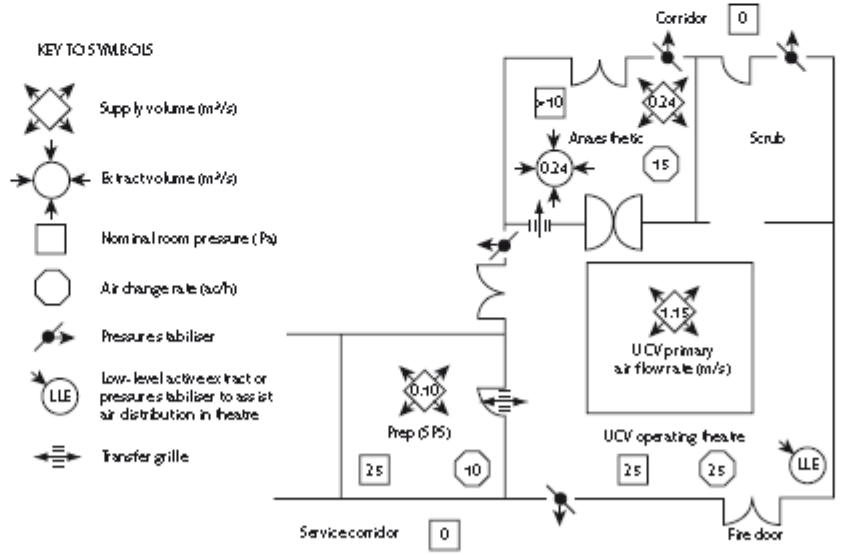


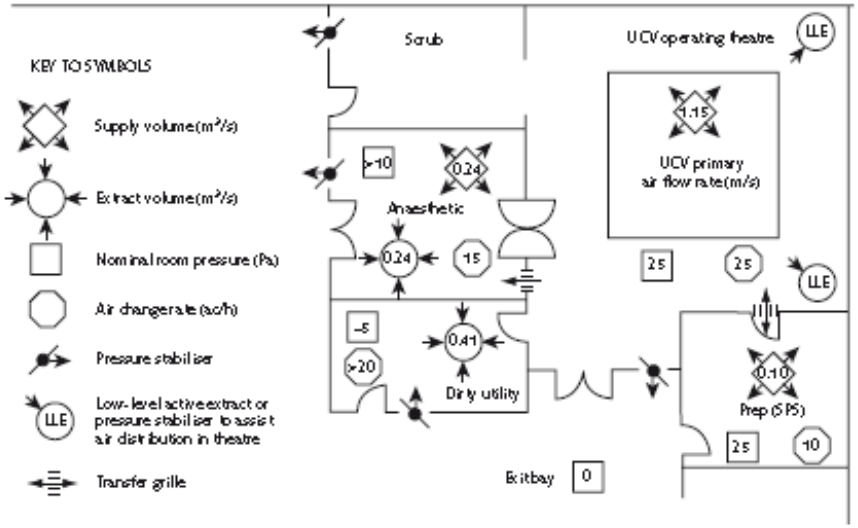
Room Configurations

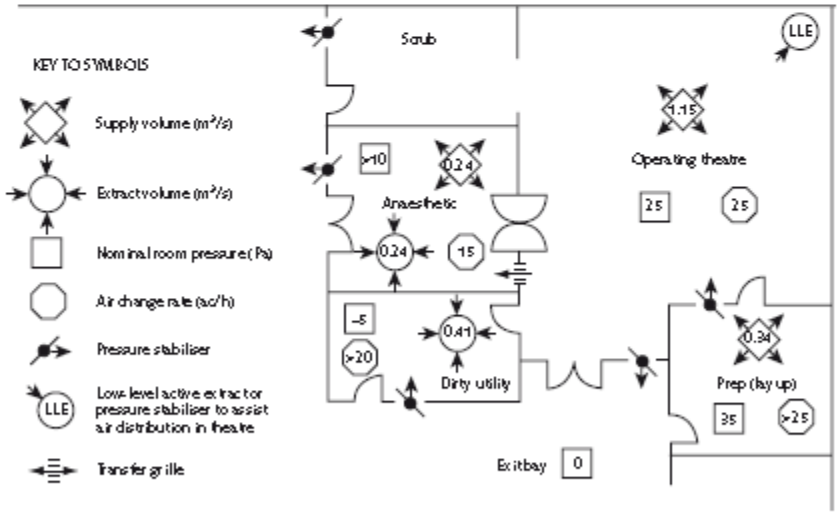


Various Room Designs

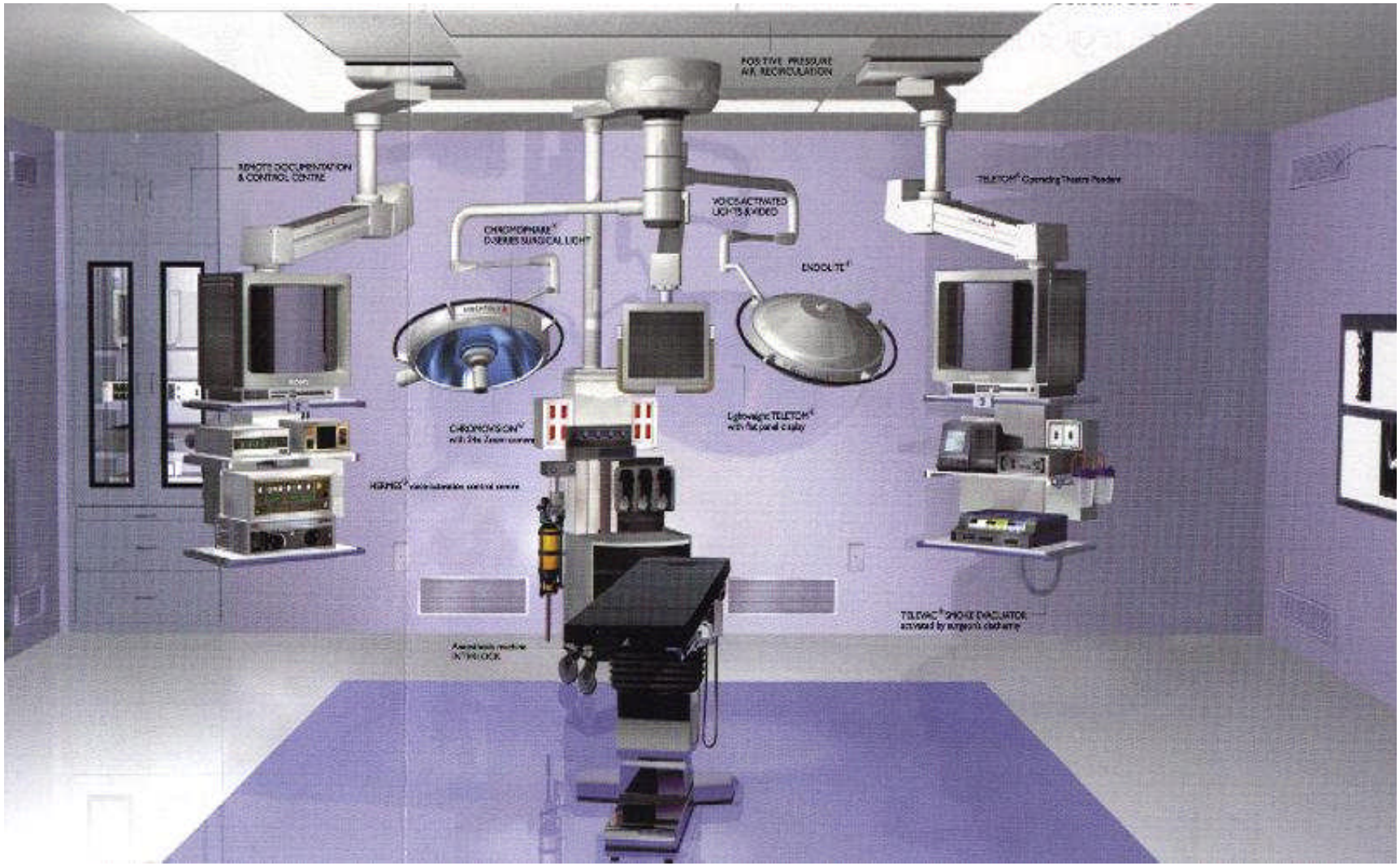




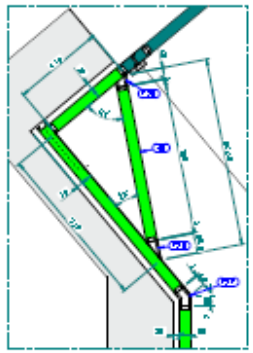




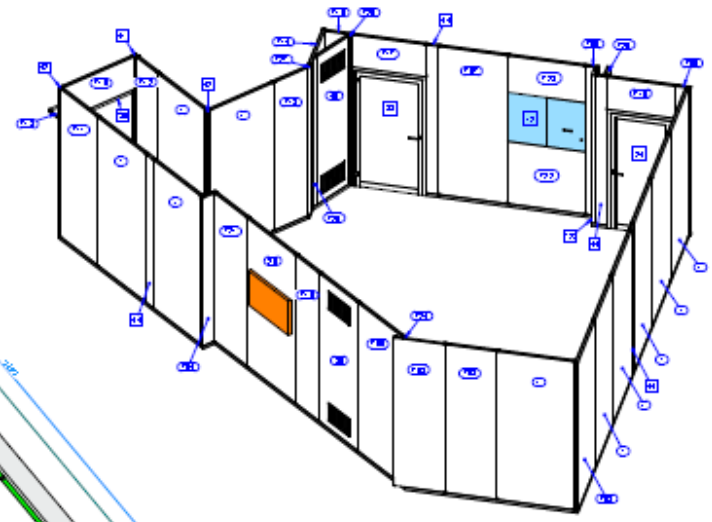
Modern Operation Room

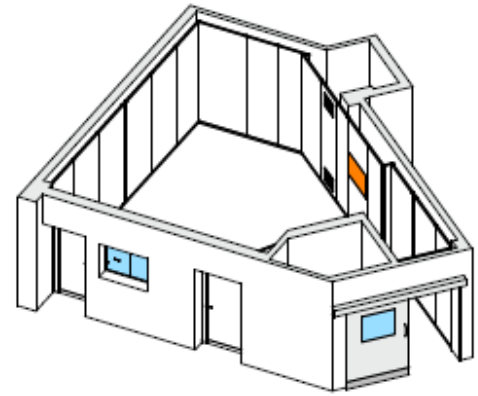



HANAUPORT


air return starts C
1:10

Layout of the operating theater 7
Operating theater 7
opening side of the cable channel


Isometry

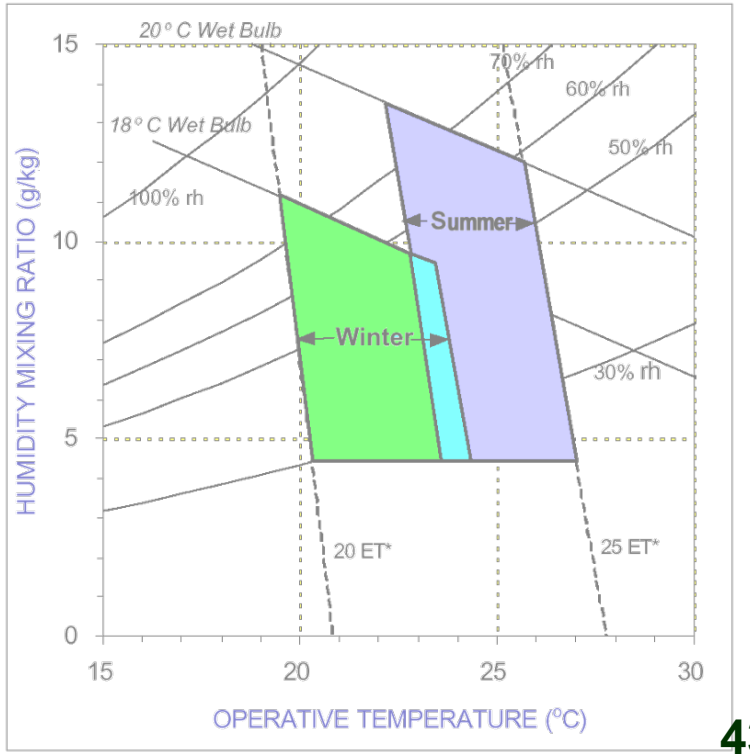


Comfort in Hospitals

In 1966, ASHRAE standard 55-1966, Thermal environmental conditions for human occupancy introduced a definition for thermal comfort which has become widely used and quoted "Thermal comfort is that condition of mind that expresses satisfaction with the thermal environment."

The comfort air conditioning is defined as "The process of treating air to control simultaneously its temperature, humidity, cleanliness, and distribution to meet the comfort requirements of the occupants of the conditioned space." ASHRAE Fundamentals 2001.

- Low air velocity, which must not be higher than approximately 0.25 m/s in the occupancy regions of the room (occupancy level is usually defined as the region from floor up to 1.7 m).
- Entrainment of room air by the primary air stream outside of the zone of occupancy in order that air motion and temperature differences reduced to acceptable limits before the air enters the occupancy zone.
- Counteraction of the natural convection and radiation effects within the room.
- Construct the successful air distribution system, it requires an accurate judgement, which depends on the integration of the data and the information. Then, the successful system depends on the nature and the characteristics of the space, the types of space flow and related applications to it, and the aspects of the air flow system design requirements.



Healthy and Hygiene Principles

Hospital air conditioning resumes a more important role than just the promotion of comfort. In many cases, proper air conditioning is a factor in patient therapy; in some instance, it is the major treatment. Studies show that patient in controlled environments generally have more rapid physical improvement than do those in uncontrolled environments, ASHRAE Applications 1999.

Although proper air conditioning designs are helpful in the prevention and treatment of disease, the application of air conditioning to health facilities presents many specific problems. Those are not encountered in the conventional comfort conditioning design, ASHRAE 1999.

The World Health Organization (WHO) defines health as "A state of complete physical, mental, and social well-being and not merely the absence of disease or disability"
Last 1983; defines health as "A state characterized by anatomic integrity, ability to perform personally valued family, work, and social roles; ability to deal with physical biologic; and social stress; a feeling of well-being; and freedom from the risk of disease and Untimely death"
Higgins 1983; defines as adverse health effect as a biological change that reduces the level of well being or functional capacity.

Air conditioning, therefore, includes the entire heat exchange operation as well as the regulation of velocity, thermal radiation and quality of air, as well as the removal of foreign particles and vapors, Stoecker et al. 1985.

Healthy and Hygiene Factors

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

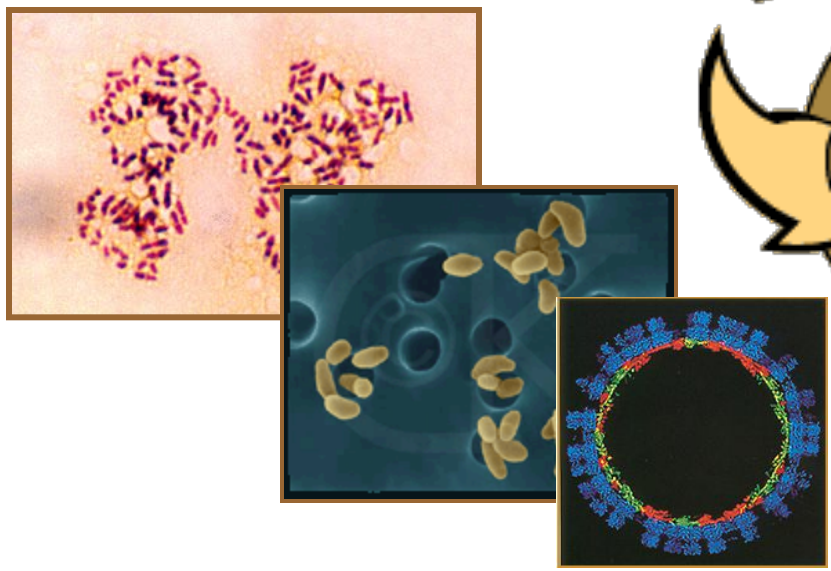
- The specific requirements for ventilation and filtration to dilute and reduce contamination in the form of odor, air-borne microorganisms and viruses, and hazardous chemical and radioactive substances.

- The different temperature and humidity requirements for various areas.

- The design sophistication needed to permit accurate control of environmental conditions.

Factors influencing healthy and Hygiene

1. Pressure Relationship
2. Air Movement Efficiency
3. Contaminant Concentration



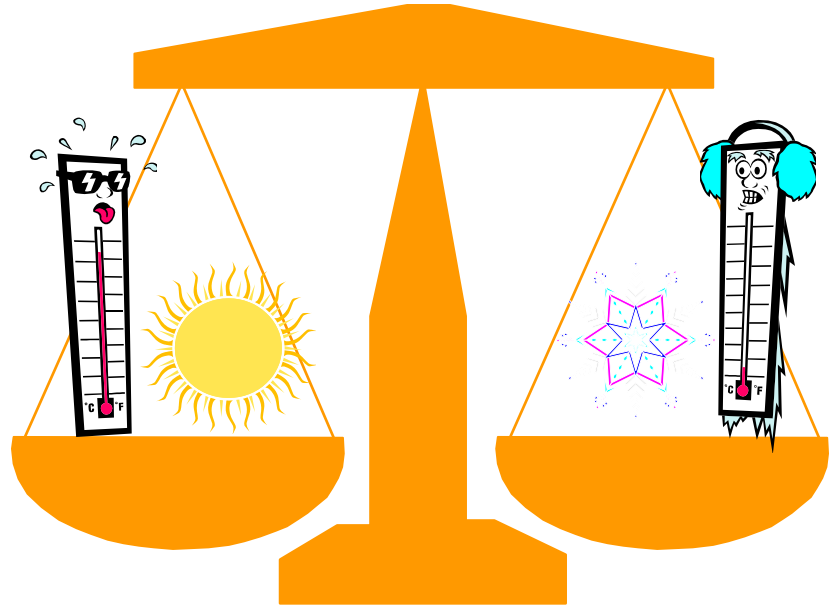
Temperature Control

Codes and guidelines specify temperature range criteria in some hospital areas as a measure for infection control as well as comfort. Local temperature distributions greatly affect occupant comfort and perception of the environment. If the ambient indoor air temperature is too warm, people perceive the environment to be stuffy with little airflow. This condition can often result in fatigue and lethargy.

Furthermore, high temperatures may cause increased outgassing of toxins from furnishings, finishes, building materials, etc. Alternatively, ambient temperatures that are too cool can cause occupant discomfort such as shivering, inattentiveness, and muscular and joint tension.

- The temperature should be controlled by change of supply temperature without any airflow control.
- Temperature difference between the warm and cool regions should be minimized to decrease the airflow drift.
- Good airflow distribution is required to create homogenous domain without large difference in the temperature distribution.
- Acceptable temperature in the occupancy zones and in the patient beds.

Experimental Programs in the hospitals provides a good information to assess the efficiency of the HVAC systems and provide a suitable guide for the maintenance engineers and the environmental engineers.



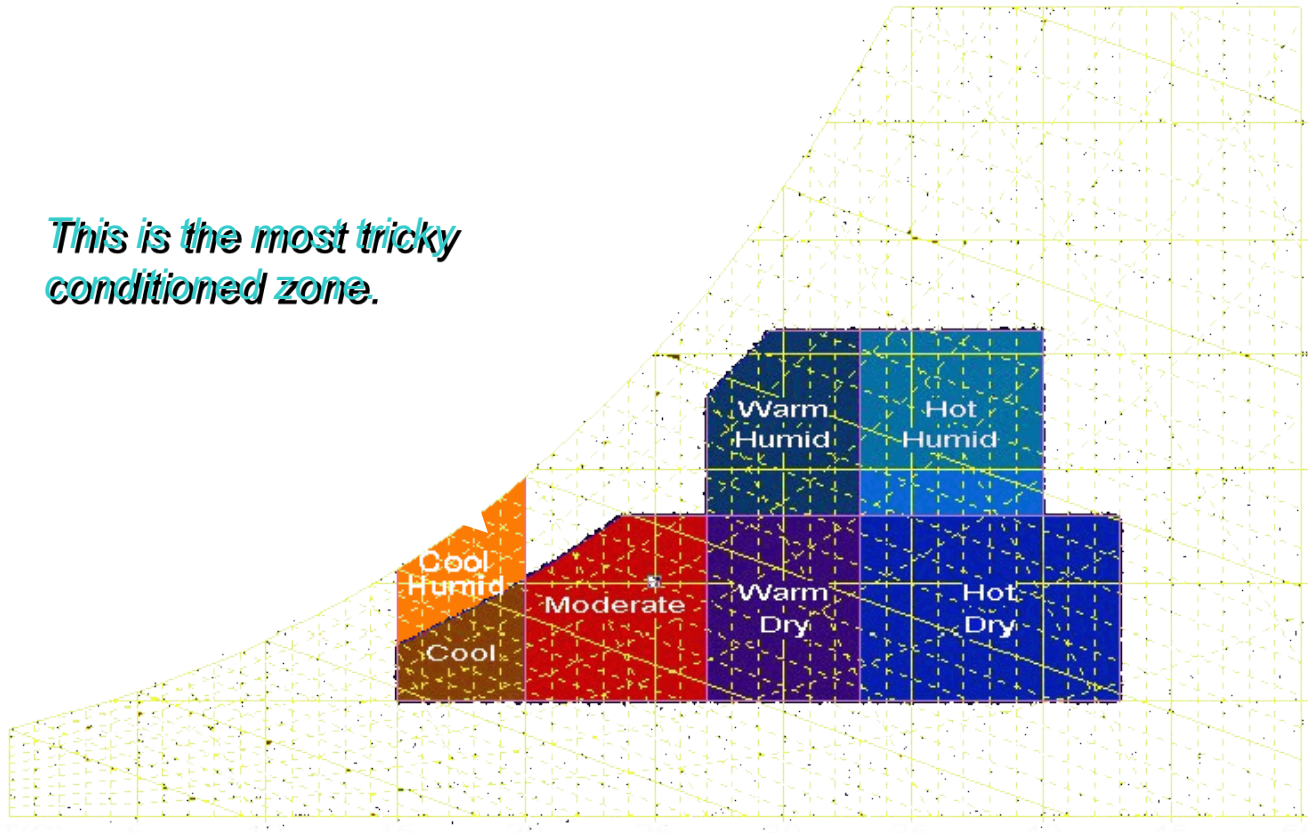
Relative Humidity Control

Relative humidity affects human comfort directly and indirectly. It is a thermal sensation, skin moisture, discomfort, and tactile sensation of fabrics, health and perception of air quality. Low humidity affects comfort and health. Comfort complaints about dry nose, throat, eyes and skin occur in low humidity conditions, typically when the dew point is less than 2 °C. The upper humidity limit was a dew point of 17 °C in the ASHRAE standards, based not so much on comfort as on considerations of mold growth and other moisture related phenomena

At lower levels of humidity, thermal sensation is a good indicator of overall thermal comfort and acceptability. But at high humidity levels, thermal sensation alone is not a reliable predictor of thermal comfort.

Most of Healthcare Workers could not be able to define the problem of the air-conditioning systems.
They complaints that the space is cold and they perspire in that cold space.
The answer "*Avoid the most tricky conditioned zone*"

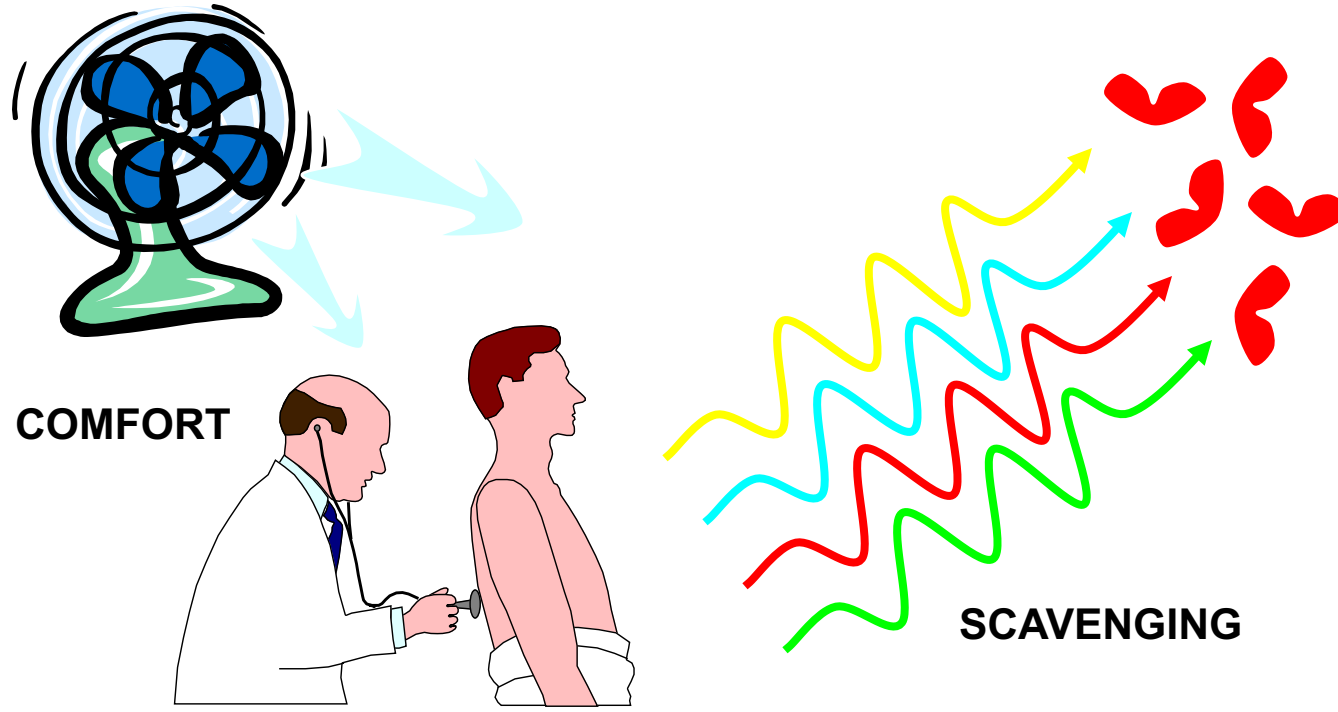
This is the most tricky conditioned zone.



Airflow Velocity Control

The laminar airflow concept developed for industrial clean room use has attracted the interest of some medical authorities. There are advocates of both vertical and horizontal laminar airflow systems. Laminar airflow in surgical operating theatres is airflow that is predominantly unidirectional when not obstructed. Laminar airflow has shown promising results in rooms used for the treatment of patients who are highly susceptible to infection. Among such patients would be the badly burned and those undergoing radiation therapy, concentrated chemotherapy, organ transplants, amputations, and joint replacement.

This condition participates directly on the airflow distribution in the room and the value of scavenging velocity in the room. For high-contaminated areas, the local velocity should be greater than or at least equal to 0.2 m/s, which has back influence on the value of the supplied air to overcome this condition. For patient rooms 0.1 m/s is sufficient in the occupied area. The unidirectional laminar airflow pattern is commonly attained at a velocity of 0.45 ± 0.10 m/s.

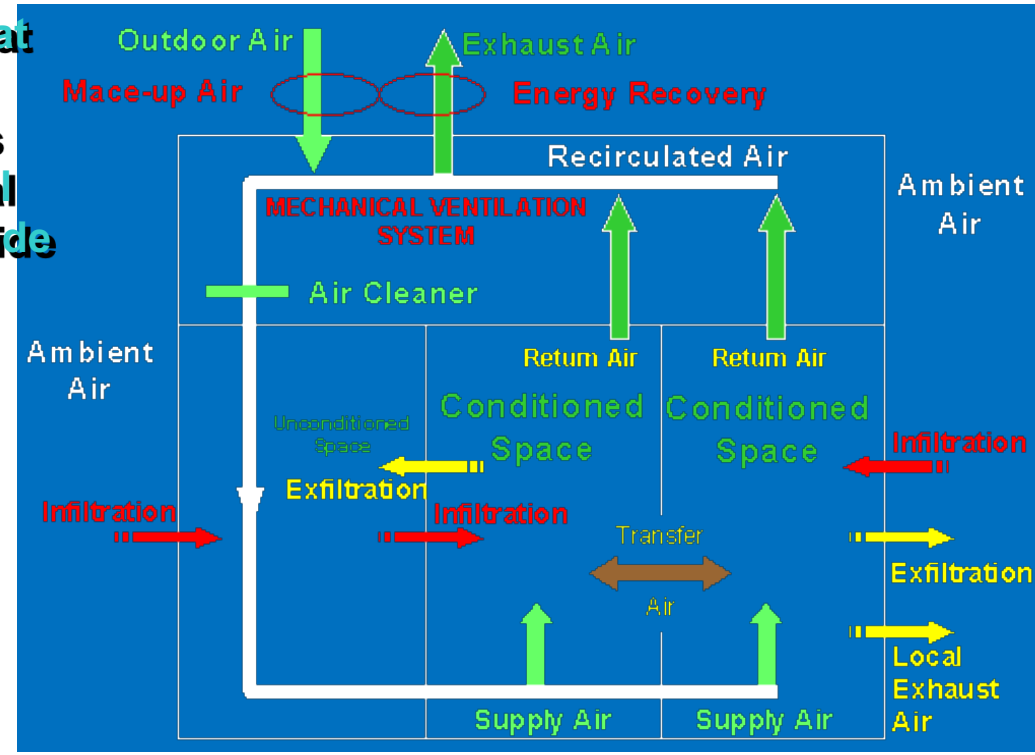


Pressure Relationship Control

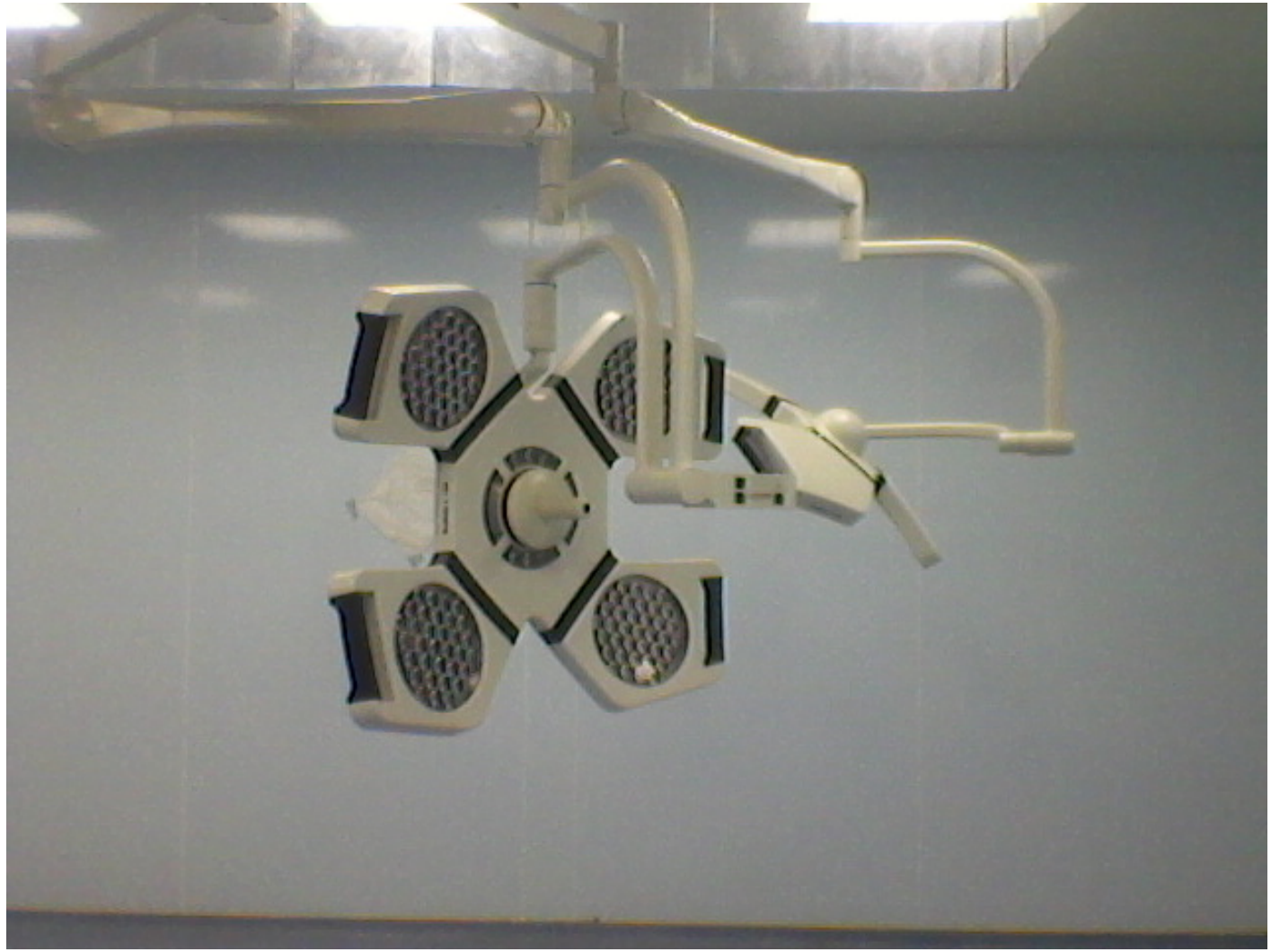
Ventilation recommendations for comfort, asepsis, and odor control in areas of acute care hospitals that directly affect patient care are presented by the healthcare standards. These recommendations do not necessarily reflect the criteria of the American Institute of Architects (AIA) or any other group. Specialized patient care areas, including organ transplants and burn units, should have additional ventilation provisions for air quality control. Design of ventilation system must, as much as possible, provide air movement from clean to less clean areas. In critical care areas, constant volume systems should be employed to assure proper pressure relationships and ventilation, except in unoccupied room.

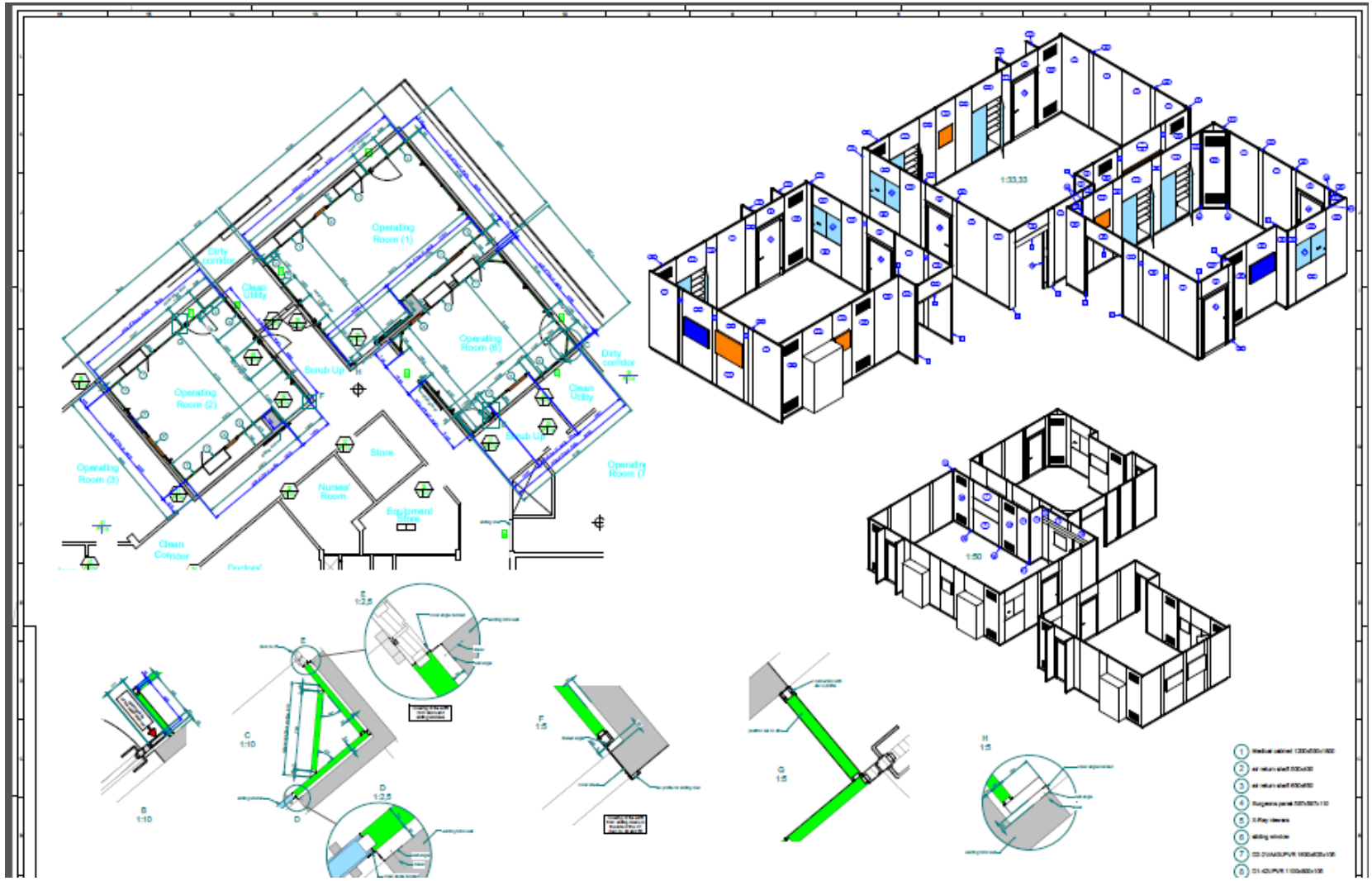
Air Change per Hour (ACH) plays in important role to provide a free contamination place. The patient rooms are served by (2 ACH – 6 ACH) in usual. Some critical rooms could be served by value up to 12 ACH. The critical rooms, such as the surgical operating theatres, are supplied by (15 ACH – 25 ACH) in usual. There are some guidelines, which advise the value of 60 ACH for the critical areas. Actually the proper value of the ACH could be enhance the airflow distribution in the medical space.

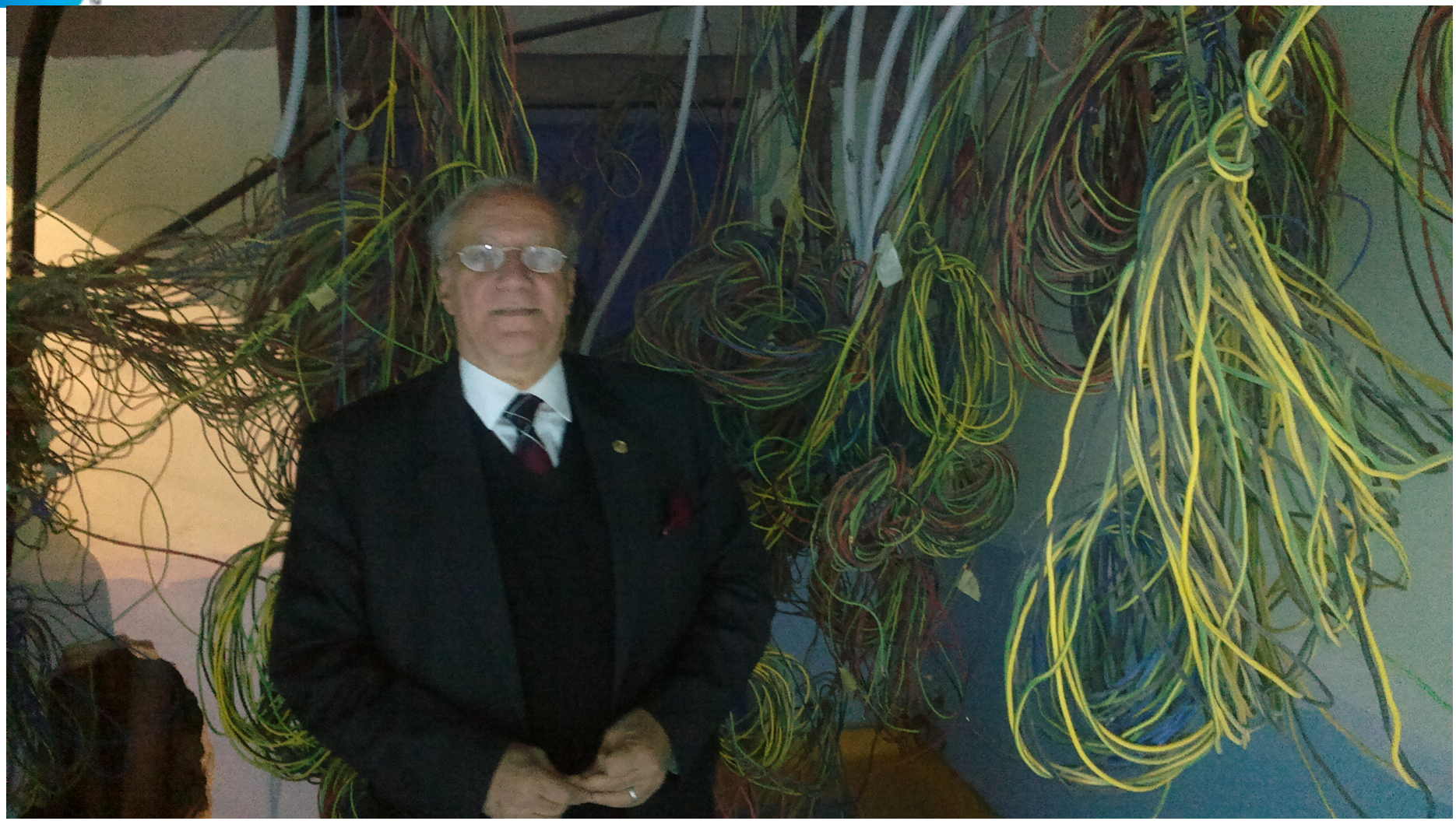
It was found that the minimum value of ACH is 40 in the critical spaces to provide an optimum airflow distribution.



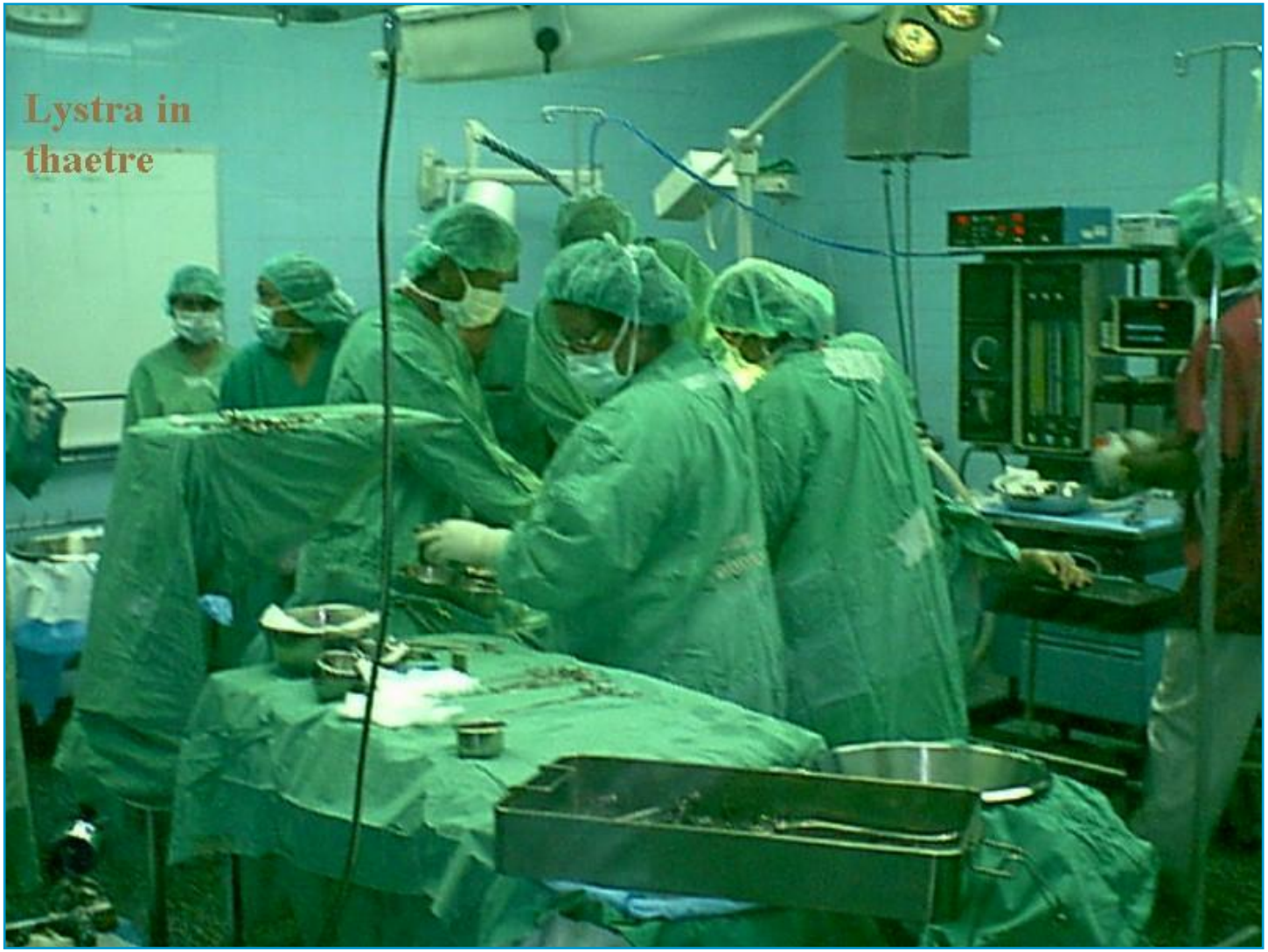
Isolation Rooms




Operating Room (1)
Operating Room (2)
Operating Room (3)
Operating Room (6)
Operating Room (7
Dirty corridor
Clean Utility
Scrub Up
Store
Nurses' Room
Equipment Room
Clean Corridor
1:33,33
1:50




Altro Whiterock


Lystra in
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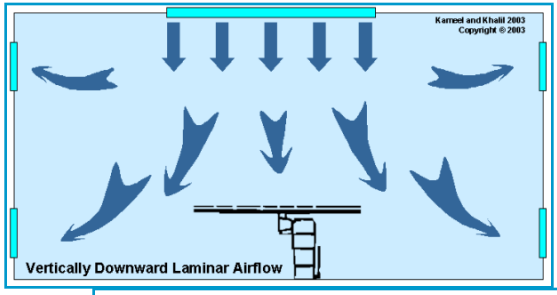
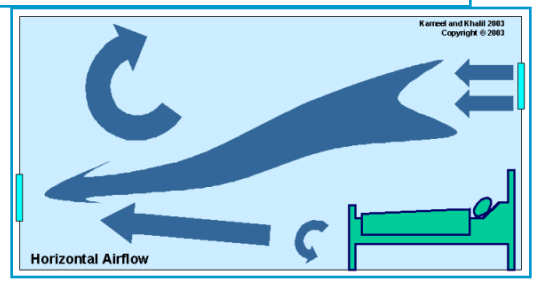
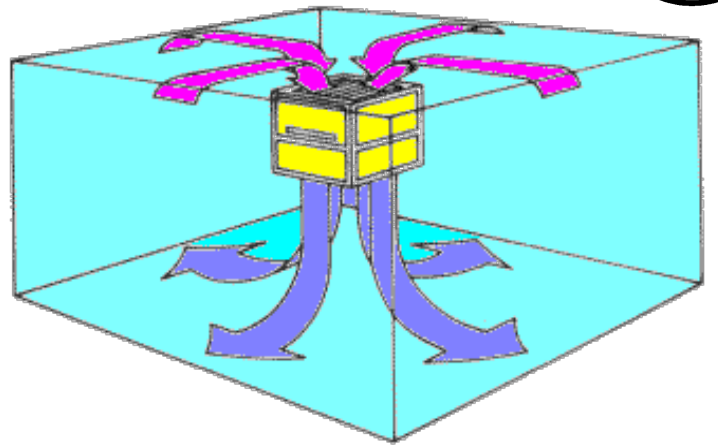
Airflow Movement Control

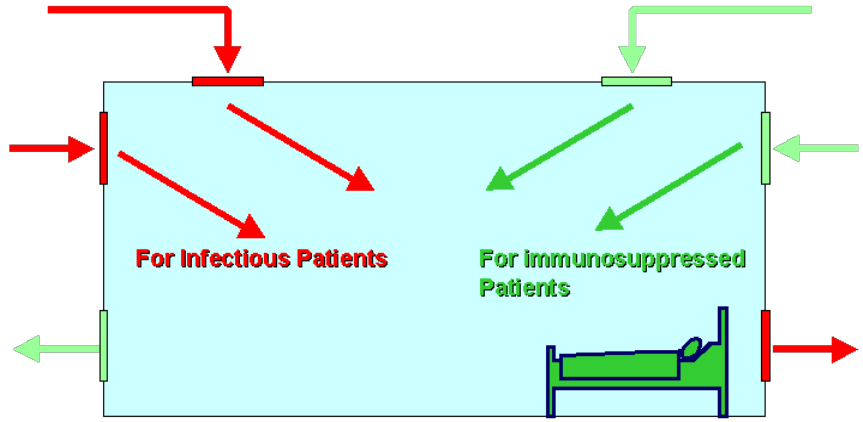
In general, outlets supplying air to sensitive ultraclean areas should be located on the ceiling, and perimeter or several exhaust outlets should be near the floor. This arrangement provides a downward movement of clean air through the breathing and working zones to the floor area for exhaust. The bottom of the return or exhaust openings should be at least 75 mm above the floor.





In the critical sections, such as the surgery rooms, the surgery bed should be located in the influence area of the supply outlets and away from the extraction port locations. This type of critical rooms, which is served by the piston flow configuration, should be wide enough to aid the environmental engineer to implement the critical room by the right distribution of equipment and furniture. Actually the orientation of the operating table and other equipment in the surgery room have a great influence on the airflow distribution efficiency.

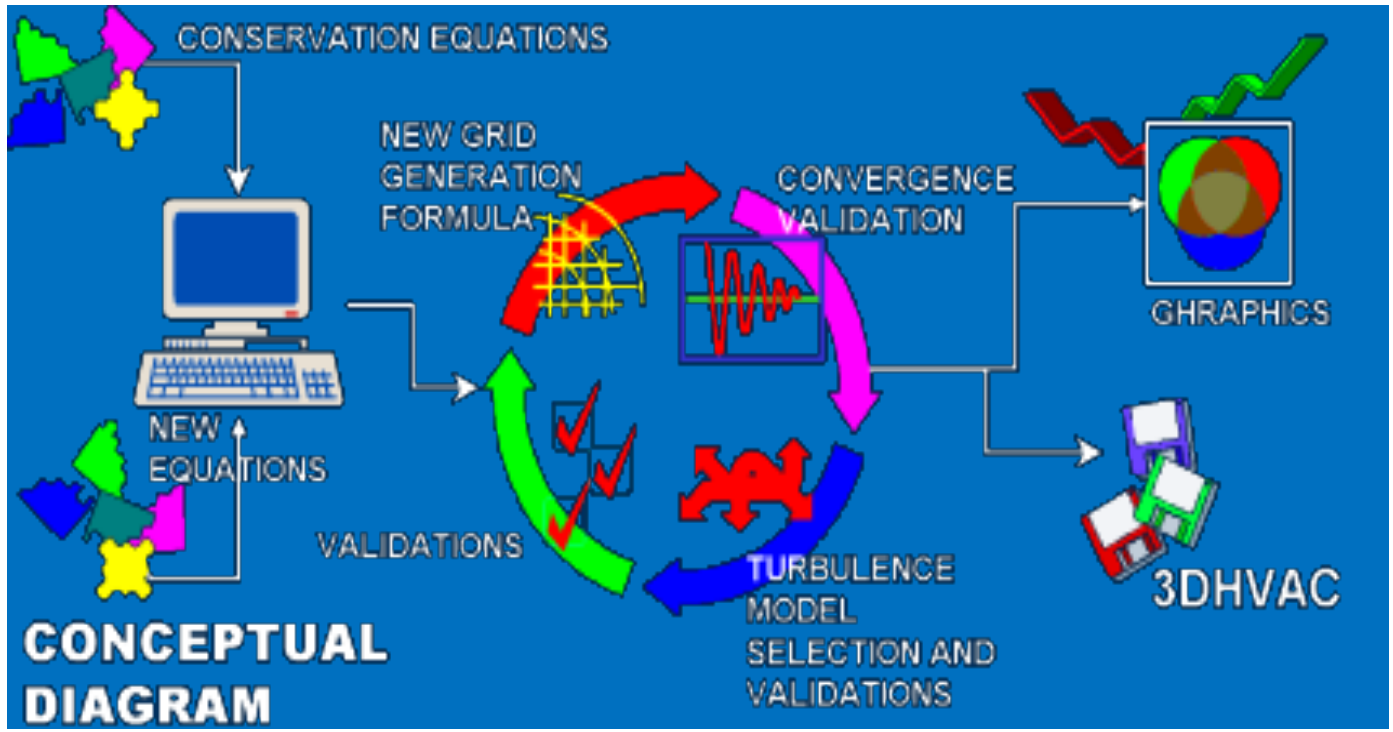




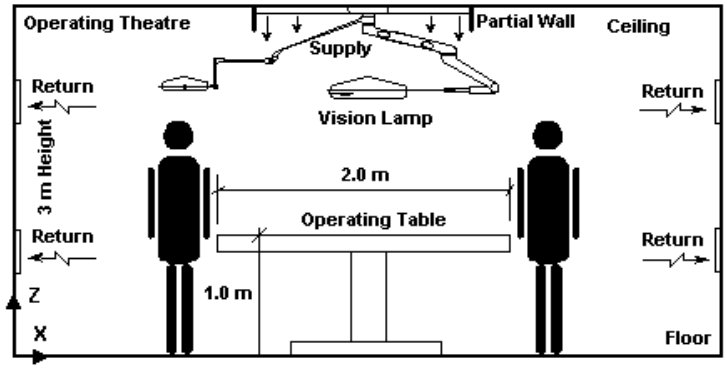
In the isolation rooms for infectious patients, the patient bed should be located closing to the extraction ports. The infectious isolation rooms should be maintained in negative pressure, and located closing to positive pressure areas even in the part load of these areas. In the isolation rooms for immunosuppressed patients, the air should be their guard from the infection. The immunosuppressed patient's bed should be located in the side of supplied air, or closing to the supply outlets.

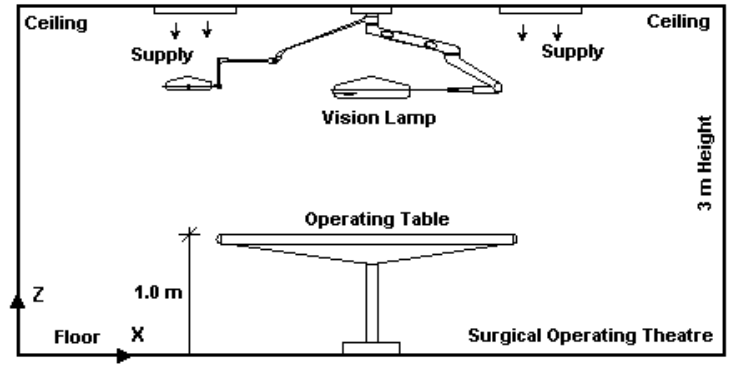
NUMERICAL METHOD

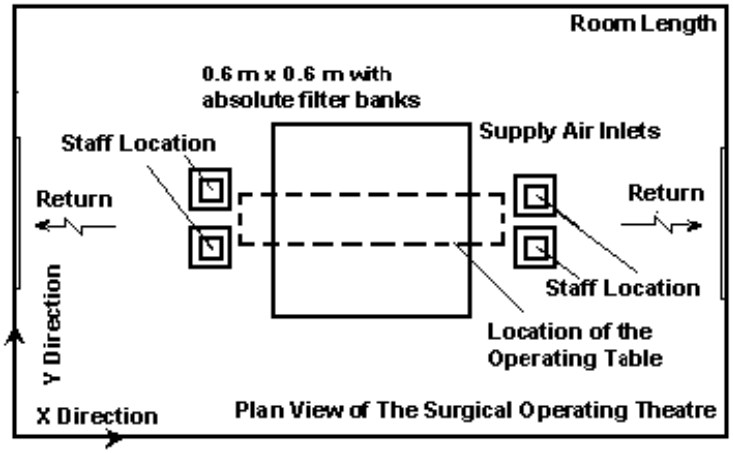
3DHVAC Validations

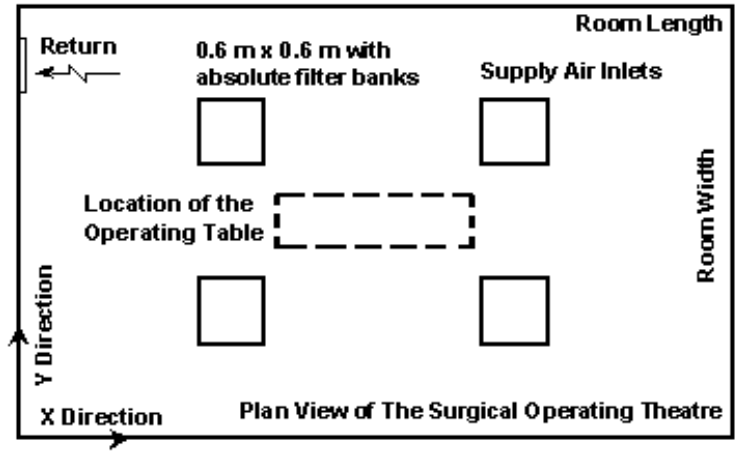


OPERATING THEATRE ARRAGEMENTS



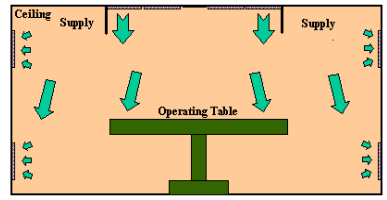


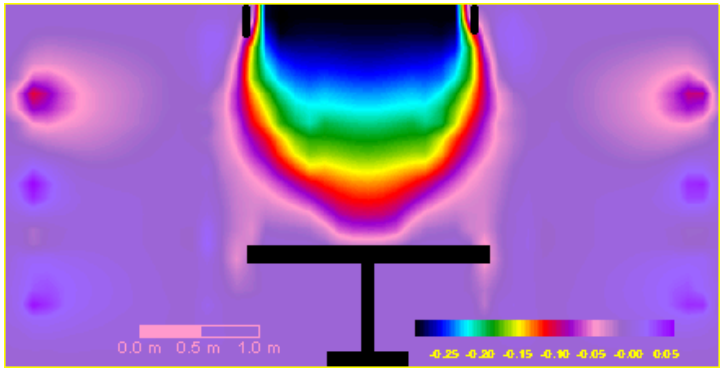


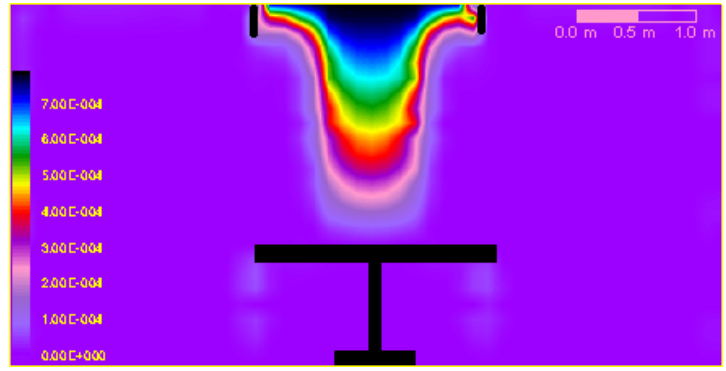


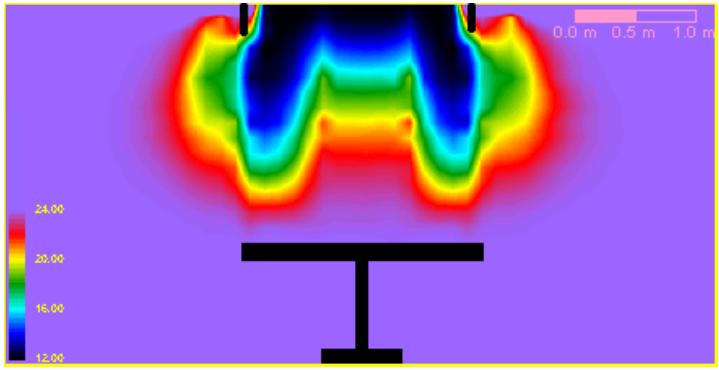
RESULTS AND DISCUSSIONS

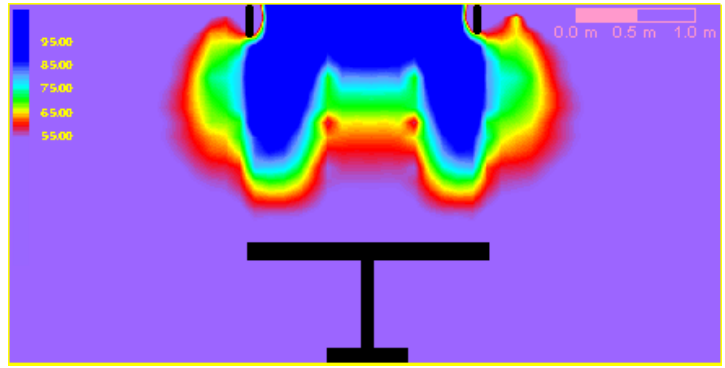
Surgical Operating Theatre





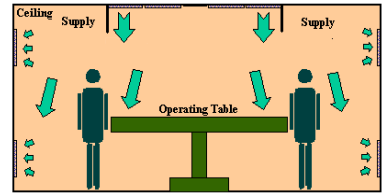


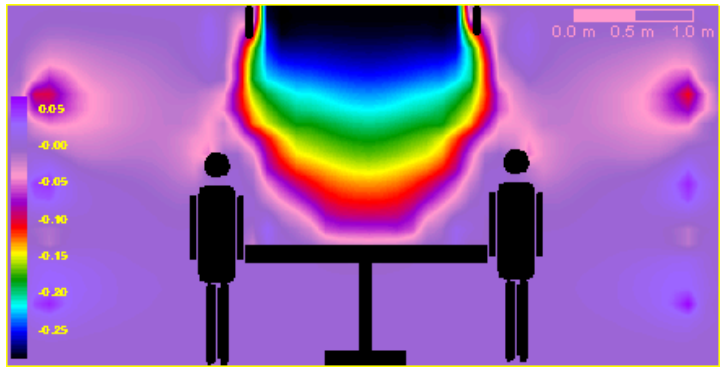


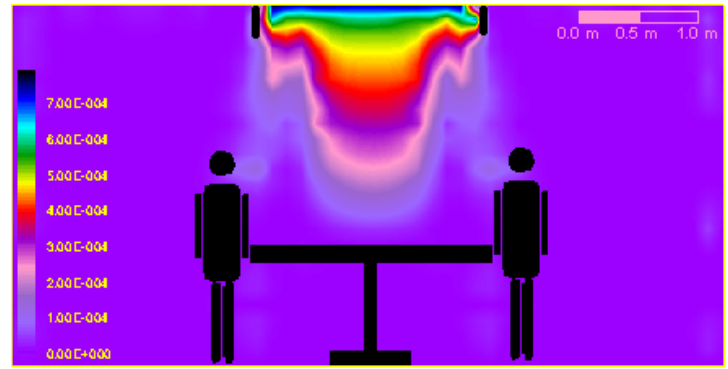


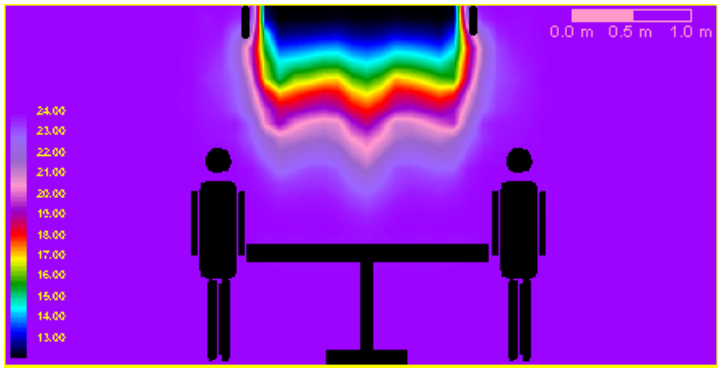
RESULTS AND DISCUSSIONS

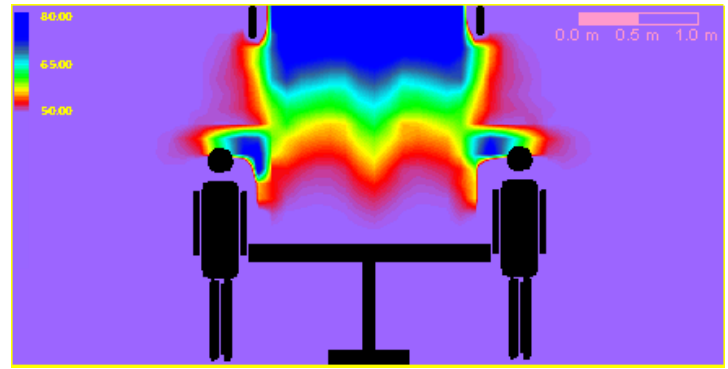
Surgical Operating Theatre





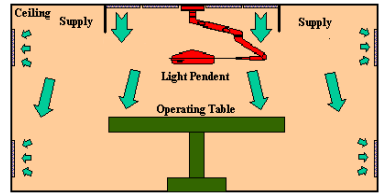


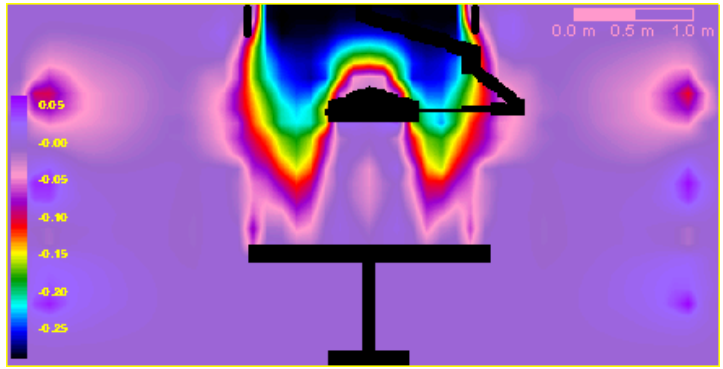


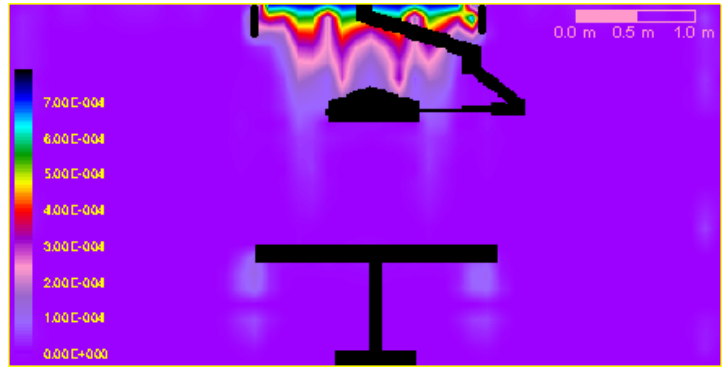


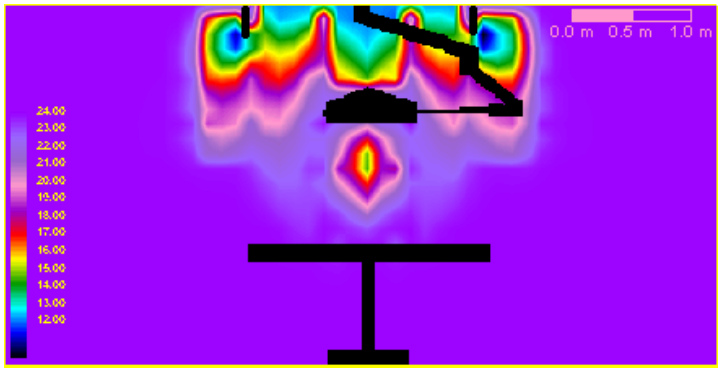
RESULTS AND DISCUSSIONS

Surgical Operating Theatre







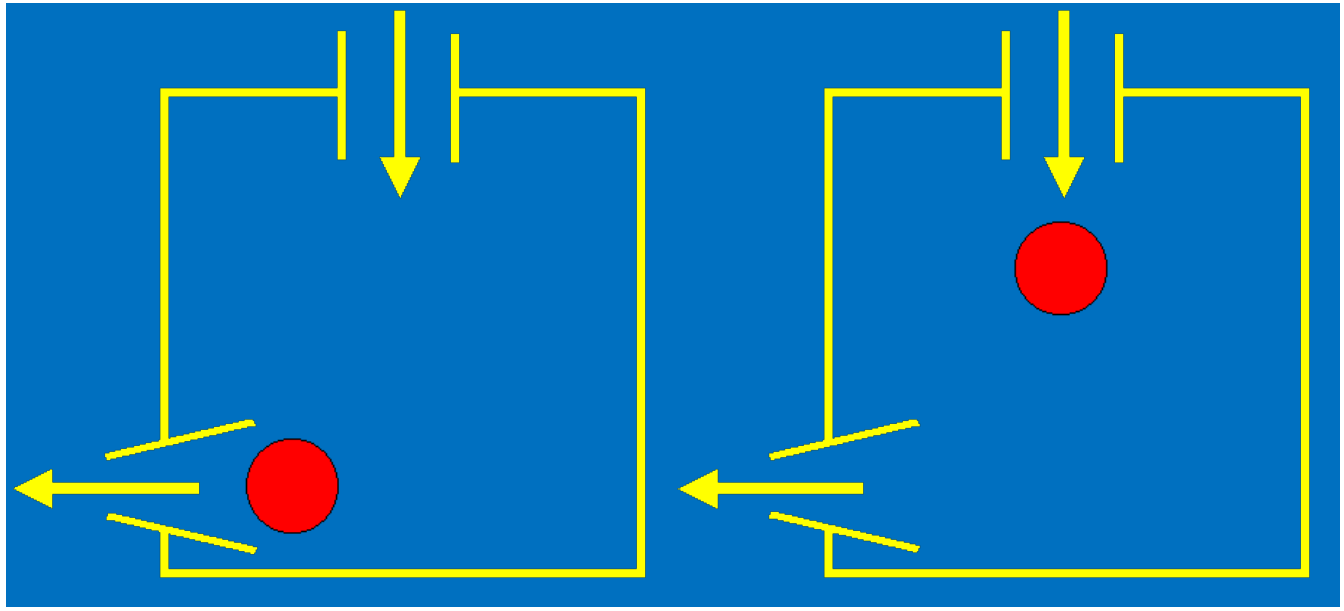


Contaminant Concentration Control

Air quality must also be maintained to provide a healthy, comfortable indoor environment. Sources of pollution exist in both the internal and external environment. The indoor air quality is controlled by removal of the contaminant or by dilution. ASHRAE standard 1981 prescribes both necessary quantities of ventilation for various types of occupancies and methods of determining the proportions of outside air and recirculated air. Although proper air conditioning designs are helpful in the prevention and treatment of diseases, the application of air conditioning to health facilities presents many specific problems. Those are not encountered in the conventional comfort conditioning design, ASHRAE 2001.

Mainly the contaminant distribution depends on the location of the pollutant source relative to the outlets in inlets of the airside system. This represents the importance of the furniture and medical equipment on the contaminant distribution. The velocity of the airflow and the airflow direction contributes of decreasing the contaminant concentration.

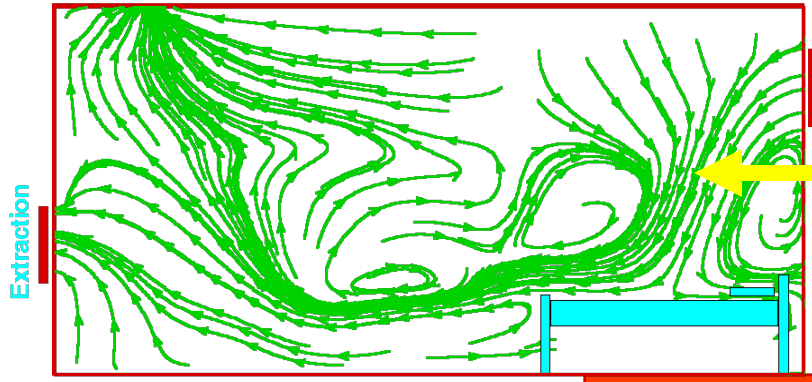
The recalculation zones and the turbulent air provides unclean environment in the healthcare facilities. The unidirectional laminar and free turbulent airflow is recommended in the hospitals in general.



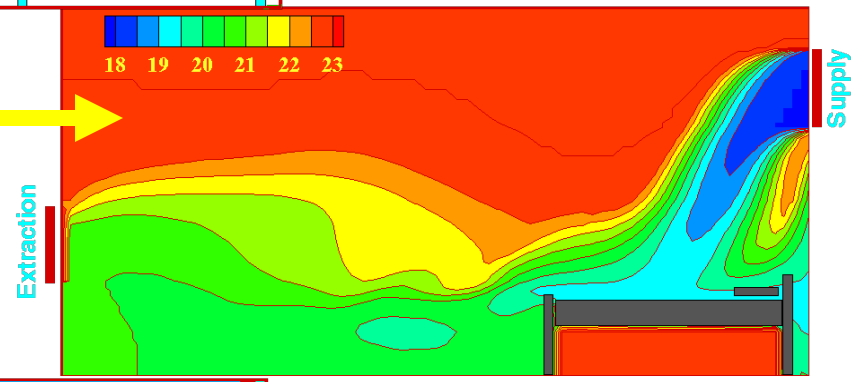
Theoretical Investigation Methods

In the isolation rooms for immunosuppressed patients, whose have high susceptibility to infection, the air should be their guard from the infection. The creation of air curtain near the immunosuppressed patient is recommended here to be an additional defense. The immunosuppressed patient's bed should be located in the side of supplied air, or closing to the supply outlets.

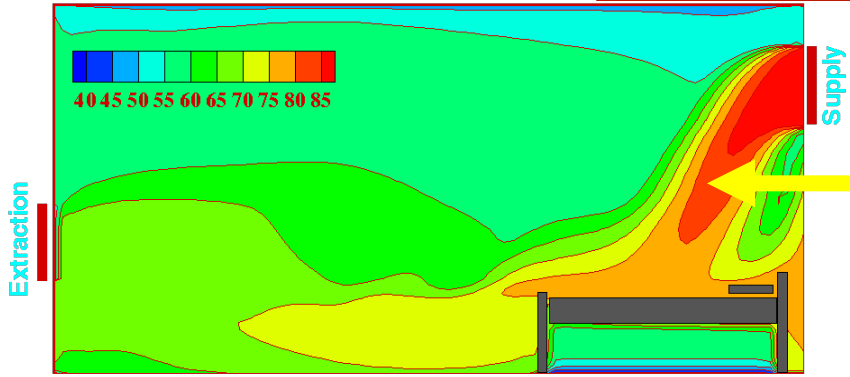
Isolation Rooms for immunosuppressed Patients



Air Defense Streamlines



Hottest Region

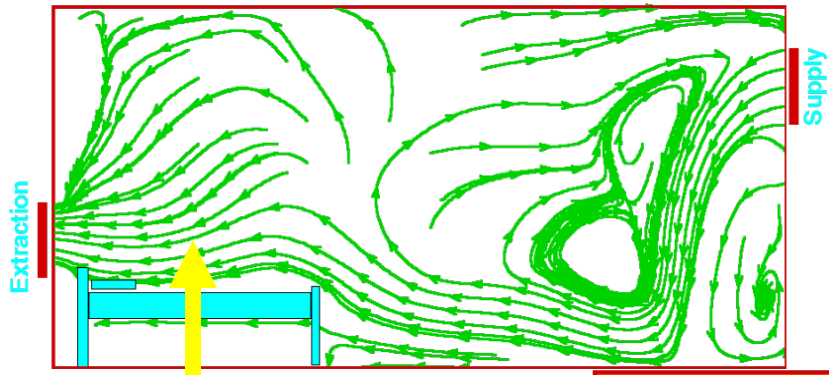


Humid Region

Theoretical Investigation Methods

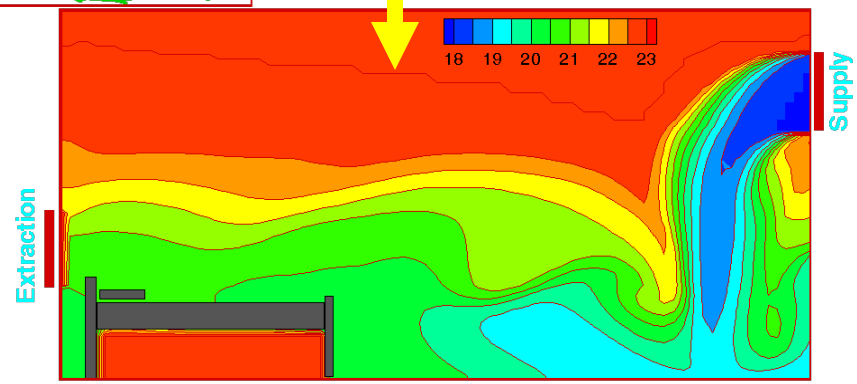
In the isolation rooms for infectious patients, the patient bed should be located closing to the extraction ports. The streams of the air will defend for the HCW and visitors and will extract the infected air from the room. The infectious isolation rooms should be maintained in negative pressure, and located closing to positive pressure areas even in the part load of these areas.

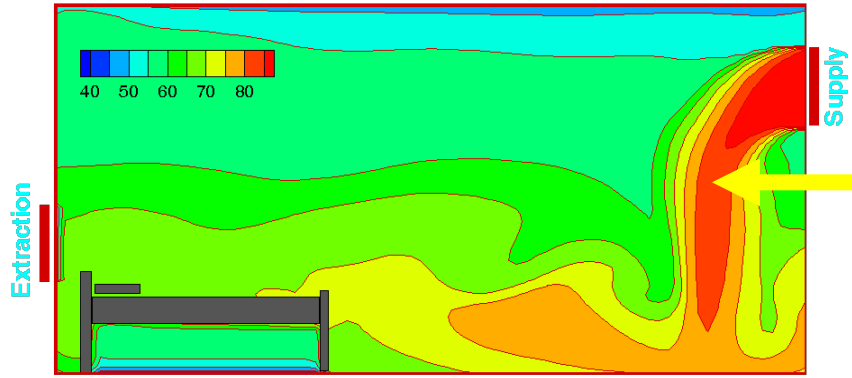
Isolation Rooms for Infectious Patients



Air Scavenging Streamlines

Hottest Region



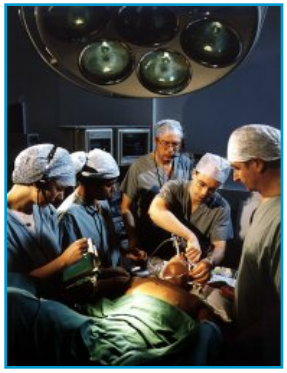


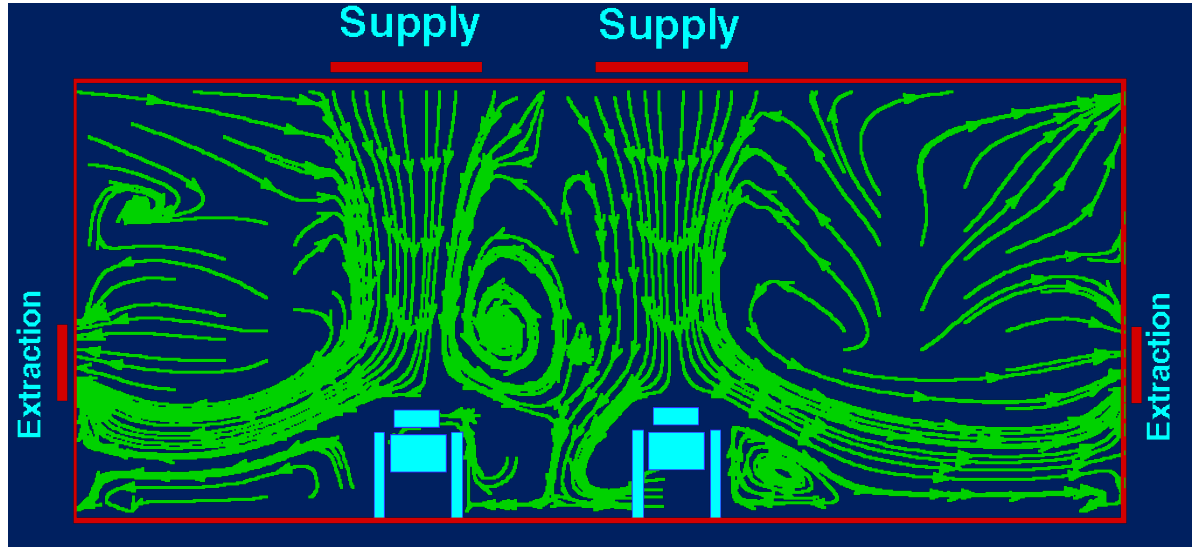
Humid Region

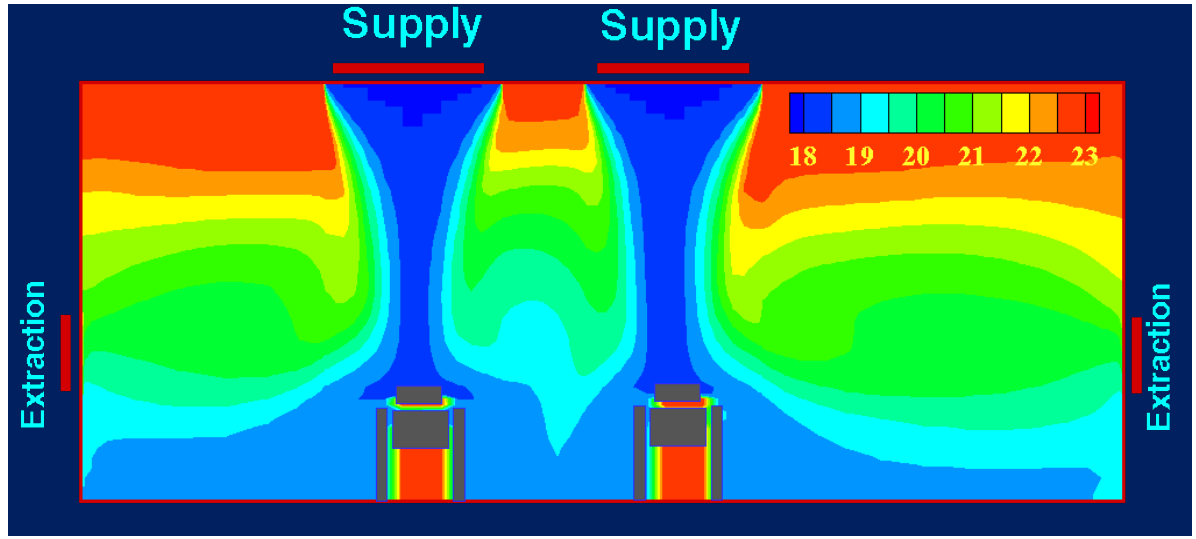
Theoretical Investigation Methods

Surgical Operating Theatres and ICU

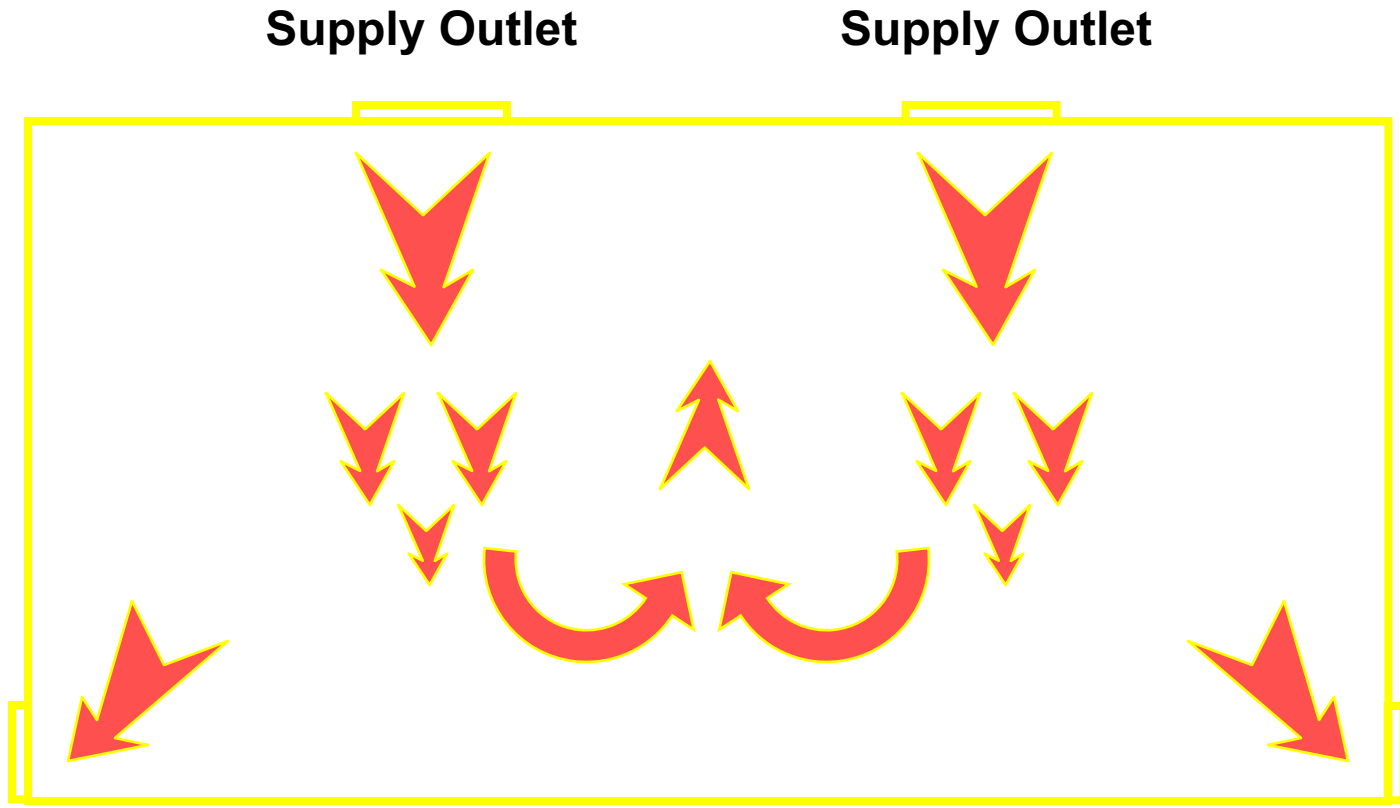
In the critical sections, the patient bed should be located in the influence area of the supply outlets and away from the extraction port locations. This type of critical rooms, which is served by the piston flow configuration, should be wide enough to aid the environmental engineer to implement the critical room by the right distribution of equipment and furniture. Actually the orientation of the bed and other equipment in the room have a great influence on the airflow distribution efficiency.







Problem Under Investigation

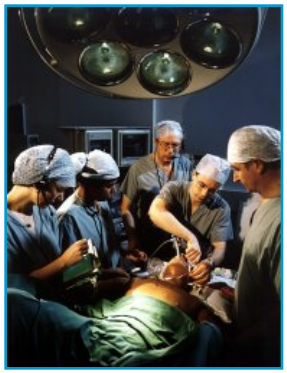


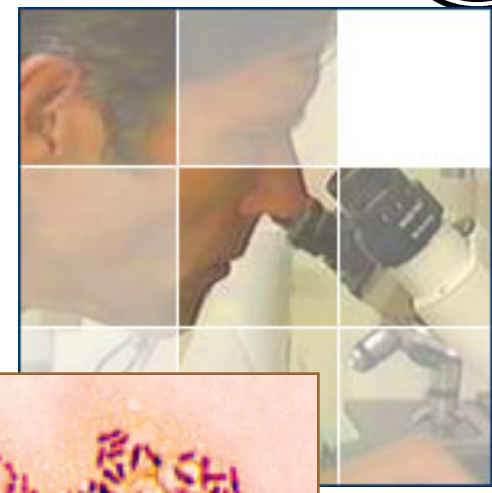
Environmental Contamination Infection

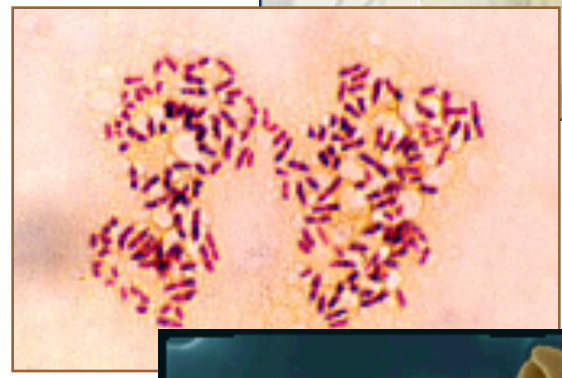
The following section deals with the various types of pollutants, and their potential sources. Contaminants can be classified in four broad headings, each of which represents a wide variety of pollutants:

* Organic Compounds;
* Inorganic Compounds;
* Particulate Matter; and
* Biological Contaminants.

It must be understood that these classifications are intended to facilitate the categorization of contaminants. Although the pollutants are classified into these categories, certain contaminants may belong to two or more classifications, depending upon their nature, Lee 1996. The most dangerous bacteria that may be transmitted as infective aerosols are Staphylococcus aureus and Mycobacterium tuberculosis. Staphylococcal infections have occurred especially in nurseries and operating rooms.

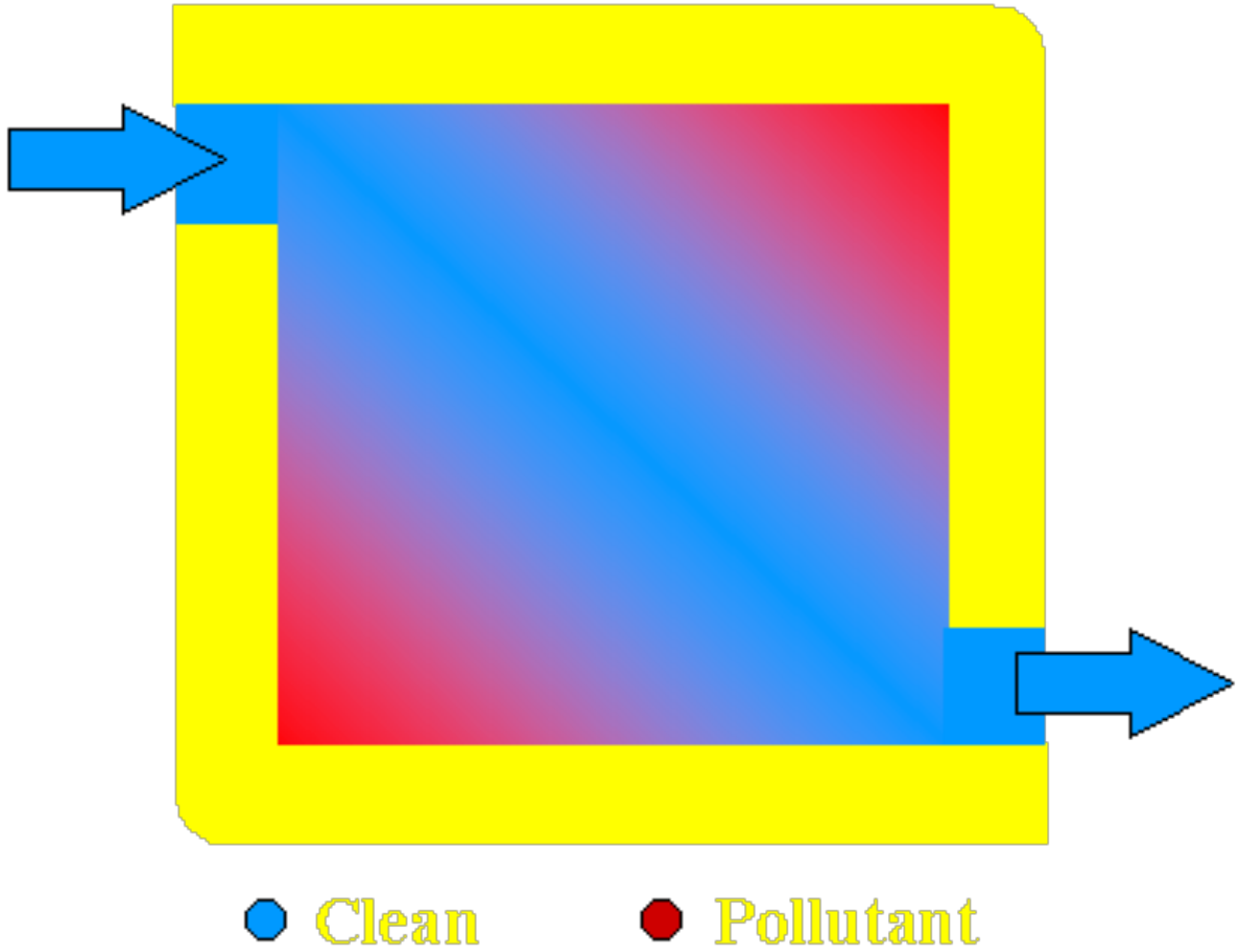






Indoor Air Quality and Airflow Pattern

To be able to formulate an analytical or even empirical expression relating the contaminant removal efficiency to the existing airflow pattern and contaminant emission pattern, a relation between contamination and airflow should be established. It is assumed that any contaminant, after it is either emitted inside the room or added to the room with the supply air, is perfectly passive, which means that these contaminants flow exactly like air. In practice, this assumption is not always valid. For example, relatively large dust particles will be influenced by gravity, and another example is the heavy gases. This sort of contaminant can not be considered as passive in this respect.



Indoor Air Quality versus Airflow Pattern

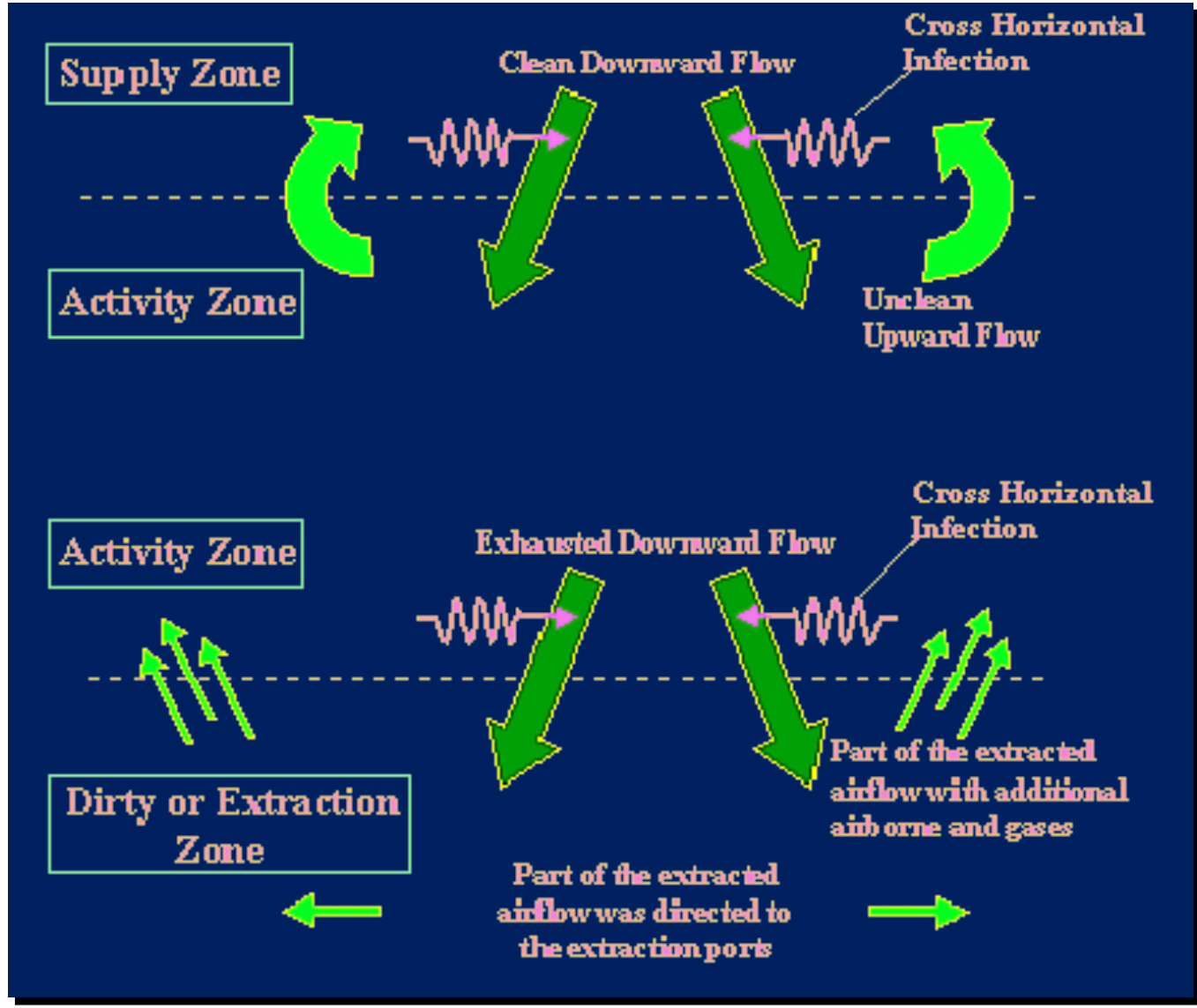
Hospitals and other healthcare facilities are complex environments that require ventilation for comfort and to control hazardous emissions. Indoor air quality is more critical in health care facilities due to many dangerous microbial and chemical agents present and the increased susceptibility of the patients. To build ventilation system that is capable of efficiently fulfilling all requirements, often even contradictory, is a great challenge. In addition, the importance of good indoor climate is not yet unanimously recognized. In addition, indoor climate fails often to be comfortable.

From previous concluding results, the designers of HVAC systems should consider the importance of the air distribution; the positioning of operating furniture and the using of partial walls may be useful to maintain the air environment in the surgical operating theatres.

To achieve and maintain good Indoor Air Quality (IAQ) conditions, it is necessary to remove or dilute airborne contamination in the enclosed space. Ventilation air distribution pattern has a great effect on the IAQ in enclosed spaces especially healthcare applications. The primary tasks of ventilation system are to remove the contaminated air from the room and to supply the occupied region of the room with clean air, Etheridge et al. 1996.

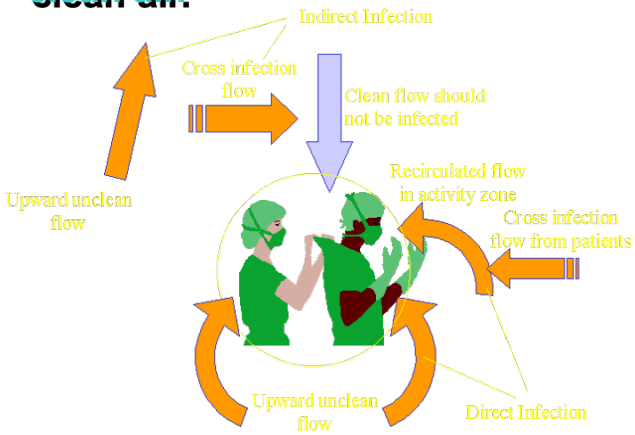
Actual Room Designs

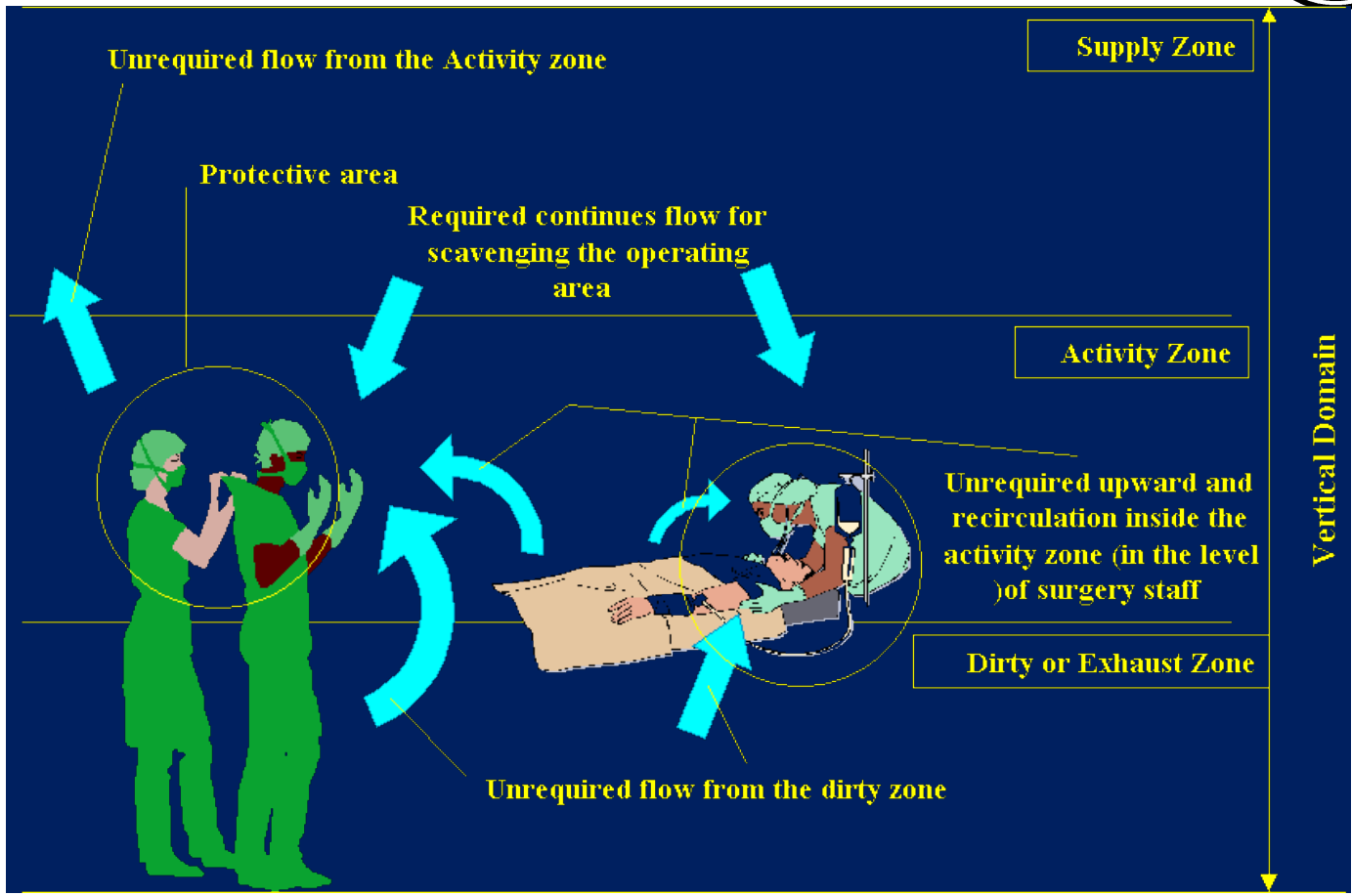
The airflow has a great influence on the aseptic environment of the activity zone. Need for a criterion capable of yielding the air distribution effectiveness in the activity zone for different design, is urgently required to assist the designers to construct the optimum HVAC design for the given architecture design. This index should account for the influence of the presence of the horizontal and vertical flow in the activity zone, and the influence of the flow that comes from the neighboring zones especially the exhaust zone. So the index will depend on the weighting of the flow direction to the ideal case that was presented in the present investigation.



Air Quality for Healthcare Users

Hypothetically, the protective areas are the areas that receive clean air only and scavenge all the pollutant air. Receiving any polluted air from any other zone or area (directly or indirectly) decreases the air quality level of the protective area. The direct way stems from the upward flow from the dirty zone to the activity zone. The indirect way arises from receiving polluted air from the clean zones, which should supply the protective areas by the clean air.

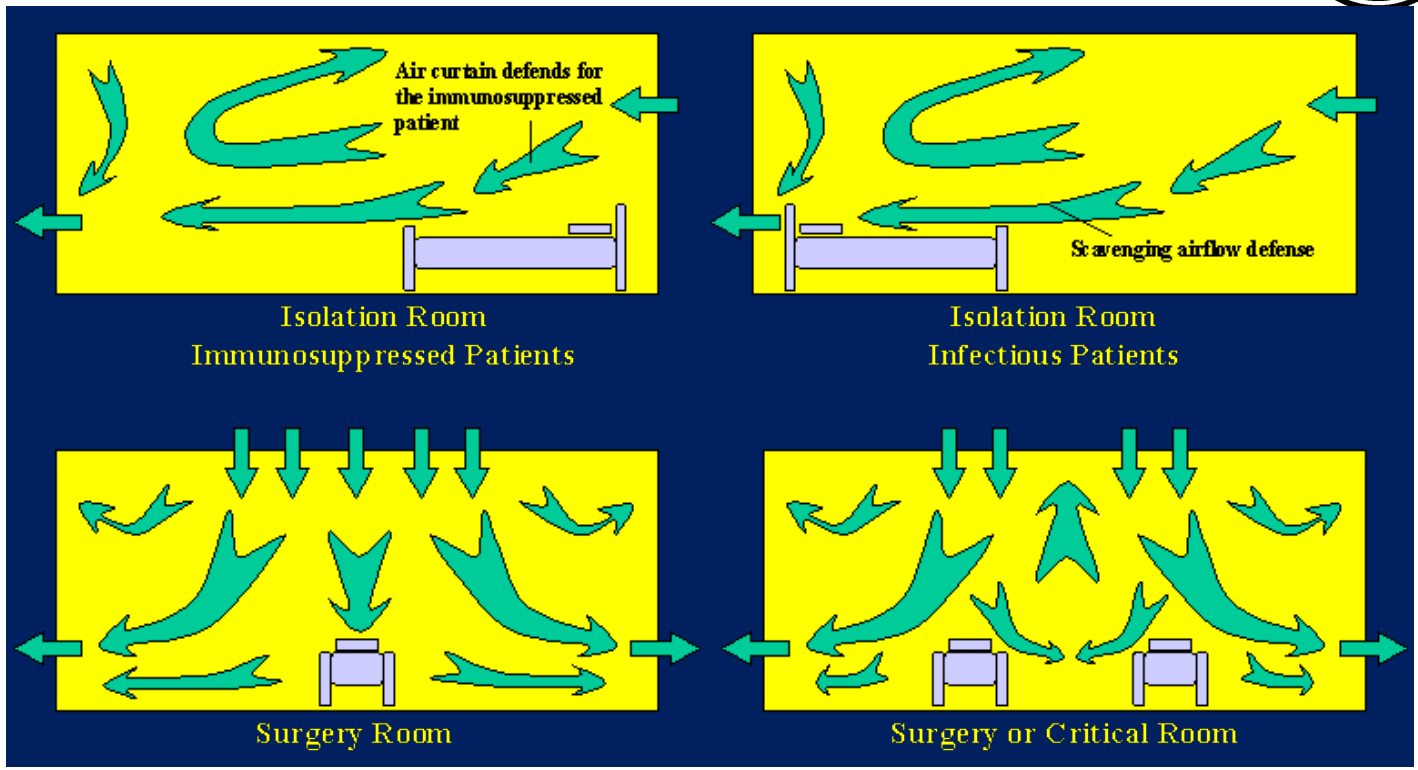




The first rule that should be followed is creating a protective area around the patients and surgery team or at least at the respiration level of persons. The whole domain can be divided to three main zones, namely; supply zone, activity zone, and dirty or exhaust zone. Only the complete "piston effect" flow can prevent the backward or the reverse interaction from the pollutant zones to less pollutant or clean zones (Kameel, 2002).

Airflow Pattern

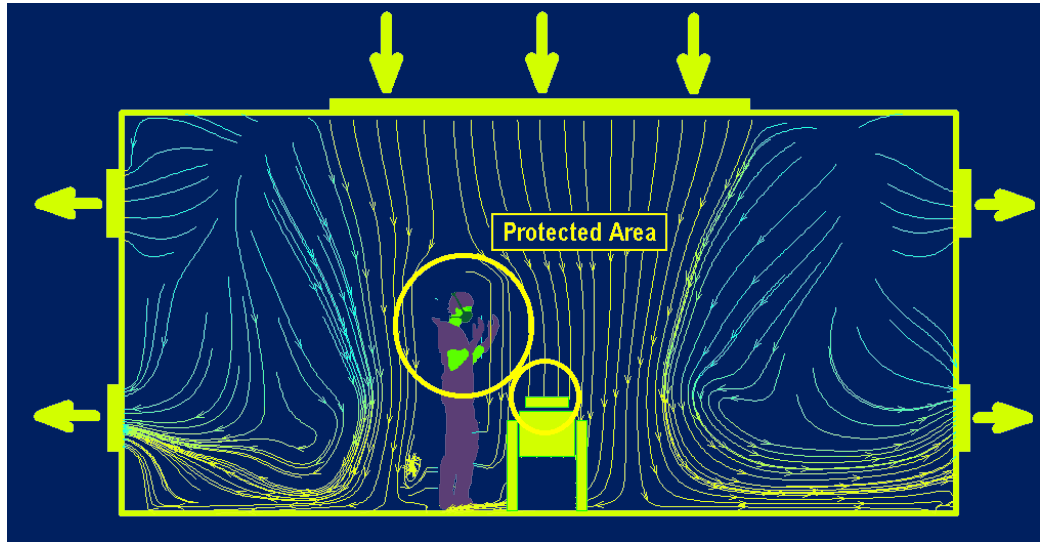
This location in most cases participates in the healing of the patient, and reduces risks of infection from the patients to the HealthCare Workers (HCW) and visitors or from others to the patients. Indeed, this location varies according to the facility function and to the patient case.



In the isolation rooms for infectious patients, the patient bed should be located closing to the extraction ports. In the isolation rooms for immunosuppressed patients, whose have high susceptibility to infection, the air should be their guard from the infection. The creation of air curtain near the immunosuppressed patient is recommended here to be an additional defense. In the critical sections, such as the surgery rooms, the surgery bed should be located in the influence area of the supply outlets and away from the extraction port locations.

Protection of Healthcare Rooms Users

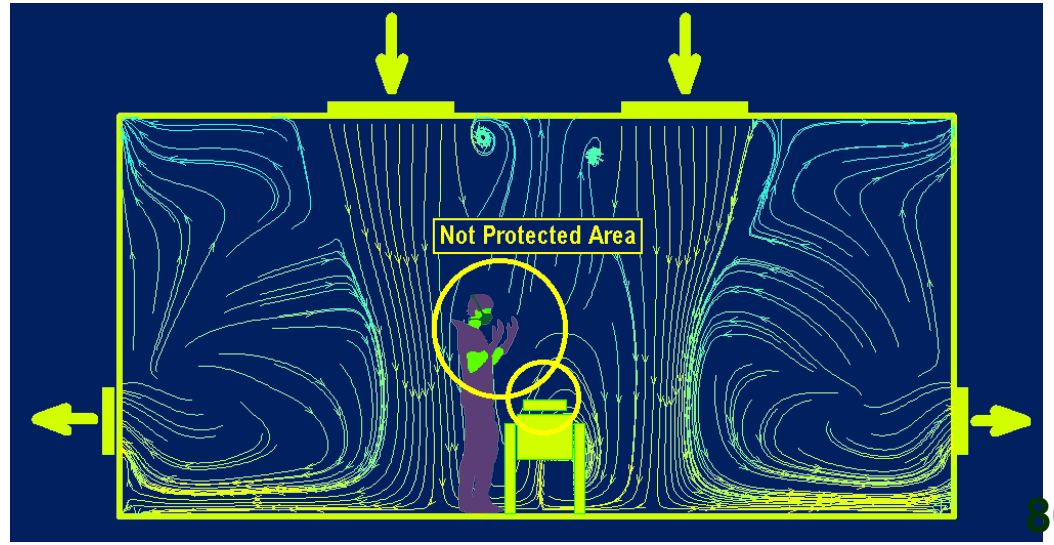
The present work made use of the computer program 3DHVAC (Kameel, 2002), (Kameel and Khalil 2003). The program solves the differential equations governing the transport of mass, three momentum components, energy, relative humidity, and air contaminant local-mean-age in three-dimensional configurations.



This design provide optimum protection to the Healthcare Staff and patients with lower energy saving.

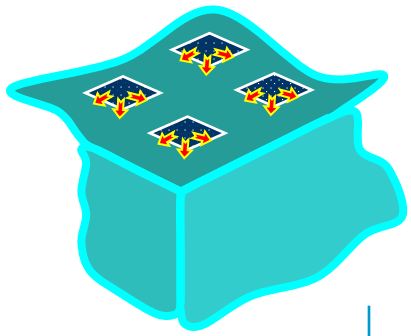
In the present study, the HVAC airside analysis is based on the analysis of the streamline pattern of the flow and the ratio of the circulation zones' volume to the space volume with the aid of integrated Neural Network program (Kameel, 2002). A sample of the results of such analysis is shown here.

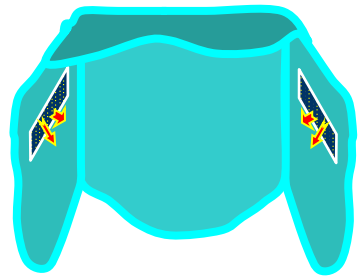
This design provide optimum energy saving with lower protection to the Healthcare Staff and patients.

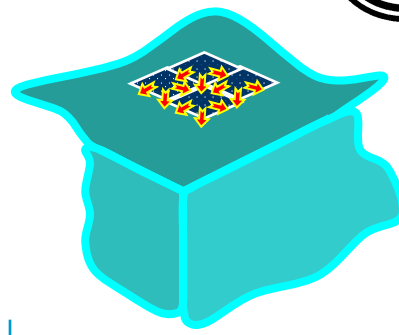


Airside Design (Alternatives)

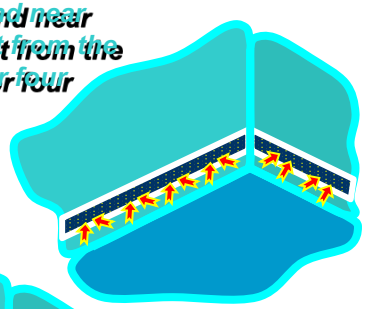
This table represents different types of these trials. This Table introduces an analysis for each design.



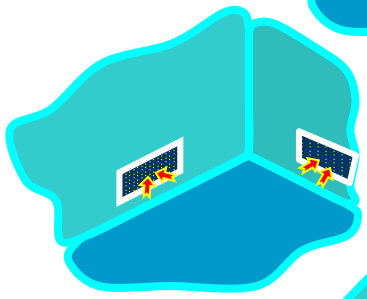




One level and near floor extract from the four walls or four corners.



One level and near floor extract from the two opposite walls.



Two levels extract from two opposite walls.

The presence of the upward airflow in the operating area does not provide optimum protection to the patients or the surgery team. The strength of the side recirculation zones near to the walls and ceiling are increased due to the exclusion of the upper extract ports.

The horizontal cross flow is not recommended even with all types of extracts, due to the strong horizontal jet flow interactions and consequent effects on the airflow pattern and turbulence in the operating area and the activity zone, which enhances the infection. The infection possibility is increased with this type of supply air arrangements. This type also is not energy efficient due to the presence of air short circuits between the supply and the extraction due the nearing of the outlets and inlets

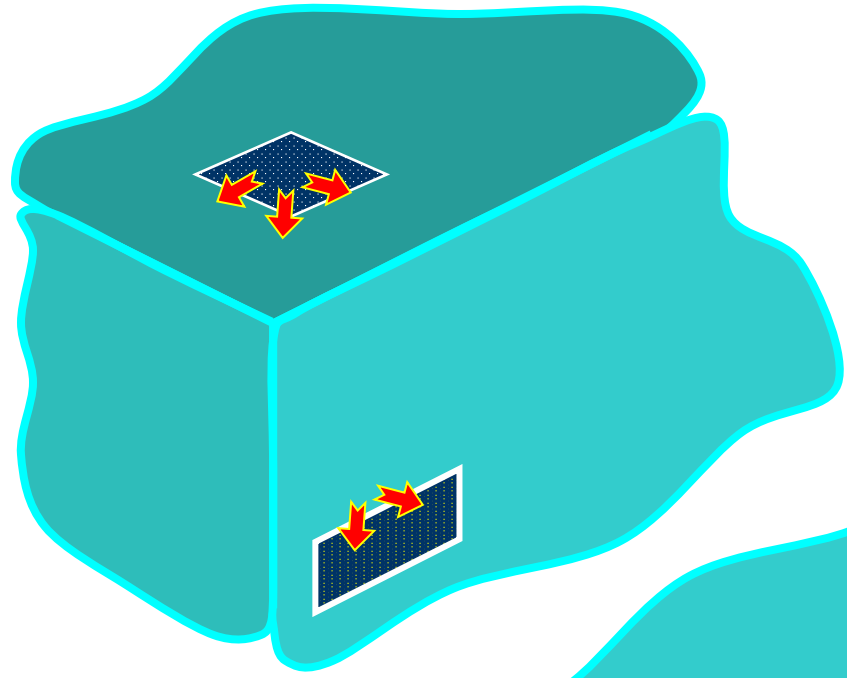
This design results in increasing strength of the recirculation zones near to the walls and ceiling. But provides a complete protection of the operating area. Using the partial wall is highly recommended.

This design is not recommended due to the presence of large areas of recirculation zones.

Airside Design (Real Example)

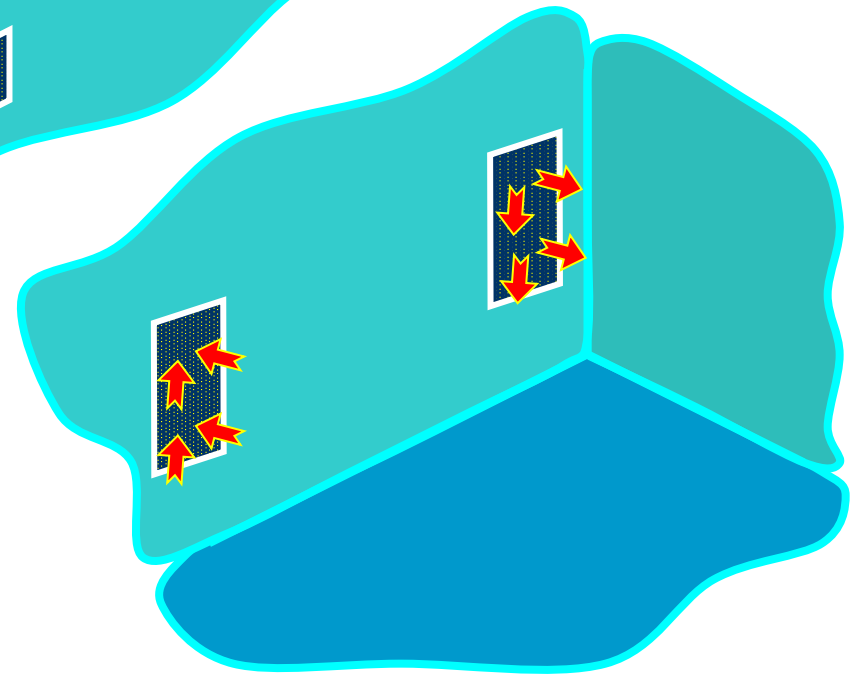
New Kasr El-Aini Teaching Hospital

Some of these solutions are already existed in the real practice.

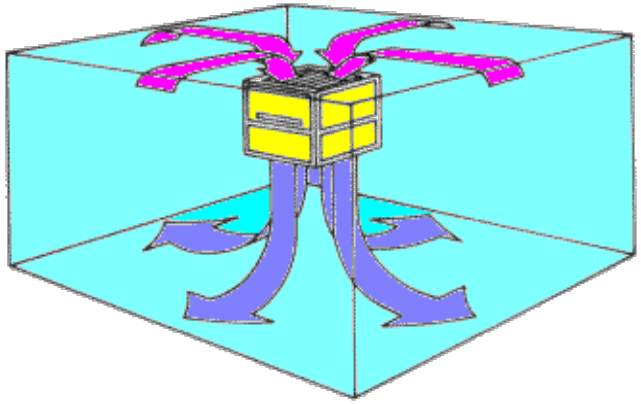


These design don't provide the optimum airflow distribution, and cause very large recirculating areas in the room.

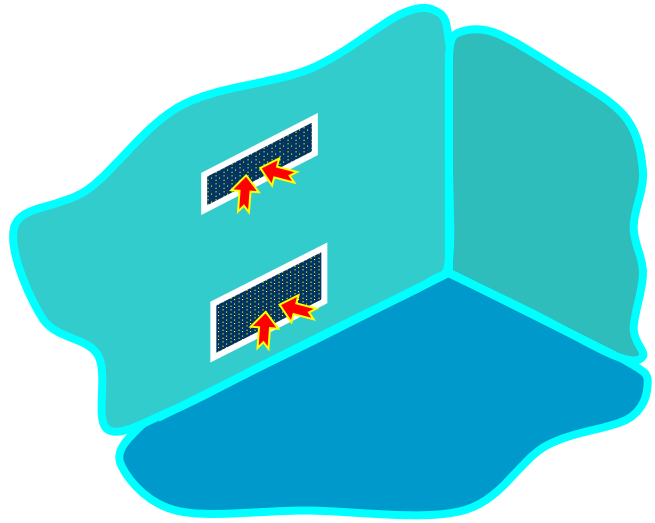
Also, these design don't provide the optimum utilization of the input energy in the cooled air. Most of the supplied cooled air is wasted by the short circuit of the flow.

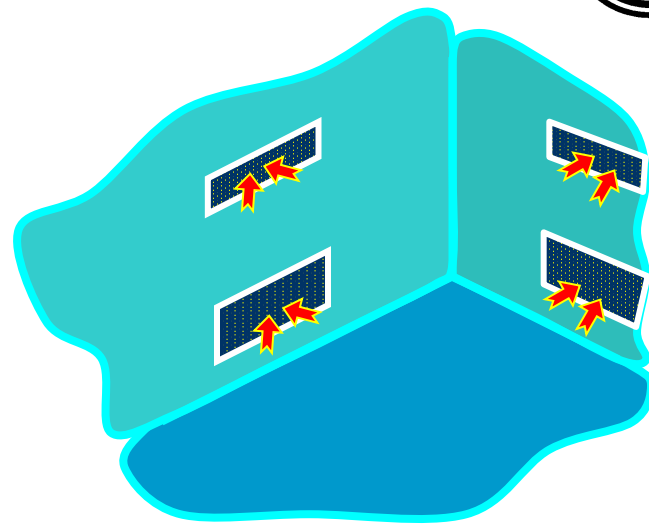


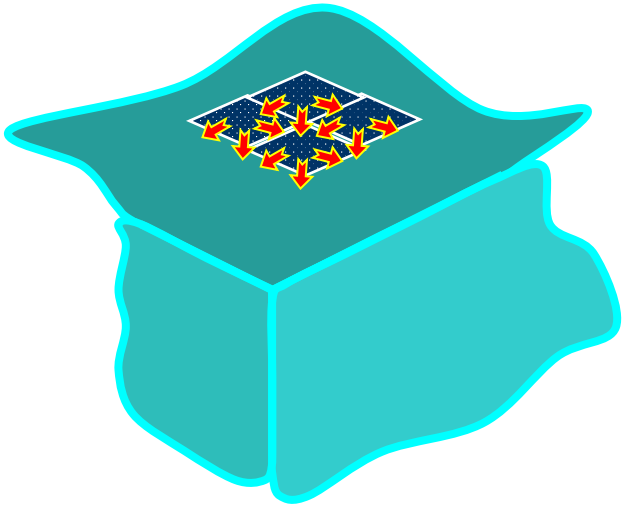
Airside Design (Optimum for SOT)



In general, outlets supplying air to sensitive ultraclean areas should be located on the ceiling, and perimeter or several exhaust outlets should be near the floor.







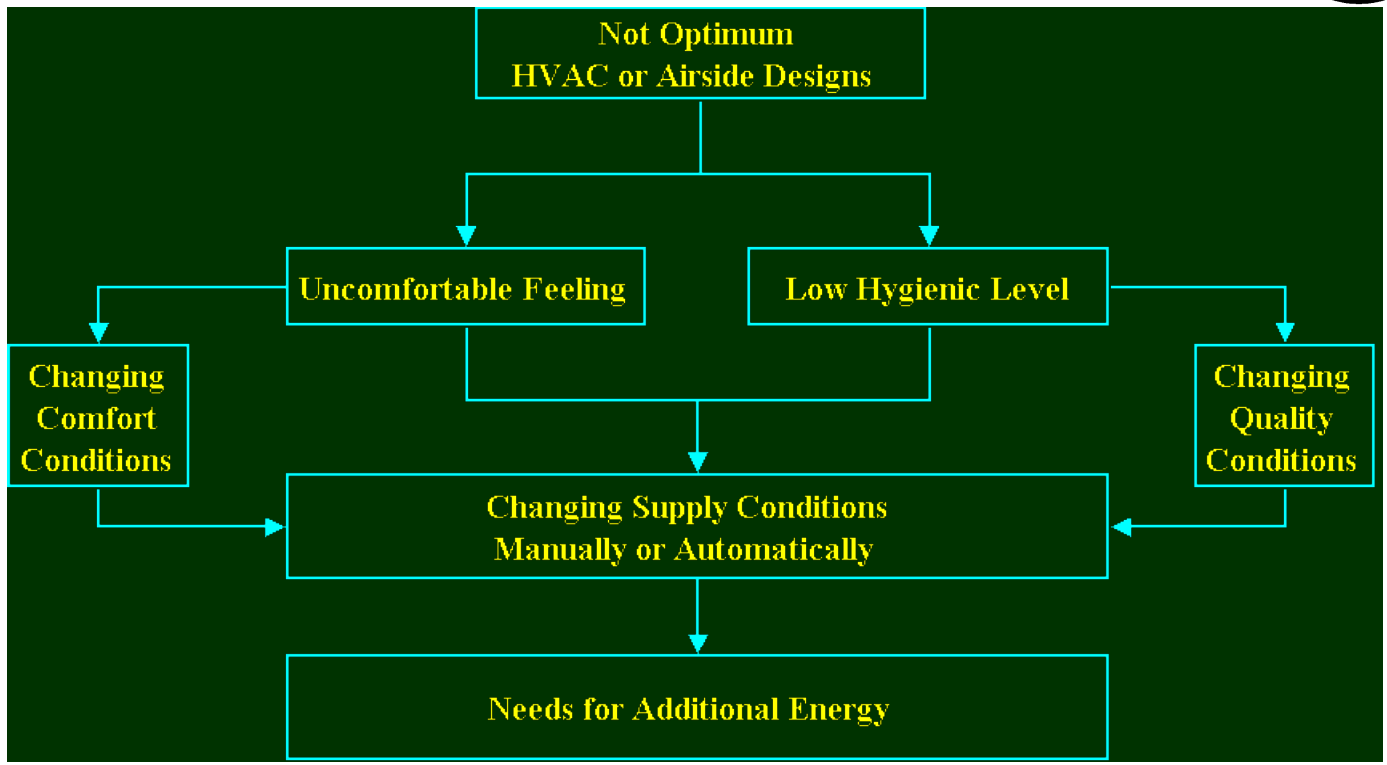
This analysis of airside designs, energy efficiency, and Indoor Air Quality (IAQ) performance indicated the necessity of careful selection of the optimum locations of the supply outlets and extraction ports.

This design is recommended. The extract ports can be located on the wider opposite walls to enhance the design efficacy.

This design is highly recommended to provide a complete clean environment with fewer areas of the recirculation.

Supply Conditions

It was found the strong dependence relation between the correct supplying conditions and comfort. Actually, The dependence on supply conditions only to save the energy is not valuable. This trend leads the researches to unrealistic results. One should investigate the roots of the energy-wasting problem in the air-conditioned spaces due to the HVAC systems. Indeed, the optimum airside configuration design can save the energy directly.

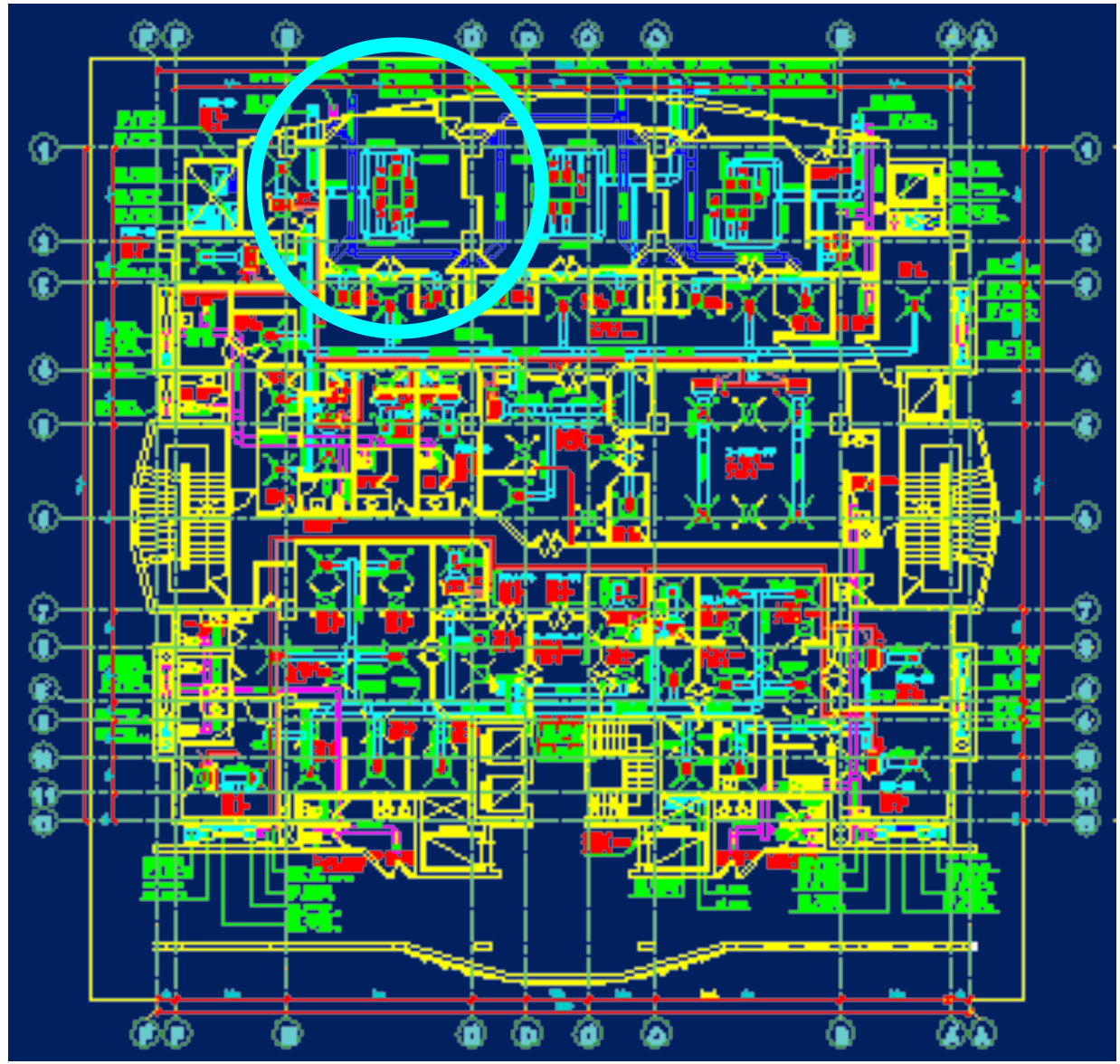


Incorrect Supply Conditions are a reason for energy waste
Incorrect HVAC Airside Design participates in energy losses

El-Rahmma Hospital – Second Floor

Real Applications

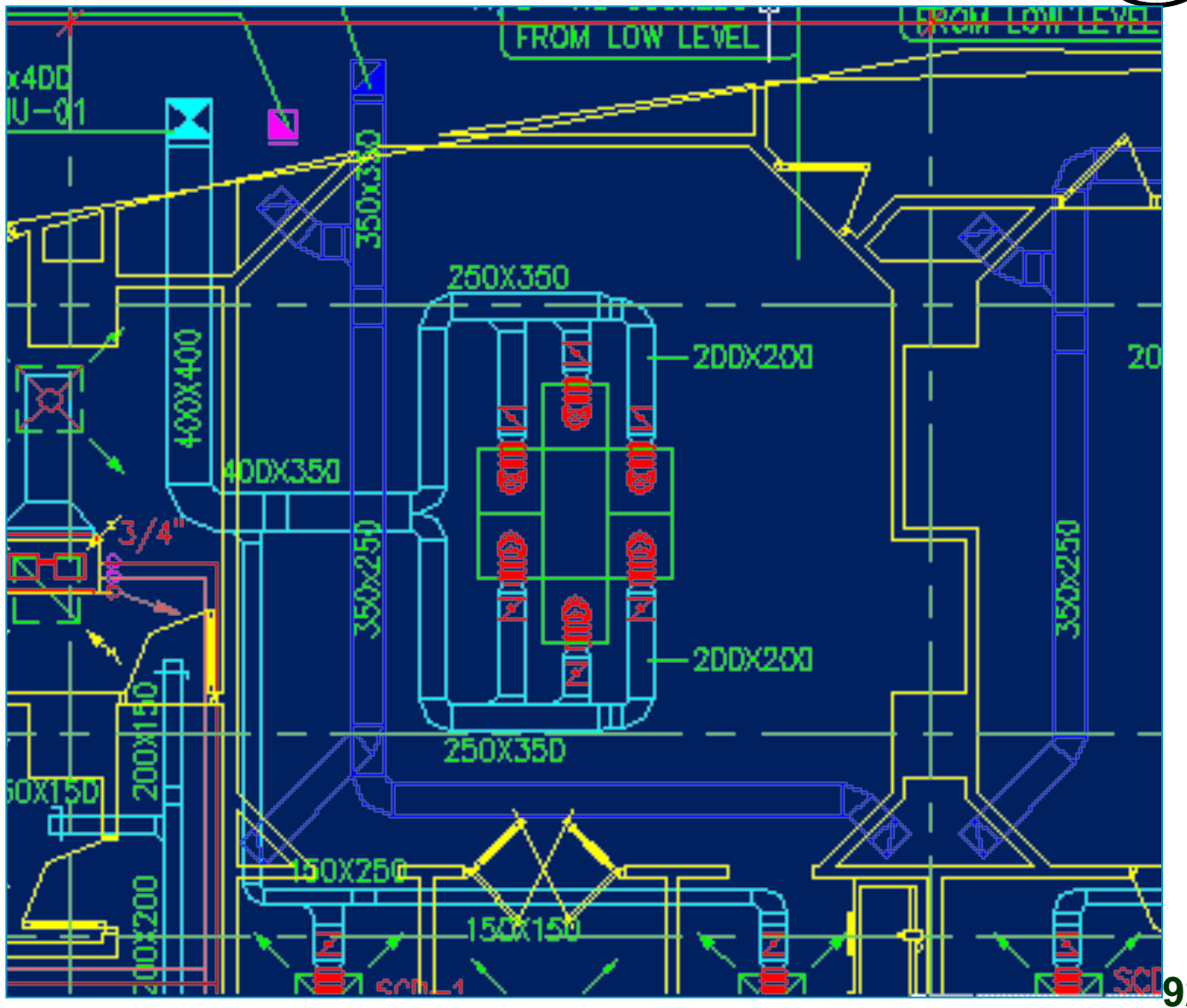
CONSULTING ENGINEERING BUREAU
CEB
Prof. Dr. E. E. KHALIL



El-Rahmma Hospital – Surgical Operating Theatre

Real Applications

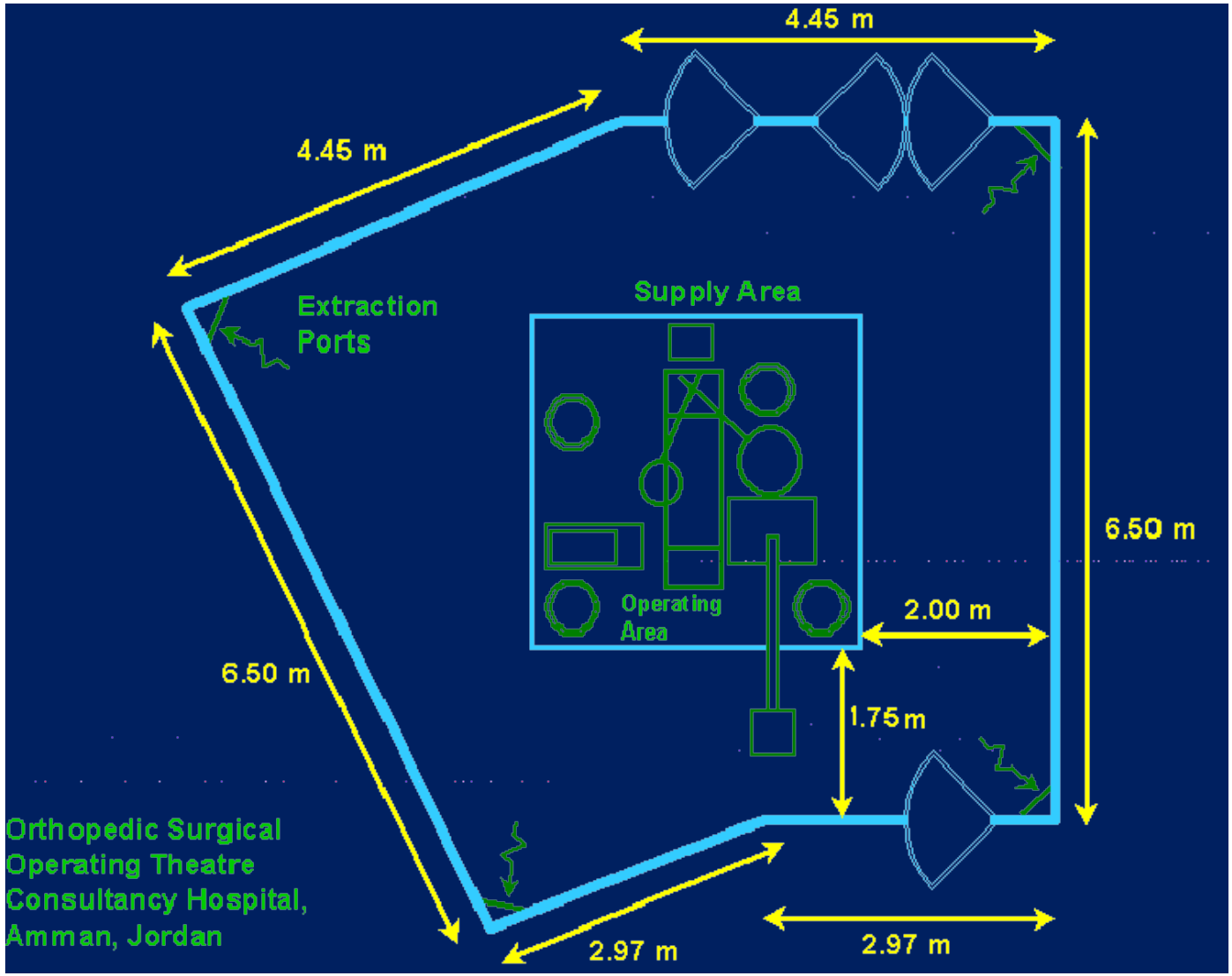
Prof. Dr. E. E. KHALIL



Consultant Hospital – Amman, Jordan

Real Applications

Prof. Dr. E. E. KHALIL

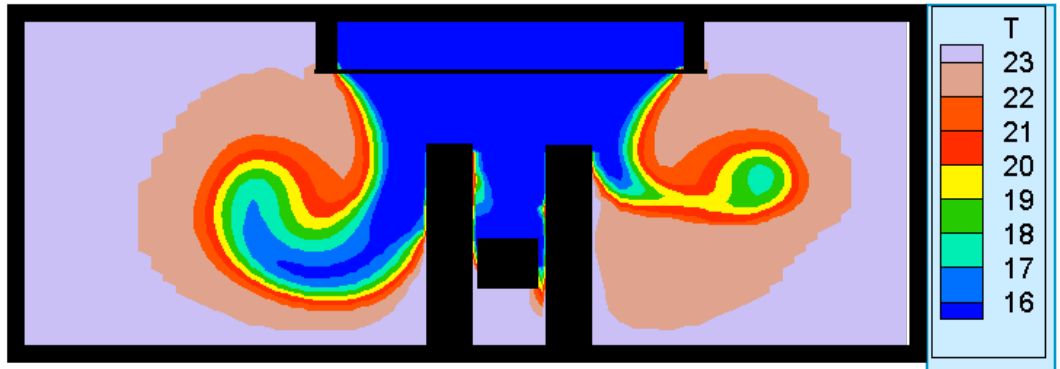


Consultant Hospital – Amman, Jordan

Real Applications

Prof. Dr. E. E. KHALIL

10 Seconds



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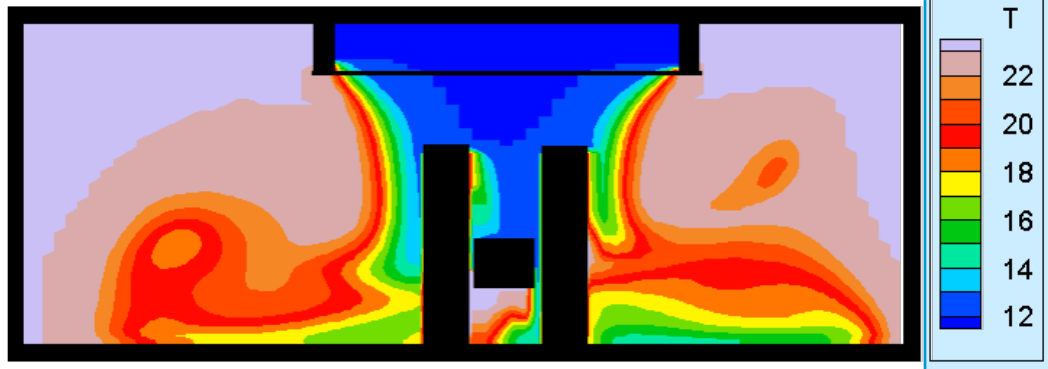

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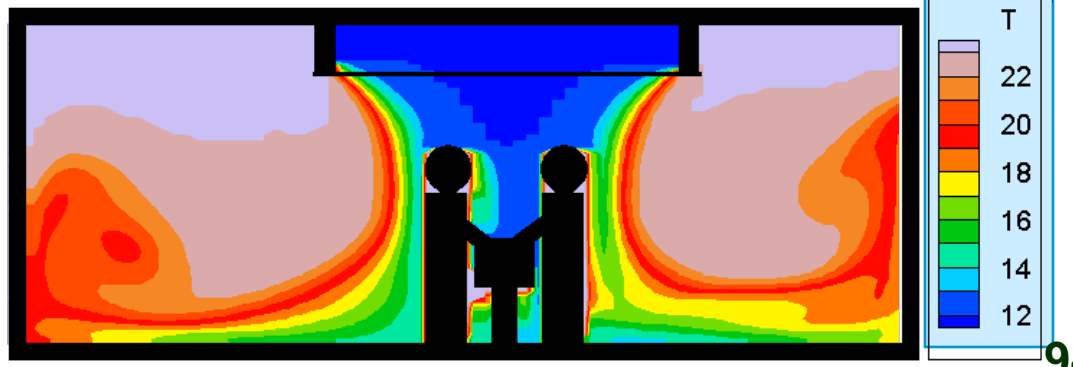
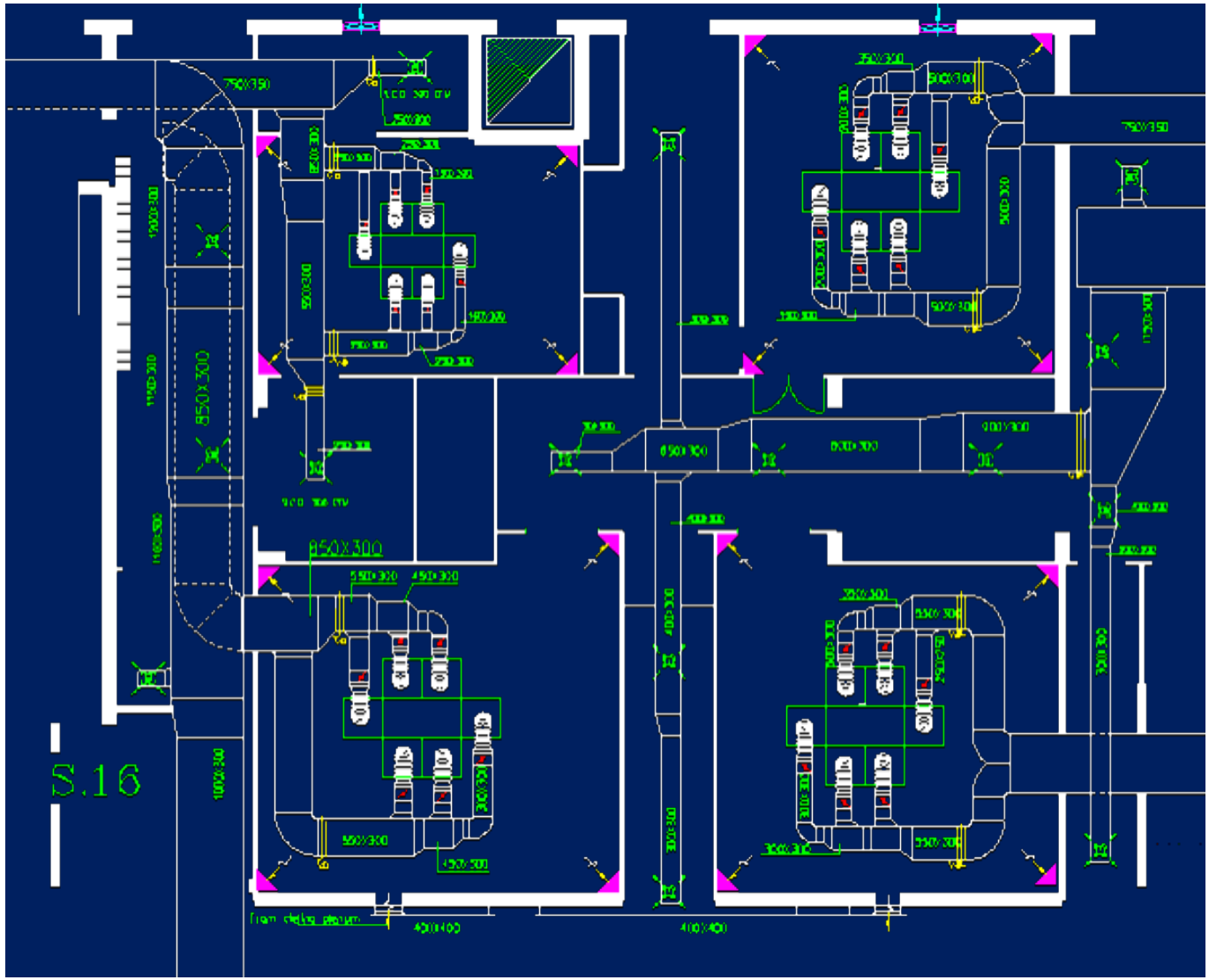


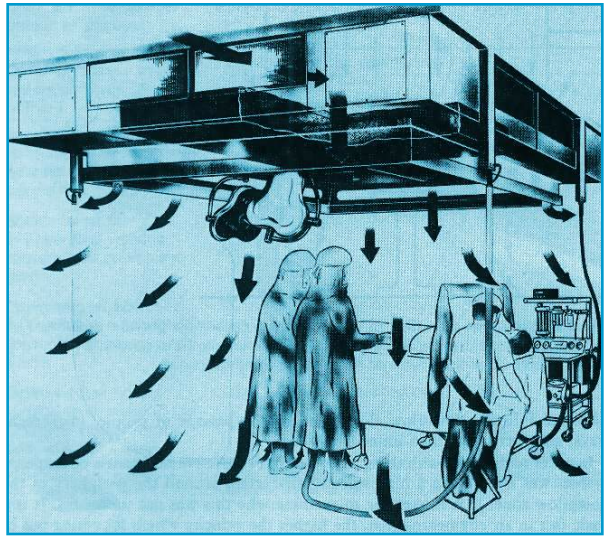
Suez Canal Hospital – Operating Wing

Real Applications

Prof. Dr. E. E. KHALIL



Recommendations

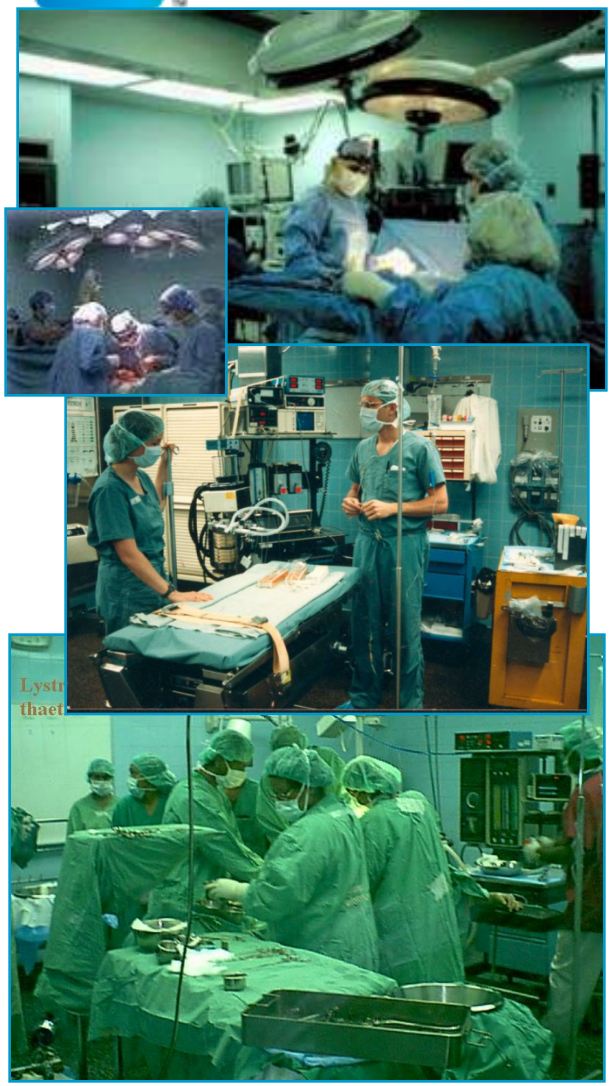


The air is not a medium only but it is a guard in the critical applications. The airflow can be used as an engineering tool to provide “free contaminant” area. The proper direction of the airflow increases the possibilities of pollutant scavenging from the healthcare applications.

The proper airflow direction starts from the optimum design of the HVAC airside system and the optimum election of the supply outlets and extraction ports. The present work introduced a preliminary trail to find the optimum HVAC airside design in the healthcare facilities. The numerical tool, that used here, was found so effective to predict the airflow pattern in the healthcare facilities with reasonable cost. So it is recommended to use the CFD utilities as a preliminary tool to explore the optimum HVAC airside design.

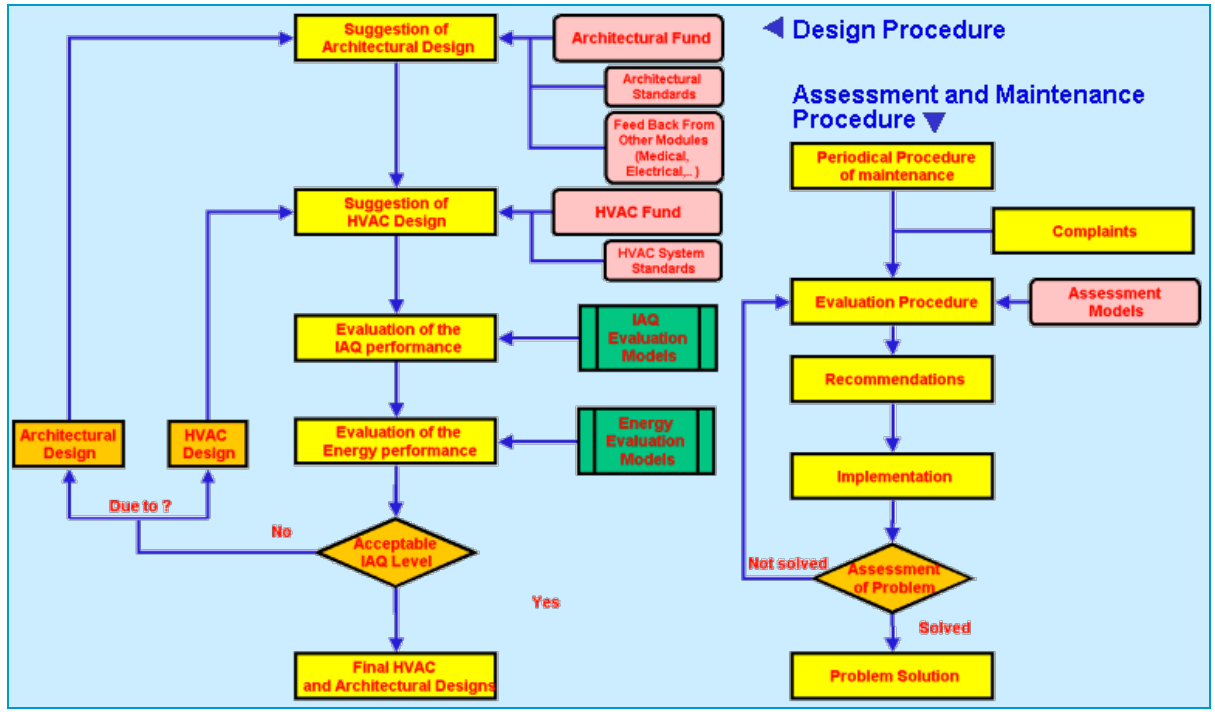
Indeed, the optimum HVAC airside design starts from the architectural design of the healthcare facilities. The good architectural design allows the HVAC designers to locate the supply outlets and extraction ports in the optimum location. So the HVAC airside design should be started from the planning phase of the hospital.

Recommendations



The critical areas should be located in separate sections or divisions. Indeed, in the large hospitals, it is preferable to locate the critical areas in separate floors. Especially the surgical operating rooms should be located in separate suite.

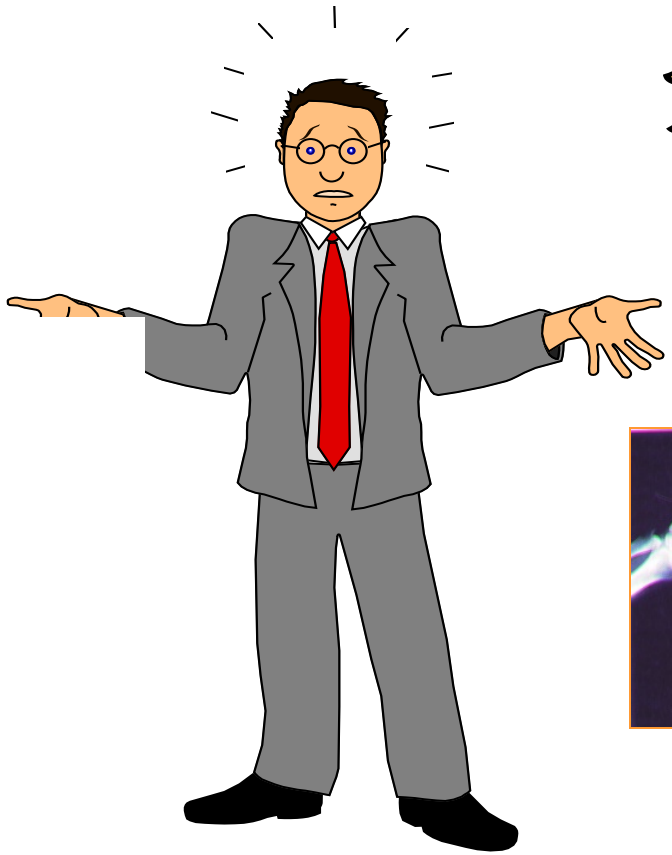
For the already existing designs with poor airflow distribution, the environmental engineer in the hospitals can improve the airflow pattern by redistributing the medical equipment and furniture in the proper location.

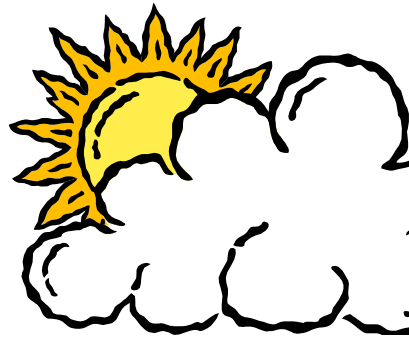


Acknowledgement

- We would like to acknowledge the technical support of CUFE, Kasr Al Aini Teaching Hospitals and IIR and ISO TC205 Commissions.
- Thanks are also due to my research group and students for their valuable inputs

I REST MY CASE YOUR HONOURS

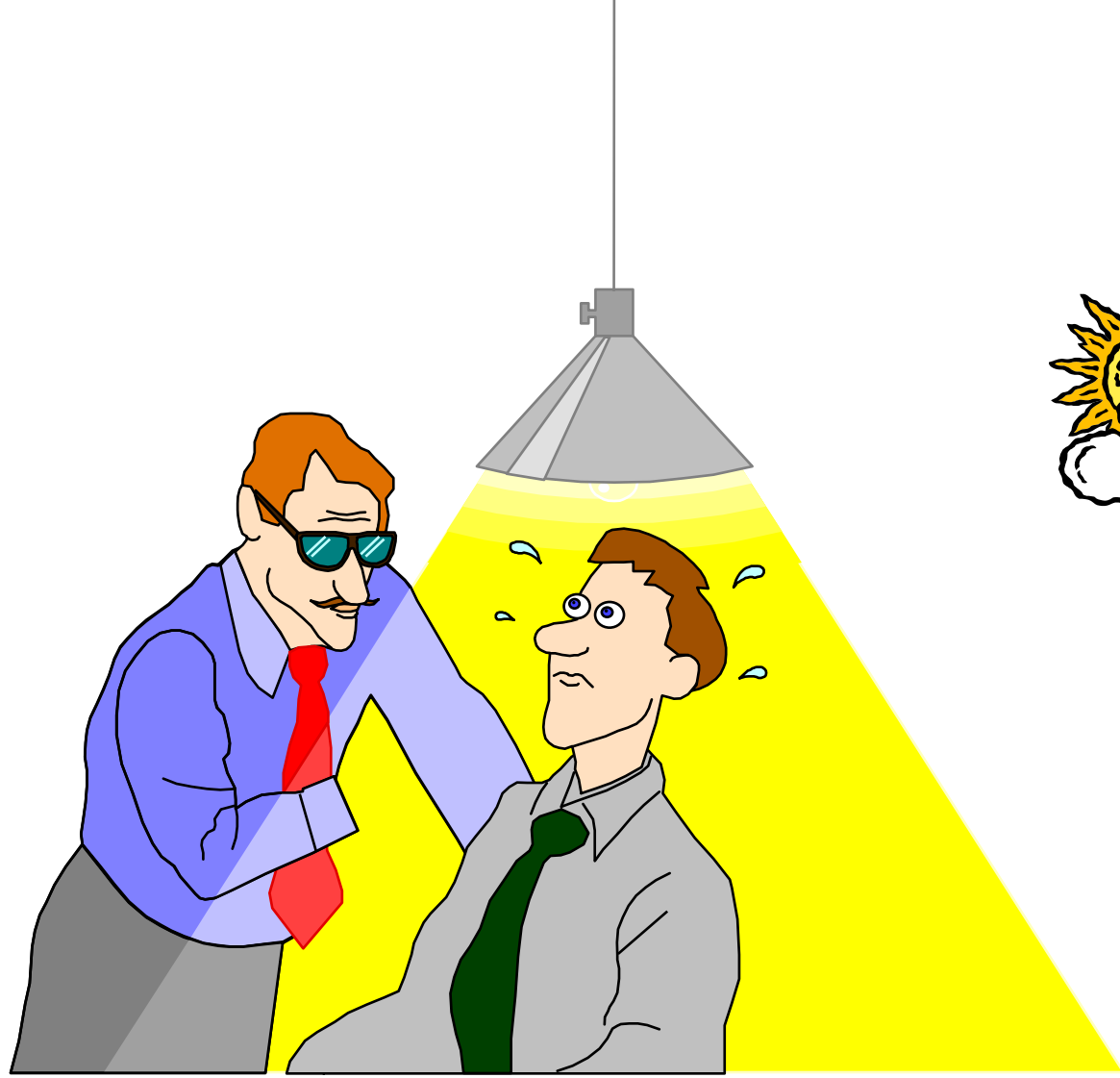




The End

Thank You

It is very gratifying to find some one that silently appreciates your efforts



Yes ……. I have two hands