Overview of US Healthcare HVAC Systems Design for Airborne Infection Control Spaces

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Introduction
Healthcare "Cleanrooms and Airborne Infection Control Spaces" are sometimes called "Environment-Controlled Spaces" - specially constructed enclosed areas, their environments may have following controlled parameters:

- Temperature
- Humidity
- Sound and Vibration
- Airflow Pattern
- Pressurization
- Microbial Contamination
- Particle Contamination
- Chemical Contamination
- Medical Specific

Special & Unique Requirements
US Healthcare Facilities Design Guidelines and Standards

- 2007 ASHRAE - Handbook Chapter 7
- 2003 ASHRAE - "Hospital and Clinics HVAC Design Manual"
- 2006 AIA - "Guidelines for Design and Construction of Hospital and Health Care Facilities"
- 2005 NFPA Standard 99 - Standard for Health Care Facilities
- 2006 CDC - "Infection Control Guidelines"
- 2003 CDC - "Guidelines for Environmental Infection Control in Health-Care Facilities"

Healthcare-Related Design Guidelines in US

- WHO Interim Guidelines - Infection Prevention and Control of Pandemic - and Epidemic-Prone Respiratory Diseases in Health Care
- 2004 JCAHO Environment of Care - Essentials for Health Care
- Aerobiological Engineering Handbook - Airborne Disease Control Technologies
- 2007 IEEE, National Electrical Safety Code (NESC)

General Building Codes in US

Architectural Design:
- 2006 International Building Code

Engineering Design:
- 2006 International Mechanical Code
- 2006 International Plumbing Code
- 2006 International Fire Code
- 2006 International Energy Conservation Code

Major Airborne Pathogens

Typical Annual Cases - Major airborne pathogens, the spheres represent the relative size of the microbes.
Airborne Infection Risk Management
An Critical Portion of Infection Control Risk Assessment (ICRA)

Source controls
- Patients with Tuberculosis, Chicken pox, Measles, Smallpox, SARS, Monkey pox, antibiotic resistant microbes.
- Cough etiquette and respiratory hygiene

Administrative controls
- Construction of infection control infrastructure
- Early detection, isolation, treatment and report

Personal protective equipment (PPE)

Engineering controls
- Patient placement (room layout, configuration)
- Space environmental control

Typical Environment-Controlled Spaces

- Operating Room (Operation Theatre)
- Airborne Infection Isolation Room (AII)
- Protective Environments (PE)
- Critical-Care Room

Operating Room (1)

Proper temperature (68-72°F, 20-23°C), humidity (<60% RH) and ventilation control for the comfort of surgical personnel and patients, environmentally discourage the growth and transmission of microorganisms. Conventional operating-room ventilation systems produce a minimum of about 15 ACH of filtered air for thermal control, 3 ACH (20%) of which must be fresh air. Air should be introduced at the ceiling and exhausted near the floor.

Constant volume air handling systems are common in operating rooms, variable systems are permitted for use "only if" they continue to provide a positive room pressure (normally 0.01-0.03 in. wg or 2.5-8 Pa differential) with respect to the corridors and adjacent areas and the required ACHs are maintained when the room is occupied.

HEPA-filtered (99.97%) laminar airflow and UVGI (Ultraviolet Germicidal Irradiation) as additional measures could reduce SSI (Surgical-Site Infection) risk for certain operations. Laminar airflow is designed to move clean air over the aseptic operating field at a uniform velocity (0.3–0.5 m/s), either vertically or horizontally, sweeping away particles in its path, and recirculated air is passed through a HEPA filter.

Operating Room (2)
Airborne Infection Isolation Room

- Proper temperature (68-73°F, 20-23°C), humidity (<60% RH) and ventilation control, minimum ventilation 12 ACH, anteroom 11 ACH.
- Maintain negative pressure with close monitoring and control of airflow direction (normally -0.01 to -0.03 in. wg or -2.5 to -8 Pa differential, min. negative 3 in. wg or -7.5 Pa).
- Seal room below 0.5 ft² (465 cm²) of air leakage (called Effective Leakage Area under 4 Pa pressure differential test).
- Filtration (99%) to air in the room. Air from negative pressure rooms and treatment rooms is to be HEPA-filtered (99.97%) and exhausted directly to the outside. Recirculation is not allowed. Isolation rooms can be constructed ideally with an anteroom. UVGI fixtures can be placed in upper room, or inside the ducts as an additional measure.
- Personal protective equipment such as respirators (NIOSH type N95 or powered purifier) for healthcare workers prior to entering isolation rooms.

Protective Environments

- These rooms are to be designed for high-risk, immuno-compromised patients (BMT, organ transplant, burn, late-stage HIV…) to minimize fungal spore counts (measured in CFU) in air.
- Proper temperature (68-73°F, 20-23°C), humidity (<60% RH) and ventilation control, minimum ventilation 12 ACH.
- Ideally, incoming air by HEPA filters, supply air on one side of the room, across the patient, and exhausted out through the opposite side of the room.
- Positive room air pressure of 2.5 Pa (0.01” w.g.) relative to the corridor, and 0.45±0.09 Pa at a minimum of 85 CFM (0.8 CFM/ft²) supply.
- Seal room below 0.5 ft² (465 cm²) of air leakage.
Critical-Care Room

Proper temperature (68-73°F, 20-23°C), humidity (45% RH).

Minimum staff ACH of 6 ACH for thermal control, 2 ACH (33%) of which must be fresh air.

Based on the patient type and critical-care suite configuration, positive, negative or neutral room pressure (normally from -0.01 to 0.01 in. wg or -2.5 to 2.5 Pa differential) with respect to the corridors and adjacent areas.

Filtered (95%) supply airflow, and recirculated air is allowed.
Temperature, Humidity & Ventilation Requirements (For Nursing Facilities)

Microbiological Contamination & Control

Unlike non-viable particles, which can’t reproduce, microorganisms could reproduce at a rapid speed if nutrition and environment are favorable.

Microorganism can be classified as bacteria, algae, fungi, protozoa and viruses. Some of these are essential, useful and harmless, while others are harmful and dangerous.

Example
Design Criteria – Operating Room

Example
Floor Plan – Operating Room
AHU Flow Diagram (with Possible Options)

- Exchanger only
- Exchanger + reheat pipe
- Exchanger + auxiliary supply
- Dual Return paths
- Supply air with possible direct OA mixing

Complex (multi-functional) AHU System (Discharge at 55°F year-around)

- Exhaust only
- Exhaust with heat pipe
- Exhaust with enthalpy wheel
- Dual Return paths

Use only with psychrometric analysis!!!

Airborne Contaminant Removal - Filtration

ACH and Time Required for airborne-contaminant removal at filter efficiencies of 99% and 99.9%

<table>
<thead>
<tr>
<th>ACH</th>
<th>99% Efficiency</th>
<th>99.9% Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>2</td>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td>3</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>5</td>
<td>2.5</td>
<td>2.5</td>
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<tr>
<td>10</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>20</td>
<td>0.75</td>
<td>0.75</td>
</tr>
</tbody>
</table>

Based on an empty room with no aerosol-generating source, and with perfect mixing. Practically the removal times will be longer in rooms with imperfect mixing or persons present and generating aerosol.

Possible Filter Locations in AHU System

Filtration in HVAC System (For General Hospitals)

<table>
<thead>
<tr>
<th>Area Description</th>
<th>Number of Filter Banks</th>
<th>Filter Eff. No. 1 (%)</th>
<th>Filter Eff. No. 2 (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lab + other spaces, space/air handling, and operating rooms</td>
<td>2</td>
<td>30</td>
<td>98</td>
</tr>
<tr>
<td>Laboratories</td>
<td>1</td>
<td>80</td>
<td>-</td>
</tr>
<tr>
<td>Administrative, halls, offices, and building</td>
<td>1</td>
<td>30</td>
<td>-</td>
</tr>
</tbody>
</table>
### Filtration in HVAC System (For Outpatient Facilities)

<table>
<thead>
<tr>
<th>Area Designation</th>
<th>Max. Number of Beds</th>
<th>Filterbed No. 1</th>
<th>Filterbed No. 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating rooms, examination, and treatment areas requiring aseptic conditions</td>
<td>2</td>
<td>90</td>
<td>-</td>
</tr>
<tr>
<td>Operating rooms, imaging, radiology, and recovery areas</td>
<td>1</td>
<td>80</td>
<td>-</td>
</tr>
</tbody>
</table>

Additional equipment or filters should be considered in airborne contaminant exceedances or cases where the presence of biological, chemical, or radiological materials is suspected.

**Notes:**
- Hospital facilities or planes should be considered in airborne contaminant exceedances or cases where the presence of biological, chemical, or radiological materials is suspected.
- The presence of airborne contaminants should be considered in airborne contaminant exceedances or cases where the presence of biological, chemical, or radiological materials is suspected.
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### Filtration in HVAC System (For Nursing Facilities)

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<th>Filterbed No. 2</th>
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</tr>
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The presence of airborne contaminants should be considered in airborne contaminant exceedances or cases where the presence of biological, chemical, or radiological materials is suspected.

### Filtration in HVAC System (For Psychiatric Hospitals)

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<thead>
<tr>
<th>Area Designation</th>
<th>Max. Number of Beds</th>
<th>Filterbed No. 1</th>
<th>Filterbed No. 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating rooms, examination, and treatment areas requiring aseptic conditions</td>
<td>2</td>
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<tr>
<td>Operating rooms, imaging, radiology, and recovery areas</td>
<td>1</td>
<td>80</td>
<td>-</td>
</tr>
</tbody>
</table>

The presence of airborne contaminants should be considered in airborne contaminant exceedances or cases where the presence of biological, chemical, or radiological materials is suspected.

### Typical Airborne Sampling, Flow Control and Treatment Devices

- HEPA / ULPA Filter
- Bag-in/Bag-out multiple filters
- Air Filtration
- Handhold Particle Counter
- Microbial Air Sampler & Agar Media
- Portable Particle Counter
- Air Particle Sensor
- Particle Sampling
- Microbial Sampling
- Room Airflow and Pressure Controls
Water-Borne Microbial Contamination Control

- Hot-Water Distribution System - Maintain constant flow recirculation and water temperature above 124°F (51°C), and maintain cold water temperature below 68°F (20°C). If using hot water above 150°F (66°C), then preset thermostatic valves are needed at all point-of-use fixtures to minimize the risk of scalding.
- When a significant water disruption or an emergency occurs, raise the hot-water temperature to 160°F–170°F (71°C–77°C) for decontamination and flush each outlet of the system for 5 minutes or longer before use. Or, add residual-free chlorine to achieve >2 mg/L throughout the system overnight.
- Perform laboratory diagnostic tests for legionnaires on suspected cases.
- Humidity controls – Monitor to ensure proper moisture removal from the rooms and outside air intake.
- Locate duct humidifiers upstream from the final filters, and straight duct length for moisture to be completely absorbed.
- Use ducted steam humidifiers, if possible, to reduce potential for microbial proliferation within the system, and avoid use of cool mist humidifiers.

Sample Exterior Views of US Hospitals

- Sample Exterior Views of US Hospitals

Q & A