# A study on Indoor Air Quality in Major Hospitals in Sultanate of Oman

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Abstract:

Indoor air quality (IAQ) is one of major critical issues in hospitals and medical facilities, as patients have less immunity. IAQ as specialized area is emerging throughout world, worldwide researchers are working on this subject. This study examines the compliance of critical hospital ventilation systems (in operating theatre and Airborne Infection Isolation (AII) room) in five major government hospitals in the Sultanate of Oman with the local and international standards. The compliance of the IAQ standards is one element of airborne infection control. The findings and recommendations of this study will be useful to the policy makers of health care industries to update the existing policies on critical ventilation systems.

## 1.Introduction

World Health Organization [1] categorized air pollutants into four categories: classical air pollutants (such as ozone and particulate matter), organic air pollutants (such as Benzene and carbon monoxide), inorganic air pollutants (such as Asbestos and Vanadium), and indoor air pollutants. The indoor air we breathe indoor can be contaminated by ambient air pollution, odours, skin flakes, bacteria, solvent vapours released by furnishings, and ozone released by copiers. These contaminants have a significant impact on the health condition and the comfort of the building occupiers [2]. Indoor air quality (IAQ) is crucial issue in hospitals and medical facilities, as patients have less immunity. In addition, it affects the working conditions and health of the working staff in the hospital. The degradation of the indoor air quality (IAQ) in hospitals is caused by many reasons, such as reduced ventilation, building materials and furnishings, deferred maintenance, chemicals and pesticides. However, heating, ventilation, and air conditioning (HVAC) systems, is one of the main sources of this degradation. Balaras & et al. [3] stressed the important roles of HVAC systems in determining the indoor air quality on hospitals. It is an established fact that 80% to 90% of bacterial contaminations of wounds in hospitals come from ambient air. Many researchers suggested the compliance of the hospital ventilation systems with the international standards of indoor air ventilation. Examples of these standards include ASHRAE standard for ventilation and acceptable indoor air quality [4] and ANSI/ASHRAE Standard 170-2017 Ventilation of Health Care Facilities [5]. The latter standard is more often used for health care applications than the former standard. The ANSI/ASHRAE Standard 170-2017 Ventilation of Health Care Facilities provides the required minimum ventilation design parameters for health care facilities. These parameters include pressure relationship with adjacent areas, minimum air changes of outdoor air per hour,

minimum total air changes per hour, all room air exhausted directly to outdoors, air recirculated by means of room units, relative humidity, and design temperature. This study examines the compliance of critical hospital ventilation systems (in operating theatre and Airborne infection isolation AII room) in five major hospitals in the Sultanate of Oman with the local and international standards including HTM Standard 03-01 [6], AIA guidelines [10] and GCC Infection prevention and control manual [7]. The study investigates the design, maintenance, operation, performance of these critical systems in order to identify the issues/problems of these systems, and suggests the best practices and recommendations to ensure the clean air in health care facilities in Oman.

## 2.Research Approach and Methodology

Five major Government aided hospitals in Oman were selected for study. Hospitals are named as A, B, C, D and E. These five hospitals are located in different cities in Oman. The study focuses on two critical ventilation systems in: operating theatre and AII rooms. Ten sample operating theatres and eight AII rooms were examined in this study. In the first phase of the study, field visit checklists and interviews with the HVAC engineers and supervisors of the respective hospitals were used to collect information about the design, maintenance and operation of the examined critical ventilation systems. In the second phase, air flow rate, velocity, temperature, relative humidity, flow direction measurements were acquired for each critical ventilation system. The air flow direction between the spaces was investigated using smoke test. Relative humidity and ambient air room temperature, and flow velocity were measured via TSI Thermoanemometer Articulated Probe 966. The Thermoanemometer was calibrated from 0-60oC for temperature, 10-90% for relative humidity, 0-40 m/s for flow velocity. It has accuracy of ±0.015 m/s for velocity, ±0.3°C for temperature, and ±3% for relative humidity. The Thermoanemometer resolution is 0.01 m/s for velocity, 0.1°C for temperature, and 0.1% for relative humidity. The relative humidity and ambient air room temperature were averaged over five locations: four room corners and room centre. Due to its high sensitivity to low velocity measurement, the Thermoanemometer Articulated Probe was used to acquire flow velocity and volume flow rate for the diffuser array in operating theatres according to ISO 14644-3. The diffuser array was divided into small grid cells of equal area (not exceeding 30x30 cm). Flow velocity was acquired at the center of each grid cell for 10 seconds. Velocity measurement was taken 15 cm downstream of the diffuser array. Thermoanemometer acquires standard velocity, which is the velocity with reference to the standard conditions of 21.2oC, 101.4 kPa and 0% relative humidity. The velocity was averaged over the grid cells and multiply by the flow area to calculate the standard air flow rate. Air changes per hour is calculated using the following formula

$$ACH = \frac{Volume\ flow\ rate\ (m^3/s)}{space\ volume\ (m^3)} \times 3600$$

For other types of diffusers, registers and grilles, standard volume flow rate was measured using TSI Capture hood PH371-B. The Capture hood was calibrated before acquiring data. Depending on the size of the exhaust outlet, two hood sizes were used: 610x610 mm and 406x406 mm. To minimize measurement error due to air swirl motion inside the capture hood

and air back pressure due to the presence of the capture hood, the capture hood is equipped with swirl x-flow conditioner and back pressure compensation flap. The capture hood can measure between 42 to 4250 m3/h at accuracy of ±3% of the reading. The standard volume flow rate was acquired according to ISO 14644-3. To insure the repeatability of the readings, measurements was acquired two times (or more if necessary) for each exhaust outlet.

## 3.Discussion and Results

### 3.1Design of critical ventilation systems

The design of the critical ventilation systems was investigated using field visit checklist and interviews with the HVAC engineers and supervisors. Please refer to design checklist in Appendix A. The following comments were observed:

1) Usage of fan coil unit FCU in hospitals A, B&C in some AII rooms for air recirculation, while outdoor air is supplied via central HVAC systems: Fan coil units are prone to excess condensation accumulation in drip pans, and filter cleaning difficulty [9]. According to ASHRAE Standard 170-2017 recirculating room HVAC units must not be used in AII rooms and AII anterooms, because it is difficult to clean these units and hence air contamination risk is higher. Recirculating units with HEPA filters can be a temporary and supplemental control measure. HTM Standard 03-01 also recommends not to install fan coil unit in patent bed rooms as these rooms they can increase healthcare-associated infections (HAIs). According to AIA guidelines fan coil units must be used in patient rooms as recirculating units, while outdoor air must be supplied by central HVAC system. The fan coil units, according to the guidelines, must be equipped with cleanable or replaceable filters with a minimum efficiency of 68% weight arresting ability, and it has to be cleaned/replaced in a regular basis.

2) Usage of variable volume (VAV) HVAC system in hospitals B&C in some AII rooms, and in operating theatres in hospital A: In variable air volume (VAV) HVAC system, room air temperature is controlled by varying supply air volume flow rate. This system is usually not used for critical spaces, as it may compromise the pressure difference between these spaces and the common space

3) Patient private rooms in the medical wards are used occasionally as AII rooms in hospitals B, C, D&E: According to ASHRAE Standard 170-2017, air from AII rooms retrofitted from standard patient rooms has to be exhausted directly to outdoor. If this is impractical, the recirculated air from AII room has to pass through HEPA filter. Another issue in using patient private rooms for this purpose it that the exhaust discharge outlets for these rooms in most of these hospitals are located close to the adjoining roof level where maintenance staff are usually working. According to ASHRAE Standard the minimum distance between the exhaust discharge outlet of AII rooms and adjoining roof level should be at least 3 m in order to protect the personnel who may need to access the roof from the contaminated air.

4) No sufficient distance between outdoor air intake and the exhaust discharge outlet in ICU & AII rooms ventilation system in hospital A, and operating theatre ventilation system in hospital C.

5) No filter blank-off panel is attached to the filter bank frame for the air handling units' in

Hospitals A, B, D and E.

6) Usage of energy recovery system for AII rooms in Hospital C without regular leak inspection: Energy recovery system is used to transfer the heat from air supply to the air exhaust without mixing the two streams. Plate heat exchanger is used in Hospital C for heat recovery. ASHRAE Standard does not recommend utilizing energy recovery system for AII rooms unless there is a sufficient atmospheric air gap between the supply and exhaust airstream components.

7) Unsuitable location of exhaust air grilles and registers in AII rooms in Hospitals D&E: Exhaust Air grilles and registers in AII rooms in Hospitals D&E are not located above the patient's head.

**3.2Operation and Maintenance of critical ventilation systems**

The operation and maintenance of the critical ventilation systems was investigated using field visits checklist and interviews with the HVAC engineers and supervisors. Please refer to operation and maintenance checklist in Appendix A. The following comments were observed:

1) There is no common effective procedure for testing ambient air pressure difference between operating theatre room and adjacent areas: In fact, it was found that air is flowing from the corridor to the operation theatre (OT4) in Hospital C. The positive pressure difference between the operating theatre and the adjacent areas (+2.5 Pascal is recommended by ASHRAE ensures flow of air from clean area to less clean area. The five hospitals apply different pressure test intervals (no test, one test every 2 months, one test every 12 months, test when it is requested by the infection control department) and testing methods (smoke testing, flowmeters, or even tissue paper). According to HTM Standard performance verification (including ambient air differential pressure) of all critical ventilation systems must be performed at least once per year, and in some circumstance several verification is required per year. Different qualitative test methods can be used to indicate the differential ambient pressure, such as smoke testing, flutter strips, ping-pong balls, or even tissue paper [10].

2) The ambient air pressure difference between AII room and adjacent areas is not continuously monitored in vast majority of the AII rooms. Moreover, there is no common alternative procedure implemented for testing the ambient air pressure difference between AII room and adjacent areas: In fact, the AII rooms in male surgical ward in hospital A, and medical and heart surgery-paediatric ward (AII room number 1) in hospital B both have positive pressure compared to the anteroom and the corridor instead of negative pressure. In both rooms, the anteroom has positive pressure compared to the corridor. The negative pressure difference between the AII rooms and the anteroom, (-2.5 Pascal is recommended by ASHRAE and between the anteroom and the corridor prevents the air contaminated with airborne microorganisms from spreading to the common areas. ASHRAE Standard recommends the installation of continues differential ambient pressure monitor for AII rooms or using visual means (smoke tubes and flutter strips) to indicate the flow direction if the monitor is not available. GCC Infection prevention and control manual provided step-step instructions for the routine monitoring of negative pressure rooms. According to the GCC manual, the ambient

pressure difference should be checked and documented at least once per month if it is not occupied, or daily if it is occupied by patient with airborne infectious disease. According to the GCC manual, hand-held monitor can be used if no fixed monitor is installed. These documents, according to the GCC manual, have to be forwarded to the environmental health section of the Infection & Prevention Control (IP&C) Department.

3) Visual inspections of the final filters in Hospitals B&D are performed less frequent than

requirement: Visual inspections of the final filters are necessary to check air bypass or pressure drop. According to ASHRAE Standard final filter visual inspection should take place once per month. In Hospitals B&D, final filter visual inspection take place during the planned preventive maintenance and annually, respectively.

4) Inspection of the fire/smoke dampers are not included in the inspection checklists in Hospitals C, D&E: Fire/smoke dampers are automatically closed whenever fire take places in the air handling unit or smoke is drawn into the unit in order to prevent spread of fire and toxic smokes to the ventilated spaces. According to HTM Standard the operation of the fire and smoke dampers has to be visually checked annually with a help of a test switch as part of annual system verification.

5) No annual verification of air changes per hour ACH for the critical ventilation systems in Hospitals A, B, C&E: The performance of the critical ventilation systems must be verified at least annually. The annual verification includes verification of ACH, ambient air temperature, ambient air differential pressure, ambient air humidity…etc.

6) No DOP (Dispersed Oil Particulate) test is carried out for HEPA filters after installation/replacement in all examined hospitals.

8) No duct cleaning has been performed in Hospitals A, B, C& E.

9) Lack of awareness within health care/HVAC maintenance workers about ventilation of AII

rooms in all hospitals

## 4.Conclusion and Recommendations

This study examines the compliance of critical hospital ventilation systems in five major hospitals in the Sultanate of Oman with the local and international standards. The study focuses on two critical ventilation systems in: operating theatre and AII rooms. Ten sample operating theatres and eight AII rooms were examined in this study. Information about the design, maintenance, operation, and measured parameters was collected about these critical ventilation systems. In summary, the study concludes the following findings and recommendations for the critical ventilation systems in the five examined hospitals:

1) Since most of the examined critical ventilation systems were commissioned during 80s and 90s of the last century, it will rather difficult to upgrade these systems to satisfy the latest national and international standards. System upgradation may require: 1) shifting variable volume system (VAV) to constant volume system, 2) increasing the distance between the air intake and exhaust outlet for ventilation systems to at least 8 m, 3) eliminating/modifying

energy recovery system for AII room ventilation, 4) providing two exhaust grilles in each operating theatre, 5) changing the location of the exhaust air grill/register in AII rooms, 6) eliminating the use of fan coil units in AII rooms.

2) Patient private rooms in the medical wards are occasionally used as AII rooms in most of the sample hospitals. Air from AII rooms retrofitted from standard patient rooms has to be exhausted directly to outdoor. If this is impractical, the recirculated air from AII room has to pass through HEPA filter.

3) No clear and effective procedure is implemented to monitor air changes per hour ACH and air flow direction/ambient air differential pressure for operating theatres and AII rooms. The effective procedure requires clarity in the tests steps, tests frequency, responsible entity, and availability of calibrated monitoring devices, and sufficient training for the HVAC maintenance staff.

4) Fire/smoke dampers are not included in the inspection checklists in number of the examined hospitals. Failure of this device during fire accidents at/close to air handling units is a potential safety risk, because it can lead to spread of fire and toxic smokes to the ventilated spaces.

5) No Dispersed Oil Particulate test (or similar test) is carried out for HEPA filters after installation/replacement in all sample hospitals to test the integrity and the leak of the HEPA filter.

6) The total ACH for most of the sample AII rooms is equal or below 50% of the minimum required total ACH. This means that these spaces are relatively highly contaminated with airborne microorganisms. On the other hand, the measured total ACH for vast majority of the sample operating theatres is slightly lower than the minimum ACH requirements by international standards.

7) In 90% of the sample operating theatres, the average air velocity from the diffuser array is between 0.05 and 0.1 m/s, which is lower than flow velocity recommended by ASHRAE Standard.

In conclusion Concerned authorities to realise the importance of IAQ and its relevance in HVAC systems and take a proactive approach to ensure the safety of patents and health care workers. This study was limited in Government aided hospitals. It is strongly recommended to carry out similar or better version of this study in private hospitals in Oman. These studies will help to formulate the procedures and local codes to design, operate and maintain HVAC systems in hospitals in Oman.

## 5.References

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[2] Al-Rajhi, S., Ramaswamy, M., & Al-Jahwari, F. (2010). IAQ in Hospitals-Better Health through Indoor Air Quality Awareness.

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[4] ASHRAE 1999. ASHRAE Standard 62, Ventilation for acceptable indoor air quality. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

[5] Standard 170-2017, Ventilation of Health Care Facilities, https://www.ashrae.org/technicalresources/standards-and-guidelines/read-only-versions-of-ashrae-standards

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[9] ASHRAE 1999. 1999 ASHRAE Handbook - HVAC Applications, Ch. 7, Health Care Facilities. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

[10] The American Institute of Architects and The Facilities Guidelines Institute. Guidelines for design and construction of hospital and health care facilities, 2001. Washington, DC: American Institute of Architects Press, 2001.

## Appendix A: Visit Checklists and Interview Questions

### Design Checklist

**Name of the Hospital:** **Date of the visit:**

**Name/position/contact of the interviewed engineer:**

**System 1:** **Code:**

Type & information of inspected HVAC system:

Year of installation:

Type of "all air system": Single zone/multi-zone/dual duct/Reheat system*

Percentage of Outside Air (see appendix B for measurement):

Air is supplied to:

Sketch/drawing/photo:

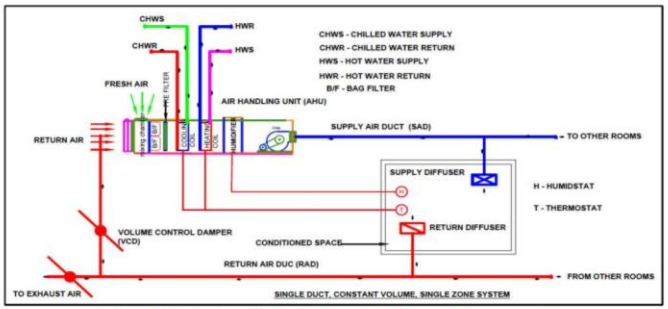

Figure 3.Schematic of Single duct, constant volume, single zone system

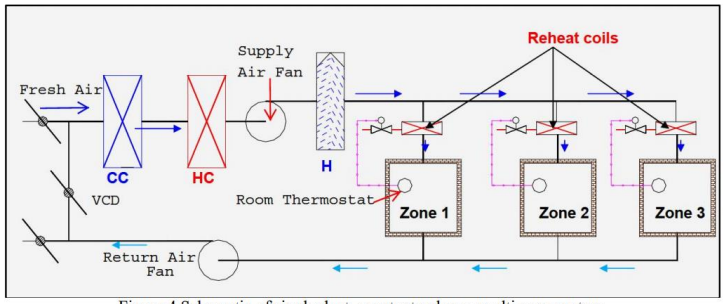

Figure 4.Schematic of single duct, constant volume, multi zone system

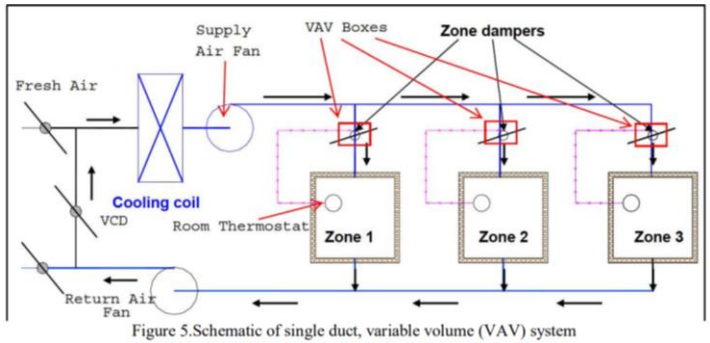

Figure 5.Schematic of single duct, variable volume (VAV) system

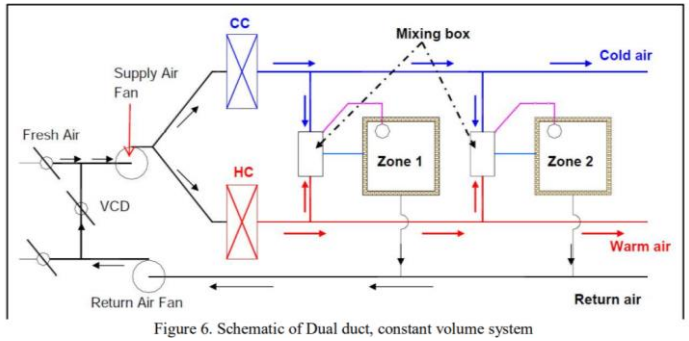

Figure 6. Schematic of Dual duct, constant volume system

| Category | Point | System 1<br>Code:<br>Space: | System 2<br>Code:<br>Space: | System 3<br>Code:<br>Space: |
|---|---|---|---|---|
| 6.1.1 Ventilation upon loss of electrical power | **Space ventilation and pressure relation requirements** are maintained, even upon loss of electrical power in: Airborne infection isolation (AII) rooms, Protective environment (PE) rooms and operation theatres and delivery rooms | | | |
| 6.1.2 Heating and cooling sources | Provide **heat sources** and essential accessories in number and arrangement sufficient to accommodate the facility needs (reserve capacity), even when any one of the heat sources or essential accessories is not operating due to a breakdown or routine maintenance. | | | |
| | For **central cooling systems** greater than 400 tons (1407 kw) peak cooling load, the number and arrangement of cooling sources and accessories shall be sufficient to support the owner's facility operation plan upon a breakdown or routine maintenance of any of the cooling sources. | | | |
| 6.2 Air Handling | **AHU casing**: The casing shall be designed to prevent water intrusion, resist corrosion, and permit access for inspection and maintenance. | | | |

| | | | | |
|---|---|---|---|---|
| unit (AHU) design | **All Airstream surfaces** in equipment and ducts should have resistance to: mold growth, and erosion (should not break away, crack, peel flack off) | | | |
| 6.3 Outdoor air intakes and exhaust discharges | **Outdoor air intakes:** shall be located a minimum of 8 m from cooling towers and all exhaust and vent discharges. | | | |
| | Outdoor air intakes shall be located such that the bottom of the air intake is at least 2 m above grade. | | | |
| | New facilities with moderate-to-high risk of natural or man-made extraordinary incidents shall locate air intakes away from public access. | | | |
| | All intakes shall be designed to prevent the entrainment of wind-driven rain, shall contain features for draining away precipitation, and shall be equipped with a bird screen of mesh no smaller than 0.5 in. (13 mm). | | | |
| | +Intakes should be at least 1 m above the roof level | | | |
| | **Exhaust discharges:** Exhaust discxharge outlets from AII rooms (and lab chemcial fume hoods and others spaces that can hold patients with respiratory disease) is loacated such that they reducde the potential for the recirculation of exhausted air back into the building. | | | |
| | Ehhaust discxharge outlets from AII rooms (and lab chemcial fume hoods) are arranged to discharge to the atmosphere in a vertical direction (with no rain cap or other device to impede the vertical momentum) and sholud be at least 3m above the adjoining roof level. | | | |
| | Ehhaust discxharge outlets from air from AII rooms (and lab chemcial fume hoods) is located not less than 8m horizontally from outdoor air intakes, openable winodws/doors, and areas that are normally accessible to the public. | | | |
| 6.4 Filtration | Record MERV for filter bank 1 | | | |
| | Record MERV for filter bank 2 | | | |
| | Measuring device is used to measure Differential pressure across the filter | | | |

| | | | | |
|---|---|---|---|---|
| | Filter bank 1 is placed upstream of the heating and cooling coils such that all mixed air is filtered. | | | |
| | Filter bank 2 is placed downstream of all wet-air cooling coils and the supply fan.<br>Filter bank 2 has sealing interface surfaces. | | | |
| | Filter-bank blank-off panel is permanently attached to the filter-bank frame, and have sealing surfaces equal to or greater than the filter media installed within the filter bank frame. | | | |
| | Filter frames are durable and proportioned to provide an airtight fit with the enclosing ductwork. All joints between the filter segments and enclosing ductwork has gaskets or seals to provide a positive seal against air leakage. | | | |
| 6.5 Heating & Cooling Systems | **Drain pans** are slopped to drain liquid water, and the drain outlet is at the lowest part of the pan. | | | |
| | **Drain pan** is equipped with a trap or sealing device to maintain seal against ingestion of ambient air (if drain pan is under negative pressure relative to drain outlet) | | | |
| | **Radiant cooling system**: water temperature is below dew point temperature of the space | | | |
| | **Gravity type heating and cooling systems** (such as radiator and convectors) are not used in OR. | | | |
| | **Humidifier**: Steam or adiabatic high-pressure water atomizer are used | | | |
| | **Humidifier**: located within AHU/ductwork to avoid accumulation in downstream filters and insulations. | | | |
| | **Humidifier**: is equipped with shutdown valves, which should be closed if AHU is not in operation. | | | |
| | **Humidifier**: Humidity sensor is located at sufficient distance downstream of the humidity injector with cut-off control to limit RH in the duct to less than 90% | | | |

| | | | | |
|---|---|---|---|---|
| | **High-pressure water atomizing Humidifier**: water in high-pressure water atomizer is pre-treated (RO, UV sterilization, submicron filter), and drained completed when not in use. Ports are available in the piping for water testing. Moisture eliminator is installed to avoid moisture accumulation in ductwork. | | | |
| 6.7 Air distribution System | Spaces with pressure relation are equipped with fully-ducted return/exhaust | | | |
| | Air stream surfaces have resistance to mold growth and erosion | | | |
| | Air distribution system is provided with access, doors, panels for inspection and cleaning | | | |
| | Maintenance access is provided for smoke/fire dampers | | | |
| 6.8 Energy recovery system | Energy recovery system is located upstream of filter bank 2 | | | |
| | Energy recovery system does not allow for any cross-contamination between the air supply and the exhausted air | | | |
| | Energy recovery system is not used for AII rooms or for combination of PE/AII rooms | | | |
| 6.9 Insulation & Duct lining | Duct lining is not be installed in the ductwork downstream of filter bank 2, and within 4.57m downstream of the humidifier | | | |

## Operation and Maintenance of Critical HVAC systems (OR & AII rooms )

Name of the Hospital: Date of the visit:

Name/position/contact of the interviewed engineer (optional):

| | Category | Question |
|---|---|---|
| 170-2017 (Informative appendix A.1) | **Pressure difference for** | 1. Do the air pressure difference between operating theatre room and adjacent areas is monitored/tested? |

| | | |
|---|---|---|
| | **operating theatre** | 2. If the answer is (yes), how often monitoring/test is carried out? |
| | **HEPA filter** | 3. When HEPA filter is present within operating theatre room diffuser, the filter is replaced based on pressure drop (yes, no, not applicable) |
| | **Continues operation** | 4. Operating and Caesarean delivery room ventilation systems are operating at all times, except during maintenance and during conditions requiring shutdown by the building's fire alarm system. (yes, no, not applicable)<br>5. If the answer is (no), when these ventilation systems are often switched off? |
| | **Pressure difference for isolation room** | 6. Does the air pressure difference between isolation room and adjacent areas is monitored/tested?<br>7. If the answer is (yes), how often monitoring/test is carried out? |
| | **Filter inspection & replacement** | 8. How often final filters and filter frames are visually inspected for pressure drop and bypass?<br>9. In what bases, filters are replaced? |
| 170-2017 (Informative appendix A.2) | **Fan coil unit & heat pump** | 10. How often Fan coil unit & heat pump drain pans under cooling coils are cleaned? |

| | | |
|---|---|---|
| HTM03-01 (part B)- Annual inspection and verification requirements | **Inspection & Verification** | 11. How often critical ventilation systems (ICU, OR & AII rooms ) are inspected?<br><br>12. Inspection of critical Ventilation systems includes (tick the relevant boxes):<br>□ Check if the system is still required;<br>□ Check if the AHU conforms to the minimum standard;<br>□ Check if the fire containment has not been breached;<br>□ Check if the general condition of the system is adequate for purpose;<br>□ Check if the system overall is operating in a satisfactory manner.<br>□ A simple check sheet is used to record the result of the inspection.<br><br>13. How often critical ventilation systems are verified?<br><br>14. Annual verification of critical Ventilation systems includes (tick the relevant boxes):<br>□ Verify that the system achieves minimum standards specific to the application;<br>□ Verify that the system is operating to an acceptable performance level;<br>□ Verify that the system remains fit for purpose |
| Guidelines for Environmental Infection Control in Health-Care Facilities: Recommendations of CDC and the Healthcare Infection Control Practices Advisory Committee (HICPAC). | **Testing & measurements** | 15. When & how often DOP testing is carried out for HEPA filters?<br><br>16. Does hand-held, calibrated equipment is used to provide numerical measurements for air temperature, relative humidity, negative-positive air pressure inside rooms, and air flow rate through diffusers? If yes, how often this equipment is calibrated? And how often numerical measurements are carried out? |
| | **Air intakes** | 17. Do the HVAC intakes are inspected and freed from bird droppings? If yes, how often? |

| | | |
|---|---|---|
| Section: (Infection Control Impact of HVAC System Maintenance and Repair) | **Excess humidity and moisture** | 18. Does there any efforts to limit excess humidity and moisture in the infrastructure and on air-stream surfaces in the HVAC system? If yes, please explain how excess humidity and moisture are limited. |
| | **Duct cleaning** | 19. Does duct cleaning is carried out? If yes when & how often? |
| 170-2017<br>10. Planning, construction and system start up | **After construction & before system start up** | 20. After construction & before system start up **(**for HVAC system servicing surgery, and critical care spaces): (tick the relevant boxes)<br>□ The duct system is free of construction debris.<br>□ The supply diffuser in operating room, Delivery rooms, trauma rooms, wound intensive care rooms, PE rooms, and critical and intensive care rooms are opened and cleaned before the space is initially used and at regular intervals thereafter.<br>□ The permanent HVAC system is not operated unless protection from contamination of the air distribution system is provided |

**Space Ventilation**

**Name of the Hospital:** **Date of the visit:**

**Name/position/contact of the interviewed engineer:**

**Space 1:** **Code:**

Type of the Inspected room: Critical & intensive care /operating room/AII rooms with anteroom/AII rooms without anteroom/ AII-PE combination room with anteroom/ AII-PE combination room without anteroom.

Usage & information about the space:

Type & information of inspected HVAC system:

Year of installation:

Type of “all air system”: Single zone/multi-zone/dual duct/Reheat system*

Percentage of Outside Air:

<table>
<tr>
<td>7. Space ventilation-hospital spaces (Consider Anteroom as separate space)</td>
<td>
1) Draw sketch of the hospital space (indicating S: supply& E: exhaust<br><br>
2) Write Dimensions of the space & height (meter) in the sketch.<br>
3) Flow direction:<br><br>
<table>
<tr><td>Space with respect to anteroom</td><td></td></tr>
<tr><td>Anteroom with respect to corridor</td><td></td></tr>
</table>
<br>
4) Set up (CHECK HOOD SIZE)<br>
-Pressure tool: capture hood-back-pressure compensation (OR) manual Run-average.<br>
-Select test number<br>
-check reading 2 times<br>
Write Q(total) for each inlet & outlet in the sketch with +ve/-ve sign with +ve/-ve sign (<u>Design & Standard</u>) ($m^3/s$). Also write Pressure & Temperature.<br><br>
5) Set hotwire for:<br>
-Pressure tool: none<br>
-Flow setup: rectangular duct + enter x y<br>
-setting time constant: 10 sec<br>
-data logging>log/display mode: auto-save/run avg<br>
-Select test number<br>
- Total area of the Primary supply diffuser array ($m^2$)=<br>
Primary supply diffuser array: Sketch it and Divide it into grid cells of equal area. Individual area should not exceed approximately (60x60 cm) (but NOT less than 4 points). Measure at the center of the grid (By pressing arrow for each sample) and take measurements for 10 sec. Write average velocity (m/s) in the sketch below. Also write Pressure & Temperature.<br>
6) Application>Turbulence intensity: The unit takes three-minute sample of the velocity readings in that position. Do not move the probe during that time. Unit will display the current velocity reading during that time.
<table>
<tr><td>average velocity</td><td></td></tr>
<tr><td>standard deviation</td><td></td></tr>
</table>
</td>
</tr>
</table>

| | |
|---|---|
| Calculated turbulence intensity | |

**7) % of outside air:**

| | |
|---|---|
| **Design % of outside air** | |
| **Actual % of outside air** | |

$$\%\,\text{outside air} = \frac{\text{return air measurement}^* - \text{supply air measurement}^*}{\text{return air measurement}^* - \text{outside air measurement}^*} \times 100$$

**8) Measurement of T($^{O}$C) & RH(%):**

| | **Inside the space** | | **Using BMS** | |
|---|---|---|---|---|
| | **Value** | **time** | **Value** | **time** |
| **T($^{O}$C)** | | | | |
| **RH(%)** | | | | |

**9) Type of supply air supply& exhaust /location with respect to patient bed/surgery table (specify in the sketch):**

- **Group A: In or near ceiling, horizontal discharge**
- **Group B: In or near floor, vertical non-spreading discharge**
- **Group C: In or near floor, vertical spreading discharge**
- **Group D: In or near floor, horizontal discharge**
- **Group E: In or near ceiling, vertical discharge**

| | Yes | No | N/A | Comments |
|---|---|---|---|---|
| **Air movement is flow clean to less clear areas** | | | | |
| Pressure relationship to adjacent areas in Pascal (even is variable air volume system or load shedding system is used for energy conservation) | | | | |
| + If anteroom is provided for AII rooms , AII rooms has negative pressure with respect to anteroom & anteroom has negative pressure with respect to corridor. | | | | |

| | | | | | |
|---|---|---|---|---|---|
| | **+ Space (with & without anteroom) is equipped with pressure monitor/or visual means to monitor pressure difference between the space and the corridor** | | | | |
| | Outdoor ACH (see appendix C for calculations) | | | | |
| | Total ACH (Supply: positive pressure rooms/exhaust: positive pressure rooms) [can be reduced if room is not occupied, but test for occupied case] (see appendix C for calculations) | | | | |
| | **All room air (including air from toilet & anteroom) exhausted directly to outdoors (not recirculated to other areas or mixed with other exhausts)** | | | | |
| | **For AII rooms retrofitted from patient rooms, and it is impractical to exhaust directly to outdoor, recirculated air passes first through HEPA filter** | | | | |
| | **Air recirculated by means of room units (Recirculating room HVAC unit refers to a unit that is physically mounted in the space and that includes a coil; such as fan coil units, heat pumps, and induction units.)** | | | | |
| | Design Relative humidity (%) | | | | |
| | Design temperature ($^{O}$C) | | | | |
| | Type of supply air outlets (table 6.7.2):<br>• Group A: In or near ceiling, horizontal discharge<br>• Group B: In or near floor, vertical non-spreading discharge<br>• Group C: In or near floor, vertical spreading discharge<br>• Group D: In or near floor, horizontal discharge<br>• Group E: In or near ceiling, vertical discharge | | | | |
| | **+Operating room diffusers are within the primary supply array & non-aspirating (non-aspirating: a diffuser that has unidirectional downward airflow from the ceiling with minimum entrainment of room air)** | | | | |
| | **+ Wound intensive care unit/PE room diffusers are non-aspirating** | | | | |

| | | | | | |
|---|---|---|---|---|---|
| | Location of supply/exhaust outlets with respect to patient bed/surgery table<br>(draw or take picture if permitted) | | | | |
| 7.3 Critical Care units | **Wound intensive care unit (burn unit) is equipped with individual humidity control to supply the required humidity** | | | | |
| 7.4 Surgery Rooms | **Each operating room OR has individual temperature control** | | | | |
| | Primary supply diffuser array in OR is designed as follows: (tick relevant boxes)<br>☐ airflow is unidirectional downwards<br>☐ average velocity is between 25-35 cfm/ft$^2$<br>☐ **Diffusers are concentrated to provide an air flow pattern over the patient and surgical team**<br>☐ **The coverage area of the Primary supply diffuser array extend at least 305mm beyond the footprint of the surgical team on each side.**<br>☐ **Less than 30% of the extended area beyond the footprint of the surgical team is used for non-diffuser uses.** | | | | |
| | **Operating room is provided with at least 2 low side wall return or exhaust grilles spaced at opposite corners or as far apart as possible (the bottom of these grilles should be at least 203 mm above the floor)** | | | | |
| | **Sterilization room: Steam and ethylene oxide escaped from steriliser is exhausted using exhaust hood or any suitable means.** | | | | |
| | **Imaging procedure room: invasive procedure takes place, ventilation requirement for procedure rooms hould be fulfilled. If anaesthetic gases are applied, ventilation requirement for OR room should be fulfilled.** | | | | |