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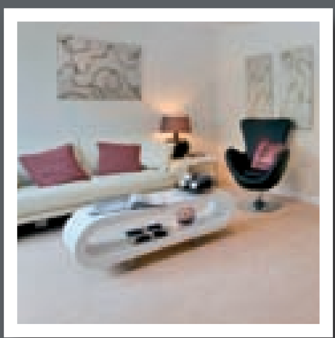

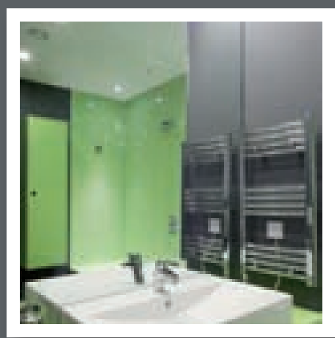

MECHANICAL VENTILATION WITH HEAT RECOVERY IN NEW HOMES

INTERIM REPORT

VENTILATION AND INDOOR AIR QUALITY TASK GROUP

January 2012

Housing research in partnership with BRE Trust

Zero Carbon Hub

The Zero Carbon Hub was established in the summer of 2008 to support the delivery of zero carbon homes from 2016. It is a public/private partnership drawing support from both Government and the Industry and reports directly to the 2016 Taskforce.

The Zero Carbon Hub has developed five workstreams to provide a focus for industry engagement with key issues and challenges:

- Energy Efficiency
- Energy Supply
- Examples and Scale Up
- Skills and Training
- Consumer Engagement

To find out more about these workstreams, please visit www.zerocarbonhub.org.

If you would like to contribute to the work of the Zero Carbon Hub, please contact info@zerocarbonhub.org

This report is available as a PDF Download from **www.zerocarbonhub.org**

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NHBC Foundation

The NHBC Foundation was established in 2006 by NHBC in partnership with the BRE Trust. Its purpose is to deliver high-quality research and practical guidance to help the industry meet its considerable challenges.

Since its inception, the NHBC Foundation's work has focused primarily on the sustainability agenda and the challenges of Government's 2016 zero carbon homes target. Research has included a review of microgeneration and renewable energy techniques and the groundbreaking research on zero carbon and what it means to homeowners and housebuilders.

The Zero Carbon Hub is grateful to the NHBC Foundation for its support in the dissemination of the guidance arising from this consultation.

Further details of the latest output from the NHBC Foundation can be found at www.nhbcfoundation.org

Cover images
left: Brookwood Farm. courtesy William Lacey Group
centre: Greenwatt Way. courtesy SSE
right: Cub. courtesy Cub Housing Solutions

Foreword

Recent revisions to Approved Document L (Conservation of fuel and power) have targeted reductions in CO_2 emissions from the operation of buildings as part of national greenhouse gas reduction policy now enshrined in the UK's Climate Change Act and the current Carbon Plan. At the same time as encouraging the reduction in energy loss due to air infiltration, through Approved Document L, revisions to Approved Document F (Ventilation), on the provision of controlled natural ventilation and mechanical ventilation, have sought to make sure that indoor air quality is not compromised.

In dwellings, as the UK moves forward to meet the 2016 Zero Carbon target, we have limited feedback from the impact of the 2010 Parts L and F revisions but it now appears the compliance calculations are leading increasing numbers of house builders towards greater airtightness in fabric and mechanical systems for ventilation. At the same time, there is increasing scientific awareness of the behaviour of potentially polluting materials and substances in the indoor environment and some of our European neighbours are looking to control these pollutants at source.

Our Task Group was convened following the Zero Carbon Hub's 2009 Report on Recommendations for a Fabric Energy Efficiency Standard (where recommendations deliberately equated to a set of construction options where mechanical ventilation was not a necessary requirement for compliance), and on the threshold of further proposed revisions to Approved Document L in 2013. Our Group comprises a broad cross section of industry practitioners and academics, and we believed it was timely to consider feedback from UK and international research and from built examples of relevant domestic developments, as well as current knowledge of source control. Our concerns were also articulated by the 2010 Innovation and Growth Team's Low Carbon Construction report, which included two recommendations on indoor air quality and health and wellbeing of occupants.

This Interim Report makes recommendations for changes needed to ensure that whilst delivering energy benefits, our homes deliver a healthy internal environment.

I am most grateful to members of the Task Group and colleagues who have contributed to this report.

Lynne Sullivan, OBE

Chair, Ventilation and Indoor Air Quality Task Group

Greenwatt Way, Slough

A number of key projects are contributing to a better understanding of the performance of MVHR, including the SSE's Greenwatt Way development in Slough.
Image courtesy SSE

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The Task Group offers special thanks to Derrick Crump, Institute of Environmental Health, Cranfield University, for authoring Chapter 6 on Source Control and to Veronica Brown, Institute of Environmental Health, Cranfield University for collation of references on emissions from building and consumer products.

Contents

1 Executive summary

Background

Higher standards of airtightness Tackling the loss of heat through unintended (adventitious) ventilation has become one of the principal challenges for the house-building industry in recent years. Successive changes to Approved Document L of the Building Regulations (setting more ambitious energy and CO_2 targets), more strictly defined ventilation provisions introduced through Approved Document F and the introduction of mandatory sample air permeability testing have all encouraged homes to be built to a higher standard of airtightness. The positive effects that improved airtightness should deliver on energy efficiency and reduction of CO_2 emissions do, however, need to be balanced against the potential for reduction in indoor air quality. The Ventilation and Indoor Air Quality (VIAQ) Task Group was set up to address these concerns.

The trend towards MVHR The transition towards airtight homes means that purpose-provided ventilation is now more necessary than ever before. Approved Document F was revised in 2010 specifically to cater even for homes that are completely airtight and which would need larger purpose-provided ventilation openings, with the potential to cause substantial heat loss. For this reason, ventilation options that are able to recover heat from the outgoing ventilation (exhaust) air have an obvious attraction. The Task Group came to the view that the current trend towards mechanical ventilation with heat recovery (MVHR) will continue and it is likely to become the dominant form of ventilation in new homes. For this reason, the Task Group's discussions did not consider other forms of ventilation allowable under Approved Document F.

Indoor air quality (IAQ) Appropriate indoor air quality can be defined as the absence of air contaminants/pollution which may impair the comfort or health of building occupants and a principal reason for the ventilation required by Approved Document F is to control chemical, physical or biological contaminants in the air that people breathe. Those contaminants that may be present in homes include moisture, combustion by-products, emissions from building materials and furnishings, allergens including mould spores and particulates from cooking and cleaning products.

Health Previous desk research by the NHBC Foundation in 2009 identified a range of studies from the UK and other countries which point to a link between IAQ and health of occupants. The health effects include a range of serious conditions such as allergic and asthma symptoms, lung cancer, chronic obstructive pulmonary disease, airborne respiratory infections, cardiovascular disease. The report also noted the prevalence of 'sick building syndrome', symptoms of which include respiratory complaints, irritation and fatigue.

Amongst the conclusions of a subsequent report by the World Health Organisation is that *'sufficient epidemiological evidence is available from studies conducted in different countries and under different climatic conditions to show that the occupants of damp or mouldy buildings, both houses and public buildings, are at increased risk of respiratory symptoms, respiratory infections and exacerbation of asthma. Some evidence suggests increased risks of allergic rhinitis and asthma'.*

The VIAQ Task Group considered that evidence does exist to support a strong connection between poor indoor air quality and a variety of undesirable health consequences. Whilst there may not yet be sufficient evidence to make a direct connection as to the direct effects of specific pollutants and specific health consequences, it is considered appropriate to adopt the precautionary principle and take measures to ensure good IAQ in new homes.

Existing studies The Task Group also looked for existing studies of IAQ in homes and was able to find very limited evidence from the UK. Only a few homes built to contemporary standards of airtightness have been studied in the UK but, worryingly, these studies identified high levels of relative humidity and nitrogen dioxide in a significant minority of the homes surveyed and high total volatile organic compound levels in over half of the homes. Evidence from other countries was also reviewed and the Task Group concluded that many pollutants are present within the internal environment of homes and that these tend to be at their highest in new homes or homes that have been recently refurbished.

Controlling pollution at source

Building materials The materials used to construct homes can, themselves, give rise to contaminants and Section 6 deals with source control – reducing the emissions from building materials. Although this is a topic which is specifically not addressed by current Building Regulations in the UK, the report identifies a range of existing schemes within Europe, the USA, Japan and Korea which are generally adopted on a voluntary basis (with the notable exception of mandatory schemes in Germany and France), focused primarily on volatile organic compounds.

ECPD Work is progressing through the European Construction Products Directive covering emissions from construction products to indoor air and ultimately products will be labelled with their class of performance. The VIAQ Task Group considers this to be a welcome medium-term step that has the potential to reduce one part of the emissions that occur within homes.

MVHR

Performance Evidence from a few studies points to the fact that, working correctly, MVHR is able to have a positive effect on IAQ and health, but clearly this can only be expected to be realised in practice if the system is functioning correctly. The Task Group considers that examples of failures in typical design, installation and commissioning practice are all too common and these will have the effect of reducing the performance of systems. Badly performing systems may not deliver the anticipated carbon savings and may result in degraded IAQ with related consequences for health.

Controls and maintenance The Task Group noted that although good control is essential to the correct operation of systems, good practice in the design and provision of controls is uncommon. Clearly this needs to be addressed. Realising good performance throughout the life of systems also requires that maintenance is undertaken in accordance with manufacturers' requirements. In this regard the Task Group noted that many systems have been installed in locations, such as roof spaces, where access for user-maintenance is restricted. It also noted anecdotal reports that a market for replacement filters does not exist at present, which suggests that even basic maintenance is not being undertaken, possibly because users are not aware of the requirement for it.

2 Interim recommendations

2.1 Build a better base of evidence on the installed performance of MVHR Systems

The Task Group is concerned at the lack of monitoring data that exists for MVHR systems. This is a serious issue, given the expectation that these are expected to become the dominant form of ventilation, for new homes. Further evidence of their effects on indoor air quality and carbon emissions must be gathered as an urgent priority.

2.2 Develop a robust approach to MVHR

The transition towards MVHR must be supported by a significant change to present practice that has been shown to be lacking in many respects. The following issues must be addressed in particular:

Design

System design It is essential that the original design is undertaken by a competent individual in accordance with manufacturers' guidance and established good practice and that any proposals for re-design that may arise during construction are subject to proper approval by the system designer.

Type of unit Care needs to be taken to ensure that the MVHR unit selected for the home is suitable for the specific home.

The Passivhaus Institute sets detailed standards for components that can be deemed 'Passivhaus suitable components' covering a range of issues including efficiency, hygiene and acoustic performance. An assessment should be made of these standards to establish their suitability for general application (in whole or in part) as minimum standards for general application in the UK.

Location of MVHR unit Careful consideration needs to be given to the location of MVHR units and ductwork. Issues to be taken into account include the following:

- easy access to the MVHR unit is necessary to allow for filters to be changed by the occupants and for servicing and repair
- for maximum efficiency the MVHR unit and ductwork should be located within the insulated envelope of the home
- if located in unheated spaces both the MVHR unit and ductwork should be insulated to a similar standard as the envelope of the home
- the two outside ducts should be kept short and they should be fitted with vapour-proof insulation to minimise condensation risk
- if an insect filter is fitted to the intake it must be accessible for periodic cleaning/replacement.

To ensure efficiency of operation and access it is important that these issues are considered at the earliest stages of design with homes being designed around the ventilation system. It is unlikely that the loft will provide a preferred location in most cases, although other options may be more limited in smaller homes.

Noise The system should be designed to minimise noise generated in use. This will include the use of appropriately sized ducts and, where appropriate, suitable mountings for the MVHR unit.

Controls All MVHR systems should be fitted with indicators that show they are working, and whether they are in normal or boost and/or bypass mode. There should be a clear indication, preferably both visual and audible to show when the unit is not working and when maintenance is needed.

Appropriate, simple user controls should be provided in sensible, accessible locations (e.g. not tucked away awkwardly inside a cupboard). They should be easy to use, and clear and intuitive for occupants. The controls should encourage the selection of the correct operation for different external weather conditions; for example summer bypass and frost protection.

Advanced sensing controls (demand control ventilation) would appear to offer great potential for maximising energy efficiency while ensuring that good IAQ is maintained. This may fit into a 'smart homes' approach to controlling homes' services. However more evidence is needed to prove that the apparent benefits can actually be delivered in practice.

Consideration should be given to the desirability of requiring automatic operation of the boost mode when cooking appliances are in use, particularly when gas cooking appliances are installed in a home.

Installation

High standards of installation must be achieved for systems to work efficiently and safely. The installation should comply with the design and must ensure that units are installed with the unit appropriately located and mounted and the ductwork correctly routed and connected. Condensate drainage must be installed to the correct falls and where connected to the soil and vent pipe a (dry) self-sealing waste trap should be provided. Ductwork should generally be of rigid material, with flexible ducting being used only where indicated in the design. Insulation should be provided as shown in the design. Care should be taken to ensure that the correct types of grilles are used for inlet and outlet terminals. As noted above, any proposals for re-design that arise during construction should be subject to proper approval by the system designer.

Commissioning

Evidence suggests that commissioning is a common area of weakness, although it is essential for correct functioning of systems. The commissioning procedure should be undertaken in accordance with the recommendations of the Domestic Ventilation Compliance Guide and it is essential that it is done by a competent person.

User advice

User instructions currently issued with new MVHR units do not generally seem to be targeted at typical users. These should be developed to give simple clear guidance on operation and include advice on summer and winter operation. Guidance should be given on issues such as opening windows and there should be unambiguous instructions for maintenance.

How this can be achieved

Although the Domestic Ventilation Compliance Guide includes much useful and relevant guidance, the Task Group considers that it lacks clarity because it deals with all four types of ventilation system. The guidance is text-heavy and contains no useful images. The guidance should be redrafted to take account of the recommendations in this report.

One or more competency schemes are needed to cover the implementation of MVHR through from design to commissioning. The BEAMA scheme (see Appendix) appears to include many of the key attributes. It is essential that scheme(s) are robust and incorporate appropriate levels of surveillance.

2.3 Source control

Improving the control of emissions at source would appear to be an obvious step towards improving indoor air quality in general. It therefore seems anomalous that Building Regulations currently provide so little guidance in this area.

Consideration should be given as to how Building Regulations and other mechanisms could be used to guide builders and consumers towards selecting products that have been assessed as having low emissions.

3 Background

Increasingly stringent air permeability standards have become a key element in achieving high energy efficiency, low carbon homes. Concerns raised in relation to whether the internal environment of homes may be adversely affected by the drive towards better airtightness led the Zero Carbon Hub and the NHBC Foundation to commission the report *Indoor air quality in highly energy efficient homes – a review* **(1)**. Published in July 2009, the report summarised the existing research and confirmed the need for further work in this field.

As a result, the Zero Carbon Hub set up the Ventilation and Indoor Air Quality (VIAQ) Task Group to review the existing evidence and consider the associated issues in detail. The Task Group is chaired by Lynne Sullivan, OBE, Chair of the Building Regulations Advisory Committee Part L Working Party and members were selected (page 3) to represent the broad range of interests involved.

The VIAQ Task Group first met in September 2010 and its work is scheduled to conclude with a final report in 2012. This report is a summary of interim findings and recommendations.

An early decision of the Task Group was that the scope of its work would not extend into thermal comfort or overheating, a phenomenon that appears to be growing in significance for highly insulated and airtight energy efficient new homes. This decision was in line with the distinction made in Approved Document F **(2)** between the ventilation needed for the removal of 'stale' indoor air from a building and its replacement with 'fresh' outside air (which is within its scope) and the ventilation needed as a means to control thermal comfort, which is not.

Although the Task Group recognised the need for work in the area of overheating it was not considered to be within scope and resources were not available to extend its activity into that area. Other work is however currently underway including a project supported by the NHBC Foundation **(3)** that is aimed at improving the industry's knowledge of overheating. The project, due to report in 2012, is gathering data from incidences of new homes in which overheating has been a problem and considering the health consequences. In parallel, the NHBC Foundation is developing simple guidance on the basic rules that should be followed in the design of new homes to minimise overheating.

4 Introduction

Homes in the UK have not historically been constructed with airtightness in mind and little attention has been paid to designing or constructing homes to minimise air leakage. Traditional features such as open chimneys have combined with leaky construction to ensure that homes were well ventilated, although that came at the cost of thermal comfort and energy efficiency. In general, the issue of indoor air quality was not considered or questioned.

In recent decades, the energy efficiency agenda has focused attention on designing and constructing homes that are more energy efficient and the avoidance of unintended air leakage paths has become a key target in minimising heat loss. The mantra 'build tight and ventilate right' sums up the house builder's challenge – to design and build homes to be airtight and then to purposely provide the necessary ventilation that can be controlled by the occupants.

Targets for air permeability of new homes were introduced into Approved Document L1A to the Building Regulations in 2006 **(4)** and a limiting value of $10m^3/hr/m^2$ at 50 Pa was set. Air permeability testing of a sample of homes was also introduced for the purpose of demonstrating compliance. House builders adapted rapidly to the new requirements and early test results demonstrated that homes could often be built to a far higher level of airtightness than the limiting standards allow.

SAP, the Standard Assessment Procedure **(5)** used to demonstrate compliance with Approved Document L1A, uses the air permeability figure as one of the inputs to determine the home's CO_2 emissions, together with other design aspects such as wall, roof, floor and window insulation values. Already many house builders building to 2006 requirements are choosing to adopt air permeability targets substantially tighter than the limiting value of $10m^3/hr/m^2$ for reasons of practicality and/or cost-effectiveness. And as CO_2 targets become ever more stringent on the journey towards the 2016 zero carbon homes standards, it is expected that designers will routinely adopt air permeability targets of $5m^3/hr/m^2$ and well below.

At low air permeability levels reliance cannot be placed on the ability of the home to ventilate itself – it is very unlikely that homes will normally include features such as cross-ventilation paths or open chimneys, and the minor gaps in the building fabric that would previously have provided adventitious ventilation will no longer be present. The consequence is that reliance will be placed solely on the ventilation provided to satisfy Approved Document F (Means of Ventilation).

4.1 Building Regulations requirements for ventilation

Approved Document F 2010 (ADF 2010) defines ventilation as follows:

'**Ventilation** *is the supply and removal of air (by natural and/or mechanical means) to and from a space or spaces in a building. It normally comprises a combination of* **purpose-provided** *ventilation and* **infiltration**.'

ADF 2010 requires an adequate means of ventilation to be provided for people in buildings and commissioning and testing of fixed ventilating systems and controls. For new dwellings (Figure 1) it describes four systems:

System 1 Background ventilators and intermittent extract fans
System 2 Passive stack ventilation (PSV)
System 3 Continuous mechanical extract (MEV)
System 4 Continuous mechanical supply and extract with heat recovery (MVHR)

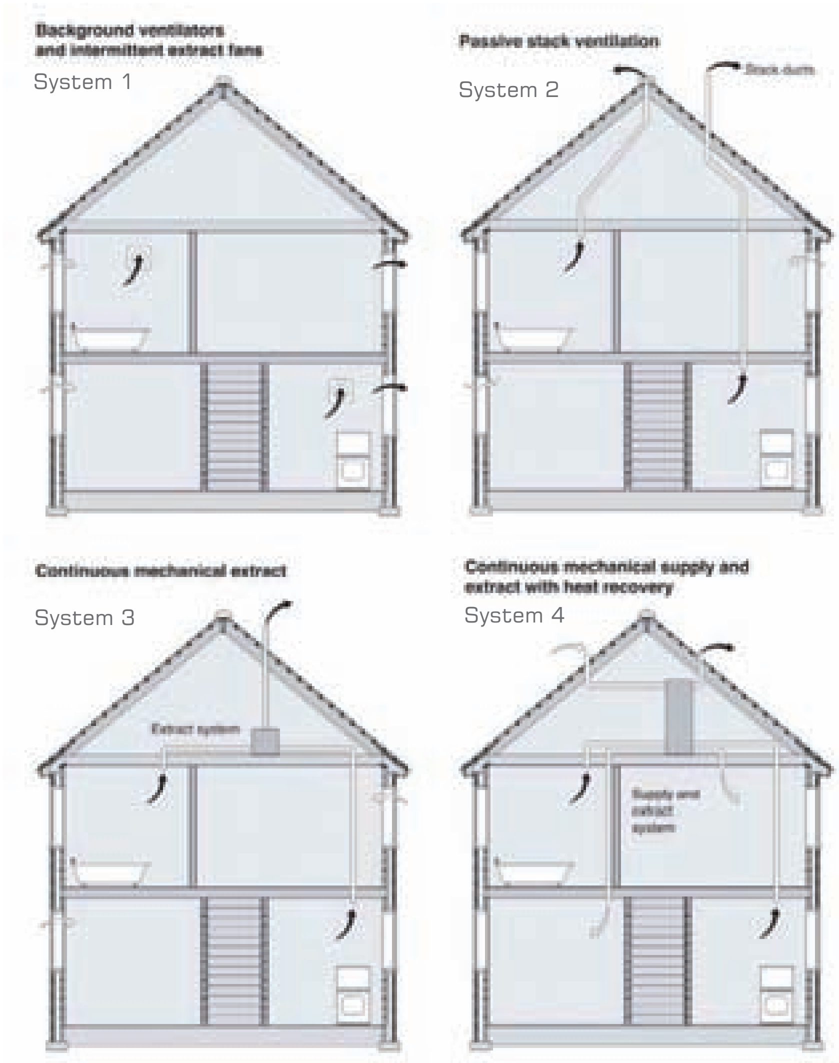


Figure 1 The four systems included in Diagram 2a from Approved Document F, 2010

Because of concerns about ensuring healthy indoor environments and the lack of guidance on source control of pollutants ADF 2010 increased the ventilation provisions for homes with a design air permeability tighter than or equal to $5m^3/hr/m^2$. The following Tables 1, 2 and 3 summarise the requirements for two typical home types with design air permeability less than $5m^3/hr/m^2$. Figures are stated in both square millimetres (mm^2) as per the Approved Document and also square centimetres (cm^2) to help readers visualise the areas needed. For the purpose of comparison an A4 page has an area of 63,000 mm^2/630 cm^2 and a standard postcard, 17,500 mm^2/175 cm^2.

Home type	Background equivalent ventilator area
Ground floor flat with cross ventilation (total floor area $50m^2$, one bedroom)	45,000 mm^2 (450 cm^2)
Ground floor flat with single-sided ventilation (total floor area $50m^2$, one bedroom)	90,000 mm^2 (900 cm^2)
Semi-detached house (total floor area $88m^2$, three bedrooms)	60,000 mm^2 (600 cm^2)

Table 1 Requirements for home with ventilation System 1: Background ventilators and intermittent extract fans [design air permeability less than $5m^3/hr/m^2$]

Home type	Background equivalent ventilator area	Passive stack area
Ground floor flat with or without cross-ventilation (total floor area $50m^2$, one bedroom)	29,000 mm^2 (290 cm^2)	6,000 mm^2 (60 cm^2) (two PSV units at 3,000 mm^2 per unit)
Semi-detached house (total floor area $88m^2$, three bedrooms)	51,000 mm^2 (510 cm^2)	9,000 mm^2 (90 cm^2) (three PSV units at 3,000 mm^2 per unit)

Table 2 Requirements for home with ventilation System 2: Passive stack ventilation (PSV) [design air permeability less than $5m^3/hr/m^2$]

Home type	Background equivalent ventilator area
Ground floor flat (total floor area $50m^2$, one bedroom)	5,000 mm^2 (50 cm^2)
Semi-detached house (total floor area $88m^2$, three bedrooms)	12,500 mm^2 (125 cm^2)

Table 3 Requirements for home with ventilation System 3: Continuous mechanical extract (MEV) [design air permeability less than $5m^3/hr/m^2$]

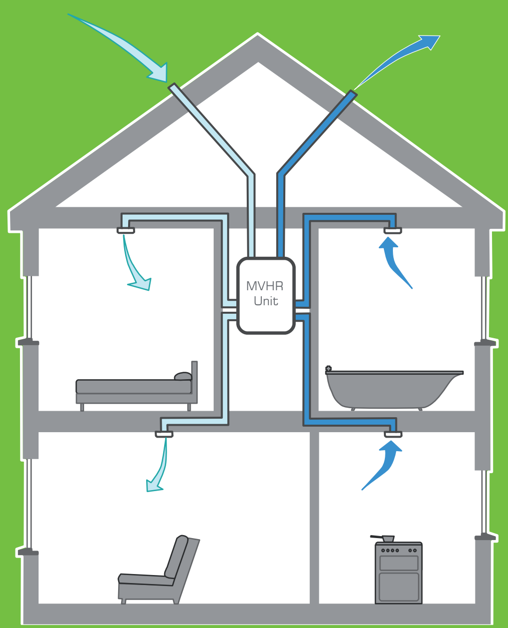
As homes become more airtight and insulation standards improve, the relative significance of ventilation as a source of heat loss increases and features such as additional insulation or solar panels will need to be provided to compensate for the ventilation heat loss.

An alternative to Systems 1 to 3 is System 4: Continuous mechanical supply and extract with heat recovery (more commonly known as 'mechanical ventilation with heat recovery' or 'MVHR'). Ventilation is provided by means of a ducted system where incoming ventilation air is pre-warmed by means of a heat exchanger that extracts heat from the outgoing exhaust air. Amongst the advantages of MVHR is that the only ventilation openings through the building fabric are for the inlet and outlet ducts.

Properly specified, in airtight homes, the provision of MVHR can be beneficial in terms of the SAP assessment because the ventilation heat loss is assumed to be minimised. For this reason, as the industry moves towards the zero carbon homes target, it is would appear highly likely that MVHR will become the dominant ventilation system in the majority of new homes. Indeed, MVHR has already established itself as a standard part of homes built to the Passivhaus standard (6). For this reason this report deals exclusively with MVHR, although some of the observations made in this report will apply regardless of the type of ventilation system that is used.

Mechanical ventilation with heat recovery

MVHR is a multi-room ducted system that combines supply and extract ventilation in one solution. It continuously provides fresh air to habitable rooms whilst pre-warming it with recovered heat from the extract air which would otherwise have been vented outside and therefore lost.



Warm moist air is extracted from wet rooms such as bathrooms and kitchens through ductwork to a central unit. Supply ventilation air from outside the home is passed through a heat exchanger in the central unit by the heat in the extract air. MVHR systems are able to recover around 90% of the heat that would otherwise be lost (measured in accordance with the 2005 SAP Appendix Q test). The warmed air is then distributed throughout the home by ductwork and diffusers at ceiling level ensure that draughts are avoided.

The system runs most of the time at a low background rate but when more rapid ventilation is required because of increased moisture generation, such as showering or cooking, the system is switched to a boost rate, either manually or by sensor control.

5 Indoor air quality

5.1 What is indoor air quality?

According to Crump *et al* [1] appropriate IAQ can be defined as the absence of air contaminants/pollution which may impair the comfort or health of building occupants. Indoor air pollution can be defined as chemical, physical or biological contaminants in the breathable air inside a habitable building (or other place, such as a car) and can include:

- combustion by products such as carbon monoxide (CO) and nitrogen dioxide (NO_2)
- ozone
- allergens including mould spores
- chemical emissions or particulates from building materials finishes or furnishings
- cleaning products, personal care products, air fresheners and pesticides used indoors
- tobacco smoking, hobbies, cooking, and other occupant activities as well as dry cleaned clothes
- bioeffluents (from respiration of occupants and pets)
- ground gas intrusion including radon.

Table 4 on page 16 (from [1]) summarises the main sources and types of pollutant: the principal ones are considered in more detail below.

Formaldehyde, a very volatile organic compound (VVOC), and **Volatile organic compounds** (VOCs) are emitted over weeks or years from new building products, furnishings and consumer products such as computers and printers. They are also present in cleaning products and air fresheners. Vinyl floorings and paints can also be a source of semi-volatile organic compounds (SVOCs). VOCs are at the highest levels in new homes (Bone *et al.* 2010 [7]).

Tobacco smoke contains a complex mixture of organic compounds and remains a significant source of airborne pollution in many homes.

The principal sources of **inorganic pollutant gases** in indoor air include the combustion of fuel (mainly from open flued or flueless gas appliances, including cookers) and respiration by occupants.

Carbon dioxide (CO_2) is a natural constituent of air, which is normally harmless. It is present in buildings at higher concentrations than outdoors, due to respiration and as a product of combustion. **Carbon monoxide** (CO), a poisonous gas, can be produced by heating and cooking appliances where there is incomplete combustion. These appliances are also the main sources of nitrogen oxides (NO_x, including NO_2).

Source	Main air pollutants
Outdoor air	SO_2, NO_x, ozone, particulates, biological particulates, benzene
Combustion of fuel	CO, NO_x, VOCs, particulates
Tobacco smoke	CO, VOCs, particulates
People	CO_2, organic compounds
Building materials	VOCs, formaldehyde, radon, fibres, other particulates, ammonia
Consumer products	VOCs, formaldehyde, pesticides
Furnishings	VOCs, formaldehyde
Office equipment, including HVAC	VOCs, ozone, particulates
Bacteria and fungi	VOCs, biological particulates
Contaminated land	Methane, VOCs, contaminated dusts eg metals
Ground	Radon, moisture
Washing and cleaning	Moisture
Animals (e.g. mites, cats)	Allergens

Table 4 Sources and types of indoor air pollution

Ozone is produced by a natural photochemical reaction in the upper atmosphere where it has a beneficial effect, but it is also formed as a component of smog in polluted atmospheres and is then a risk to health. As well as entering buildings as a component of polluted outdoor air, it can be created by electrical equipment and it can react with internal surfaces and other airborne pollutants to create new compounds and ultrafine particles.

Moisture in the air has a direct effect on health and comfort and is also important to the occurrence of biological agents (e.g. mould and dust mites). For comfort and for breathing comfort indoor air should neither be too moist nor too dry.

Particulates can be generated by mechanical processes such as cleaning and the physical activity of occupants, as well as from smoking tobacco, combustion, and cooking. They can be of biological origin, such as the faecal pellets of the house dust mite, spores or hyphal fragments of surface moulds and yeasts, bacteria and pollen as well as allergenic particles from pets and pests (e.g. cockroaches). Particulates can be generated indoors or come from outdoor sources, such as pollen or diesel fumes from transport.

Radon, a naturally occurring radioactive gas can enter buildings from the ground, dependent on the geology, the construction type and the presence of effective radon protection measures such as gas proof membranes. Other ground gases may be present, particularly on land contaminated by historic uses.

5.2 Indoor air quality and health

Many research studies point to a link between indoor pollution and adverse effects on human health with symptoms ranging in severity from perception of unwanted odours through to cancer.

NHBC Foundation review 2009

In summary below are highlighted some recent studies reviewed by Crump et al (1) in the NHBC Foundation report NF18:

EC The European Commission Scientific Committee on Health and Environmental Risks (SCHER, 2007 (8)) reviewed current approaches to risk assessment of indoor air pollutants. It concluded that indoor air may contain over 900 chemicals, particles and biological materials with potential health effects. They note that concentrations of pollutants are usually higher indoors than outdoors and that people spend most of their time indoors. They recommend a focus on evaluating sources of pollutants and seeking to reduce exposures because of the difficulties of regulating the diverse range of indoor air scenarios. They identify a need for more research including work on exposure, reactions between pollutants, combined and mixture effects, causative factors to explain the link between dampness and health and development of health-based guideline values.

Carrer *et al.* (2009 (9)) reviewed the main studies of indoor air-related health effects and prioritised the following diseases as being caused or aggravated by poor indoor air quality:

- allergic and asthma symptoms
- lung cancer
- chronic obstructive pulmonary disease (COPD)
- airborne respiratory infections
- cardiovascular disease (CVD)
- odour and irritation (sick building syndrome symptoms).

Allergic and asthma symptoms are increasing throughout Europe affecting between 3 to 8% of the adult population with higher prevalence in infants (29–32% in Ireland and UK in 1995/96). According to Asthma UK (10), there are now 5.4 million UK asthma sufferers, which is the highest in Europe as a percentage of the population. The cause of allergic diseases is considered to be a complex interaction between genetic and environmental factors and asthmatic patients are sensitive to allergens present in the indoor environment and are often hyperactive to a number of gases and particles. The following may have a role in the development of allergy and asthma:

- Microbial agents (endotoxin of Gram-negative bacteria, fungal spores and fragments, bacterial cells, spores and fragments, microbial metabolites and allergens including house dust mites, pet allergens and fungal allergens).
- Chemicals (formaldehyde, aromatic and aliphatic chemicals, phthalates or plastic materials, products of indoor chemical reactions involving ozone and terpenes).

Lung cancer is the most common cause of death from cancer in the EU (about 20% of all cases). Most are due to active smoking, but it is estimated that 9% are due to radon exposure in the home and 0.5% in males and 4.6% in females are due to exposure to environmental tobacco smoke. There is some evidence of risk due to combustion particles including PM2.5 (particulates with an aerodynamic diameter below 2.5 μm) in ambient air, and due to diesel exhaust and indoor cooking oil and coal burning.

Chronic obstructive pulmonary disease (COPD) is a chronic respiratory disorder that is usually progressive and associated with an inflammatory response of the lungs to noxious particles or gases. It is estimated that the prevalence of clinically relevant COPD in Europe is between 4 and 10% of the adult population. About 70% of COPD related mortality is attributed to cigarette smoking. Other risk factors identified are environmental tobacco smoke, biomass combustion fumes, particulates in ambient air and long-term exposure to mould/dampness.

Airborne infectious diseases include Legionnaire's disease, tuberculosis, influenza and SARS (severe acute respiratory syndrome). Reservoirs in aquatic systems such as cooling towers, evaporative condensers and humidifiers have been the source of airborne agents in outbreaks of Legionella and pneumonia. Symptoms of these diseases can be aggravated by exposure to ETS and combustion particles.

Cardiovascular disease (CVD) is the leading cause of death in industrialised countries accounting for 42% of deaths in the EU. Causes include exposure to environmental tobacco smoke, particulates, CO and other gaseous pollutants (NO_2 in particular).

Sick building syndrome (SBS) describes cases where building occupants experience acute symptoms and discomfort that are apparently linked to the time spent in the building, but for which no specific illness can be assigned. Symptoms include respiratory complaints, irritation and fatigue.

Jacobs *et al.* (2007 [11]) reviewed knowledge of the links between health and the quality of the indoor environment of homes, and policies in the USA, to address these risks to health. Indoor air pollution is one of the top four health risks identified by the US Environmental Protection Agency (EPA). On average people spend 90% of their time indoors where pollutants may be two to five times higher than outside and occasionally 100 times higher. This pollution is estimated to cause thousands of cancer deaths and hundreds of thousands of cases of respiratory health problems each year. Millions of children have experienced elevated blood levels of contaminants from exposure to indoor pollutants. Other effects include irritation, and more subtle neurotoxicological, behavioural and other adverse effects. The associated economic costs are considerable; the EPA estimating that net avoidable costs in 2001 alone were likely to be between $150 billion and $200 billion.

Mitchell *et al* (2007 [12]) reviewed current knowledge on health effects and indoor environmental quality and suggested:

- a particular need for research on interactions of multiple exposures
- risks to particular vulnerable groups (e.g. children)
- benefits of interventions and trade-offs for ventilation and energy efficiency
- better measurements of dose, particularly for biological agents.

While smoking is the greatest risk factor for lung cancer, causing more than 30,000 cases each year, radon is the second most common cause in the UK and it is estimated, by the Health Protection Agency (2008 [13]), that it causes 2000 cases per year. To protect against this risk, the HPA has recommended that all new properties should incorporate methods to reduce internal levels of radon. They comment that the low ventilation rates common in modern buildings for energy conservation reasons can encourage the build-up of radon gas concentrations indoors.

Mendel (2007 [14]) reviewed 21 research studies that have associated residential chemical emissions from indoor materials and activities with risk of asthma, allergies and pulmonary infections. Risk factors identified most frequently included formaldehyde or particleboard, phthalates or plastic materials, and recent painting. Others such as aromatic and aliphatic chemical compounds were suggestive. Elevated risks were also reported for renovation and cleaning materials, new furniture and carpets or textile wallpaper. It is concluded that while these risk factors may only be indicators of truly causal factors, the overall evidence suggests a new class of residential risk factors for adverse respiratory effects that is ubiquitous in modern residences. If the associations are proved to be causal, Mendel considers it would mean that there is a large-scale occurrence of adverse respiratory and allergic effects in infants and children that is preventable and related to modern residential building materials and coatings, and possibly exacerbated by decreased ventilation.

Fisk *et al*. (2007 [15]) undertook a meta-analysis of 33 studies investigating an association between occurrence of indoor dampness and mould with adverse health effects. This found building dampness and mould to be associated with an approximately 30 to 50% increase in a variety of respiratory and asthma-related health outcomes. The studies included those recording visible dampness and or mould, or mould odour, by investigators or the occupants themselves.

Wargockj *et al.* (2002 [16]). The evidence for the effects of ventilation on health, comfort and productivity in non-industrial indoor environments was reviewed by this multidisciplinary group of scientists. They concluded that ventilation is strongly associated with comfort (perceived air quality) and health (SBS symptoms, inflammation, infections, asthma, allergy, short-term sick leave).

Ventilation rates above 0.5 air changes per hour in homes were found to reduce infestation of house dust mites in Nordic countries.

Venn *et al*. (2003 (17)) investigated the relationship between exposure to some indoor air pollutants and the occurrence of childhood wheezing illness in a study of 410 homes in Nottingham. They reported indoor concentrations of total volatile organic compounds (TVOCs), some individual VOCs, formaldehyde, and NO_2, took measurements of surface dampness and recorded presence of mould. Visible mould was only identified in 11 homes but was significantly associated with an increased risk of wheezing illness. The risk of wheezing was significantly increased by dampness. Among the 193 cases with persistent wheezing, formaldehyde and damp were associated with more frequent nocturnal symptoms.

Osman *et al*. (2007 (18)) measured concentrations of particulates (PM2.5) and NO_x in air and endotoxins in house dust in homes of 148 patients in Scotland suffering from severe COPD. PM2.5 was significantly higher in smoking households and these levels were associated with the poorer health status of the patients.

Niven *et al*. (1999 (19)) reviewed studies that had sought to manipulate the internal environmental conditions to control house dust mites. Reducing humidity appeared to provide some benefits in Scandinavian homes but studies of installing MVHR in British homes had not proved effective against house dust mites. The researchers fitted MVHR units with dehumidification in homes of 10 asthmatics and monitored dust mite allergen in dust over a 15 month period. They also monitored 10 control homes not fitted with MVHR. Average humidity in the bedroom was lower in the MVHR homes but there was no significant reduction in allergen levels.

Further research and information identified

In addition to sources of information presented in the earlier review (1) additional supplementary research has been identified:

World Health Organization (2009 (20)). Problems of indoor air quality are recognised as important risk factors for human health in low- middle- and high-income countries. Indoor air is also important because populations spend a substantial fraction of time within buildings. In residences, day-care centres, retirement homes and other special environments, indoor air pollution affects population groups that are particularly vulnerable due to their health status or age. Microbial pollution involves hundreds of species of bacteria and fungi that grow indoors when sufficient moisture is available. Exposure to microbial contaminants is clinically associated with respiratory symptoms, allergies, asthma and immunological reactions.

The biological indoor air pollutants of relevance to health are widely heterogeneous, ranging from pollen and spores of plants coming mainly from outdoors, to bacteria, fungi, algae and some protozoa emitted outdoors or indoors. They also include a wide variety of microbes and allergens that spread from person to person. There is strong evidence regarding the hazards posed by several biological agents that pollute indoor air; however, the World Health Organization working group convened in October 2006 concluded that the individual species of microbes and other biological agents that are responsible for health effects cannot be identified from current work. This is due to the fact that people are often exposed to multiple agents simultaneously, to complexities in accurately estimating exposure and to the large numbers of symptoms and health outcomes due to exposure. The exceptions include some common allergies, which can be attributed to specific agents, such as house-dust mites and pets.

The presence of many biological agents in the indoor environment is due to dampness and inadequate ventilation. Excess moisture on almost all indoor materials leads to growth of microbes, such as mould, fungi and bacteria, which subsequently emit spores, cells, fragments and volatile organic compounds into indoor air. Moreover, dampness initiates chemical or biological degradation of materials, which also pollutes indoor air. Dampness has therefore been suggested to be a strong, consistent indicator of risk of asthma and respiratory symptoms (e.g. cough and wheeze). The health risks of biological contaminants of indoor air could thus be addressed by considering dampness as the risk indicator.

The report's conclusions include:

- Sufficient epidemiological evidence is available from studies conducted in different countries and under different climatic conditions to show that the occupants of damp or mouldy buildings, both houses and public buildings, are at increased risk of respiratory symptoms, respiratory infections and exacerbation of asthma. Some evidence suggests increased risks of allergic rhinitis and asthma. Although few intervention studies were available, their results show that remediation of dampness can reduce adverse health outcomes
- There is clinical evidence that exposure to mould and other dampness-related microbial agents increases the risks of rare conditions, such as hypersensitivity pneumonitis, allergic alveolitis, chronic rhinosinusitis and allergic fungal sinusitis
- Toxicological evidence obtained in vivo and in vitro supports these findings, showing the occurrence of diverse inflammatory and toxic responses after exposure to microorganisms isolated from damp buildings, including their spores, metabolites and fragments
- While groups such as atopic and allergic people are particularly susceptible to biological and chemical agents in damp indoor environments, adverse health effects have also been found in nonatopic populations
- The increasing prevalence of asthma and allergies in many countries increase the number of people susceptible to the effects of dampness and mould in buildings.

Davies *et al.* (2004 **(21)**) reviewed the literature for evidence of links between ventilation rates in dwellings and moisture related respiratory health with a particular focus on house dust mites and fungal growth. The authors say that there is general consensus that a link exists between ventilation rates in dwellings and respiratory hazards (for example, house dust mites). There is also general consensus of a link between these respiratory hazards and respiratory problems, but it is not clear to what extent hazards cause ill-health. Most existing data are inadequate for conclusions to be drawn as to whether ventilation rates directly cause respiratory problems. Also discussed are the many difficulties in attempting to establish these relationships and the need for larger studies is suggested.

Richardson *et al*. (2005 [22]) reviewed existing literature, finding evidence of a link between asthma and a small number of indoor environmental factors. There is currently only reasonable evidence for one causative factor for asthma in the indoor environment and that is house dust mite allergen. Although there is a lack of medical evidence for reducing the high number of known sensitisers, such as mould, this is because of a dearth of research rather than evidence of no association.

As well as changes to the airtightness of homes, this paper stresses that activities within the home have changed. Housecleaning routines predominantly use vacuum cleaners and a variety of chemical-based cleaning agents, adding to the environmental burden indoors. A good quality indoor environment is important because most people spend more than 90% of their time indoors, and more than half of this time at home.

The University of Chicago (2003 [23]) stated "clear evidence" that poor air quality contributes to negative effects on those suffering with asthma with annual direct health costs of $9.4billion. In 2000, asthma cases were responsible for nearly 2 million emergency room visits at a cost of almost $2billion & nearly 13 million lost school days.

The US Institute of Medicine (2011 [24]) identified extensive scientific literature on the effects of poor indoor air quality, damp conditions, and excessively high or low temperature on human health. Epidemiologic literature reviewed by the committee indicates that pollution intrusion from the outdoors, emissions from building components, furnishings and appliances, and occupant behaviours introduce a number of potentially harmful contaminants into the indoor environment. Dampness problems in buildings are pervasive, and excessive indoor dampness is a determinant of the presence or source strength of several potentially problematic exposures, notably exposures to mould and other microbial agents and to chemical emissions from damaged building materials and furnishings. Damp indoor environments are associated with a number of respiratory and other health problems in homes, schools, and workplaces. Extreme heat has several well-documented adverse health effects. The elderly, those in frail health, the poor, and those who live in cities are more vulnerable to exposure to temperature extremes and to the effects of exposure. Those population groups experience excessive temperatures predominantly in indoor environments.

Less information is available on the effects of adverse indoor environmental conditions on the productivity of workers and students. Available studies indicate that inadequate ventilation is responsible for higher absenteeism and lower productivity in offices and schools. Indoor comfort is also important: experiments suggest that work performance and school performance decrease when occupants perceive that a space is too warm or cool or the ventilation rate is too low.

Based on the research studies reviewed, there seems little doubt that poor IAQ is associated with a variety of undesirable health effects. Although it is suggested that further research would be needed in order to reach a full understanding of the direct links of specific pollutants, the precautionary principle should be adopted and measures taken to ensure good IAQ in new homes. The need to do so may be even greater in homes that are occupied by infant, elderly and/or frail people.

5.3 Indoor air quality in homes

The NHBC Foundation report NF18 [1] describes various national studies which have measured the indoor air quality in homes. Some of those studies are briefly summarised here.

UK No published studies of IAQ in highly energy efficient homes have been identified. However studies of homes which have not been built to high energy efficiency standards (and are therefore less airtight) have shown high VOC levels in some cases, with newer homes tending to have higher levels than other homes. A study of homes with gas cooking was identified where high levels of CO and NO_2 were encountered.

Since the publication of the Indoor air quality review [1], *Ventilation and Indoor Air Quality in Part F 2006 Homes* [25] has been published by CLG. Based on a small-scale study of 22 occupied homes built to comply with Approved Documents L and F (2006), it found that 4 homes were likely to be at risk of high relative humidity, 4 homes which exceeded recommended NO_2 levels and over half the homes exceeded recommended total VOC (TVOC) levels.

Canada NRC-IRC (2008 [26]) refers to increasing concerns about the effectiveness of mechanical ventilation systems to provide acceptable IAQ and large gaps in knowledge about the correlation between IAQ and the health of occupants. This has led to a new study of 100 homes occupied by families with asthmatic children in Quebec. Over a three year period modifications will be made to the ventilation and air distribution systems to improve IAQ and a follow-up study will be undertaken to assess any changes in IAQ and health.

Another study monitored 20 homes, 16 of which were constructed to the R-2000 improved energy efficiency standard. Elevated formaldehyde levels were recorded, particularly where ventilation systems were not operated as intended.

Sweden In a study of VOC levels in 178 randomly selected residential buildings in 2000 [27] about 120 individual VOCs were identified and of these 27 had a mean concentration above 10 $\mu g/m^3$. The mean TVOC concentration was 350 $\mu g/m^3$ and the concentration of formaldehyde alone was 12 $\mu g/m^3$.

Japan Yoshino *et al.* (2006 [28]) identified homes with high levels of VOCs. Concentrations were higher in new homes and homes following refurbishment, in those with high airtightness and low air change rates, and where there was new furniture or where moth crystals were used.

Saijo *et al.* (2004 [29]) measured VOCs in 96 dwellings and found concentrations of some individual VOCs and the sum of the concentrations significantly related to health symptoms of residents. They also found that dampness was significantly related to health symptoms.

Takeda *et al.* (2009 [30]) studied health symptoms in 343 residents in 104 newly built homes and found sick house symptoms in 21.6% of the dwellings. The research found a statistically significant link between formaldehyde, dampness and alpha-pinene concentration and symptoms.

Korea A study of 848 new apartments revealed VOC concentrations above guideline values. A separate study found that concentrations increased after occupancy due to emissions from furniture in particular. Cheong (31).

Denmark In addition to the studies referred to above from the previous UK review (1), we have subsequently identified a Danish study (32) measuring the energy performance and indoor environmental quality in 10 Passivhaus homes fitted with MVHR which met target levels of relative humidity and CO_2.

In conclusion, based on the information reviewed, many pollutants are commonly present within the internal environment of homes. Many of these are at their highest levels in new homes and homes that have been newly refurbished. Some of the studies also provide further significant evidence of a correlation between IAQ and health symptoms.

Brookwood Farm, Woking

William Lacey adopted MVHR as part of the energy strategy for its award-winning Brookwood Farm development. Image courtesy William Lacey Group

6 Source control

6.1 Introduction

Table 4 in Section 4 listed the wide range of types of pollution impacting on indoor air quality and their sources. These can be categorised as outdoor and indoor sources. Outdoor air is used for ventilation and therefore forms the baseline for the quality of air entering the building. Its quality depends upon local and regional sources of pollution and the effectiveness of control measures such as catalytic convertors for motor vehicle engine exhausts and flue gas cleaning. Levels of some pollutants such as benzene, nitrogen dioxide and particulates (PM10) are regulated under the European Ambient Air Quality Directive **(33)** as well as UK legislation and monitoring networks provide information about prevailing concentrations and are used by government authorities to issue public warnings of high pollution episodes.

As ambient pollution levels vary on both a regional and local scale then the location of a building is an important aspect determining the quality of the surrounding outdoor air. Building design can minimise the entry of pollutants and for example may involve the siting of the building (away from pollution sources), placement and design of ventilation provision (away from pollution sources such the nearest busy road) and use of filtration in MV systems, most commonly for removal of particulates, although other vapours and gases could potentially be removed but at higher cost.

As well as pollution of the ambient air it is possible that soil gas beneath the building contains hazardous substances; these may be of natural origin such as radon released by the bedrock or be contaminants such as organic chemicals present because of previous historic uses of the site or neighbouring land (Crump *et al* 2004 **(34)**). Design measures such as impermeable membranes in the floor structure to prevent radon and other contaminants entering the building should be applied as a control measure in these circumstances. The Building Regulations provide advice on design measures to minimise ingress of both polluted ambient air (Approved Document F **(2)**) and ground pollutants, including moisture, (Approved Document C **(35)**). They also require appropriate works to prevent foul air from drainage systems entering the building (Approved Document H **(36)**) and ensure adequate air for combustion of fuel in heating appliances and appropriate provision of flues for removal of fumes generated (Approved Document J **(37)**). Therefore these approaches that prevent or minimise entry of pollutants into the living space are important aspects of control of sources of pollution indoors, but they do not address control of sources contained within the living space. With regard to these interior sources there are four main control strategies:

1. Ban particular products or components from use indoors e.g. prohibiting smoking in public places
2. Select products with low or zero emission of pollutants
3. Local ventilation of recognised pollution sources e.g. cookers, shower rooms
4. Adequate general ventilation of occupied spaces.

A further potential tool is air cleaning, involving the filtering of air that may be recycled within the building or room. The systems can range from active systems that treat air within the mechanical ventilation system of the building to devices in individual rooms that may be fixed or stand alone. Also passive products such as wall materials with enhanced properties for absorption of some pollutants are available on the market. These are not widely applied in the domestic dwelling market except for dehumidification, and to some extent airborne allergen control, and are not discussed further in this section.

The banning of particular products or substances within products because of high safety concerns is an effective means of control. Examples include asbestos products, lead in interior paint and the banning of smoking in enclosed public spaces and workplaces. A further aspect is to restrict the use of particular products to prevent applications where the risks of indoor pollution are higher as required by Approved Document D (38) that restricts the use of urea formaldehyde foam wall insulation to cavity masonry walls because of concerns about formaldehyde ingress into the living space in other types of structures. There are of course limitations on the possibilities for banning products, the extreme example being that having no occupants would be useful for source control because people themselves emit pollutants.

Moving from strategy 2 to 4 (of those listed on page 25) has increasing disadvantages with respect to the ability to prevent occupant exposure to pollutants. There is also an increase in the amount of energy required for the control strategy to be effective while still providing appropriate thermal regulation and air flow to achieve occupant comfort and wellbeing. Therefore the optimal strategy to address all pollutants that cannot be addressed by 1 would be to incorporate the maximum use of source control by strategy 2 and then use of 3 and 4 to manage residual sources. Hence the emphasis is on prevention of the pollution rather than removal of pollutants generated.

Arguably the main barriers to the application of strategy 2 has been the lack of knowledge about many sources, combined with a poor general appreciation of the importance of indoor air quality for occupant health and performance during past decades of relatively low energy costs. A general lack of knowledge about existing labelling schemes for low-emitting products among architects and end users in several European countries was reported by Bluyssen *et al.* (2010 (39)). These factors have resulted in a lack of demand for low-emitting products in many countries, including the UK, and therefore the absence of associated pressures to justify development costs and promotion in the market. The current position is summarised in Approved Document F 2010 (2) as follows:

'Source control is not considered within the main guidance of the Approved Document owing to limited knowledge about the emission of pollutants from construction and consumer products used in buildings and the lack of suitable labelling schemes for England and Wales. Some construction products such as glass, stone and ceramics are by their nature low emitters of air pollutants. Currently, some paints are labelled for their volatile organic compound (VOC) content, and some wood-based boards (Class 1, BS EN 13986:2004) are available with low formaldehyde emission. This allows suitable products to be chosen when good indoor air quality is a priority, but at the present time it is not practical to make an allowance for the use of these products in the ventilation requirements. Further

information about control of emissions from construction products is available in BRE Digest 464'.

It is interesting to note that according to the US Environment Protection Agency, the level of pollutants may run two to five times, & occasionally more than a 100 times higher than the outdoors [40]. Preventing indoor air quality problems is generally less expensive than identifying and solving them after they occur.

This chapter focuses next on the potential for a greater use of interior source control to achieve improved indoor air quality by considering schemes developed in some other countries to label products based on their emissions of pollutants to indoor air. It also outlines activities within Europe to harmonise test methods to characterise products based on emissions in support of the implementation of Essential Requirement 3 (Hygiene, Health and the Environment) of the Construction Products Directive (Directive 89/106/EEC [41]). The labelling schemes are mostly of voluntary status although in Germany and France some aspects are the subject of national regulation.

6.2 Labelling schemes

Europe

The European Collaborative Action (ECA) 2005 [42] describes the evolution of schemes during the late 1980s and early 1990s to identify products manufactured in an environmentally friendly manner that have been tested for their relevance to indoor air quality. These were industrial based schemes such as GUT (Association for Environmentally Friendly Carpets) in Germany that was launched in 1990 or government initiated such as the Blue Angel scheme introduced in Germany in 1986 that required testing of formaldehyde emissions from wood products such as furniture, parquet and wall panels. Other now well established schemes were introduced in 1995 both in Finland (Classification of Indoor Climate, Construction and Finishing Materials) and in Denmark (Indoor Climate Label) and are quite widely applied in other Scandinavian countries. With the intention of planning for implementation of Essential Requirement 3 of the Construction Products Directive (CPD), a German government task force (AgBB) published a labelling scheme in 2001 and in 2004 the German Institute for Building Technology (DIBt) made the AgBB test procedure mandatory for flooring materials requiring approval with regard to resistance to fire.

In 2009 a major development occurred in France because of concerns that the existing voluntary AFSSET emission testing protocol was not resulting in an increase in the use of low emitting products (Maupetit and Mandin, 2009 [43]).The French government proposed the mandatory labelling of VOC emissions from building and decoration products as part of the consensus action 'Le Grenelle Environnement' which also defines very ambitious objectives in terms of energy saving for the building sector. The French government notified the Commission and introduced a regulation requiring that building, decorating and furnishing products placed on the market after 1 January 2012 will require labelling with emission classes based on chamber tests and products on the French market before that date must be labelled from 1 September 2013 (French Republic, 2009 [44] 2010 [45]). The French government also announced their intention to consider regulation of emissions from other indoor products such as air fresheners and cleaning agents.

The characteristics of the current European labelling schemes are detailed in ECA (2005 [42]) and the application of the main schemes, along with sources of further information, are summarised in Table 5. While the schemes predominantly focus on building materials and furnishings, The Blue Angel scheme extends to domestic and office electronic appliances.

Scheme	Detail	Website
M1 Emission Classification of Building Materials **Finland**	Voluntary (private), promoted by Government, all types of construction products	http://www.rts.fi/english.htm
The Indoor Climate Label (ICL) **Denmark**	Voluntary (private), promoted by Government; open to all types of products relevant to indoor air	http://www.dsic.org/dsic.htm
Committee for Health-related Evaluation of Building Products (AgBB) evaluation scheme **Germany**	Relevant for floorings and adhesives; promoted by government and mandatory through inclusion in approval procedure for selected construction products by DIBt (Deutsches Institut fur Bautechnik); also applied voluntarily to other building products.	http://www.umweltbundesamt.de/produktee/bauprodukte/agbb.htm
Agency for Environmental and Occupational Health and Safety (AFSSET) scheme **France**	Voluntary protocol for all building products and finishes; Proposed in the framework of the first French National Environment and Health Action Plan (NEHAP)	http://www.afsset.fr
The GUT Label **Germany**	Voluntary (private); textile floor coverings	http://www.pro-dis.info/about-gut.html?&L=0
GEV-EMICODE (ECI) **Germany**	Voluntary (private);products for installation of floor coverings	http://www.emicode.com/
The Blue Angel Eco Label **Germany**	Voluntary (private);promoted by Government; several types of products for indoor use	http://www.blauer-engel.de/en/blauer_engel/index.php

Table 5 Current European material labelling schemes and contact points from Bluyssen *et al*, 2008 [46]

There is no UK based labelling scheme although a number of UK manufacturers have their products tested to meet requirements in other countries including Germany and the USA in order to access these markets. The BREEAM environmental assessment scheme for new non-domestic construction (2011 version [47]) includes provision for the award of one credit (of the total of 132 credits available in the building assessment) for use of some construction and furnishing products that meet European standard requirements for:

- VOC content (decorative paints and varnishes)
- Formaldehyde emission (timber and wood-based products, ceiling tiles, resilient and textile flooring, and wall coverings)
- VOC emission (flooring adhesives).

The equivalent environmental assessment method for dwellings, the Code for Sustainable Homes, does not address indoor air quality or emissions from products used indoors (CLG, 2010 [48]). The toxicity information contained in the BRE Environmental Profiles which are called up by the Code relates to the *content of* the material rather than a test of the *emissions from* the material.

In Sweden the BASTA scheme [49] exists and is run as a non-profit making limited company owned jointly by IVL Swedish Environmental Research Institute and The Swedish Construction Federation. The scheme is aimed at speeding up the phasing out of hazardous substances in construction. Product suppliers are responsible for the assessment, which addresses a number of properties of a product's chemical ingredients. Only products that meet these requirements can be registered with the BASTA scheme.

LEED is the leading environment assessment method for homes in the US, operated by the US Green Building Council. It includes some requirements [50] for source control related to combustion appliances (e.g. no use of un-flued appliances) and for VOC emissions from materials (e.g. flooring and insulation products). It also recognises certification to the US Environmental Protection Agency Indoor AirPLUS label [51] for new homes which includes some criteria for use of low emitting materials

The main focus of existing labelling schemes is the emission of volatile organic compounds (including formaldehyde) from construction and furnishing products. All schemes require laboratory testing of samples of products in an enclosed chamber or cell to determine the amount and type of emissions. However there are significant differences between the schemes with regard to the requirements for testing and the means of evaluation of emission data. Some of the key differences are:

- Whether desk based evaluation of the composition of the product is part of the assessment
- The use of single compound VOC concentrations for the assessment or only TVOC e.g. the AgBB and AFSSET schemes involve extensive lists of individual VOCs whereas the M1 scheme considers only TVOC, formaldehyde and carcinogenic VOCs. In the AgBB scheme concentration in air values are defined for a list of 174 VOCs using an approach first described by a European expert group in 1997 (ECA, 1997 [52]). This group derived concentration in air values for individual VOCs that represent the lowest

concentration above which, according to best professional judgement, the pollutant may have some effect on people in the indoor environment. These values were known as 'Lowest Concentrations of Interest' (LCIs)

- The range of substances other than VOC considered in the evaluation e.g. fibres, ammonia, formaldehyde
- The inclusion of sensory (odour and irritation) tests in the evaluation
- Evaluation as pass/fail or graded according to performance classes
- Details of test method e.g. duration, emission scenario.

This range of requirements for the various schemes results in significant costs to industries wishing to provide low emitting products in different markets within Europe (Crump 2009 **(53)**). In response to this concern, and to further encourage the development and application of low emitting products, an EU expert group convened by the EC Joint Research Centre established a consensus on the scope for harmonisation of existing schemes. A Working Group produced a framework for convergence (ECA, 2010 **(54)**). This framework includes common core criteria on testing and evaluation methodologies as well as some optional criteria to be applied locally. Some key points in the framework are listed below.

- Testing procedures should be based on existing international standards
- For the evaluation of indoor material emissions, the preparatory Working Group agreed to refer to the EU carcinogens classification
- The evaluation criteria should cover all contaminants of concern to health and comfort and be based on scientific evidence when available. The LCI (Lowest Concentration of Interest) approach is considered as the most feasible strategy to assess the health effects of compounds from buildings materials
- An expert group should be initiated to propose common European LCI values. Limits should be set also for substances not having LCI values (i.e., "non-assessable" substances)
- TVOC should not be used alone as an indicator for evaluating health effects from indoor material emissions. A common approach for TVOC definition along with an upper limit for TVOC should be established
- Sensory evaluation (odour and irritation) is considered to be an important part of the assessment of material emissions.

This harmonisation process was taken forward by an expert group convened by the EU Joint Research Centre and supported by European Directorates General, DG ENTR, DG SANCO, DG ENV and DG ENER. As part of this activity a workshop was held in September 2010 involving a wide range of representatives of industry, labelling schemes, public health authorities as well as experts from universities and research organisations **(55)**. The workshop addressed the need for a common approach to setting of LCI values in Europe for the assessment of emissions from indoor materials. A framework was established and the following scope and objectives of a working group was agreed to take forward this aspect of harmonisation:

1. To devise a harmonised procedure for establishing a list of compounds and LCI values (including consideration of carcinogens) for the evaluation of

emissions from building products taking into account existing procedures used in some Member States and to recommend an appropriate health-protective, science-based, transparent and yet pragmatic approach

2. To propose a flexible framework that enables future review of the procedure to take into account new knowledge (e.g. data resulting from the European Chemicals Regulation, REACH implementation process [56]) and revise the content of the LCI list both in terms of number of compounds and LCI values

3. To establish LCI values for compounds not currently on the LCI list.

The group aim to produce a common list of LCIs by the end of 2012 and is liaising closely with the Expert Group on Dangerous Substances that is advising the Commission on the establishment of classes of performance with regard to emissions to indoor air under the Construction Products Directive.

Other countries

USA Hodgson *et al*. (2011 [57]) present an overview of VOC emission labelling schemes in the USA and their application in green building rating systems; the authors consider that the lack of any single public or private organisation to co-ordinate the schemes results in a number of deficiencies in their implementation. The main schemes are as follows;

California Standard Practice Section 01350 Section 01350 was developed by the California Department of Public Health (CDPH) in 2000 to define a VOC emission testing protocol and emission limits (Stensland, 2009 [58]). The goal was to provide better information for the selection of interior building materials and contained a testing protocol linked explicitly to the State's exposure guidelines (Chronic Reference Exposure Levels or CREL). These guidelines include chemicals with established CRELs and those listed as either probable or known carcinogens or reproductive toxicants.

Californian Collaborative for High Performance Schools (CHPS) The CHPS requires contractors bidding for construction of new schools and other public building projects to guarantee that they will only use materials whose emissions have been tested and certified by an accredited laboratory using the 01350 test protocol (Woolfenden, 2009 [59]).

The ANSI/BIFMA Furniture Emissions Standards – The Business and Institutional Furniture Manufacturers Association International (BIFMA) established a scheme in 2005 for determining low-emitting VOC performance for business and institutional furniture products (Randal, 2009 [60]).

The Green Label Plus program The Green Label program was launched in 1992 by the Carpet and Rug Institute (CRI) to help specifiers to identify products with very low emissions of VOCs. The latest revision includes carpets and adhesives (Hurd, 2009 [61]).

FloorScore Flooring Products Certification program – Floor/score is a voluntary, independent certification program established in 2005 that tests and certifies hard surface flooring and associated products for compliance with Section 01350 criteria (Freeman, 2009 [62]).

Greenguard Certification Program There are currently three product certification program (Greenguard, 2010 (63)):

- Greenguard Indoor Air Quality Certified which applies to low-emitting building materials, furniture, furnishings, finishes, cleaning products, electronics and consumer products
- Greenguard Children and Schools Certified for products used in environments where children and other sensitive populations spend extended periods of time
- Greenguard Premier Certified which is a health-based certification program for which products of all types are eligible.

Japan and Korea Azuma *et al* (2008 (64)) reviewed the existing governmental and industrial voluntary standards and guidelines concerning indoor air quality and labelling of emissions in Japan. Several labelling systems exist, for example the wallpaper industry has established voluntary standards for emissions of VOCs from their products based on the German labelling systems. Levin (2010) (65)) reported quite extensive testing of emission from construction materials in Korea but there was no scheme developed for certification and labelling.

6.3 The European Construction Products Directive

After some considerable delay the European Commission wishes to implement Essential Requirement 3 (ER3) of the CPD that was adopted in 1989. In 2005 it issued Mandate M/366 to the European Standards organisation (CEN) and technical committee TC351 was formed to prepare draft standards covering two broad areas of emission (or release); one to cover emissions from construction products to indoor air and the second to address release to soil and ground water. Also included are packages of work to look at emission of radiation to indoor air and the relevance and use of content testing of products either as a simplified substitute for emissions measurement, or where specific substances are subject to control or market restriction in use. Harmonised test methods will then be available to CEN TCs responsible for standards on particular types of construction products so that the ER3 requirements can be addressed in product specifications.

The implementation of the work will be through the revision of product mandates to amend the harmonised technical specifications (ENs) for construction products where a relevant emission is likely and is subject to regulation in a Member State. The mandates and the specific product requirements are overseen by the European Commission with the assistance of its Expert Group on Dangerous Substances. Wherever possible any relevant emission or release will be expressed in technical classes of performance and linked to the existing requirements in Member States. This should eliminate or prevent barriers to trade resulting from new national emissions schemes.

Methods for characterising the emissions are being developed within WG2 of TC351. As far as possible the new harmonised method is based on the chamber testing approach and analytical methods already available within the ISO 16000 series of standards on indoor air quality. The key standards for VOC and formaldehyde measurement are parts 3, 6, 9 and 11 (Yu and Crump, 2011 **(66)**). Specifically for determination of formaldehyde from wood based panel products, which are the subject of German regulatory requirements, the chamber method described in European standard EN717-1 must be applied. The draft harmonised standard for VOC emission determination is the subject of robustness and validation testing during 2011/12 before being finalised as a European standard. Secondary or derived tests shown to be correlated with the chamber test may also be used and may be particularly appropriate for quality control tests (Brown and Crump, 2011 **(67)**). Sensory testing is not included as part of the harmonised standard although it is an important aspect of labelling schemes currently applied in Finland and Denmark and is the subject of a major research programme in Germany to inform possible inclusion in the AgBB scheme.

When implemented construction products will, where relevant, be subject to measurement of emissions of regulated dangerous substances and the level of release will form part of the CE Marking of the product. This will provide guidance to the designer or specifier in selecting the most relevant product for the intended application and end use. Ultimately this should encourage the use of low emission products and improvements in indoor air quality.

This system will address regulatory requirements in Member States but does little to reduce the number of voluntary schemes for labelling or measurement of emissions across Europe. The European Commission hopes the provision of a scheme linked to CE Marking of construction products will reduce or eliminate the need for such schemes but their voluntary nature – even if becoming *de-facto* market requirements – means that they cannot be legislated against. Hence there may still be a number of different measures for emissions from products although current initiatives to harmonise these requirements as much as possible should minimise the extra burden of testing required.

In the future, the change from the CPD to the Construction Products Regulation (CPR) will further enhance this work and extend the life cycle of the product assessment beyond the 'in-use' phase. The European Chemicals Regulation, REACH **(56)** Implementation process (Registration, Evaluation, Authorisation and restriction of Chemicals) further requires the assessment of the presence of any dangerous substances in construction products where the substance is intended to be released under normal or reasonably foreseeable conditions of use (Article 7 of REACH). Such information forms part of the manufacturer's health dossier and the product Safety Data Sheet.

6.4 Consumer products

While the focus of the above initiatives is predominantly impacting on construction products and furnishings it is known that consumer products (e.g. cleaning and personal care products, air fresheners, electrical goods, candles and incense) can play a significant role in determining the total level of VOC emissions (Ayoko, 2009 **(68)**). These are increasingly the subject of research and for example the European project EPHECT (Emission, Exposure Patterns and Health Effects of Consumer products in the EU **(69)** is seeking to develop tools to better estimate people's exposure to chemicals arising from such products and develop a database of chemicals released by products during use. It is likely that improved understanding will lead to pressures for greater labelling of such products based on their emission to indoor air.

6.5 Outlook and conclusion

A greater use of low emitting products will reduce the pollution load in buildings and therefore reduce the risk of the build up of concentrations that could cause adverse effects on the health and wellbeing of occupants. It is a preventive and passive strategy for management of indoor air quality. To be effective it requires the wide availability of low emitting products at reasonable cost and specifiers and users who are aware of the advantages of using these products.

Voluntary schemes in some other countries have driven the development of low emitting products and future regulatory requirements are expected to further increase this trend. Without national requirements these developments may not impact strongly in the UK, although UK exporters will need to meet these requirements if they are to continue to be competitive. The CPD has a role of removing barriers to trade in Europe and does not implement limits on emissions from indoor products, although it will provide a system for declaring emission properties of construction products. Therefore there is a high degree of uncertainty about whether current initiatives for source control will result in any significant reduction in amounts of VOC emissions released indoors in the UK. If low-emitting products are to play an important role in reducing risks of poor air quality in airtight homes to counteract concerns about lower than traditional air change rates and ventilation systems at higher risk of poor performance (because of occupant behaviour and inadequate maintenance), there is the need for a process to promote the use of such products in UK homes and thereby take advantage of the initiatives that have taken place in other countries and at the European level.

Low-emitting products only reduce some types of pollution being emitted from some of the wide range of indoor sources. Therefore even if labelling schemes result in high use of low-emitting building, furnishing and consumer products this approach to controlling indoor air pollution should be regarded as only part of an effective strategy for indoor air quality management. Pollution sources will remain, such as cooking and heating, people and pets, radon from the ground and residual VOC emissions from 'low-emitting' products. Also, management of water vapour is a vital aspect of indoor air management not addressed by low-emitting products. Therefore source control provides substantial benefits but does not preclude the need for provision of adequate ventilation to achieve a healthy indoor environment.

7 MVHR

MVHR systems have been installed widely throughout the world and their adoption in the UK has been increasing over recent years. Current UK figures show annual sales of 18,400 units (April 2010 to March 2011) and it is assumed that the majority of these were for installation in new homes, although some will have been for the refurbishment market and some for replacements.

7.1 Effect on indoor air quality/health

Some available research suggests that, installed properly and operating correctly MVHR can have a positive effect on IAQ and health, although conversely it is expected that a system not working well would have a detrimental effect.

A study by Lowe and Johnston **(70)** in which MVHR was retrofitted into some local authority homes indicates the beneficial effect on IAQ that MVHR can have. Bone *et al.* **(7)** also refer to the benefits to population health that could arise from reduced exposure to ambient particles from using mechanical ventilation systems with filtration of fine particles (PM2.5) in the incoming air, provided that systems are appropriately maintained. They also identify research that demonstrates improvements in symptom scores for throat irritation, cough, fatigue and irritability among those moving into new airtight homes with MVHR systems compared with those moving into standard new homes.

Howieson *et al* **(71)** refer to changes in the design and use of the domestic environment over the latter part of the 20th century that are likely to have led to a significant increase in house dust mite concentrations and that this may be the prime cause of the rising incidence of asthmatic symptoms in children, the UK having the world's highest prevalence of asthma symptoms in 13–14-year-olds. This study demonstrates that because MVHR reduces humidity levels dust mite re-colonisation rates are reduced and this is likely to result in an improvement in air quality and lung function. This conclusions from this work should be seen alongside those drawn by Niven page 20.

Findings **(72)** from a post-occupation survey of the MVHR-equipped Sigma House at the BRE Innovation Park included that the overall relative humidity in the home was well within the range accepted for healthy living conditions. Positive comments were made by the occupants in relation to low levels of dust and the general feeling of good air quality.

However, it is clear that a benefit will only arise if the MVHR system is working well (having been designed, installed, commissioned, operated and maintained correctly). Van der Pluijm, 2010 **(73)** refers to a study of 28 homes in the Netherlands in which the MVHR systems did often not perform as intended. In most of the 28 dwellings the indoor air quality was poor. This was confirmed by a second study by the municipal health office Eemland **(74)** involving a further 99 dwellings, which gave rise to negative coverage on a 2008 current affairs TV show.

7.2 Design & installation

Lowe and Johnston (70) identified fundamental problems with retrofit MVHR installation:

- 50% of MVHR units had been installed the wrong way round (i.e. the supply and exhaust ductwork was reversed)
- Some MVHR units were not insulated
- Some ductwork within cold loft spaces was not insulated
- Condensate drains were installed to an insufficient gradient.

In a Canadian study involving 60 new homes, Hill (75) identified fundamental issues with installation, including:

- missing or compressed insulation on supply ductwork
- the use of poorly installed flexible ductwork which reduces air flow by up to 30% to 40%
- lack of traps in condensate tubes
- potential pollutant sources within 2m of the supply grille, which could contaminate the supply air
- over- and under-ventilation with respect to building code requirements.

In the Sigma house (72) it was found that the MVHR unit created a hot spot with radiant heat evident in the bedroom adjacent to it.

The Task Group considered that not all MVHR systems are currently being designed to a sufficiently high standard, possibly due to the limited availability of appropriately trained, competent individuals. The Task Group also noted that systems are often subject to a large degree of 're-design' during installation because the system does not 'fit' the building – an example would be the presence of a steel beam not shown on drawings that would require re-routing of ductwork. Clearly it is important that changes made on site do not compromise the design intent.

NHBC's experience of inspecting homes under construction confirms a low standard of installation of some systems. MVHR units and the ductwork are bulky items and without careful design and planning, their installation can give rise to issues of concern. Accommodating the ductwork within new homes in straight runs of rigid ductwork is challenging and there is often excessive use of flexible ductwork, which can adversely affect performance.

A 2007 BRE project (76) which looked at installation aspects of MVHR for the EST Energy Efficiency Best Practice in Housing programme noted standards of installation were often improved where there was manufacturer input during the installation phase. In these situations the extent of use of flexible ductwork was reduced and there was less use of duct-tape, which may not be adequately durable.

The Domestic Ventilation Compliance Guide 2010 (77) published alongside ADF provides guidance on the installation of MVHR, covering the salient issues, although, it has been suggested, not presented in a manner best suited to installer readers.

Through its Ventilation Systems Competent Persons Project Group the British Electrotechnical and Allied Manufacturers Association (BEAMA) is in the process of developing a scheme to address installation issues. See Appendix A for further details.

7.3 Commissioning

Proper commissioning is necessary to ensure satisfactory performance of MVHR systems, affecting IAQ, comfort and energy efficiency. However, evidence from the Canadian and BRE/EST studies referred to above suggests that it is often not carried out to an appropriate standard with under-ventilation being the result. Lowe and Johnston had similar experience with systems commonly being commissioned with fans set at high speeds and therefore consuming almost twice as much energy as they should.

The Domestic Ventilation Compliance Guide 2010 published alongside Part F provides recommended minimum requirements for the commissioning of MVHR. However, additional evidence emerging from current projects confirms that commissioning is currently overlooked or undertaken to an unacceptably low standard.

7.4 Controls, operation and user guides

Also of great importance to the success of MVHR is occupants' ability to operate their systems and there is also research evidence that raises concerns in this regard.

Stevenson and Rijal **(78)** found from a study of the Sigma House at the BRE Innovation Park that both the MVHR and the room thermostat control dials fitted there showed no indication of what the numerals on them related to (e.g. 1 = hot or cold, boost?) which left occupants puzzled. They also found user guides to be lacking:

'Although it was clearly written and relatively straightforward, the guide book tended to utilise generic information extracted from manufacturers' manuals and failed to adequately contextualise these for the particular home the family were occupying. This resulted in confusion as guidance was given in some instances on technology which was not in the home. In the event, the family did not use the guidebook but tended to rely on a trial and error process to find out how features actually worked. While this worked for the more familiar domestic items such as the cooker and washing machine, the family did not understand how the heating ventilation and lighting systems worked even at the end of their two week occupancy period'.

In a post-occupancy study of 25 homes built to EcoHomes excellent standard, Gill, Tierney, Pegg and Allan **(79)** found that only four of the dwellings utilised their MVHR at any time other than when cooking, and others would ventilate stuffy air in summer or winter by using the windows. Of those four, only one suggested that they used it regularly whereas the others used it 'if remembered'. The study notes that the controls were integrated into the oven hood which may prohibit instinctive use.

Macintosh and Steemers **(80)** in a case study of a development of 59 urban homes found that in a period of one year 47% of residents completing a questionnaire said that they had made no adjustments to their MVHR system controls throughout the whole year; one had it permanently disabled, two had it on 'boost' continually and the remainder left it on 'normal'. 32% used the system more in the summer than in the winter. Only 21% actually had the system on more in cold weather than when it was hot, as it should be used for saving energy.

Bone and Crump report a study **(7)** in which only 76% of occupants in the energy-efficient houses operated their MVHR throughout the winter, 58% during the summer and 10% didn't even realise they had MVHR.

The Canadian study **(75)** reported that, although most occupants understood the general purpose of their MVHR, comprehension of the technical aspects required to use and maintain the system properly was low, despite more than half having had the operation explained to them and most having been provided an operating manual (only 32% reported that they had read their manual). It also comments on the lack of remote controls in living areas, particularly in newer homes,

Van der Pluijm **(73)** refers to mis-control of systems in order to minimise sound nuisance (a common phenomenon also with extract fans and cooker hoods) and in response to occupants sensing of low humidity or draughts. He suggests the potential for automatic controls to overcome the problem but recommends that further work is needed.

Bordass, Leaman and Bunn **(81)** have established end-user requirements for control devices for heating, cooling and ventilation, which include the need for controls to be simple to use and easy to understand.

Evidence has been reported of problems encountered during the cold winter on 2010-11, an example of which was that when the outside temperature fell to -17°C, incoming air was being supplied at just -7° C. Unsurprisingly occupants' reaction was to turn the systems off but it is suggested that systems should as standard include a thermal sensor that would provide the appropriate control in such circumstances.

Conversely MVHR systems have the capacity to increase internal temperatures and in certain summer conditions could increase the risk of overheating. The correct specification of controls to allow a summer by-pass should reduce that risk.

User guides for a selection of MVHR systems were reviewed and these were generally considered to be too complex to be easily understood by ordinary users. It seemed that insufficient attention had been paid to producing them.

The adoption of demand control ventilation which automates the operation of MVHR systems may have advantages for users and reduce energy/CO_2 use. It may reduce some of the uncertainty in the way that systems are operated.

7.5 Maintenance

In order to ensure that MVHR systems continue to operate correctly, there is a need for systems to be maintained. Typically this involves regular cleaning around the ceiling grilles and vacuum cleaning the filters and/or changing them from time to time. Periodic cleaning or replacement of the heat exchanger may also be necessary to ensure continued efficiency is maintained. Manufacturers' recommendations for maintenance differ but clearly what is actually needed in practice will depend on a variety of factors including occupants' cooking habits and the quality of the external air.

In the Canadian study (75) most occupants (81%) reported that they regularly cleaned the ventilation system components, but many systems were found to require maintenance. Forty-two percent had systems with dirty filters, cores or cabinets, 17% had blocked air intakes and 46% had unbalanced supply and exhaust air flows. Of the occupants that reported indoor air quality problems (26%), 60% had substandard ventilation, 62% had unbalanced supply and exhaust air flows and 56% had dirty filters, heat recovery cores or MVHR units. The study recommends that installers should also be encouraged to offer MVHR maintenance agreements to homeowners and/or impress upon them the importance of proper operation and maintenance and that the industry should also be encouraged to develop trouble indicating devices (e.g., trouble lights) or failsafe controls to indicate component failure or overdue maintenance.

The Netherlands study also points to malfunctioning of systems due to poor maintenance/dirty air filters.

In spite of the need for regular changing of filters it is reported (1) that there is currently no market for replacement filters with several manufacturers reporting no filter sales at all. This suggests that maintenance is not being undertaken – even at the most basic level. It is suggested that the development of cost-effective maintenance services by manufacturers and other providers would be highly desirable and would help to discourage home owners from ignoring system maintenance.

7.6 Carbon benefit: performance in practice

The VIAQ Task Group was not able to identify projects that have involved long-term monitoring of installed MVHR systems that has allowed their carbon benefit in practice to be demonstrated. It is hoped that evidence, including that from monitoring currently underway at the SSE Greenwatt Way development should be available for the group to consider in advance of the publication of the Group's final report.

Modelling by AECB (82) using SAP and PHPP to demonstrate the positive energy/CO_2 benefit of MVHR concluded that:

- MVHR does provide net carbon savings, if the system is efficient and well-designed and installed
- The current level of internal gains assumed in SAP diminishes the apparent benefits of MVHR. This is because the gains appear to be meeting the fresh air heating load a fair amount of the time
- As lighting appliances and hot water systems get more efficient, there will be less "free" heating and the benefits of MVHR will become clearer.

Realising the performance in practice requires reasonable assumptions to have been made in the SAP of the efficiency of MVHR systems. The 2007 BRE study for the EST Energy Efficiency Best Practice in Housing programme noted, 'The current 'in use factor' for MVHR system fan power is 25%. The installed system fan power values were generally found to be between 30 and 42% greater than the laboratory measured values. One system was found to be 66% greater.

Design innovation allows space-saving inclusion of MVHR ducting and ease of installation.
Image courtesy Miller Homes

Good practice: MVHR unit (above cylinder) in easily accessible position and within the heated envelope of the home

8 Building the evidence base

The Task Group is aware of the following projects currently underway that could deliver additional information for inclusion in the final report:

- SSE Greenwatt Way
- Saxon Weald/Osborne Bryce Lodge
- Rowner Renewal Monitoring Project
- Good Homes Alliance monitoring programme
- TSB monitoring programme
- And possibly others

9 Interim conclusions

- A variety of pollutants arising from a number of sources exist in the indoor environment of homes. Levels of many of those pollutants are likely to be at their highest levels in newly-built homes and homes that have been recently refurbished due to emissions from building materials and furnishings.

- Based on a number of international studies reviewed, the consensus is that poor IAQ is connected with various undesirable health effects. This reinforces the need for the design, construction and commissioning of buildings to be undertaken with IAQ firmly in mind.

- An increasing trend towards more airtight homes could exacerbate pollutant levels particularly if the ventilation system does not operate as intended. Also anecdotal reports suggest that drying-out periods may be extended, with elevated humidity levels lasting for a longer period.

- Our understanding of emissions from building materials is developing and in the medium term there is the scope for emissions to be reduced through the careful selection of building materials and changes to consumer products, etc. However emissions labelling schemes in the UK are not yet sufficiently advanced for widespread use and so cannot be depended on yet to reduce the pollution load in new homes.

- With over 18,000 MVHR units sold in 2010-11, MVHR already has a significant foothold in new UK housing. The Task Group is of the view that the use of MVHR will continue to grow and become the dominant form of ventilation, standard in most new homes post-2016. This is for the reason that MVHR is beneficial in terms of the SAP assessment because the ventilation heat loss is minimised.

- However, to realise the benefits of MVHR, in terms of both energy/CO_2 emissions and IAQ, and to avoid any adverse consequences, systems must be properly specified in airtight homes and close attention needs to be paid to system design, installation, commissioning and operation. There is much evidence from the UK and abroad that many systems have significant failings in these areas and there needs to be a concerted focus to address these.

- Although modelling has demonstrated the positive effect that MVHR can have on both energy/CO_2 emissions, there is a dearth of evidence to confirm that this is realised in practice. It is hoped that further evidence will become available over the next few months, which will help inform the final VIAQ report.

Appendix BEAMA Ventilation Competency Scheme

BEAMA is working with Competent Person Scheme providers to launch an 'Approved Contractor' variant for new build dwellings in Autumn 2011. The scheme will lead to reduced 'in use' factors for ventilation systems and will be backed by a training course.

The ventilation industry has been developing a competency strategy since SAP Appendix Q was first launched and the initial monitoring highlighted specific installation and commissioning issues with ventilation systems (largely driven by design deviations and lack of design awareness). Industry has been working extensively on training modules to support National Occupational Standards and a Qualification Criteria Framework developed with Summit Skills. The first course was launched by BPEC in 2011.

The overall objective is to develop a trained and competent workforce that could be recognised under a formal competent persons scheme for new build applications. This competency would support the Part F checklist and be a route to reducing the in use factors in SAP compliance calculations. SAP 2010 has a specific convention that allows for reduced in use factors to be used if the system is installed and commissioned by an 'approved contractor', or in this case competent person

Industry is now working on a revised AD F checklist that includes 'stage post' sign off at first and second fix stage and the necessity to document details of a design.

Ensuring customer contact and post completion operational performance Industry has advised DCLG that a Benchmark type scheme is required. In the initial proposal for an Approved Contractor scheme, the flow diagram recommended that a 'control document' such as a Benchmark checklist with customer address details be sent to the manufacturer.

There are legal implications for this and in recent times industry has been promoting a method by which the customer completes the form and returns it to the manufacturer or, the house builder pre-completes it for the customer and sends it on his/her behalf. The manufacturer is then able to begin a dialogue with the customer which will include the offer of free filters and signals to remind about control and service/maintenance.

Increased onus to be put on house builders to handover systems correctly and encourage customers to complete Benchmark type documentation As noted above the industry advocates the completion of an information form to return to the manufacturer of the unit. The house builder may be required to undertake this task for the customer. Coupled with this, the industry strongly supports regulations that push the onus onto the house builder to ensure effective handover of building service documentation and advice to communicate the need to use controls/keep the system switched on, and maintain the system.

Assure removal of in use factor rating as stated at design stage

MVHR Factors

40% in use

30% in use

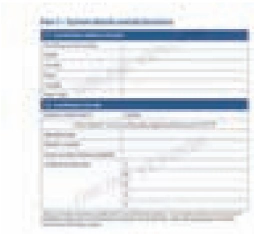
Trained Operatives Working to Design and Meeting MTC Through BPEC Training/equivalent and Registered with AC Scheme

Specifier ? (understand design)
Installer √ (interpret design and risks)
Services Manager √ (checklist/responsibility)

(dark green)	Non Approved contractor
(light green)	Approved contractor

beama

Control Document= modified ADF checklist



Checklist is control document provided to SAP Assessor to prove stages signed off by AC, design in place.
AC PROOF

Copy to:
SAP Assessor √
Manufacturer √
Customer √

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