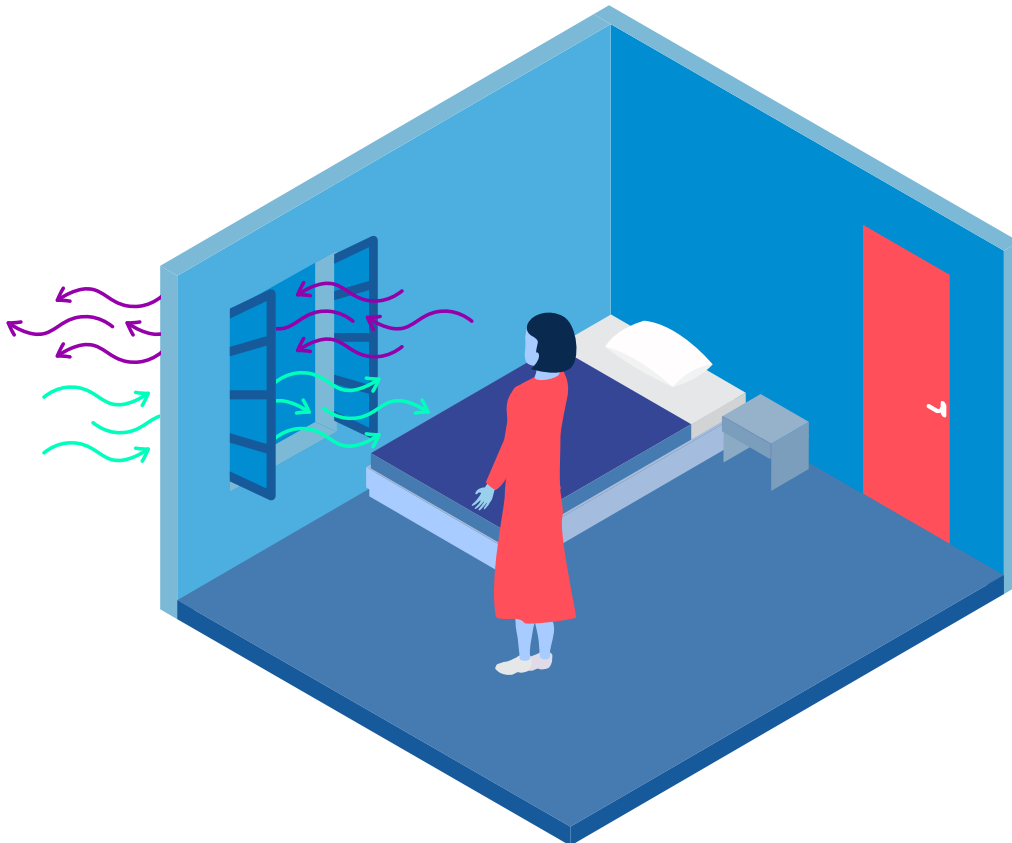




World Health
Organization

Roadmap to improve and ensure good indoor ventilation in the context of COVID-19



Roadmap to improve and ensure good indoor ventilation in the context of COVID-19



**World Health
Organization**

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Acknowledgements

This document was developed in consultation with the Environment and Engineering Control Expert Advisory Panel (ECAP) for COVID-19, with the following members, and Techne, the World Health Organization (WHO) Technical Science for Health Network.

Stefano Capolongo (Polytechnic of Milan, Italy); Bryan Christensen (Centers for Disease Control and Prevention, United States of America); Guilherme Coelho (Technische Universität Berlin, Germany); Jim Crabb (Mazzetti, ASHRAE Advisory Committee, United States of America); Nizam Damani (Southern Health and Social Care Trust, United Kingdom of Great Britain and Northern Ireland); Joost Hoopman (Radboud University Medical Center Nijmegen, The Netherlands); Frank Kelly (Imperial College London, United Kingdom); Nino Kuenzli (Swiss Tropical and Public Health Institute, Switzerland); Jarek Kurnitski (Tallinn University of Technology, Estonia); Fernanda Lessa (Centers for Disease Control and Prevention, United States of America); Yuguo Li (University of Hong Kong, Special Administrative Region (SAR), China); Marcel Loomans (Eindhoven University of Technology, Netherlands); Stephen Martin (Centers for Disease Control and Prevention, United States of America); Shaheen Mehtar (Infection Control Africa Network, South Africa); Arsen Krikor Melikov (University of Denmark, Denmark); Donald K Milton (University of Maryland, United States of America); Lidia Morawska (Queensland University of Technology, Australia); Catherine Noakes (University of Leeds, United Kingdom); Daniela Pedrini (Italian Society of Architecture and Engineering for Healthcare, International Federation of Healthcare Engineering, Italy); Jonathan Samet (Colorado School of Public Health, United States of America); Mitchell Schwaber (Israel Ministry of Health, Israel); Chandra Sekhar (National University of Singapore, Singapore); Ollie Seppänen (Aalto University, Finland); Wing Hong Seto (University of Hong Kong, SAR, China); Kwok Wai Tham (National University of Singapore, Singapore); Walt Vernon (Mazzetti, Vice Chair for ASHRAE 189.3, United States of America); Jean-Pierre Veyrenche (School of Business and Development 3A, Lyon and Paris, France); Pawel Wargocki (University of Denmark, Denmark).

WHO Secretariat: Maria Purificacion Neira (Chair), Kamal Ait-ikhlef, Benedetta Allegranzi, Anja Borojevic, Michele Di Marco, Luca Fontana, Sophie Gumy, Pierpaolo Mudu, Francis Roosevelt Mulemba, Nathalie Laure Roebbel, Jordi Sacristan Llobet, Anna Silenzi, Maria Van Kerkhove.

Abbreviations

ACH	Air Changes per Hour
AGP	Aerosol-Generating Procedures
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
CADR	Clean Air Delivery Rate
ECAP	Environment and Engineering Control Expert Advisory Panel
HCW	Health Care Worker
HEPA	High-Efficiency Particulate Air
HVAC	Heating, Ventilation and Air Conditioning
IAQ	Indoor Air Quality
IPC	Infection Prevention and Control
MERV	Minimum Efficiency Reporting Value
PM	Particulate Matter
REHVA	Federation of European Heating, Ventilation and Air Conditioning Associations
WHO	World Health Organization

Glossary

Aerosol-generating procedures (AGP):

Defined as any medical procedures that can induce the production of aerosols of various sizes (e.g. tracheal intubation, non-invasive ventilation, tracheostomy, cardiopulmonary resuscitation, manual ventilation before intubation, bronchoscopy, dental procedures) (1).

Age of air, local: The time it takes for supply air to reach a certain indoor point (2).

Air changes per hour (ACH): Ventilation airflow rate (m^3/hr) divided by room volume. It indicates how many times, during 1 hour, the air volume of a space is fully replaced with outdoor air (2).

Air cleaner: Device used for removal of airborne particulates and/or gases from the air. Air cleaners may be added to heating, ventilation and air-conditioning systems (HVAC) systems or stand-alone room units (2). Single-space air cleaners with high-efficiency particulate air (HEPA) filters (either ceiling mounted or portable) can be effective in reducing/lowering concentrations of infectious aerosols in a single space. The effectiveness of portable HEPA filters will depend on the airflow capacity of the unit, the configuration of the room including furniture and persons in the room, the position of the HEPA filter unit relative to the layout of the room, and the location of the supply registers or grilles (3). Note that air cleaners do not replace normal ventilation as they are only able to remove a particular part of the indoor air contamination.

Air conditioning: Form of air treatment in which temperature is controlled, possibly in combination with the control of ventilation, humidity and air cleanliness (2). Note that air-conditioning units in the case of, for example, split units often have no ventilation component. Therefore, ventilation requirements are to be put in place in addition to the use of air conditioning.

Air diffusion, mixing: Air diffusion where the mixing of supply air and room air is intended (2).

Air, exhaust: Air removed from a space and discharged to the atmosphere by means of mechanical or natural ventilation systems (2).

Air extract, mechanical: The process of

extracting air with the aid of powered air movement components, usually fans (2).

Air extract, natural: The process of extracting air by means of wind forces or density differences or a combination of the two (2).

Air, indoor: Air in the treated room or zone (2).

Air, mixed: The mixture of outdoor air and recirculated air (2).

Air, outdoor: Controlled air entering the system or opening from outdoors before any air treatment (2).

Air, recirculation: A part of extracted air which is not exhausted from the building, but it is recirculated back into spaces (2). The air can be treated before being recirculated (thermal, air quality).

Air, supply: Air delivered by mechanical or natural ventilation to a space, composed of any combination of outdoor air, recirculated air or transferred air (2).

Air transportation: Transportation of a specified airflow to or from the treated space generally by means of ducts. Along the ducts, devices for the purpose of treating the air (e.g. cleaning, heating, cooling, humidifying or dehumidifying, etc.) and known as air treatment devices, may be inserted (2).

Clean air delivery rate (CADR) (m^3/hr): Usually used in relation to portable air cleaner devices. **Cross ventilation:** Cross ventilation occurs where there are ventilation openings on both sides of the space. Air flows in one side of the building/room and out the other side through, for example, a window or door. Cross ventilation is usually wind driven (4).

Fan coil: A component of a HVAC system containing a fan and a heating or cooling coil, used to distribute heated or cooled air. Where the unit does not include a ventilation component, ventilation in the room has to be taken care of in parallel.

Filter: Device for removing particulate matter from a fluid or gas (2).

Flow rate, ventilation: Volume flow rate (m^3/hr) (l/s) (ACH) at which ventilation air is supplied or removed from a room or a building through

the ventilation system or infiltration through the building envelope (2).

Heat exchanger: A device in which heat is transferred between two mediums which do not come in contact (2).

Heat exchanger, air-to-air plate: Heat exchanger designed to transfer thermal energy from one air stream to another without moving parts. Heat transfer surfaces are in the form of plates. This exchanger may have a parallel flow, cross flow or counter flow construction or a combination of these (2).

Heat exchanger, rotary: A device incorporating a rotating cylinder or wheel for the purpose of transferring energy from one air stream to the other. It incorporates heat transfer material, a drive mechanism, a casing or frame, and includes any seals which are provided to retard the bypassing and leakage of air from one air stream to the other (2).

Heat exchanger, twin coil: Heat exchanger designed to transfer thermal energy from one air stream to another without moving parts. Heat transfer surfaces are in the form of tubes. This exchanger may have a parallel flow, cross flow or counter flow construction or a combination of these (2).

Heat recovery: Heat utilized from a heating system, which would otherwise be wasted (2).

High-efficiency particulate air (HEPA): HEPA air filter classes E10 to H14 according to EN 1822 (2). Facilities that choose to use HEPA filters should follow the manufacturer's instructions, including on recommended cleaning and maintenance procedures for HEPA filters. Otherwise, portable air cleaners with HEPA filters can lead to a false sense of security as their performance decreases due to filter loading (3).

Minimum efficiency reporting value (MERV): Minimum reported efficiency in specified particle size ranges during the test (2).

Pressure difference: Difference between pressures measured at two points or levels in fluids or gases (2).

Pressure, negative: Condition that exists when less air is supplied to a space than is exhausted

from it, so the air pressure within that space is less than that in the surrounding areas. Under this condition, if an opening exists, air will flow from the surrounding areas into the negatively pressurized space (2).

Pressure, positive: Condition that exists when more air is supplied to a space than is exhausted from it, so the air pressure within that space is greater than that in the surrounding areas. Under this condition, if an opening exists, air will flow from the positively pressurized space outward to the surrounding areas (2).

Single-sided ventilation: Single-sided ventilation relies on opening(s) on one side only of the ventilated enclosure. It is possible to get buoyancy-driven exchanges through a single opening if the opening is reasonably large in the vertical dimension (4).

Source control: A preventive strategy for reducing airborne contaminant levels in the air through removal of the material or activity generating the pollutants (2) or through removing the pollutant at source by means of localized exhausted strategy.

Split system: A two-component heating and cooling or cooling only system. The condensing unit is installed outside, the air handling unit is installed inside. Refrigerant lines and wiring connect them together (2). Generally, this system has no ventilation component and recirculates conditioned air.

Stack effect: Pressure difference caused by the difference in density between indoor and outdoor air due to indoor/outdoor buoyancy forces (2).

Ventilation: Ventilation is the process of supplying outdoor air to and removing indoor air from a space, for the purpose of controlling air contaminant levels, potentially accompanied by humidity and/or temperature, by natural or mechanical means (5).

Ventilation, mechanical: The active process of supplying air to or removing air from an indoor space by powered air movement components (2).

Ventilation, natural: Ventilation occurring as a result of only natural forces, such as wind pressure or differences in air density, through doors, windows or other intentional openings in the building (2).

Ventilation system: A combination of appliances designed to supply interior spaces with outdoor air and/or to extract polluted indoor air (2).

Whirlybird: A wind-driven turbine located on a roof to improve extraction of air from a building.

Executive summary

Context

The risk of getting COVID-19 is higher in crowded and inadequately ventilated spaces where infected people spend long periods of time together in close proximity. These environments are where the virus appears to spread by respiratory droplets or aerosols more efficiently, so taking precautions is even more important.

Understanding and controlling building ventilation can improve the quality of the air we breathe and reduce the risk of indoor health concerns including prevent the virus that causes COVID-19 from spreading indoors.

Methods

The roadmap was developed after conducting a scoping review of the available literature and an assessment of the available guidance documents from the major internationally recognized authorities on building ventilation. The available evidence and guidance were retrieved, collated and assessed for any discrepancies by international expert members of the World Health Organization (WHO) Environment and Engineering Control Expert Advisory Panel (ECAP) for COVID-19. The roadmap development process included two expert consultation sessions via virtual meetings, and two rounds of written submissions, to gather technical contributions and to ensure consensus building for the adaptation of recommendations. This process considered infection prevention and control (IPC) objectives, resource implications, values and preferences, ethics, and research gaps within the roadmap development.

Outcomes

This process resulted in a roadmap on how to improve ventilation in indoor spaces. The roadmap is divided into three settings – health care, non-residential and residential spaces – and takes into account different ventilation systems (mechanical or natural). The roadmap is aimed at health care facility managers, building managers, as well as those members of the general public who are providing home care or home quarantine.

1. Introduction

Knowledge about transmission of the SARS-CoV-2 virus is continuously evolving as new evidence accumulates. According to available evidence, SARS-CoV-2 mainly spreads between people when an infected person is in close contact with another person. Transmissibility of the virus depends on the amount of viable virus being shed and expelled by a person, the type of contact they have with others, the setting and what IPC measures are in place. The virus can spread from an infected person's mouth or nose in small liquid particles when the person coughs, sneezes, sings, breathes heavily or talks. These liquid particles are different sizes, ranging from larger "respiratory droplets" to smaller "aerosols". Close-range contact (typically within 1 m) can result in inhalation of, or inoculation with, the virus through the mouth, nose or eyes (6–11).

Aerosol transmission can occur in specific situations in which procedures that generate aerosols are performed. The scientific community has been actively researching whether the SARS-CoV-2 virus might also spread through aerosol transmission in the absence of aerosol-generating procedures (AGP) (12, 13). Some studies that performed air sampling in clinical settings where AGP were not performed found virus RNA, but others did not (14). The presence of viral RNA is not the same as replication and infection-competent (viable) virus that could be transmissible and capable of initiating invasive infection. A limited number of studies have isolated viable SARS-CoV-2 from air samples in the vicinity of COVID-19 patients (15, 16). Outside of medical facilities, in addition to droplet and fomite transmission, aerosol transmission can occur in specific settings and circumstances, particularly in indoor, crowded and inadequately ventilated spaces, where infected persons spend long periods of time with others (10). High-quality research is required to address the knowledge gaps related to modes of transmission, infectious dose and settings in which transmission can be amplified. Currently, studies are under way to better understand the conditions in which aerosol transmission or superspreading events may occur.

1.1 Public health and social measures

WHO has published numerous recommendations for measures (17–21) to prevent spread of COVID-19, among which is ensuring good ventilation in indoor settings, including health care

facilities, public spaces and residential areas. A well-designed, maintained and operated system can reduce the risk of COVID-19 spread in indoor spaces by diluting the concentration of potentially infectious aerosols through ventilation with outside air and filtration and disinfection of recirculated air. Proper use of natural ventilation can provide the same benefits. The decision whether to use mechanical or natural ventilation should be based on needs, resource availability and the cost of systems to provide the best control to counteract the risks.

This document accompanies the published recommendations cited above. It elaborates and expands on recommended actions targeting ventilation as listed in the above cited documents and provides health care facility managers, building managers (including long-term care, non-residential and residential facilities) as well as for the general public when implementing home care and home quarantine, with an operational tool to enhance indoor ventilation as an environmental and engineering control for the COVID-19 pandemic and beyond. It is neither prescriptive nor exhaustive and should be adapted to national regulatory frameworks and local social, cultural and economic contexts. The roadmap is not intended to replace other guidance and plans, but rather to complement them by helping facility managers ensure that key considerations are addressed.

1.2 Scope of the document

SARS-CoV-2 transmission is particularly effective in crowded, confined indoor spaces where there is poor or no ventilation (22). Therefore, ensuring adequate ventilation may reduce the risk of COVID-19 infection (23). This roadmap aims to define the key questions users should consider to assess indoor ventilation and the major steps needed to reach recommended ventilation levels or simply improve indoor air quality (IAQ) in order to reduce the risk of spread of COVID-19. It also includes recommendations on how to assess and measure the different parameters, specifically in health care, non-residential and residential settings. It is meant to be a technical document helping users to analyse building HVAC systems in order to implement, if required, the different strategies proposed to improve HVAC's ability to mitigate and reduce the risk of COVID-19 transmission.

Note: Indoor ventilation is part of a comprehensive package of prevention and control measures that can limit the spread of certain respiratory

viral diseases, including COVID-19. However, ventilation alone, even when correctly implemented, is insufficient to provide an adequate level of protection. Correct use of masks, hand hygiene, physical distancing, respiratory etiquette, testing, contact tracing, quarantine, isolation and other IPC measures are critical to prevent transmission of SARS-CoV-2.

The roadmap provides guidance for health care facility managers, building managers (including long-term care, non-residential and residential facilities) as well as for the general public when home care and home quarantine are required.

2. Methodology

The methods used to develop the roadmap included two stages. First, a scoping rapid review on building ventilation and transmission of SARS-CoV-2 was undertaken. A search (see Annex 1 for the search strategy) of the WHO COVID-19 database and existing COVID-19 rapid review collections up to 2 December 2020 identified 1174 citations, 99 of which were reviewed at the full-text level. Six articles met broad inclusion criteria on ventilation systems and transmission of SARS-CoV-2 (three peer-reviewed articles and three preprint articles – see Annex 1 for details). Of the peer-reviewed studies, one was a validation study of an isolation space created by modifying a HVAC system in a hospital in Pennsylvania, United States of America. A second study evaluated transmission between patients and health care workers (HCW) in negative pressure isolation rooms in Daegu, Republic of Korea. The third study was an outbreak investigation in an air-conditioned restaurant in Guangzhou, China. Of the included preprint studies, two were studies of SARS-CoV-2 transmission on the Diamond Princess cruise ship. A third preprint study evaluated the role of HVAC systems in transmission in an academic medical centre in Oregon, United States of America. In addition, a review and adaptation of all relevant technical guidance published by the globally recognized leading international and regional heating, refrigerating and air-conditioning associations and federations, namely the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) and Federation of European Heating, Ventilation and Air Conditioning Associations (REHVA), and review and adaptation of the available guidance on HVAC systems in the context of COVID-19 published by the US Centers for Disease Control and Prevention

and the European Centre for Disease Prevention and Control was undertaken. Links to the technical documents and guidelines considered are available in Annex 2.

Key findings from the identified studies and the relevant recommendations from the existing guidance were extracted and collated. Discrepancies in the extracted findings and recommendations were then reviewed in consultation with national and international expert members of the ECAP for COVID-19. The ECAP constitutes an ad-hoc advisory panel supporting the WHO's World Health Emergencies preparedness, readiness and response to COVID-19 and includes, amongst other, members of the Global Infection Prevention and Control Network, engineers and architects from relevant professional engineering and architecture networks, organizations and institutions specialized in health care settings, technical experts from ministries of health and similar institutions (see Acknowledgements); and WHO staff and consultants from different departments including Environment, Climate Change and Health, Infection Prevention and Control, and Operations Support and Logistic. The roadmap development process included two expert consultation sessions, via virtual meetings, to gather technical contributions and consensus building for the adaptation of recommendations taking IPC objectives, resource implications, values and preferences, ethics and research gaps into account. In addition to the virtual meetings, two rounds of written input by contributors were used to finalize the roadmap. All authors contributing to this document and members of the external and internal review panels signed conflict of interest statements. No conflicts of interest were declared.

3. Key information

Ventilation is the intentional introduction of clean air into a space while the stale air is removed. Ventilation moves outdoor air into a building or a room and distributes it within the building or room. If local outdoor conditions require, e.g. high particulate matter (PM) concentration, treatment of the outdoor air may be needed before introducing it into the building.

The general purpose of ventilation in buildings is to ensure that air in the building is healthy for breathing. At present this is achieved mainly by diluting pollutants originating in the building

with clean air, and by providing an airflow rate to change this air at a given rate thus removing the pollutants. Ventilation is also used for odour control, containment control and often combined with climatic control (temperature and relative humidity).

Building ventilation has three basic elements:

- ventilation rate (m^3/hr , l/s or ACH) – the volume of outdoor air that is provided into the space;
- airflow direction – the overall airflow direction in a building and spaces, which should be from clean zones to dirty zones; and
- air distribution or airflow pattern – the external air should be delivered to each part of the space in an effective and efficient manner and the airborne pollutants generated in each part of the space should also be removed in an effective and efficient manner.

There are three methods that may be used to ventilate a building: natural, mechanical and hybrid (mixed mode) ventilation. This roadmap only considers mechanical and natural ventilation as all key questions and strategies described can also be adopted for hybrid ventilation.

4. Settings

To provide maximum utility of a ventilation system and provide greater general dilution of air contaminants throughout the space, mechanical and natural systems can be used independently of the settings. However, each setting has specific ventilation requirements defined by national and international regulatory bodies which differ according to the ventilation objectives. For instance, ventilation systems in medical facilities are in place as an environment and engineering control for infection prevention (24) while, for residential buildings, they are mainly to create a thermally comfortable indoor environment with acceptable indoor air quality (25).

The roadmap focuses on three different settings according to specific IPC objectives. Each setting is described below to facilitate understanding and knowledge of implementation strategies in all contexts.

4.1 Health care settings

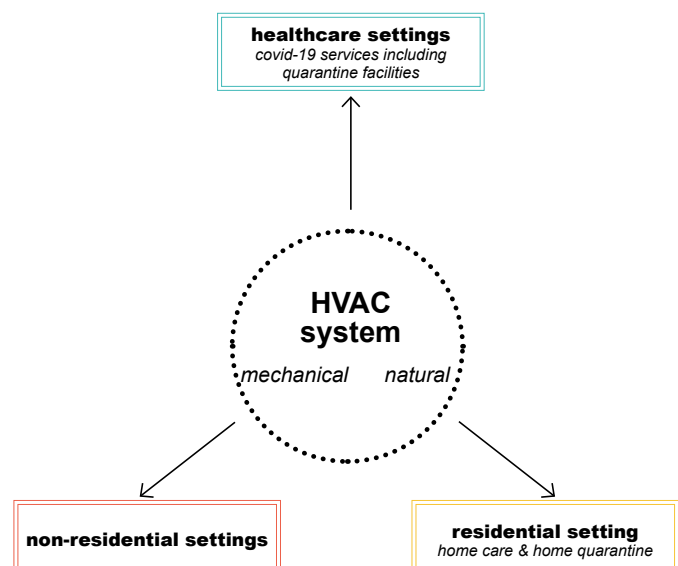
Adequate ventilation in all patient care areas plays a key role to help prevent and reduce infections. Nevertheless, this document specifically targets COVID-19 structures such as COVID-19 treatment centres and wards including quarantine,

community facilities and long-term care facilities. Some risk factors, such as the presence of confirmed and suspected cases, the proximity required to provide medical care, AGP potentially performed, and visitor influx, make these settings particularly vulnerable. For the above reasons, together with other IPC measures described in their specific guidance, these settings require strict ventilation requirements to enable a safe working environment and reduce the risk of health care associated infections amongst HCWs, patients and visitors.

4.2 Non-residential setting

For this document “non-residential setting” refers to public and private indoor spaces characterized by a heterogeneous occupancy rate with people not belonging to the same household, such as workplaces (26), schools (19) and universities, accommodation sector buildings (27), and religious and commercial spaces. The load of air pollution or infectious aerosol potentially released in a building depends on the activities performed inside, the number of occupants and whether or not the occupants are wearing masks.

National, regional or international requirements are available for each setting and several interim guidance documents have been developed. However, in order to strengthen proposed IPC measures, simplify the COVID-19 risk assessment and facilitate the implementation of corresponding countermeasures, a minimum ventilation rate per person is proposed. This figure, directly linked to space occupancy, will allow the assessment and improvement of ventilation and, if not possible, the adjustment of maximum building occupancy. Note that buildings repurposed in community and quarantine facilities are included in the chapter “4.1 Health care settings”.



4.3 Residential settings

In the context of the current COVID-19 outbreak, WHO recommends the rapid identification of COVID-19 cases and their isolation and management either in a medical facility or an alternative setting, such as the home. Additionally, in many contexts, health services are delivered at community level and in the home by community health workers, traditional medicine practitioners, social care workers, or a variety of formal and informal community-based providers. Specific guidance for safe home care (20) and home quarantine (28) are already available and provide recommendations on IPC measures including how to assess a potential isolation area space in residential settings. This roadmap aims to strengthen the use of ventilation as an environment and engineering control measure to reduce the risk of COVID-19 transmission amongst household members whenever a person is under home care or home quarantine and should be considered as a complementary part for the already existing IPC guidance.

5. Important considerations

5.1 Vector-borne diseases

Vector-borne diseases are human illnesses caused by parasites, viruses and bacteria that are transmitted by vectors; the commonest one being mosquitoes, the vector for malaria, dengue, and yellow fever. Other flying vectors also contribute to human illness such as human African trypanosomiasis and leishmaniasis. Every year more than 700 000 deaths result from these diseases. The burden of these diseases is highest in tropical and subtropical areas, and they disproportionately affect the poorest populations (29).

One of the most used, affordable and sustainable measures to prevent and reduce the incidence for some vector-borne diseases is the installation of mosquito screening on windows, doors and other entry points. Unfortunately, simple mosquito screening on windows may reduce the natural ventilation rate significantly and this should be taken into account when calculating air changes. For the above reasons, especially where vector-borne diseases are endemic, it is essential to consider strengthening vector control activities while improving indoor ventilation.

5.2 Outdoor air pollution

Outdoor air pollution is a major environmental

health problem affecting all countries. Ambient (outdoor) air pollution in both cities and rural areas is estimated to cause about 4 million (30) premature deaths worldwide per year. People living in low- and middle-income countries disproportionately experience the burden of outdoor air pollution.

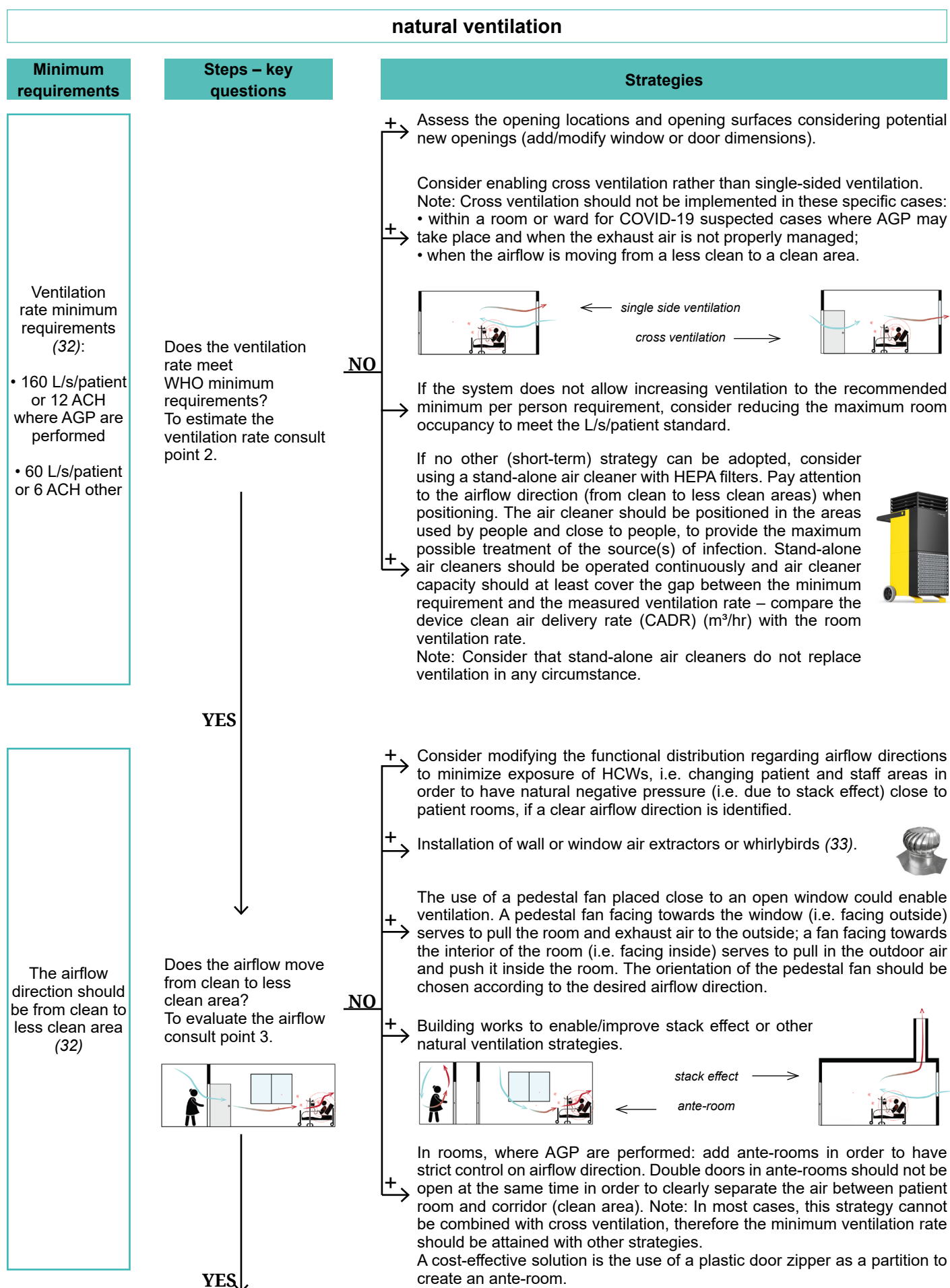
Avoiding air pollution through staying indoors may be beneficial but the effect largely depends on the level of indoor risks (e.g. indoor and household air pollution, presence of sick persons). Also, there is uncertainty about the reduction in exposure of populations, and the health benefits of staying indoors are not clear or may be reversed, depending on various circumstances, and the potential benefits and harms depend from specific local factors. As shown in a recent report, efficacy of portable indoor air filters (or portable indoor air cleaners) in real-world situations (i.e. not laboratory or occupational settings) showed that they are efficient to reduce indoor particulate matter (PM_{2.5}) concentration by 40–82% but that little improvement of health effects were demonstrated (31) (mainly for healthy adults). It would, however, be premature to recommend the use of portable air filters as a public health measure to protect from air pollution for many reasons. Thus, the use of portable indoor air filters might be proposed for people with pre-existing conditions, such as chronic obstructive pulmonary disease, heart failure or lung transplants, who should stay at home and be protected from exposure to air pollution. Yet, given the current COVID-19 pandemic, indoor air filtration and recirculation should be carefully considered, taking into account the COVID-19 mitigation measures. If appropriate, consider outdoor air pollution levels while assessing and improving indoor ventilation by using natural ventilation and outdoor air filtration. For example, in areas constantly experiencing high levels of outdoor air pollution or at times/episodes of air pollution, (outdoor) air filtration may be more appropriate than increasing ventilation rates.

6. How to use the roadmap

Owners and building managers should consider evaluating their building systems to check that they are operating in proper order (per design or current operational strategies), are capable of being modified to align with HVAC mitigation strategies, and to identify deficiencies that should be repaired. Several recommendations should be considered in consultation with HVAC professionals.

The finalized roadmap is divided into three settings: health care, non-residential and residential spaces such as private houses. For each category there is a further stratification according to the ventilation system – mechanical or natural ventilation. After identifying the correct setting and ventilation system, the reader should start from the top, beginning with the central column labelled “step – key questions”. On the left side, the minimum requirements and standards are proposed for each key question, while on the right side, the different strategies to improve the specific matter. Strategies are listed in order of preference from the most effective to the least effective, i.e. if more than one strategy can be implemented, the first one, the one on top, should be preferred. However, it is worth highlighting that neither the cost nor the time required for implementation were considered. As a rule of thumb, the strategies at the top of the list, while being the most effective, can be the most expensive and take the longest to implement. When implementing the roadmap, building owners and managers should consider, amongst other factors, weather conditions and outdoor air pollution. For a few specific cases, it is preferable to implement two or more strategies simultaneously. Those cases are marked with a plus (+) symbol in between the strategies to be combined.

6.1 Health care settings including quarantine facilities



Air should be exhausted directly to the outside away from air intake vents (34)

Is the exhausted air correctly managed?

NO

Use of fences to avoid passage of people close to openings (windows and doors), keeping people or animals at a distance at least of 4 m. No action is needed if the air is exhausted from the roof or 2 m higher than people (i.e. due to stack effect, whirlybirds).

YES

Heating and air conditioning with recirculating units should be used carefully and after assessment

Air conditioning and heating are performed by non-ducted (with indoor air recirculation) convectors such as split or fan coil units.



YES

Use of split system and fan coil units is discouraged because they are difficult to maintain, provide poor filtration and contribute to turbulence, potentially increasing the risk of infection (35).

Avoid use of split system and fan coil units for COVID-19 patients (36), especially where AGP are performed and consider using alternative heating and cooling systems and local exhaust systems.

Split systems can be used only in single room (suspected or confirmed cases) and in shared room hosting cohorted confirmed inpatients.

Note: Non-ducted recirculating units do not replace ventilation in any circumstance.

Whenever in-room recirculating units with poor filtration are used, consider creating a negative pressure relative to the corridor to reduce the potential for aerosols to escape from the room. Negative pressure can be created by increasing the airflow of extracted air from the room by installing extractor fans or devices. Units should be cleaned carefully in between patients (36).

If alternative air conditioning and heating are not available/feasible, consider running the air-conditioning and heating units at minimum velocity to reduce turbulence where AGP are performed. Where thermal conditioning (high temperatures) is needed, ensure that direct airflows between individuals are avoided.

Except for single room (suspected or confirmed cases) and shared room hosting cohorted confirmed inpatients.

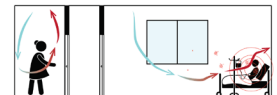
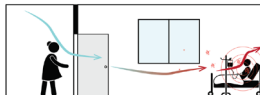
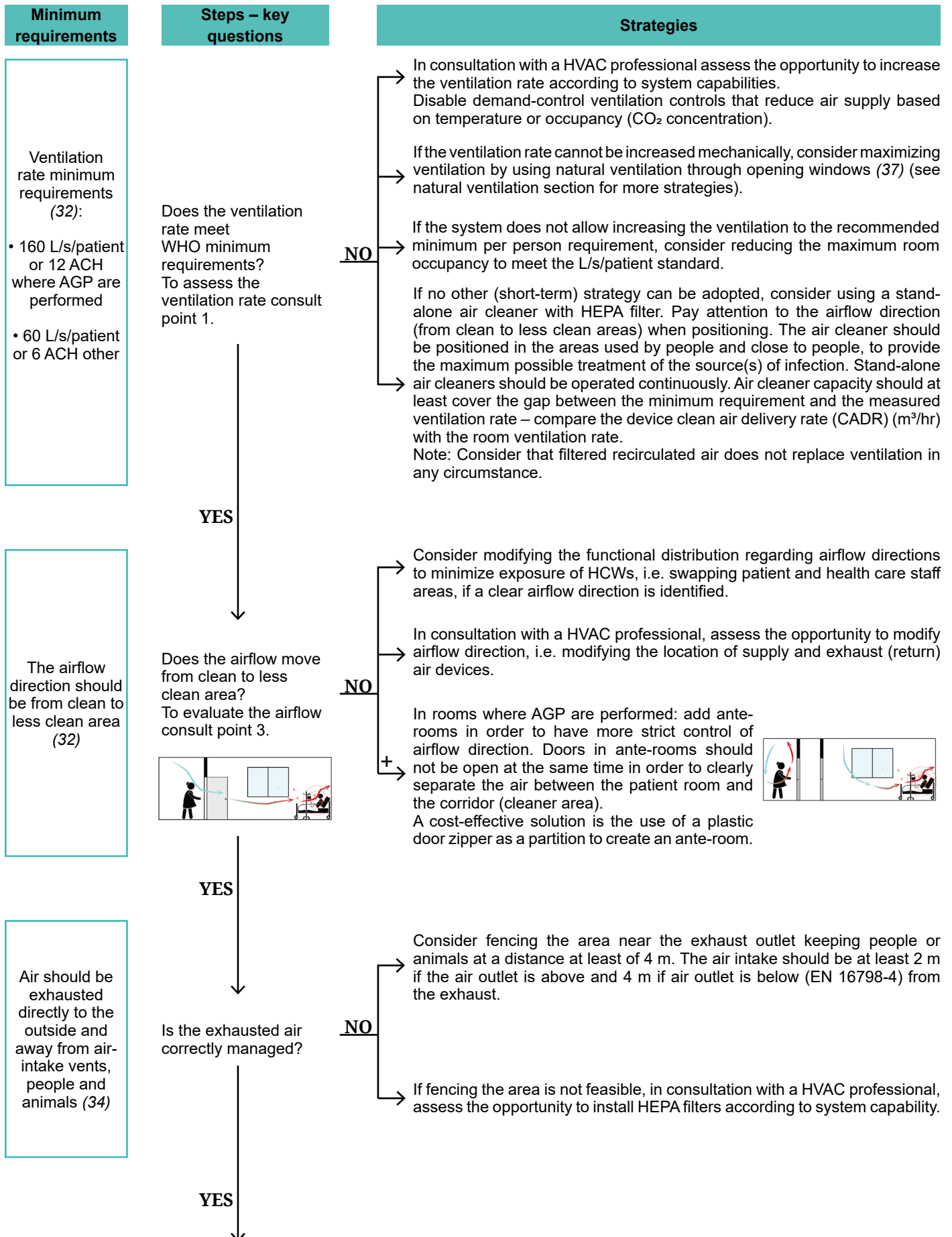
Note: Consider non-ducted recirculating units do not replace ventilation in any circumstance

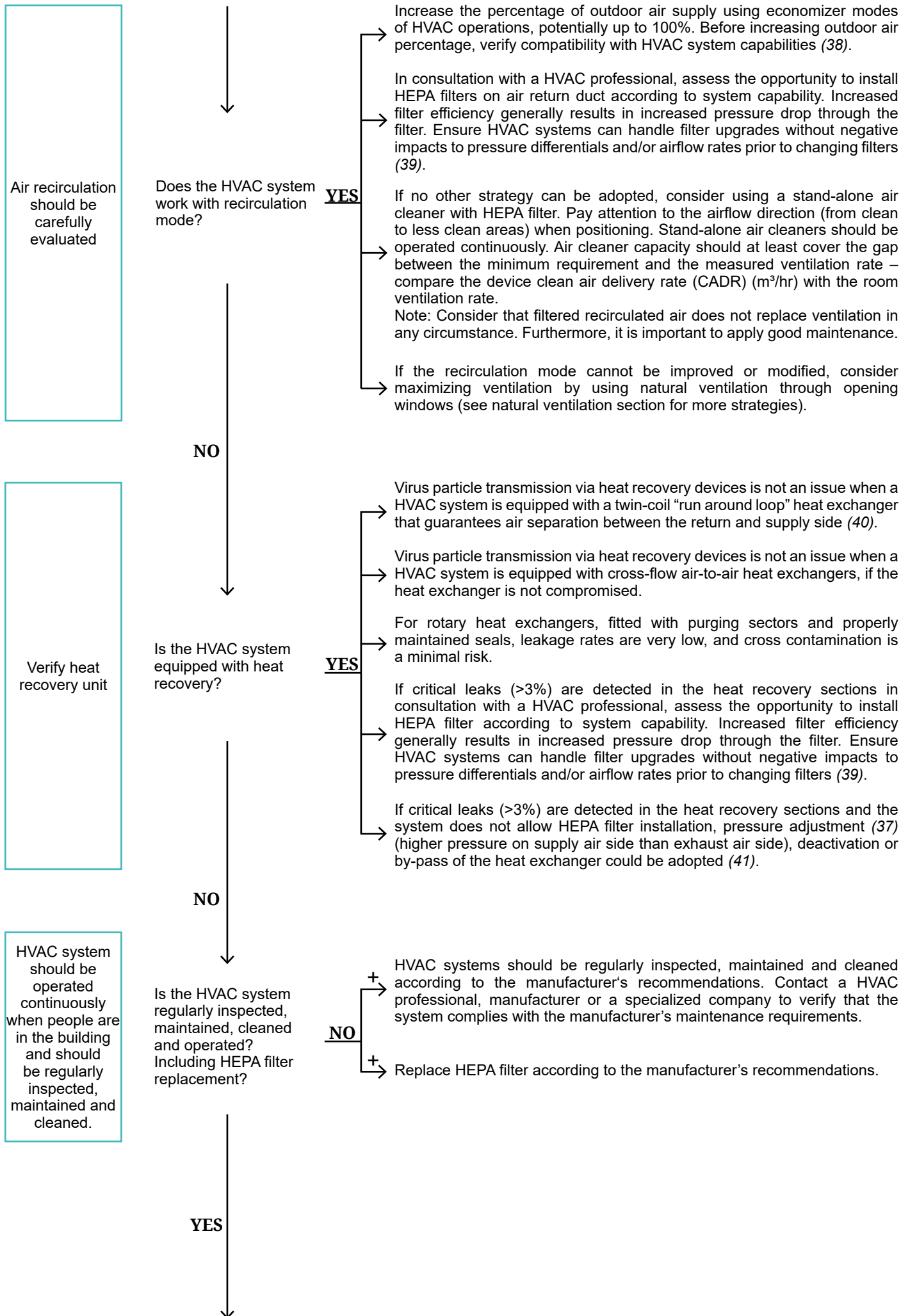
Considering modifying the position of the heating/cooling unit to direct the airflow to the less clean zone or install an extractor to control the airflow where AGP are performed.

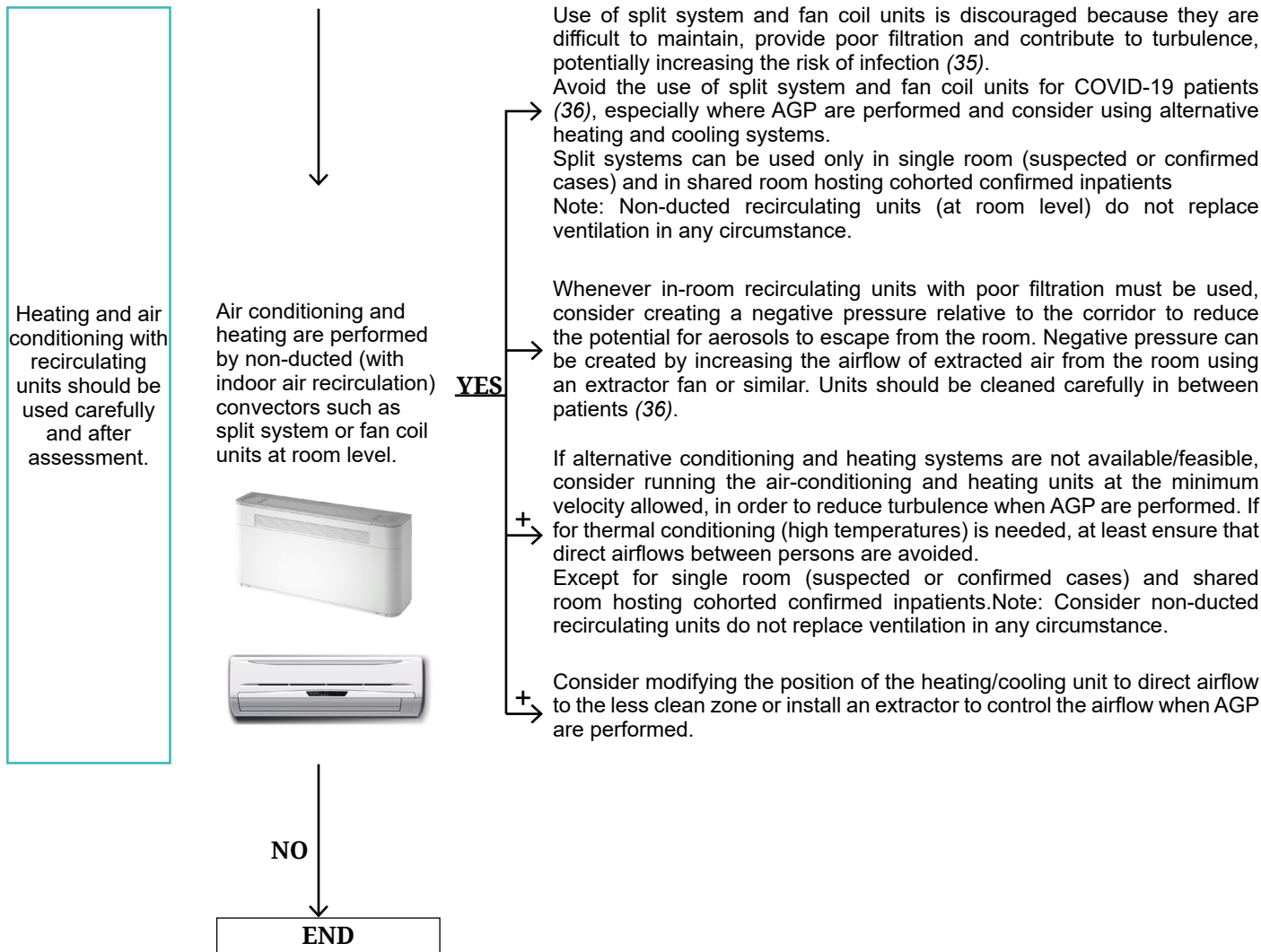
NO

END

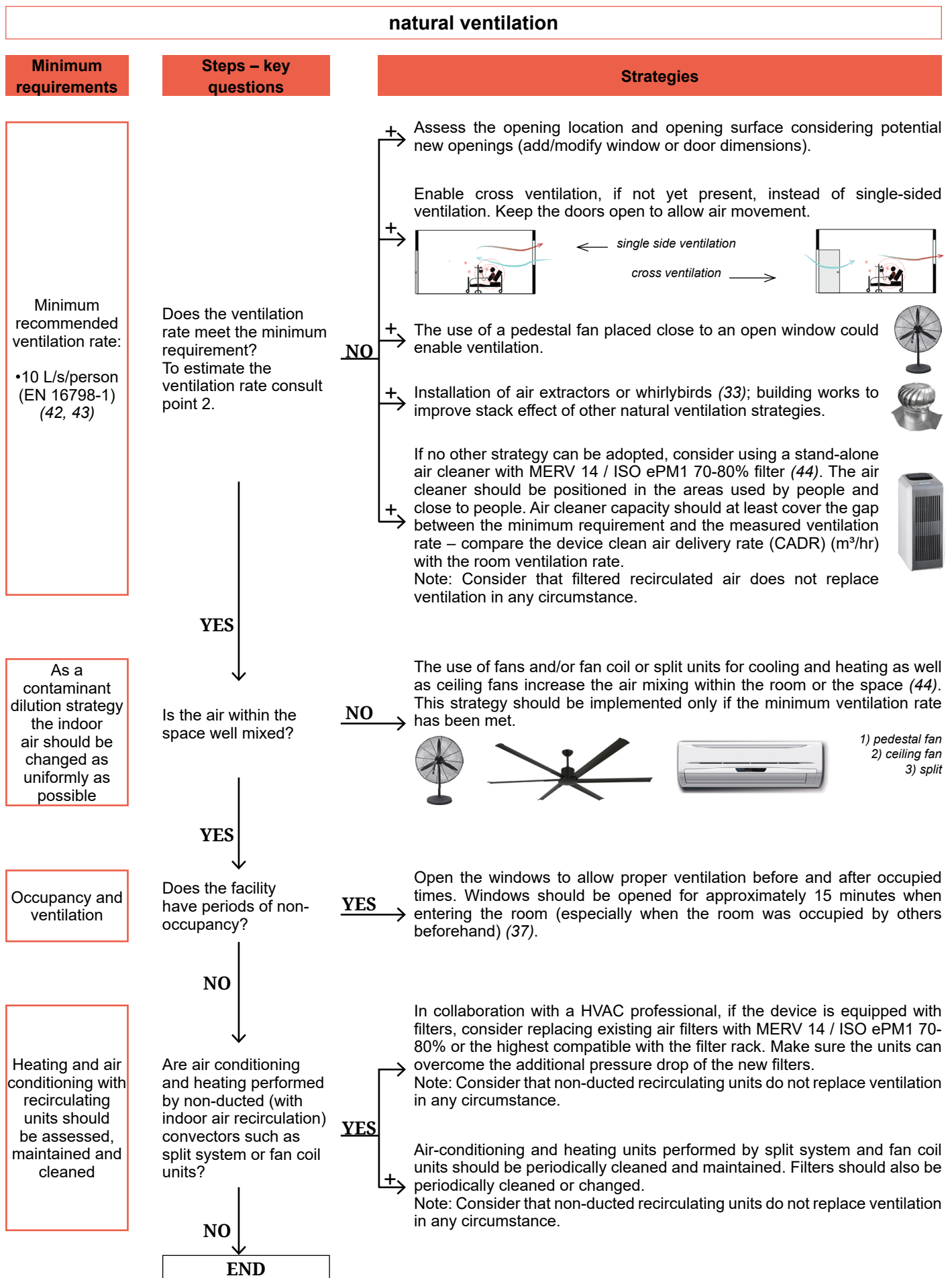
mechanical ventilation



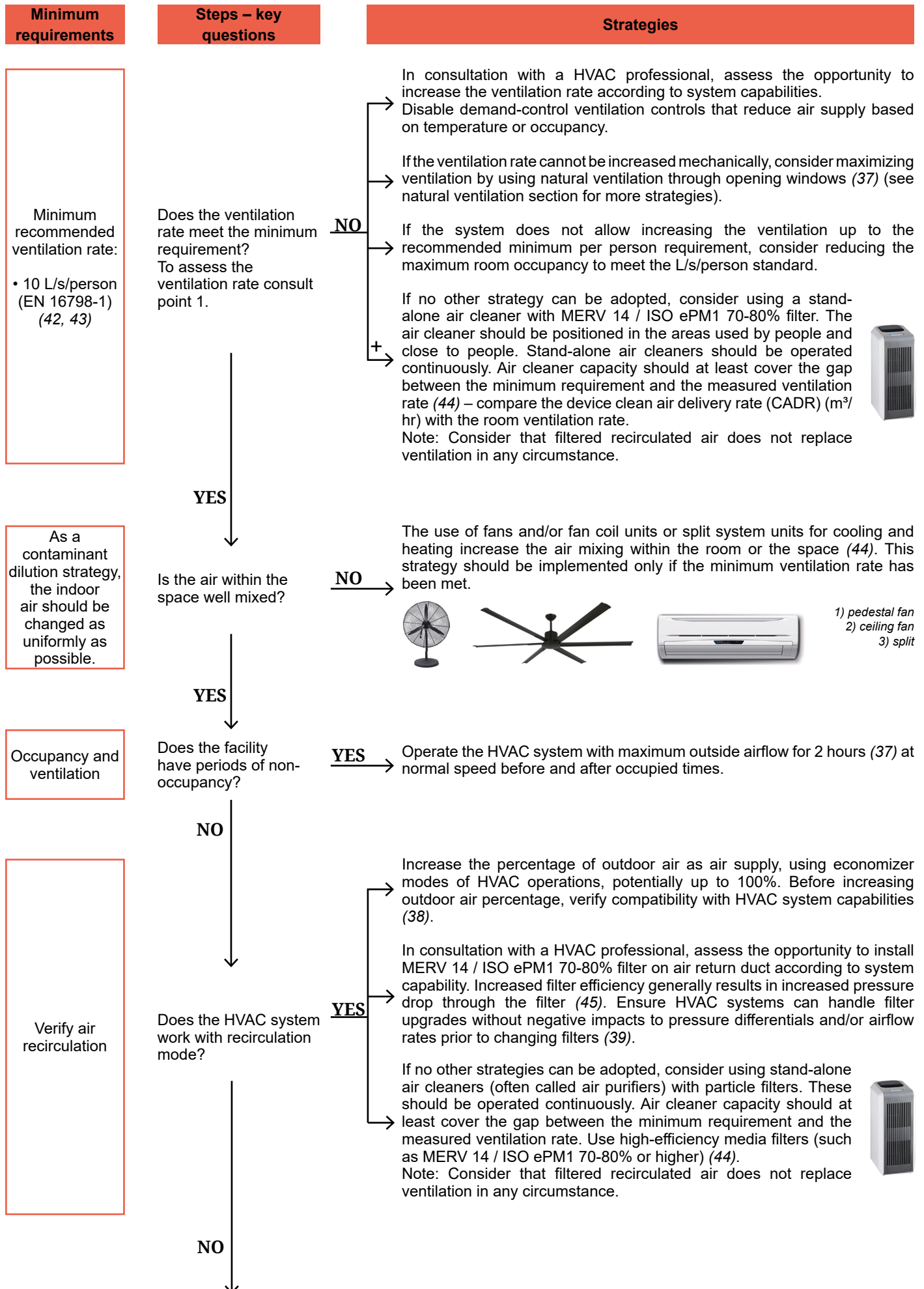


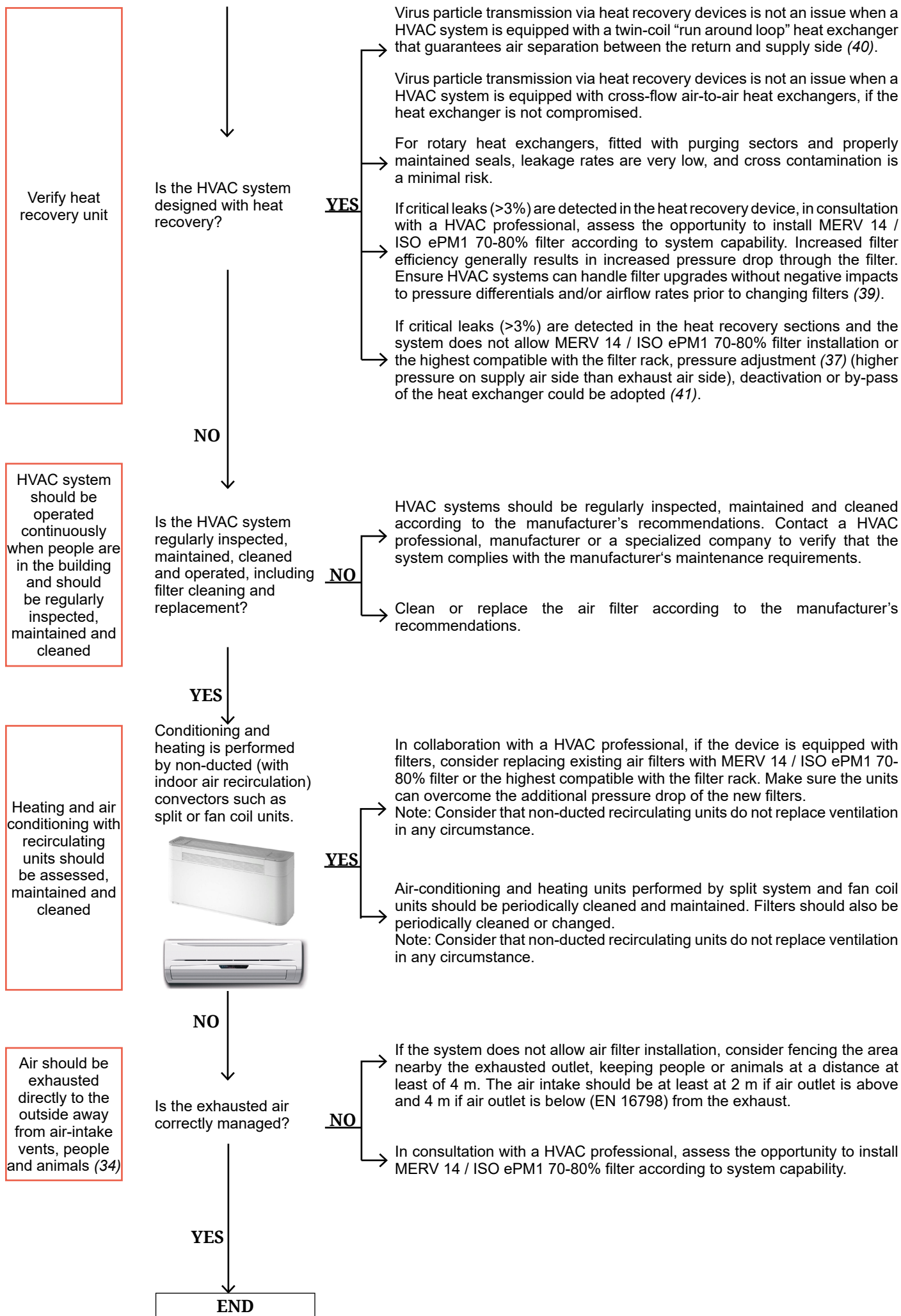


6.2 Non-residential settings



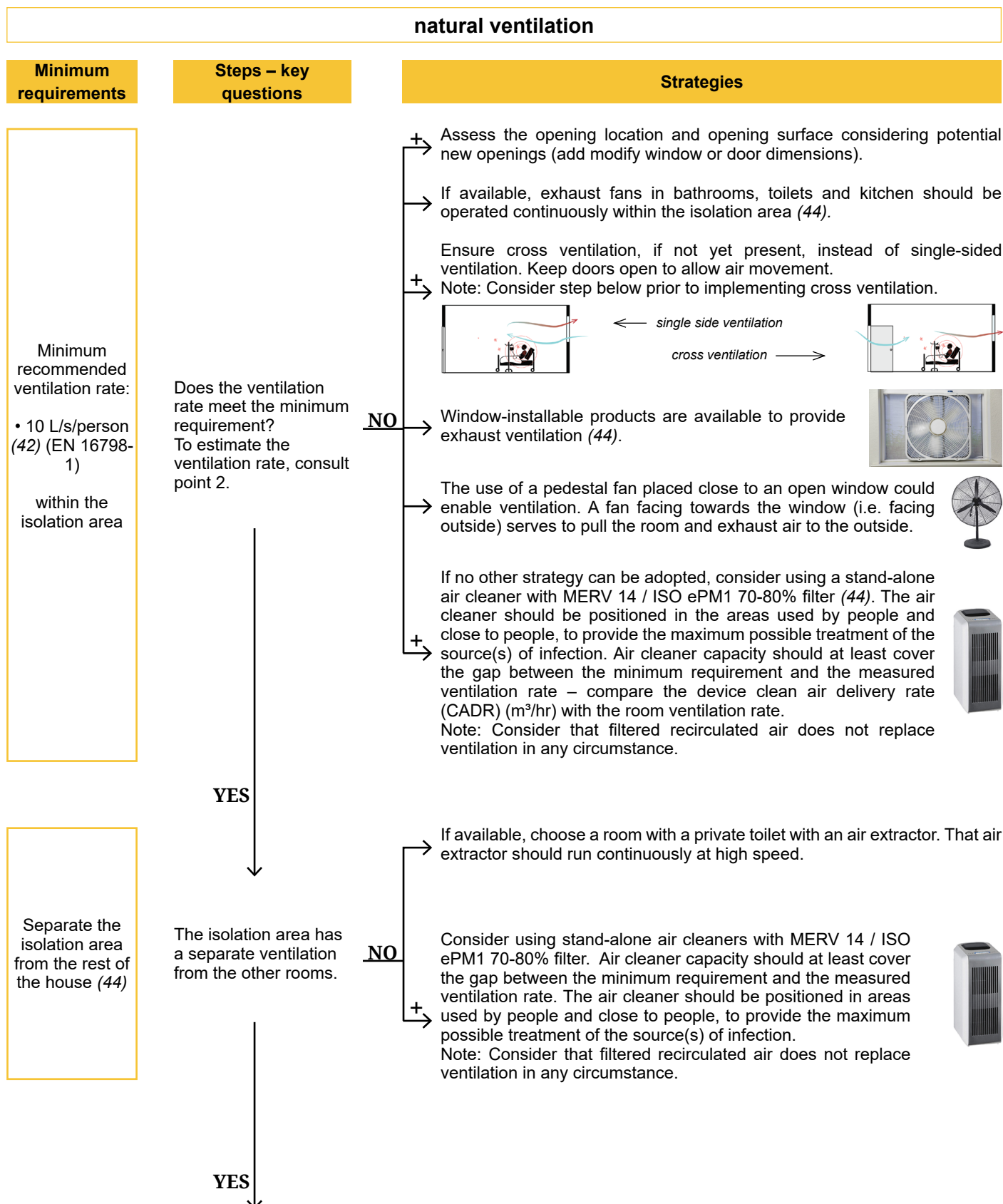
mechanical ventilation





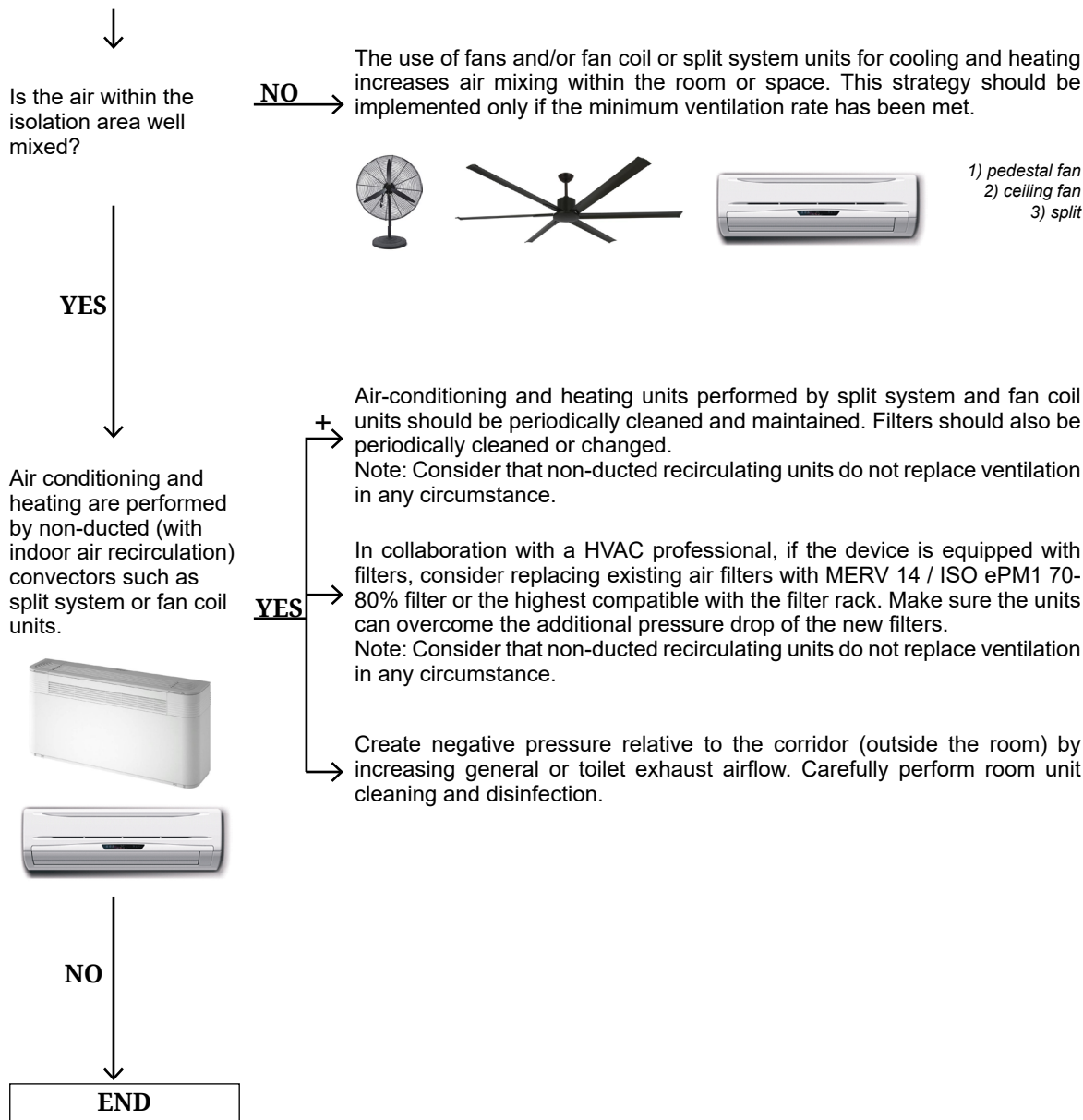
6.3 Residential settings including homes and self-quarantine at home

This section refers specifically to the isolation area, space or room previously identified for home care or self-quarantine according to the available guidance. The recommendations proposed are based on the assumption that the house and the identified isolation area can be considered as separated spaces. Hence, the following strategies should not be considered for the whole residential area but for the isolation space only. Note: Long-term care facilities are not included.

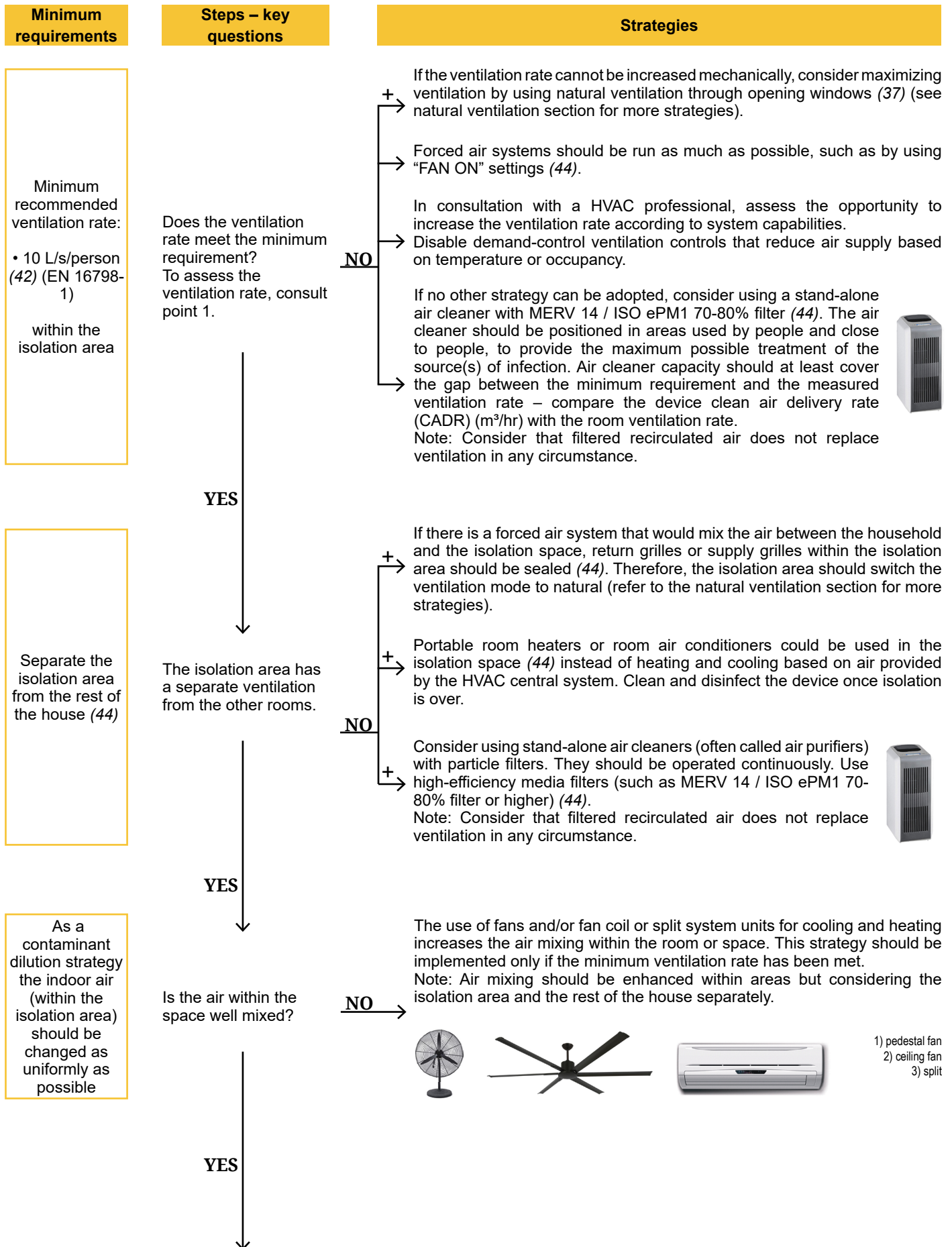


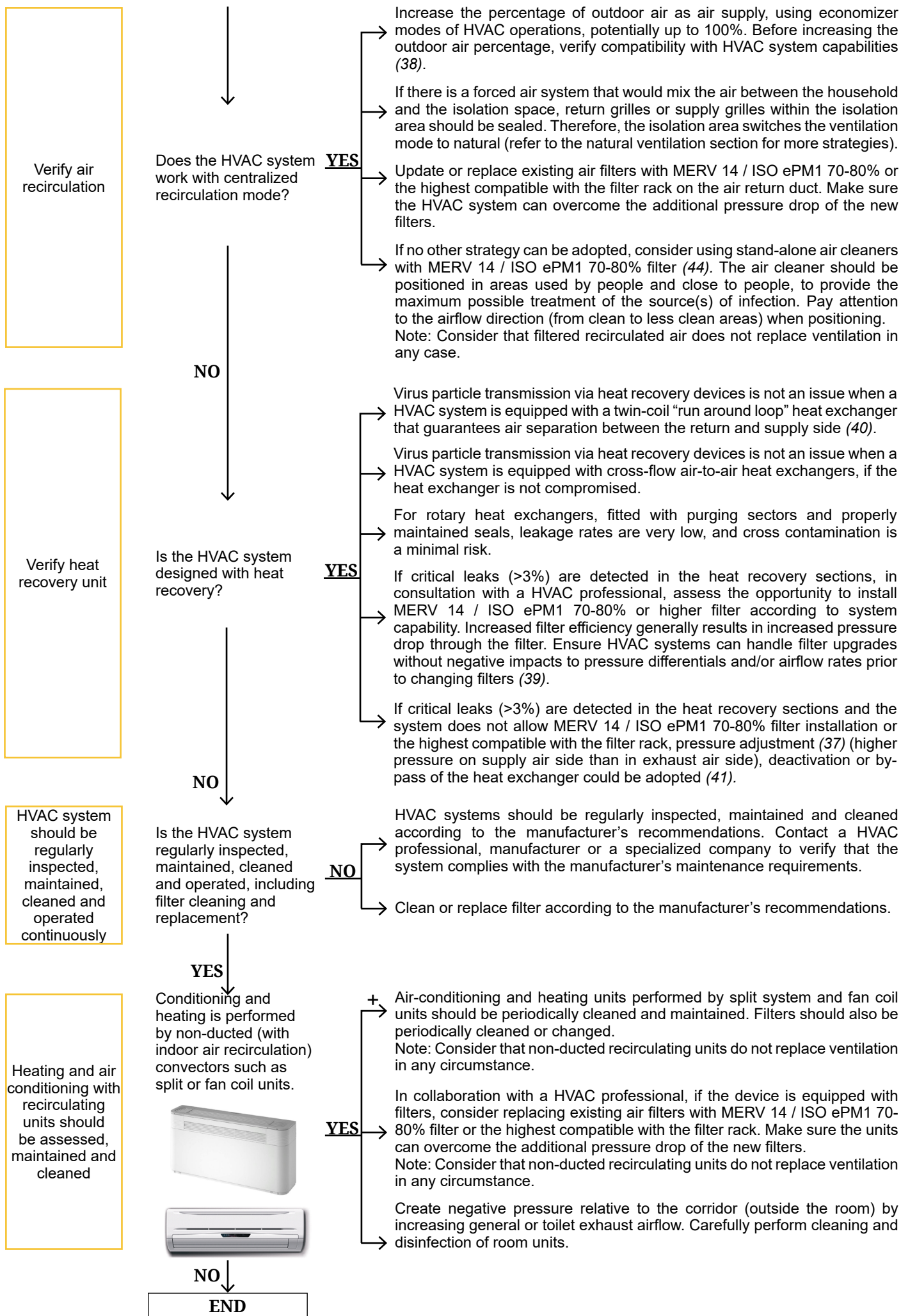
As a contaminant dilution strategy, the indoor air (within the isolation area) should be changed as uniformly as possible.

Heating and air conditioning with recirculating units should be assessed, maintained and cleaned



mechanical ventilation





7. Evaluating ventilation

Ventilation rate and airflow direction are key elements to be assessed and evaluated before undertaking any action on the ventilation system. This first evaluation will provide the baseline and allow the user to better understand the gap between the ventilation system functionality and the proposed requirements. A second evaluation should be carried out once improvement strategies have been implemented. Comparing the second evaluation with the initial baseline will provide an overview of the effectiveness of the implemented improvement strategies and a clear understanding of the new ventilation rate and flow.

Mechanical and natural ventilation systems require different methods to evaluate the ventilation airflow rate.

Point 1) Minimum ventilation rate – mechanical ventilation system. How to assess it?

Each mechanical ventilation system is designed for specific airflow rates. Consult the technical manual to verify the system capacity.

Point 2) Minimum ventilation rate – natural ventilation system. How to estimate it?

As a rule of thumb, wind-driven natural ventilation rate through a room can be calculated as follows (20):

Ventilation rate [L/s] = $k \times \text{wind speed [m/s]} \times \text{smallest opening area [m}^2\text{]} \times 1000 \text{ [L/m}^3\text{]}$

$k = 0.05$ in the case of single-sided ventilation

$k = 0.65$ in the case of cross ventilation

in the case of mosquito net presence = ventilation rate $\times 0.5$

wind speed: the wind speed refers to the value at the building height at a site sufficiently away from the building without any obstructions (e.g. at an airport) (32)

Point 3) Airflow direction. How to evaluate it?

The airflow direction is usually assessed through a gas tracer. However, other cost-effective solutions can be used, such as incense sticks or other smoke generators – a smoke test can be used to highlight the direction of the airflow.

Annex 1: Search strategy and included studies

Search strategy

Concept	Search strategy	Results (2 December 2020)
Ventilation, filtration	hvac OR "air conditioning" OR "forced air" OR "air flow"~3 OR (enclosed AND (space* OR area*)) OR "forced ventilation" OR window* OR fans OR (air AND (recirculation OR recirculated OR ducted OR duct OR ducts OR filterat* OR purif* OR cleaner*)) OR "air exchange"~5 OR HEPA OR mh:("Air Microbiology" OR "Ventilation" OR "Air Filters" OR "Air Conditioning" OR "Filtration" OR "Air Pollution, Indoor" OR "Heating" OR "Air Movements" OR "Air Pollutants") OR MERV	1174

Included studies

Author	Title	Journal and date	Key findings
PUBLISHED LITERATURE			
SL Miller, et al.	Implementing a negative pressure isolation space within a skilled nursing facility to control SARS-CoV-2 transmission	Am J Infect Control 2 October 2020	Validation study of an isolation space at a skilled nursing facility in Pennsylvania, USA. Goal: minimize disease transmission between residents and staff. Isolation space was created by modifying an existing HVAC system; performed computational fluid dynamics and Lagrangian particle-based modelling to test containment and possible transmission. No transmission between residents isolated to the space occurred, nor any transmission to staff or other residents.
SY Lee, et al.	Crucial role of temporary airborne infection isolation rooms in an intensive care unit: containing the COVID-19 outbreak in South Korea	Crit Care 18 May 2020	In an academic hospital in Daegu, Republic of Korea, temporary airborne infection isolation rooms (AIIRs) were assembled. An air volume control damper was used to maintain a negative pressure gradient between pre-existing AIIRs and the ante-room (-5.0Pa) at a level below the standard negative pressure (-2.5Pa) recommended for these facilities. The common negative pressure isolation zone was equipped with five mobile negative-air machines that generated negative pressure (-5.0Pa) compared with the ante-room. Airflow in isolation rooms reached 15–20 air exchanges per hour. Over a 4-week period, 7 patients were treated: 6 patients required mechanical ventilation, 2 patients were treated with extracorporeal membrane oxygenation, and continuous renal replacement therapy was provided to 1 patient. The COVID-19 team included 5 physicians and 40 nurses. All HCWs in the newly remodelled ICU were screened for COVID-19 after the first 2 weeks on duty; no tests were reported as positive.
J Lu, et al.	COVID-19 Outbreak Associated with Air Conditioning in Restaurant, Guangzhou, China, 2020	Emerg Infect Dis 2 April 2020	Epidemiological investigation in Guangzhou, China. During 26 January to 10 February 2020, an outbreak of COVID-19 occurred in an air-conditioned restaurant, involving 3 family clusters. From an examination of the potential routes of transmission, authors concluded that the most likely cause of the outbreak was droplet transmission prompted by air-conditioned ventilation.

PREPRINT LITERATURE			
Xu P, et al.	Transmission routes of Covid-19 virus in the Diamond Princess Cruise ship	medRxiv 14 April 2020	Diamond Princess cruise ship study. Collected the daily number of 197 symptomatic cases, and that of the 146 passenger cases in two categories (those who stayed and did not stay in the same stateroom). Infections started on 28 January and finished by 6 February for passengers except those who stayed in the same stateroom with infected individual(s). No other confirmed cases were identified among the disembarked passengers in Hong Kong, SAR, China, except an 80-year-old passenger. No confirmed cases were reported in three other stopovers between 27–31 January associated with disembarked passengers or visitors from the ship. However, two Okinawa taxi drivers became confirmed cases in association with driving the ship's passengers. Infection among passengers after 6 February was limited to those who stayed in the same stateroom with an infected passenger. Infections in crew members peaked on 7 February, suggesting significant transmission among crew members after quarantine on 5 February. Authors concluded that the central air-conditioning system did not play a role in transmission and that transmission appears to have occurred through close contact and fomites.
O Almilaji and PW Thomas	Air recirculation role in the infection with COVID-19, lessons learned from Diamond Princess cruise ship	medRxiv 9 July 2020	Diamond Princess cruise ship study. Analysis of count data published on 21 February 2020 and collected by the ship's onboard clinic. By using only passenger count data from the first prepared dataset of 115 symptomatic cases with symptom onset dates during the quarantine period of 6–17 February, analysis showed that 20% occurred in cabins with a previous case, and 80% occurred in cabins without a previous case. Results showed that symptomatic infection rate with recoded symptom onset in cabins with previously confirmed cases was not significantly higher than that in cabins without previously confirmed cases during the whole quarantine period. No evidence was found to conclude that SIRR in the cabins with previously confirmed cases was not significantly higher than that in cabins without previously confirmed cases on and after the median quarantine period day.
PF Horve, et al.	Identification of SARS-CoV-2 RNA in Healthcare Heating, Ventilation, and Air Conditioning Units	medRxiv 28 June 2020	Objective: to assess the potential role of HVAC systems in airborne viral transmission by determining the viral presence on air handling units in a setting where COVID-19 patients were treated (Oregon, USA). The presence of SARS-CoV-2 RNA was detected in 14/56 (25%) of samples taken from nine different locations in multiple air handlers. While samples were not evaluated for viral infectivity, the presence of viral RNA in air handlers raises the possibility that viral particles can enter and travel within the air handling system of a hospital, from room return air through high efficiency MERV 15 filters and into supply air ducts. No known transmission events were determined to be associated with these specimens; however, findings may suggest the potential for HVAC systems to facilitate transmission by environmental contamination via shared air volumes with locations remote from areas where infected persons reside.

Annex 2: Relevant technical guidance

Guidance developer	Reference	Hyperlink
ASHRAE	ANSI/ASHRAE/ASHE Standard 170-2017 Ventilation of health care facilities. 2017.	https://www.ashrae.org/technical-resources/standards-and-guidelines/standards-addenda/ansi-ashrae-ashe-standard-170-2017-ventilation-of-health-care-facilities
ASHRAE	HVAC design manual for hospitals and clinics (second edition). 2013.	https://www.ashrae.org/technical-resources/bookstore/hvac-design-manual-for-hospitals-and-clinics
ASHRAE	Handbook HVAC fundamentals. 2017.	https://www.ashrae.org/technical-resources/ashrae-handbook
ASHRAE	Technical resources for health care settings	https://www.ashrae.org/technical-resources/healthcare
ASHRAE	Technical resources for reopening of schools and universities	https://www.ashrae.org/technical-resources/reopening-of-schools-and-universities
ASHRAE	Technical resources for multifamily building owners/managers	https://www.ashrae.org/technical-resources/multifamily-buildings
ASHRAE	Technical resources for residential settings	https://www.ashrae.org/technical-resources/residential
ASHRAE	Technical resources for commercial settings	https://www.ashrae.org/technical-resources/commercial
ASHRAE	Filtration/Disinfection	https://www.ashrae.org/technical-resources/filtration-disinfection
US Centers for Disease Control and Prevention	COVID-19 employer information for office buildings. 4 January 2021.	https://www.cdc.gov/coronavirus/2019-ncov/community/office-buildings.html
European Centre for Disease Prevention and Control.	Heating, ventilation and air-conditioning systems in the context of COVID-19. 2020.	https://www.ecdc.europa.eu/en/publications-data/heating-ventilation-air-conditioning-systems-covid-19
REHVA	COVID-19 guidance document. 3 August 2020.	https://www.rehva.eu/fileadmin/user_upload/REHVA_COVID-19_guidance_document_V3_03082020.pdf
WHO	SARI treatment centers: interim guidance, 28 March 2020	https://www.who.int/publications/i/item/10665-331603
WHO	Natural Ventilation for Infection Control in Health-Care Settings: guidance 2009	https://www.who.int/water_sanitation_health/publications/natural_ventilation/en/
WHO	Considerations for quarantine of contacts of COVID-19 cases: interim guidance, 19 August 2020	https://www.who.int/publications/i/item/considerations-for-quarantine-of-individuals-in-the-context-of-containment-for-coronavirus-disease-(covid-19)
WHO	Home care for patients with COVID-19 presenting with mild symptoms and management of their contacts: interim guidance, 17 March 2020	https://apps.who.int/iris/handle/10665/331473
WHO	Infection prevention and control during health care when COVID-19 is suspected: interim guidance, 19 March 2020	https://www.who.int/publications/i/item/10665-331495
WHO	Aide-memoire: infection prevention and control (IPC) principles and procedures for COVID-19 vaccination activities, 15 January 2021	https://apps.who.int/iris/handle/10665/338715
WHO	COVID-19 management in hotels and other entities of the accommodation sector: interim guidance, 25 August 2020.	https://apps.who.int/iris/handle/10665/333992
WHO	Considerations for school-related public health measures in the context of COVID-19: Annex to Considerations in adjusting public health and social measures in the context of COVID-19, 14 September 2020	https://www.who.int/publications/i/item/considerations-for-school-related-public-health-measures-in-the-context-of-covid-19
WHO	Rational use of personal protective equipment for COVID-19 and considerations during severe shortages: interim guidance, 23 December 2020.	https://apps.who.int/iris/handle/10665/338033
WHO	Laboratory biosafety guidance related to coronavirus disease (COVID-19): interim guidance, 28 January 2021.	https://apps.who.int/iris/handle/10665/339056

WHO	Prevention, identification and management of health worker infection in the context of COVID-19: interim guidance, 30 October 2020.	https://apps.who.int/iris/handle/10665/336265
WHO	Water, sanitation, hygiene, and waste management for SARS-CoV-2, the virus that causes COVID-19: interim guidance, 29 July 2020.	https://apps.who.int/iris/handle/10665/333560 .
WHO	Infection prevention and control guidance for long-term care facilities in the context of COVID-19: interim guidance, 8 January 2021.	https://apps.who.int/iris/handle/10665/338481 .
WHO	Mask use in the context of COVID-19: interim guidance, 1 December 2020.	https://apps.who.int/iris/handle/10665/337199
WHO	Transmission of SARS-CoV-2: implications for infection prevention precautions: scientific brief, 09 July 2020.	https://apps.who.int/iris/handle/10665/333114 .

Note: Links accessed 12 February 2021.

Annex 3: Air filter category

Composite Average Particle Size Efficiency % in Size Range μm (ASHRAE standard 52.2-2012)			ASHRAE Standard (52.2-2012)
Range E1	Range E2	Range E3	Minimum Efficiency Reporting Value
0.3 - 1.0 μm	1.0 - 3.0 μm	3.0 - 10.0 μm	MERV
50% $\leq$ E1	85% $\leq$ E2	90% $\leq$ E3	MERV13
75% $\leq$ E1	90% $\leq$ E2	95% $\leq$ E3	MERV14
85% $\leq$ E1	90% $\leq$ E2	95% $\leq$ E3	MERV15
95% $\leq$ E1	95% $\leq$ E2	95% $\leq$ E3	MERV16

International and European Standard (EN ISO 16890)		
ePM1 classification	ePM2,5 classification	ePM10 classification
0.3 $\mu\text{m} \leq x \leq 1 \mu\text{m}$	0.3 $\mu\text{m} \leq x \leq 2.5 \mu\text{m}$	0.3 $\mu\text{m} \leq x \leq 10 \mu\text{m}$
ePM1 (95)	ePM2.5 (95)	ePM10 (95)
ePM1 (90)	ePM2.5 (90)	ePM10 (90)
ePM1 (85)	ePM2.5 (85)	ePM10 (85)
ePM1 (80)	ePM2.5 (80)	ePM10 (80)
ePM1 (75)	ePM2.5 (75)	ePM10 (75)
ePM1 (70)	ePM2.5 (70)	ePM10 (70)
ePM1 (65)	ePM2.5 (65)	ePM10 (65)
ePM1 (60)	ePM2.5 (60)	ePM10 (60)
ePM1 (55)	ePM2.5 (55)	ePM10 (55)
ePM1 (50)	ePM2.5 (50)	ePM10 (50)

International standard (ISO 29463) European Standard (EN 1822)		
Filter class (ISO 29463)	Filter class (EN 1822)	Efficiency at MPPS
-	-	%
	E10	>85
ISO 15E - ISO 20E	E11	>95
ISO 25E - ISO 30E	E12	>99.5
ISO 35H - ISO 40H	HEPA - H13	>99.95
ISO 45H - ISO 50U	HEPA - H14	>99.995

References

- 1 WHO. Severe acute respiratory infections treatment centre: interim guidance 28 March 2020. Geneva: World Health Organization; 2020 (<https://www.who.int/publications/i/item/severe-acute-respiratory-infections-treatment-centre>, accessed 12 February 2021).
- 2 REHVA. Definitions of terms and abbreviations commonly used in REHVA publications and in HVAC practises. Brussels: Federation of European Heating, Ventilation and Air Conditioning Associations; 2012.
- 3 WHO. Infection prevention and control during health care when COVID-19 is suspected: interim guidance, 19 March 2020. Geneva: World Health Organization; 2020 (<https://apps.who.int/iris/rest/bitstreams/1272420/retrieve>, accessed 12 February 2021).
- 4 CIBSE. Natural ventilation in non-domestic buildings. London: Chartered Institution of Building Services Engineers; 2005.
- 5 ASHRAE. Interpretation IC 62.2-2016-1 of ANSI/ASHRAE standard 62.2-2016. Ventilation and Acceptable Indoor Air Quality in Residential Buildings. 2016–2018. American Society of Heating, Refrigerating and Air-Conditioning Engineers; 2017.
- 6 Y Shen, Li C, Dong H, Wang Z, Martinez L, Sun Z, et al. Community outbreak investigation of SARS-CoV-2 transmission among bus riders in Eastern China. *JAMA Intern Med.* 2020;180(12):1665-1671. doi: 10.1001/jamainternmed.2020.5225.
- 7 Chan FKW, Yuan S, Kok KH, To KKW, Chu H, Yang J, et al. A familial cluster of pneumonia associated with the 2019 novel coronavirus indicating person-to-person transmission: a study of a family cluster. *Lancet.* 2020;395(10223):514–523 ([https://doi.org/10.1016/S0140-6736\(20\)30154-9](https://doi.org/10.1016/S0140-6736(20)30154-9), accessed 12 February 2021).
- 8 Huang C, Wang Y, Li X, Ren L, Zhao J, Hu Y, et al. Clinical features of patients infected with 2019 novel coronavirus in Wuhan, China. *Lancet.* 2020;395(10223):497–506.
- 9 Burke RM, Midgley CM, Dratch A, Fenstersheib M, Haupt T, Holshue M, et al. Active monitoring of persons exposed to patients with confirmed COVID-19 – United States, January–February 2020. *MMWR.* 2020;69(9):245–246. doi: 10.15585/mmwr.mm6909e1.
- 10 WHO. Transmission of SARS-CoV-2: implications for infection prevention precautions. Geneva: World Health Organization; 2020.
- 11 WHO. Coronavirus disease 2019 (COVID-19): situation report, 73. Geneva: World Health Organization; 2020.
- 12 Wei J, Li Y. Airborne spread of infectious agents in the indoor environment. *Am J Infect Control.* 2016;44(9):S102-8.
- 13 McCarthy, JE, McCarthy MT, Dumas BA. Long range versus short range aerial transmission of SARS-CoV-2. 2020. arXiv: 2008.03558 [q-bio.OT].
- 14 Lednicky JA, Lauzardo M, Fan ZH, Jutla A, Tilly TB, Gangwar M, et al. Viable SARS-CoV-2 in the air of a hospital room with COVID-19 patients. *Int J Infect Dis.* 2020;100:476–482. doi: 10.1016/j.ijid.2020.09.025.
- 15 Lednicky JA, Lauzardo M, Fan ZH, Jutla A, Tilly TB, Gangwar M, et al. Viable SARS-CoV-2 in the air of a hospital room with COVID-19 patients. medRxiv. 2020. doi: 10.1101/2020.08.03.20167395.
- 16 Ring N, Jepson R, Ritchie K. Methods of synthesizing qualitative research studies for health technology assessment. *Int J Technol Assess Health Care.* 2011;27(4):384–390. doi: 10.1017/S0266462311000389.
- 17 WHO. Mask use in the context of COVID-19. Geneva: World Health Organization; 2020 ([https://www.who.int/publications/i/item/advice-on-the-use-of-masks-in-the-community-during-home-care-and-in-healthcare-settings-in-the-context-of-the-novel-coronavirus-\(2019-ncov\)-outbreak](https://www.who.int/publications/i/item/advice-on-the-use-of-masks-in-the-community-during-home-care-and-in-healthcare-settings-in-the-context-of-the-novel-coronavirus-(2019-ncov)-outbreak), accessed 12 February 2021).
- 18 WHO. Rational use of personal protective equipment for coronavirus disease 2019 (COVID-19) and considerations during severe shortages. Geneva: World Health Organization; 2020 (<https://apps.who.int/iris/handle/10665/331695>, accessed 12 February 2021).
- 19 WHO. Considerations for school-related public health measures in the context of COVID-19. Geneva: World Health Organization; 2020 (<https://www.who.int/publications/i/item/considerations-for-school-related-public-health-measures-in-the-context-of-covid-19>, accessed 12 February 2021).
- 20 WHO. Home care for patients with suspected or confirmed COVID-19 and management of their contacts. Geneva: World Health Organization; 2020 ([https://www.who.int/publications-detail/home-care-for-patients-with-suspected-novel-coronavirus-\(ncov\)-infection-presenting-with-mild-symptoms-and-](https://www.who.int/publications-detail/home-care-for-patients-with-suspected-novel-coronavirus-(ncov)-infection-presenting-with-mild-symptoms-and-)

management-of-contacts, accessed 12 February 2021).

- 21 WHO. Cleaning and disinfection of environmental surfaces in the context of COVID-19: interim guidance. Geneva: World Health Organization; 2020.
- 22 ECDC. Heating, ventilation and air-conditioning systems in the context of COVID-19. Stockholm: European Centre for Disease Prevention and Control; 2020.
- 23 Dai H, Zhao B. Association of the infection probability of COVID-19 with ventilation rates in confined spaces. *Build Simul.* 2020;13(6):1321-1327. doi: 10.1007/s12273-020-0703-5.
- 24 Nembhard MD, Burton DJ, Cohen JM. Ventilation use in nonmedical settings during COVID-19: cleaning protocol, maintenance, and recommendations. *Toxicol Ind Health.* 2020;36(9):644-653. doi: 10.1177/0748233720967528.
- 25 Lai D, Qi Y, Liu J, Dai X, Zhao L, Wei S. Ventilation behavior in residential buildings with mechanical ventilation systems across different climate zones in China. *Build Environ.* 2018;143:679-690. doi: 10.1016/j.buildenv.2018.08.006.
- 26 WHO. Considerations for public health and social measures in the workplace in the context of COVID-19. Geneva: World Health Organization; 2020.
- 27 WHO. COVID-19 management in hotels and other entities of the accommodation sector. Geneva: World Health Organization; 2020 (<https://apps.who.int/iris/handle/10665/333992>, accessed 12 February 2021).
- 28 WHO. Considerations for quarantine of contacts of COVID-19 cases. Geneva: World Health Organization; 2020 ([https://www.who.int/publications/i/item/considerations-for-quarantine-of-individuals-in-the-context-of-containment-for-coronavirus-disease-\(covid-19\)](https://www.who.int/publications/i/item/considerations-for-quarantine-of-individuals-in-the-context-of-containment-for-coronavirus-disease-(covid-19)), accessed 12 February 2021).
- 29 WHO. Vector-borne diseases. Geneva: World Health Organization; 2020 (<https://www.who.int/news-room/fact-sheets/detail/vector-borne-diseases>, accessed 12 February 2021).
- 30 WHO. Ambient (outdoor) air pollution. Geneva: World Health Organization; 2018 ([https://www.who.int/news-room/fact-sheets/detail/ambient-\(outdoor\)-air-quality-and-health](https://www.who.int/news-room/fact-sheets/detail/ambient-(outdoor)-air-quality-and-health), accessed 12 February 2021).
- 31 WHO. Personal interventions and risk communication on air pollution. Geneva: World Health Organization; 2020.
- 32 Atkinson J, Chartier Y, Pessoa-Silva CL, Jensen P, Li Y. Natural ventilation for infection control in health-care settings: WHO guidelines. Geneva: World Health Organization; 2009.
- 33 MSF. Environmental measures to prevent TB transmission in resource-limited settings having a high TB-HIV burden. *Médecins Sans Frontières*; 2011.
- 34 CDC. Guidelines for preventing the transmission of tuberculosis in health-care settings, with special focus on HIV-related issues. Atlanta (GA): Centers for Disease Control and Prevention; 1990 (<https://www.cdc.gov/mmwr/preview/mmwrhtml/00001897.htm>, accessed 12 February 2021).
- 35 ASHRAE. HVAC design manual for hospitals and clinics (second edition). American Society of Heating, Refrigerating and Air-Conditioning Engineers; 2003.
- 36 ASHRAE. Technical resources for health care settings. American Society of Heating, Refrigerating and Air-Conditioning Engineers; 2020.
- 37 REHVA. REHVA COVID-19 guidance document. 3 August 2020. Federation of European Heating, Ventilation and Air Conditioning Associations; 2020.
- 38 CDC. COVID-19 employer information for office buildings. Atlanta (GA): Centers for Disease Prevention and Control; 2021.
- 39 ASHRAE. Filtration/Disinfection. American Society of Heating, Refrigerating and Air-Conditioning Engineers; 2020.
- 40 Pi CH, Chang YS, Kang BH. An experimental study on air leakage and performance characteristics of a desiccant rotor. *International Institute of Refrigeration*; 2011.
- 41 AICARR. Protocollo per la riduzione del rischio da diffusione del del SARS-CoV2-19 mediante gli impianti di climatizzazione e ventilazione in ambienti sanitari. 2020:1-4.
- 42 ASHRAE. Handbook HVAC fundamentals. American Society of Heating, Refrigerating and Air-Conditioning Engineers; 2017.
- 43 REHVA. REHVA COVID-19 guidance document.version 4. 17 November 2020. Federation of European Heating, Ventilation and Air Conditioning Associations; 2020.
- 44 ASHRAE. Technical resources for residential settings. American Society of Heating, Refrigerating and Air-Conditioning Engineers; 2020.
- 45 ASHRAE. Technical resources for commercial settings. American Society of Heating, Refrigerating and Air-Conditioning Engineers; 2020.

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