

2 Mechanical (HVAC) Engineering Design

This HVAC design guideline written for healthcare facilities, is a consolidated document listing out the design requirements for all new construction and major renovation healthcare projects. Compliance to this document, which stipulates minimum performance design standards, ensures that facilities will be of the highest quality. This is an international guideline based on best practice.

Substantial variance from this Design Manual may be proposed by the design consultant to promote new concepts and design enhancements. Variance shall not conflict with Federal Regulations, Local Municipality Laws, Executive Orders, or the needs of the end users. Substantial variance shall be reviewed by each local authority.

This document is intended for the Architect/Engineer and others engaged in the design and renovation of healthcare facilities. Where direction described in applicable codes are in conflict, the AE shall comply with the more stringent requirement. The A/E is required to make themselves aware of all applicable codes and ordinances and assure compliance thereto.

The document should be read in conjunction with other parts of the International Health Facility Guidelines (Part A to Part F) & the typical room data sheets and typical room layout sheets.

Key Objectives

The HVAC systems should be designed to achieve the following key objectives.

Mechanical services that deliver the anticipated levels of comfort and functionality.

A zero-tolerance approach to patient safety and infection control.

Compliance with the applicable codes and standards.

Appropriate pressure differentials between adjacent spaces and departments in clinical facilities.

Adherence to air changes per hour requirements as per code.

Reliable operation at the extreme outside design temperatures.

Reducing operating and maintenance costs shall be a key component in all new constructions.

Flexibility for future modification and expansion.

Energy efficiency & appropriate local or international green building code such as LEED, BREAM, Green Star etc.

An appropriate level of consistency across facilities, recognizing the specific demands of each facility and clinical specialty.

Abbreviations & Reference Standards List

Abbreviations List

Abbreviation	Description
ΔT	Delta T
A/E	Architect Engineer
ACH	Air Changes Per Hour
AHU	Air-Handling Unit
AI	Airborne Infection Isolation
BMT	Bone Marrow Transplant
BSC	Biological Safety Cabinet
C	Celsius
CAPEX	Capital Expenditure
CD	Construction Documents
CFC	Chlorofluorocarbon
cfm	Cubic Feet Per Minute

Abbreviation	Description
CO2	Carbon-dioxide
CRAC	Computer Room Air Conditioner
CT	Computerized Tomography
CV	Constant Volume
DB	Dry Bulb
DD	Design Development
DOAS	Dedicated Outside Air System
DX	Direct Expansion
EEG	Electroencephalography Laboratory
EER	Energy Efficiency Ratio
EMG	Electromyography
ERCP	Endoscopic Retrograde Cholangiopancreatography
ETO	Ethylene Oxide
fpm	Feet Per Minute
fps	Feet Per Second
GE	General Exhaust
Gpm	Gallons Per Minute – US
GWP	Global Warming Potential
HCFC	Hydro chlorofluorocarbons
HEPA	High-Efficiency Particulate Arrestance
HFC	Hydrofluorocarbons
HFO	Hydrofluoro-Olefins
Hp	Horsepower
HVAC	Heating, Ventilation and Air Conditioning
HX	Heat Exchanger
ICU	Intensive Care Unit
IAQ	Indoor Air Quality
IMRT	Intensity-Modulated Radiation Therapy
I/O	Input/output
IR	Infrared Radiation
IT	Information Technology
IRMM	Infection Risk Management Mode
kg	Kilograms
kPa	Kilopascal
kWh	kilowatt hour
L/s	Liters per Second
LCC	Life Cycle Cost
LCCA	Life Cycle Cost Analysis
m/s	Meters per second
MERV	Minimum Efficiency Reporting Valve
MRI	Magnetic Resonance Imaging
NC	Noise Criteria

Abbreviation	Description
NICU	Neonatal Intensive Care Unit
OA	Outdoor Air
ODP	Ozone Depletion Potential
OPEX	Operational Expenditure
OT	Occupational Therapy
OR	Operation Room
Pa	Pascal
PACU	Post Anesthesia Care Unit
PE	Protective Environment
PET	Positron Emission Tomography
ppm	Parts Per Million
QA/QC	Quality Assurance/Quality Control
RA	Return Air
RDS	Room Data Sheets
RH	Relative Humidity
SA	Supply Air
SE	Special Exhaust
TB	Tuberculosis
TAB	Testing, Adjusting and Balancing
UPS	Uninterruptible Power Supply
VPS	Variable Primary System
VSD	Variable Speed Drive

Reference Standards List

Local/international regulations, guidelines or standards as listed below are required to be followed while designing healthcare facilities unless superseded by this document. The requirements given in these regulations or standards are not repeated generally in this document; however specific additional healthcare specific requirements emphasized in the following sections will take precedence over referenced standards. Local standards will always take precedence over international standards. The editions mentioned are current editions and latest editions of the documents, at the time of registration of the project shall apply. Since this is an international guideline, all reference standards cannot be mentioned but

Items marked with * indicate optional compliance.

Summary of Key Design Codes, Standards and Reference Documents for HVAC Design		
SUBJECT	DOCUMENT	EDITION OR LATEST
General HVAC Design	ASHRAE 170 - Ventilation of Healthcare Facilities	2021
	ASHRAE HVAC Design Manual for Hospitals and Clinics Second Edition*	2013
	ASHRAE 62.1 Ventilation for Acceptable Indoor Air Quality	2016
	ASHRAE 241 – Control of Infectious Aerosols 2023	
General Building Codes	IBC	2021
	CIBSE B0 to B4	2016
Pharmacy HVAC Design Reference	USP 795 - Pharmaceutical Compounding - Non-sterile preparations	2015
	USP 797 - Pharmaceutical Compounding - Sterile preparations	2015

Summary of Key Design Codes, Standards and Reference Documents for HVAC Design		
SUBJECT	DOCUMENT	EDITION OR LATEST
Refrigeration Systems	USP 800 – Hazardous Drugs – Handling in Healthcare Settings	2014
	ASHRAE 15- Safety standard for refrigeration systems	2013
	ASHRAE 34 Designation and safety classification of refrigerant	2013
Thermal Comfort	ASHRAE 55 Thermal environmental conditions for human occupancy	2017
Ventilation for Catering Facilities	NFPA 96- Ventilation control and fire protection of commercial cooking operation	2014
Sustainability	ASHRAE 189.3 Construction, and Operation of Sustainable High-Performance Health Care Facilities *	2017
Laboratory HVAC Design	ANSI/AIHA Z9.5 - Laboratory Ventilation*	2012
	ANSI/NSF 49 - Biosafety Cabinetry: Design, Construction, Performance and Field Verification	2014
	ASHRAE laboratory Design Guide: Planning and Operation of Laboratory HVAC Systems second edition*	2015
	Laboratory Safety Guidance – OSHA*	2011
Fire Safety	NFPA 13- Standard for the Installation of Sprinkler System	2022
	NFPA 45 - Standard on Fire Protection for Laboratories Using Chemicals	2015
	NFPA 90A - Installation of Air Conditioning and Ventilating Facilities	2018
	NFPA 90B- Standard for the Installation of Warm Air Heating and Air-Conditioning Systems	2018
	NFPA 92 - Standard on Smoke Control Systems	2018
	NFPA 99 - Health Care Facilities Code	2018
	NFPA 101 - Life Safety Code Handbook	2018
	NFPA 5000 - Building Construction and Safety Code	2018
	Civil Defense Authority	
Access and Maintenance	ASHRAE 180 - Standard Practice for Inspection and Maintenance of Commercial Building HVAC Systems*	2012
UL Standards	UL 1995 Heating and Cooling Equipment	2015
	UL 555 Fire Dampers	2013
	UL 705 Standard for Power Ventilators	2017

Infection Control & HVAC

It is important to note the below mentioned functions desired from the HVAC system serving a healthcare facility, as compared to other building types for which the HVAC system is simply designed for thermal comfort.

Infectious diseases are spread by several different routes. Tuberculosis and in some cases influenza, the common cold, and other diseases are spread by the airborne route. The spread can be decelerated or controlled by heating, ventilating, and air-conditioning (HVAC) systems. The designer must keep these aspects in mind & consider it an ethical responsibility to comply with all relevant codes and standards.

For healthcare facilities, HVAC systems play a very important role in reducing airborne infections by:

- Air Change Rates to reduce the residence time of particles in the air.
- Filtration and air cleaning to remove microbes.
- Ultraviolet Germicidal Irradiation (UVGI) to in-activate the viable agents and prevent growth.
- Pressurization of spaces to move air from clean to less clean and dirty area.

- Temperature and humidity control to reduce propagation.
- 100% exhaust from designated high-risk spaces to remove the particles from the space. It is recommended to design the HVAC system for areas where the risk of infectious spread is high such as waiting rooms and emergency department, ensuring its capability to function in Infection Risk Management Mode (IRMM) during high-risk events like a pandemic.
- Proper air distribution to reduce the deposition of particles and provide a designed path to the exit.
- Pressurization of the entire building to reduce air infiltration from outside.
- Plasma air filtration for the return air is acceptable practice in accordance with ASHRAE 241.

Life Safety & HVAC

The HVAC systems should follow design requirements stated within the NFPA & other relevant referenced standards. Points to note are listed below.

Fire Dampers, Smoke Dampers and Combination Fire and Smoke Dampers should be provided in accordance with the local code and in line with the Fire and Life Safety Drawings. All such dampers should be clearly shown in the design drawings.

It is encouraged to utilize dampers that have the ability to be remote tested in healthcare facilities in order to routinely check and maintain the dampers. This ensures that in a critical life safety event the damper operation is ensured.

Mechanical smoke management should be provided for atriums, corridor, and open circulation spaces.

Mechanical pressurization should be provided for egress stairs, lift hoist ways & lift lobbies for fire lifts.

If the air handling units return ducting is utilized for smoke control, the system design zoning should be carefully matched with the smoke zones, which in turn should line up with fire alarm and fire sprinkler zones. All other requirements related to duct construction and fan rating should be adhered to such as fire rating for the ductwork and the extract fan etc.

It is recommended to install dedicated extract air ducts for corridor and open circulation spaces smoke management, where required by code, rather than utilizing AHU ducts which would complicate AHU control and operation sequences, especially for typical in-patient floors. Using AHU return duct would also warrant replacement of ducting, post fire incident. Makeup air can, however, be provided through the AHU supply fans.

HVAC Services Reliability, Redundancy & Resiliency Requirements

The HVAC system designed for a healthcare facility is providing mission critical filtration, cooling, humidification & dehumidification as well as pressure regime management to the various critical healthcare spaces within the hospital.

Thus, the failure of an HVAC system component can lead towards a loss of pressurization which could be life threatening to an immune-compromised patient and can also result in a spread of viral infections.

The following section will list out the key requirements for an HVAC system to meet these challenges.

Reliability

Reliability of an HVAC system is the quality of the system components, installation, commissioning, and facility maintenance.

To ensure reliable construction and operation, the International health facility guidelines aim to introduce a prequalification system for the design consultants. Part A of these guidelines provide more information on the proposed system.

It is encouraged that owners and facility operators get involved early in the design process and provide feedback on the system components and operational aspects of the design.

For future healthcare projects, HVAC equipment manufacturers that have a strong local presence and full-service support shall be selected. All applicable components should be tested at the local

Laboratories or other equivalent facilities worldwide and test certificates provided for record. Witness testing is encouraged for all major HVAC system components.

Redundancy

In simple terms, redundancy can be thought of the amount of standby equipment that is available to cover a system or component in the event of a partial system failure.

Standby equipment requirement should always be aligned with the owner's facility operation plan.

Key system components in healthcare facilities must be configured in N+1 configuration. A guidance is provided below

Redundancy Requirements for Healthcare Facilities		
SYSTEM COMPONENT	DESIRED OPTIMAL REDUNDANCY LEVEL	ALTERNATE ALLOWED
Water Cooled Chillers	N+1	Deviation allowed for smaller hospitals & clinics if loss of one chiller does not affect critical cooling.
Air Cooled Chillers	N+1	Deviation allowed for smaller hospitals & clinics if loss of one chiller does not affect critical cooling.
Central Steam Boilers	N+1	Deviation allowed for smaller hospitals & clinics if loss of one boiler does not affect critical cooling.
Hydronic Heat Exchangers	N+1	
Chilled Water & Hot Water Pumps	N+1	
Operation Theatre Air Handling Units	N+1	AHU's with dual fans with each sized at 100% of the airflow or fan arrays with one additional fan are allowed as an alternate to N+1 AHU's.
Air-Side Equipment – Hygienic Air Handling Units (Critical Care, LDR, Emergency, Diagnostic Imaging, Laboratory, Oncology, In-patient pharmacy, Radiotherapy, Renal Unit, CSSD, Surgical Suite, Isolation Rooms)	N+1 (Fans) Each sized at 100% airflow & Critical Cooling.	Fan Coil Units can be used for Emergency, Imaging, Oncology, in patient pharmacy, Radiotherapy and renal departments but their use is highly discouraged.
Server Room	N+1	N+1 Precision Control Units or single indoor unit with dual coils & dual fans backed up by independent heat rejection equipment.
Critical Rooms Dedicated Exhaust Fans (Isolation Rooms, Bronchoscopy, Nuclear Medicine Hot Labs, Emergency and Radiology Waiting Rooms, Lab Fume Hoods, CSSD Sterilizers & Washers, Pharmacy hazardous-drug exhausted enclosures)	N+1	
Fire & Life Safety / Smoke Control System / Pressurization System Fans	N	As per local Fire and Life Safety code requirements

Resiliency

For the HVAC system, resiliency can best be thought of how much of the total system continues to operate in the event of a failure of one part of the system. Resiliency is critical to business continuity which is essential for public hospitals operating under disaster management and helps mitigate revenue losses in case of system failures for private hospital operators.

Resiliency must be built into the design, during the concept design stage. The consultant must evaluate the risks associated with the failure of a system component, engage in an effective dialogue with client/owner/operator and determine ways and means to mitigate the risks.

External risks associated with climatic conditions such as Sand/Snow/Hailstorms & heavy rainfall should also be evaluated and intake and exhaust louvers should be positioned & sized so that they can handle an extreme event.

Major equipment located below grade must be evaluated for flash flood risk.

Operating weights of equipment's should be considered for structural design. Critical weights of equipment's such as absorption chillers should also be considered to ensure that the structure can handle the HVAC equipment loadings.

Redundant systems should be routinely operated through BMS and tested at design conditions.

Some of the major equipment risks are mitigated by the table in the previous section on redundancy, but distribution systems such as ductwork and pipework should be configured in a way that eliminates a single point of failure.

Ring mains, multiple risers, dual connections to larger AHU coils, bypass over major control valves with proper isolation, Individual VFD's per fan, bypass for VFD's, manifolded air handling unit configuration are some of the measures that can be adopted for better system resiliency.

HVAC System Zoning & Emergency Operation

HVAC System Zoning

HVAC systems for clinical buildings shall generally be zoned to match the smoke control compartments for the building. The intention is to ensure that the impact of one zone being shut down is minimized. If this approach results in an excessive quantity of air handling units, more than one zone can be combined with fire and smoke dampers to separate them. In this case designers shall consider arranging the distribution ductwork so that only part of the system has to be shut down in a fire alarm condition.

By zoning the system using smoke control compartments it is unlikely that the capacity of a single air handling unit would exceed 16,500 L/s (60,000 m³/hr.). If it does the designer should consider dividing the air volume between two air handling units. It is encouraged that consultants prepare zoning diagrams during the concept design stage to clearly demarcate HVAC zones for coordination & clarity.

HVAC Systems Emergency Operation

Emergency generators are to be provided for the buildings to supply power to the HVAC system in a loss of power supply from the grid.

As described in the Electrical section, the capacity of the generators is determined using a risk classification process. The HVAC designer shall work with the electrical designer for the building to determine which HVAC systems are to be provided with emergency power through this process. The result of this analysis should also be used to assess how systems are zoned.

As a minimum all critical areas identified in this standard SSU, CSSD, Surgical Suite, Labor & Delivery Suite/Birthing Unit, Recovery, Emergency, Intensive Care, Nursery & Inpatient Rooms) should be provided with backup cooling/heating fed from emergency power. The space ventilation and pressure relationship requirements for Isolation rooms, Operating rooms including Caesarean section, should be maintained, via backup power. Refer to the electrical section, detailing the requirements for different risk categories within the hospital.

It is encouraged that mechanical consultant table the electrical power requirements (normal power or emergency power) in the mechanical equipment schedules in order to obtain clarity for the electrical engineer.

HVAC Services Acoustic Requirements

The HVAC system shall be designed to be compliant to ANNEXURE- Acoustic A-2. Other equivalent standards are also acceptable. Specific requirements for HVAC system components should be obtained from Annexure A-2 -Acoustic Values and ASHRAE standards.

Lining of ductwork is not allowed in healthcare facilities after final filtration, as per ASHRAE 170 except in terminal units, sound attenuators and air distribution devices (plenum boxes etc.). Such lining should be provided with an impervious cover, or carry certifications citing no vapor absorption and be acceptable to local civil defence requirements. CAV/VAV boxes which cannot meet acoustic requirements, should be provided with downstream attenuators in critical areas.

Backup power generator is if installed within hospital buildings should be provided with critical hospital grade silencers.

Car park exhaust and make up air fans should be provided with sound attenuators to reduce the sound during normal mode operation.

Acoustic Ratings for plant room doors should be carefully specified with detailed coordination between trades.

HVAC Services Future Proofing & Spare Capacities

Due to the nature of medical facilities, changes to internal layouts and upgradation of the medical equipment is quite common, which results in HVAC cooling/heating load variances. The designer should engage in an effective dialogue with the owner/operator to determine the allowance to be kept for future expansion as well as retrofitting and modifications within departments.

As a strong recommendation this guide asks for 20% extra useable area allocated for mechanical shafts for additional pipework and ductwork. It is also recommended that mechanical AHU rooms for medium to large hospitals should allow for space for an additional air handling unit for every 10 air handling units. Mechanical Pump rooms should be provided with space for 1 additional pump for both primary and secondary systems

HVAC System Selection – Distribution

The intent of this section is to provide a guidance for HVAC systems selection process for healthcare facilities as well as list out acceptable and unacceptable HVAC systems. Specific Room design guidance is provided at the end of this document in a separate section, which should be read in conjunction with this section.

Acceptable HVAC Systems-Distribution

All-air systems shall be used for all new facilities and major renovations of existing facilities where above ceiling clearance is available to accommodate HVAC air distribution systems. All-air systems designs shall provide for the admittance of minimum required outdoor air in all operating conditions. The use of constant volume (CV) systems shall be carefully considered and only utilized if proven more cost effective through a Life Cycle Cost Analysis (LCCA), or if required due to the area served.

The following list of systems is acceptable for air-distribution systems within healthcare facility.

Variable Air Volume with terminal reheat

This distribution system is acceptable in all facilities and is considered as the preferred solution for general clinical areas.

VAV terminal units shall be in a pressure independent configuration to maintain airflow under fluctuating upstream duct pressures as system flow changes.

Supply air VAV terminals shall be provided with integral hot water reheat coil or electrical reheat coil for areas with permanent occupancy as deemed necessary through heat load calculations.

Supply air temperature differential to room temperature shall not exceed 10°C in heating mode to prevent stratification.

Terminal units shall be equipped with sound attenuators as necessary to meet acoustic requirements.

Supply air temperatures shall be reset based on demand to minimize cooling and reheat loads.

VAV terminal units shall be provided for both supply and return/exhaust air systems for areas where mandated pressure control is required.

Terminal humidification is discouraged except in operating theatres.

Minimum air volumes for VAV boxes shall be in accordance with the room air change rate, as per the Table in this standard for ventilation. This will generally be higher than the typical 30% minimum for a conventional commercial VAV system. The tender drawings & specs should indicate minimum value for each VAV box.

Fan Coil Units

Chilled water-based Fan Coil Units are not recommended solution for administration and support areas as well as clinical areas as constraints in filtration requirements for recirculation by room units.

For Larger facilities, use of FCU is discouraged due to higher energy consumption, maintenance issues and the need to access clinical spaces to replace components such as filters, fan motors and control valves.

In specific cases fan coil units may also be used in circulation spaces, if there are high sensible cooling loads from heat gain through the building envelope or in spaces where there are localized heat gain from electro-mechanical equipment's; such as plant rooms, electrical and telecom rooms.

Care must be taken to place FCU's outside of the electrical/telecom rooms to avoid chilled water piping within the room.

Fan coil units shall not be used to dehumidify the outdoor air as outdoor air has a high moisture fraction. A dehumidified outdoor air supply should be ducted to the Fan coil units through a dedicated 100% outdoor air handling unit, utilizing energy recovery.

DX or VRF based Fan coil units are also acceptable where there is no centralized source of chilled water for smaller installations.

Displacement Ventilation

Displacement ventilation is an acceptable solution for non-clinical areas only, however it is not good practice. It is not recommended in clinical areas due to the restrictions created by the fixed location of the supply diffusers. Where displacement ventilation is used, the designer shall co-ordinate locations of terminals carefully with the interior design proposals to ensure thermal comfort is achieved and future flexibility is not compromised.

Displacement ventilation can be particularly effective in spaces with lofty ceilings such as entrance areas atriums or spaces with high occupancy levels such as lecture halls.

If utilizing displacement ventilation, the designer shall avoid, due to open corridors with adjacent clinical spaces .

Natural Ventilation

Natural ventilation is not prohibited but ducted mechanical ventilation will still be required to ensure adequate number of air changes, even if natural ventilation is available.

Depending on climatic conditions, temperature, humidity, risks of natural disasters, natural ventilation constituting of operable windows is not a preferred option anymore. Furthermore, this leads to unfiltered outside air which due to increasing urbanization is under continuous degradation with major cities around the world having poor outside air quality. Thus, hospitals and healthcare facilities are encouraged to duct in outside air through mechanical ventilation.

Unacceptable HVAC Systems – Distribution

The following systems are unacceptable and should not be used in future healthcare projects.

Chilled beams or chilled ceilings due to concerns over potential condensation and associated infection control risks.

Dual duct VAV systems.

HVAC Systems Design Criteria & Relevant Applicable Codes

The following section aims to provide a general brief for the HVAC systems for new construction and major renovation healthcare projects.

External Design Criteria

The external design conditions can be obtained from <https://ashrae-meteo.info/v2.0/index.php> with this standard Climatic database or other local data sources. The design conditions should be carefully vetted, especially the wet bulb temperature for worse case air intake for outside air.

Link for climatic condition available in this standard, 20-year projected DB and WB conditions are encouraged to be used for water/air cooled chillers and cooling towers, respectively.

Design Criteria	Value to be utilized
Outside design conditions for cooling load calculation	Utilize Annual Cooling Load Conditions 0.4% Values.
Outside design conditions for fresh air	Utilize Evaporation Conditions 0.4%.
Outside design conditions for heating load	Utilize Annual Heating values 99.6%.
Outside design conditions for humidification	Utilize Humidification values 99.6%
Outside design conditions for selecting air cooled HVAC equipment (Recommended)	Projected Dry Bulb for next 20 years, Refer to link
Outside design conditions for selecting cooling towers (Recommended)	Projected Wet Bulb for next 20 years, Refer to link

Envelope Design Criteria

As a best design practice, the following values are suggested to be used for future healthcare projects following the iHFG guideline.

Component	Recommendation (U- W/m2. K)
Roof	U-0.3 (Insulation entirely above the slab) U- 0.2 (Cold Climates) Solar Reflectance Index (SRI) > 78
External Wall	U-0.4 (Mass Walls) U-0.3 (Cold Climates)
Floors	As per project requirements
Doors	U-0.74 (Swinging) U-1.45 (Non-Swinging)
Vertical Fenestration (Full Assembly)	40% max (Window to Wall Ratio) U-1.9 or lower (Thermal Transmittance) 0.25 max (Solar Heat Gain Coefficient) 0.15 min (Light Transmittance)

It is encouraged to improve upon the recommended values for medium to large healthcare facilities as they are operational round the clock and consume the most energy as compared to any other building type.

Internal Design Criteria

The internal design criteria for facilities is split up into two categories, clinical and non-clinical spaces.

The below tables would identify the performance level for internal spaces clinical and the associated ceiling with respect the heat gain from internal sources for both spaces.

Non-clinical ancillary support buildings that are part of the development shall follow the guidelines for non-clinical spaces

Non-Clinical Spaces

Criteria	Requirements
Temperature	The internal temperature requirement for non-clinical spaces shall be set at 24 °C DB.
Relative Humidity	General non-clinical spaces would not be provided with active relative humidity control, unless it is a requirement related to specialist equipment within the space. The designer to ensure that maximum relative humidity is kept within 60% by employing BMS control algorithms.
Electrical Lighting	Lighting loads shall be based on an average watts/m2 figure for each type of room based on a representative lighting layout. General guidance can be obtained from ASHRAE 90.1.2016 Lighting Power Density.
Electrical Small Power	Where there are specific equipment rooms, the heat loads shall be based on the 'worst case' values from the potential range of suppliers. Where there are no specific equipment layouts, allowances for small power loads shall be made on an average watts/m2 basis as appropriate for the space type. Refer to ASHRAE Handbook Fundamentals 2017 Chapter 18 Non-Residential Cooling and Heating Load Calculations.
Occupancy	The design shall be based on the furniture layout or ASHRAE 62.1, whichever is the more onerous.
Infiltration	The building should be designed to be at positive pressure with respect to the atmosphere, always. Infiltration load should only be considered for high rise.
Ventilation	The minimum requirements for ventilation shall be as specified in the ASHRAE Standard 62.1.2016.
Acoustic Requirements	The design for HVAC system should follow the acoustic requirements listed out in Annexure A-2

Clinical Spaces:

Criteria	Requirements
Temperature	Internal design temperatures shall generally be in accordance with ASHRAE Standard 170 & HVAC room design segment in this document. If there is an equipment specific space temperature requirement listed in the Room Data Sheets (RDS) it will supersede ASHRAE requirements.
Relative Humidity	Internal relative humidity shall generally be in accordance with ASHRAE Standard 170. If there is an equipment

Criteria	Requirements
	specific temperature requirement listed in the Room Data Sheets (RDS) it will supersede ASHRAE requirements.
Electrical Lighting	Lighting loads shall be based on an average watts/m ² figure for each type of room based on a representative lighting layout. General guidance can be obtained from ASHRAE 90.1.2016 Lighting Power Density.
Electrical Load Due to Medical Equipment	Medical equipment heat dissipation loads shall be based on the Room Data Sheets (RDS) listed values. RDS values should represent actual equipment heat dissipation values using 'worst case' manufacturer's published data from the range of potential suppliers.
Occupancy	Design occupancy for each space shall be as specified on the room data sheets. If no occupancy is provided, the design shall be based on the furniture layout or ASHRAE 62.1, whichever is the more onerous.
Infiltration	The building should be designed to be at positive pressure with respect to the atmosphere, at all times. Infiltration load should only be considered for high rise.
Ventilation	The minimum requirements for ventilation shall be as specified in the ASHRAE Standard 170.2017. For spaces not listed under ASHRAE 170, utilize ASHRAE 62.1.
Acoustic Requirements	The design for HVAC system should follow the acoustic requirements listed out in Annexure A-2

Air Intake & Exhaust

The air intake and exhaust louvers/vents positions should be carefully planned for healthcare facilities to ensure that there is no recirculation of air. Minimum separation distances mentioned in ASHRAE standards to be minimum 8m from Fresh Air and Exhaust Air termination.

Harsh climatic conditions warrant special attention to the air intake air louvers. As a minimum the intake outdoor air should be drawn into the system through sand trap louvers sized at 1m/s across the face area of the louver to provide an 80% or higher filtration efficiency at coarse sand grain size (355-425 microns).

For bigger healthcare facilities providing a central air intake to the 100% outside air energy recovery air handling unit it is recommended to utilize a self-cleaning inertial air cleaner. The air cleaner provides 99% efficiency at a sand grain size of 10 to 100 microns. Due to the high velocity intake it also overcomes the constraints regarding the large face area, which are a problem for the standard sand trap louver.

Washable aluminum filters can be provided at the rear of the sand trap louver. If provided, designer should ensure access for proper maintenance. If proper access cannot be guaranteed, enabling the removal of the filters without shutting down the AHU, the filters should not be provided for the air intake louvers as dirty filters would clog the air stream providing higher pressure drop and in turn reduced air volume.

Based on the ambient acoustic levels, determined through a survey conducted at the site by a professional acoustic consultant, if required the outdoor air intake & exhaust should be provided with a sound attenuator.

Buildings shall maintain a positive pressurization (5-10% net positive). Tighter buildings are eligible for less net pressurization. Designers should ensure enough outside air is provided for adequate pressurization. It is encouraged to undertake blower door testing for facility integrity as part of the testing and commissioning process.

Filtration

Mechanical filtration plays a very important role in ensuring that the hospital continues provide best in class care & is fit for occupancy. Mechanical filtration is one of the key elements to healthcare HVAC design and is of primary significance regarding air quality & infection control.

All air handling units directly serving the spaces & outside air handling units serving downstream terminal units, should be provided with a 1st stage filtration of no less than MERV 8/ePM₁₀ 60% rating and a final filter downstream of all wet-air cooling coils and supply fan according of no less than MERV 14/ ePM₁ 70% rating.

Majority of the spaces are highly critical departments [Critical Care, OT, NICU, Procedure rooms, Recovery Rooms, Isolation Rooms, X-Ray Rooms (surgery/critical care & catherization/angiography), Endoscopy Rooms, Autopsy Room, etc.] where cleaning difficulty and potential building of contamination has led to the requirement of no-recirculation of air. Refer to Annexure A-3 for filtration requirements.

Ultraviolet (UV-C) disinfection (also called ultraviolet germicidal irradiation [UVGI]) is used to inactivate microorganisms. The use of UV-C is encouraged for healthcare projects specially for cooling coil surfaces to avoid fungal amplification. The peak effective wavelength range for inactivation of microorganisms is near 254 nm. Use of upper air UV for patient rooms in critical care or isolation rooms is also encouraged to deactivate the virus spread.

Alternative filtration techniques such as electronic filters and air cleaners using photocatalytic oxidation (PCO) are not encouraged to be used because of negative health effects that arise from exposure to ozone and its reaction products. Substantial technical evidence is required on the use of these techniques, validated by international agencies, test standards and standard engineering bodies, local authorities etc. If utilized, they are not considered a replacement for mechanical filtration but can be considered as aides to achieve better indoor air quality.

Materials

The table below provides basic information on reference design standards for core HVAC system components. It is highly recommended that the materials and system components carry certifications citing compliance to the following standards or approved equals for all new construction and major renovation healthcare projects. Latest versions of the following will apply at the time of the project registration.

Certification & Design Standards for All Facilities		
SUBJECT	DOCUMENT	EDITION
Ductwork	DSP DW/144 Specification for sheet metal ductwork. Third edition	2016
	DSP DW/172 Specifications for kitchen ventilation systems.	2018
	SMACNA HVAC Systems Duct Design	2006
	SMACNA HVAC Duct Construction Standards-Metal & Flexible	2005
Pipework	ASME B31.9 Building Services Piping	2014
	ASTM A53 Pipe, Steel, Black and Hot-Dipped, Zinc Coated (Galvanized), Welded and Seamless.	
	ASME B31.5 - Refrigeration Piping	2016
Filter Standards	ASHRAE 52.2-Method of Testing General Ventilation Air-Cleaning Devices for Removal Efficiency by Particle Size	2017
	ISO Standard 16890 Air Filters for General Application	2016
HEPA Filter Standard	EN 1822 High efficiency air filters (EPA, HEPA and ULPA). Aerosol production, measuring equipment, particle counting statistics	2009
	ISO 29463 High efficiency filters and filter media for removing particles from air	2017
Fan Coil Units & Package Units	Eurovent RS 6/C/002-2017 Rating Standard for Certification of Non-Ducted Fan Coil Units	2017
	Eurovent RS 6/C/002A-2017 Rating Standard for Certification of Ducted Fan Coil Units	2017
	AHRI 340/360 Performance Rating of Commercial and Industrial Unitary Air-Conditioning and Heat Pump Equipment	2015
	AHRI 310/380 Standard for package terminal AC and Heat Pump	2017
	AHRI 410 Forced-Circulation Air-Cooling and Air-Heating Coils	2001
	AHRI 440 Performance Rating of Room Fan-Coils	2008
	ANSI/AHRI 1230 Performance Rating of VRF Multi Split AC & Heat Pump Equipment	2010
Standard Air Handling Unit Construction	Eurovent RS 6/C/005-2017 Rating Standard for Certification of Air Handling Units	2016
	AHRI 1350 Mechanical Performance Rating of Central Station Air-handling Unit Casings	2014
	AHRI 430 Performance Rating of Central Station Air-handling Unit Supply Fans	2014
Hygienic Air Handling Unit Construction	VDI 6022 - Ventilation and indoor-air quality - Hygiene requirements for ventilation and air-conditioning systems.	2011
	DIN 1946-4 - Ventilation and air conditioning - Part 4: Ventilation in buildings and rooms of health care	2008

Certification & Design Standards for All Facilities		
SUBJECT	DOCUMENT	EDITION
	Eurovent RS 6/C/011-2017 Rating Standard for Certification of Hygienic Air Handling Units	2017
Boilers & Chillers	ANSI/AHRI 1500 Performance Rating of commercial Space Heating Boilers	2015
	ARI 550/590 Performance Rating of Water Chilling Packages Using the Vapor Compression Cycle	2017
Cooling Towers	CTI (Cooling Technology Institute) STD-201 Certified	2013
Ventilation Equipment	AMCA 210 Laboratory Methods of Testing Fans for Certified Aerodynamic Performance Rating	2016
	AMCA 300 Reverberant Room Methods for Sound Testing of Fans	2014
	AMCA 301 Methods for Calculating Fan Sound Ratings from Laboratory Test Data	2014

Hydronic System Design

Hydronic refers to the science of heating or cooling with water. Open systems are open to the atmosphere at least one location, such as cooling towers. Closed systems on the other hand are not open to the atmosphere.

Piping systems distribution scheme can be direct or reverse return. With the advent of Pressure Independent control valves (PICV), direct return systems outweigh the advantages offered by reverse return both in terms of cost and system simplification, so they are encouraged for new healthcare facilities.

All new facilities using hydronic cooling or heating system, should utilize pressure independent two-way control valves.

Hydronic piping distribution schemes should either be constant primary / variable secondary pumping or variable primary pumping. For Variable Primary Flow, the chillers must be provided with automatic isolation valves and the decoupler line provided with a control bypass actuated by a flow meter ensuring that the minimum flow through the chiller is guaranteed. Care must be taken in correct sizing of expansion tanks and air separators especially for heating hydronic systems.

Variable Primary Flow pumping systems are the preferred choice for future medium to large scale healthcare projects because they offer

- Low installed cost
- Reduced Mechanical room footprint
- Higher system efficiency
- Best response to Low Delta T syndrome.

Constant primary / variable secondary systems are also acceptable. Pumps should be in headered configuration and located in a controlled environment.

Refer to the Figure 2.1, 2.2, 2.3 for illustrative example of the various distribution schemes.

Pipe material should be Black Steel Schedule 40 with welded or grooved joints.

HVAC Insulation Requirements

All insulation should be rated to DIN EN 13501 A1, A2, B, C with S1 or S2 smoke performance and D0 droplet performance. ASTM E-84/UL 723 is only applicability should be checked as per material type. The system rating shall be based on insulation, jacket, adhesives, coatings, fittings, and cements. Any treatment of jackets or facings to impede flame and/or smoke shall be permanent.

Thermal performance, Vapor permeability and environmental performance should be as per local regulations. Anti-microbial requirements should be as per VDI 6022 or ASTM G21 or approved equal standard.

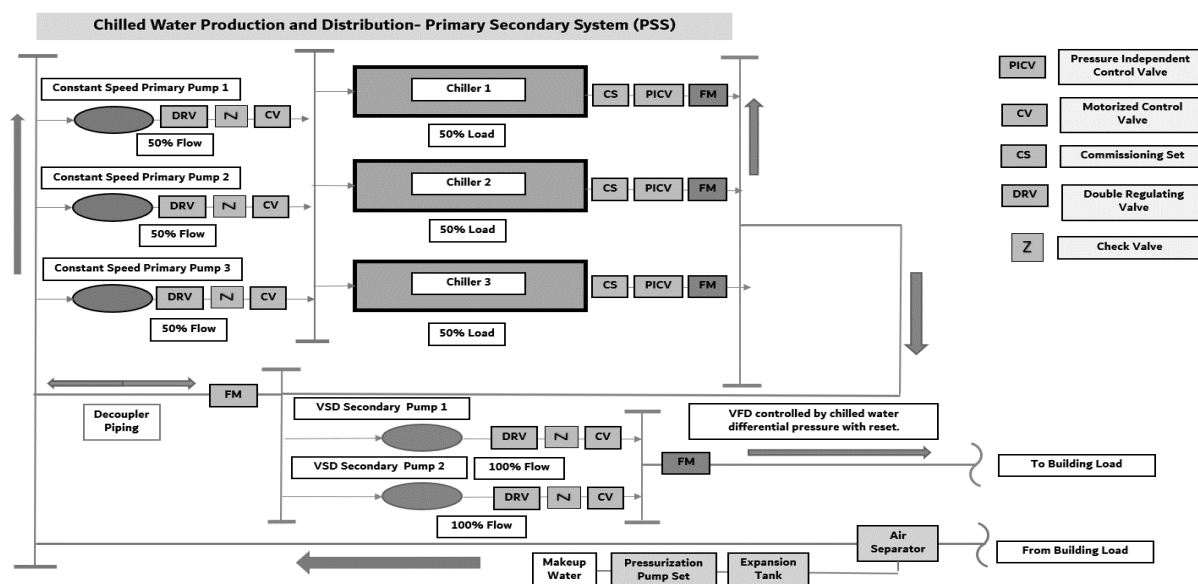


Figure 2.1

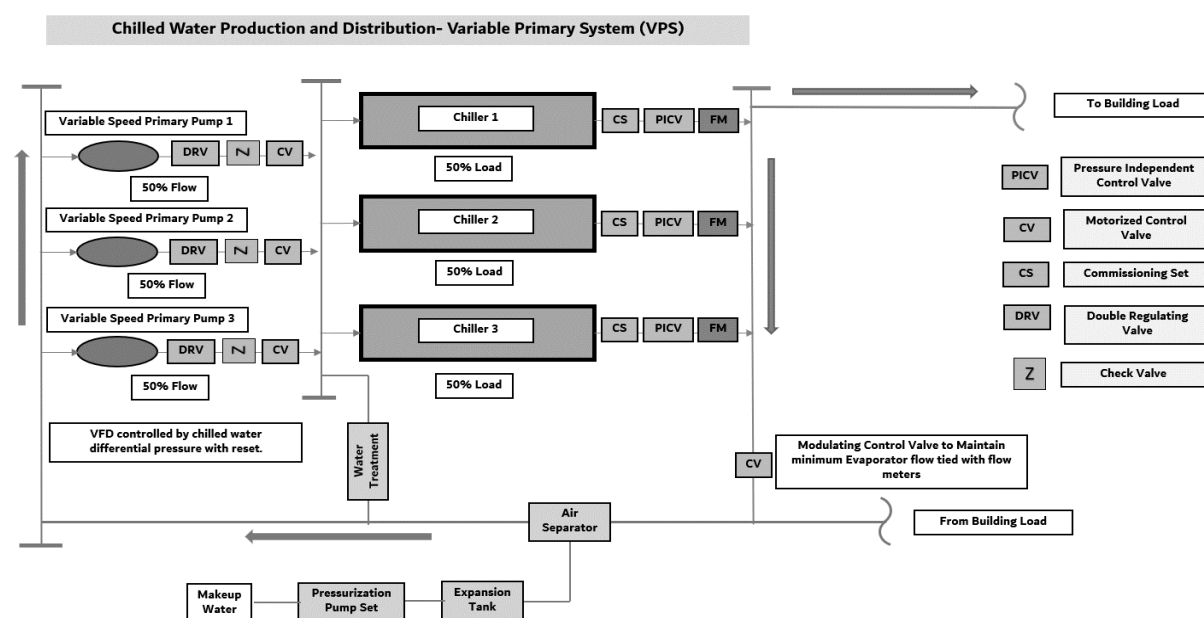


Figure 2.2

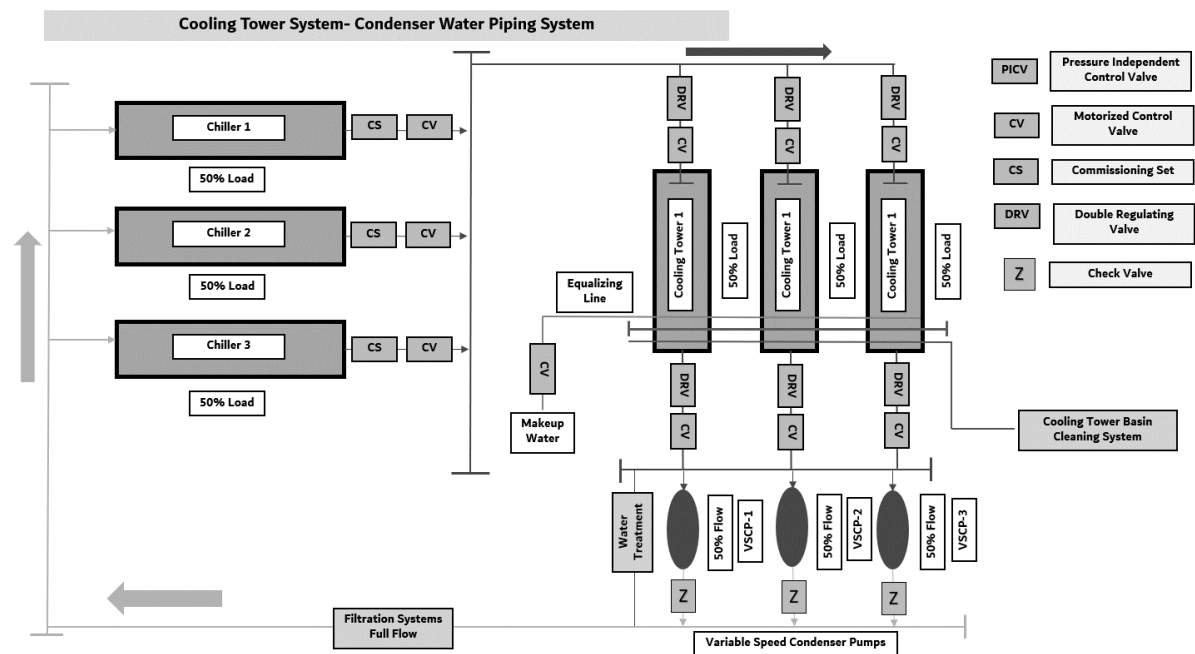


Figure 2.3

HVAC System Location Access & Maintenance

Major Equipment

Location

All significant HVAC equipment such as FAHU's, AHU's shall be located in enclosed mechanical plant rooms. The only HVAC equipment which may be located externally is the following:

- Exhaust Fans.
- Heat Rejection Equipment. (e.g. Air-cooled chillers, Air cooled condensers, Cooling Towers, etc.)
- Staircase & Lift core Pressurization Fans.
- Smoke Management Fans.

Rooftop/Exposed air handling units are not recommended in high humidity/hot conditions. Mechanical rooms shall be provided with air-conditioning & ventilation. In temperate/cold climates air handling units can be located on rooftop/exposed.

Access

Mechanical rooms and roofs with mechanical equipment shall be provided with staircase and preferably lift access to facilitate maintenance and equipment replacement. Access to mechanical rooms and roof mechanical areas shall be directly from cores or main corridors. It is not acceptable for the access to mechanical rooms to be through treatment or patient care areas.

Clear access routes through mechanical rooms and roof areas shall be provided from the staircases. Routes shall be clearly and permanently marked on the mechanical room floor. The minimum clear height for access routes shall be 2000mm or higher if dictated by the dimensions of equipment.

Steps on access routes are not acceptable. If changes of level are needed, or if services must be run at low level across an access route, a ramp must be provided.

Service Shafts

Location

Service shafts shall be strategically located to provide rational and flexible services installations and minimize the size of the distribution ductwork and pipework on each floor. It is recommended that main ductwork shafts are located away from stair cores and elevator shafts to allow ducts to enter and leave the shaft on all sides.

Pipework shafts are most suited to locations adjacent to structural cores.

In clinical facilities, shafts shall not be located inside surgery suites or critical care areas. If the designer encounters a specific situation where a shaft is needed in one of these spaces it should be discussed and agreed with AHJ during the schematic designs stage, through architectural design submission.

Access

Pipework shafts shall be provided with access doors at each floor level to allow for inspection and maintenance and installation of additional pipework in the future. Removable floor gratings are recommended to be provided where clear openings exceed 450mmx450mm.

Ductwork shafts shall be provided with access doors as needed to enable cleaning. It is anticipated that installation of additional ductwork would require the removal and replacement of wall finishes.

Terminal Equipment Locations

Locating HVAC equipment in ceilings above patient, staff and public areas shall be avoided where possible. Where it is necessary, its location shall be carefully selected to minimize the disturbance during maintenance and limit the infection control measures which are required to access it.

In clinical facilities it is not acceptable under any circumstances to have HVAC equipment accessed from the space in any of the areas listed below. Terminal units should be located outside the rooms in corridor spaces or other back of house spaces.

- Surgical Suite/ Zone
- Treatment Room
- All Critical Care Areas (ICU, CCU, NICU, PACU)
- Patient Rooms (permitted over ensuite)
- Sterile Store
- Fire Escape Horizontal Exit Passageway

The only exception is room side accessible terminal HEPA filters and fan filter units (FFU), where access is obtained through special housing's allowing quick replacement. All HEPA filters should be located at terminal locations.

Maintenance Strategy

It is strongly suggested that the designer develops an access and maintenance strategy document. This document shall clearly describe the access and maintenance strategy for all mechanical systems, including HVAC, plumbing and medical gas. Document shall be made available during the 90% stage inspection stage. The document must identify the strategy for plant maintenance and replacement including the following considerations:

- Locations with Accessible ceilings for terminal units (VAV, FCU etc.)
- Access and Maintenance clearances for major equipment.
- Major plant removal routes with mechanical rooms.
- Infection control and patient safety implications.

Design Considerations - HVAC Equipment's

The following section outlines the important design considerations that should be kept in mind while selecting HVAC equipment for healthcare facilities.

Central Plants

If the project is significantly large, it is beneficial to locate all major MEP equipment at a central location. This will help optimize the cost and increase the overall efficiency of all the systems.

District cooling availability for the project should also be ascertained at an early stage and if approved by the local district cooling provider the building should be designed to be hooked up to district cooling system. The building still must provide critical cooling (SSU, CSSD, Surgical Suite, Labor & Delivery Suite/Birthing Unit, Recovery, Emergency, Intensive Care, Nursery & optionally Inpatient Rooms) in case of failure of the district cooling network, by means of local heat rejection equipment owned by the building owner.

Remotely located central plant may use directly buried piping or use trenches/tunnels to connect to hospital building. When utilizing service tunnels, a minimum of 2000mm clear depth should be considered with a 900mm access passageway in between pipes to allow for sufficient space for maintenance.

Central Chilled Water Plant Considerations

The following recommendations are for central chilled water plants.

- Select cost-effective and optimum central chilled water plants and/or small chilled water systems to meet the project-specific requirements. Each installation shall consist of multiple (minimum two) chillers.
- For central plants and small systems, it is recommended to conduct a comprehensive study to evaluate and define the lowest life-cycle cost performance of the chilled water system. The study shall address both CAPEX and OPEX.
- Chillers shall be rated and certified as per AHRI conditions.
- Where a central plant serves more than one air handling system, the capacity of the central plant shall be calculated based on the peak simultaneous load, not the sum of the individual loads. In addition, the following diversity factors are reasonable when calculating central cooling plant capacity. The actual calculated central plant capacity shall be specific to the nature and size of the system(s) however and should be determined via computer simulation.
 - Lighting 0.9
 - Equipment 0.85
 - People 0.8
- For air cooled chiller in noise-sensitive locations, include chiller manufacturer's standard acoustic options in the design.
- Imaging systems such as MRIs, PET, CT Scanners, LINAC require chilled water for equipment process cooling. Central plants should be sized to cover process loads, if use of plant central chilled water use is approved by the imaging equipment manufacturer, otherwise a dedicated chiller plant must be provided. Typically, the chiller, buffer tanks, and pumps for these applications are provided by the manufacturer of the imaging equipment for installation by others.
- Potable water cooling should be provided as per the hydraulics engineering section of this report.
- Adequate space should be provided for equipment removal and maintenance. Replacement routes should be marked on the design drawings. Design for non-disruptive access to all chillers, pumps, cooling tower, and cooling tower components without the need to disassemble or remove other equipment or systems and/or building components such as piping, doors, walls etc.
- Higher delta T should be utilized to obtain energy savings by lowering pumping costs.
- Consider VFD driven equipment for further energy savings for any pump consuming over 7.5kW.
- Arrange piping, especially piping in hydraulic decoupler to ensure that all water flow meters have ideal flow conditions for accurate measurement. Follow worst case flow meter recommendations.
- Cooling Towers should be provided with an automatic basin cleaning system, which help in mitigating risks associated with natural calamities & the risk of legionella associated with manual cleaning.
- Cleaner environment friendly refrigerants should be utilized. ODP value should be 0 and GWP value should be less than 2500. HFO's are being developed which have much lower GWP values <10 and are encouraged for use.

Central Hot Water Plant Considerations

The following recommendations are for central hot water plants.

- Select cost-effective and optimum central hot water plants and/or small hot water systems to meet the project-specific requirements. Each installation shall consist of multiple (minimum

two) Boiler/Calorifier etc.

- For central plants and small systems conduct a comprehensive study to evaluate and define the lowest life-cycle cost performance of the hot water system. The study shall address both CAPEX and OPEX.
- Adequate space should be provided for equipment removal and maintenance. Replacement routes should be marked on the design drawings.
- Higher delta T should be utilized to obtain energy savings.
- VFD driven equipment should be utilized, for further energy savings.

Energy Benchmarking

Medium to Large scale healthcare projects are encouraged to apply the principles mentioned in ASHRAE 189.3 Construction, and Operation of Sustainable High-Performance Health Care Facilities.

In addition, LEED v4 for Healthcare guiding principles are also encouraged to be utilized for a sustainable healthcare building.

HVAC Major Source Equipment's

The following section lists out the specific requirements for major HVAC source equipment's to be utilized for healthcare projects. The aim is not to create an equipment specification list but to highlight essential elements of design related to each equipment which must be considered due to the critical nature of the healthcare facilities & the challenging climatic conditions.

Water Cooled Chillers

- Water cooled chillers can be centrifugal/screw or absorption type. Most common water-cooled chillers utilized are centrifugal chillers with single compressor or dual compressors based on the tonnage.
- Chillers should be in air-conditioned environment, with adequate clearance space for maintenance.
- Consultant is encouraged to undertake an LCC study for VFD chillers vs. standards chillers & also for the type of chillers used.
- Refrigerants with 0 ODP and less than 2500 GWP should be utilized for future healthcare projects.
- Provide emergency chilled water flanged piping connections covered with blind flanges and isolation valves for emergency chilled water service where redundant chillers are not installed.
- Chillers should adhere to the performance metrics listed in ASHRAE 90.1 or equivalent.

Air Cooled Chillers

- Air cooled shall be screw type for tonnage over 100 tons. Scroll type chillers can be utilized for smaller installations. Reciprocating chillers are not allowed to be installed in future healthcare projects.
- Consultant is encouraged to undertake an LCC study for VFD chillers vs. standards chillers.
- Provide emergency chilled water flanged piping connections covered with blind flanges and isolation valves for emergency chilled water service where redundant chillers are not installed.
- Chillers should adhere to the performance metrics listed in ASHRAE 90.1 or equivalent.

Cooling Towers

- Induced draft-type, counter-flow, factory-fabricated, and factory-test cooling towers are preferred choice for new construction and major renovation projects. The cooling towers shall be certified by the Cooling Tower Institute (CTI) and shall meet OSHA safety requirements.
- It is recommended that the Cooling Tower structure should be stainless steel, with FRP removable louvers and an FRP or Stainless-Steel basin.
- Consultant is encouraged to undertake an LCC study for VFD cooling tower fan motors vs. standard motors.
- Cooling Towers should be provided with a Basin cleaning system.

- Legionnaires Disease: When a new hospital building is constructed, place cooling tower(s) in such way that the tower drift is directed away from the hospital's air-intake system and design the cooling towers such that the volume of aerosol drift is minimized.

Heat Exchangers

- Heat exchangers used for HVAC applications for district cooling systems should comply with the regulations from the relevant district cooling provider etc.
- For potable water pre-conditioning and other applications plate and frame type heat exchangers should be utilized. It is recommended that two heat exchangers as a minimum are provided, each sized at 50% of the load.
- For low temperature hot water circuit for heating, heat exchangers can either be plate & frame type or shell & Tube type. It is recommended that two heat exchangers as a minimum are provided, each sized at 50% of the load.

HVAC Major Airside Equipment's

The following section lists out the specific requirements for major HVAC air side equipment's to be utilized for healthcare projects. The aim is not to create an equipment specification list but to highlight essential elements of design related to each equipment which must be considered due to the critical nature of the healthcare facilities.

Outside Air Energy Recovery Air Handling Units

Outside air units should employ means of energy recovery. Approved methods include

- Air to Air Plate Type Heat Exchangers. Preferred choice for areas where no cross contamination is permitted such as OR's.
- Heat Pipes. Allowed for all areas but offer lower energy savings.
- Total Energy Recovery Wheels. Allowed & encouraged for all areas except OR's. Must have a cross contamination limit of less than 0.04% by particulate count and have a purging section.
- Run around Coils. Allowed for all areas but offer lower energy savings.

Outside air energy recovery should not be employed for the following air streams. These should be directly exhaust to ambient with dedicated exhaust.

- Exhaust from all fume hoods and bio-safety cabinets.
- Kitchen Exhaust (Range hood and wet exhaust).
- Autopsy Exhaust.
- Isolation Room Exhaust.
- Wet Exhaust from cage and cart washers.
- ETO- Ethylene Oxide Sterilizers Exhaust.
- Refer to the Figure 2.4,2.5,2.6 for outside air handling unit approved configurations.
- Refer to the AHU section for other applicable notes.

Typical Healthcare Outdoor Air Handling Unit with Energy Recovery Design – Type A- Plate Type Heat Exchanger with Horse Shoe Heat Pipe

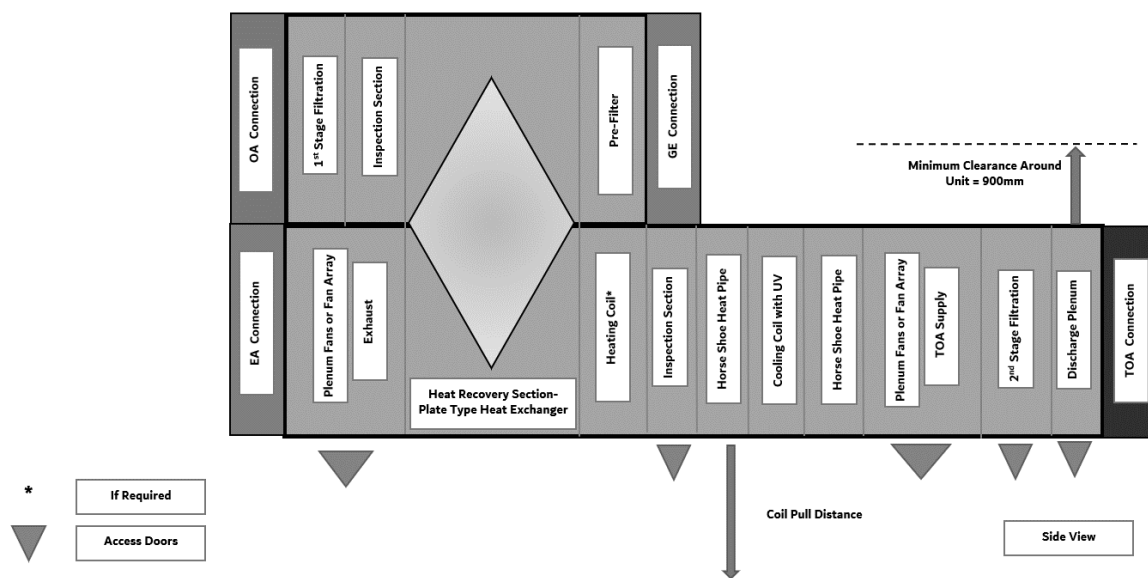


Figure 2.4

Typical Healthcare Outdoor Air Handling Unit with Energy Recovery Design – Type B – Enthalpy Wheel with Horse Shoe Heat Pipe

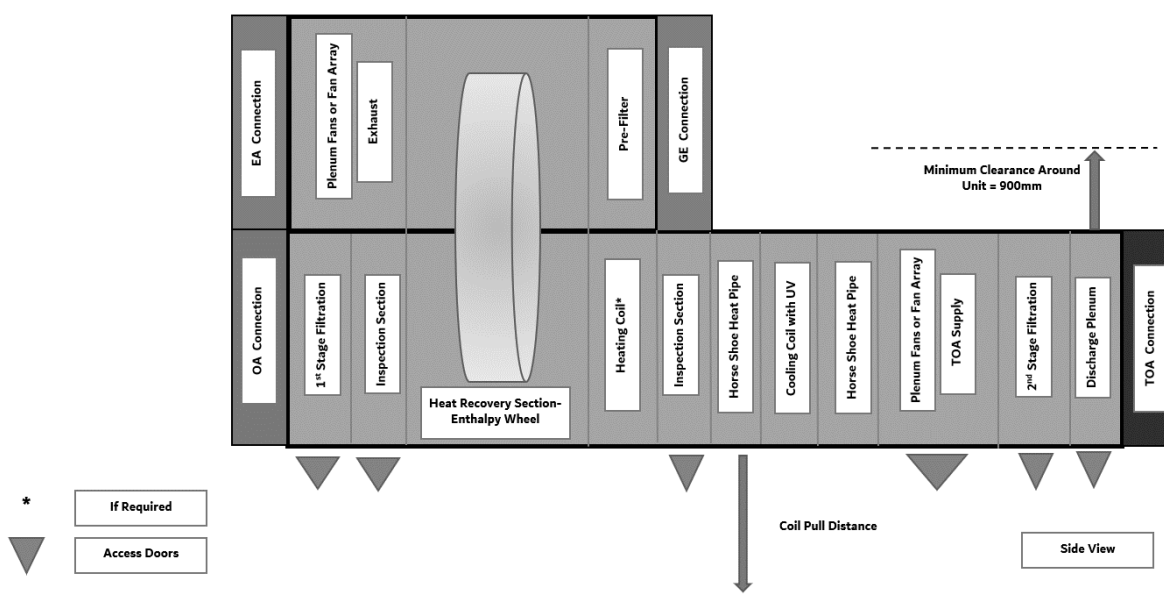


Figure 2.5

Typical Healthcare Outdoor Air Handling Unit with Energy Recovery Design – Type C – Double Energy Recovery Wheels

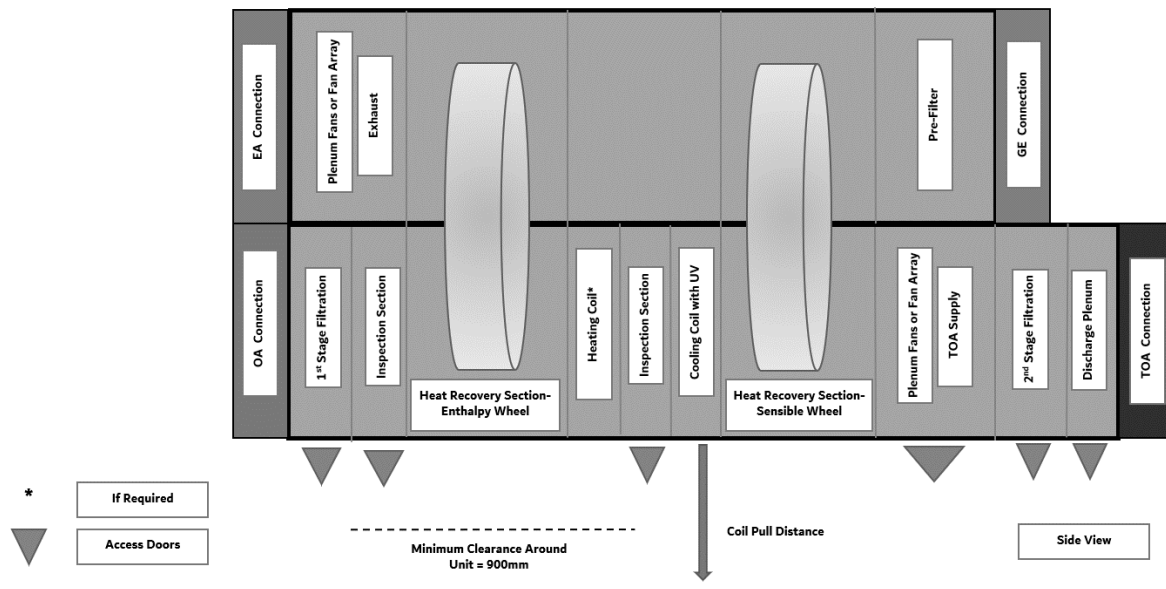


Figure 2.6

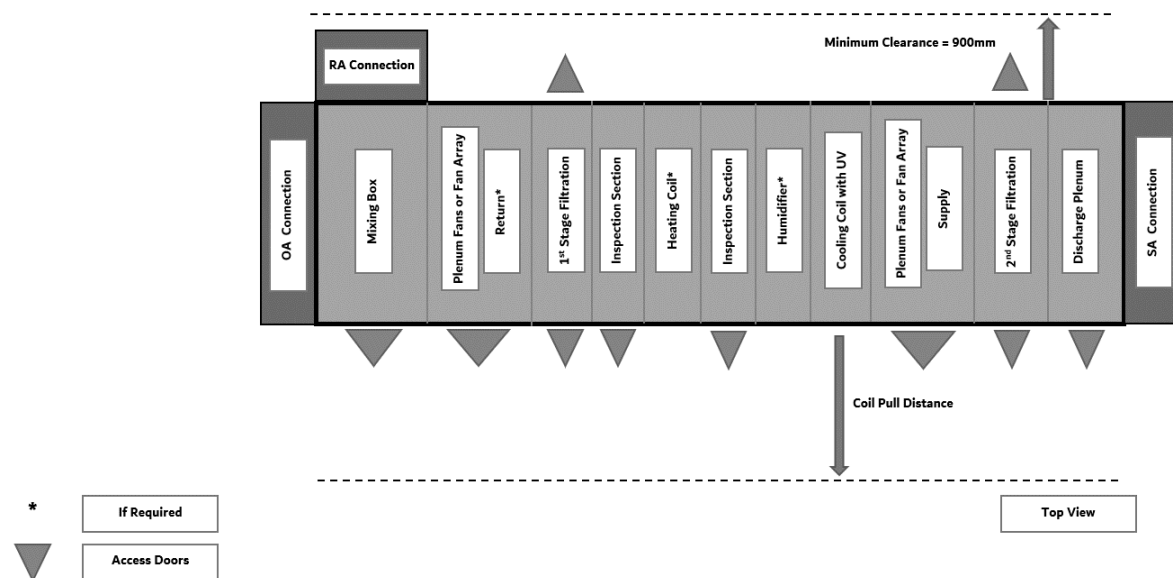
Air Handling Units

- The capacity of a single air-handling unit shall not exceed 50,000 m³/hr. [16,500 L/s].
- Air handling units shall be AHRI or Eurovent certified, factory-fabricated, and the standard product of one manufacturer. All air-handling units shall be constructed in modular and draw-through configuration. Use of blow-through air-handling units are not permitted, as fully saturated air leaving the cooling coil causes damage to the downstream filters and sound attenuators.
- Air handling units serving clinical areas should be hygienic type units. Refer to the materials section for required certifications and standards.
- To prevent cross contamination, separate AHU's should be provided as a minimum for the following spaces.
 - Operating Theatres
 - Mortuary
 - Main Kitchen
- Each air-handling unit shall be installed as a standalone entity without any physical interface with another air-handling unit. Selection of stacked (one on the top of another) air handling units is not permitted. Use of a common return air fan for two or more air-handling units is also not permitted.
- Use of a single or multiple plenum fan (fan array) is permitted & encouraged over housed, air-foil centrifugal fans. Fan motors shall be premium efficiency.
- Where room air can be returned to the system, provide a dedicated return or relief air fan for each air-handling unit to facilitate room-by-room air balance, economizer cycle, and intended volumetric air balance. Provide a direct digital control (DDC) interlock between the supply and return or relief air fans.
- Variable frequency drives (VFD) shall be utilized in all air handling units and rooftop units. Building type (e.g., hospital, outpatient facility, etc.) will determine level of redundancy required for VFDs. VFDs shall include either a bypass switch or be configured in a manner that failure of one VFD does not disable the entire unit. Fan motor shall be high efficiency.
- Each cooling coil shall not exceed six (6) rows and ten (10) fins per inch (FPI). Design two (2) coils in a series arrangement if the cooling coil capacity requirement exceeds the capability of a 6 row, 10 FPI coil. Chilled water shall be piped in series through both coils, and a 42-inch access section shall be provided between the two equally sized coils

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- Maximum cooling coil discharge face velocity shall not exceed 450 fpm. Heating coil discharge face velocity shall not exceed 800 fpm.
- Ultraviolet (UV) lamps shall be located on the leaving air side of the cooling coil.
- Access doors (or panels) on the air handling unit sections shall always open against the positive side of the door and shall not be blocked by internal filter casings or internal equipment components. Micro switches or safety switch interlocks need to be provided at access doors or panels on UV sections to protect maintenance personnel from possible injuries.
- Refer to Figure 2.7 for general AHU approved configuration.

Typical Healthcare Hygienic Air Handling Unit Design



Fan Coil Units

- All Fan Coil Units must be provided with a source of treated precooled dehumidified fresh air through the DOAS systems. Direct injection of outside air dumped over the ceiling void or ducted to units is not allowed.
- Fan coil unit systems served by chilled water with hot water or electric heating are an attractive solution for areas requiring special control or out of hours operation. Such areas include computer/communication rooms, lift machine rooms, distribution communications and electrical rooms, PABX rooms and administration areas. Fan coil units are not recommended for clinical areas where recirculation to be properly filtered.
- Fan Coil unit's usage is highly discouraged for new constructions for areas other than mentioned above, where adequate space for distribution ductwork can be provided.
- Select fan coil units that deliver the required capacity at medium speed.
- For new construction and major renovation, PICV should be provided for each FCU.
- FCU shall be located outside of patient occupied spaces/rooms for ease of maintenance.

Terminal Units (VAV, CAV)

- All terminal units shall be pressure-independent type and equipped with DDC controls. All air terminal units (constant volume or variable air volume) serving perimeter or interior spaces with permeant occupancy & mandated air change requirements as per Annexure A-1-Ventilation Rates, shall be equipped with integral reheat coils.
- The maximum and minimum air volume settings shall be factory set, but field adjustable. The minimum setting for each space should be dictated by the air change requirement, the ventilation requirement for multi zone VAV's based on ASHRAE 62.1 and the makeup air requirement for exhaust. The designer should list out minimum settings for each VAV box in the detailed design drawings.

- All rooms requiring acoustic treatment according to Annexure A-2- Acoustics, should be provided with terminal sound attenuators.
- Variable Air Volume (VAV) boxes shall be located outside of patient occupied spaces for ease of maintenance.

Air Valve Terminals

- If VAV systems are specified, Venturi Air Terminals or Air Valves with high speed actuators are highly recommended to be utilized for all new construction and major renovation for the following space types in lieu of VAV boxes due to their higher reliability and stable airflow control.
- Operation Theatre
- Pharmacy Clean Rooms
- Isolation Rooms
- Laboratories with Fume Hoods (Should be equipped with a 3 sec or faster response actuator)
- Additional rooms as identified by the building end user that have strict pressure control requirements due to infection control issues.
- Venturi air terminal should be programmed as using the variable air volume approach with maximum energy savings. Usage based controls can also be employed at the facility owner's discretion. Each airflow control device shall be factory characterized on air stations NVLAP Accredited.
- Venturi Air Valves shall be located outside of patient occupied spaces for ease of maintenance.
- For an AHU provided with downstream venturi air terminals, it is preferable to utilize all venturis instead of a combination of venturi terminals and VAV/CAV terminals due to varying pressure drops. Low speed venturis and constant air venturis can be used for non-critical areas, for cost savings.

Humidifiers

- The need for humidification should be ascertained by psychrometric studies. If humidification is required at a large scale it can be achieved through a clean steam network utilizing steam boilers or electric steam generators.
- If active humidification is only required for critical areas such as OT, burns unit etc. it is better to be achieved by small individual package electric humidifiers.
- The humidifier should be located prior to the cooling coil and fed with clean steam (steam generated from RO or DI water and piped using stainless steel). Smaller ceiling mounted electric units should also be fed with RO or DI water.
- If duct mounted humidifiers are used 304 stainless steel ducting should be provided for a minimum of 1.5m downstream and 0.5m upstream of the humidifier. Designer Team to verify the absorption distance for each application and adjust the length of stainless steel accordingly. Duct sections downstream of steam humidifiers shall be sloped to a low point with drain valve and cap.

Diffusers, Registers and Grilles

Diffusers, Registers, and grilles should be specified as per the project requirements and in alignment with the clinical and interior design. Air Diffusion Performance Index (ADPI) shall conform to selection criteria given in ADPI table of the "Room Air Distribution" chapter of the ASHRAE Handbook – HVAC Applications 2015.

Terminal HEPA filters for all spaces other than OT's served by dedicated AHU's should be Fan powered type, catering for the entire pressure drop of the filter, allowing for the AHU supply fan to be sized for only the pressure drop of the secondary filtration.

Ductwork

- Rectangular galvanized steel has consistently been shown to be more cost effective as compared with rigid circular ductwork which is both less efficient in its space requirements and normally more expensive because of the excessive costs of fittings.

- All clinical areas shall be provided with a fully ducted system. Use of the ceiling void, for air delivery (supply or return) is not allowed, only back of house areas and admin areas can use return air plenum but should be provided with appropriate sealing and smoke sensors.
- Duct sizing is to be based on the recommended velocity and pressure drop ranges in the project specifications, SMACNA & ASHRAE or equivalent.
- Air handling duct systems shall be designed to be accessible for duct cleaning, generally by the provision of access panels. Access panels shall be fitted at each reheat coil and fire and smoke damper to allow annual Essential Services inspection.
- It is encouraged to provide anti-microbial coating on the internal surface of the duct complying with ASTM 3152 and ASTM G21 or equivalent standard.
- Commercial dishwasher exhaust, steam sterilizer, and sterile washer exhaust shall be type 304 stainless steel with welded joints.
- Laboratory hood exhaust ductwork shall be 304 stainless steel with welded joints.
- Kitchen hood exhaust shall be 16-gauge black steel where concealed and 18-gauge, type 304 stainless steel, welded and polished to a No. 3 finish, where exposed.

HVAC Services Instrumentation and Control

HVAC Instrumentation and Control systems which are commonly part of the BMS systems are integral to the proper operation of a healthcare facility. BMS Control systems form the backbone of the operation and maintenance system for HVAC and provide the facility management team with information regarding equipment life & operational performance.

The following points should be kept in mind while designing a BMS system for healthcare applications.

- The BMS system shall be suitable, compatible, scalable, and flexible to meet the demands imposed by healthcare facilities. The system shall have spare capacity at field level to allow for departmental changes and equipment changes.
- All actuation shall be electronic.
- Specific requirements related to control actuators, control valves, control dampers, end switches, safeties and safety alarms, control wiring, air flow measuring stations, room temperature & humidity sensors, DDC control systems servers & tablet displays should be detailed within the project drawings and specifications.
- A detailed Input/output point list should be prepared by the consultant in consultation with specialist solution providers and included as part of the project tender documentation.
- BMS systems should be configured to optimize energy usage.
- Control algorithms should be programmed to utilize the data collected and allow for effective energy recovery, air-side filter diagnostics, critical alarms, and sensor calibration checks.
- Ensure system is capable of robust metering. Separate sub-meters should be allocated for lighting, HVAC plant, HVAC distribution, general power, service water heating, renewables, and whole building power & water as a minimum. Energy use should be benchmarked every month. Facility managers should be trained on continuous benchmarking.

HVAC Systems Commissioning & Handover

The HVAC systems commissioning is an important phase in the project timeline and is critical in confirming that the design parameters are met by the installed system and the system meets the minimum code requirements related to air changes, filtration effectiveness and infection control.

For medium to large scale healthcare projects an independent commissioning agent (CxA) should be employed the facility owner/client to oversee the commissioning process.

The following points should be kept in mind while preparing for commissioning of HVAC systems for healthcare facilities.

- Method Statements should be provided by the contractor during the commissioning phase for all HVAC equipment.
- Testing and Commissioning plan should be developed by the contractor in consultation with the CxA to provide a clear and concise roadmap for the implementation of the commissioning

process and to provide a record of the results of the commissioning process.

- The design consultant should engage with the owner and the facility management team and develop the Owner's Project Requirements (OPR). Furthermore, these should be formulated in a report along with the design narrative, submitted as part of the construction documentation submitted to the contractor.
- Follow ASHRAE Guideline 0-2013 and ASHRAE Guideline 1.1-2007 for HVAC&R Systems commissioning.
- It is encouraged to develop monitoring-based procedures and identify points to be measured and evaluated to assess performance of energy and water through advanced meters.
- It is encouraged to perform a building flush out for IAQ prior to occupancy or conduct testing for IAQ for particulate matter and inorganic gasses to kept under allowances mentioned in codes and standards.
- As a minimum space pressurization report is required for the following spaces:
 - Class N & Class Q -Airborne Infection Isolation Rooms
 - Class P- Protective Environment Rooms
 - Bone Marrow Transplant
 - IVF Labs and Procedure Rooms
 - Operating Rooms
 - Interventional Imaging Rooms
 - Pharmacy Clean Rooms
 - Laboratory Clean Spaces
 - Sterile Processing Rooms
 - Sterile Storage Rooms
 - Vivarium Areas
 - Operating Rooms and other clean rooms should be tested for particle counts as per international standards.
- The commissioning agent (CxA), Testing Adjusting and Balancing Contractor (TAB), MEP Contractor, Controls Contractor (BMS Contractor) should work together on the commissioning of systems and provide all reports and test results as well as arrange for witness testing for agreed systems for the owner's representative and the supervision consultant.
- Functional Testing for all critical systems should be included in the scope of works.
- O&M Manuals for all HVAC equipment should be provided by the contractor.
- Training on the systems installed should be conducted by the contractor's team for the owner's facility management team.
- FM Team should keep a record of all O&M activities on site, preferably through an electronic record keeping system.

HVAC- Room Side Design

The intent of this section is to identify key design elements related to the various spaces found within a healthcare environment and provide a checklist that must be adhered to for approval of new construction and major renovation projects.

Operating Rooms

Following requirements must be adhered too for Operating Room HVAC systems.

- Proper temperature (18-22°C), humidity (20-60% RH) and ventilation control for the comfort of surgical personnel and patients & to environmentally discourage the growth and transmission of microorganisms for general operating rooms.
- Operating-room ventilation systems should produce a minimum of about 20 ACH of MERV 17 HEPA (99.995% MPPS as per EN 1822) filtered air for thermal control, 4 ACH (20%) of which must be outside air. Air should be introduced at the ceiling and exhausted near the floor.

- Each operation theater should be provided with a dedicated air handling unit.
- Air Handling units for operation theater should be provided with VFD's to allow for variable speed to cater for HEPA filter loading.
- Air handling units should supply constant volume (20 ACH) airflow. Constant volume systems are common and should be the basis of design as complicated systems lead to operational issues during operation and maintenance.
- Variable systems are permitted for use "only if" they continue to provide a positive room pressure (normally +0.01-0.04 in. wg or +2.5-10 Pa differential) with respect to the corridors and adjacent areas and the required ACHs are maintained when the room is occupied. This can be achieved by communicating fixed offset air-valves. Active Monitoring of pressure is required through a pressure display monitor, connected to the BMS system. Space temperature, humidity and air change rate shall be displayed simultaneously. Pressure monitor should have an IP-54 rated housing, resistant to spray wash down & decontamination chemicals. Accuracy RSS of at least +/-0.25% full scale. This guide recommends an air differential of 10 Pa. Refer to figure 2.8.
- HEPA-filtered airflow should be dissipated through laminar airflow diffusers. Laminar airflow must be designed to move clean air over the aseptic operating field at a maximum face velocity (0.15–0.3 m/s), sweeping away particles in its path. All laminar flow diffuser should be room side accessible. Laminar flow array should entirely cover an area equivalent to the footprint of the surgical table plus 305mm on each side as a minimum.
- UVGI (Ultraviolet Germicidal Irradiation) should be provided as additional measure to reduce SSI (Surgical-Site Infection) risks.
- Medical plume evacuation system should be provided for OR's using lasers and other instruments generating plumes. This equipment should be part of the medical equipment package as a standalone equipment.
- Amount of reheat should be minimized, through supply air temperature reset, if humidity conditions can be met, and through reduced airflow when the operating room is not occupied.
- Special low temperature requirements related to heart and orthopedic surgery should be ascertained early in the design process and a corresponding low temperature chilled water circuit be provided to meet the surgeon's desired temperature (if required). It is to be noted that temperatures as low as 16 C DB can be required in operating rooms. Special elevated temperature requirements related to burn and pediatric units should also be ascertained, and systems designed to suit with space heating & humidification.
- Surgeons should only be allowed to set the dry bulb temperature. Humidity display should be provided.
- Humidity and temperature sensors should be provided in the return air duct for system control.
- In general, operating room air handling units should be designed at 2 m/s air velocity at the coil to allow for lower leaving air temperatures.
- In general, operating room chilled water pipes to the AHU should be designed at higher velocities in the range of 1.8 m/s to 2 m/s to allow for better heat transfer.
- Refer to Figure 2.8 for operating room airflow configuration and pressure relationship.

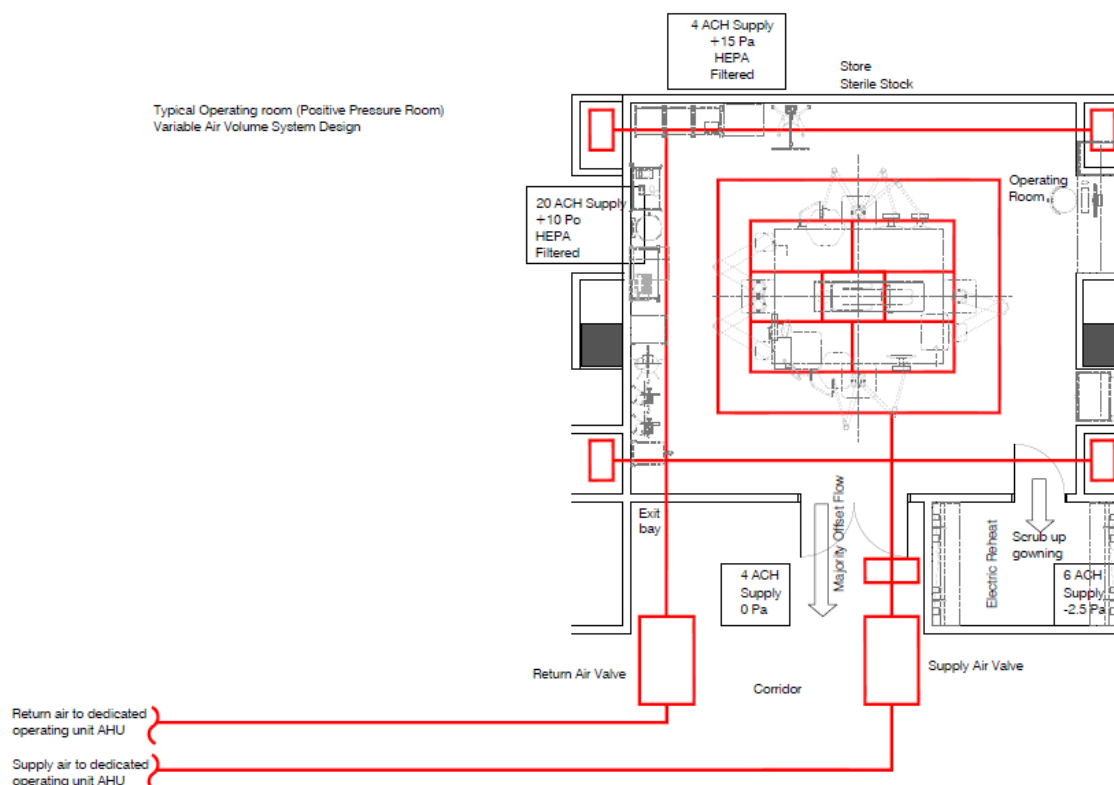


Figure 2.8

Imaging Rooms

Following requirements must be adhered too for Imaging Room HVAC systems.

- Imaging rooms can be grouped into 4 types as mentioned below, each having their respective requirements.
 - X-Ray (CT, Radiography, Fluoroscopy)
 - Ultrasound (Diagnostic Treatment)
 - Magnetic (MRI)
 - Nuclear (PET Scan, Linear Accelerator LINAC, Nuclear Camera, Gamma Knife)
- In general Imaging rooms fall under diagnostics which require 6 ACH minimum of supply air with 2 ACH of outside air & a Temperature requirement (21-24°C), humidity (<60% RH).
- Imaging rooms do not require dedicated air handling units and can be served from the same air handling unit serving the rest of the radiology suite.
- Imaging rooms designed for treatments such as fluoroscopy (e.g. vascular, cardiac catheterization, interventional lab, cystoscopy, electrophoresis(EP)) carry a prescriptive requirement for treatment rooms 15 ACH of supply air with 3 ACH of outside air but are recommended to be designed to operating rooms standard as mentioned in section 2.15 for future flexibility. All relevant clauses applicable should be adhered to.
- Data should be obtained from Room Data sheets for the control room, procedure room and equipment room heat dissipation.
- Wherever possible water-cooled medical equipment should be preferred. Process water cooling can be provided via dedicated medical grade chillers backed up by central chilled water system or with the central chilled water system backed up by chilled potable water. Discussion on the system and its criticality should be brought up by the designer to the facility owner during concept design.
- MRI rooms must be designed to cater for the heat load produced by the equipment. As a minimum 6 ACH of supply air and 2 ACH of outside air should be provided. Following key considerations should be accounted for.

- All materials in the room should be nonferrous.
- No rotating equipment (motors, fans) should be placed within the 1 gauss field.
- Chilled water requirements as per point above.
- Provide an insulated stainless-steel quench pipe with proper thrust restraints sized as per manufacturer guidelines and vented to outside with the exclusion zone clearly marked.
- Provide an emergency exhaust fan sized at 12ACH to exhaust helium. This can also be used to purge clean agents in case of fire.
- Provide an overpressure relief grille.
- PET & SPECT Scan rooms are diagnostic rooms requiring 6 ACH SA/2 ACH OA. All air should be exhausted via the general exhaust system from the scanning rooms. Chilled water requirements as per point 6. Hot labs, Radio pharmacies provided with PET and SPECT scan rooms normally house BSC II Hoods and should be provided with dedicated hood exhaust with bag-in bag-out filtration for isotopes and general exhaust from the space.
- LINAC rooms are also diagnostic rooms with no invasive procedures being carried out. Regular requirements of 6ACH SA/ 2 ACH OA will suffice. Humidity should be kept less than 50%. Chilled water requirements as per point 6. Modern day LINAC's are often coupled with MRI's within the same suite. Care should be taken to accurately calculate the heat dissipation and cater for all requirements of MRI room as per point 7.

Laboratories

Following requirements must be adhered too for Laboratories HVAC systems.

- Proper temperature control (21-24°C), maximum 60% RH with 6 ACH SA/ 2 ACH OA should be provided for all labs.
- All Laboratory work areas should be 100% exhausted to outside through general exhaust passed through heat recovery.
- Fume hoods and Bio Safety cabinets located within the labs should be exhausted to the ambient through high plume dilution fans through proper filtration. Exhaust from BSC cabinets can be combined into a single manifold, provided they carry the same class of air and exhausted through N+1 exhaust fan. Similar approach can be adopted for Fume cupboards. Engineer should minimize the number of fans for operational efficiency and maintainability of the system.
- Labs containing Fume Hoods or BSC cabinets should be provided with laminar flow diffusers located at appropriate locations.
- Flammable cabinets should be provided with ventilation with dedicated exhaust fan and discharge.
- Variable systems are permitted for use "only if" they continue to provide a negative room pressure (normally -0.01-0.04 in. wg or -2.5-10 Pa differential) with respect to the corridors and adjacent areas and the required ACHs are maintained when the room is occupied. This can be achieved by communicating fixed offset air-valves for the supply, general exhaust, and hood exhaust (one per BSC). Active Monitoring of pressure is required through a pressure display monitor, connected to the BMS system. Space temperature, humidity and air change rate shall be displayed simultaneously. Pressure monitor should have an IP-54 rated housing, resistant to spray wash-down & decontamination chemicals. Accuracy RSS of at least +/- 0.25% full scale.
- Laboratory sterilizing areas should be provided with 10 ACH SA/ 2 ACH OA.

Pharmacy

Following requirements must be adhered too for Pharmacy HVAC systems.

- As a minimum Pharmacy spaces should be provided with temperature control (21-24°C), maximum 60% RH with a 4 ACH SA/ 2 ACH OA.
- Pharmacy should be kept at positive pressure. VAV systems are permitted without compromising on the pressure requirement.
- In-patient pharmacy providing compounding facilities should be designed according to USP

797.

- Vault, if designed for controlled substances should be provided with cooling with supply and return air.
- Pharmacy clean rooms (if required by clinical planning) should be designed to ISO Class 7 Standard according to ISO 14644, unless stated otherwise for the project by the operator, providing a minimum of 40 ACH of HEPA filtered air, with a ceiling coverage between 30%-40%, keeping the maximum face velocity under 0.15 m/s and providing low level return. These should be provided with an ISO Class 8 ante room, providing a minimum of 20 ACH of HEPA filtered air.
- HEPA filters modules should be fan filter type to reduce central fan size.
- Clean rooms should be kept at positive pressure except when used for hazardous drugs which should be negative pressure with associated ante room at positive pressure. Clean rooms should be certified to ISO 14644 standard.
- Hazardous drugs compounding clean rooms are provided with BSC cabinets. The exhaust from these cabinets should be filtered with a carbon filter and a hepa filter before being discharged through a high plume dilution fan or an exhaust stack.
- Clean room personal are wearing heavy protective clothing so lower temperature should be considered as a design requirement, 20 C.

Patient Rooms

Following requirements must be adhered too for Patient Room HVAC systems.

- As a minimum Patient rooms should be provided with temperature control (21-24°C), maximum 60% RH, with a 6 ACH SA/ 2 ACH OA.
- Each patient room should be provided with a thermostat linked with the BMS system (if available).

Intensive Care Rooms- Critical Care Rooms

Following requirements must be adhered too for Intensive Care Room HVAC systems.

- Intensive Care rooms include specialized rooms such as Surgical Intensive Care (SICU), Medical Intensive Care (MICU), Cardiac Care Unit (CCU), Pediatric Intensive Care Unit (PICU), Neonatal Intensive Care Unit (NICU), High Dependency Unit (HDU) etc. All these rooms require a minimum of 6 ACH SA/2 ACH OA with temperature range of 21- 24°C, and 30-60% RH.
- ICU areas should not be served with recirculating type units such as FCU's.
- Reheat should be provided to each ICU room/bay. Thermostat should be linked with the BMS system (if available).

Morgue & Autopsy

Following requirements must be adhered too for Morgue & Autopsy HVAC systems.

- As a minimum Morgue & Autopsy spaces should be provided with temperature control (20-24°C), maximum 60% RH with a 12 ACH SA/ 2 ACH OA.
- Air should be supplied via unidirectional flow diffusers.
- Exhaust grilles should be located at both high level and low level.
- All air should be exhausted outside through dedicated ductwork.
- Direct exhaust connection to the autopsy table should be provided. Exhaust air should be HEPA filtered, UV treated, and carbon filtered for odors and discharged at a high velocity, preferably using a stack. Since autopsy is normally not carried out at private facilities, this requirement will not apply.
- Body Holding refrigerators should be designed by the specialist manufacturer. Designer to take the heat dissipated for the refrigerators into account while designing the HVAC system.
- Negative room pressure (normally -0.01-0.04 in. wg or -2.5-10 Pa differential) with respect to the corridors and adjacent areas is required. Active Monitoring of pressure is required through a pressure display monitor, connected to the BMS system.

Isolation Rooms

Isolation rooms can be classified into 3 categories.

- Class N- Airborne Infection Isolation Rooms (AIIR) – Negative Pressure Isolation Room
- Class Q – Quarantine Isolation – Negative Pressure Isolation Room with Clean and Dirty Utility.
- Class P- Protective Environment Isolation Rooms (PE)- Positive Pressure Isolation Room.
- Class S- Standard Isolation Room - Contact Isolation Room- Neutral Isolation Room.
- Switchable Pressure Isolation Rooms – No longer allowed by standards like FGI/ASHRAE.

Class N- Negative Isolation Room

- Proper temperature (21-24°C), humidity (<60% RH) and ventilation control, minimum 12 ACH SA/ 2 ACH OA, anteroom 10 ACH SA.
- Use of negative pressure rooms with close monitoring and control of airflow direction (normally -0.01 to -0.04 in. wg or -2.5 to -10 Pa differential). Negative pressure to be maintained during un-occupied mode by communicating Air Valves. Provide differential pressure monitor with alarm points to building automation system. Space temperature, humidity and air change rate shall be displayed simultaneously. Pressure monitor should have an IP-54 rated housing, resistant to spray wash down & decontamination chemicals. Accuracy RSS of at least +/- 0.25% full scale. This guide recommends a negative pressure of 10 Pa for the class N room. Refer to figure 2.9.
- Seal room below 0.5 ft²(465 cm²) of air leakage (called Effective Leakage Area under 4 Pa pressures differential test)
- Exhaust air grille should be placed over the patient head or at low level near the head. Air from negative pressure rooms is to be HEPA-filtered with a bag in bag out filter and exhausted directly to the outside with dedicated N+1 high plume dilution exhaust fans discharged 10 feet above roof level. Recirculation is not allowed. Air from other AIIR rooms can be mixed provided each room is providing with a VAV or Air Valves prior to connection.
- UVGI fixtures may be placed in upper room, or inside the ducts as an additional measure, but are not a mandatory requirement.
- Pressure relationship should be negative with respect to the ante room with the ante room negative with respect to the corridor.
- Refer to Figure 2.9 for AIIR room airflow configuration. Room exhaust and supply air valves should be VAV type while the remaining

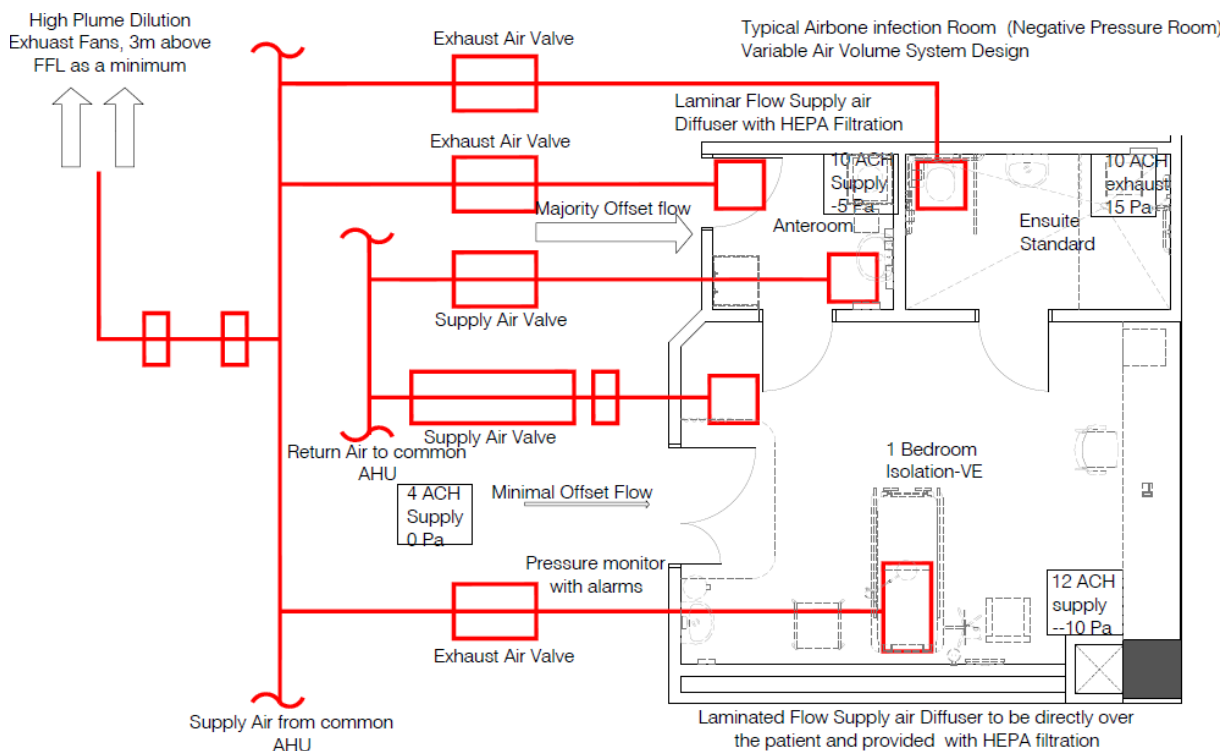


Figure 2.9

Class Q- Negative Isolation Room

- All the requirements for Class N rooms must be adhered too for Class Q rooms.
- In addition, supply should be provided with HEPA filters similar to Class P rooms.
- Class Q isolation suite will contain a dirty utility as well. That should also be exhausted to outside, similar to the bedroom, ante room and toilet.

Class P-Positive Isolation Room

- These rooms are to be designed for high-risk, immuno-compromised patients (BMT, organ transplant, leukemia, burn, late-stage HIV) and to minimize fungal spore counts in air.
- Proper temperature (21-24°C), humidity (<60% RH) and ventilation control, minimum 12 ACH SA/ 2 ACH OA, anteroom 10 ACH SA.
- Incoming air through HEPA filters or fan powered HEPA filters mounted in laminar flow diffusers, supply air on top of the patient bed and exhaust out through the opposite side of the room, preferably at low level.
- Pressure of +2.5 Pa (0.01" w.g.) relative to the corridor as a minimum. Provide differential pressure monitor with alarm points to building automation system. Space temperature, humidity and air change rate shall be displayed simultaneously. Pressure monitor should have an IP-54 rated housing, resistant to spray wash down & decontamination chemicals. Accuracy RSS of at least +/-0.25% full scale. This guide recommends a positive pressure of 10 Pa for the isolation room. Refer to figure 2.10. Room return and supply air valves should be VAV type while the remaining valves for ante room and toilet can be CAV types.
- Seal room below 0.5 ft²(465 cm²) of air leakage (called Effective Leakage Area under 4 Pa pressures differential test)
- UVGI fixtures can be placed in upper room, or inside the ducts as an additional measure.
- Pressure relationship should be positive with respect to the ante room with the ante room positive with respect to the corridor.
- Refer to Figure 2.10 for PE room airflow configuration.

Class S-Contact Isolation Room

- These isolation rooms are used to provide physical isolation for patients having a communicable disease which is not airborne as chicken pox, etc. Requirements for regular patient rooms apply.

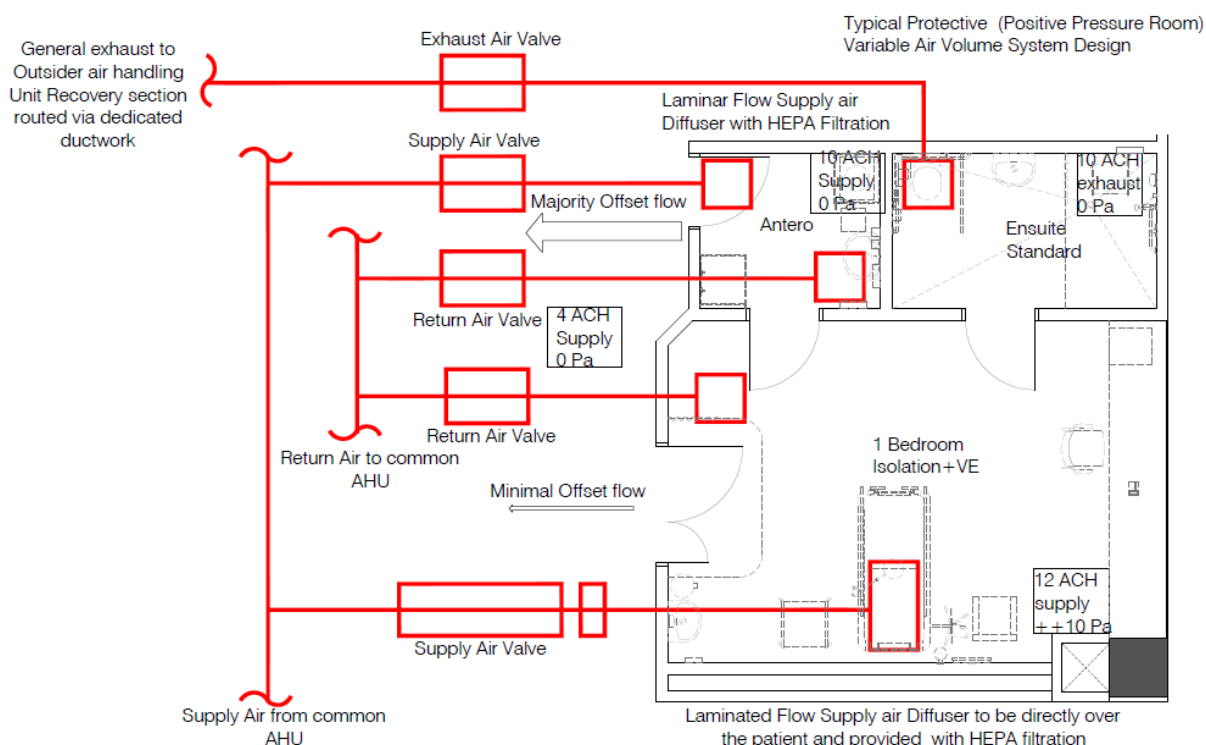


Figure 2.10

SSU (CSSD)

Following requirements must be adhered too for SSU(CSSD) HVAC systems.

- SSU(CSSD) can be broken down into 3 areas.
 - Dirty Area – 6 ACH SA/2ACH OA with 100% dedicated exhaust and negative pressure. Temperature 16-23°C
 - Clean Area- 4 ACH SA/2 ACH OA with positive pressure. Temperature 20-23°C
 - Sterile Store – 4 ACH HEPA filtered SA/ 2 ACH OA with positive pressure. Temperature 24°C
- Means of recording daily temperature and humidity should be provided via the BMS system for all spaces.
- Exhaust ductwork should be stainless steel for durability.
- Direct exhaust from washers, disinfectors and sterilizers should be provided as per the Room Data Sheets.
- Where ethylene oxide (ETO) sterilizers are used and ETO is stored system shall be designed to provide 100% dedicated exhaust to outside. Upon loss of exhaust system airflow, an audible and visual alarm shall activate in the sterilizer work area, and at a location that is continually staffed.

Renal Dialysis & Chemotherapy

Following requirements must be adhered too for Renal Dialysis Patient Bays systems.

- Room/Bay can be considered as having the same requirements as standard patient room.
- Consider radiant heating panels directly over the patient chair/bed for radiant heating as dialysis/chemo patients are frequently cold, anemic & immobile for the duration of the treatment.

- Consider low design velocities of below 0.25 m/s at the treatment bed/chair, preferably through laminar flow diffusers.

Recovery (Post Anesthesia Care Unit)

Following requirements must be adhered too for PACU Recovery area HVAC systems.

- As a minimum PACU room should be provided with temperature control (21-24°C), 30- 60% RH, with a 6 ACH SA/ 2 ACH OA.
- Low level return should be provided with stainless steel grilles to capture the anesthetic gasses being exhaled by the patients and allow for better flushing of the space.
- Each room/bay should be provided with a thermostat linked with the BMS system (if available).

Emergency

Following requirements must be adhered too for Emergency area HVAC systems.

- Decontamination Room: Temperature control (21-24°C), with a 12 ACH SA/ 2 ACH OA, negative pressure. All air should be 100% exhaust with dedicated ducting.
- Exam/Treatment Room: Temperature control (21-24°C), maximum 60% RH, with a 6 ACH SA/ 2 ACH OA, positive pressure.
- Resuscitation (Trauma) Room: Temperature control (21-24°C), 20-60% RH, with a 15 ACH SA/ 3 ACH OA, positive pressure. If Trauma is to be utilized as emergency Operating room under the hospital's disaster management scheme, operating room requirements should be imposed.
- Triage: Temperature control (21-24°C), maximum 60% RH, with a 12 ACH SA/ 2 ACH OA, negative pressure. All air should be 100% exhaust with dedicated ducting.
- Emergency Department Public Waiting Area: Temperature control (21-24°C), maximum 60% RH, with a 6 ACH SA/ 2 ACH OA, negative pressure. All air should be 100% exhaust with dedicated ducting.

Burn Units

Following requirements must be adhered too for Burn Unit Room HVAC systems.

- As a minimum Burn Units rooms should be provided with temperature control (21-32°C), 40-60% RH, with a 6 ACH SA HEPA Filtered with laminar flow diffusers / 2 ACH OA. Room should be at positive pressure.
- Each patient room should be provided with a thermostat linked with the BMS system (if available).
- Each patient room should be provided with an individual humidifier and a humidistat to control the humidity level in the room.
- Each patient room should be provided with reheat sized to raise the temperature to 32°C inside the room.

Bone Marrow Transplant Rooms

Requirements for Protective Environment PE Isolation rooms should be applied for Bone Marrow Transplant rooms.

Hydrotherapy & Therapeutic Pools

Following requirements must be adhered too for Hydro-Therapy Pool HVAC systems.

- Should be provided with temperature control (26-28°C), with the ability to reheat up to 32°C, with a minimum of 10 ACH SA / 100% exhaust from the space. Space should be at negative pressure.
- Provide a dedicated or common wet exhaust system with welded stainless-steel ductwork. To allow for energy saving, VAV system can be employed via supply and exhaust terminal during unoccupied mode.
- The Spinal cord injury patient requires 33°C (92°F) water temperature, while the patient with

multiple sclerosis requires 28°C(84°F) water temperature. The pool equipment should be designed to accommodate rapid water temperature change, where both patient types can use the same pool on a given day based on schedule. Humidity control should be appropriately designed to cater for the water evaporation from the pool surface.

Psychiatric Rooms

Requirements for standard patient rooms apply, in addition

- Care must be taken that all grilles/diffusers and other HVAC devices must be suicide and vandal resistant.
- Use duct mounted sensors and allow for heavy-gage construction to resist damage and vandalism and reduce injury.
- Special Anti-Ligature devices should be used.

Procedure Rooms

Following requirements must be adhered too for Procedure Room HVAC systems.

- As a minimum procedure rooms should be provided with temperature control (21-24°C), 20-60% RH, with a 15 ACH SA with laminar flow diffusers / 3 ACH OA. Room should be at positive pressure.
- If aesthetic gasses are administered all requirements related to operating rooms should be applicable.

Endoscopy Procedure Rooms

Following requirements must be adhered too for Endoscopy Procedure Room HVAC systems.

- Gastrointestinal Endoscopy procedure room:
 - As a minimum should be provided with temperature control (21-23°C), 20-60% RH, with a 6 ACH SA with laminar flow diffusers / 2 ACH OA. Room shall have no mandated pressure requirement, but its preferable to be under negative pressure.
- Endoscopy/Bronchoscopy:
 - As a minimum should be provided with temperature control (20-23°C), 20-60% RH, with a 12 ACH SA with laminar flow diffusers / 2 ACH OA. Room shall be negative pressure with dedicated 100% exhaust ducting to outside.
 - This is more common scenario and endoscopy rooms should be designed as a worse case to this requirement, unless noted otherwise by the operator.
- Endoscopy ERCP procedure room:
 - If specifically designed by the clinical planning team as a dedicated ERCP (Endoscopic Retrograde Cholangiopancreatography) room the following requirements shall supersede the previous requirements.
 - As a minimum should be provided with temperature control (20-23°C), 20-60% RH, with a 15 ACH SA with laminar flow diffusers / 3 ACH OA. Room shall have positive pressure requirement.
- Endoscope Cleaning Rooms:
 - As a minimum should be provided with temperature control (21-24°C), 20-60% RH, with a 10 ACH SA / 2 ACH OA. Room shall have negative pressure requirement. All air should be exhausted to outside with dedicated ducting.

Outpatient Clinics & Support Spaces

The HVAC systems for outpatient clinics & support functions are often not designed to the same level of redundancy as in-patient facilities. It is encouraged that the consultant engages with the owner/facility manager early in the design process to figure out the requirements for the clinics and day surgery units, endoscopy & imaging procedures if present.

Any particular low temperature requirements for day surgery units should be advised by the owner's representatives and the consultant should undergo an analysis of whether the requirements are achievable by the proposed system design.

IVF Clinics/ Fertilization Centres

Following requirements must be adhered too for IVF HVAC systems.

- IVF Clinics typically contain the following spaces.
 - Procedure Room & Embryo Transfer Room: The procedure room & embryo transfer room should be treated as an OR and all requirements for operating room should be complied.
 - Recovery Room/Bays: Recovery bays should be treated as PACU rooms and all requirements should be taken for PACU rooms.
 - Laboratories (Embryology, Andrology, Cryogenics, etc.): Labs for IVF center represent ultra-clean labs. In addition to the requirement for laboratory mentioned in the previous section all air should be HEPA filtered with laminar flow diffusers. Pressure requirement should be positive pressure (+0.01-0.02 in. wg or +2.5+5 Pa differential). ISO Class 7 certification testing is highly recommended.
 - Infectious Labs: Infectious labs should be provided with the same systems as other IVF labs, but the air pressure regime should be negative. (-0.01-0.02 in. wg or -2.5-5 Pa differential)
 - Sample Collection Rooms: Sample collection rooms should be kept at negative pressure via the adjoining shower area exhaust.
- HVAC air handling units serving the laboratories, procedure and embryo transfer rooms should be provided with carbon filters, with activated alumina impregnated with potassium permanganate & HEPA filters in the air handling unit. HEPA filters can also be installed at the terminal locations instead of the air handling units if dedicated air handling units are not used.

Data Centre

Following requirements must be adhered too for Data Centre/Server Room HVAC systems.

- As a minimum Server rooms should be provided with temperature control (19-22°C), 30-60% RH, with supply air governed by the heat load for the servers but not less air required to cool 0.5 kW/m² of data hall of heat load, to cover for future expansion.
- Server Room should be cooled by precision ac units or close control ac units, providing cooling and humidity control, located within the server room with adequate clearance space or preferably adjacent to the server room in a dedicated mechanical room.
- A minimum of two close control units should be provided for each server room in N+1 arrangement, one fed from the central chilled water circuit and one fed from a dedicated DX machine for medium to large scale healthcare facilities. For smaller facilities and outpatient facilities one close control unit can be provided with dual coil arrangement and dual fans. Close control units shall be fed from emergency power.
- Server Rooms rack should be arranged in hot aisle and hot cold arrangement, where applicable.
- Server Rooms should be conditioned through raised floor arrangement, with perforated floor tiles provided for up to 6kW rack load and fan powered tiles or rack containment provided for higher heat loads.
- Use of Fan coils to provide backup cooling is not permitted.

Hyperbaric Chamber

Following requirements must be adhered to for Hyperbaric Chamber HVAC system design.

- Hyperbaric Chambers rooms fall under diagnostics which require 6 ACH minimum of supply air & with 2 ACH minimum of outside air. Due to the nature of the facility and a requirement from NFPA 99 Chapter 14, all air should be exhausted to outside. A Temperature requirement (21-24°C), humidity (<60% RH).
- Exhaust air should not be merged with other exhaust and should not be passed through any heat recovery device.
- Hyperbaric Chambers should also comply with ASME's Safety Standard for Pressure Vessels for Human Occupancy (ASME PVHO)

- For larger multi person chambers, it is highly recommended that the chamber manufacturer provides a dedicated A/C and Ventilation system for the chamber itself. This would keep in mind the appropriate capacity and inlet angles for the air to ensure optimum thermal comfort for multiple person hyperbaric chambers.