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International Energy Agency's
Energy in Buildings and Communities
Programme

Air Infiltration and Ventilation Centre

Residential ventilation and health

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1 Context

AIVC Technical Note 68 (TN 68) Residential Ventilation and Health" is one of the outcomes of the work performed under the framework of AIVC's project "Ventilation & Health" and benefited from contributions by several authors and many structured discussions held during specific sessions at AIVC events. TN 68 summarised studies that prioritise pollutants in the indoor environment and presented a summary of pollutants driving the indoor health risks and their sources. The document also described methods to reduce exposures of contaminants using different control strategies with a special emphasis on the role of ventilation.
To ease the dissemination of this key AIVC publication, the AIVC Board agreed to develop this Ventilation Information Paper (VIP) briefly presenting the technical note's key outcomes.

2 Summary

The document starts with an overview of pollutants in domestic dwellings that have been measured, prioritizes pollutants for mitigation in the indoor environment and identifies potential health outcomes. Furthermore, it describes control strategies to reduce health effects from these and other pollutants, including different strategies to reduce exposure and the role of ventilation. The last part of the document lists the research needs.

NOTES:
[1] Throughout the text reference is made to the literature used for the development of TN 68 (noted as [REF]). These citations are listed only in the reference section of TN 68. The reference list at the end of this document includes only new references used for the purpose of this summary.
[2] Clicking on the book icon displayed next to each numbered chapter redirects and opens the corresponding chapter within AIVC TN 68

3 Pollutants that have been measured in domestic dwellings 📖

Hundreds of pollutants have been measured in domestic dwellings, and it is estimated that exposure to indoor air pollution at home can constitute 60 – 95% of our total lifetime exposure. Both short term and long-term exposure to indoor pollutants has been implicated in the development of both acute and chronic human health effects such as asthma or allergic symptoms and respiratory and cardiovascular disease. Indoor air pollutants, chemical and biological, have both indoor and outdoor sources. Table 1 lists some of the pollutants measured indoors and shows the source of their origin, and their presence indoors and/or out.

Table 1: Major pollutants in dwellings with the associated sources of their origin; (O) indicates sources present outdoors and (I) sources present indoors

Compound	Selected major sources
1,4-Dichlorobenzene	Carpets (nylon, synthetic) (I), laminate floorings (I), household fumigant (mothballs, moulds) and deodorants and air fresheners (I)
2-Ethylhexanol	Solvent, products containing plastic (plasticizer) (I)
Acetaldehyde	Photochemical oxidation and combustion of other carbon/hydrocarbon compounds (I,O), motor vehicle exhausts from traffic (O), tobacco smoking (I), carpets (I), floorings incl. resilient non-rubber based and cork (I), gypsum products (boards) and plaster boards (I), wood based panels (I), paints and varnishes (I), thermal insulation products (I)
Acetone	Humans (I), carpets (I), paints and varnishes (I), external and internal wall ceiling finishes (acoustical ceiling panels) (I), adhesives (I), wood based panels (chipboard, fiberboard) (I), floorings (cork) (I), gypsum products (boards) and plaster boards (I), plastic laminates and assemblies (I), resilient floorings rubber based (I), thermal insulation products (I)
Acrolein	Combustion of organic matter (O,I), biocides (O), motor vehicle exhaust from traffic, also biodiesels (O), tobacco smoking (I), cooking (frying in oils) (I)
Alpha-Pinene	Plant oils (O), carpets (I), adhesives (I), floorings (I), wood based panels (I), paints and varnishes (I), adhesives (I), cleaning products and deodorizers (I)
Benzene	Motor vehicle exhausts (O), tobacco smoking (I), flooring and sealants with rubber, lubricants and dyes, detergents and pesticides (I)
CO	Unvented/improperly vented combustion in homes (I) outdoor combustion (O)
CO_2	Humans (I) unvented combustion (i.e. from cooking, unvented alcohol or natural gas fireplaces) or improperly vented combustion (i.e. back drafting from draft-induced ventilated furnaces) in homes (I) outdoor combustion (i.e. traffic, power plants, and biomass burning) (O)
Ethanol	Humans (I), ethanol fireplaces (I), air fresheners (I), deodorizers (I), cleaning products (I)
Ethylbenzene	Motor vehicle exhausts (O), pesticides, synthetic rubber products (I), paints and inks (I)
Formaldehyde	Photochemical oxidation and combustion of other carbon/hydrocarbon compounds (I,O), motor vehicle exhausts from traffic (O), tobacco smoking (I), cosmetics and disinfectants (I), carpets (I), resins and wood based panels (urea formaldehyde wood products) (I), paints and varnishes (I), gypsum products (boards) and plaster boards (I), internal and external wall finishes incl. acoustical ceiling panels (I), floorings (vinyls, PVC) (I), adhesives (I), thermal insulation products with fiberglass (I), corks (I)
Limonene	Common solvent and additive in cosmetic products, deodorizers and cleaning agents (I), adhesives (glues) and paints (I), 3D printers (I), carpets (I), wood based panels (I) resilient floorings rubber based (I)
Naphthalene	Household fumigant (mothballs) (I), concrete and plasterboard (wallboard or drywall) (plasticizer) (I)
NO_x	Unvented/improperly vented combustion in homes (I) outdoor combustion (O)
Ozone	Atmospheric reactions (O), transport from upper atmosphere (O), electronic equipment operating at high voltage (I), air cleaners and ozone generators (I), printers (I)
Phenol	Plastic materials and cosmetic products (I), adhesives (I), floorings incl. resilient non-rubber based (I), plaster boards with synthetic resins (I), acoustical ceiling panels (I), paints and varnishes (I), cork panels (I), gypsum boards (I), laminates (I)
Phthalates	Products containing plastic such as floorings (PVC), paints and adhesives (I), solvents in hygienic products, lotions and perfumes (I), pesticides (O,I), carbonless copy paper (I), flame retardants (I)
PM2.5/PM10, particles with aerodynamic diameters less than 2.5µm and 10 µm respectively	Unvented/improperly vented combustion in homes (I) outdoor combustion (O) secondary organic aerosol formation (I/O) aerosol product use (I) re-suspension of particles (I) physical processes (I/O)

Polycyclic aromatic hydrocarbons (PAHs)	Motor vehicle exhaust (O), combustion (O), emissions from heavier fractions of petroleum such as roofing, tars and asphalt (O), smoking (I), cooking (I) and gas fired appliances (I)
SO_2	Combustion of sulfur containing fuels (O)
Styrene	Rubber, plastic, insulation, fiberglass (I), carpets (backing) (I), floorings (I), gypsum products and plaster board (I)
Tetrachloroethene	Solvent for organic materials, “dry cleaning” (I)
Toluene	Motor vehicle exhausts from traffic (O), common solvent for paints, paint thinners, silicone sealants, rubber, printing ink, adhesives (glues), lacquers, leather tanners, and disinfectant (I), internal and external wall ceiling finishes and acoustical panels (I), carpets and rubber based resilient flooring (I), fiberboards (I), gypsum products and plaster boards (I), plastic laminates and assemblies (I)
Trichloroethene	Solvent for organic materials, “dry cleaning” (I), paints, inks, varnishes and adhesives (I), consumer products such as cleaning fluids for rugs, spot removers, and correction fluids (I), carpets (I), wood based panels (fiberboards) (I), resilient floorings non rubber based (I)
Ultra fine particles (UFP) with an aerodynamic diameter less than 100 µm	Similar as for PMs and additionally atmospheric reactions creating secondary aerosols (O,I)

4 Priority indoor pollutants

It is difficult to define ‘good air quality’ but methodologies are available to identify priority pollutants for health and wellbeing. The process of identifying ‘priority indoor air pollutants’ is an essential step towards defining adequate ventilation or ‘health-based ventilation standards’. Previous research studies, such as the EU ENVIE Study (de Oliveira et al. 2009) REF, Logue et al. 2011 REF, and the WHO (WHO, 2011) REF have identified six priority pollutants for chronic exposure that should be considered when setting ventilation standards; they are listed in Table 2. Table 2 also includes a list of pollutants, although limited by lack of research data, for which there maybe potential acute exposure concerns. Notably, Table 2 does not refer to pollutant mixtures e.g., environmental tobacco smoke, or e-cigarette aerosol, WHO has highlighted the need to develop tools to assess the impact from exposure to mixtures and so they should also be considered when developing health-based ventilation standards.

Some of the methodologies used to assess and rank the impact of pollutants indoors are described in detail and examples of their application are provided in Technical Note AIVC 68 and include:

- Hazard Assessment: This involves comparing measured or modelled pollutant concentrations to published guidelines or standards thought to represent ‘safe’ exposure concentrations. Regulatory agencies such as the US Environmental Protection Agency (US EPA, 1991) REF, the California Environmental Protection Agency (Cal EPA, 2005) REF, the European Commission (EC, 2021) and others have developed legislation and standards for some priority outdoor pollutants. The World Health Organisation (WHO, 2005) REF, (WHO, 2009) REF, (WHO, 2010) REF have published recommended guidance on threshold limits for both outdoor and indoor pollutants. The Toxicological Excellence for Risk Assessment, ITER publish a database which summarises guidelines and standards from several groups, including standards published by groups such as the USEPA and WHO for many indoor and outdoor pollutants (http://www.tera.org/iter/index.html). One limitation of the Hazard Assessment approach is that there are many new and emerging pollutants for which there is limited toxicological and epidemiological data and so there are no available health-based guidance values.
- Impact Assessment: impact assessment estimates are calculated using health data which link exposure to health outcomes. Many impact assessments have been completed for outdoor air pollutants, less on

indoor pollutants due to the lack of exposure response data for many of the priority indoor pollutants. One US based impact assessment study (Logue et al. 2011b) REF estimated population impacts due to chronic inhalation of non-biological pollutants indoors at home. Their study estimated the damage attributable to exposure to indoor air pollution in US Homes to be comparable to road traffic accidents and heart disease damage.

- Cumulative Risk Assessment (CRA): CRA uses statistical comparisons of exposed versus non exposed populations to a combination of hazards or stressors and aims to assign specific causes or sources of harm or to disease on a population. CRA can be used along with Burden of Disease (BoD) analysis, to calculate the DALY or Disability Adjusted Life Years. DALYs are the equivalent years of life lost to illness or disease and include years of life lost (YLL) to premature death and equivalent life years lost to reduced health or disability (YLD). Previous CRAs completed on indoor air include the EnVIE project (de Oliveira et al. 2004) REF within Europe which identified combustion products, bio aerosols, and VOCs as the main contributors to indoor air related health impacts within the EU.
- Cost benefit analysis (CBA) used in conjunction with impact assessment and or cumulative risk assessment CBA involves monetizing the change in health impact due to exposure or an intervention.

4.1 The impact of specific sources on indoor concentrations

Identifying the source of an indoor air pollutant is an important step towards designing interventions such as ventilation to reduce concentrations and exposure indoors, while at the same time controlling the amount of outdoor pollutants coming into the building. Technical Note AIVC 68 describes two indoor pollutant sources to illustrate this point; the use of natural gas appliances indoors and the resultant increase in nitrogen dioxide (NO_2) and carbon monoxide (CO) concentrations and the impact of outdoor particulate matter on indoor PM2.5 concentrations. A summary of the literature describing studies measuring typical pollutant concentrations indoors linked to the source is provided.

Nitrogen dioxide exposure can cause adverse respiratory health effects. US based research studies suggest significant accumulations of indoor NO_2 and CO concentrations in homes using unvented gas cooking, with concentrations often exceed acute US based guidelines and standards (Logue et al., 2014) [REF]. It is important to Identify the source and magnitude of exposure to such pollutants so that the use of safer ventilated combustion systems can be promoted indoors.

Outdoor air is one of the most common sources of an array of indoor pollutants including particulate matter (PM), ozone, nitrogen dioxide and others. Factors such as outdoor concentrations, building leakage, building ventilation (natural or mechanical) and meteorological conditions all impact on the concentration of pollutant that infiltrates indoors. Technical Note AIVC 68 focuses on outdoor PM as a source of indoor PM, previous studies have estimated that up to 56% of indoor PM2.5 can originate from outdoor sources (RIOPA Study, Weisel et al. 2005) [REF]. There has been extensive literature focusing on measurement of outdoor particulate matter concentration and some also on indoor concentrations, studies typically measure the health-related aerosol fraction of PM or median aerodynamic particle mass concentrations i.e. PM10, PM2.5, PM1 etc, Technical Note AIVC 68 focuses on studies of PM2.5, exposure to which has been linked to development and exacerbation of cardiovascular and respiratory disease.

4.2 Priority pollutants

In order to develop health-based ventilation standards it is necessary to identify priority indoor air pollutants associated with both chronic and acute exposure indoors. Technical Note AIVC 68 summarises a number of priority indoor pollutants which have been associated with chronic health effects; this list is reproduced in Table 2.

Table 2: Priority pollutants in the indoor residential environment for consideration in making ventilation standards

Priority Pollutants for Chronic Exposure (ranked by population impact)	**Potential Acute Exposure Concerns**
Particulate matter	Acrolein
Mould/ moisture	Chloroform

Formaldehyde	Carbon Monoxide
Acrolein	Formaldehyde
	NO_2
	PM2.5

5 Identification of potential health outcomes

Characterising human exposure to indoor air pollution is an important step in understanding the relationship between exposure and impact on human health. Some pollutants are chronic agents, health effects are observed following repeated or multiple exposures over an extended length of time, often decades, examples include development of cardiovascular diseases or respiratory disease such as chronic obstructive pulmonary disease (COPD) due to exposure to particulate matter.
Other pollutants are considered acute agents, here the adverse health effect occurs often after a single exposure for example carbon monoxide poisoning. Hundreds of pollutants have been measured indoors and new pollutants are continually added each year, often our ability to detect new pollutants significantly exceeds our ability to understand the human health effects of exposure. Computational tools in-silico assessments and in-vitro studies or are promoted by regulatory agencies such as the European Chemicals Agency (ECHA, 2021). In-vitro testing involves performing the toxicological test on samples of tissues or in cells, outside of a living animal. Currently our understanding of the health effects of outdoor air pollution far exceeds that of our understanding of the human health effects of many indoor air pollutants.
Technical Note AIVC 68 provides an overview of the toxicity of indoor air pollutants based on available toxicological and epidemiological studies. Health outcomes associated with exposure to six classes of indoor pollutants are summarised, they include: criteria pollutants, air toxics and volatile organic carbons, mould and moisture, semi-volatile organic compounds and biological agents are briefly discussed.

5.1 Criteria Pollutants

The US EPA defined six criteria pollutants in the 1970 Clean Air Act (CAA, 1970), including carbon monoxide, nitrogen dioxide, particulate matter, ozone, lead and sulfur dioxide, several research studies have linked exposure to each of the six pollutants with negative health impacts, and all apart from lead impact indoor air. Depending on the pollutant, chronic or acute exposure is linked to the health outcome, for example chronic exposure to outdoor particulate matter (PM2.5 – Particulate matter less than 2.5 µm in diameter) has been associated with development with cardiovascular and respiratory ill health (references) and other diseases. Chronic exposure to ozone and nitrogen dioxide have been linked to early death (Samet et al. 1997; Jerrett et al. 2010) REF and respiratory illness respectively (Hasselblad et al. 1992) REF.
Although the health risks associated with acute exposures to carbon monoxide are well documented, the Impacts of acute exposure to the criteria pollutants are more difficult to determine.

5.2 Air toxics and VOCs

VOCs are defined as volatile organic carbons with low volatility so that they can evaporate at room temperature, air toxics are a group of 187 chemicals defined in the US 1990 Clean Air Act as potentially harmful to humans. Commonly detected indoor pollutants such as formaldehyde and poly brominated diphenyl ethers (PBDEs) are examples of chemicals included in this category. Formaldehyde has a variety of indoor sources including, compressed wood products, glues and adhesives and causes both acute (sensory irritation) and chronic (cancer) health effects. PBDEs have been added to flame retardant products widely used to flame proof electronic goods and household furnishings, exposure to PBDE causes endocrine related disorders and exposure to some PBDE congeners are thought to cause cancer (US EPA, 2021).
Further information on the acute and chronic health impacts associated with exposure to these chemicals can be obtained from resources published by the US EPA (Integrated Risk information System (IRIS), 2021), the World Health Organisation (WHO) and other agencies.

5.3 Mould and Moisture

The presence of moisture indoors can support the growth of microorganisms indoors such as fungi and mould which depending on the species can produce biological aerosols containing toxic spores which, which if inhaled can cause an allergic response, upper respiratory symptoms and asthma. Moulds generate spores which can then release toxic metabolic volatile organic compounds or mycotoxins. Moisture on surfaces can promote the decomposition of certain construction materials which can then release odorous and irritant chemicals. A gap in insulation at the junction between a wall and a roof or floor will be colder than the surrounding area, increasing the risk of condensation build up and mould growth.

5.4 Semi volatile organic compounds

Semi volatile organic compounds have high boiling points but can partition to the air at low concentrations and then stick to indoor surfaces including dust. Dermal exposure is thought to be an important exposure pathway for these compounds, and ventilation on its own is not a sufficient control measure to prevent exposure. Chemicals in this category include dioxins and polycyclic aromatic hydrocarbons. Adverse health outcomes associated with human exposure to SVOCs include endocrine disruption, diabetes and numerous other health effects.

5.5 Biological exposures

Biological agents such as mould, bacteria, allergens, viruses, arising from pet dander, damp building materials and infected persons can be spread in doors especially if there is poor ventilation and in confined indoor spaces. Exposure to biological agents (bacterial endotoxins, mould spores) has been associated with the development of respiratory diseases such as asthma and bronchitis. Previous research has shown a positive relationship between increased ventilation rates, low humidity and reduced illnesses in schools (Mendell et al., 2013, Alsmo and Alsmo 2014)REF. There has been much interest and scientific debate lately in the role of ventilation in preventing the transmission of SARS-CoV-2. National guidelines regarding the operation of HVAC in EU countries recommend that ventilation systems are maintained and operated as per national technical guidelines, and that the re-circulation of air should be avoided. Naturally ventilated buildings should ensure frequent air circulation and air exchange by through the opening of windows (CIBSE UK, 2020, European Centre for disease prevention and control 2020).

6 Ventilation based control Strategies to reduce health effects due to indoor air quality

Known sources of indoor pollutants should be controlled by either elimination or source control e.g. tobacco smoking or e-vaping should not be permitted indoors, when cooking indoors properly performing cooking hoods should be used. Building ventilation should be used to control/dilute other emissions which are unavoidable indoors. It is difficult to assess the impact of ventilation on exposure to indoor pollutants, as pollutant concentration is impacted by so many other factors including; occupant activities, the re-suspension of settled dust e.g. on carpets and also occupant interface with the ventilation system.

6.1 Types of residential ventilation

6.1.1 Ventilation processes

Four basic ventilation principles are defined in Technical Note AIVC 68;

– Displacement ventilation –here the air ‘displaces’ room air e.g. operating theatres or industrial clean rooms
– Full mixing –air is introduced at a velocity that creates sufficient turbulence to allow complete mixing so that pollutants are uniformly mixed in the space e.g. residential ventilation
– Local displacement –the ventilation pushes the pollutant away from the breathing zone
– Local exhaust-extract ventilation e.g. extract grilles, cooker hoods or industrial local extract ventilation systems

6.1.2 Methods of providing whole house or room ventilation

Irrespective of the ventilation design, it is essential that outdoor air is unpolluted and that the system is maintained. Four principle ventilation systems are briefly described in Technical Note AIVC 68 and illustrated in Figure 1.

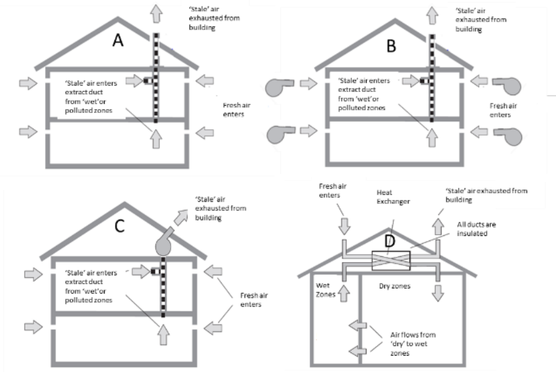

Figure 1: Four principles of ventilation system: A) Passive and natural ventilation, B) Mechanical supply and natural exhaust ventilation, C) Mechanical exhaust and natural supply, and D) Balanced ventilation system.

- Passive and Natural Ventilation –Openings such as windows, grilles or slits in habitable rooms provide outside air to the habitable rooms. Exhaust air is normally passively ducted from wet rooms such as in toilet rooms and the kitchen. Stack effect plays an important role
- Mechanical supply and natural exhaust ventilation-Less influenced by weather compared to Passive and natural ventilation, here the air is provided to the building mechanically and naturally exhausted from wet rooms.
- Natural supply and mechanical exhaust systems – Air is normally exhausted from wet rooms and the kitchen.
- Balanced systems with mechanical exhaust – air is typically exhausted from wet rooms and air is supplied to habitable rooms. Systems usually employ heat or moisture exchangers to reduce energy loss due to ventilation, this ventilation system requires a high level of building air tightness as it is reliant on a balanced system.

6.1.3 Task Ventilation

Task ventilation is normally associated with a particular activity in the building, and is often manually operated e.g. cooker hoods or bathroom extract. Bathroom exhaust ventilation is designed to remove moisture, pollutants and bio-effluents from bathroom air, design and ongoing maintenance is important to maintain indoor air quality and avoid moisture build up and mould growth.

6.1.4 Home Depressurization and backdrafting

As buildings become more air tight, to avoid depressurization and backdrafting, especially in buildings with exhaust ventilation, supply air should be sufficient for all exhaust fans.

6.1.5 Ventilation Control Strategies

Most ventilation systems are not optimised to provide the best indoor air quality, demand control technologies employ sensors to provide more ventilation when needed, either based on indoor CO2 concentration or RH as an indicator of occupancy. New sensor technologies based on the measurement of volatile organic compounds are also available, however in many cases are not very accurate. Control solutions for ventilation should be based on the location of the building (e.g., outdoor sources such as traffic or high humidity) and indoor sources and occupant practices (open combustion, occupant practices).

6.2 Review of existing residential ventilation standards

It has been established that indoor air quality has an important role to play in health, exposure to indoor air pollutants has a significant burden on health. Ventilation standards, although designed to control carbon dioxide concentrations as a measure of bio-effluents, can help protect the health and comfort of building occupants, but the current lack of scientific knowledge in this area means that the current approach relies on good engineering judgement. Technical Note AIVC 68 provides a summary of the current methods used to estimate required flow rates and also existing standards.

6.2.1 Human Effluents and carbon dioxide

Good indoor air quality is often perceived as the absence of odour, and carbon dioxide (CO_2) is frequently used as a marker for bio-effluent and can be related to nuisance odour. In fact CO_2 has been used as a basis for ventilation of buildings since the work of Pettenkofer (Pettenkofer, 1858)[REF] who established that an indoor concentration of 1000 ppm is likely to represent an acceptable odour free indoor concentration. Assuming an outdoor air concentration of between 500 ppm, Pettenkofer recommended limiting the difference between indoor and outdoor to 500 ppm, which is equivalent to an adult flow rate of 10 litres per second (10 L/s) per person, this value is the basis for many ventilation standards today. More recent research concludes that 1000 ppm should not impact on the performance of building occupants (Satish et al., 2012) [REF].

6.2.2 Future Ventilation Standards

6.2.2.1 Ventilation for Health and for comfort

Any ventilation standard or strategy based on health must first understand the pollutants of concern, define acceptable exposure concentrations and understand indoor sources and source strength. This is an area of ongoing research, a number of indoor air pollutants associated with chronic health effects have been identified e.g., PM2.5, radon and others, however progress is hindered by a lack of information on the contribution of different indoor sources, exposure and the role of occupant behaviour. A ventilation strategy for comfort should control unpleasant odours and provide favourable thermal comfort. Any ventilation strategy should be capable of addressing both health and comfort.

6.2.2.2 European Ventilation standards

There are a variety of ventilation standards across the EU (Dimitroulopoulou, 2012, Brelih and Olli., 2011) [REF], most standards specify flow rates for the whole house or specific rooms e.g., wet rooms. The basis for ventilation standards varies, some requirements are based on occupancy, floor area, number of rooms etc. Required whole house ventilation rates and task ventilation rates (range hoods, bathroom extract etc) vary greatly from country to country. In practice ventilation flow rates are influenced by many factors and commissioning is recommended to check that actual ventilation flow rates met design values.

6.3 Other measures to improve indoor air quality

The most obvious solution to improving indoor air quality, is first to avoid the introduction of specific pollutants into the home, *Source Control*, for example by eliminating open combustion with fossil fuels for heating or cooking helps reduce the emission of combustion related pollutants.

Air Cleaning and filtering by removal of gaseous or particulate pollutants through an air filter or other medium, of course the energy and health impacts of the filtration techniques available vary widely (ASHRAE, 2015) [REF].

Enclosure or isolation of the pollutant source, for example placing a boiler in a garage remote from the house.

7 Research needs

The final section of AIVC Tech note No. 38 summarises challenges, tasks and research needs in the area of Residential Ventilation and Health. The research needs were compiled following two AIVC workshops (2012) with input from experts working in the areas of ventilation, medicine, epidemiology, buildings systems and building policies. The research priorities were also subject to external review at a 3rd AIVC workshop in 2012. Research topics are relevant to the entire building stock and include basic research needs and also solutions for achieving good indoor air quality.

Basic research needs for achieving good indoor air quality in buildings with low risk for health (with a particular focus on highly energy efficient buildings) are listed in the following starting with the needs that should be addressed at first and considered to have the highest priority:

1. Studying the impact of user behaviour on the control of indoor air quality.
2. Development, implementation and harmonization of new, advanced and harmonized methods for monitoring indoor air quality, and health and comfort effects in buildings.
3. Definition of ventilation parameters and requirements for buildings that are harmonized across all relevant policies, regulations and standards.
4. Identification of pollutants of concern especially in highly energy efficient buildings.
5. Determination of occupant expectations of highly energy efficient buildings in relation to indoor air quality and whether they differ from those of traditional and retrofitted buildings.
6. Investigation of differences in health risks in traditional buildings, energy retrofitted buildings and new highly energy efficient buildings.

7. Examination of the impact of non-building related variables (gender, age, social and work status) on health and comfort requirements.
8. Development of an improved and simplified toxicological characterization of building related pollutants.
9. Identification of sources of pollutants of concern in indoor environment

Tasks and issues that need to be addressed in relation to solutions, processes and technologies required for achieving good indoor air quality in buildings with particular focus on highly energy efficient buildings and reducing health risks are listed in the following starting with the tasks having the highest priority:

1. Evaluation of new advanced ventilation strategies based on health and comfort criteria.
2. Identification of barriers that block innovation in the building process having the goal of achieving good indoor air quality.
3. Identification of methods that will encourage the active involvement of building occupants in creation of healthy and comfortable indoor air quality (methods affecting occupants' operational habits and activities).
4. Studying the potential of flexible building design to account for and respond to variables influencing indoor air quality.
5. Comparison of performance of natural ventilation, mechanical ventilation, ventilation on demand and any other ventilation solutions in particular in the context of highly energy efficient buildings, taking into account the purpose and circumstances of their use.
6. Development and implementation of harmonized methodology for measurements and health-based evaluation of chemical emissions from building materials and consumer products, and comprehensive performance classes of products including the evaluation of the impact of the labelling of building materials and consumer products in the context of healthy, comfort and highly energy efficient buildings.

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The Air Infiltration and Ventilation Centre provides technical support in air infiltration and ventilation research and application. The aim is to promote the understanding of the complex behaviour of the air flow in buildings and to advance the effective application of associated energy saving measures in the design of new buildings and the improvement of the existing building stock.