CIBSE

COVID-19: Ventilation

Version 5

16th July, 2021

Introduction

In April 2020, CIBSE acknowledged the potential for airborne aerosol transmission of SARS-CoV-2. The first edition of *COVID-19: Ventilation* was published on 9th May 2020, and subsequent versions were released on 12th May 2020, 15th July 2020, 23rd October 2020 and 16th July 2021. This guidance adopts a precautionary approach, advocating that indoor spaces should be ventilated as much as reasonably possible.

The World Health Organization (WHO) updated its guidance to acknowledge the possibility of airborne transmission on 9th July 2020; Public Health England updated its guidance on 9th October 2020 (PHE, 2020), noting the possibility of airborne transmission particularly in poorly ventilated indoor spaces; and the Centers for Disease Control and Prevention in the US recognises that transmission appears to have occurred when there is inadequate ventilation (CDC, 2020).

On 23rd October 2020, the UK government issued a paper prepared by the Environment and Modelling Group of the Scientific Advisory Group for Emergencies, confirming that ventilation is an important mitigation measure in controlling SARS-CoV-2 transmission (SAGE-EMG, 2020).

The evidence continues to suggest that in poorly ventilated indoor spaces, airborne aerosols are a possible transmission route of SARS-CoV-2, and the precautionary advice remains valid. Maintaining good levels of ventilation remains the key focus, even in colder weather conditions, whilst minimising occupant discomfort due to draughts and lower indoor temperatures.

The risk of exposure follows a law of diminishing returns as the ventilation rate is increased. That is, the ventilation rate should be increased above the minimum statutory rates wherever possible, but this must be balanced against the need to moderate energy demand and carbon emissions and to ensure the thermal comfort of occupants. Ventilation should be provided year-round, but the strategy and delivery rate may vary by season.

As businesses continue to manage the return of staff to work and the continuing operation of buildings through the pandemic, a number of issues will need to be considered for the safety of those entering buildings.

Although most government restrictions will no longer apply after 19th July 2021, it remains prudent to continue to heed government and local guidance, and any legal obligations, should they change or be re-introduced.

Employers have a duty of care to ensure, as far as reasonably practical, the health of their employees at work. Providing adequate ventilation is an important component of a healthy work environment, and is prescribed by law in regulation 6 of the Workplace (Health, Safety and Welfare) Regulations 1992 (HMSO, 1992).

The Health and Safety Executive (HSE) provides guidance on building safety in general (HSE, 2021) and on air conditioning and ventilation in particular (HSE, 2021), and this is applicable throughout the UK.

The UK government and devolved administrations have produced guidance for employers, employees and the self-employed to help them understand how they can work safely during the pandemic; see the website Working safely during coronavirus (COVID-19) (BEIS/DCMS, 2021). This guidance reminds employers of their legal responsibility for the safety of all those entering workplaces:

> 'To help you decide which actions to take, you need to carry out an appropriate COVID-19 risk assessment, just as you would for other health and safety related hazards. This risk assessment must be done in consultation with unions or workers.'

Undertaking this risk assessment may require advice from competent persons, such as professionally registered engineers who are chartered or incorporated engineers registered with the Engineering Council.

In some cases, the occupancy of a room or zone may be reduced due to social distancing criteria and ordinarily this might result in a reduction of the ventilation airflow required. However, in order to reduce risks associated with viral transmission, the ventilation rate should be increased as much as reasonably possible.

It is preferable not to recirculate air from one space to another. However in certain weather conditions, closing recirculation dampers in some systems may make the supply air unacceptably cold (or hot), and this may lead to a reduction in the supply rate of outside air to occupied spaces below the recommended minimum (10 l/s/person for typical offices) so that a comfortable temperature can be maintained. In these instances, there is a balance between two risks: the risk of recirculating contaminated air between multiple rooms or zones against the risk of reducing the supply of outside air and increasing the build-up of contaminants (including the virus) in a single room or zone. Recirculation should be considered only if there is no other way of maintaining an adequate provision of outside air to occupied spaces without causing undue occupant thermal discomfort or energy demand. Guidance on recirculation is given in section 4.2.2.

In naturally ventilated spaces, windows and vents are often the mechanism for providing outside air. In colder months, the natural forces that drive air through these openings (wind, indoor/outdoor temperature difference) are greater, so windows and vents do not need to be opened as wide. Opening only high-level vents can increase the mixing of the incoming outside air with air in the space, and ensures that incoming air is warmed before it reaches the occupied zone. This makes it possible to introduce more cold outside air into the space without causing significant discomfort. It is better to open all windows or vents only a small amount to aid mixing and warming. If natural ventilation openings are the only mechanism for delivering outside air into a space, it is important that these are not completely closed when the spaces are occupied; this can result in very low ventilation rates, and increased risks of airborne viral transmission.

Nondispersive infrared (NDIR) CO_2 monitors are useful devices that help to assess whether adequate ventilation is being provided to an occupied zone. In many spaces, a supply of outside air at 10 l/s/person is prescribed, which will result in a maximum CO_2 concentration of 800-1000 ppm. Indoor ventilation dilutes exhaled CO_2 from occupants, and so the CO_2 concentration in a space is often used to help indicate ventilation rates. CO_2 concentrations that regularly exceed 1500 ppm indicate poorly ventilated spaces, and attention should be given to improving the outside air provision to such spaces. For more information see Section 0.

Sensors that automatically reduce the ventilation rate during periods of low occupancy may need to be disabled or reset to prevent this. For example: if a space normally contains 20 people, the ventilation may be set at 200 l/s (in order to provide 10 l/s/p). If the number of occupants reduces, the ventilation rate of 200 l/s should be maintained (as long as thermal comfort can be maintained), thus increasing the per capita airflow rate.

Equivalent CO_2 sensors (eCO_2 sensors) should not be used. These devices only measure volatile organic compounds (VOCs), and estimate CO_2 concentration based on the concentration of VOCs in the air. They do not directly measure indoor CO_2 concentration.

Germicidal ultraviolet (GUV) devices have been proposed for air cleaning. These use light on the UV-C spectrum, and have been shown to inactivate coronaviruses. There is significant emerging evidence of the efficacy of UV-C sources at a wavelength of 254 nm to deactivate SARS-CoV-2. There are still uncertainties about a variety of factors affecting UV performance, including dose and exposure time, and how these might depend upon the ventilation rate of outside air. In addition, consideration will need to be given to the specific room and system configuration, air flow, distribution and humidity, as well as the safe deployment of UV for occupants and building operations personnel. An additional section of this version of this guidance addresses the potential use of UV and important safety considerations; see section 6.

For further guidance on utilising air cleaning devices, refer to the CIBSE guidance document *Covid-19: Air cleaning technologies* (CIBSE, 2021).

In ventilating indoor spaces with SARS-CoV-2 in mind, the key actions to be aware of are:

- Understand the ventilation system.
- Understand where there may be poorly ventilated spaces or areas.
- Increase the ventilation rate as much as reasonably possible without compromising occupant thermal comfort; this may require changes to CO_2 set points (for both mechanical ventilation and automated windows).
- Avoid recirculation/ transfer of air from one room to another unless there is no other way of providing a sufficient ventilation rate to all occupied rooms.
- Recirculation of air within a single room is only acceptable when it is combined with a supply of outside air.

- Where thermal (or enthalpy) wheels are installed to recover heat: a competent engineer or technician should check that the configuration and operating conditions are such that any leakage is from the supply side to the extract side. This will minimise the risk of transferring contaminated air into the supply.

About this guidance

This COVID-19 ventilation guidance is for business owners, employers, building owners, managers, operators and those maintaining buildings.

It is intended to give business owners and managers an outline of ventilation systems commonly encountered in buildings and to advise on how they can be used, now and in the future, to maintain adequate air quality and reduce the risks of airborne infection.

It is also intended to assist building managers and those who operate and maintain building systems in identifying the areas of a building, and elements of ventilation systems, that may need particular attention in order to reduce risk to building occupants.

It is relevant to all types of building ventilation system, whether natural, mechanical or full air conditioning.

It is relevant both for the reopening of buildings after a period of inactivity and for continuing the operation of buildings during the coronavirus pandemic (or in the case of a new endemic virus) to ensure adequate ventilation provision.

It considers the requirements for achieving adequate ventilation, and in particular ventilation provision during the cooler months. It is to be read in conjunction with government guidance (see the Introduction for detail of various online resources).

This guidance is organised as follows:

- Section 1 explains the importance of ventilation in relation to COVID-19.
- Section 2 explains what can be done to reduce risks related to building ventilation.
- Section 3 explains different building ventilation systems and their key operating characteristics.
- Section 4 explains how to operate these different ventilation types to reduce SARS-CoV-2 transmission risk. This includes preparing ventilation systems for the re-occupation of buildings, and the consideration of ongoing operation and maintenance.
- Section 5 considers how to optimise the use of natural ventilation in winter.
- Section 6 considers the use of UV disinfection and air cleaning devices.

This guidance has been written in the context of a temperate oceanic climate as experienced in the UK, and outlines the main actions that should be taken regarding ventilation. However, the principles of providing adequate ventilation generally and identifying poorly ventilated spaces are relevant outside the UK.

It will inform safe working practices and the provision of ventilation in non-residential buildings. It is intended primarily for offices, schools, educational buildings, retail premises and industrial buildings where occupants are mainly sedentary.

Specialist advice may be needed for buildings related to healthcare; advice should be sought from the NHS and Public Health England (or the corresponding devolved or local agency).

Advice should also be sought regarding buildings related to food production, or for indoor spaces where activities known to increase respiratory aerosols take place (such as singing, loud speech and aerobic exercise). CIBSE is working closely with other institutions to provide guidance for ventilation of specialist indoor spaces.

The advice contained in this document specifically concerns the ventilation provision in indoor spaces and identifies methods of reducing the risk of far field (> 2m) viral infection transmission indoors. This is one of several measures recommended in order to reduce the risk of SARS-CoV-2 transmission indoors. This advice should be used in conjunction with other systems where locally appropriate, including working from home, use of face-coverings, social distancing, reducing exposure times, good hygiene practices, workplace cleaning and test and trace.

If a confirmed case or case(s) of COVID-19 has been identified in a building user or visitor, current government advice should be consulted.

COVID-19: Ventilation is under continual review.

Principal changes to version 5

This version of *COVID-19: Ventilation* contains a revised introduction addressing the change in government restrictions, and links to *COVID-19: Air cleaning technologies* (CIBSE, 2021).

Changes have been made to the text throughout to improve readability, and to add detail on the use of CO_2 monitors drawing on findings of the recent paper *EMG and SPI-B: Application of CO2 monitoring as an approach to managing ventilation to mitigate SARS-CoV-2 transmission, 27 May 2021* (SAGE-EMG, 2021).

Contents

1 How indoor ventilation can help reduce the number of COVID-19 cases

Building ventilation is an important part of a healthy building environment, as it brings a stream of outside air into a building and removes stale air. Stale air includes body odours, exhaled breath and airborne pollutants such as those from cleaning products and furniture.

Ventilation is important for the dilution any airborne pathogens. There is a greater risk of catching an illness in a poorly ventilated room than in a well-ventilated room; in a poorly ventilated room, occupants are exposed to a higher concentration of airborne pathogens, and the exposure risk increases with the time spent in the space.

Risk is a function of exposure and duration exposed. The risk of airborne infection to the individual can therefore be reduced by:

- reducing time spent in the location
- reducing airborne exposure concentration of infectious material
- reducing risk of contact spread through regular handwashing and surface cleaning.

The ventilation rate and its method of delivery influence both far field airborne exposure and deposition rate. Ventilation is unlikely to reduce the risk of near field airborne transmission significantly, where higher concentrations of pathogens in the exhaled puff of an infector can be inhaled by a susceptible person in close contact.

2 COVID risks

The main risk of far field SARS-CoV-2 transmission is from asymptomatic or pre-symptomatic people who occupy a building without knowledge that they are shedding viral particles. Current government advice should be consulted in order to reduce risks posed by symptomatic individuals.

Evidence is mounting that the SARS-CoV-2 virus, which causes COVID-19, can be spread by very small particles – called aerosols – which are released by an infected person when they cough, sneeze, talk and breathe, alongside larger droplets that are released simultaneously (Tang, et al., 2020) (Wilson, et al., 2020).

Larger droplets are acted upon by gravity, and fall after a period of time; the two-metre social distancing measure was developed to ensure contact with these larger droplets is reduced.

However, fine aerosols (some of which may contain viral particles) can remain airborne for several hours. Although it is difficult to definitively prove the airborne aerosol transmission of SARS-CoV-2, the same mechanism of transmission has been identified in similar viruses (for example, SARS-CoV-1). There is emerging evidence that shows high rates of infection in poorly ventilated rooms, which suggests that this is a potential transmission route. Measures to reduce the risk of inhaling these small particles, which may cause infection, are therefore recommended.

These aerosols are at their highest concentration in the exhaled puff, and the two metre social distancing measure helps reduce exposure. Aerosols that are small enough to remain airborne become diluted in indoor air. Without suitable ventilation they can build up, increasing the risk of exposure for susceptible individuals. Ventilation can play an important role in minimising the build-up of aerosols in a space, and will reduce exposure risk. Other interventions to minimise aerosol generation and emission include the wearing of face coverings and minimising respiratory activities known to generate more aerosols, such as singing.

As our understanding of the significance of the various transmission routes of SARS-CoV-2 develops, we recommend increasing the supply rate of outside air to occupants wherever it is reasonably practical as a precautionary measure.

This is particularly important in poorly ventilated areas. Increasing the ventilation rate helps to dilute any airborne contaminants, and reduces the risk of exposure for building users.

Increasing the ventilation rate lowers exposure risk, but with a law of diminishing returns. Therefore, increasing the ventilation rate in a poorly ventilated space reduces the risk more than providing the same increase in a well ventilated space.

During the heating season, it is necessary to balance the benefits of increased ventilation rates against the need to maintain the thermal comfort of the occupants. The same is true in mechanically cooled spaces in the cooling season.

This guidance takes a risk-averse approach to reducing indoor pollution without significant energy use or capital cost, and is subject to change as transmission routes become more clearly defined.

2.1 Minimise risks

To minimise the risks of far-field airborne aerosol transmission of SARS-CoV-2, the general advice is to increase the air supply and exhaust ventilation, supplying as much outside air as reasonably possible. The underlying principle is to dilute and remove airborne pathogens as much as possible, extracting them to the outside and reducing the chance that they deposit on indoor surfaces or are inhaled by room users. Recirculation and the transfer of air from one room to another should be avoided unless there is no other way of providing adequate ventilation to all occupied rooms.

The risk of airborne transmission is greatest in poorly ventilated areas and areas that are occupied for long periods of time. Poorly ventilated spaces are often smaller rooms with limited outside air supplies. Spaces that are stuffy or smelly are also likely to be poorly ventilated. It is particularly important to increase the supply of outside air to these spaces. It is recommended that occupancy density is reduced where possible and practical.

In rooms and zones where there is no direct supply of outside air, consideration should be given to limiting access to these spaces by building users, especially where it is likely that they would be occupying such a space for considerable lengths of time (longer than 30 minutes). This may include basement rooms or storage areas which rely on infiltration of air from other spaces.

Ventilation should be balanced against other factors, particularly thermal comfort and energy demand. It is recommended that the ventilation strategy should achieve the minimum ventilation rate for the space over the occupancy period defined in current standards. In most circumstances this is already required by law.

In England, the Building Regulations (HMSO, 2010) require that an adequate means of ventilation be provided in a building; and Approved Document F: *Ventilation* (MHCLG, 2010) sets out what, in ordinary circumstances, may be considered as reasonable provision of an adequate means of ventilation. Alternative legislation, regulations and guidance are in place in the devolved UK nations and worldwide; ensure that local standards have been consulted. Approved Document F (MHCLG, 2010) states that at the very least adequate ventilation should be provided year-round, as poor indoor air quality negatively impacts health, wellbeing and productivity. For further discussion of the evidence base for this, see *Health and wellbeing in building services (TM40)* (CIBSE, 2021), in particular chapters three and nine.

Wherever possible, outside air flow rates should be increased to provide more than the minimum rates for adequate airflow for Building Regulations compliance, wherever it is reasonable to do so without causing undue thermal discomfort or a significant increase in energy demand.

In naturally ventilated buildings, strategies such as intermittent airing (purge ventilation) and partial window opening to complement background ventilation may enable this to be achieved. When it is reasonable to do so, ventilation rates should be increased as much as reasonably possible without compromising thermal comfort. The use of alternative ventilation or air cleaning strategies in a space may be needed to help maintain thermal comfort whilst ensuring adequate ventilation. See *COVID-19: Air cleaning technologies* (CIBSE, 2021) for more information, particularly section 4.3.

In ventilating indoor spaces with SARS-CoV-2 in mind, the key actions to be aware of are:

- Understand the ventilation system.
- Understand where there may be poorly ventilated spaces or areas.
- Increase the ventilation rate as much as reasonably possible without compromising occupant thermal comfort; this may require changes to CO_2 set points (for both mechanical ventilation and automated windows).
- Avoid recirculation/ transfer of air from one room to another unless there is no other way of providing a sufficient ventilation rate to all occupied rooms.
- Recirculation of air within a single room is only acceptable when it is combined with a supply of outside air.

Where thermal (or enthalpy) wheels are installed to recover heat: a competent engineer or technician should check that the configuration and operating conditions are such that any leakage is from the supply side to the extract side. This will minimise the risk of transferring contaminated air into the supply.

3 Understanding ventilation

It is important to establish what kind of ventilation provision exists in a given building, and how ventilation rates can be increased. This section is designed to help the reader identify the ventilation system or systems present, noting that there may be different regimes in different rooms of the building.

Some spaces may have more than one type of ventilation provision, so the type of ventilation provision must first be established on a room by room (or zone by zone) basis.

In order to minimise risk of aerosol transmission, following the advice in Section 4 for the ventilation type identified in each room or zone. This will maximise the delivery of outside air into each zone, and thus reduce the risk of aerosol transmission beyond two metres (the recommended distance between two possible infectors), helping to protect building users.

3.1 Natural ventilation

The term 'natural ventilation' is used to describe ways that outside air can be brought into a building without using fans or other mechanical means. This includes airflow through openings in the building envelope such as windows, doors, roof turrets and other vents, as in the images below.

Figure 1 Three methods of natural ventilation: openable windows (top left), doors (top right) and roof turrets (bottom)

3.1.1 Mixing boxes

A relatively new technology, these systems use a fan to mix outside air entering a room through natural ventilation openings with some of the air already in the room. This is a useful energy saving system in the heating season as it warms the cooler outside air before it enters the room, reducing the heating in the room and reducing cold draughts.

3.2 Mechanical ventilation

Mechanical ventilation is used to describe the means of bringing air into a building using mechanical means, such as fans. Often outside air is deliver into a building via ductwork, and there are several ways in which this can be achieved.

Some ventilation strategies use both natural and mechanical ventilation within the same space; this is often termed mixed-mode ventilation. Typically mechanical ventilation may be the primary means of delivering outside air into the room year-round. Openable windows provide the additional benefit of allowing more outside air in to help cooling during the summer or to purge the room, for example from a smell caused by a spillage.

3.2.1 Supply and extract

The main principle of supply and extract ventilation is that one series of ducts and inlet grilles delivers outside air into a space, while another set of ducts extracts stale air from the space and exhausts it to the outside.

There are a number of different systems that use this method. The grilles that deliver the incoming air can be located in diffusers in the ceiling, on the wall or on the floor. For the system to provide adequate outside air, it is essential that these grilles are kept free from blockages.

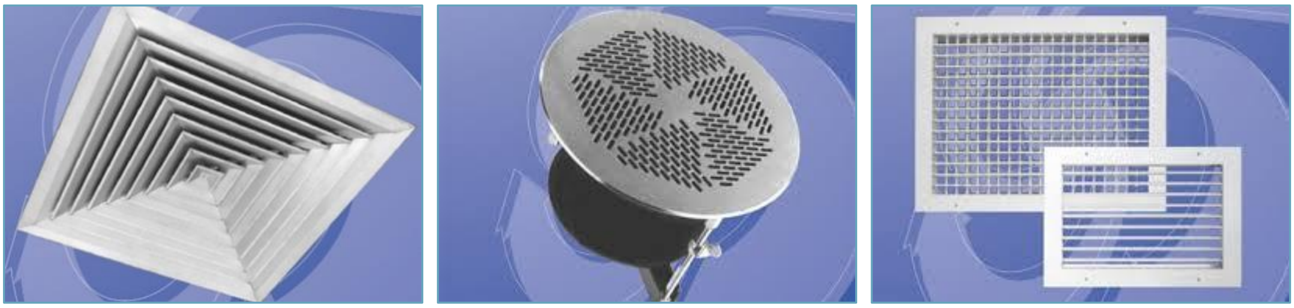

Figure 2 Typical examples of air supply inlets: ceiling diffuser (left), floor diffuser (middle) and wall diffuser (right). Images courtesy of Gilberts (Blackpool) Ltd.

3.2.2 Heat recovery

Some mechanical ventilation systems use heat recovery to extract warmth from stale exhaust air, and use that heat to warm the incoming outside air. This has energy-saving benefits in the heating season, as it helps to reduce the amount of heating needed to warm a space. Some heat recovery systems work on a room/ zone by room/ zone basis, mixing some of the exhaust air with the incoming outside air; a portion of exhaust air is thus recirculated back into the room.

Care should be taken where air is recirculated within a space. If this type of system is present, read the recirculation actions carefully in section 4.2.2.

3.2.3 Extract only

In an extract-only system, a fan is used to extract air directly to the outside. Fresh outside air enters the room to replace the extracted air through infiltration – for example, via gaps under the door. These systems are typically employed in toilet blocks and wet room facilities.

3.2.4 Air conditioning

Ducted air conditioning systems typically use a mechanical ventilation system. Outside air is first 'conditioned' before being moved along ductwork and into a room. These systems can include warming of the air in winter or cooling in summer, and can also adjust the humidity of the air.

Some systems that are commonly known as 'air conditioning' or 'air conditioning units' only condition the air in a room; they warm or cool the air in a room and recirculate it, but are not part of a wider ventilation system. These are often referred to as 'comfort cooling' or 'comfort heating'. It is important to understand that these systems are not delivering outside air, and are therefore not diluting any airborne pathogens.

3.2.4.1 Split air conditioning systems

A split air conditioning system has two main parts: an outdoor compressor with an outdoor coil and an indoor air-handling unit (hence the term 'split' – it is in two units). A conduit carries the power cable, refrigerant tubing and a condensate drain between the outdoor and indoor units.

These are typically wall- or ceiling-mounted, and are quite common, but do not supply any outside air into a room. A separate ventilation system is required.

3.2.4.2 Fan coil units

These units are usually ceiling-mounted or installed in raised floors. A fan passes air over either a heating or cooling coil and into the room. Fan coil units generally have a chilled water coil for cooling and either a hot water coil for heating or an electric heating element. They may be connected to ventilation ducts from the air handling unit to provide outside air, or they may recirculate room air.

3.2.4.3 Chilled beams

These are installed near the ceiling to provide cooling, and come in two forms:

Active chilled beams: These form part of a ventilation system, and are used to chill incoming outside air as it passes into a room from a ducted supply.

Passive chilled beams: These cool the air already in a room by absorbing heat, and do not bring outside air into the room. They will create air-mixing due to convection currents caused by the beam cooling air at high level; this air then falls to the floor, creating airflow.

Table 1 Types of mechanical ventilation

System	Outside air or recirculated?
Split air systems only recirculate room air.  	Recirculated
Fan coil units can be connected to ventilation ducting from an air handling unit to provide outside air; or, can recirculate room air with a fan.   	Both are possible
Passive chilled beams recirculate room air via convection. 	Recirculated
Active chilled beams are connected to ducting, and condition incoming outside air. 	Outdoor air

3.3 Specialist localised exhaust ventilation

In some settings, specialised extract ventilation is used to remove a lot of air from a specific location – some examples are cooker hoods in kitchens, local exhaust on workshop machinery and fume hoods. Although these systems generally remove large volumes of air, it is important to ascertain where the replacement air is coming from. It may come directly from outside through windows or doors, or air may enter from other rooms or zones within the building, such as adjacent corridors or adjoining rooms. In the case of large factory floors, replacement air is likely to come from outside. Specialised local exhaust ventilation is the subject of specific workplace regulations; for more specialist advice and to find practitioners with expertise in these systems, contact the Institute of Local Exhaust Ventilation Engineers.

3.4 No obvious ventilation strategy

Some spaces may not have an identifiable ventilation system. For example, it is common for corridors and staircases not to be ventilated, as these are deemed to be transient spaces; they rely instead on air infiltration from neighbouring spaces. Where staircases, lobbies or common areas have no obvious continuous ventilation and are used by a significant number of occupants, possibly multiple tenants from different 'user bubbles', it is important to purge these areas regularly. The method of purging will need to be considered on a building-by-building basis, taking account of the fire strategy for the building.

Rooms or zones that are occupied routinely without any obvious ventilation strategy are a significant risk, and ventilation provision should be addressed. Until adequate ventilation is provided it may not be appropriate to use the room or zone other than for very short durations.

4 Recommended actions to improve ventilation

4.1 Natural ventilation

4.1.1 Opening windows

Openable windows and vents should be used more than normal, as long as security is considered and the open windows do not cause a hazard to anyone moving outside. If possible windows should be open at least 15 minutes prior to room occupation.

In warmer weather opening windows is a typical behavioural response, however it is important that windows are kept open, even if only by a small amount, when it is cooler outside. It is important to balance the need to minimise the risk of airborne infection against the need for occupants to be comfortable. In cooler weather even a small opening can deliver significant ventilation flows, and this can minimise risk to occupants of the space.

A CO_2 monitor can be helpful in assessing ventilation provision to aid ventilation opening modulation; see section 0.

Opening windows can result in draughts that cause occupant discomfort. Where possible, discomfort should be mitigated by ensuring building users are not located directly in a draught for long periods, for example by moving desks and other room furniture. Current requirements for distancing may make this more feasible. Relaxing dress codes so that warmer clothes may be worn is highly desirable.

Where there are both high-level and low-level openable windows in a room, it is recommended to open the high-level windows during cooler weather in the first instance; incoming air will be warmed as it flows down into the room, thereby reducing cold draughts. This also improves mixing of the outside air with air in the room before it reaches the occupied zone.

To maximise airflow when draughts are not a concern, both high and low windows should be opened. This does not just increase opening area but creates a more efficient flow, thereby increasing the dilution of pollutants.

If it is windy, cold or raining then it may not be practical to fully open the windows or vents; however they should be open as far as reasonably possible without causing discomfort. Section 5 provides further guidance on managing air flow through natural ventilation openings under these conditions.

During warmer weather and on brighter sunny days, it may not be appropriate to have the heating on during the cooler mornings, as this may exacerbate overheating in the afternoon.

4.1.1.1 Single-sided ventilation

Where a room only has openable windows or vents only along one side, consideration should be given to areas within the room where air may become stagnant. It is generally considered that rooms can be well ventilated with single-sided ventilation if the depth of the room is less than twice the height; or in the case of rooms with both high- and low-level windows, if the depth of the room is less than two and a half times the height.

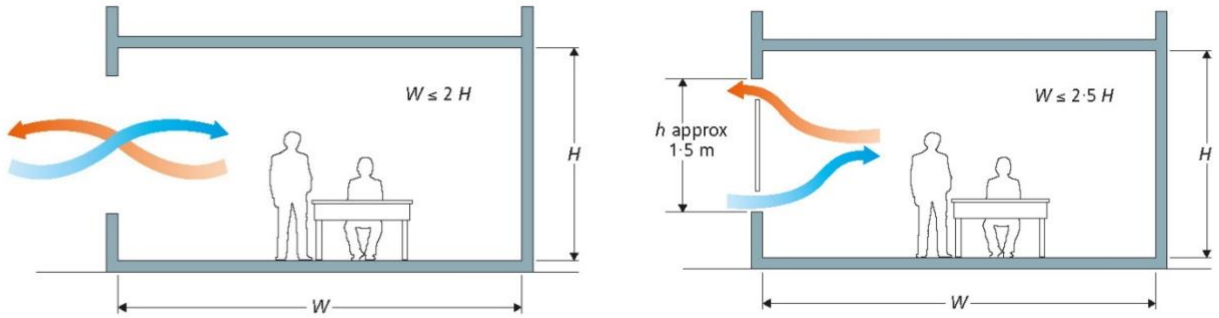

Figure 3 Two rooms with single-sided ventilation: one opening (left); and both high-level and low-level openings (right)

In deeper plan rooms, it is advisable to place a local recirculation unit or fan at the back of the room to enhance air disturbance, reducing the risk of stagnant air. This is particularly important when a small room has multiple or transient occupancy.

When assessing the future occupancy of a space, the ventilation mechanism should be considered alongside achievement of the required two metres separation.

4.1.1.2 Cross ventilation

Greater air flow can be achieved when windows and vents can be opened on different facades to allow air flow through a room. This can also include layouts where cross ventilation occurs by air entering through the external façade, traveling across the floor plate to a central atrium where it is exhausted up and out through vents at roof level.

It is generally recommended that cross ventilation flows should not exceed 15 metres or five times the floor to ceiling height (whichever is the smallest).

Air pollutants are more concentrated on the leeward side of the room, where the air exhausts, compared to the windward side, where outside air enters the room. However, in the case of reducing the risk of COVID-19 transmission, this consideration can be relaxed. Cross ventilation will increase the outside airflow, and consequently increase the dilution and removal of any airborne pathogens.

Cross ventilation pathways where air travels from one occupied room or zone into another should be avoided if possible by keeping internal partition doors closed, unless opening such partitions significantly increases the total volume flow rate of outside air.

Fire doors should not be kept open unless fitted with approved automatic closers so that they function as fire doors in the event of an alarm or fire.

4.1.1.3 Roof turrets

In normal operation mode, roof turrets should usually open proportionally in response to air quality and temperature in the space.

If the space is highly occupied, for example during lunch in a school hall, it is advisable to use the manual boost to temporarily increase the ventilation rate. Manual boost should also be used if the occupants are undertaking activities that can increase aerosol generation, for example aerobic exercise, singing or talking loudly.

If activities known to increase aerosol generation are to be undertaken, the latest government advice should be considered. Manufacturers may also provide product-specific guidance.

4.1.1.4 Automated windows and vents

Some windows and vents are controlled automatically and open in response to indoor air quality and temperature.

For more frequent window opening (for example when the external conditions are favourable to increasing ventilation rates), use manual override or adjust the CO_2 setpoint to a lower value.

Ventilation should be balanced against other factors, particularly thermal comfort. It is recommended that the ventilation strategy should achieve the equivalent minimum ventilation rate for the space over the occupancy period as defined in current standards, and therefore CO_2 setpoints should be adjusted to open vents to deliver these flow rates as a minimum.

As it can take some time for CO_2 concentration to increase to the setpoint value, it may be appropriate to use manual override to open the windows a little initially in order to provide some background ventilation.

4.1.1.5 Windows in toilet blocks

If windows are the only means of ventilating a toilet block, they should be left open as long as reasonably possible, and windows in adjoining rooms should also be open. In winter, they do not need to be open as wide as in the summer.

Many internal toilets blocks have passive stack or mechanical extract systems. The principle of this ventilation system is that air will flow into the toilet block as the door to the block is opened, thus ensuring that contaminants and odours are kept within the toilet block and do not enter adjacent rooms.

As such, opening windows in toilet blocks with mechanical extract ventilation may reverse the air flow when doors open, allowing contaminated air to flow from the toilet block into the adjacent room; this is to be avoided. Therefore, in internal toilet blocks with mechanical extract ventilation systems, the extract ventilation should remain constantly on during occupied periods. Windows should remain closed. A notice may be required on the toilet doors or walls to explain this and discourage opening.

In external toilet blocks with no adjoining rooms, open windows can supplement the mechanical ventilation and can be left open. It is important to keep toilet doors closed so that the ventilation dilutes and removes any pollutants rather than recirculating them to the rest of the building.

4.1.1.6 Window restrictors

Restrictors will reduce the opening area of a window, and therefore the potential for ventilation. However they may be essential for safety and security of occupants. Removal of restrictors to boost air flow should only be done after a risk assessment considering the risk of clashes with people outside (for windows on the ground floor) and the risk of falls from upper floors.

4.1.1.7 Security considerations for open windows

There are security issues to consider with respect to leaving windows open, especially when the building is not occupied. A walk-round may be required to ensure that all windows that pose a security issue are closed before the building is vacated, and windows reopened as early as possible before reoccupation by the majority of the building users. Where leaving windows open does not cause a security issue it is recommended to do this overnight on warm or hot days to maximise purge of the room air. On cold days and nights this may cause overcooling and significant discomfort, so should be avoided.

4.1.2 Open external doors to boost ventilation

For small buildings with limited ventilation openings, such as small shops or offices within a secure compound, external doors may be used to increase ventilation as long as care is taken over security. Opening doors for ventilation provision is not ideal, as they are not easily modulated. Alternative ventilation strategies should be considered in the medium to long term.

Keeping internal doors open may be appropriate where a significant increase in air movement and ventilation rate is delivered. It is however important to note that fire doors should not be kept open unless fitted with approved automatic closers, so that they function as fire doors in the event of an alarm or fire.

4.1.3 Mixing boxes

Mixing boxes are designed to supply air to a single room or zone, so the mixing mode can still be used if this enables more outside air to be supplied to the room and reduces draughts when the outside air temperature is low. However, to maximise outside air provision, the device should be used in full outside air mode if reasonable to do so.

4.2 Mechanical ventilation

4.2.1 Supply and extract

In buildings with mechanical ventilation systems, extended operation times are recommended.

Change the clock times of system timers to start ventilation at nominal speed at least an hour before the building usage time, and switch to lower speed an hour after the building usage time.

In demand-controlled ventilation systems, change CO_2 setpoint to a lower value if this assists in maximising the reasonable flow of outside air (for example in favourable seasons) in order to maintain the operation at nominal speed.

Refer to manufacturer's guidance for help. Relative humidity should be kept above 40% wherever possible.

4.2.2 Heat recovery

There are several methods by which heat recovery can be achieved; the manufacturer's literature for the system installed should provide information on what method is employed. For buildings completed since 2002, the building log book should also provide information on the ventilation system and how it is intended to operate.

4.2.2.1 Twin coil unit or plate heat exchange

This system keeps the supply air and the extract air streams physically separate; only the heat energy is transferred, and the air streams never mix. On this basis the heat recovery device can remain online, but the unit should be inspected to ensure there are no leaks that could lead to transfer of air from exhaust duct to supply duct.

4.2.2.2 Regenerative rotary air to air heat exchangers (also known as enthalpy or thermal wheels)

These heat recovery devices carry a risk of air leakage and moisture transfer between the supply and exhaust air streams at the rotary heat exchanger. The magnitude of a leakage will vary depending on the installed configuration of the fans and the relative pressures in the supply and extract ducts.

Where properly configured, direct air leakage passes from the supply to the extract duct and is therefore not a concern.

Actual configuration and pressure balances should be checked by an engineer, and poorly configured or balanced systems should be remedied or else must be bypassed.

It is possible that viral material can be absorbed by the surfaces of the wheel and transferred into the supply air flow, but there is no evidence of this happening, and the risks of such viral transfer are outweighed by the need to maintain ventilation rates. However, if adequate ventilation rates with suitable thermal comfort can be provided without use of the regenerative rotary heat exchanger, it is advisable to bypass the system if that provision is available; or if no bypass is available in these circumstances, the rotor should be turned **off**.

The heat recovery function is usually integral to system design, in terms of simultaneously delivering adequate air flow and meeting heating or cooling demand. If the only way to provide adequate and safe outside air flows is by using the thermal wheel, then it is advisable to turn the rotor **on.** Not doing so will result in a greater build-up of any indoor viral contaminant. The expected reduction in dilution of any potential indoor viral source with inadequate ventilation flow rates is considered to be a greater risk for viral transmission than the potential for viral transfer across the thermal wheel.

Turning the rotor on will improve thermal comfort conditions, and offers the added benefits of maintaining the energy efficiency and appropriate humidity levels.

In summary, the benefits of maintaining high outside air rates to dilute internal viral contaminants outweigh the risks of viral particles being transferred via a correctly configured thermal wheel.

Systems should be checked for configuration and correct operation by a competent engineer. Personnel should adopt the usual safety procedures for dusty work, and should wear appropriate personal and respiratory protective equipment.

4.2.2.3 Recirculation sectors in centralised air handling units

Recirculation within central air handling units serving multiple rooms or zones may increase the risk of cross-infection. There is some evidence of viral material being detected in air handling units, although its viability is not known (Horve, et al., 2021). Transfer of viral material from one zone to another poses as much lower risk than that posed by far-field airborne transmission in a single zone containing an infected person; to minimise risk, it is preferable to operate with the recirculation dampers closed when reasonable to do so.

However, in certain weather conditions closure of the recirculation dampers may lead to unsatisfactory temperature conditions, and consequently a reduction in the rate of supply of outside air to the occupied spaces to levels below that deemed adequate (10 l/s/person for typical offices). In these instances, there is a balance of risks to be considered with recirculation: the increased risk of cross-contamination between rooms or zones, and the reduced risk of contaminant build-up as a result of maintaining adequate levels of provision of outside air.

It is recommended that recirculation is used if there is no other way of maintaining adequate levels of outside air to occupied spaces. However, it should not be used if adequate levels of outside air can be reasonably provided with the recirculation dampers closed (with due consideration to thermal comfort and energy use).

Some air handling units and recirculation sectors may be equipped with return air filters. These filters do not normally filter out particles with viruses effectively, since they are rated with standard efficiencies (G4/M5 or ISO coarse/ePM10 filter class) rather than high efficiency particulate air (HEPA) filter efficiencies.

HEPA filters, or other filters capable of filtering out virus particles, should be used only in systems designed for use with higher efficiency filters. Otherwise, there is a high possibility of air leaking around the HEPA filter due to the increased resistance of the unit, which will eliminate any benefit gained from installing the HEPA filter. The increased resistance of the filter may also reduce the rate of supply of outside air. This can also have unintended consequences in other parts of the system; for example, it may place excessive demand on fans.

The advice of a competent engineer should be sought, and manufacturer guidance should be consulted before modifying installed filters or changing the grade of filter installed.

4.2.3 Duct cleaning

Duct cleaning does not reduce risk of viral infection, as any viral particles encapsulated in aerosols that settle in ductwork will become unviable over time. Unlike pathogens such as bacteria and fungi, which can continue to multiply in such environments, viruses require a host cell for replication. Therefore, no changes are needed to normal duct cleaning and maintenance procedures.

In kitchens and catering facilities, regular duct cleaning is required for fire safety and to meet other public health requirements, and should be conducted as normal with appropriate precautions in place.

4.2.4 Outside air filters

Outside air is not seen as a high-risk source of SARS-CoV-2 viral aerosols. Therefore, it is not necessary to modify or alter the grade of existing outside air filters and replace them with other filter types. They should be changed in line with the standard maintenance regime requirement.

For a fuller explanation of filters and the relevant standards commonly applied in the UK see https://www.cibsejournal.com/technical/understanding-hepa-filters/.

4.2.5 Changing filters

Filters must be replaced according to normal procedure when pressure or time limits are exceeded, or according to scheduled maintenance intervals. Clogged filters are not a contamination source in this context, but they reduce supply airflow which has a negative effect on the ability to remove and dilute concentrations of contaminant. Thus, HVAC maintenance personnel may be at risk when filters (especially extract air filters) are not changed in line with standard safety procedures. Filters may have active microbiological material on them, including viable viruses, particularly in any building where there has recently been an infection. Filters should be changed with the system turned off and technicians must use appropriate PPE including gloves and eye protection, overalls and personal respiratory protection. Used filters must be disposed of in a sealed bag in the appropriate waste stream.

4.2.6 Extract only

If the ventilation provision is extract only and the make-up air (the air that enters the room to replace that exhausted) is outside air from infiltration through the building fabric (i.e. gaps; see CIBSE TM23) then this is unlikely to present an increased risk of viral transmission. However, if the main make-up airflow pathway is from another room or zone then it will increase the risk of spreading any airborne viral particles between zones.

For extract ventilation in toilet blocks please see section 4.1.1.5, windows in toilet blocks. In toilet blocks with mechanical extract ventilation the extract ventilation should remain constantly on and windows in the toilet block remain closed. A notice may be required on the toilet doors/walls to explain this and discourage opening. Airflow through windows can change pressure differences in the toilet block and could encourage airflow out of the toilet block into adjacent spaces.

4.2.7 Split air conditioning systems

Within a room or zone these systems are good at providing thermal comfort by warming or cooling the indoor air and the air movement they provide can help prevent stagnant areas of air within a room. However, it is important to understand that they do not provide any outside air into the room or zone and without a dedicated source of outside air supply into a room they could be responsible for recirculating and spreading airborne viral particles into the path of socially distanced building users. If there is no source of outside air provision from either natural or mechanical ventilation when these units are in operation then the space should only be used for short periods of time.

4.2.8 Fan coil units

If there is a good outside air ventilation supply (either mechanical or natural) to the room or zone then the action of the fan coil unit fan will help de-stratify the air and reduce the chance of pockets of stagnant air, helping to dilute any airborne pathogens.

If a room or zone has no or very little outside air ventilation provision then the action of a fan coil unit could create air movement that is likely to spread any airborne viral particles throughout the room and the advice is to turn off the fan coil unit fan.

4.2.9 Chilled beams

Active chilled beams: These form part of the ventilation system and are used to chill incoming outside air as it passes into a room. These can operate as normal.

Passive chilled beams: These cool air already in a room by absorbing the heat. They do not bring outside air into the room. They will cause air mixing due to convection currents, but as with fan coil units, if there is a good supply of outside air these can still be operated and do provide comfort.

If a room or zone has no (or very little) outside air ventilation provision, the chilled beams may generate air movement that is likely to spread airborne viral particles throughout the room. Under these circumstances, the chilled beams should be switched off.

4.3 Air cleaning devices

Air cleaning devices effectively remove particles from air, but do not remove CO_2, odours, gaseous pollutants or volatile organic compounds. To be effective, air cleaners must be fitted with HEPA filters (or another high-efficiency filter capable of filter out virus particles). A substantial proportion of room air must also pass through the air cleaner.

Air disinfection or cleaning using UV or HEPA filters (or a combination of the two) has great potential to reduce the aerosol transmission of infectious agents in a variety of contexts, particularly in scenarios where achieving adequate ventilation is difficult or not possible. However, current data does not allow firm conclusions to be reached about how such technologies should best be used in existing situations to effectively reduce levels of contamination in the air and to mitigate the aerosol transmission of infection.

Because the airflow through air cleaners is limited, the floor area that can be effectively served is normally quite small, typically less than 10 m^2. Thus it is essential that the device is sited in an appropriate location.

The cleaner must not be located in a stagnant zone of a room. An air cleaner located in the centre of a room will clean more air, in most cases, due to the air circulation. Air cleaners should be located within the occupant zone: the region normally occupied by people within a space. This can be assumed to span from the floor to a height of 1.8 metres; from more than 1.0 metres from outside walls/ windows/ fixed heating, ventilating or air conditioning equipment; and from 0.3 metres from internal walls.

Locating air cleaners close to the breathing zone is an alternative; however this requires one air cleaning device per person, and is unlikely to be a viable or practical option in most scenarios.

Special UV cleaning equipment for room air treatment is effective at killing bacteria and inactivating viruses, but is normally only a suitable solution in health care facilities; see section 6 for further information.

For further information on air cleaning devices, and appropriate metrics to consider when choosing one, see *COVID-19: Air cleaning technologies* (CIBSE, 2021).

4.4 Specialist localised exhaust ventilation

Specialist localised exhaust ventilation is provided for workplace and process-specific safety reasons, and should continue to be operated as normal. The Institute of Local Exhaust Ventilation Engineers, a division of CIBSE, provides specialist advice and a list of accredited practitioners who have particular expertise in these systems.

It is worth considering where make-up air into the room with specialised ventilation is coming from; ideally the make-up air should come from outside, rather than from adjacent rooms.

4.5 No obvious ventilation strategy

If there is no obvious ventilation strategy in a room or zone, building users should be discouraged from using the space.

If the space is used for short durations, such as a stairwell or corridor, more robust cleaning regimes should be implemented.

5 Natural ventilation in winter

The amount of outside air that can be reasonably provided during winter is likely to be less than in the summer due to the impacts of air temperature on occupant comfort.

The risk of SARS-CoV-2 transmission via aerosols at distances greater than 2 metres is highly likely to increase in poorly ventilated spaces. It is therefore important that all reasonable steps are taken to avoid poor ventilation of indoor spaces as far as possible.

Poorly ventilated spaces can be identified by a lack of any dedicated supply of outside air, a stuffy feel or unpleasant smells; or, if using a CO_2 monitor, sustained CO_2 levels greater than 1500 ppm measured with sedentary occupants, or greater than 800 ppm in low occupancy spaces - or when respiratory activities (singing, loud talking) increase aerosol emission.

Ventilation plays a key role in diluting airborne SARS-CoV-2 in respiratory aerosols. The potential benefits of increasing ventilation to a poorly ventilated space are greater than in a well-ventilated space. There is therefore a law of diminishing returns in increasing ventilation rates.

Increased ventilation in winter may lead to behavioural responses in occupants that result in ventilation provision being deactivated or minimised. For example, increased ventilation could result in colder indoor environments or cold draughts; this could cause occupants to close, reducing or turn off ventilation provision, and thus failure to reach the goal of increased ventilation.

In winter, the driving forces for natural ventilation - pressure differences caused by wind and differences in temperature between indoors and outdoors - are usually greater. Thus, smaller openings can deliver an adequate flow rate.

Adjusting natural ventilation openings can be complemented by purging a space: that is, opening windows or ventilators fully for several minutes during unoccupied periods, such as during breaks or between meetings.

What follows provides guidance for adjusting various ventilation openings to deliver adequate outside airflows whilst minimising occupant discomfort.

Please note that this section does not cover hybrid and mechanical systems. Advice regarding recommendations on using proprietary systems in the delivery of adequate air flow during cooler months should be sought from the manufacturer.

5.1.1 Single set of high- and low-level openings

Where a space has high- and low-level windows or ventilators, it is preferable to open the high level vents first to provide outside air, and to open the low level windows to further maximise airflow when reasonable.

The turbulent plume of cooler outside air entering through high level vents will mix with warm room air as it falls under gravity, tempering, or warming, the cooler air before it enters the occupied zone.

A helpful draught plume calculator that enables this effect to be measured is available in *Building Bulletin 101: calculation tools* (ESFA, 2014).

A safe means of opening and closing high level vents should be supplied in workplaces.

5.1.2 Multiple openable windows and/or vents

Where a room has multiple openable windows or vents, it may be possible to deliver adequate ventilation using only one opening. However, it is usually possible to create a more comfortable indoor environment, with respect to draughts, if the airflow is achieved through opening all of the vents by a smaller amount than by opening a single opening by a large amount.

If there are openable vents at both high and low level, then the principle of opening as many high-level vents should initially be considered (see 0).

5.1.3 Sash windows

As with high- and low- level windows, it is better to open the high level sash to encourage entrainment of outside air with the warm indoor air in the first instance. Opening the bottom sash will further increase outside airflow.

5.1.4 Additional vents

There are ventilators and louvre systems that can be modulated and operate in a similar way to windows. The principles of opening high-level vents, and opening multiple vents a small amount, should be considered in the first instance.

5.2 CO_2 Monitors

CO_2 is present in exhaled breath, and therefore its concentration represents the fraction of air that has been exhaled by individuals in the space. It is a proxy for occupancy and/or a ventilation rate, but it is not a direct proxy for infection risk.

In many spaces a minimum supply of 10 l/s/person of outside air is prescribed, which will result in a maximum CO_2 concentration of 800-1000 ppm. Further information on suggested outside air supply rates for various building types is available in Table 1.5 of CIBSE Guide A: *Environmental design* (CIBSE, 2015).

Measurements of elevated CO_2 levels in indoor air are an effective method of identifying poor ventilation in multi-occupant spaces. However, in low occupancy or large volume spaces, a low level of CO_2 cannot necessarily be used as an indicator that ventilation is sufficient to mitigate transmission risks.

Multi-occupant spaces that are used regularly and are poorly ventilated (below 5 l/s/person or above 1500 ppm CO_2 for prolonged periods) should be identified and prioritised for improved ventilation rates.

In spaces with low occupancy or where enhanced aerosol generation is likely (such as through aerobic exercise, singing or loud speech) ventilation should be sufficient to maintain CO_2 concentrations below 800ppm (typically 10-15 l/s/person). It may be wise to consider additional mitigations, such as reduced exposure (occupancy) times, the use of face coverings, restricting the size of groups and reducing the duration of activities.

The latest government advice should be sought with respect to undertaking high-aerosol-generating activities indoors.

If CO_2 monitors are to be deployed, they should be non-dispersive infrared (NDIR) CO_2 monitors, which detect CO_2 in the space. The less expensive equivalent CO_2 (eCO_2) sensors should not be used. These do not detect CO_2, but infer a CO_2 concentration by measuring room volatile organic compound (VOC) concentrations instead.

Further information on the application of CO_2 monitoring as an approach to managing ventilation to mitigate SARS-CoV-2 transmission was published by SAGE-EMG on 11th June 2021, and is available here: *EMG and SPI-B: Application of CO2 monitoring as an approach to managing ventilation to mitigate SARS-CoV-2 transmission, 27 May 2021* (SAGE-EMG, 2021). Additional guidance released by HSE on 14th July also discusses CO_2 monitoring; it is available here: *Ventilation and air conditioning during the coronavirus (COVID-19) pandemic* (HSE, 2021).

CO_2 monitors are not a direct proxy of airborne viral concentrations (which is a function of the likelihood of an infector(s) being present and their viral load), and as CO_2 does not deposit or decay, CO_2 levels do not capture the effect of these removal mechanisms on airborne viral concentrations. For a more detailed discussion see the CIBSE Journal article *Why space volume matters in COVID-19 transmission* (Jones & Iddon, 2021).

If CO_2 monitors are deployed it would be helpful to provide information to employees and customers, so they can have some understanding of what the monitors show and what interventions to the ventilation strategy they can use. Perhaps a simple sign with a QR code link, posted in a place where it will be easily seen, would be a good idea.

It may also be wise to provide training or to inform people in other ways about the monitors, detailing what they are for, why they are useful and what people should do in response to them.

5.2.1 Occupant comfort

A person's sensation of warmth is influenced by the following main physical parameters, which constitute the thermal environment:

- air temperature
- mean radiant temperature
- relative air speed
- humidity.

Besides these environmental factors there are personal factors that affect thermal comfort:

- metabolic heat production
- clothing.

It is possible to adjust the personal environmental factors to improve occupant comfort, particularly where outside air supply may decrease occupant comfort. *Guide A: Environmental design* (CIBSE, 2015) describes the predictive mean vote (PMV) method of measuring occupant thermal comfort, which can be used to see how changes to apparel and metabolic activity can improve occupant thermal comfort.

5.2.2 Clothing

Clothing provides a layer of insulation that contributes to the occupant's perception of comfort, which is dependent upon the material and fit.

Typical winter wear would have a value of 0.8 to 1.0 clo, although studies in recent decades in Europe and the UK have found values generally at the lower end. This may be a result of occupants acclimatising to, and expecting, warmer indoor environments in the winter. For example, compare typical winter office clothing of the 21st Century with that in vogue at the turn of the 20th Century, when many more layers and heavier materials were traditionally worn.

To improve occupant comfort, particularly in naturally ventilated indoor spaces, occupants should be encouraged to dress appropriately. Relaxation of dress codes should be considered if necessary to allow warmer clothes to be worn during cooler weather.

Notwithstanding the benefit of warmer clothes to improve occupant comfort, the heating design of naturally ventilated indoor spaces should include provision to temper the incoming air required for adequate ventilation.

Whilst it would be expected that the indoor design air temperatures will be maintained, air temperature is only one component of thermal comfort and so warmer clothes will also be of benefit for comfort. For example, it is quite common to be comfortable in shorts and t-shirt early on a summer morning, when the air temperature may be 18°C, but to be uncomfortable wearing the same apparel in the winter when the room air temperature is also 18°C.

5.2.3 Metabolic rate

Sedentary activities have a relatively low metabolic activity, which can contribute to occupant thermal discomfort. Encouraging periods of activity - movement around the room, or some light exercise, will help to improve thermal comfort. This also aids in meeting the the Health and Safety (Display Screen Equipment) Regulations (HMSO, 1992), which require regular breaks or changes in activity when using computer screens and also recommend regular movement to improve health.

5.3 Position of occupants in relation to openable vents

Where possible, increasing the distance of occupants from openable vents gives more time for incoming cool air plumes to mix with warm room air prior to entering the occupied zone.

6 UV disinfection

Ultraviolet germicidal irradiation (UVGI) is a long-established technology using UV-C light at wavelengths around 254 nm. It appears to have considerable potential to inactivate SARS-CoV-2 and other pathogenic coronaviruses, as at the appropriate wavelength it disrupts the structure of the nucleic acids which form the virus genome.

What follows is a brief overview; for further information on UV disinfection, see *COVID-19: Air cleaning technologies* (CIBSE, 2021).

Early studies indicate that SARS-CoV-2 is relatively easily inactivated by UV-C light. When aerosolised, the virus is likely to show a similar susceptibility to UV as other coronaviruses in air.

It may be possible to install UVC disinfection equipment within some mechanical ventilation systems, and this may be a viable solution for reducing levels of active viral material in spaces where it is difficult to provide good ventilation.

UV disinfection should be seen as a supplementary measure for reducing the concentration of pathogens. It does not remove other contaminants, and it is not an alternative to adequate ventilation. Where there is adequate ventilation, the cost benefit of using UV may be limited.

UV systems take several forms:

- **Upper room germicidal ultraviolet (UV) systems**: This may be installed in the upper areas of a room, acting on the air above head height and relying on air mixing to enable it to be effective on the whole volume of air in the space over a period of time.
- **In-duct UV**: This is installed in the air distribution, disinfecting air as it passes through the system. The efficacy is a function of the power of the UV lamp and the velocity of the air passing across it.
- **Room air cleaning device**: This can be part of a room air cleaner which passes air from the room through a combination of filters and UV radiation.

When specifying any UV installation it is necessary to consider the size of the room - and for upper room systems, the height of the spaces to be served - and the existing ventilation system, the flow rate through the device, duct or space, the location of the equipment, the noise produced and any other unintended effects on air quality.

Some UV technologies can be hazardous to health if applied or operated incorrectly.

Installation of UV will involve some capital cost.

6.1 Upper room UVGI

Upper room systems shine UV light on the air above head height to deactivate viral material, relying on mixing in the space. Thus they are not limited by the rate of airflow through a duct or cleaning unit.

Initial assessments of the effectiveness of UV to deactivate similar viruses suggest that UV is effective against SARS-CoV-2. Upper room UV is likely to be at its most effective in poorly ventilated spaces, and can be installed reasonably easily at a low cost.

Sizing a system is not always straightforward, and it is essential that systems are installed by competent professionals who understand the safety requirements for UV-C radiation sources in occupied zones.

6.2 In-duct UVGI

These systems use UV-C lamps mounted in the return or supply air ducts of mechanical ventilation systems to disinfect the air.

Although the lamps can be placed in either the return or supply air ducts, it is generally preferable to install them on the return air side of the air handling unit. Here, they disinfect air that may be recirculated and also protect up-stream duct-work, filters and coils from becoming contaminated.

It is important to design the installation appropriately for the volumes and air flow rates in the system.

6.3 UV room air cleaning devices

UVGI room air cleaners are use UV-C lamps mounted inside an enclosure, with a fan to draw air through the irradiated zone.

They may also employ filters, and can vary in size, but only disinfect the air that passes through the device.

6.4 UV disinfection: safety

When a UV system is used to reduce the risk of exposure to viral particles in the air, it is important that it fails safely so that building managers are made aware of any failures to the UV system immediately. This makes it possible to implement alternative measures in order to ensure that occupants are protected.

This could be achieved by allowing some additional system capacity to cover a lamp failure, allowing maintenance and replacement to be undertaken during unoccupied hours when the system can be shut down safely.

UV-C light is highly biologically active and can damage human tissues. As UV wavelengths of light are invisible to humans, damage can occur without it being noticed initially.

Exposure to UV light can result in inflammation of the cornea of the eye (known to skiers and mountaineers as sun-blindness). Certified safety eye-wear for use with UV-C should always be worn when working on UV systems.

UV-C light can also cause reddening of the skin similar to sunburn. A review by the International Commission on Illumination (CIE) concluded that upper-room UVGI air disinfection could be safely used without significant long-term risk (CIE, 2010).

Upper room, in-duct, and many portable UV systems are designed to operate whilst the room is occupied. They must be installed in such a way that it is possible for occupants to avoid exposure to UV light.

Any other form of UV air cleaning technology located in rooms must only be operated when the room is vacant, and there must be robust means of preventing anyone entering the space during the time when the UV lamps are operating.

6.5 UV disinfection: summary

Each UV engineering control measure has advantages and limitations, and none of them can entirely eradicate the risk of transmission.

Upper room UV can reduce the risk of transmission, particularly in poorly ventilated spaces. In-duct systems may be effective, but only when duct velocity and radiation intensity are managed to achieve a high level of disinfection. Portable units may also be effective, although careful attention is needed to size them appropriately for a room or zone.

In all cases, it is essential to establish that the equipment is appropriate for its intended use, can be safely maintained, and is tested and certified for the proposed use with recognised and accredited testing certification arrangements.

Care should be taken with portable or in-duct units to check the noise of the unit when in use.

There is a need for better data describing the performance of UV technologies, and case studies reporting successful real-world applications.

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