MINISTRY OF HEALTH
SINGAPORE

GUIDANCE FOR ASSESSMENT AND MAINTENANCE OF EFFECTIVE VENTILATION IN ACUTE CARE HOSPITALS: BEST PRACTICE RECOMMENDATIONS FOR INFECTION PREVENTION AND CONTROL

2024

FOREWORD

The COVID-19 pandemic has highlighted the importance of adequate ventilation in preventing the spread of infectious diseases within healthcare facilities. As healthcare facilities around the world continue to face challenges related to infection prevention and control (IPC), it is crucial that we prioritise the implementation of measures that will help protect healthcare workers, patients, and visitors.

This set of guidelines has been developed to provide practice guidance for IPC personnel in assessing ventilation effectiveness and implementing mitigation measures together with the engineering and facilities teams in acute care hospitals. It is an expert opinion based on the latest research, learning points from the COVID-19 pandemic and international recommendations.

The guidelines are intended to be used by acute care hospitals. They aim to provide a simplified framework for assessing and maintaining ventilation systems in existing facilities, including new construction projects within the facilities. It is not intended to replace any existing guidelines and/or standards for construction of new healthcare buildings. Healthcare facilities should refer to the relevant documents (e.g., IPC Specifications for New Healthcare Buildings, Pandemic Planning for Healthcare Infrastructure etc.;) for specific building specifications.

We recognise that effective ventilation is just one aspect of a comprehensive IPC programme. However, it is a crucial component that can help reduce the spread of infectious diseases within healthcare facilities. We hope these guidelines will be useful to IPC personnel in creating safe and healthy environments for both healthcare workers and patients.

We strongly encourage all acute care hospitals to implement these guidelines to the best of their abilities. We will continue to work with the experts to enhance this guideline in the coming years and explore the feasibility of extending the applicability of these guidelines to other healthcare facilities, such as nursing homes, and outpatient clinics.

Prof Dale Fisher,

NIPC Chairperson

ACKNOWLEDGEMENT

The *Guidance for Assessment and Maintenance of Effective Ventilation in Acute Care Hospitals: Best Practice Recommendations for Infection Prevention and Control* has been endorsed by the National Infection Prevention and Control Committee (NIPC). The composition of the NIPC is provided in Table 0.1.

Table 0.1: Composition of NIPC

S/N	Name	Role	Designation
1	Adj Asst Prof Kalisvar Marimuthu	Chairperson	Senior Consultant, Department of Infectious Diseases, TTSH & National Centre for Infectious Diseases (NCID)
2	Prof Dale Fisher	Advisor	Senior Consultant, Division of Infectious Diseases, University Medicine Cluster, National University Hospital (NUH)
3	A/Prof Ling Moi Lin	Member	Director, Infection Prevention and Epidemiology, Singapore General Hospital (SGH)
4	Adj Asst Prof Surinder Pada	Member	Director and Senior Consultant, Infectious Diseases, Ng Teng Fong General Hospital (NTFGH)
5	Dr Louisa Sun	Member	Consultant, Division of Infectious Diseases, Alexandra Health (AH)
6	Dr Tan Si Huei	Member	Consultant, Laboratory Medicine, Changi General Hospital (CGH)
7	A/Prof Thoon Koh Cheng	Member	Senior Consultant, Infectious Disease Service and Infection Control Committee Chair, KK Women's and Children's Hospital (KKH)
8	Dr Ray Lin	Member	Clinical Lead, Infection Prevention and Control Office, WH
9	Ms Poh Bee Fong	Member	Deputy Director of Nursing and Infection Control Lead Nurse, TTSH
10	Dr Margaret Soon	Member	Director of Nursing, NCID
11	Adj A/Prof Brenda Ang	Member *(Former)*	Clinical Director, Department of Infection Prevention and Control, Tan Tock Seng Hospital (TTSH)
12	Ms Sharon Wong	Member *(Former)*	Senior Nurse Clinician, Infection Prevention and Control, Sengkang General Hospital (SKH)

MOH would like to acknowledge Adj Asst Prof Kalisvar Marimuthu (Senior Consultant, Department of Infectious Diseases, TTSH & NCID) for leading the group in writing the guidance document. The members of the workgroup who contributed in their individual capacity to the drafting of the *Guidance for Assessment and Maintenance of Effective Ventilation in Acute Care Hospitals: Best Practice Recommendations for Infection Prevention and Control* are listed in Table 0.2.

Table 0.2: Composition of the Workgroup (in alphabetical order)

Name	Designation
Dr Darius Beh Lian Lian	Consultant, Department of Infectious Diseases, TTSH & NCID
Mr Roch Edward Ruben	Senior Engineer, Facilities Management, SKH
Er Joseph Toh Siaw Hui	Director, Healthcare Infrastructure Projects Division, MOH Holdings (MOHH)
Mr Lee Jang Young	Senior Manager, Green Mark Department, Building and Construction Authority (BCA)
Mr Li Jiayu	Senior Principal Research Officer, Environmental Epidemiology & Toxicology Division, Environmental Health Institute, National Environmental Agency (NEA)
Dr Margaret Soon	Director of Nursing, Nursing Administration, NCID
Er Phua Suan Yang	Deputy Director, Healthcare Infrastructure Projects Division, MOHH
Ms Sharon Wong	Senior Nurse Clinician, Infection Prevention and Control, SKH
Adj Asst Prof Surinder Pada	Director and Senior Consultant, Infectious Diseases, NTFGH
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Ms Yang Junjing	Senior Scientist, Environmental Epidemiology & Toxicology Division, Environmental Health Institute, NEA

CONTENT

ABBREVIATIONS

AC Air Conditioning

ACMV Air Conditioning and Mechanical Ventilation

ACH Air changes per hour

AHU Air Handling Unit

ASHRAE American Society of Heating, Refrigerating and Air Conditioning Engineers

A&A Addition and Alteration

BMS Building Management System

BCA Building and Construction Authority

CADR Clean Air Delivery Rate

CO_2 Carbon Dioxide

eACH Effective Air Changes Per Hour

FCU Fan Coil Unit

FM Facilities Management

HEPA High-Efficiency Particulate Air

HTM Health Technical Memorandum

HTM03-01 Health Technical Memorandum 03-01

IAQ Indoor Air Quality

IPC Infection and Prevention Control

MERV Minimum Efficiency Reporting Value

MV Mechanical ventilation

MMV Mixed-mode ventilation

NCID National Centre for Infectious Diseases

NEBB National Environmental Balancing Bureau

NR No Requirement

NV Natural Ventilation

N_2O Nitrous Oxide

Pa Pascals

RH Relative Humidity

SS 553 Singapore Standard 553

WHO World Health Organisation

GLOSSARY

ACMV system: mechanical systems serving the building's cooling and ventilation needs, which include air-handling and distribution systems to provide not only a comfortable environment but also ventilation to dilute and remove contaminants, provide conditioned air, and assist in controlling the transmission of airborne infection (ASHRAE, 2021). An ACMV system should be designed such that it can maintain a comfortable and healthy environment under all the operating conditions that can be expected, in an energy-efficient manner.

Air-Conditioning (AC): process of treating air to meet the requirements of a conditioned space by controlling its temperature, humidity, cleanliness, and distribution (ASHRAE, 2022).

Air cleaning system: a device or combination of devices applied to reduce the concentration of airborne contaminants such as microorganisms, dusts, fumes, respirable particles, other particulate matter, gases, vapours, or any combination thereof.

Critical system: ventilation systems serving the following areas: critical and intensive care, emergency departments, airborne infection isolation (AII) rooms, protective isolation rooms, bronchoscopy, sputum induction and pentamidine administration, sterilising and supply, autopsy room, and any other system that clearly meets the definition that "a loss of service from such a system would seriously degrade the ability of the facilities to deliver optimal healthcare".

SS 553-2016: code of practice for air-conditioning and mechanical ventilation in buildings: https://www.singaporestandardseshop.sg/Product/SSPdtDetail/112b67fc-8c96-4dd4-8d8a-e71a5b4d4df8

Fabric: refers to building fabric, encompassing the structural materials that compose a building such as the walls, floors, windows, and doors.

FCU (Fan Coil-Unit): a simple unit consisting of a heating or cooling coil and are generally not connected to ductwork.

Plant: denotes the ventilation system equipment room, as outlined in HTM03-01. In a Singapore Civil Defence Force (SCDF) document, the term "plant" is also utilized for the ACMV equipment room.
https://www.scdf.gov.sg/docs/default-source/scdf-library/fssd-downloads/hb_v4_ch7.pdf

RECOMMENDATION 1

A multidisciplinary team comprising of facilities management, engineering, and infection prevention & control (IPC) should be appointed by the hospital management to work together to ensure good indoor air quality in both clinical and non-clinical areas.

1.1 The team should consider developing and implementing a hospital-wide programme with dedicated funding to assess, improve and maintain adequate ventilation.

Notes for Recommendation 1

A team comprising of facilities management, engineering and infection prevention and control is best suited to ensuring ventilation adequacy in all areas of hospital. Facilities management have knowledge of the existing infrastructure and are responsible for maintenance and adherence to standards and building codes. Engineering teams can assist with more specialised assessments of ventilation adequacy or air flow studies and can propose strategies to augment and improve ventilation.

The infection prevention and control (IPC) team[1] provides guidance on the disease-specific clinical requirements of the facility and highlight areas where ventilation assessments need to be conducted in response to findings of outbreak investigations or where healthcare associated airborne transmission has occurred. The IPC team should also be able to conduct the necessary ground monitoring for gap identification and adherence to compliance strategies. With this multidisciplinary expertise, the team should be responsible for analysing recommendations in this document and overseeing their implementation in the respective healthcare facilities.

The team should escalate urgent ventilation-related issues to the hospital management, especially those that require resource for rectification and mitigation. Mitigation measures should adequately address shortfalls in ventilation e.g., if portable air purifiers are proposed, the effective air changes per hour (eACH) generated by the model's clean air delivery rate (CADR) should be factored in to ensure it meets minimum requirements for overall air changes per hour (ACH) for that area.

[1] IPC Team: Refers to the unit or department comprising of doctor and Infection Prevention Nurse (IPN).

RECOMMENDATION 2

Healthcare facilities should assess the effectiveness and adequacy of ventilation in patient care and non-patient care areas at regular intervals.

2.1 Healthcare facilities should conduct ventilation adequacy assessments for all patient care and non-patient care areas.

2.2 All ventilation systems should be subjected to at least a simple visual inspection annually.

2.3 Regular and proper ACMV equipment and system maintenance should be carried out as per SS 553-2016[2] recommendation.

2.4 All critical healthcare ventilation systems should be inspected at least half-yearly and Certified at least once every two years and as needed.

2.5 The team should consider using carbon dioxide (CO_2) monitoring as a proxy for ventilation adequacy by working towards maintaining the CO_2 below 800 ppm.

2.6 Healthcare facilities should consider using the WHO assessment tool mentioned in the WHO document "Roadmap To Improve And Ensure Good Indoor Ventilation In The Context Of COVID-19" (WHO, 2021).

Notes for Recommendation 2

All ventilation systems should be subjected to at least a simple visual inspection annually. The purpose of the inspection is to establish that:

a) The plant conforms to the minimum standard;
b) The general condition of the system is adequate for purpose;
c) The system overall is operating satisfactorily.

It is recommended that a sample checklist be used to record the result of the inspection. Sample checklist is given in Annex A; In addition to the visual inspection, regular and proper ACMV equipment and system maintenance should be carried out as per SS 553[2] recommendation.

[2] Refer to page 8 for additional information on SS 553-2016 code of practice.

All critical healthcare ventilation systems[3] should be inspected at least half-yearly and certified at least once every two years. The multidisciplinary team appointed by the hospital management (as per Recommendation #1) is responsible for ensuring the inspection is conducted and may achieve this by carrying it out directly or delegating the task to the appropriate team within the facility. In some circumstances the Certification may need to be carried out more frequently e.g., when the design pressure regimes are out of range and could not be reinstated or based on risk assessment. The sample checklist of the half-yearly inspection is detailed in Annex A. The purpose of the Certification will be to additionally ensure that the system:

a) Achieves minimum standards specific to the application;
b) Is operating to an acceptable performance level;
c) Remains fit for purpose.

Facility Certification should be conducted once every two years. The certification is intended to establish that:

a) The plant conforms to the minimum standard;
b) The general condition of the system is adequate for purpose;
c) The fabric of the area served is suitable for the function;
d) The system performance is adequate with respect to the functional requirement – this will require:
    - The measurement of all system supply, return and exhaust airflow rates;
    - The calculation of room ACH if applicable;
    - The measurement of room differential pressures if applicable;
    - The measurement of room noise levels;
    - Temperature, humidity, and any application-specific air velocity measurements;
    - A check of the control functions;
    - Microbiological air-quality sampling if required;
    - Any other application-specific tests or measurements as required.

Specialist Contractors (National Environmental Balancing Bureau (NEBB) certified company preferred) should be engaged to carry out the certification of the facilities with Testing & Commissioning Reports endorsed and submitted to the multidisciplinary team for review and action. Documents to be properly archived and retrievable.

[3] Refer to glossary in Page 8 for definition of critical ventilation system.

For both critical and non-critical ventilation systems, ACMV Contractors should be engaged to carry out proper air balancing, calibration of equipment and devices, and testing and commissioning of the facility, if the design parameters of the ventilation system are out of range during the visual inspections and could not be reinstated by FM. Facilities may refer to Appendix 13-1 of the Infection Prevention and Control Specifications for New Healthcare Buildings 2024 to conduct a gap analysis comparing the as-built design specification to determine whether upgrading the ventilation system is necessary. A summary of the visual inspection and certification requirements is tabulated in Table 2.1.

Table 2.1: Visual Inspection and Certification Requirements

Ventilation System	Critical System[3]	Non-critical System	Remarks
i. Visual Inspection	Half-yearly	Yearly	ACMV Contractors should be engaged to troubleshoot the system, if the design parameters of the ventilation system are out of range and could not be reinstated by FM. The scope of the visual inspection could be included in the building servicing and maintenance contract, if applicable.
ii. Certification	Once every two years	No requirement	Specialist Contractors (NEBB certified company preferred) should be engaged to carry out the certification*.

***** *A NEBB certified ACMV tester is recommended because of the following:*

a) A firm/individual which is certified by NEBB indicate that the firm/individual is highly skilled and have undergone the requirements set forth by NEBB to prove proficiency in each given discipline. Certified firms have a reputation for integrity and responsible performance.

b) A NEBB certified firm will have designated certified employee within the firm to supervise all NEBB related work.

c) NEBB Certified individuals will remain current with industry trends through continuing education in their related field.

However, if a non-NEBB certified ACMV tester is engaged, the following items should be verified:

a) Proper testing procedure (testing and measurement procedure) and documentation format (report).

b) The correct testing instrument (accuracy and within instrument measurement range) shall be used for the tests and ensure within the calibrated lifespan.

c) *Testing personnel are competent in using the measurement instruments and understands the testing procedure.*

CO_2 monitoring is a quick and technically easier way to conduct ventilation assessments compared to direct ventilation rate measurements. It may help to identify pockets of under-ventilated spaces in both clinical and non-clinical areas. High CO_2 levels suggests insufficient outdoor air intake and/or overcrowding.

Ventilation assessment should also be considered as part of an outbreak investigation of pathogens with capacity for airborne transmission. Inadequate ventilation is associated with higher risk of aerosol/airborne transmission. The National Environment Agency (NEA) Singapore has recommended a threshold below 800ppm in the context of COVID-19, which is similar to the recommendation from REHVA and US CDC. The RESCOP1 commission has proposed a lower threshold of 700 ppm. This workgroup recommends a threshold of 800 ppm as an indicator for adequate ventilation in hospital settings. The workgroup agrees that this threshold will need to be reviewed as more data emerge in this field.

Facilities can refer to the following guide for CO_2 monitoring:

a) Use a non-dispersive infrared (NDIR) portable CO_2 meter or install real-time CO_2 sensor with following recommended specifications:
   - Able to measure between 300 to 3,000 ppm or more and can be calibrated;
   - Logging frequency of at least once per minute;
   - Accuracy of not more than ±50 ppm or ±5% and resolution of 10 ppm or less.

b) Measurement locations and positions
   - At spaces with highest occupant density;
   - Between 75 cm and 120 cm from the floor at breathing zone level;
   - Away from windows, door, supply air vent;
   - Over 50 cm away from people.

c) Measurement
   - Over a period of 5 min per location;
   - Take measurements during peak occupancy;
   - Take several measurements throughout the day;
   - Take average readings, record the number of occupants, and the ventilation mode.
   - The frequency of CO_2 monitoring may be considered based on the need for facility level ventilation adequacy assessments. Routine and regular

monitoring of adequacy of ventilation, especially before and after significant changes to room occupancy or ventilation system e.g., after renovation or major A&A works that generates dust, can be considered.

d) Interpret the results
   - It is recommended to keep the CO_2 levels below 800 ppm to reduce risk of transmission of airborne infectious diseases.

Other verifications for ventilation effectiveness include:

a) Measuring temperature, humidity;
b) Measuring room differential pressures to understand the direction of the flow by
   - Visual test (puff cloud or tissue flows);
   - Differential pressure sensor; and
c) Measuring waste anaesthetic gas (N_2O) if applicable.

RECOMMENDATION 3

Healthcare facilities should be aware of and have the capacity to implement mitigation measures to ensure effectiveness and adequacy of ventilation in patient care and non-patient care areas.

3.1 Healthcare facility's multidisciplinary team should consider short-term and long-term mitigation strategies to improve ventilation.

3.2 Depending on the environmental condition, building parameters, and availability of resources and expertise, facilities should select the most appropriate strategy for their institution.

3.3 When considering mitigation strategies for rising environmental temperatures by introducing additional air-conditioning and spot-cooling, it is crucial to prioritize maintaining adequate ventilation, as the closure of windows in such scenarios may compromise ventilation in the wards.

Notes for Recommendation 3

Indoor air quality (IAQ) mitigation strategies can be divided into short-term and long-term strategies. Short term strategies are implemented in situations where permanent rectifications measures are not feasible (e.g., older buildings) or when mitigation measures are urgently needed. Short-term strategies are generally less resource intensive. Examples of short-term strategies include:

a) Increasing natural ventilation (when outdoor air condition allows) by fully or partly opening windows, air vents and doors but do not prop fire doors open. Position fans to blow air out of windows to increase air exchange.
b) Improving mechanical ventilation by further opening the outdoor damper.
c) Ensuring adequate air cleaning on recirculated air and/or in room air to provide clean air. Reference on air cleaning technologies can be taken from NEA's Technical Advisory on Use of Air-Cleaning Technologies to Mitigate COVID-19 Aerosol Transmission Risk

When considering mitigation strategies for rising environmental temperatures by introducing additional air-conditioning and spot-cooling, it is crucial to prioritize maintaining adequate ventilation, as the closure of windows in such scenarios may compromise ventilation in the wards. However, closure of windows can lead to build up in condensation and mould and can present a fall risk for patients. As such, hospitals should consider surfacing such interventions to the multidisciplinary team as described in Recommendation 1. The multidisciplinary team should devise and implement mitigations strategies to improve comfort without compromising ventilation quality.

Long-term strategies are usually more resource intensive and include:

a) Architectural modifications to existing infrastructure to improve natural ventilation;
b) Installation of extra exhaust or supply fans;
c) Installation of dedicated outdoor air processing units at building/premises level; and
d) Installation of new centralised ACMV system including outdoor air supply.

Practical strategies to improve ventilation adequacy are summarised in Table 3.1.

Table 3.1: Strategies to Improve Ventilation Adequacy

Design Parameters	Mitigation Measures	Remarks
Pressure regime (If applicable) - no reverse airflow for clean and containment facilities.	a) Explore portable ante room – to achieve directional airflow. b) Install low air leakage doors or ceilings and seal up all service penetrations on walls – to minimise air leakage and to achieve required pressure regime.	

Min. outdoor ACH	a) Increase outdoor ACH if the system can accommodate. b) Carry out air purging as mitigation measures, if necessary.	For air purging, need to ensure room pressure regime, cleanliness, temperature, and humidity are not adversely affected
Min. room ACH/Air filtration	Provide HEPA portable air cleaners as mitigation measures, if necessary.	
Space Temperature/ Relative Humidity	a) Maintain design space conditions based on functional needs. b) Install portable dehumidifier/air-con unit, If necessary	To ensure adequate indoor air quality is achievable (refer to SS 554).

RECOMMENDATION 4

Healthcare facilities should identify the modes and specifications of ventilation at both patient care and non-patient care areas at regular intervals.

4.1 Healthcare facilities should identify and document the ventilation modes and specifications in all patient care and non-patient care areas.

4.2 Modes of ventilation to be identified by the healthcare facilities include natural ventilation (NV), mechanical ventilation (MV), mixed-mode ventilation (MMV), and no ventilation or adventitious ventilation.

4.3 In addition to the general areas listed above, facilities should also identify specialised ventilation areas within their premises and be familiar with the commissioning specifications and standards used to develop these facilities.

Notes for Recommendation 4

Natural ventilation is provided by thermal, wind, or diffusion effects through doors, windows, or other intentional openings in the building which should have an aggregate effective open area of not less than 5% of the floor area of the room or space.

a) The effective open area of a sliding window is the unobstructed area when the sliding window is opened fully;

b) The effective open area of any opening installed with fixed louvers shall be assumed to be 50% of the area of the opening;

c) The effective open area of casement windows shall be assumed to be 50% of the window opening for windows that can be opened at least 30 degrees or more, while no effective open area will be taken for windows that are restricted from opening to an angle less than 30 degrees.

Windows and openings intended for natural ventilation shall be able to open to the exterior of the building; a recess exceeding 3m from the external building wall, and of minimum width 3.0m or an airwell with a minimum width of 3m and a minimum area open of 10m^2 to the sky or complying with BCA's acceptable solutions (BCA, 2022). As recommended in HTM 03-01 Specialised Ventilation for Healthcare Premises (Part A) (HTM03-01, 2021a), if the natural ventilation provided is cross flow, clear air paths with up to 6m inwards from the external façade need to be maintained. Beyond this distance, natural ventilation might not be sufficient and mixed-mode or mechanical ventilation should be provided. If natural ventilation is single sided, it will usually only be effective for a 3 m depth within the space. Beyond that it should be supplemented by mixed mode or mechanical ventilation.

Mechanical ventilation is provided by mechanically powered equipment such as motor-driven fans and blowers but not by devices such as wind-driven turbine ventilators and mechanically operated windows.

Mixed-mode ventilation is a hybrid using natural and mechanical ventilation systems and include:

a) ACMV system may serve as supplemental ventilation and/or cooling to natural ventilation; and
b) Dampers and fans are fitted in purpose-made ventilation openings or installed separately to ensure a minimum airflow rate while taking advantage of natural ventilation effects when present.

No ventilation (infiltration only) or adventitious ventilation: the indoor and outdoor air exchange mainly through leaks (unplanned openings) in a building envelope.

Table 4.1: Summary of the components for ventilation modes as described above

	Ventilation mode			
	Mechanical Ventilation	**Natural Ventilation**	**Mixed Mode Ventilation**	**No Ventilation (Infiltration only)**
Mechanically powered ventilation	Yes	No	Yes	No
Intentional opening for ventilation	No	Yes	Yes	No
With air-conditioning system/device	• With ACMV system • With exhaust fan and split air con or FCU	• With open windows/ doors and split air-con	• With ACMV system and open windows or doors	• Enclosed space with split air con or FCU without outdoor air supply
Without air-conditioning system/device	• With exhaust fan but without air-con	• With open windows/ doors only	• With open windows or doors and exhaust/ supply fan	• Enclosed space without air-con

	Ventilation mode			
	Mechanical Ventilation	**Natural Ventilation**	**Mixed Mode Ventilation**	**No Ventilation (Infiltration only)**
With air cleaning system	• With ACMV system • With ACMV system and air cleaning system connecting to ductwork. • With exhaust/supply fan and air cleaning devices (e.g., portable air purifier)	• With open windows/ doors and air cleaning devices (e.g., portable air purifier)	• With ACMV system and other air cleaning system connecting to ductwork and with open windows or doors. • With open windows or doors, exhaust/ supply fan and air cleaning devices (e.g., portable air purifier)	• Enclosed space with air cleaning devices (e.g., portable air purifier)
Without Air cleaning system	• With exhaust/supply fan, but without air cleaning devices	• With open windows/ doors only but without air cleaning devices	• With open windows or doors, exhaust/ supply fan but without air cleaning devices	• Enclosed space without air cleaning system

	Ventilation mode			
	Mechanical Ventilation	**Natural Ventilation**	**Mixed Mode Ventilation**	**No Ventilation (Infiltration only)**
With both air-conditioning and air cleaning system	• With ACMV system • With ACMV system with air cleaning system connecting to ductwork • With exhaust/supply fan, split air con or FCU, and air cleaning devices (e.g. portable air purifier)	• With open windows/ doors, split air con or FCU without outdoor air supply, and air cleaning devices (e.g., portable air purifier)	• With ACMV system and open windows or doors • With open windows or doors, exhaust/ supply fan, and air cleaning devices	• Enclosed space with air-con and air cleaning devices (e.g., portable air purifier)

In addition to the general areas listed above, facilities should also identify specialised ventilation areas within their premises and be familiar with the commissioning specifications and standards used to develop these facilities, e.g., HTM03-01 etc. These areas may include:

a) The operating department;
b) Treatment rooms, endoscopy, and minimally invasive suites;
c) Critical care area;
d) Diagnostic and interventional imaging and cardiology suites;
e) Obstetrics/maternity;
f) Infectious diseases unit and isolation facilities;
g) Bone marrow and other transplant units;
h) Chemotherapy and oncology unit;
i) The pharmacy department;
j) The pathology department, mortuary, and post-mortem suite;
k) Sterile services department; and
l) Burns unit

Healthcare facilities may consider applying World Health Organisation's multimodal improvement strategy in ventilation improvement.

A multimodal strategy consists of several of elements or components (3 or more; usually 5) implemented in an integrated way with the aim of improving an outcome and changing behaviour. It includes tools, such as bundles and checklists, developed by multidisciplinary teams that take into account local conditions. The 5 most common components include:

a) System change (that is, availability of the appropriate infrastructure and supplies to enable good ventilation in the facility) (build it);
b) Training and education of IPC staff, health care workers, facility managers and key players which may be facility specific (teach it);
c) Monitoring infrastructures, practices, processes, outcomes and providing data feedback (check it);
d) Reminders in the workplace/communications (sell it); and
e) Culture change with the establishment or strengthening of a safety climate (live it).

Figure 1. WHO multimodal improvement strategy

A comprehensive overview of the WHO's multimodal improvement strategy for healthcare facilities to integrate to for ventilation improvement.

System change

Healthcare facilities should set up a team (workgroup or committee) comprising IPC, FM team, engineers, and other stakeholders (as described in Recommendation 1). This team should identify the necessary infrastructure, equipment (e.g., CO_2 monitors and portable air purifiers), and other resources (including human resource) required for ventilation improvement. Dedicated funds should be allocated for work by this team. The funding request can be incorporated into the annual IPC and/or facility management team's budget estimation for approval by the hospital management. Major infrastructural changes to existing healthcare buildings are largely not possible. As such, the team could consider other strategies discussed in this document (e.g., portable air purifiers and use of exhaust fans) for indoor air quality improvement.

Human and infrastructural factors influencing adherence of healthcare workers to ventilation improvement strategies should be analysed and appropriate mitigation strategies should be put in place. For example, there is a possibility portable air purifiers may be turned off because staff use the power source for other purposes. In this instance, option to facilitate the healthcare workers' needs without compromising the function of portable air purifier should be explored and may include installation of more power sockets.

Training and education

It is recommended that facilities incorporate training and education of their ventilation improvement strategies. The facility level workgroup may consider targeted training for ventilation improvement. Targeted training is usually conducted when implementing an intervention in response to ventilation related problems in a specific area. Targeted training can be theoretical and/or practical and can be delivered as on the job training.

Additionally, facilities should consider incorporating importance of ventilation improvement and principles of ventilation improvement strategies as part of the facility-level IPC training and education programs provided to all healthcare workers, including new joiners as well as regular updates and competence checks of existing and previously trained staff.

Monitoring and feedback

Monitoring of selected parameters including surrogates for ventilation (e.g., CO_2 level), impact of poor ventilation (e.g., airborne pathogen clusters) and staff compliance to ventilation improvement strategies (e.g., keeping HEPA filters in operation) can help identify gaps and prioritize interventions. Monitoring should not be seen as a component separate from implementation but as an essential step in identifying gaps and allowing most appropriate interventions for local implementation.

Monitoring of the following indicators could be considered where appropriate:

a) Adequacy of ventilation using CO_2 levels.
b) Ward infrastructure for adequate ventilation.
c) Incidence of airborne pathogen clusters among patients and staff.
d) Staff compliance to ventilation improvement strategies.
e) Healthcare worker knowledge and perception of airborne pathogens and ventilation.

Feedback of these monitoring and evaluations should be provided to the relevant stakeholders using a no-blame approach with the intention to raise awareness, and to convince healthcare workers and other stakeholders of the need for improvement.

Monitoring, evaluation, and feedback data should be systematically collected and analysed. Data should be presented regularly at infection control committee meetings and circulated to relevant stakeholders.

Reminders and communications

Reminders are a powerful way to communicate the importance of ventilation in healthcare settings, and the roles and responsibilities of all healthcare workers in ensuring adequate ventilation. Facilities may consider:

a) Reminders to keep windows open to allow inflow of fresh air in naturally ventilated wards.
b) Reminders to ensure portable HEPA filters are turned on in enclosed room, i.e. closed windows and doors.

Facilities should develop targeted reminders to achieve the goal of adequate ventilation within their institution based on the resources available to them.

Culture change

Culture change is a slow and steady process that requires continuous implementation of WHO multimodal strategies. Ventilation improvement as a strategy to prevent nosocomial airborne pathogen infections should be given demonstrable support at every level of the healthcare system. At senior management level, support for ventilation improvement can be in the form of funding support for equipment and other resources. Senior management should also be champions and role models for ventilation improvement.

Facility IPC and engineering teams should co-develop and implement the interventions. They should be empowered to assess the adequacy of ventilation and implement interventions. Regular ventilation improvement campaigns could be considered to create awareness and ownership among all healthcare workers.

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ANNEX A

<u>Table A-1</u>: Assessment for Ventilation Adequacy (Visual Inspection Check List)

Design Parameters	Assessment methods	Result of Inspection	Remarks
AAPressure relationship	a) Check room pressure using portable differential pressure sensor/meter, or from Building Management System (BMS), if available. b) Verify directional airflow using a smoke test. c) Trend log the pressure regime using the BMS or other suitable methods.		Facilities Management (FM) could carry out assessment. The result of the assessment should be communicated to IPC. IPC could monitor the pressure monitors (e.g., at the entrance to airborne infection isolation rooms, AIIR) during routine IPC rounds and communicate abnormalities to FM team. Additionally, all staff entering the AIIR should be advised to verify the pressure gradient prior to entry.
	<u>Rectification/Troubleshooting</u>: a) Out of pressure range could be caused by leaky building enclosure. b) Check if window and doors are properly closed, and the gaskets are in good conditions. c) Check if all service penetrations on room enclosure are properly sealed (e.g., check for deterioration of sealants). d) Check for faulty equipment and controls, e) Check for any blocked/choked supply or exhaust air grilles.		Rectification/troubleshooting to be carried out by FM. The outcome should be communicated to IPC and the appointed multidisciplinary team.

Design Parameters	Assessment methods	Result of Inspection	Remarks
Min. outdoor ACH	a) By CO_2 measurement: i) Check the adequacy of outdoor air ventilation using a portable CO_2 meter to measure the indoor CO_2 levels or from BMS. ii) To reduce risk of transmission of airborne infectious diseases, CO_2 levels below 800 ppm over the measurement period should be targeted. b) Check the outdoor ACH from the BMS, or direct measurement from the outdoor air duct.		IPC/FM could carry out the assessment. Records of CO_2 monitoring should be kept by IPC/FM team for look-back purposes (e.g., when an airborne pathogen transmission cluster occurs).
	<u>Rectification/Troubleshooting:</u> a) Check if outdoor air fan is turned-on/no obstruction. b) Check if outdoor air filter is choked/dirty by visual inspection, or check the filter differential pressure reading, if available – to replace filter if necessary c) Check for faulty equipment and controls d) Carry out room purging, if purging system is provided.		Rectification/troubleshooting to be carried out by FM. Outcome should be communicated to IPC and the appointed multidisciplinary team.

Design Parameters	Assessment methods	Result of Inspection	Remarks
Min. total ACH/ Filter Efficiencies	a) Check if ventilation fan (e.g., AHU or FCU) is operating at design speed. – Check VSD setting of AHU, or fan speed setting of FCU (at equipment control panel, or from BMS). b) Check type of filters provided in the air-con system. c) Check pressure drop of filter is within design range (pressure gauge typically provided for AHU system) from equipment control panel, or from BMS. - Dirty filters with high pressure drop will reduce room ACH, and increase power consumption of the ventilation fan d) Check if filter integrity test is conducted for HEPA filter - request for filter test reports.		Assessment could be carried out by FM.
	<u>Rectification/Troubleshooting</u>: a) Reset the ventilation fan speed to design value. b) If pressure drop of filter is higher than the recommended final resistance (e.g., 450 Pa for MERV 14 filters), the filter should be replaced. c) To conduct filter integrity test for all new HEPA filter replaced.		a) Rectification/ troubleshooting to be carried out by FM. Outcome should be communicated to IPC. b) Filter integrity test to be conducted by Specialist Contractor

Design Parameters	Assessment methods	Result of Inspection	Remarks
Space Temperature/ Relative Humidity	a) Check space conditions using portable temperature/humidity meter, or from BMS. b) Out of range space conditions indicate potential problems on the air-con system (e.g., faulty sensors, equipment, and controls). High humidity may cause mould growth and infection control issues.		Assessment could be carried out by FM. IPC could assess RH of space with pre-installed humidity monitor during IPC rounds.
	<u>Rectification/Troubleshooting:</u> a) Check for faulty equipment and sensors. b) Check control functions and set-points of air-con equipment. c) Check for air leakages through building enclosures (e.g., air infiltration through above ceiling spaces).		Rectification/troubleshooting to be carried out by FM.

Remark: (1) AHU – Air Handling Unit. (2) FCU – Fan Coil Unit. (3) VSD – Variable Speed Drive.

------------ End of Guidelines ---------------