Heating, Ventilation & Air-Conditioning in Hospitals

Part 4 (Room Design)

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Room Design (General)

- Room design
  - Many spaces in hospitals have special requirements of ventilation
  - This requirement arises from
    - Infection control
    - High internal load
    - Special equipment
    - Unique processes, and
    - Unique patient
  - Air changes, pressurisation, outdoor air, relative humidity etc. for these spaces have been provided in ASHRAE standard 170 (Table 7.1)

Room Design

- Room Pressurisation
  - Many spaces in hospitals require maintenance of a differential pressure relative to adjacent spaces
    - Operating rooms, Protective Environment room rooms, CSSD (except decontamination and cleaning room) need positive pressure
    - Airborne infection isolation room, soiled storage, toilet, bronchoscopy, sputum collection room, laboratory fume hoods, biosafety cabinets, PET and nuclear medicine, chemotherapy preparation rooms need negative pressure

Room Design

- Pressurisation causes unidirectional airflow
- But this designed airflow may be disturbed due to various reasons
  - One such factor is opening and closing of the room door
- Therefore, opening and closing of the pressurised rooms should be kept at a minimum
- An anteroom can reduce airborne contaminant concentration by containment and dilution of the migrating air
  - This can protect the adjacent corridor from excess airflow into or out of the isolation room

Room Design

- To maintain pressurisation, a tight envelop should be provided
  - Walls must extend from floor to structure
  - All openings (such as electrical and medical gas outlets) must be sealed
  - A specific differential must be maintained between supply and return/exhaust air
  - Airflow from one space to another occurs through cracks or gaps in walls, ceilings, floors, and around perimeter of the doors and windows

Room Design

- The sum of these areas of infiltration and exfiltration is called the leakage area
- This flow of air in or out of the space is a function of the leakage area and pressure differential across all surfaces of the room
- Isolation can only be maintained when airflow is unidirectional from all surfaces
- Airflow differential is a measurable quantity
- This differential should be maintained at a minimum of 0.01 inch of water relative to adjacent spaces
  - This is equal to 2.5 Pascal

Room Design

- Isolation Rooms
  - These rooms are generally classified into four types
    - Airborne infectious isolation (AII) rooms
      - These rooms are for patients having an airborne communicable disease
    - Protective environment (PE) rooms
      - These rooms are for patients having weak immune system
    - Combined AII/PE rooms
      - These rooms are for patients who are suffering simultaneously from both weakened immune system as well as airborne communicable disease

Room Design

- Contact isolation room
  - These rooms are for patients who are suffering from a communicable disease but is not airborne
- All these rooms have specific design features
  - All Rooms
    - In these rooms, airborne pathogens are contained, diluted and exhausted outside
    - There are two major design issues for these rooms

Room Design (All)

- These criteria are
  1. Negative air pressure relative to all adjoining space
  2. An air distribution pattern within the room designed to reduce airborne infection
- An anteroom is not mandatory
  - An anteroom is advantageous and highly recommended
  - This helps in maintaining pressurisation, air distribution pattern and minimise transfer of air with the corridor
  - Within the isolation room itself, the air distribution should be so designed as to minimise exposure to health workers and other non-infected people

Room Design (AII)

- An AII room with 12 ACH shall have airborne particles moving around for five minutes before exiting
- The preferred design approach tries to achieve effective air-mixing and dilution ventilation
- Room air distribution helps in providing thermal comfort and ventilation for space occupants and processes.
    - Besides air terminals, terminal units, fan-coil units, local ducts, and rooms themselves may affect room air diffusion,

Room Design (All)

- Staff protection is afforded by minimising the concentration of airborne microorganisms
- Ventilation effectiveness is maximised by Type A ceiling mounted, horizontal throw diffusers with
  - The maximum throw reaching the far wall, and
  - Ceiling mounted exhaust registers

Room Design (All)

- The exhaust register, if located over patients bed, can increase the systems overall efficacy
  - As it is located in the path of the patients cough-induced plume
- Location of the placement of diffuser and its throw are important
  - The location should not be such that the high velocity throw reaches the doorway and through to the anteroom or corridor
  - This will potentially counteract the desired air transfer pattern
- Enough conditioned air needs to be provided to satisfy the cooling load

Room Design (All)

- For room supply airflow, the major factors are
  - Total room supply airflow quantity
  - Room supply air temperature
  - Diffuser type
  - Diffuser throw height (or outlet velocity);
    - This is associated with the amount of mixing provided by a floor diffuser (or room conditions near a low-sidewall TDV diffuser)

Room Design (All)

- For room heat loads, the major factors are
  - Magnitude and number of loads in space
  - Load type (point or distributed source)
  - Elevation of load (e.g., overhead lighting, person standing on floor, floor-to-ceiling glazing)
  - Radiative/convective split
  - Whether pollutants are associated with heat sources

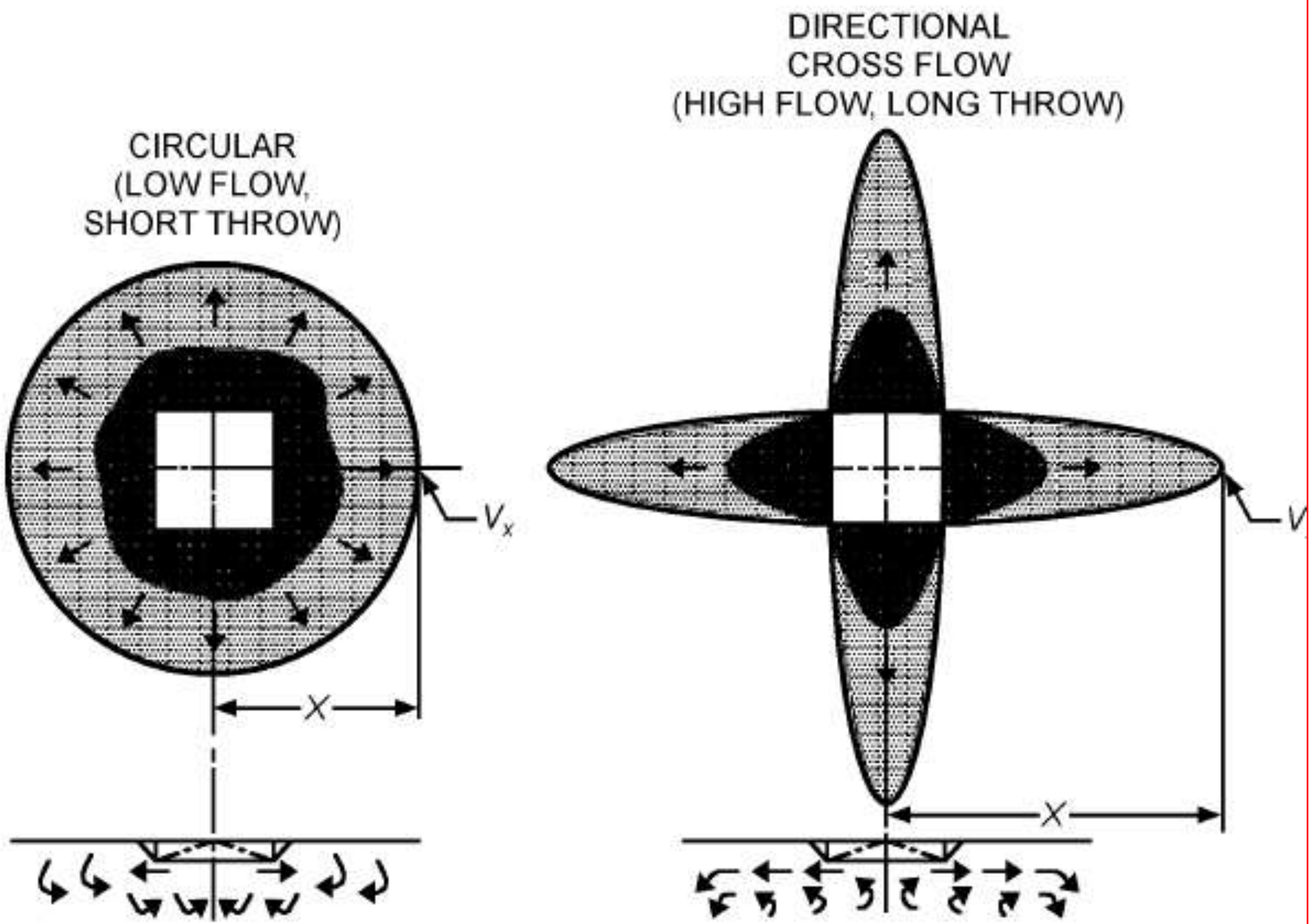

Fig. 2 Example Airflow Patterns of Outlet Group A1

From 2017 ASHRAE Handbook - Fundamentals

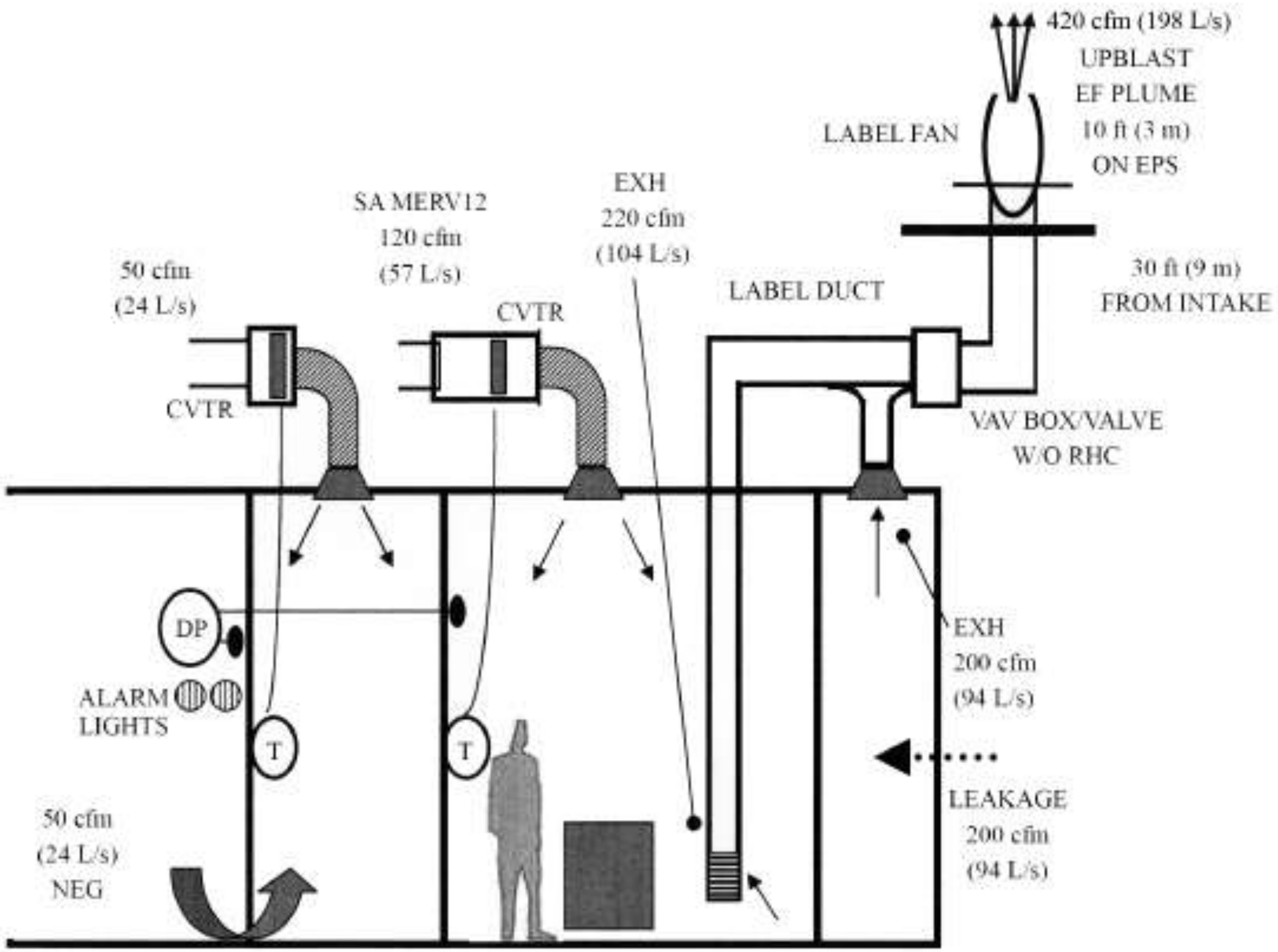

Figure 8-17 *Airborne Infectious Isolation (AII) Room Arrangement*

Source:
ASHRAE HVAC Design Manual for Hospitals and Clinics

Note
CVTR = Constant Air Volume Reheat System
VAV – Variable Air System

Room Design (AII)

- AII room heat gain
  - The heat load consists of:
    - two room occupants (a patient and a caregiver),
    - lighting,
    - solar loads, and
    - wall conduction,
  - Heat gains can easily exceed 4000 Btu/h [1172 W].
  - This magnitude of gain requires about 185 cfm [87 L/s] of 55°F [12.8°C] air.

Room Design (AII)

- Exhaust volume should be more than the supply air volume
- There should be a relative pressure sensing device permanently installed within the wall of the patient's room
  - The placement of the device should be the same even if an anteroom is present
  - The device reads the pressure differential between the corridor and the patient room
- Based on this reading, the device controls supply airflow or both supply and exhaust airflow rates
- The room must be operated with door closed so the reading in the sensing device is 0.01 in. of water [2.5 Pa] in normal conditions

Room Design (AII)

- Supply air to the AII room
  - There is no need to have 100% outdoor air
  - The supply air must be filtered at least to the levels of the general patient spaces.
  - An MERV 14 filter can be used
- Exhaust from the AII room
  - All air must be exhausted directly to the outdoors
  - If combined with other exhausts, HEPA filtration to be done before combining the exhaust flows from other areas

Room Design (All)

- Exhaust Grilles and Registers
  - They should be located directly above, or at the head of the patient bed
- Supply Air Grilles
  - Group A or E outlets should be used for supply air
  - They should be located in the centre of the room or slightly toward the entrance
  - High airflow rates and high air diffusion performance should be provided
  - A 95% air diffusion performance index (ADPI) can be achieved with a good Group A diffuser and a single ceiling return

Room Design (AII)

- Exhaust grilles in AII rooms require special design attention
- Low sidewall grilles if used have the potential to get clogged with lint from bed making and gowns
- Failure to keep grille clean often result in over pressurisation of the AII room
- This will create an effect that is desired
- Air flow volume
  - Depend substantially on
    - Cooling load and the size of the leakage area

Room Design (All)

- If cooling needs are lower,
  - The air change rate can be lower
  - This is to be at the minimum of 12 air changes per hour
- If the leakage area is larger,
  - The exhaust must be greater
  - Pressure differential of 0.01 inch or 2.5 Pascal must be obtained
- An alarm mechanism to be provided to warn the clinical staff of loss of negative pressure

Room Design (All)

- A pressure indicator must be visible from outside the room.
  - Negative pressure status of the room must be validated
  - The controls must be tested to ensure that they are functioning
- This is necessary to ensure that room pressure cannot become positive relative to the environment.
- Room exhaust must be on emergency power
- The exhaust should be well identified
  - So that maintenance and operation staff can take measure for prevention of exposure to contamination

Room Design (PE)

- Protective Environment (PE) Room
  - These rooms are require for bone marrow transplant, oncology, haematology, and similar rooms for Immunocompromised patients
  - Design considerations of PE rooms are similar to AII rooms
    - Room Air pressure control
      - Positive with respect to all adjoining areas
    - Air distribution pattern within the room
      - Should be favourable to airborne infection control

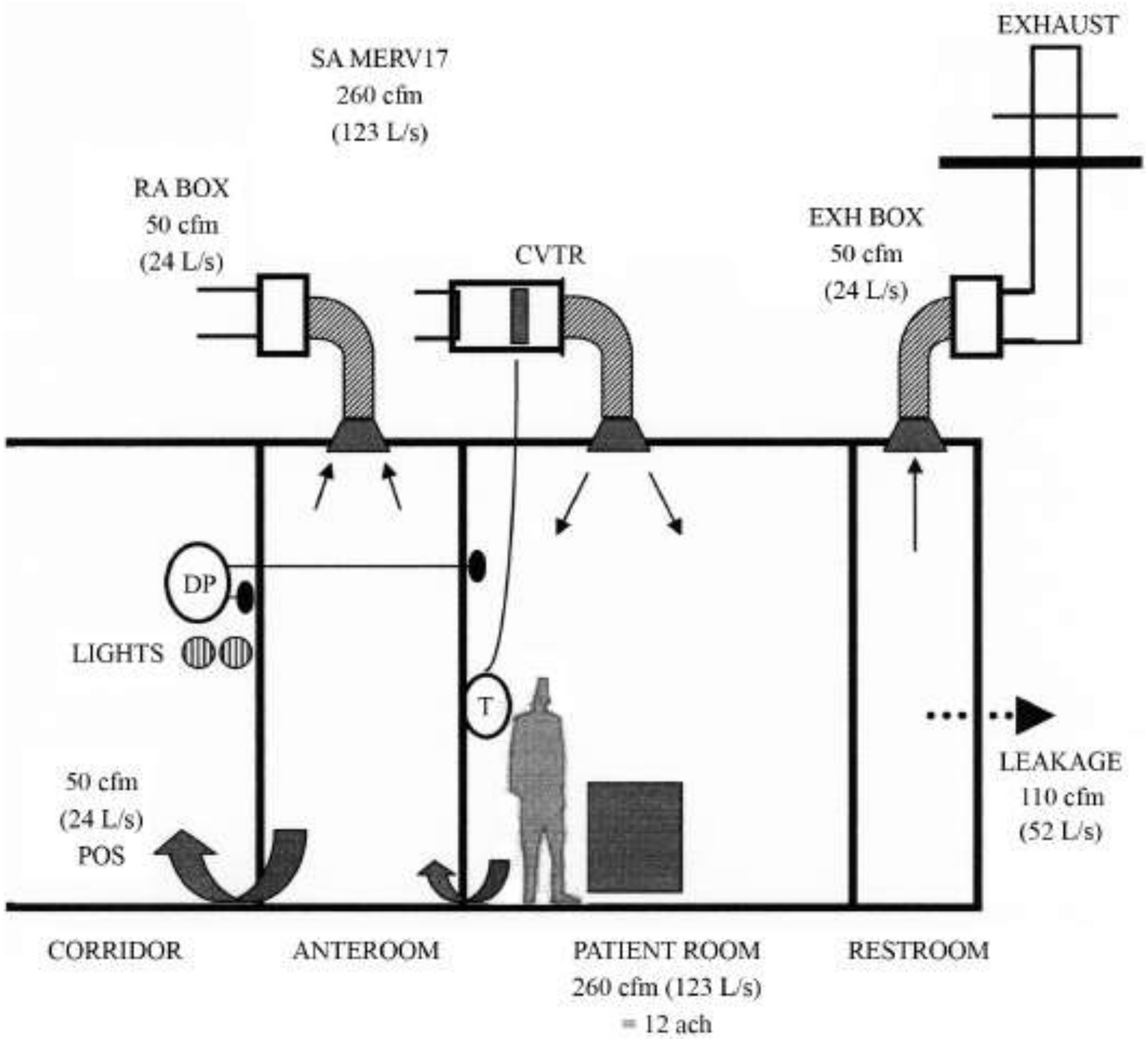

Figure 8-18 *Schematic Diagram of PE Room*

A PE Room

Room Design (PE)

- An anteroom for a PE room is not mandatory, but
  - Is advantageous to maintain pressurisation and the air pattern for patient protection
  - Maintaining positive pressure with respect to anteroom is required in PE room
  - PE rooms should be sealed to minimise air leakage, and/or
  - Increased differential air volume to maintain a differential pressure of 0.01 in. of water (2.5 Pa)

Room Design (PE)

- A unidirectional flow approach should be adopted
  - Air is introduced at low velocity (100 fpm [0.5 m/s]
  - This is done from ceiling mounted, non-aspirating flow diffusers of group E with HEPA filters within the diffuser
  - Air is exhausted at floor level near the entrance to the room
  - This will ensure establishing a vertically downward wash of clean air through the breathing zone of the patient
  - Also during its passage from ceiling to floor the air shall pick up contaminants and pass out of the room through the exhaust register

Room Design (PE)

- This approach needs more air than for a well-mixed room to maintain cleanest air at the patient
- In the cooling season, some advantage can be taken by allowing the air to “dump” somewhat down to the bed
- In the heating in colder climates, however, the air must be forced down at bed level
- The velocities of the air should be around 50 to 75 fpm (0.25 to 0.38 m/s] without entraining room air

Room Design (PE)

- A higher room temperature can allow cooler supply air to fall to the bed (even in the heating season)
  - Therefore, a radiant-heat source near the window is an advantage
  - This heater is to be controlled independently from the supply air temperature
- Example:
  - Room supply air temperature may be set at a fixed temperature
  - The radiant panel varied to maintain 75^0F to 78^0F, using a thermostat in the heating season

Room Design (PE)

- PE rooms require continuous monitoring of pressurisation
  - An alarm is also needed to warn the clinical staff when the required pressure differential is not maintained
  - A differential pressure indicator should be visible from outside the room
- Positive-pressure status must be validated at commissioning
  - The controls also should be tested
  - This is necessary to ensure that pressure cannot become negative relative to the corridor
- The supply fan must be on emergency power

Room Design (Combined AII/PE)

- Combined AII/PE rooms
  - These rooms are required for treating a patient who is simultaneously immunodefficient and is also suffering from airborne infectious disease
    - Example : A patient of HIV with pulmonary tuberculosis
    - An anteroom is mandatory in a combined Airborne Infection Isolation and Protective Environment room

Room Design (Combined AII/PE)

- There are two views about airflow and pressurisation of a combined AII/PE room
  1. The room is negative to the anteroom and the anteroom is at positive differential pressure with the corridor
  2. The room is positive to the anteroom and the anteroom is negative to the corridor
- Requirements for pressure differential indicator and the alarm is same as the AII or PE rooms
- The supply and the exhaust systems both must be on emergency power
- The exhaust should be well identified to protect the maintenance staff from being exposed to contamination

Room Design (Contact)

- Contact Isolation Rooms
  - Some patients may be suffering from contagious diseases but cannot be spread through airborne route
  - Example:
    - Chicken pox
  - There is no specific ventilation requirement for this type of isolation
  - The patient can be treated in a single standard room with usual ventilation for any other patient room

Room Design (Burn)

- Burn Units
  - These are basically protective isolation rooms
    - These rooms need careful humidity control and
    - Ability to raise temperature when required
  - Clinicians vary in their approach for treatment, therefore they should be consulted for their requirements
  - Generally, Relative Humidity (RH) of 40% to 60% is required
  - Provision is required for raising the temperature up to 100^0F when required
  - Low sidewall returns neer the floor to be used

Room Design (Operating Rooms)

- Operating Room
  - The purpose of HVAC Systems in operating Rooms (OR) are to
    - Minimise infection
    - Maintain staff comfort, and
    - Maintain patient comfort
  - The current recommendation for air changes as per ASHRAE Standard 170:2017 and FGI guideline is 20 ACH including 4 ACH of outdoor air
  - OR to be maintained at a positive pressure differential of 0.01 in of water [2.5 Pa]
    - This needs about 200-400 cfm offset

Room Design (Operating Rooms)

- Most standard OR require MERV 14 filtration
  - Earlier for orthopaedic and organ transplant surgeries MERV 17 (true HEPA) filters were recommended
- ASHRAE standard 170:2008 or later editions have not mentioned requirement of this filter
  - Many hospitals, however, consider it a good practice
- Assuming that the final filter assembly is tight, only one final filter is necessary

Room Design (Operating Rooms)

- Placing two final filters in series, such as one in the AHU and one outside the OR, is unnecessary
- This wastes fan energy, and
    - Increases maintenance requirement
- Second final filter also necessitates maintenance personnel entering the operating room
- A schematic diagram of an OR has been provided
- It may be seen that a typical internal cooling load of 2 to 3 ton [7.0 to 10.6 kW] has been indicated

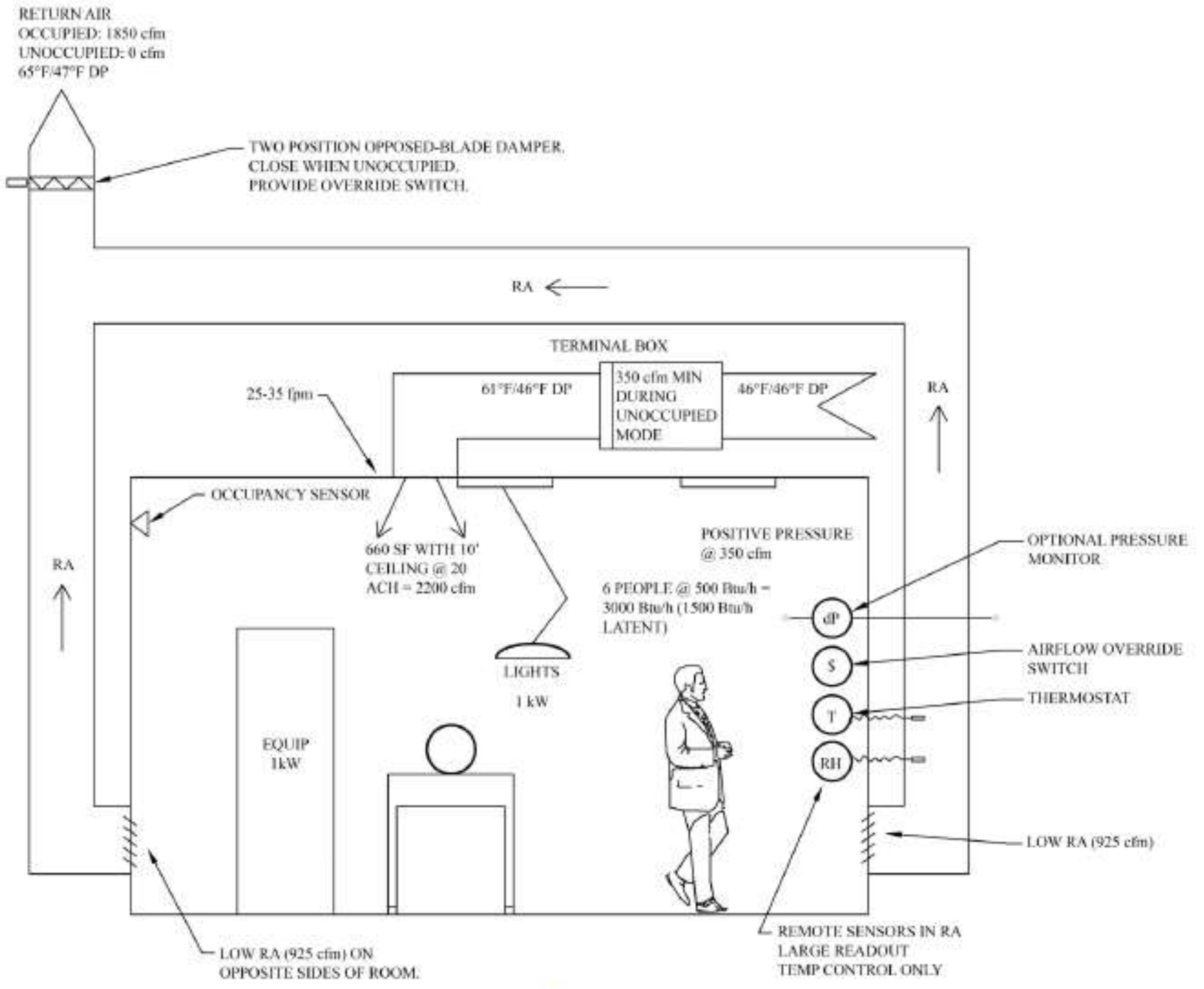

Figure 8-2 *Typical OR Layout*

Operating Room Layout

Room Design (Operating Rooms)

- The designed air change rate is 20 and supply air temperature is 47^0F to 50^0F for an operating room
  - With this parameters, the system can provide 6 to 7 tons of cooling
  - This is roughly twice that of actual load
- In almost all operating rooms, the required Air change rate determines the size of the HVAC system, and
  - It is not the internal cooling load that determines the size
- During the design phase, the users need to be consulted for their requirements of temperature and humidity
  - So that these can be matched with the HVAC systems capability

Room Design (Operating Rooms)

- The FGI and ASHRAE recommend a temperature range of 68^0F to 74^0F at 60% RH
- Many surgeons, (Orthopaedic and Cardiac) ,however, want temperature and humidity outside these ranges
  - Temperature desired may be as low as 60 ^{0}F
- As these have not been the parameters while designing the operating room HVAC System, the system shall not be able to accommodate those desires
- This inability to maintain low operating room temperature is the number one complaint by surgeons to the facility managers

Table 8-4 *Typical Operating Room (OR) Requirements*

OR Room Type	Requirements
Heart	Low temperature, fast reheat, large room
Orthopedic	Low temperature, large room, extra filtration
Cystoscopic	Medium temperature
General	Medium temperature
Pediatric	High temperature
Neurological	Low temperature, large room
Trauma	High temperature
Burn	High temperature

Requirement of Different Types of Surgeries

Room Design (Operating Rooms)

- A cooling diagram of an OR has been provided subsequently
- It may be seen that, over 40% of the cooling load of an OR in summer is due to reheat
  - In addition, 20% of the total energy use of a hospital is for fans
- Thus reducing OR airflow during unoccupied periods can save a great deal of energy use for fans, cooling and reheat
- However there are several factors that complicate setback in the OR during unoccupied periods

Room Design (Operating Rooms)

- Factors hampering unoccupied setback are:
  - Maintenance of positive pressure using supply and return control devices
    - Some older systems will not have return control
  - Maintenance of adequate ventilation for exhausting fumes from off-hour cleaning
  - Control strategies for override (light switch, occupancy sensor, time clock, etc.)
  - Rapid transition from unoccupied to occupied air changes, and
    - Simultaneously maintaining desired temperature and humidity

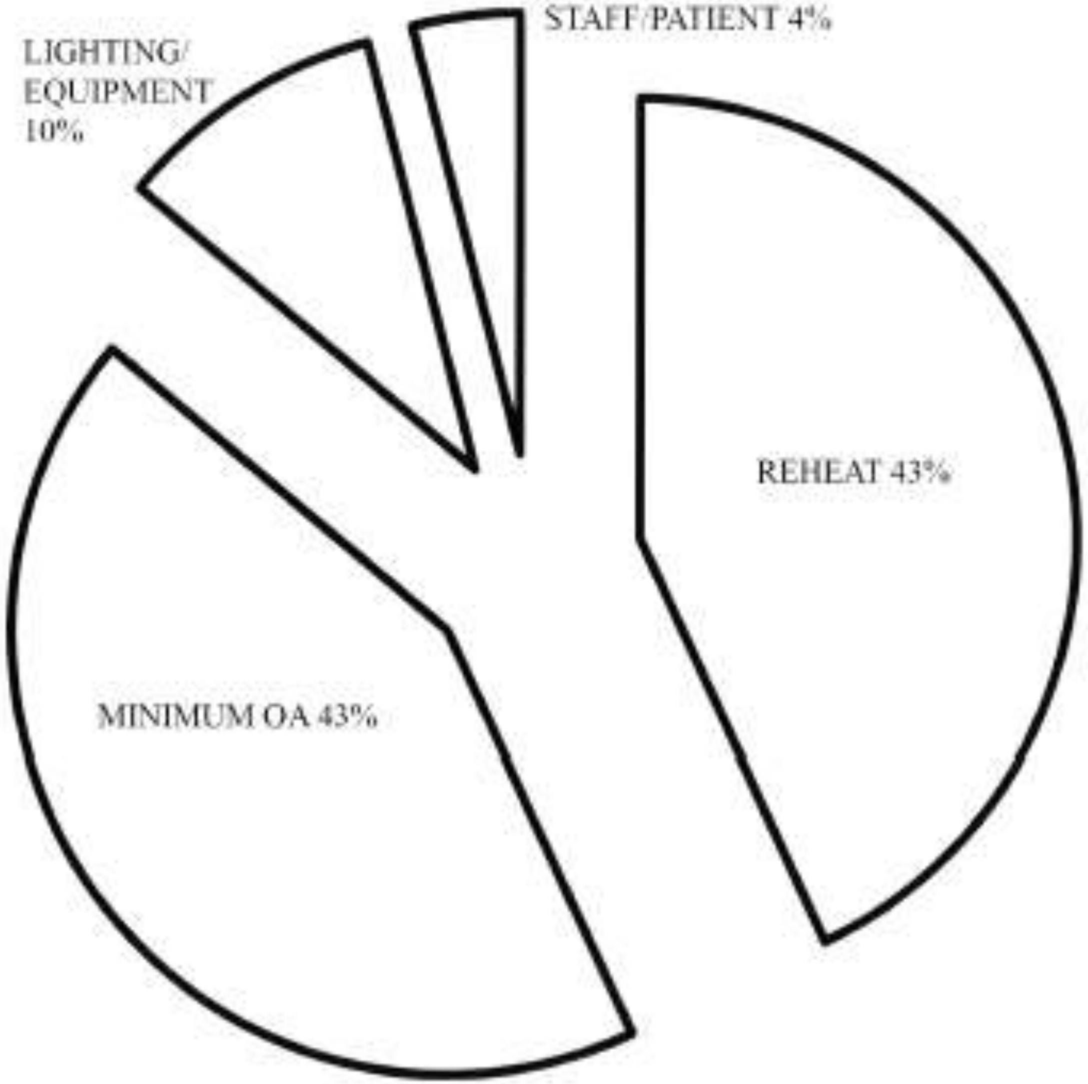

Figure 8-7 *Sources of Operating Room Cooling Loads*

Operating Room Cooling Load

Room Design (Operating Rooms)

- Air Distribution
  - The air velocity recommendations are based on the theory of small thermal plume
  - This thermal plume radiates up from an open surgical site
  - The plume is not aseptic but contains only the microbes that are already present on or in the patient
  - If the thermal plume is undisturbed, particles from the air supply and/or from the staff will be diverted and not directly impact the surgical site
  - Thus a face velocity of 20 to 30 fpm has been recommended and this velocity will not disturb the plume

Room Design (Operating Rooms)

- Majority of OR air supply systems use laminar flow diffuser arrays (Gp E)
  - About 70% of the diffuser array must be dedicated to supply air
  - They should not be blocked by OR light fixuture, booms, sprinklers, etc.
- The over the table diffuser arrays must extend 12 inch out in all directions beyond the foot print of the table
- Hospitals are increasingly installing “hybrid” operating rooms
- These ORs have inbuilt imaging equipment like CT or fluoroscopic equipment
  - Occasionally, MRI is also being installed in the OR

Room Design (Operating Rooms)

- Hybrid ORs are large
  - Total floor area may be about 1000 sqft
  - To maintain 20 ACH in a 10 ft high ceiling OR, 3333 cfm air is required
  - The other parametres in hybrid OR remains the same as in other OR
  - Usually the computers of the imaging systems are located outside in another room
    - So this will not substantially affect the cooling load of the Operating Room
    - Other rooms of the imaging systems will have different cooling load and should be considered separately

Room Design (Operating Rooms)

- Air Curtain
  - Air curtain system is another method for ventilating Operating Room
  - It consists of laminar array above the operating table of linear slot diffuser
  - It is a four sided linear slot diffuser outside the perimeter of the surgical area

Air Curtain System[18]

Room Design (Operating Rooms)

- Between 67% and 75% of the total supply air is provided by the air curtain
  - The balance is supplied through the laminar diffuser
- The laminar diffusers are sized for 25 to 35 cfm per sqft of diffuser face area
- Air curtain is sized to provide 25 to 45 cfm/linear foot of slot
- The internal dimension of the linear air curtain is approximately 3ft minimum beyond each side of the surgical table
  - This allows sufficient space around the table for the staff and equipment
- The air curtain is suitable for very large ORs
  - In these ORs large volume of air is required to achieve 20 air changes

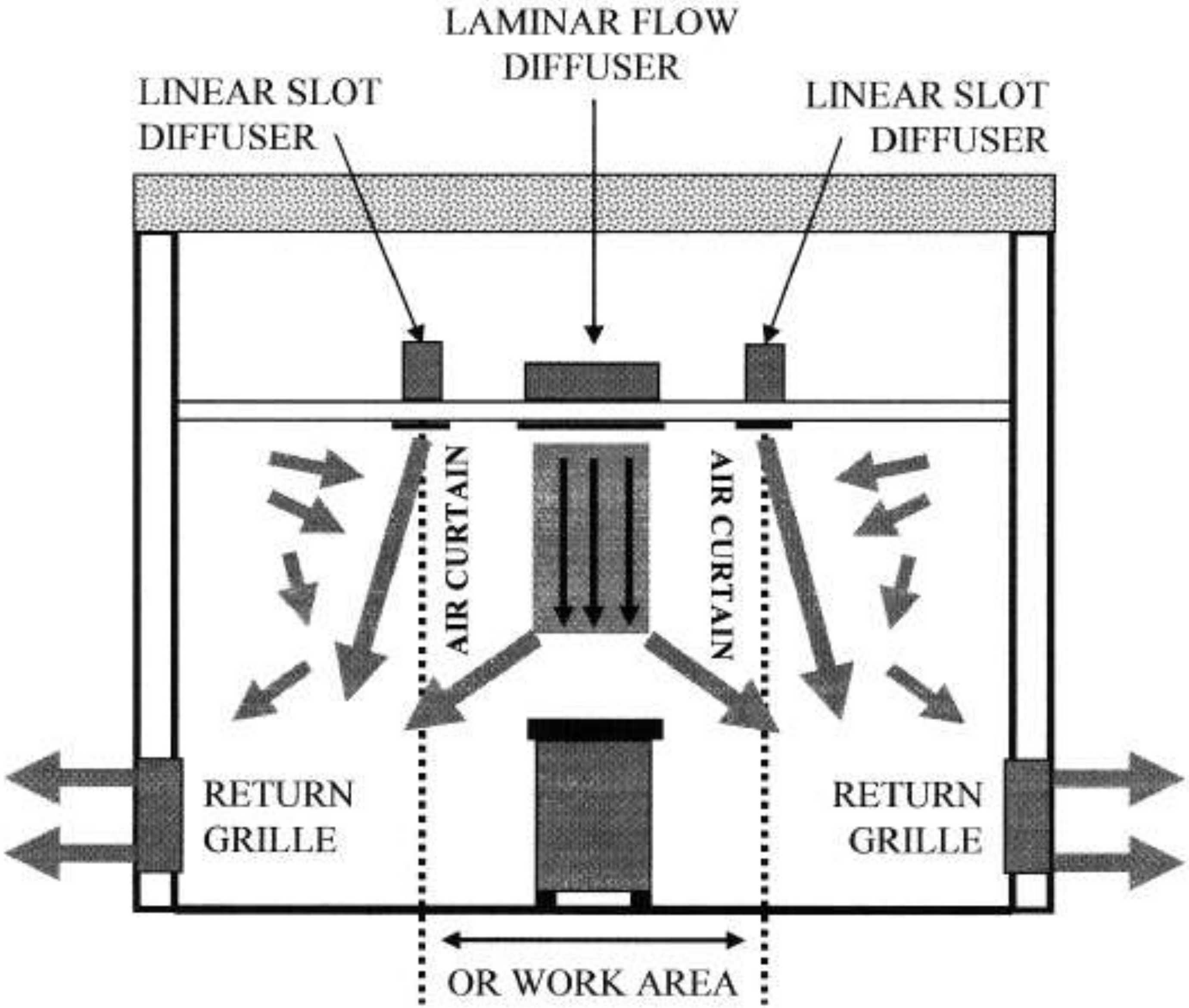

Figure 8-8 *Air Curtain Concept*

Air Curtain Systems[19]

Room Design (Imaging Room)

- Imaging Room
  - Imaging technology is advancing very rapidly
  - Imaging systems have a life of about 5 years when it becomes almost obsolete
  - It is crucial to design for flexibility to accommodate frequent change of equipment
  - With hybrid imaging room, many treatment and invasive procedures are performed in the imaging room
  - X-ray waiting area to be exhausted or with HEPA return air with 2 outdoor air may be used. Area to be at negative pressure

Room Design (Imaging Room)

- A hybrid imaging room may function as an operating room
- The ventilation need in the procedure will change from 6 ACH to 20 ACH
- This flexibility will necessitate oversizing the ventilation equipment
- Each imaging modalities in the imaging department will have different ventilation need
- Example:
  - In a PET-CT Room:
    - Depending upon the procedures, this preparation may require a dedicated hood and exhaust system for the radioactive materials.

Room Design (Imaging Room)

- Cardiac Catheterisation Room
  - This is a procedure area and requires 15 ach.
  - The fluoroscopy machine may be air or water cooled.
  - The machine may be air cooled and shall require 15 ACH
  - The computer equipment may be located in the Procedure Room,
    - Then it is possible that the air change rate may be driven by the internal load;
    - This should be doubled checked.

Room Design (Laboratory)

- Laboratory space design temperature set points often range from 21^0C to 24^0C
- Areas where personnel may wear PPE may require a lower temperature
- Air change requirements are typically 6 ACH with 2 Air Change per Hour of outdoor air
  - Exceptions are: glass washing rooms
    - This rooms require at least 10 ACH
    - Biosafety Level 3 areas may require 10 to 15 ACH

Room Design (Laboratory)

- Cooling loads and/or exhaust quantity may dominate and require higher air change rates than the minimum required by code
- Filtration for clinical laboratories consists of MERV 13 filters
- Higher filtration levels may be desirable for a specific application, but this is not common
- Use of prefilters is not mandatory but preferable

Room Design (Laboratory)

- Airflow distribution should prevent drafts and to maintain a stable room temperature
- In rooms with chemical hoods or biological safety cabinet, the supply air should be provided by laminar type, Group E diffuser
- This diffuser should be located away from the hood/cabinet
  - The purpose is that the air velocity is less than 30 fpm in front of the hood/cabinet

Canopy Hood (ASHRAE Laboratory Design Guide, 2nd Ed, pp. 55

Room Design (Emergency Department)

- Emergency Department (ED)
  - The ED is generally the point of entry for undiagnosed patients
  - Some of these patients may be carriers of dangerous diseases like tuberculosis
  - Emergency room waiting areas and Triage area are to be exhausted
    - Provision of make up air to be made
  - If HEPA filter is used, return air may be used
    - ACH 12 with 2 outside air

Room Design (Other Areas)

- Ventilation in other areas
  - There are some other areas in the hospital that have specific needs for HVAC systems
  - The ventilation in these areas should be as per the table 7.1 of ASHRAE standards 170:2017
  - These areas are:
    - Electrophysiology lab
    - Linear Accelerator
    - Nuclear Medicine
    - Computerised Tomography
    - Pharmacies

Room Design (Other Areas)

- Morgue and Autopsy
- Central Sterile Supply Department
- Renal Dialysis
- ICU
- Post anaesthesia Care unit
- Bone Marrow Transplant
- Endoscopy
- Data Centre

End of Part 4