Ventilation for Domestic Retrofit

info@retrofitacademy.org

THE RETROFIT ACADEMY

Introduction

This document explains the critical role of ventilation in domestic retrofit and summarises the ventilation-related requirements of the domestic retrofit standard PAS 2035[1]. It then presents the technical options for ventilation and provides some guidelines for specifying ventilation in accordance with the 'four Cs' of safe retrofit[2].

1. *BSI Retrofitting dwellings for energy efficiency: Specification and guidance Publicly Available Specification (PAS) 2035:2019.*
2. *For the four Cs, see May N. and Sanders, C. Moisture in Buildings: an integrated approach to risk assessment and guidance,BSI, London.*

The critical role of ventilation in retrofit

Until the 1970s, homes in the UK were mostly ventilated by wind-driven air infiltration (on the upwind sides) and air leakage (by displacement, on the downwind sides), supplemented by the opening of windows. This adventitious process admitted fresh external air and removed 'stale' internal air.

In the 1970s, the installation of loft insulation and new double-glazed windows with draught-stripping improved the airtightness of homes, so infiltration and air leakage were reduced, resulting in condensation and mould growth in 'wet rooms' (i.e. kitchens and bathrooms). Consequently, the Building Regulations were updated to require the installation of intermittent ventilation fans in wet rooms, to remove moisture at source, combined with background ventilators (sometimes called 'trickle ventilators') in living spaces and bedrooms to admit a balancing supply of 'fresh' air and provide background ventilation when the fans are not in use. Notwithstanding these innovations, wind-driven air infiltration and air leakage still provide most (more than half) of the ventilation of our homes.

Now, as we insulate walls, roofs and floors to a much higher standard, and improve airtightness, infiltration and air leakage rates are being reduced again. Consequently, it is necessary to install additional deliberate ventilation to ensure healthy internal air quality (IAQ). Without this additional ventilation, concentrations of moisture, carbon dioxide and other pollutants build up inside our homes, leading to a deterioration of the building fabric and finishes, and putting occupants' health at risk.

Therefore, if we retrofit any insulation or airtightness measures then we must compensate for the lost infiltration and air leakage by assessing the existing ventilation (if any) and upgrading, if necessary, to an adequate system. The maxim is 'No insulation without ventilation'.

What is ventilation for?

Ventilation is the process by which we remove 'stale' polluted air from inside our buildings and replace it with 'fresh' external air (which is usually less polluted).

Indoor pollutants are shown in **Figure 1**. They include moisture; carbon dioxide; volatile organic compounds (VOCs); bacteria, viruses and mites; ozone; tobacco smoke; pollen and particulates; and odours.

External sources of pollution, which often enter our homes, are shown in **Figure 2**. They include: naturally occurring non-biological particles; construction and mining chemicals; agricultural chemicals from wind erosion; pollen and other biological particles; methane, moisture and radon rising from the ground (in some areas); vehicle emissions; and industrial emissions.

Figure 1 **Indoor Pollutants**

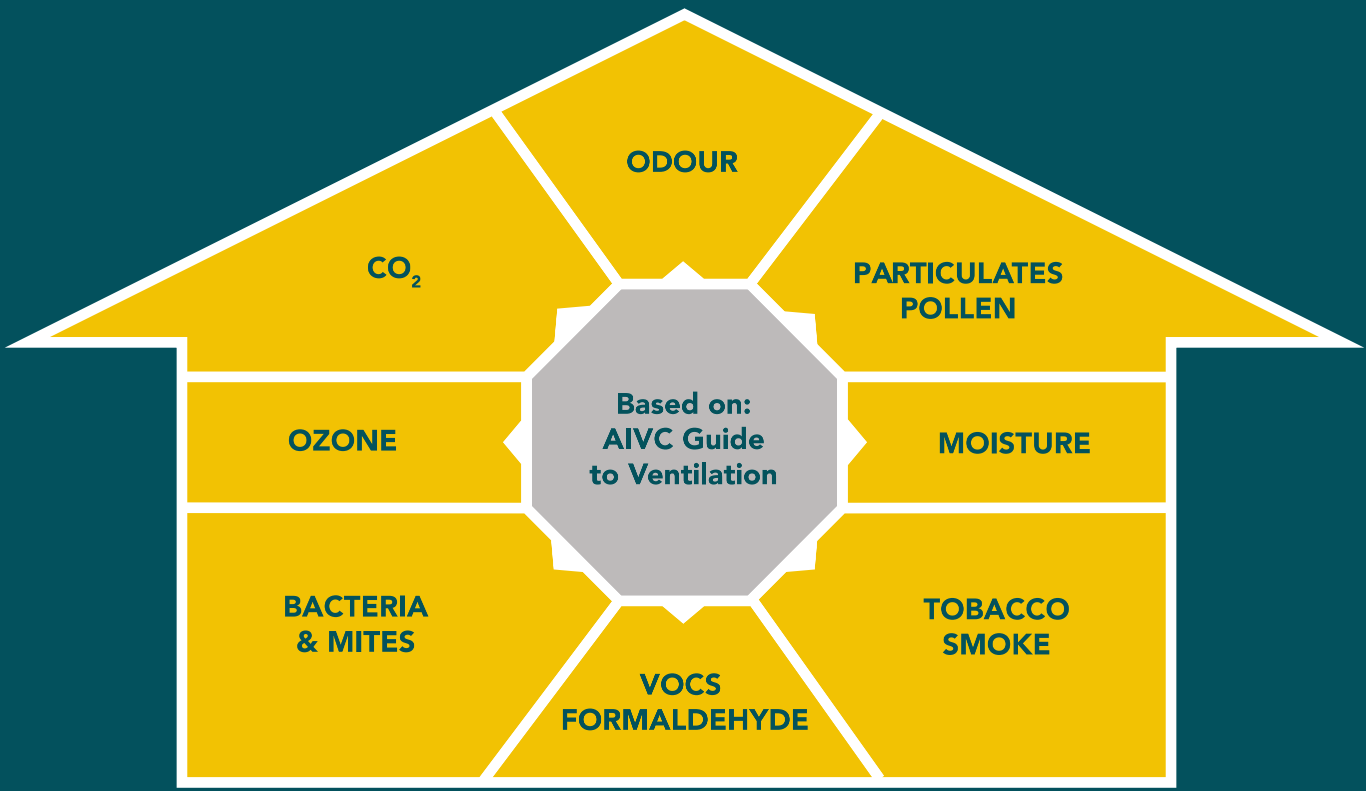
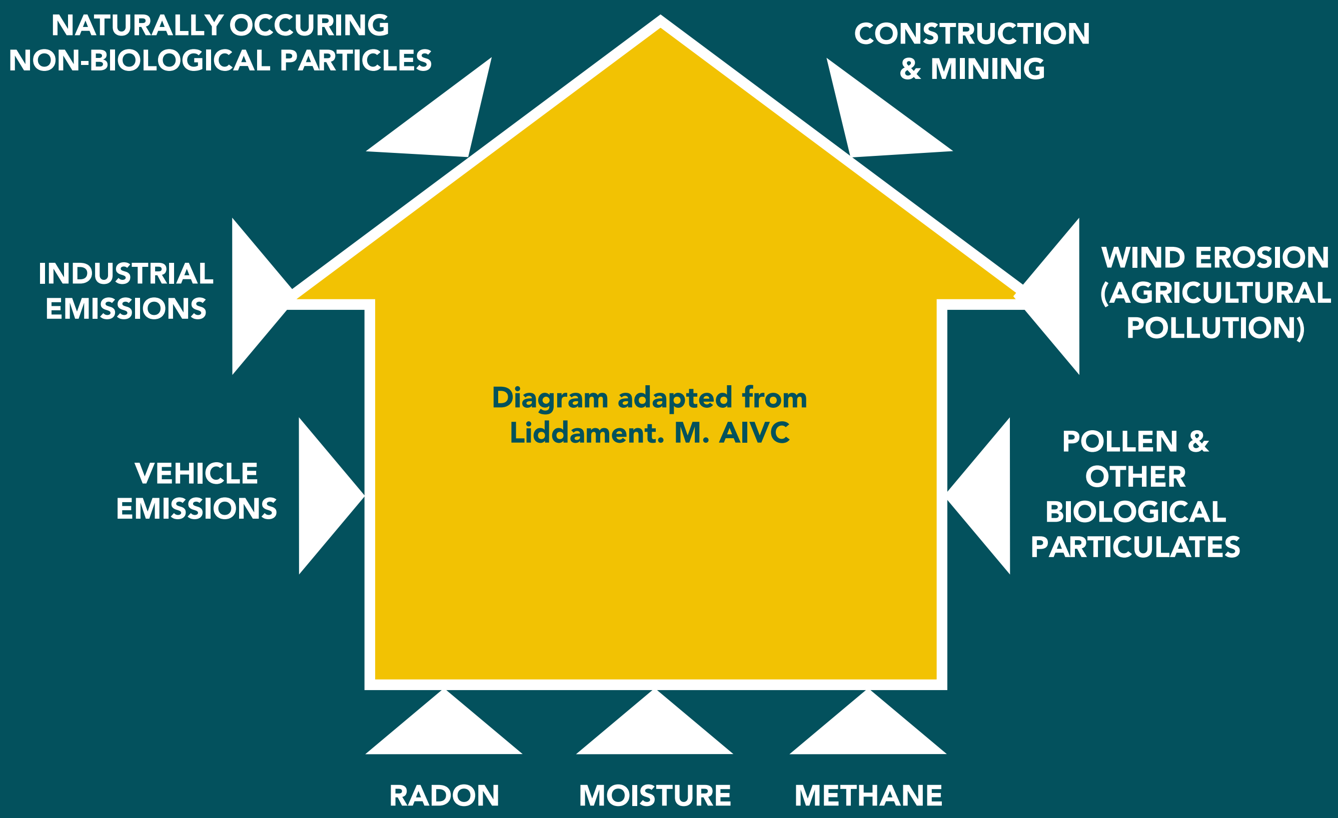


Figure 2 **External Sources of Pollution**



Radon is a radioactive gas to which exposure occurs in some areas where there are underlying granite rocks. Radon is the second largest cause of lung cancer after smoking, so we should try to exclude it from our homes, either by blocking its entry with radon barriers or by ventilating it away before it accumulates.

The five most significant sources of internal air pollution are:

Moisture

Which is generated by respiration (of people, pets and plants), bathing, cooking and drying laundry indoors. When warm moist air is chilled by contact with cold surfaces water condenses on those surfaces and promotes the growth of black mould. The spores thrown out by black mould are known to exacerbate respiratory illnesses such as asthma.

Carbon Dioxide

Which is a natural component of air but is generated by respiration and is toxic at high concentrations. (It also makes rooms feel ‘stuffy’ or ‘airless’.)

Volatile Organic Compounds (VOCs)

Which are toxic or carcinogenic chemicals emitted by paints and by adhesives in new floor finishes and furniture, and contained in many household liquids such as cleaning sprays, air fresheners and fabric softeners.

Bacteria, Viruses and Mites

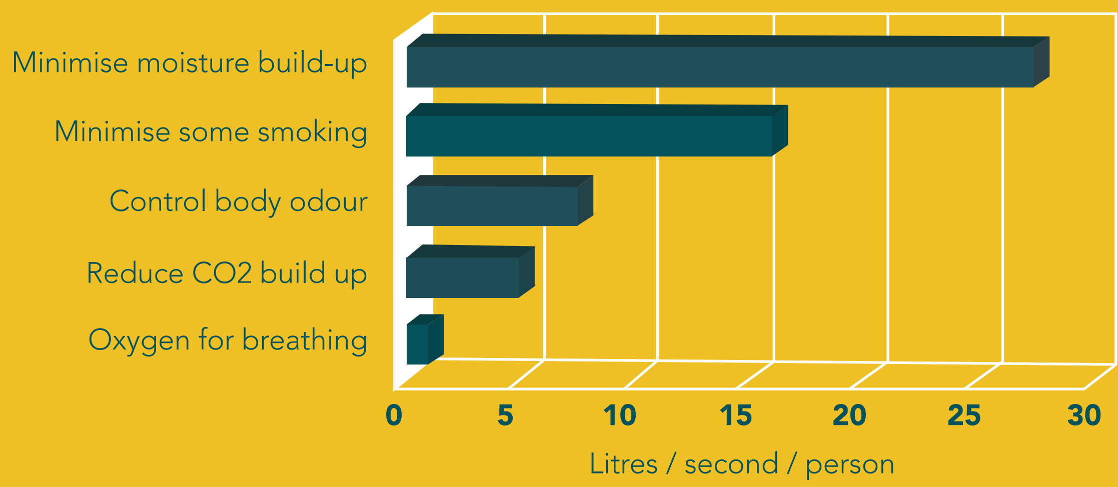
Which are sources of illness; many people are allergic to mites, and they are known to exacerbate respiratory illnesses such as asthma.

Combustion Products

Such as nitrogen dioxide and carbon monoxide from heating appliances or cooking hobs. There are highly toxic gases. Most nitrogen dioxide exposure occurs in homes with gas-fired appliances.

The amount of fresh air that we need in our homes is illustrated in **Figure 3.**

Figure 3 **Fresh Air Requirements**



The quantities in Figure 3 are not cumulative, so overall we need about 27 litres of fresh air per second per person to maintain a healthy indoor environment. That amount of fresh air is rarely achieved even by the best ventilation systems, which may explain why we do not feel well if we stay indoors for long periods without opening windows.

Deliberate, controlled ventilation, when and where we need it, is much more effective and energy-efficient than relying on uncontrolled, adventitious ventilation via wind-driven infiltration and air leakage. Therefore we try during retrofit to make homes relatively airtight, and then to ventilate them properly. The maxim is ‘built tight, ventilate right’.

What does PAS 2035 require?

If we are proposing to install any insulation or airtightness measures as part of a retrofit project, PAS 2035 requires the existing ventilation system (if any) to be assessed for adequacy, and if necessary upgraded. The requirements are in Clause 8 and Annex C.

Assessing existing ventilation

The PAS 2035 ventilation assessment is part of the whole-dwelling assessment. The existing ventilation is deemed inadequate if one or more of the following is apparent:

- there is evidence of condensation and/or mould growth in the dwelling;
- there is no ventilation system, or the ventilation system is incomplete or not functional;
- there is not an undercut of at least 7000 mm^2 beneath each internal door, to allow air to move through the dwelling; or
- there is no provision for purge ventilation of each habitable room (e.g. by opening windows) as recommended by Building Regulations Approved Document F.

An adequate, complete ventilation system is:

- an intermittent extract ventilation (IEV) system consisting of fans in all wet rooms and background ventilators (to admit fresh external air) in all living spaces and bedrooms; or
- a passive stack ventilation (PSV) system consisting of passive stacks extracting air from all wet rooms and background ventilators (to admit fresh external air) in all living spaces and bedrooms; or
- a continuous positive input ventilation (PIV) system supplying fresh air and background ventilators (to allow moist, stale air to escape) in all other rooms; or
- a continuous mechanical extract ventilation (MEV) system that extracts moist stale air from all wet rooms combined with background ventilators to admit fresh external air to all living spaces and bedrooms; or
- a whole-house supply and extract mechanical ventilation with heat recovery (MVHR) system that continuously extracts moist stale from wet spaces and supplies fresh air to living spaces and bedrooms.

However, if the proposed improvement measures are either intended to reduce the air permeability of the building envelope below 5 m^3/m^2hr @ 50Pa, or might do so, then IEV and PSV systems are deemed inadequate.

Ventilation systems that are assessed as inadequate because some components (e.g. background ventilators, door undercuts) are missing may be made adequate by adding those components.

Where a ventilation system is assessed as inadequate but no insulation or air-tightness measures are proposed, the client and/or occupants must be informed that the ventilation is inadequate and upgrading the ventilation should be included in the medium-term improvement plan, for implementation alongside any future insulation or air-tightness measures.

Upgrading ventilation

Where any insulation or air-tightness measures are proposed, and the existing ventilation is assessed as inadequate, it must be upgraded, as part of the retrofit project, during the same stage of work as the insulation and air-tightness measures are installed. Upgrading of the ventilation system must be included in the retrofit design, and ventilation upgrades should not be deferred to a later stage of the medium-term improvement plan.

Where ventilation is to be upgraded and it can be shown by testing that the air permeability of the building envelope, after installation of the proposed energy efficiency measures, is not less than 5 m^3/m^2h @ 50 Pa, then an acceptable system of ventilation is IEV or PSV in all wet spaces combined with background ventilators in all living spaces and bedrooms. In the case of PSV, the apertures of the air extract grilles (in wet spaces) should be automatically controlled in response to internal relative humidity (RH).

In all other cases where ventilation is to be upgraded the acceptable types of ventilation systems are:

- continuous MEV consisting of one or more fans extracting moist stale air from all wet spaces, combined with background ventilators in all living spaces and bedrooms to admit a balancing supply of fresh external air; or
- continuous whole-dwelling MVHR extracting moist stale air from wet spaces and providing a balanced supply of fresh external air to all living spaces and bedrooms; or
- continuous PIV, supplying fresh external air to the centre of the dwelling, combined with background ventilators in all living spaces, bedrooms and wet spaces to allow moist stale air to escape.

The advantages and disadvantages of these types of systems are described in the next section.

Ventilation Options

There are seven types of ventilation systems that may be used in domestic retrofit. Each type of system is described below, and advantages and disadvantages are identified.

Intermittent extract ventilation (IEV)

IEV consists of extract ventilation fans in wet rooms and background ventilators (sometimes called trickle vents) in living spaces and bedrooms. The role of the background ventilators is to admit a supply of fresh air when the fans are working and to facilitate wind-driven air infiltration and air leakage when they are not.

Figure 4 **An Intermittent Extract Ventilation Fan**

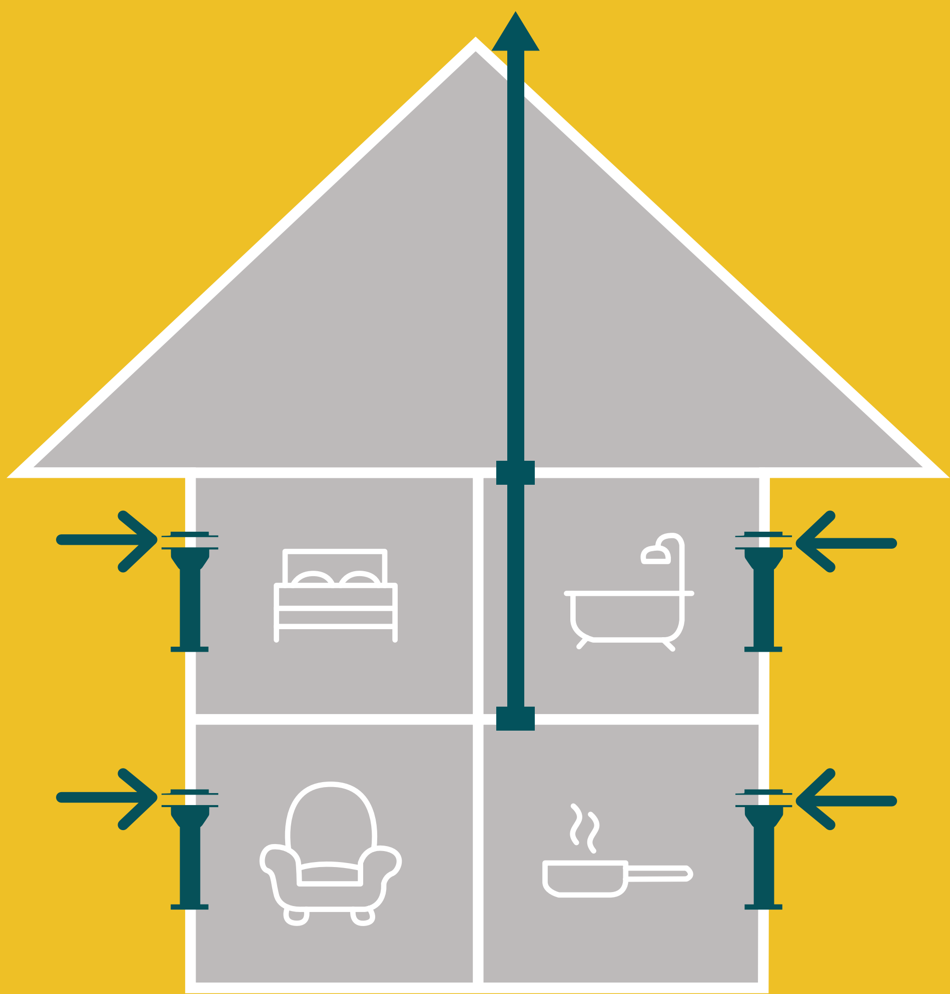
Controls are usually manual, but sometimes fans in bathrooms are linked to light switches or relative humidity sensors. IEV systems are inexpensive, relatively simple to install and well understood by occupants. However, IEV fans have relatively short lives, often needing replacing after approximately six years. Some people find the fans noisy and prefer not to use them.

Passive stack ventilation (PSV)

PSV consists of ducts from wet rooms to terminals on the ridge of the roof, through which warm, moist, stale air rises by its buoyancy, assisted by the venturi effect of the wind across the roof. A balancing supply of fresh air is drawn in through background ventilators in window heads. Often the background ventilators and the grilles in the ceilings of wet spaces are relative humidity sensitive, to provide a degree of demand control (see later). To work effectively, the passive stacks must be as straight and near vertical as possible, and they should be insulated when passing through unheated roof spaces to reduce the risk of condensation. If the background ventilators are closed the system will not work. PSV works continuously, and over twenty-four hours provides approximately the same average ventilation rate as an IEV system.

A version of PSV is available that supplies and extracts air via concentric ducts and incorporates a heat exchanger to provide heat recovery. Unfortunately, warm air rising in the extract duct loses its buoyancy when it is cooled in the heat exchanger, and cooler, fresh air falling down the duct becomes more buoyant as it is warmed in the heat exchanger. These systems are expensive (several are needed in a typical dwelling) and there is a lack of good evidence that they work as claimed. The Retrofit Academy does not recommend them for use in retrofit projects.

Figure 5 **A passive stack ventilation system**



Single room heat recovery ventilators (SRHRVs)

SRHRVs are not whole-dwelling ventilation systems and are too expensive and noisy to be used to ventilate whole dwellings. However, they are useful supplementary devices for ventilating single rooms that are difficult to connect to a whole-dwelling system.

Figure 6 **A single room heat recovery ventilator**

An SRHRV continuously extracts warm air from the room, passes it through a heat exchanger, and exhausts it to the exterior. Simultaneously, fresh outside air is passed through the heat exchanger and delivered to the room as warm fresh air. Modern SRHRVs have heat recovery efficiency of up to 85% and can deliver up to 50 m^3/hr, using between 2 W and 25 W of power. Their main disadvantage is noise; there is also a risk of 'short-circuiting' of the airflow both inside and outside the dwelling.

Some of the latest SRHRVs use alternating supply and extract: they extract air for a short period to charge the heat exchanger, then supply air for a short period until the heat exchanger is discharged. Some SRHRVs incorporate summer by-pass of the heat exchanger, and winter frost protection.

Positive input ventilation (PIV)

PIV systems provide continuous ventilation by supplying fresh outside air to the centre of a home, usually the first-floor landing or the hallway of a flat. Sometimes the air supply is taken from the loft, although care must be taken to filter out insulation fibres and dust. The system puts the home under slight positive pressure (compared with negative pressure for most other types of ventilation), so warm, moist, stale air is pushed out through background ventilators in all rooms, including wet rooms.

The perceived risk with PIV (which has not yet been properly evaluated by research) is that it may push warm, moist air into cracks and crevices in the construction, or into construction voids such as floor voids and roof spaces, where it will meet cold surfaces, causing condensation, mould growth and rot. Thus, although PIV is claimed to deal effectively with surface condensation and mould, it may simply be converting it to interstitial condensation, mould and rot, out of sight of the occupants.

Another problem with PIV is that it may not have sufficient power to ensure that moisture created in wet rooms is pushed out of the home rather than diffusing to other spaces where moisture may condense. Finally, some ventilation experts criticise PIV because, unlike most other systems, it does not supply fresh air directly to living spaces and bedrooms, where it is needed by occupants.

Because of these risks, The Retrofit Academy does not recommend the use of PIV in retrofit projects, even though it is allowed by PAS 2035.

Decentralised mechanical extract ventilation (dMEV)

A dMEV system is almost the same as an IEV system, except that the fans installed in wet rooms run continuously at 'background' level, instead of intermittently, and have intermittent boost, usually controlled by a relative humidity (RH) sensor. Background ventilators are required to admit a balancing supply of fresh air, and door undercuts are necessary to allow airflow through the dwelling.

Figure 7 **A dMEV System**

Many dMEV fans are almost silent when running in background mode, and occupants sometimes do not realise that they are working. However, dMEV fans can be noisy when running in boost mode.

A weakness of some dMEV fans is that the integral RH sensor does not put the fan into boost mode until the RH reaches 65%, which is too late for effective condensation control. Better models slowly increase the fan speed as RH rises above 50%.

A home with IEV can be converted to a dMEV system very easily, by replacement of the IEV fans with dMEV fans – this is a useful option for some of the ventilation upgrades required by PAS 2035.

Centralised mechanical extract ventilation (cMEV)

A cMEV system continuously extracts moist, stale air from wet rooms via ducts, and exhausts it to the exterior via another duct, using a single central fan that is usually located in a roof space or the top of a service cupboard. A balancing supply of fresh air is admitted via background ventilators in living spaces and bedrooms; door undercuts are necessary to permit a flow of air through the dwelling.

Figure 8 **A cMEV System**

cMEV is probably the quietest type of ventilation system because there is only a single, relatively large fan (large fans are usually quieter than several small fans doing the same work). cMEV systems also need less than half as much ductwork as MVHR, so they can be fitted easily into small homes. cMEV is almost maintenance-free and can be demand-controlled (see below), so it is often a good option for a retrofit project. Demand controlled cMEV has also been shown to deal very effectively with condensation, damp and mould problems.

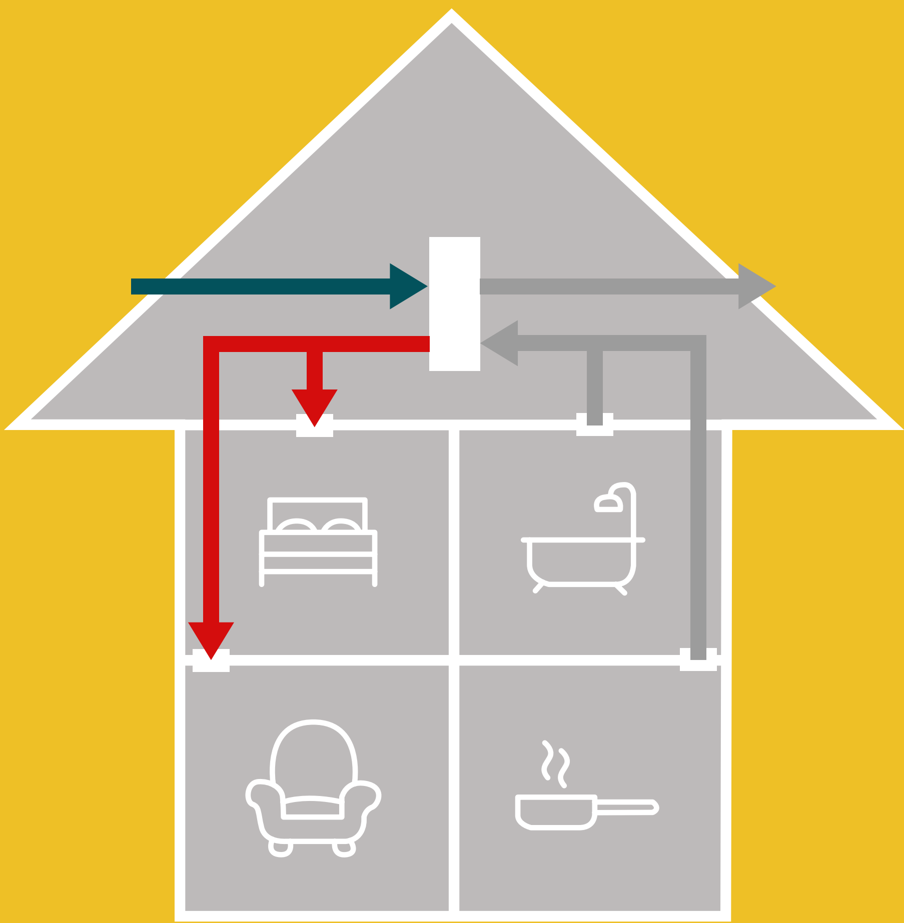
Mechanical ventilation with heat recovery (MVHR)

An MVHR system continuously extracts warm, moist stale air from wet rooms via ducts, passes it through a heat exchanger and exhausts it to the exterior via another duct. A balancing supply of fresh air is drawn from outside via other ducts, filtered and passed through the heat exchanger to warm it, and supplied to the living spaces and bedrooms via further ducts. Background ventilators are not needed, but door undercuts are necessary to allow airflow through the dwelling. Heat recovery efficiency is up to 85%, so MVHR significantly reduces the ventilation heat loss of a dwelling, as well as providing very good IAQ.

So that the cost and emissions associated with the electricity to run an MVHR system do not exceed the cost and emissions associated with the recovered heat, it is important that heat recovery efficiency is as high as possible and system fan power is as low as possible. MVHR systems that are Passive House certified are usually the most efficient and reliable.

For efficient operation, MVHR systems must also be carefully balanced – the total volumes of supplied and extracted air must be within + / - 5% of each other, so skilled commissioning is required. Filters should be cleaned or replaced one month after handover, and subsequently at intervals of not more than one year (preferably six months); blocked filters stop MVHR systems operating effectively, and can lead to condensation and mould, and health problems for occupants.

Figure 9 **An MVHR system**



MVHR systems require careful design and installation, especially if they are fitted in small dwellings. MVHR was conceived originally for new dwellings built to the Passive House standard, and it can be difficult to fit it into small existing dwellings such as Victorian terraced houses, 1930s semi-detached houses or 1960s flats.

The two fans and the heat exchanger are usually accommodated in a single box, which can be as large as a refrigerator.

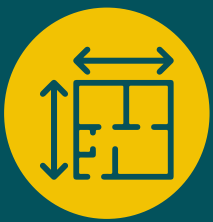
This box, and all ductwork, should be located inside the insulated envelope of the dwelling, not in an uninsulated or unheated loft space or garage. To minimise resistance, noise and fan power, ducts should be as short, smooth and straight as possible, preferably round in section with each room served by a single duct connected to a manifold. The air intake and exhaust ducts carry cold air and should be well insulated to reduce the risk of surface condensation.

Retrofit projects designed to meet the Passive House Enerphit standard must incorporate MVHR. Although MVHR significantly reduces ventilation heat loss and delivers excellent IAQ, in smaller dwellings and where the Enerphit standard does not apply, demand-controlled cMEV may be a better option, because the fan box is smaller, there is one fan, not two, and there are half as many ducts. Research has shown that a well-designed demand-controlled cMEV system often uses less energy than a typical MVHR system, even when heat recovery is taken into account.

However, MVHR systems are being improved, and the latest modular, distributed or through-the-wall MVHR systems that balance themselves automatically may be good options for some retrofit projects.

Specifying ventilation – applying the four Cs

There are many factors to be considered when specifying ventilation. The BSI document Moisture in Buildings[2] identifies four sets of principles for managing moisture risks in buildings, known as the 'four Cs'. These principles, **Context, Coherence, Capacity** and **Caution**, apply equally to ventilation systems. Noise and installation are also important considerations.



Context

A ventilation system should be suitable for the context in which it is installed. IEV and PSV systems are only suitable when the local topography and the building's location, orientation and internal layouts and dimensions allow such systems to be effective. If this is not the case, then neither IEV nor PSV is acceptable, and a different type of system should be specified.

Coherence

It is important that ventilation is treated as a key component of a coherent energy and moisture strategy for a retrofit project, embracing the building fabric, the building services and any renewable energy technologies. The ventilation system should be matched to the characteristics of the building envelope and occupancy, including the levels of insulation and airtightness. It may be appropriate to specify a supply and extract ventilation system with heat recovery (e.g. MVHR), to reduce the heat loss associated with the extraction of warm stale air.

Capacity

Condensation and mould growth in dwellings are often associated with over-occupancy. Intended levels of occupancy are often exceeded, either temporarily or for long periods, so ventilation systems need more than the minimum capacity required by Building Regulations. PAS 2035, therefore, requires ventilation system capacity (ventilation rates) to be calculated in accordance with the guidance in Building Regulations Approved Document F but assuming occupancy equal to the number of bed spaces in the dwelling, i.e. two persons in each double bedroom and one in every single bedroom.

The need for ventilation varies with occupancy and activity (e.g. cooking, bathing, drying laundry) between rooms and at different times of the day. A better approach recommended by The Retrofit Academy is to install capacity to deliver 150% of the minimum ventilation rates specified in Building Regulations Approved Document F, combined with room-by-room demand control (see below) to ensure that ventilation is only provided when and where required, to maintain energy efficiency.

2. For the four Cs, see May N. and Sanders, C. Moisture in Buildings: an integrated approach to risk assessment and guidance,BSI, London.

Caution

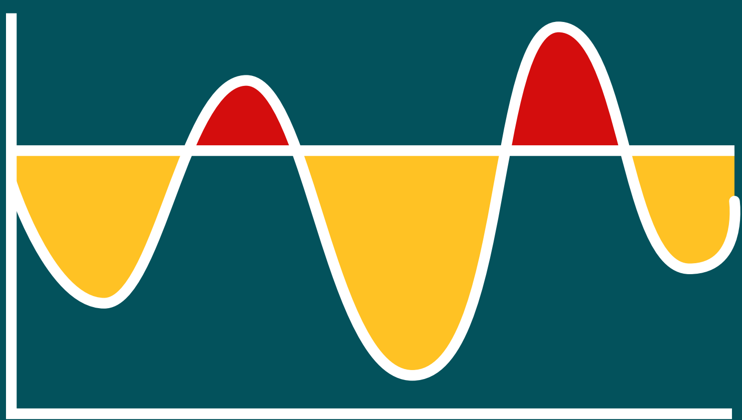
Ventilation systems that may carry perceived and unquantified moisture risks should not be specified. PIV systems slightly pressurise the interior of homes, and can drive warm moist air through gaps and crevices into cold parts of the construction, and into construction voids (e.g. beneath floors), with a consequent risk of condensation, mould growth and rot, out of sight of residents. Therefore, The Retrofit Academy and the UK Centre for Moisture in Buildings both recommend that PIV systems are not installed in dwellings until these risks have been properly evaluated.

Demand Control

Demand controlled ventilation is very common in Europe – over three million systems have been installed. It is relatively new to the UK but is beginning to set the standard here. Essentially, the ventilation rate, rather than being fixed and constant for all parts of the dwelling, is varied in accordance with demand, in the same way that a heating system responds to the internal temperature sensed by a room thermostat.

The demand for ventilation is variable because occupants come and go from the home, move between rooms and change from one activity to another – sleeping, sitting, exercising, cooking, showering, doing laundry, etc. Moisture and carbon dioxide are generated by respiration, and all these activities give rise to different levels of relative humidity and carbon dioxide concentration, in different parts of the home at different times. Demand-controlled ventilation usually senses and responds to relative humidity (RH), although some systems sense and respond to carbon dioxide concentration or even concentrations of VOCs. Without demand control, a system that delivers a constant rate of ventilation will nearly always under-ventilate or over-ventilate.

Figure 10 **Varying ventilation demand (curved line) compared with constant 'flat rate' ventilation (straight line), without demand control. The yellow area indicates over-ventilation, the red area indicates under-ventilation. With demand control, the ventilation rate tracks the curved line. (Diagram courtesy of Aereco)**



PSV systems that include RH sensitive background ventilators and RH sensitive air extract grilles in wet spaces are demand-controlled. Some dMEV fans incorporate RH sensors that speed up the fan (to provide a higher ventilation rate) when the RH reaches 65% - this is a crude form of demand control: when the kitchen or bathroom become steamy, the ventilation rate will increase temporarily.

The best-known example of a demand-controlled ventilation system is the cMEV system supplied by Aereco. This system has three key components: RH sensitive air inlets for use in living spaces and bedrooms (there are window-mounted or through-the-wall options); RH sensitive air extract grilles in wet rooms; and a constant pressure fan that responds to the opening and closing of the air inlets and extract grilles, thus varying the overall ventilation rate to match the aggregate demand of the individual spaces. RH sensitivity is achieved by opposing a tempered nylon strip to a spring in each device, which opens and closes the aperture, so the system works without electrical connections between devices, and can be commissioned simply by checking and adjusting the fan pressure. The Aereco system varies the ventilation rate continuously between RH 35% (minimum ventilation) and RH 65% (maximum ventilation).

Noise

Research shows that the most common mode of failure of domestic ventilation systems, across Europe, is being switched off by residents. The noise draws the attention of residents to the ventilation system, which they often then perceive as also creating draughts, using electricity and costing them money (although modern ventilation systems are very inexpensive to run).

Therefore PAS 2035 specifies that the maximum acceptable noise level when a ventilation system is working at its background capacity shall be 30 dBLAeqT in habitable rooms. Ventilation system designers should take account of the acoustic data provided by fan manufacturers to ensure that system noise levels are acceptable and do not cause annoyance to occupants. Noise levels lower than specified above might be desirable in bedrooms, and higher noise levels might be acceptable in less sensitive rooms, such as kitchens and some bathrooms (not adjacent to bedrooms). Noise levels should be measured as specified in BS 8233 and in accordance with the guidance in Building Regulations Approved Document F.

The quietest of the ventilation options is a cMEV system, provided that it is well-designed and installed.

Installation

Some ventilation system manufacturers lose interest in their products as soon as they leave the factory gates on the back of a truck. Yet most problems with ventilation are related to system design and specification, installation, commissioning, handover and maintenance, or some combination of these. Poor design, installation, commissioning, handover and maintenance are known to be factors associated with the failure of ventilation systems to perform as expected.

The only formal training for ventilation system installers (apart from manufacturers' in-house training on their own products) is a two-day course run by NICEIC. Some ventilation suppliers (e.g. Envirovent) will only allow their systems to be designed, installed and commissioned by their own in-house teams. Others (e.g. Aereco) provide a design service and only allow installation and commissioning by contractors trained and approved by them. In both of these examples, the installation arrangements are linked to extended warranties for the installed systems.

Because failure of ventilation systems is a common feature of retrofit projects, The Retrofit Academy recommends that great care is taken over the selection, design and specification of a ventilation system, the procurement of installations, commissioning and maintenance. Specifications should always require capacity calculations and commissioning certificates to be supplied for every system, to confirm that the intended ventilation rates are achieved in practice. Occupants should always be advised about how to use the systems, and about maintenance requirements. The Academy also recommends only using ventilation system suppliers who engage with and take some responsibility for the design, installation and commissioning processes, and who offer warranties.

THE
RETROFIT
ACADEMY

THE RETROFIT ACADEMY

info@retrofitacademy.org

www.retrofitacademy.org