International Energy Agency

Indoor Air Quality Design and Control in Low-energy Residential Buildings- Annex 68 | Subtask 1: Defining the metrics

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AIVC Contributed Report 17

September 2017

EBC is a programme of the International Energy Agency (IEA)

International Energy Agency

Indoor Air Quality Design and Control in Low-energy Residential Buildings-Annex 68 | Subtask 1: Defining the metrics

In the search of indices to evaluate the Indoor Air Quality of low-energy residential buildings

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Preface

The International Energy Agency

The International Energy Agency (IEA) was established in 1974 within the framework of the Organisation for Economic Co-operation and Development (OECD) to implement an international energy programme. A basic aim of the IEA is to foster international co-operation among the 29 IEA participating countries and to increase energy security through energy research, development and demonstration in the fields of technologies for energy efficiency and renewable energy sources.

The IEA Energy in Buildings and Communities Programme

The IEA co-ordinates international energy research and development (R&D) activities through a comprehensive portfolio of Technology Collaboration Programmes. The mission of the Energy in Buildings and Communities (EBC) Programme is to develop and facilitate the integration of technologies and processes for energy efficiency and conservation into healthy, low emission, and sustainable buildings and communities, through innovation and research. (Until March 2013, the IEA-EBC Programme was known as the Energy in Buildings and Community Systems Programme, ECBCS.)

The research and development strategies of the IEA-EBC Programme are derived from research drivers, national programmes within IEA countries, and the IEA Future Buildings Forum Think Tank Workshops. The research and development (R&D) strategies of IEA-EBC aim to exploit technological opportunities to save energy in the buildings sector, and to remove technical obstacles to market penetration of new energy efficient technologies. The R&D strategies apply to residential, commercial, office buildings and community systems, and will impact the building industry in five focus areas for R&D activities:

- Integrated planning and building design
- Building energy systems
- Building envelope
- Community scale methods
- Real building energy use

The Executive Committee

Overall control of the IEA-EBC Programme is maintained by an Executive Committee, which not only monitors existing projects, but also identifies new strategic areas in which collaborative efforts may be beneficial. As the Programme is based on a contract with the IEA, the projects are legally established as Annexes to the IEA-EBC Implementing Agreement. At the present time, the following projects have been initiated by the IEA-EBC Executive Committee, with completed projects identified by (*):

Annex 1:	Load Energy Determination of Buildings (*)
Annex 2:	Ekistics and Advanced Community Energy Systems (*)
Annex 3:	Energy Conservation in Residential Buildings (*)
Annex 4:	Glasgow Commercial Building Monitoring (*)
Annex 5:	Air Infiltration and Ventilation Centre
Annex 6:	Energy Systems and Design of Communities (*)
Annex 7:	Local Government Energy Planning (*)
Annex 8:	Inhabitants Behaviour with Regard to Ventilation (*)
Annex 9:	Minimum Ventilation Rates (*)
Annex 10:	Building HVAC System Simulation (*)
Annex 11:	Energy Auditing (*)
Annex 12:	Windows and Fenestration (*)
Annex 13:	Energy Management in Hospitals (*)
Annex 14:	Condensation and Energy (*)
Annex 15:	Energy Efficiency in Schools (*)

Annex 16: BEMS 1- User Interfaces and System Integration (*)
Annex 17: BEMS 2- Evaluation and Emulation Techniques (*)
Annex 18: Demand Controlled Ventilation Systems (*)
Annex 19: Low Slope Roof Systems (*)
Annex 20: Air Flow Patterns within Buildings (*)
Annex 21: Thermal Modelling (*)
Annex 22: Energy Efficient Communities (*)
Annex 23: Multi Zone Air Flow Modelling (COMIS) (*)
Annex 24: Heat, Air and Moisture Transfer in Envelopes (*)
Annex 25: Real time HVAC Simulation (*)
Annex 26: Energy Efficient Ventilation of Large Enclosures (*)
Annex 27: Evaluation and Demonstration of Domestic Ventilation Systems (*)
Annex 28: Low Energy Cooling Systems (*)
Annex 29: Daylight in Buildings (*)
Annex 30: Bringing Simulation to Application (*)
Annex 31: Energy-Related Environmental Impact of Buildings (*)
Annex 32: Integral Building Envelope Performance Assessment (*)
Annex 33: Advanced Local Energy Planning (*)
Annex 34: Computer-Aided Evaluation of HVAC System Performance (*)
Annex 35: Design of Energy Efficient Hybrid Ventilation (HYBVENT) (*)
Annex 36: Retrofitting of Educational Buildings (*)
Annex 37: Low Exergy Systems for Heating and Cooling of Buildings (LowEx) (*)
Annex 38: Solar Sustainable Housing (*)
Annex 39: High Performance Insulation Systems (*)
Annex 40: Building Commissioning to Improve Energy Performance (*)
Annex 41: Whole Building Heat, Air and Moisture Response (MOIST-ENG) (*)
Annex 42: The Simulation of Building-Integrated Fuel Cell and Other Cogeneration Systems (FC+COGEN-SIM) (*)
Annex 43: Testing and Validation of Building Energy Simulation Tools (*)
Annex 44: Integrating Environmentally Responsive Elements in Buildings (*)
Annex 45: Energy Efficient Electric Lighting for Buildings (*)
Annex 46: Holistic Assessment Tool-kit on Energy Efficient Retrofit Measures for Government Buildings (EnERGo) (*)
Annex 47: Cost-Effective Commissioning for Existing and Low Energy Buildings (*)
Annex 48: Heat Pumping and Reversible Air Conditioning (*)
Annex 49: Low Exergy Systems for High Performance Buildings and Communities (*)
Annex 50: Prefabricated Systems for Low Energy Renovation of Residential Buildings (*)
Annex 51: Energy Efficient Communities (*)
Annex 52: Towards Net Zero Energy Solar Buildings (*)
Annex 53: Total Energy Use in Buildings: Analysis & Evaluation Methods (*)
Annex 54: Integration of Micro-Generation & Related Energy Technologies in Buildings (*)
Annex 55: Reliability of Energy Efficient Building Retrofitting - Probability Assessment of Performance & Cost (RAP-RETRO) (*)
Annex 56: Cost Effective Energy & CO2 Emissions Optimization in Building Renovation
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Annex 71: Building Energy Performance Assessment Based on In-situ Measurements
Annex 74: Energy Endeavour

Working Group - Energy Efficiency in Educational Buildings (*)
Working Group - Indicators of Energy Efficiency in Cold Climate Buildings (*)
Working Group - Annex 36 Extension: The Energy Concept Adviser (*)
Working Group - Survey on HVAC Energy Calculation Methodologies for Non-residential Buildings

Executive Summary

The objective of present work was to develop the metric that assess the performance of solutions securing high indoor air quality in low-energy (modern) residential buildings. This was achieved by summarizing data on the levels and types of gaseous pollutants and particulate matter in low-energy buildings and comparing them with the existing exposure limits for pollutants. The result is a graphical signature showing whether any pollutant level exceeds short-term and long-term exposure limits, and indicating the associated healthy life years lost; the signature is supplemented with the information on energy use in a building.

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1. Introduction

1.1. About IEA EBC Annex 68

The overall objective of the IEA EBC Annex 68 is to provide scientific basis usable for optimal and practically applicable design and control strategies for better Indoor Air Quality (IAQ) in residential buildings. These strategies are intended to ensure minimal possible energy use. The aim of Annex 68 is to gather the existing data and provide new data on pollution sources in buildings, to model the indoor hygrothermal conditions, air quality and thermal systems, and to find the methods to optimize ventilation and air-conditioning. Annex 68 is focused on low-energy residential buildings.

There are numerous different national definitions and concepts describing low-energy buildings. Some, for example, focus on the renewable energy production on-site (NorthPass, 2012) and discuss not only the reduction of energy use. All definitions have in common that a low-energy building should achieve better or significantly better energy performance compared to a traditional contemporary building practice to reduce the use of fossil fuels such as oil, gas and coal (Thullner, 2010). In some countries or regions, low-energy buildings are defined by the building codes or in relation to the energy standard. It may happen that one building, which can be classified as low-energy in one country, use more energy than a standard building in another country. Also, standards have improved with time and the low-energy standards from the past is likely to be a standard today (Laustsen, 2008). In the present project, a building is considered as low-energy when it has a better energy performance than the typical new building following the minimum standards defined in building regulations at a given point of time in a given country.

The work of the Annex is organized in five subtasks (Figure 1): Subtask 1 is setting up the metrics to assess the performance of low-energy buildings as regards indoor air quality combining the aspirations to achieve very high energy performance without compromising indoor environmental quality. Subtask 2 is gathering the existing knowledge and providing new data about indoor air pollutants in relation to combined heat, air and moisture transfer. Subtask 3 is identifying and developing modelling tools that can assist designers and managers of buildings in accounting for IAQ. Subtask 4 is developing design and control strategies for energy efficient ventilation in residential buildings that will not lessen indoor air quality. Subtask 5 is conducting field measurements to examine and optimize different control and design strategies.

As energy performance of buildings increases, the share of embodied energy in the materials used in building renovation becomes more important. Therefore, the methodology to integrate the assessment of embodied energy use will be outlined in Annex 56.

The starting point and one of the primary purposes of Annex 68 is Subtask 1. It sets the frame for defining the target pollutants and the metrics needed to quantify IAQ level of low-energy residential buildings. This report is a summary of the approaches, developments and results achieved in this subtask.

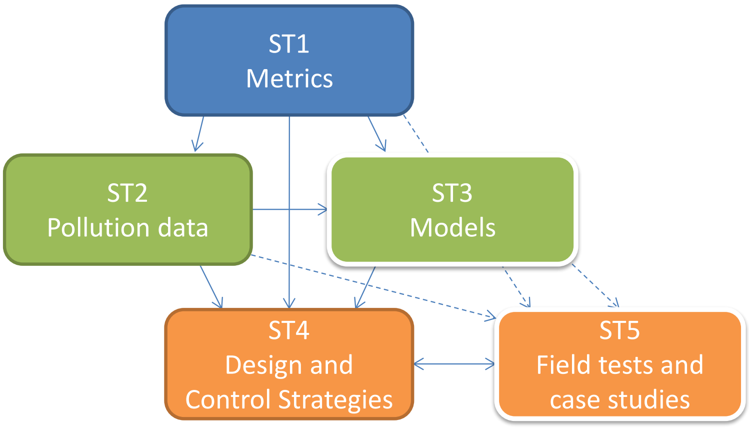


Figure 1: Schematic overview of the subtasks in Annex 68 and their interrelations.

1.2. Description of Subtask 1

The lack of an index (or a marker or a metric), which quantitatively describes the IAQ and allows its evaluation against the indices describing energy use, can be regarded as one of the major obstacles for achieving the further and closer integration of energy and IAQ strategies in building design and optimization. Such an index/metric would allow examination of different strategies for achieving high IAQ in relation to their energy performance and greenhouse gas emissions.

One important complication of developing such index is that hundreds of chemical and biological pollutants are found in indoor air, including residential environments, and there is no consensus on which compound could serve the purpose of such index, or how to integrate these compounds into one index or how such an index could be developed based on the available information on the effects of pollutants on humans; for many of pollutants such information is still lacking.

One approach that can be exercised is to identify some pollutants that are known to affect occupants' health and use them to construct the index. Then the index can be updated progressively the more data on the effects of new pollutants become available.

To define the index the following approach was proposed. First, target pollutants need to be selected. These are the pollutants that are listed by cognizant authorities as harmful and hazardous for humans during the short-term (<24h) or long-term (>week) exposures. Then the presence of these compounds in residential environments need to be checked and whether the levels exceed peak concentrations (if acute short-term effects are considered) or average concentrations (in case the long-term chronic effects are taken into account) as recommended by the cognizant authorities; these levels are usually defined for non-sensitive population. These levels will be used to define an indoor air quality index. Additionally there can be the pollutants suspected to have negative effect on IAQ, but are not listed by health authorities. They need to be identified as well. This can be attained by reviewing the literature. Their relevance needs to be assessed according to the limits of exposure and prevalence in residential buildings. The selected pollutants relevant for IAQ and the negative effects produced on humans need to be considered to construct the index. In this process, the existing indoor air quality metrics need to be reviewed to identify past integration approaches used and whether any of them can be used to define the best science-based indices for the evaluation of indoor air pollution. Finally, the value of the index or set of indices relative to IAQ should be weighed against additional energy consumption needed to improve IAQ in comparison with the current standard practices, such as increased fan operational consumption induced by higher air change rates or additional particle/gas filters, or use of other air cleaning devices.

1.3. Outline of the work of Subtask 1

Following the approach described to define the IAQ index the working plan executed in Subtask 1 consisted of the subsequent steps (Figure 2):

- Collection of data on indoor air pollution in residential buildings with a particular focus on low-energy buildings to provide an overview of the exposure of occupants to contaminants in residential buildings and to identify differences, if any, between low-energy buildings and the buildings that cannot be termed as low-energy (representative of the current building stock).
- Compilation of the pollutant Exposure Limit Values (ELV) relevant for the current project.
- Identification of target pollutants relative to indoor air quality.
- Surveying IAQ indices developed previously.
- Defining the metric(s) that can be used to achieve the objectives of Annex 68 project considering the aspect of energy consumption.

This subtask collects a large amount of data on pollutant concentration in residences and Exposure Limit Values (ELV) and uses them in developing the proposed index. The structure of the present report is as follows:

Part 1 is dedicated to summary of documented pollution levels in residential buildings. Available data from Europe (France, Belgium and Sweden), Asia (Japan, China, Hong Kong, Taiwan and Korea), Oceania (Australia) and America (USA) have been collected and reviewed. Only the data from six countries (France, Belgium, Japan, China, Australia and USA) were available in parallel to studies that measure both in non-low-energy and low-energy buildings.

Part 2 is summarizing the Indoor Air Quality Guideline values collected by the project participants: World Health Organization, Europe, Austria, Belgium, USA – California, Canada, China, France, Germany, Hong-Kong, Japan, Korea, Portugal and United Kingdom. To supplement them, the Lowest Concentration of Interest (LCI) values that are used to regulate the chemical emissions of VOC from construction products into indoor air, have also been summarized.

Part 3 presents the literature review on IAQ indices proposed previously differentiating them by different sets of target pollutants used, reference concentration levels and aggregation schemes.

Part 4 of this report defines the metrics that can be used in the present project based on the critical analysis of the previous approaches to define IAQ metrics to evaluate the IAQ in relation to the energy consumption.

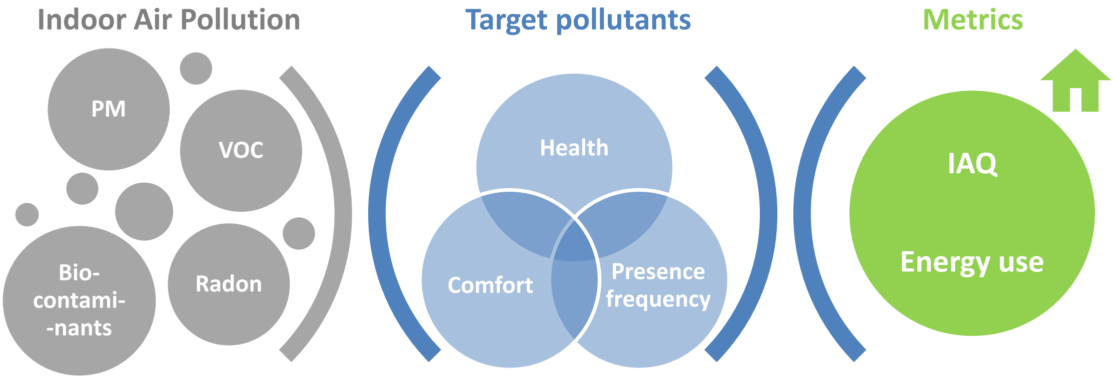


Figure 2: Schematic overview of the deliverables of Subtask 1 of Annex 68.

2. Pollutants in Indoor Air

Indoor air is a complex mixture with typically more than 200-300 pollutants. These pollutants can be classified as gaseous compounds, also called chemical or molecular pollutants (inorganic gases and Volatile Organic Compounds (VOCs)), non-viable particles (Particulate Matter with aerodynamic diameter lower than 10 µm and 2.5 µm (PM10 and PM2.5 respectively)) and bio-contaminants (Fungi and Bacteria). Depending on the objectives of the study, approach and the assessment method of air quality, it is additionally possible to distinguish other subcategories pollutants in indoor air by identifying pollutants that have similar characteristics, e.g. pollutants having similar transfer properties, pollutants having the same nature of induced pathologies, and alike.

Figure 2 shows different categories and sub-categories of indoor air pollutants. However, it may be difficult in some circumstances to fully dissociate each category or sub-category of pollutants. Thus, in the classification illustrated by Figure 3, Semi-Volatile Organic Compounds (SVOCs) can be considered a subcategory of either gaseous or particulate pollutants, or both. Due to their high boiling temperature, these compounds coexist in the condensed (liquid aerosol) and gaseous forms at room temperature. SVOCs are therefore presented as a sub-category but not linked to either of the two main categories i.e. gaseous pollutants or PMs.

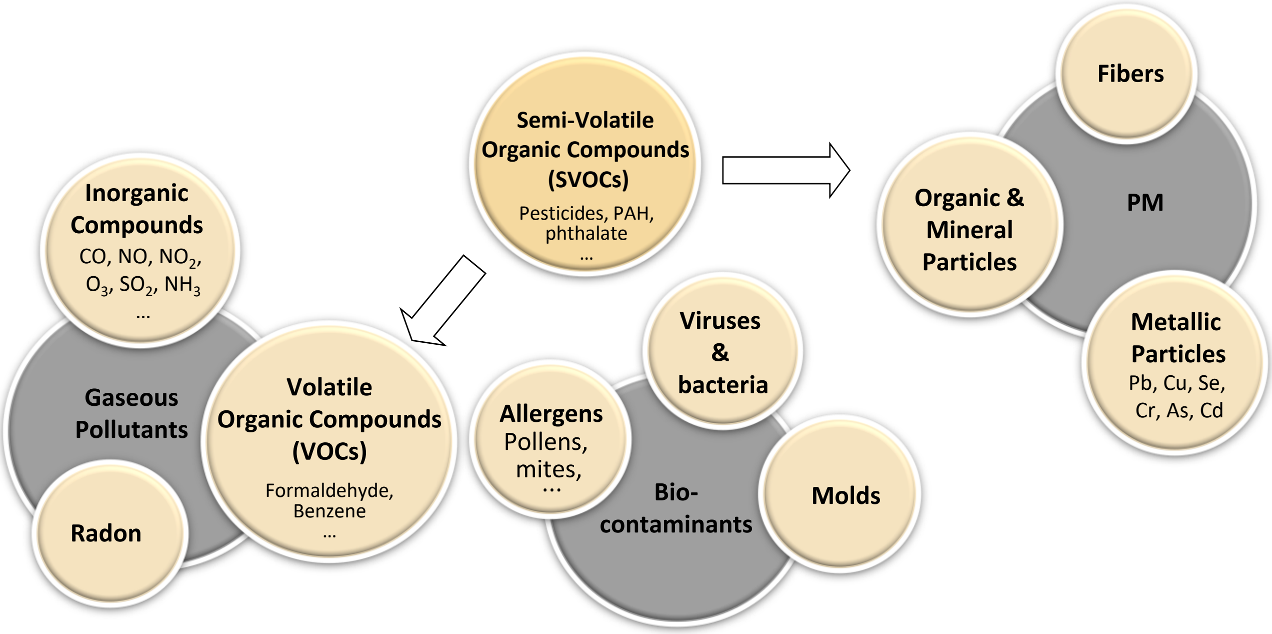


Figure 3: Classification of pollutants in indoor air.

2.1. Gaseous pollutants

2.1.1. Inorganic Compounds

Description: The typical examples of inorganic pollutants in indoor air are nitrogen oxides (NO, NO2), ozone (O3) and carbon monoxide (CO). They enter buildings in the process of airing and ventilating or by air infiltration through the building envelope. These compounds can also be directly emitted in indoor environments by combustion processes: smoking, heaters, burning incense, cooking, etc. in the case of nitrogen oxides and carbon monoxide, and by printers and copiers or other ozone sources in case of ozone.

Effects on humans: From a health point of view, nitrogen oxides and ozone are respiratory irritants; they reduce lung function and worsen chronic respiratory diseases such as asthma and allergies. Carbon monoxide is a blood poison and is completely odorless, even at very high concentrations. Its toxicity is due to its high affinity to bind to red blood cells, which is 270 times greater than that of oxygen. Inhaled CO molecules bind to hemoglobin, or displace oxygen bound to hemoglobin to form a stable compound known as carboxyhemoglobin. The anoxemia (abnormal reduction in the oxygen content of the blood) leads to an insufficient supply of oxygen to the organs, especially the heart and the brain, which can result in light symptoms (nausea, fatigue, headache, difficulty in concentration and memory) or severe ones (syncope, coma and death) depending on the level of CO concentration in the air and duration of exposure. Chronic exposure to carbon monoxide at low concentration in the air is also known to have cardiovascular effects.

2.1.2. Radon

Description: Radon is an odorless gas that originates from natural radioactivity. From the decay of uranium in the earth's crust, radon-222 diffuses to the surface and is emitted into the air. Radon molecules then emit alpha particles (first route of radon exposure to man by ionization and not inhalation). Radon progeny, polonium-218, lead-214, bismuth-214, polonium-214 and finally lead-206 (stable species) are also radioactive compounds, with low lifetime, which are found in the air in the form of particulates small enough to pass through the upper respiratory tract. This process is a second route of exposure to radon by inhalation.

Radon can penetrate into indoor environments by the use of building materials containing radon, by drains (radon is highly soluble in water), but also by direct diffusion from the soil through the slab and leaky building envelope; the latter is a main route causing elevated Radon levels. Indoor air pollution from radon is expressed through its level of activity in Becquerel per cubic meter of air (Bq/m3). Mitigation of radon is usually done independently of other mitigation measures related with IAQ control.

Effects on humans: The World Health Organization (WHO) estimated that between 3% and 14% of all lung cancers are linked to radon depending on the average radon concentration in the country and on the method of calculation (WHO, 2009).

2.1.3. Volatile Organic Compounds (VOCs)

Description: Volatile organic compounds (VOCs) are molecules containing atoms of carbon and hydrogen (hydrocarbons), and possibly oxygen atoms (carbonyl compounds) or chlorine (halogenated compounds), and having a boiling temperature ranging between 50°C and 250°C at atmospheric pressure. The VOC family consists of hundreds of compounds for which emission sources are multiple and have not been completely characterized to date. The sources of VOCs include:

- Ambient air (benzene, ethylbenzene, styrene, toluene, etc.),
- Humans, bioeffluents and hygienic products (acrolein, d-limonene, acetaldehyde, hexanal, etc.).
- Combustion of all kinds, especially smoking and cooking food, contributes to the emission of VOCs in the air (formaldehyde, acetaldehyde, benzene, naphthalene, etc.).
- Numerous cleaning products and room deodorants that use an active ingredient, detergent and/or odorant compounds of the terpene family (for example α-pinene or d-limonene), which are constituents of essential oils (extracted from plants (resins and fruits) or synthesized chemically).
- Electronic equipment, including computers, which generates aldehydes (formaldehyde, veraldehyde, acetaldehyde, etc.) but also heavy hydrocarbons (n-decane, n-undecane) and aromatic compounds (toluene, xylene, styrene, etc.).
- Copiers and printers that emit 1,4-dimethylbenzene, ethylbenzene, toluene, styrene and aldehydes such as benzaldehyde.
- Building materials and decoration products. The nature of the emitted compounds varies within the very wide limits depending on the product used, but virtually all materials, including natural materials (wood, wool used for insulation, etc.) emit VOCs

The number, composition and the high variability of concentrations in indoor environment complicate the assessment of the VOCs' impact on health. Health professionals have argued for years whether the Total Volatile Organic Compounds (TVOC) concentration obtained by integration of pollutant concentrations, was the right parameter to assess the health risks. It is now widely accepted by the scientific community that this concept is no longer valid, because the health effects related to acute or chronic exposures may be different in kind, intensity and severity depending on the compounds (from respiratory or eye irritation to the development of cancer).

Effects on humans: Among the many diseases and other health disorders that VOCs are considered to cause or promote is the so-called Sick Building Syndrome - SBS (Menzies and Bourbeau, 1997), a condition defined by WHO as “a reaction of the majority of building occupants to their indoor environment, a reaction that cannot be directly related to obvious causes such as exposure to an excessive concentration of a known contaminant or an inefficient ventilation system” (WHO, 1995).

2.1.4. Semi-Volatile Organic Compounds (SVOCs)

Description: The semi-volatile organic compounds (SVOCs) found in homes and other living spaces are of different types and originate from many sources:

- Pesticides have many uses in buildings: pest control, household insecticides released into the air as aerosols or from electric diffusers and antibacterial and anti-mildew household products. Building materials can also be a source for contamination of indoor environments by pesticides because of pest control they are subject to pre-market (wood, insulation of plant and animal origin) or by periodic treatments carried out after construction (wood, carpentry, etc.).
- Phthalates are petroleum products that have the ability to soften polymers. They thus are used in many consumer products and plastic materials found in buildings (shower curtains, toys, furniture, floor tiles, etc.).
- Polybrominated diphenyl ethers (PBDEs) are used as flame retardants to treat foams, textiles and electronic components designed for use in buildings.
- Polychlorinated biphenyls (PCBs) released into the atmosphere by industrial effluents are known to be polluting the beds of rivers and streams, contaminating the food chain as a result. These compounds have been used in adhesives and sealants for building construction and therefore can be released into the indoor air.
- Polycyclic aromatic hydrocarbons (PAHs) are emitted into the atmosphere by combustion, including indoor smoking and incense burning, and outdoor combustion engine exhaust. Other potential sources are cooking food and mothballs.

Evaluating the health impact of SVOCs is difficult largely due to their normal boiling point being greater than 250°C, which gives them both very slow emission rates and high adsorption capacity on particles suspended in the air and the surfaces of building materials. This means that the residence time of SVOCs in buildings covers very long time scales and their concentrations in air are so low that they cannot be measured without large and expensive instruments. In addition to the measurement problems, the health risk assessment related to the presence of SVOCs in indoor air is made very difficult by the fact that there are several routes of exposure: inhalation, dermal absorption, and ingestion.

Effects on humans: Despite the difficulty of assessing SVOCs exposure in indoor environments, there is persuasive evidence that they can cause a variety of adverse health effects (Jaakkola and Knight, 2008; Williams and DeSesso, 2010; Shaw, 2010; Hsu et al., 2012; De Coster and van Larebeke, 2012). Several SVOCs have been classified as carcinogens by the International Agency for Research on Cancer (IARC), e.g., chlorpyrifos (previously used for treating bedding of allergic children) and lindane (a fungicide previously used for the treatment of wood), as well as PAHs. SVOCs are endocrine disruptors, which cause disturbances of the reproductive, respiratory, central nervous, metabolic and cardiovascular systems.

2.2. Particles and Fibers

Description: The sources of particles and fibers in indoor environments are numerous. Penetration through building envelope, during airing or because of ventilation of buildings brings particulate matter from outdoors. The main indoor sources of particles include combustion of all kinds, printing, use of cosmetics (lacquers, sprays), erosion of coating materials, presence of occupants and occupants' activities. The dose of particles inhaled by an individual depends on the concentration and particle size distribution of the aerosol suspended in air. Only particles with an aerodynamic diameter less than 10 µm, which are referred to as PM10, are of interest to health risk assessment, since they are small enough to be inhaled. Particles with an aerodynamic diameter less than 2.5 µm (PM2.5), called fine particles, are small enough to pass through the upper respiratory tract and reach the lungs. Finally, submicron particles (PM1), called very fine particles, pass through the alveoli and therefore penetrate deep inside the body. This is the same with nanoparticles (PM0.1), also called ultrafine particles, which are used ubiquitously in industrial applications.

Figure 4 shows the size range of particles emitted in the air depends on their sources. It can be noted that the micro-organisms, especially bacteria and viruses, are particles of a very small size, which can enter the body by inhalation. It can also be noted that cigarette smoke represents a wide range of submicron particle sizes.

Effects on humans: Major diseases and disorders associated with exposure to particulate matter are impaired lung function, chronic obstructive pulmonary disease, cardiovascular diseases and accidents, as well as lung cancer. In the specific case of fibers, asbestos is responsible for pulmonary fibrosis and lung and pleura cancers in individuals directly exposed to this material.

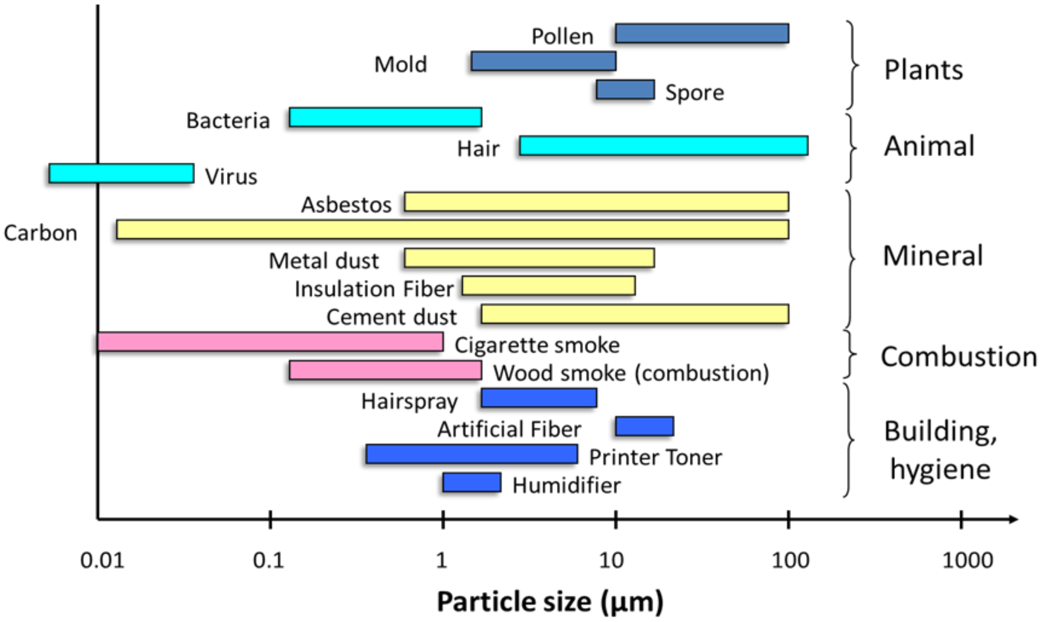


Figure 4: Size of particles suspended in indoor air according to their origin (Owen et al., 1990).

2.3. Bio-contaminants

2.3.1. Viruses and bacteria

Description: Viruses and bacteria are carried by plants, soil, humans and animals. Depending on the organism, transmission from one individual to another may occurs by direct contact, by inhalation of fine contaminated liquid particles produced by coughing, sneezing and speaking in air, or by fomites, i.e. contaminated surfaces. Fomite transmission may occur, for example, when an infected individual coughs into their hand and then touches a door handle that is subsequently touched by a susceptible individual who transfers infectious organisms to their mouth or eye mucosa. The only case where the building itself can be regarded as a source is the special case of Legionella but it is more a problem of bad maintenance of air-conditioning system and hot water storage. There are still many unknowns about the life expectancy of these species outside of their aqueous carrier, about their propensity to reproduce or to be destroyed on material surfaces. On the basis of knowledge from biology, several authors (Webb, 1959; Bateman et al., 1962; Strange and Cox, 1976; Cox, 1989; Mohr, 1991 or more recently ASHRAE, 2012) have pointed to the importance of factors such as temperature, moisture, ozone concentration on these species' life expectancy but there is a lack of statistical data on the viability of deposited species on real building materials.

Effects on humans: Although many viruses and bacteria do not cause disease or harm, some can attack cells and multiply, causing an infection within the body.

2.3.2. Allergens

Description: The allergens found in indoor air have diverse backgrounds and have very different physical characteristics:

- Pollens are particles larger than 10 µm in aerodynamic diameter, which are filtered by the building envelope and typical filters in the ventilation system or simply by deposition on the surface of ducts and other components of the installation. To this end, confinement indoors is an effective means of protection for people with allergies and asthma during pollen peak.
- Higher concentrations of dust mite allergens (Der p1 and Der f1) are measured in bedding and materials or furniture holding the dust (carpets, stuffed animals...) as dust mites feed on organic detritus such as flakes of shed human skin.
- Of all the allergies to pets (dog, cat, horse, hamster, etc.), the cat allergy is undoubtedly the most severe in terms of public health. Cat allergen presents characteristics very favorable to its release into the environment. The allergen is not cat hair itself, but a protein (Fel d1) contained in the saliva. This allergen is carried by particles smaller than 2.5 µm, which remain suspended in air and can therefore be dispersed throughout the rooms of a building. Moreover, as these particles are electrically charged, they easily attach to clothing, participating in this way in the contamination process of spaces without cat. Studies show that the concentration of Fel d1 allergen is greater in homes where there is a cat, but is often detectable in homes or other living spaces where there is no cat such as schools. Cat allergens are one of the most common causes of respiratory allergy in the world.

Effects on humans: Allergens are considered triggers for asthma, hay fever, and other respiratory illnesses and may also cause eye and skin irritation.

2.3.3. Molds

Description: Molds (or filamentous fungi) enter buildings through openings (doors, windows, ventilation) or by occupants (clothing, skin, hair). They become visible when germinating and proliferating on the surface of materials. Three conditions must be met: appropriate temperature and moisture levels and a suitable nutritional support (WHO, 2010a). Assuming that the temperature condition is always valid for heated buildings in the winter, molds grow preferentially on materials with high humidity due to water leaks or cooler building components (where relative humidity is higher than 80% above the surface) and organic matter that can serve as nutrients: wood cellulose, paper or paperboard, materials containing starch, very dusty materials. Mold exposure can occur by breathing or by direct contact with skin or mucous membranes (nose, mouth, and ears). The presence of molds in commercial buildings has been identified as a determinant of Sick Building Syndrome.

Effects on humans: Molds are also associated with asthma and allergic rhinitis and may cause sensitization or worsen allergic disease (WHO, 2010a). Infections of the respiratory tract, eyes and skin that are directly caused by mold in buildings, such as poisoning caused by toxins secreted by molds, are very rare and are only a concern for people at risk or vulnerable subgroups of the population.

3. Indoor air pollution in low-energy residential buildings

This section provides an overview of the indoor pollutants and their concentration levels measured in residential buildings in order to identify differences, if any, between the pollutants measured in buildings designed constructed using current standard practice and the practice significantly reducing use of energy resulting in so-called low-energy residential buildings. To make a distinction between long-term and short-term exposures that could result in the chronic and acute effects, both peak and average concentration levels of pollutants were collected. The potential sources of good/bad air quality in residential buildings are not the purpose of this section and they are not discussed.

3.1. Literature review

Table 1 and Table 2 summarize identified data on the types of pollutants and their concentrations measured in the residential building stock termed by the researchers who collected the identified data as low-energy stock, and all the other buildings not termed this way (which will be called in this report as non-low-energy). These data have been collected by searching for published articles in the scientific databases and by communicating with the researchers participating in the conferences dealing with indoor air problems (AIVC 2015, Indoor Air 2016 and ASHRAE IAQ 2016). The literature review has been limited to peer-reviewed articles and national research projects in the period from 2006 to 2016 i.e. studies performed in the last 10 years, i.e. the period when the concept of **low-energy buildings** has appeared in the standards and building codes in Europe following the implementation of the European Directive 2002/91/EC (EPBD, 2003), the ENERGY STAR label defined by ASHRAE (2004) and IECC (2004).

Some studies that were identified compared pollutant levels in non-low-energy and the low-energy residential buildings. Examples include: Cheng et al. (2010) for Australia, Stranger et al. (2012) for Belgium, Park and Ikeda (2006) for Japan and Logue et al. (2011a) for USA. In the case of Logue et al. (2011a), about half of exposure levels compiled by the authors come from US non-low-energy buildings, about 10% from US low-energy buildings and the remainder from other industrialized countries (Canada, Germany, France Spain, UK, Denmark, Finland, Japan, Hong Kong, South Korea, etc.). Other studies reported measurements in only one type of building. Examples include Kirchner et al. (2006a) and Derbez et al. (2015) for France and Zhang et al. (2013), Guo et al. (2009), Du et al. (2014a, 2014b) and Liang et al. (2014) for China.

Less data regarding the pollutants and their concentrations were identified for the low-energy residential buildings (Table 2) because there are fewer buildings of that type. As a result, conclusions regarding the differences between the low-energy buildings and the non-low-energy buildings can be biased and incomplete and thus should be considered with caution.

Table 1. Studies identified in the current report providing the measurements of pollutants in non-low-energy residential buildings.

	Reference	**# of measured pollutants**	**# / type of residential buildings**
Australia	Cheng et al. (2010)	13	100 dwellings
Belgium	Stranger et al. (2012)	23	356 homes
China	Zhang et al. (2013) – China 1	5	1500 homes
	Guo et al. (2009) – China 2	17	94 homes
	Du et al. (2014a) – China 3	15	296 homes
	Du et al. (2014b) – China 4	4	267 homes
France	Kirchner et al. (2006a)	56	567 houses and apartments
Hong-Kong	Guo et al. (2009)	17	100 homes
Japan	Azuma et al. (2007) – Japan 1	93	Compilation of different studies
	Guo et al. (2009) – Japan 2	17	97 homes
	Park and Ikeda (2006) – Japan 3	26	810 single-family houses + 273 apartments
Korea	Guo et al. (2009)	17	96 homes
Sweden	Langer and Beko (2013)	14	157 single-family houses + 148 apartments
Taiwan	Guo et al. (2009)	17	100 homes
USA	Logue et al. (2011a)	69	18278 homes (46% from USA and 54% from other industrialized countries)

Table 2. Studies identified in the current report providing the measurements of pollutants in new and certified low-energy residential buildings; the low-energy status was defined by the authors of these reports/measurements.

	Reference	**# of measured pollutants**	**# / type of residential buildings**
Australia	Cheng et al. (2010)	12	40 dwellings
Belgium	Stranger et al. (2012)	19	51 homes
China	Du et al. (2014b)	3	266 houses and apartments
France	Derbez et al. (2015)	22	57 houses and apartments
Japan	Park and Ikeda (2006)	26	219 single-family houses + 66 apartments
USA	Logue et al. (2011a)	31	2362 homes (9% from USA and 91% from other industrialized countries)

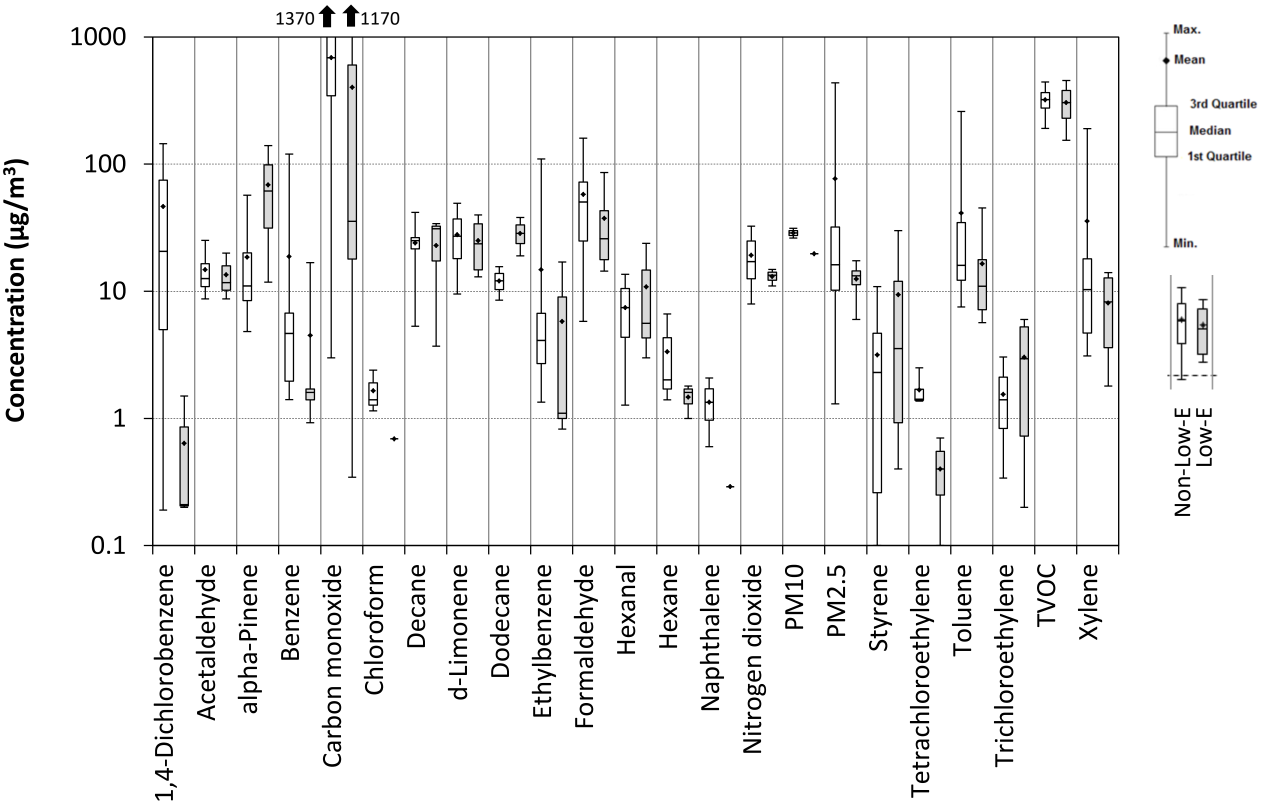


Figure 5: Average concentrations of VOCs measured in the residential buildings; data from the studies listed in Table 1 and Table 2. For each pollutant, left unshaded symbols are for non-low-energy buildings and right shaded symbols correspond to low-energy residential buildings.

Figure 5 shows an overview of the average pollutant concentration from the studies listed in Table 1. The data of Logue et al. (2011a) were not included to avoid counting the same values twice: they include some of the data from the other studies listed as non-low-energy buildings above. As expected, there is a large variation of pollutant concentration indoors as a result of different levels of outdoor pollution (mainly in Asia), indoor sources (in all countries), ventilation rates, and ventilation systems (with respect to the special filtration and air cleaning technologies). Among the 23 pollutants included, 17 have lower average concentrations in low-energy residential buildings. In particular, three of these pollutants elicit a significant decrease of their concentrations: 1,4 dichlorobenzene, carbon monoxide and toluene. Three pollutants have higher concentrations in low-energy residential buildings: α-pinene, dodecane and styrene. The lists were made of the top twenty pollutants with the highest average and maximum concentration in the non-low-energy residential buildings (**Error! Reference source not found.** and Table 4). In these two tables, the data for low-energy residential buildings collected in the present work and for non-low-energy buildings in 1994 by Brown et al. (1994) are included in the tables, if available, for comparison. For the most part, average concentrations in the non-low-energy buildings of 1994 were lower than in the newer non-low-energy buildings identified for the purpose of the present report. Maximum concentrations in non-low-energy buildings of 1994 were higher than those measured in the two categories of buildings identified for the purpose of the present report. One exception to this trend is for benzene that is found to be of high concentration in the non-low-energy buildings because of the inclusion of data from China. Pollutant concentrations (both average and maximum) are lower in low-energy buildings compared to non-low-energy buildings.

Table 3. Twenty pollutants with the highest average concentration in the non-low-energy residential buildings identified for the purpose of the present report compared with the concentrations measured in the low-energy buildings identified for this report as well as in the non-low-energy buildings summarized by Brown et al (1994).

Name	**Non-low-energy buildings (present study)**	**Low-energy buildings (present study)**	**Non-low-energy buildings (Brown et al., 1994)**
Carbon dioxide	1700	499	-
Carbon monoxide	686	402	-
TVOC	320	305	-
Ethanol	203	-	120
PM2.5	77	12	-
Heptane	63	7	-
Formaldehyde	58	37	-
1-Butanol	53	-	-
1,4-Dichlorobenzene	46	1	8
Toluene	41	16	37
Xylene	36	8	18
Acetylacetone	35	-	-
Radon	32	36	-
Acetone	29	-	32
PM10	29	20	-
d-Limonene	28	25	21
Decane	24	23	5
Nonane	20	13	5
Nitrogen dioxide	19	13	-
Benzene	19	4	8

Table 4. Twenty pollutants with the highest maximum concentration in the non-low-energy residential buildings identified for the purpose of the present report compared with the concentrations measured in the low-energy buildings identified for the present report as well as in the non-low-energy buildings summarized by Brown et al (1994).

Name	**Non-low-energy buildings (present study)**	**Low-energy buildings (present study)**	**Non-low-energy buildings (Brown et al., 1994)**
Carbon monoxide	1370	1170	-
TVOC	443	455	-
PM2.5	436	17	-
Heptane	295	9	-
Toluene	260	45	320
Xylene	190	14	178
Formaldehyde	160	86	-
1-Butanol	148	-	-
1,4-Dichlorobenzene	145	2	160
Acetone	31	-	99
d-Limonene	49	40	450
Decane	42	34	470
Nonane	34	15	220
Nitrogen dioxide	33	15	-
Benzene	120	17	70

Sections 3.2 – 3.7 compare indoor pollution levels in non-low-energy and low-energy buildings at the country level for the countries listed in Table 2; the purpose is to identify the differences in terms of the concentration levels measured in the non-low-energy and the low-energy buildings and not the sources of these differences. To examine the effects on the long-term (chronic) exposures, average (annual median or mean) values of concentration are presented. To assess the effects on short-term (acute) exposures, maximum measured concentrations were used if available.

3.2. Australia

As illustrated in Figure 6 and Figure 7, the measured pollutant concentrations in low-energy buildings are comparable to or slightly lower than in the non-low-energy ones. In case of average concentrations representative for chronic exposures, only formaldehyde concentration is found to be higher in low-energy buildings. In case of peak concentrations representative of acute exposures, those in low-energy buildings exceed of the concentrations in non-low-energy buildings for PM2.5 and toluene. The data for ozone are not statistically significant as measurements for only two non-low-energy and low-energy dwellings were available.

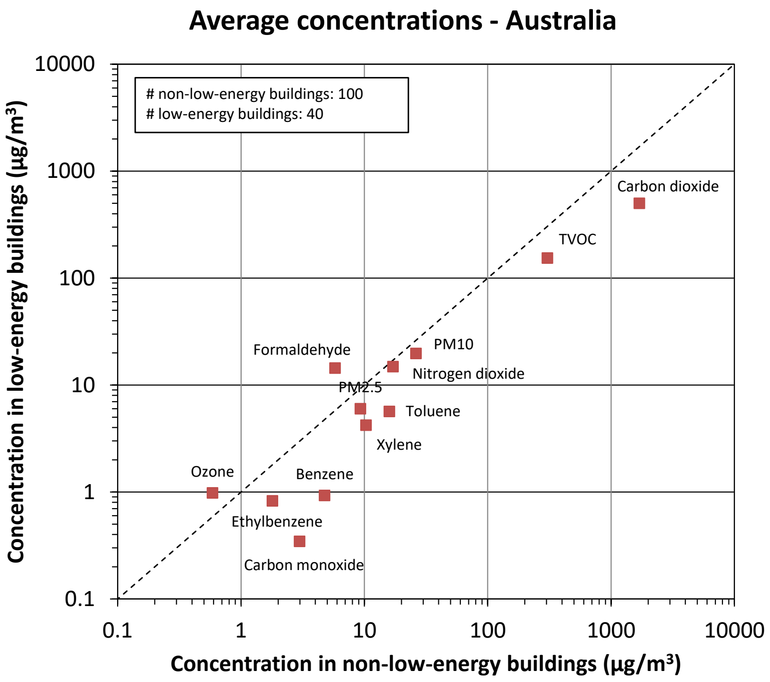


Figure 6: Annual average concentrations of pollutants measured in the low-energy residential buildings compared with the concentrations measured in non-low-energy residential buildings in Australia (Cheng et al., 2010).

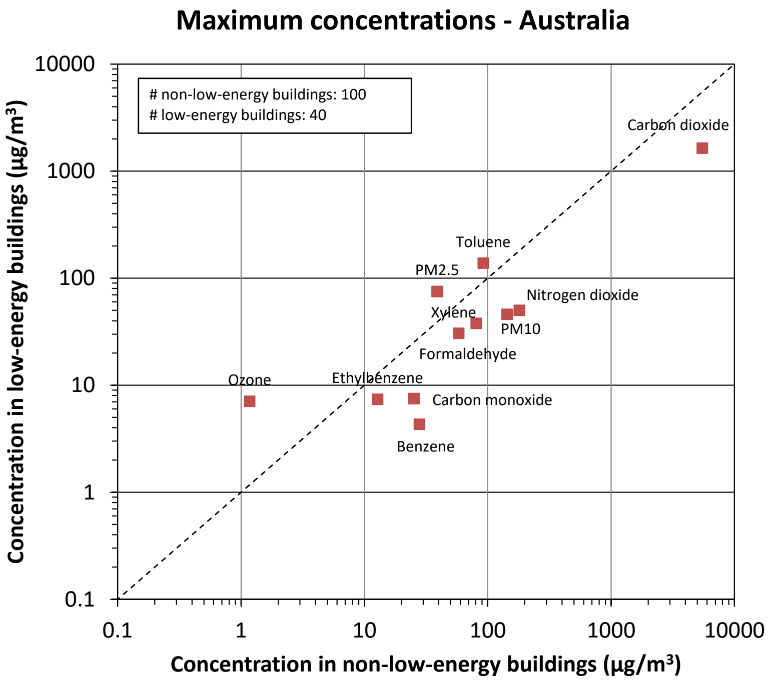


Figure 7: Maximum concentrations of pollutants measured in the low-energy residential buildings compared with the concentrations measured in non-low-energy residential buildings in Australia (Cheng et al., 2010).

3.3. Belgium

Annual concentrations of pollutants measured in low-energy buildings in Belgium (data for the Flanders region) are the same or lower that the annual concentrations in the non-low-energy buildings except for heptane, which is three times higher, and styrene, which is also slightly higher (Figure 8). All maximal concentrations are much lower in the low-energy buildings; only heptane is higher (Figure 9).

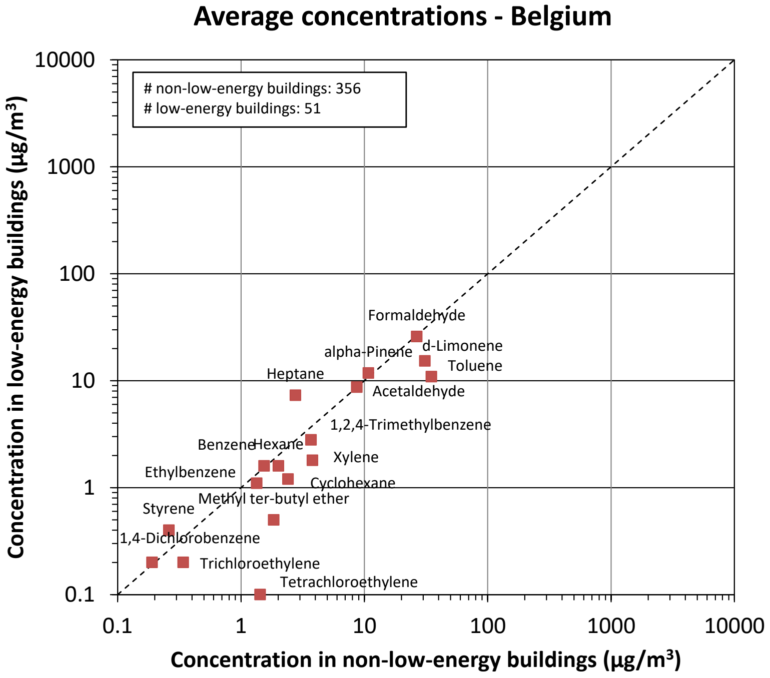


Figure 8: Annual average concentrations of pollutants measured in the low-energy residential buildings compared with the measured concentrations in non-low-energy residential buildings in Belgium (Stranger et al., 2012).

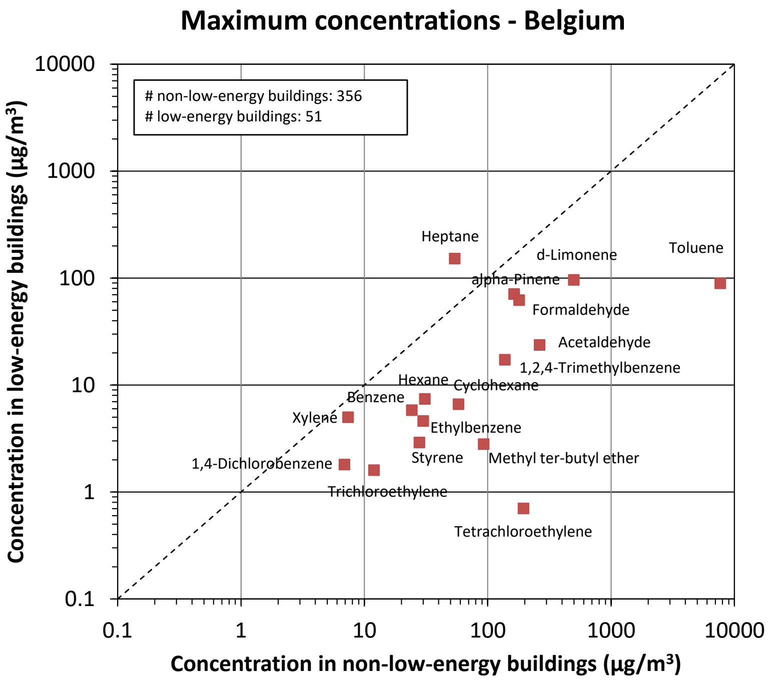


Figure 9: Maximum concentrations of pollutants measured in the low-energy residential buildings compared with the concentrations measured in non-low-energy residential buildings in Belgium (Stranger et al., 2012).

3.4. China

As regards concentrations of pollutants in low-energy buildings in China that can be compared with the concentrations in non-low-energy buildings, the data are available only for benzene, toluene, and xylene. Their concentrations were higher in the low-energy buildings.

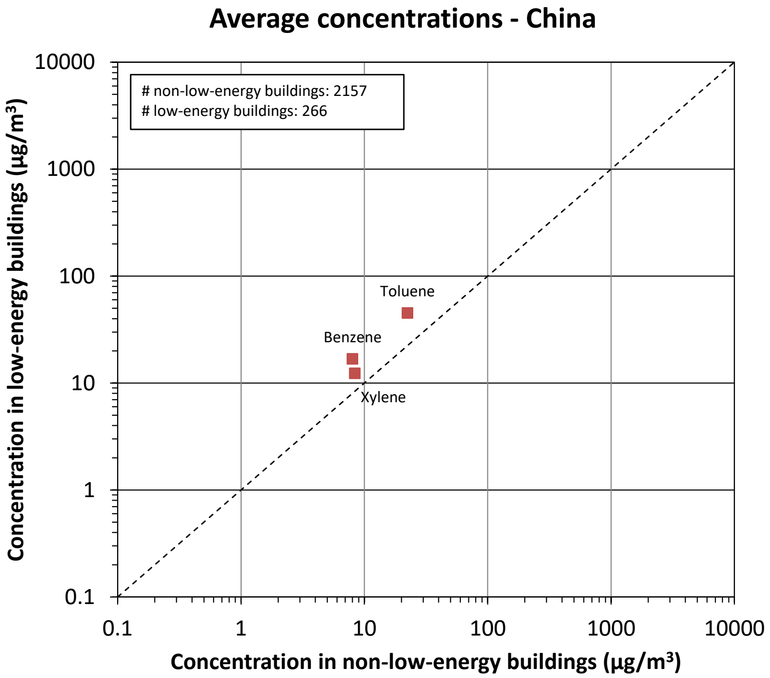


Figure 10: Annual average concentrations of pollutants measured in the low-energy residential buildings compared with the concentrations measured in non-low-energy residential buildings in China (Du et al., 2014b).

3.5. France

Figure 11 compares the annual average concentrations measured in low-energy buildings and the concentrations measured in the non-low-energy building stock. The levels are similar to those of Belgium and are lower in the low-energy buildings for all pollutants except for α-pinene, d-Limonene and hexanal. Maximum concentrations follow the same trends as in the case of annual average concentrations and the levels in the low-energy buildings are much lower (Figure 12).

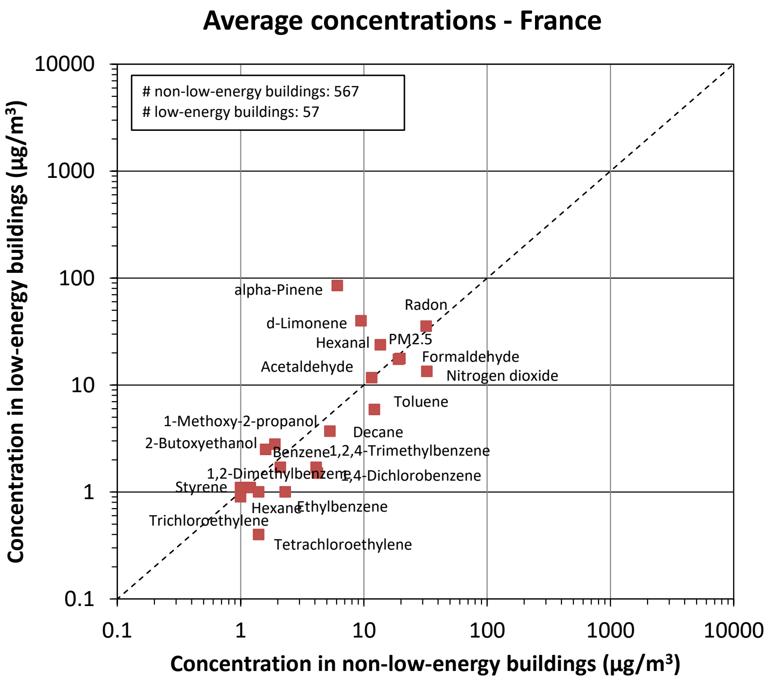


Figure 11: Annual average concentrations of pollutants measured in the low-energy residential buildings (Derbez et al., 2015) compared with measured concentrations in the non-low-energy residential buildings (Kirchner et al., 2006a) in France.

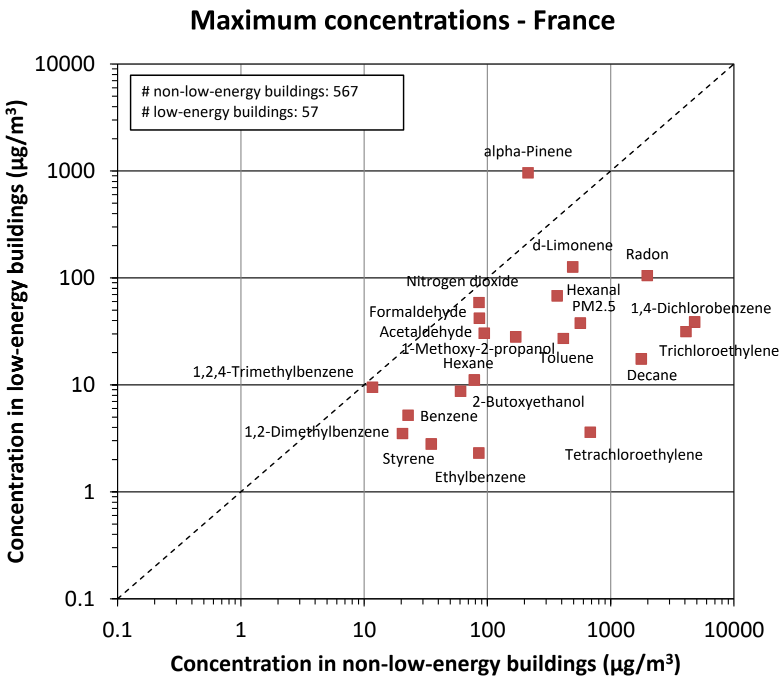


Figure 12: Maximum concentrations of pollutants measured in the low-energy residential buildings (Derbez et al., 2015) compared with measured concentrations in the non-low-energy residential buildings (Kirchner et al., 2006a) in France.

3.6. Japan

Figure 13 and Figure 14 show the comparison of annual average concentrations in new or newly refurbished buildings 1 and 3 years after completion or refurbishment, respectively. Results show that after one year, pollutant concentration levels are higher in buildings termed as low-energy compared with the non-low-energy ones, as it would be expected because of the changes in emission profiles. These levels are lower 3 years after building or renovation completion but still remain slightly higher than the concentrations measured in the non-low-energy buildings for most pollutants.

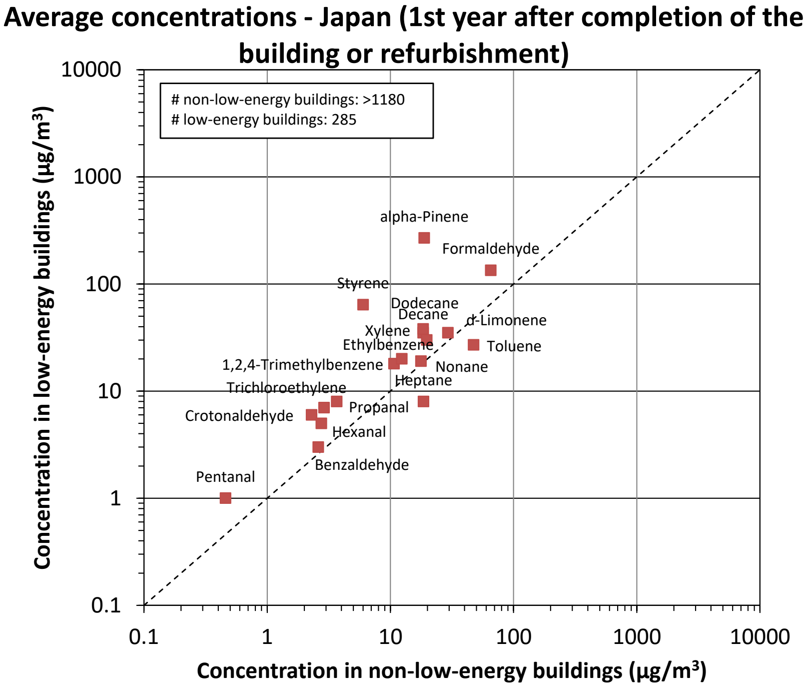


Figure 13: Annual average concentrations of pollutants measured in the low-energy residential buildings compared with the concentrations measured non-low-energy residential buildings in Japan (Park and Ikeda, 2006); measurements performed 1 year after completion of the building or refurbishment.

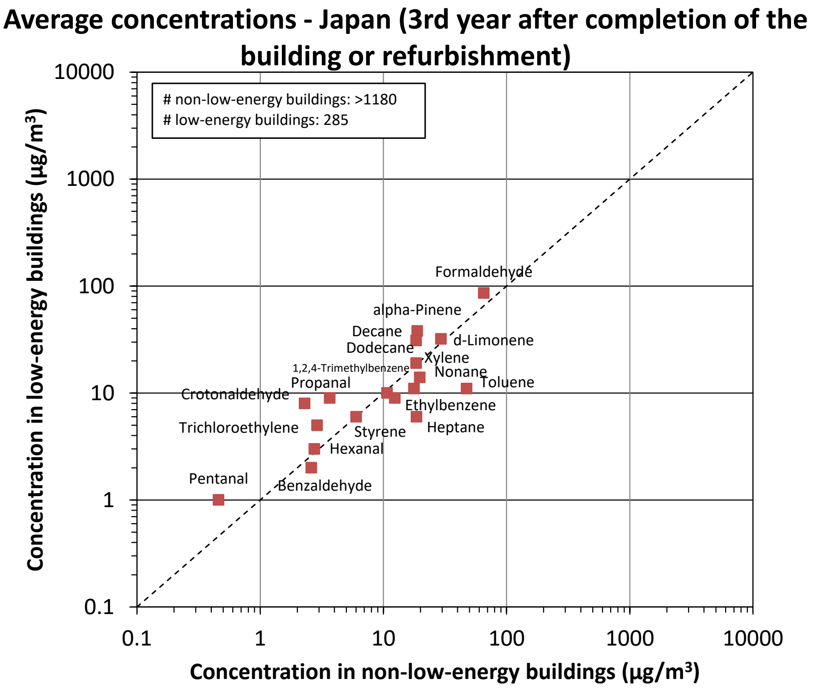


Figure 14: Annual average concentrations of pollutants measured in the low-energy residential buildings compared with the concentrations measured in non-low-energy residential buildings in Japan (Park and Ikeda, 2006); measurements performed 3 years after completion of the building or refurbishment.

3.7. USA

Figure 15 presents the concentrations of pollutants measured in studies carried out in industrialized countries where the most of data has been derived in the USA. Majority of pollutants have concentration levels that are lower in low-energy buildings; the exceptions are toluene, ethylbenzene, trichloroethylene and styrene, which were up to 10 times higher in low-energy buildings.

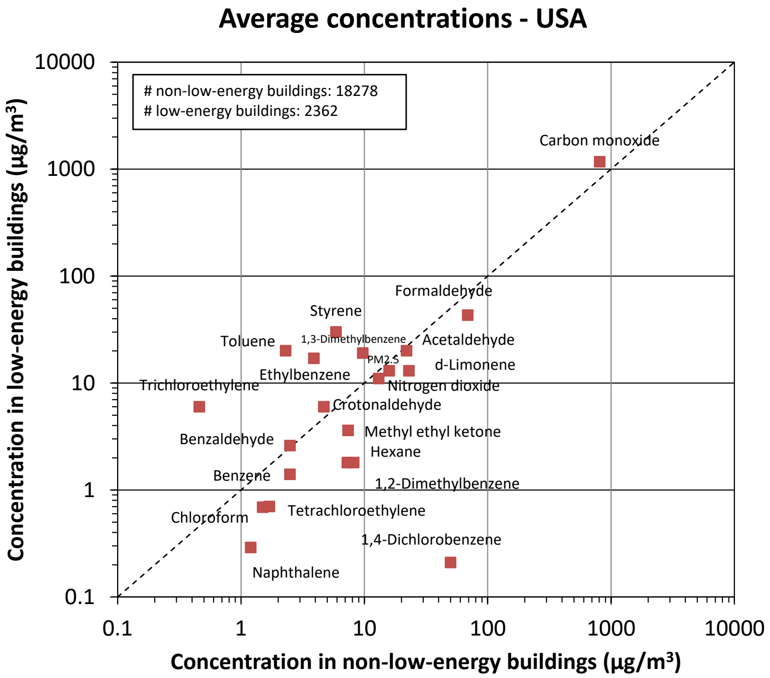


Figure 15: Annual average concentrations of pollutants measured in in the low-energy residential buildings compared with concentrations measured in the non-low-energy residential buildings in the USA (Logue et al., 2011a).

3.8. Conclusions

Indoor pollutant concentration measured in various countries all over the world were collected from in order to compare their levels in low-energy buildings and in the non-low-energy buildings. The following conclusions can be drawn from this analysis:

- Annual average concentrations were generally measured to be lower in low-energy buildings for the majority of pollutants compared with the levels measured in building not termed to be low-energy buildings. The exception to this general rule was seen for: formaldehyde, heptane, α-pinene, d-limonene, hexanal, styrene, toluene, ethylbenzene, trichloroethylene and 1,3 dimethylbenzene; these compounds were sometimes measured at higher concentration in low-energy residential buildings.
- In China and Japan, higher annual average concentrations were generally measured in low-energy buildings even after 3 years from completion construction (in the case of Japan). Pollutants measured to have higher concentrations in low-energy buildings included: formaldehyde, α-pinene, decane, dodecane, propanal, crotonaldehyde, trichloroethylene and pentanal. Some of them were also measured in higher concentrations in low-energy buildings in other countries.

- With few exceptions including heptane, styrene, α-pinene and ozone, the maximum measured concentrations were generally lower in the low-energy buildings than in the buildings not termed to be low-energy.

Many factors can affect the measured concentrations and the concentration difference between low-energy and non-low-energy buildings. They include emission of pollutants, age of building, ambient air pollution and outdoor air supply rates. The presented results were not adjusted for these factors and only crude comparisons are made. By comparing average concentration of carbon dioxide the outdoor air supply rates were inferred to be generally 2-3 times higher in low-energy buildings, however the average measured concentrations of pollutants did not follow this ratio: of the ratio of measured average concentrations in low-energy buildings to concentrations measured in non-low-energy buildings was lower.

The data presented show only pollutant levels. Pollutant concentrations alone are not sufficient to determine potential health impact. They must be compared with the relevant exposure limit values for short- and long-term exposure, which are presented in the next chapter.

4. Exposure Limit Values (ELV)

4.1. Definitions

The current report used **Exposure Limit Values (ELV)** that correspond to the concentration thresholds, above which exposure potentially presents a risk to health. Figure 16 illustrates the various ELVs that can be found for different applications as defined by different organizations.

There are essentially two types of ELVs:

- Toxicity Reference Values (TRV) - they are determined for many compounds using the data obtained in animal experiments. The limits obtained in the studies with animals were used to establish limits for humans by applying a safety factor of at least 100 (for example, if health effects in animal experiments appear at 1,000 µg/m3, the TRV for a human is set at ≤10 µg/m3). This is a common procedure when translating TRV from animal to human: a factor 10 for more sensitive population (e.g. children, old persons and sick persons), another factor 10 for longer exposure duration and a third factor 10 for suspected carcinogens (Oppl and Neuhaus, 2008). In some cases, when supplemented by knowledge from epidemiological studies, TRVs form the basis for the development of Occupational Exposure Limits (OEL) i.e. limits for occupational exposures that cannot be surpassed in the working environment.
- Guideline Values for Indoor Air (IAGV) – they are determined using the data from epidemiological studies examining correlation between health symptoms observed in a population of individuals exposed to the compound indoors. They are available only for the limited number of compounds.

In line with the toxicology paradigm “it is the dose that makes the poison”, both the concentration level and the length of exposure (duration) have to be accounted for. Consequently, different TRVs or IAGVs for different exposure times may be found for a single pollutant depending on the averaging time. An example is the exposure limit for formaldehyde which is 100 µg/m^3 for 30 min (short-term exposure from WHO, 2010b) and 10 µg/m^3 for 1 year (long-term exposure from ANSES, 2007).

Recently the European Commission has developed the list of compounds and defined their maximum allowable concentrations for the purpose of material emission testing (so-called pollutants with the **Lowest Concentrations of Interest (LCI)).** LCIs are thus not exposure limits but the guidelines for maximum concentrations during testing of emissions from building materials at the production stage before they enter the market (http://www.eu-lci.org/EU-LCI_Website/Home.html); they should not and must not be used as IAGVs. As reported in ECA (2013), *LCI refers to a 28-day test period, conforming to one of the testing times referred to in the Technical Specification TS 16516 of the horizontal testing method developed by CEN TC 351/WG*

2. Since primary emissions decline with time, this time scale is considered to constitute a 'worst case' assumption for the long-term indoor air VOC emission scenario in the absence of oxidants. It is acknowledged that the test procedure (using chambers and correction factors relating to a 'standard' room) provides only an approximation to the situation in a real indoor environment; concentrations in actual rooms will depend on emission rates of products used in the specific indoor environment, the number of sources for a given chemical, variability of environmental conditions (i.e. temperature, humidity, air exchange rate), chemical transformation, sink effects (adsorption and desorption), etc. There are 198 individual chemical compounds on the list. They are reported in Appendix B.

4.2. Reference Values for Annex 68

ELVs are established nationally and worldwide by cognizant health agencies (see Figure 16 for examples of the names and abbreviations of different limit values available and the organizations that set them up). They are established by expert committees including doctors of medicine, of toxicology, of chemistry, hygienists, pharmacists, etc. The levels proposed by these committees can differ for the same pollutant and the same exposure time depending on the data and approach used by the committee; priority is in this case the local value i.e. the closest geographical reference. Figure 17 presents a typical decision tree that is used in the process of selecting the suitable ELV for a known pollutant.

In the case of ANNEX 68 the decision tree presented in Figure 17 is modified such as priority is given to the international reference values to select the ELVs (option 1) and then the lowest limit can be selected when several ELVs are available (option 2). Option 2, which is the most conservative, was used for the purpose of selecting ELVs in Annex 68.

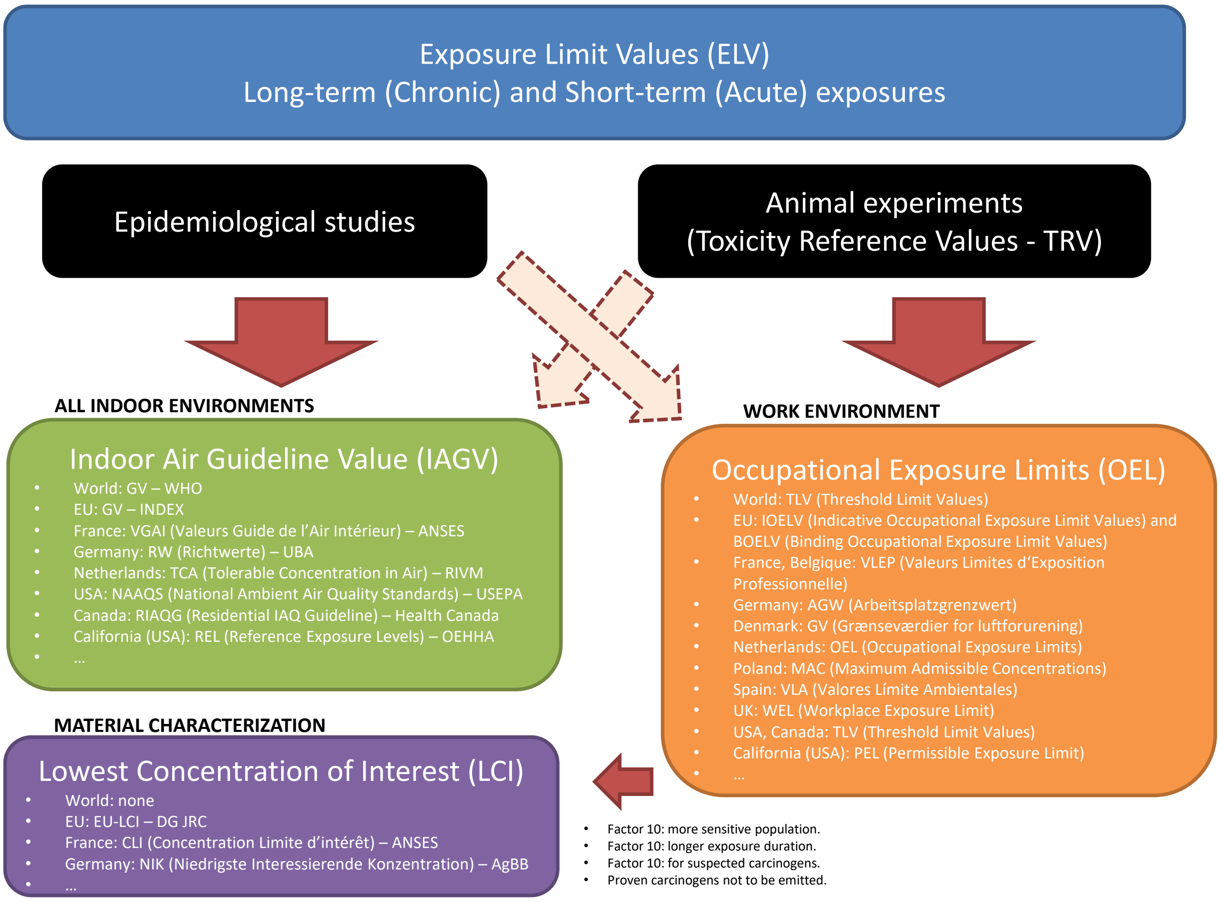


Figure 16: Exposure Limit Values as defined by different cognizant authorities.

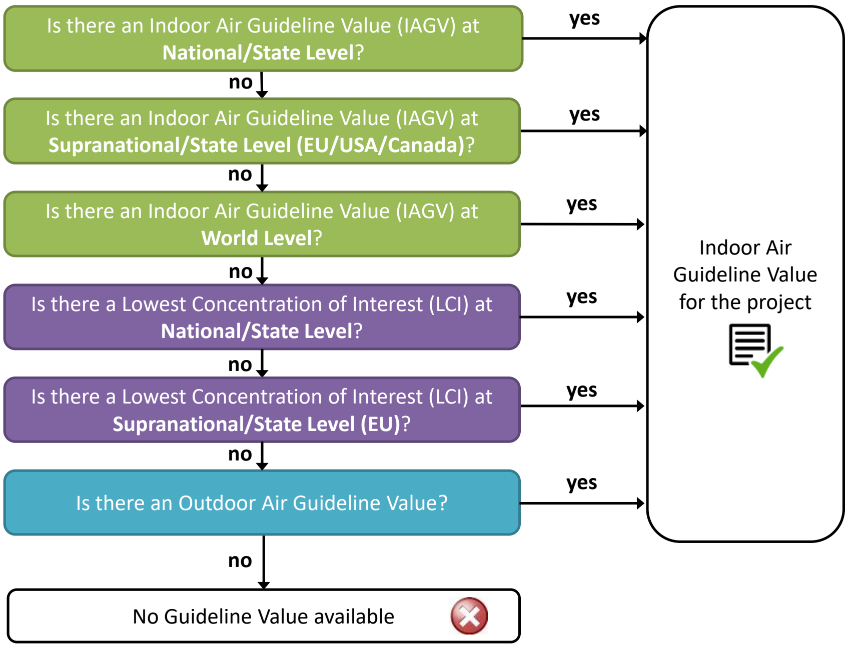


Figure 17: Decision tree used in the process of selecting a suitable Indoor Air Guideline Value for a national project.

Guideline values (IAGVs) presented in the current report were compiled from different using guideline values used in different parts of the world. Appendix A presents the IAGVs by organization or country that were used for the purpose of the current report: World Health Organization, Europe, Austria, Belgium, USA – California, Canada, China, France, Germany, Hong-Kong, Japan, Korea, Portugal and United Kingdom (UK). The list is not exhaustive, but represents the current state of knowledge and the efforts of reputable health agencies that have made advances in mitigating indoor air pollution. IAVGs were proposed to be operational in all buildings with the exception of Canada and UK, which have focused their regulations on residential buildings. Regarding Portugal, China, Hong-Kong and Korea, the values reported are stated as indoor air guidelines, but they have been specifically defined for public buildings. Many countries do not have defined IAVGs. They use occupational exposure limits for the purpose of regulating exposures in public buildings. The examples are Australia or New-Zealand.

Figure 18 shows the frequency of availability of limit values for different pollutants on the IAGV lists surveyed in the present work. In total there are 121 pollutants that are listed and among them carbon monoxide (short-term exposure), formaldehyde, nitrogen dioxide, benzene, toluene, ozone, TVOC, naphthalene, PM10, radon, styrene, xylene and acetaldehyde are at least on 6 out of the 14 lists with IAGV limits surveyed.

Figure 19 shows the variability of the long-term exposure limits (IAGVs) for the compounds for which the data was available most frequently (> 6) on the IAGV lists identified in the course of the present work. Carbon monoxide and ozone are not included in this figure as the IAGVs from WHO are always taken as reference in the lists.

The lowest IAGV found among all IAGV was used in this work as a reference level both for short-term and long-term exposure limits. When “as low as possible” is indicated for a pollutant (as for benzene, see Figure 19), the minimum non null value defined by other organizations is used. The selection is made so that the ratio between the measured concentration of a compound and its IAGV could be derived.

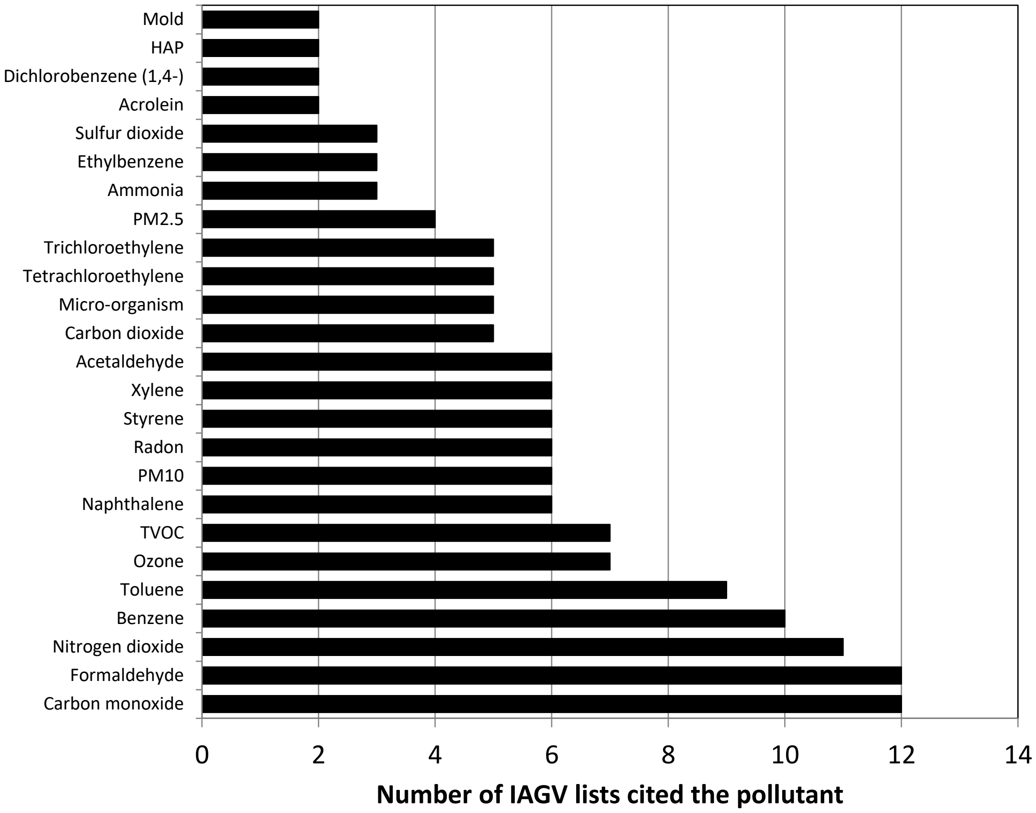


Figure 18: Frequency of reporting the limits for pollutants on the 14 IAGV lists surveyed for the purpose of the present work.

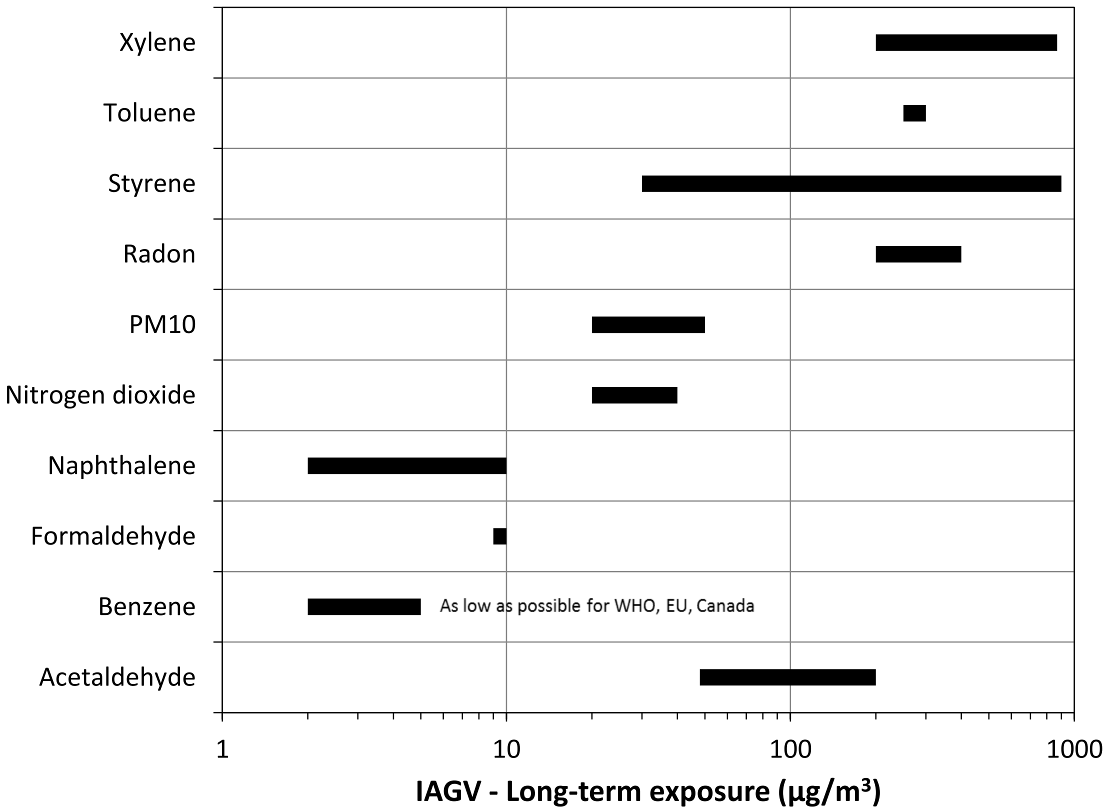


Figure 19: Variability in the long-term exposure limits for the pollutants most frequently present on the surveyed IAGV lists.

5. Pollutants of concern

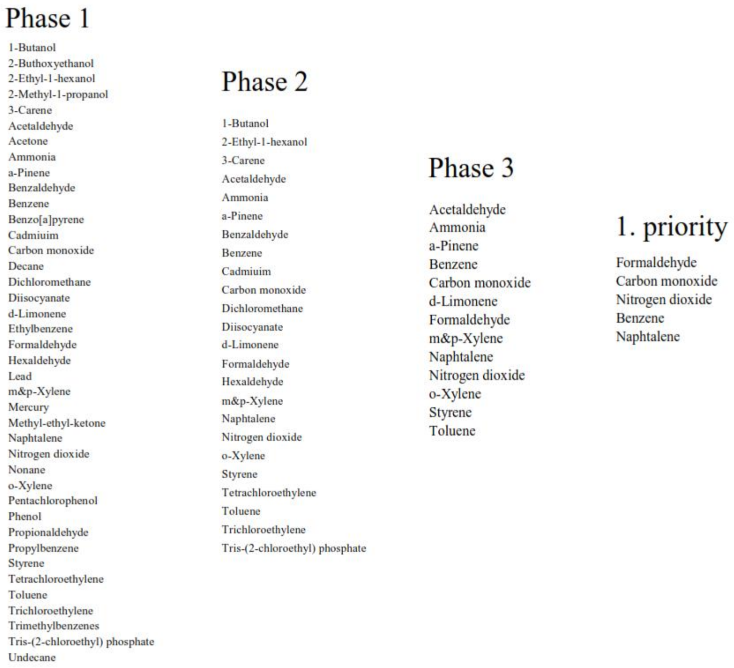
Numerous pollutants have been measured in low-energy residential buildings. It is necessary to select those that create highest health concern using the available evidence. A similar approach was used by other studies with similar purpose (e.g. INDEX, 2005; Kirchner et al., 2006a; WHO, 2010b; Logue et al., 2011a; Djouad et al., 2015). The main results obtained by these studies are reported here.

5.1. Pollutants selected by INDEX Project and WHO

The European INDEX project (2005) and the World Health Organization (WHO, 2010b) evaluated the available evidence on the hazards associated with indoor air pollutants and established the lists with target pollutants in indoor air. Figure 20 presents the results of the target pollutant selection process used in INDEX project. This selection process used the following steps:

- Phase 1: population-based studies were compiled to evaluate population exposures in Europe to selected pollutants with known indoor sources and known health effects. Only gaseous pollutants were considered.
- Phase 2: from the list produced in Phase 1, some compounds were excluded because there were no expressed concern for health at observed levels (acetone, decane, ethylbenzene, phenol, propylbenzene, trimethylbenzene), or the compounds were already regulated by use restrictions for indoor materials (pentachlorophenol), or incomplete or no dose-response data were available at observed levels (methyl-ethyl-ketone, propionaldehyde) or the main route/media for the exposure to the compound was other than indoor air (lead, mercury).
- Phase 3: odor threshold values were added to the background information.
- Phase 4: Priority: more detailed exposure and risk assessment were carried out.

Finally, benzene, carbon monoxide, formaldehyde, naphthalene and nitrogen dioxide were identified as high priority target pollutants by INDEX project (Table 5). WHO pointed out that particulate matter (PM), polycyclic aromatic hydrocarbon (PAH), radon, trichloroethylene and tetrachloroethylene have to be also considered with caution.



Phase 1

1-Butanol
2-Buthoxyethanol
2-Ethyl-1-hexanol
2-Methyl-1-propanol
3-Carene
Acetaldehyde
Acetone
Ammonia
a-Pinene
Benzaldehyde
Benzene
Benzo[a]pyrene
Cadmiuim
Carbon monoxide
Decane
Dichloromethane
Diisocyanate
d-Limonene
Ethylbenzene
Formaldehyde
Hexaldehyde
Lead
m&p-Xylene
Mercury
Methyl-ethyl-ketone
Naphtalene
Nitrogen dioxide
Nonane
o-Xylene
Pentachlorophenol
Phenol
Propionaldehyde
Propylbenzene
Styrene
Tetrachloroethylene
Toluene
Trichloroethylene
Trimethylbenzenes
Tris-(2-chloroethyl) phosphate
Undecane

Phase 2

1-Butanol
2-Ethyl-1-hexanol
3-Carene
Acetaldehyde
Ammonia
a-Pinene
Benzaldehyde
Benzene
Cadmiuim
Carbon monoxide
Dichloromethane
Diisocyanate
d-Limonene
Formaldehyde
Hexaldehyde
m&p-Xylene
Naphtalene
Nitrogen dioxide
o-Xylene
Styrene
Tetrachloroethylene
Toluene
Trichloroethylene
Tris-(2-chloroethyl) phosphate

Phase 3

Acetaldehyde
Ammonia
a-Pinene
Benzene
Carbon monoxide
d-Limonene
Formaldehyde
m&p-Xylene
Naphtalene
Nitrogen dioxide
o-Xylene
Styrene
Toluene

1. priority

Formaldehyde
Carbon monoxide
Nitrogen dioxide
Benzene
Naphtalene

Figure 20: Indoor originated compounds that were assessed and considered the most hazardous in the three phases of the hazard identification process (INDEX, 2005).

Table 5. Target pollutants in indoor air designated by INDEX Project (2005) and WHO (2010).

	CAS number	**INDEX (2005)**	**WHO (2010)**
Benzene	71-43-2	X (high priority)	X
Carbon monoxide	630-08-0	X (high priority)	X
Formaldehyde	50-00-0	X (high priority)	X
Naphthalene	91-20-3	X (high priority)	X
Nitrogen dioxide	10102-44-0	X (high priority)	X
PM2.5 and PM10	-	-	X
PAH	-	-	X
Radon	10043-92-2	-	X
Trichloroethylene	79-01-6	-	X
Tetrachloroethylene	127-18-4	-	X
Acetaldehyde	75-07-0	X (low priority)	-
Toluene	108-88-3	X (low priority)	-

Xylene	1330-20-7	X (low priority)	-
Styrene	100-42-5	X (low priority)	-
Ammonia	7664-41-7	X (further research is needed)	-
d-limonene	5989-27-5	X (further research is needed)	-
α-pinene	80-56-8	X (further research is needed)	-

5.2. Pollutants identified by IAQ Observatory

The French IAQ Observatory (Kirchner et al., 2006a) undertook a national survey in French dwellings between 2003 and 2005. Thirty chemical, biological and physical parameters were measured in 567 dwellings selected as representative of the French housing stock. The measured pollutants were then ranked using the following equation established for this purpose by the researchers from the Observatory:

$$I = I_{acute} + I_{chronic} + I_{frequency} \quad \text{with} \quad I_{acute} = f\left(\frac{C_{\max}}{ELV_a}\right) \text{ and } I_{chronic} = g\left(\frac{C_{mean}}{ELV_c}\right) + I_k \qquad (1)$$

where I is the ranking index (0 to 20), I_{acute} and $I_{chronic}$ are the indices relative to the acute and chronic health risks and range from 0 to 5 and 0 to 10, respectively. $I_{frequency}$ is the index relative to the presence frequency in the residential indoor air (0 to 5). I_{acute} depends on the ratio of the maximal concentration (C_{max}) and the Exposure Limit Value for acute effects (ELV_a). $I_{chronic}$ accounts for the chronic effect potential using the mean concentration (C_{mean}) and the Exposure Limit Value for chronic effects (ELV_c) and the carcinogen risk (I_k) that is equal to 0 if there is no effect and 5 if effects on human are proven. Functions *f* and *g* scale the concentration to ELV ratio between 0 (low value) and 5 (high value). The numbers in different indices were selected and set arbitrarily by researchers and are not based on existing evidence justifying the selection. Substances classified higher in the ranking system, i.e. having an index close to 20 are, according to the defined selection criteria, more prevalent and more harmful to health. They have average and maximum concentrations respectively close to, the chronic and acute limits and have a high probability of occurrence in the building stock.

Table 6. The list of 25 target pollutants in residential buildings defined by the French IAQ Observatory (Kirchner et al., 2006a).

Compound	**Defined by INDEX project**	**CAS number**	I_{acute}	$I_{chronic}$	$I_{frequency}$	I
Formaldehyde	x	50-00-0	4	10	5	19
Benzene	x	71-43-2	3	10	5	18
Acrolein		107-02-8	5	7	5	17
Cadmium		7440-43-9	1	10	5	16
Benzo[a]pyrene*	x	50-32-8	1	10	5	16
1,4-dichlorobenzene		106-46-7	3	8	5	16
Acetaldehyde	X	75-07-0	2	9	5	16
PM10	X	PM10	5	6	5	16
PM2.5	X	PM2,5	5	6	5	16
Benzo[a]anthracene*	X	56-55-3	1	9	5	15
Carbon monoxide		630-08-0	5	6	4	15
Chloroform		67-66-3	5	9	1	15
Fluorine		86-73-7	1	8	5	14
Pyrene*	X	129-00-0	1	8	5	14
Tetrachloroethylene	X	127-18-4	0	9	5	14
Trichloroethylene	X	79-01-6	0	9	5	14
Furfural		98-01-1	3	6	5	14
Ethylbenzene		100-41-4	0	8	5	13
Nitrogen dioxide	X	10102-44-0	3	5	5	13
Bromoform		75-25-2	5	7	1	13
Styrene		100-42-5	2	5	5	12
Toluene	X	108-88-3	3	4	5	12
d-limonene	X	5989-27-5	3	4	5	12
Chlorine		7782-50-5	1	6	5	12
PAH (eq-BaP)	x		1	10	1	12

* PAH

Table 6 lists the compounds with their respective ranking indices (*I*) in the descending order. The method proposed by the Observatory has the advantage that it is easy to follow because all compounds are ranked by one number only. However, there is no scientific basis for addition of health risks related to acute effects (high concentration, short time) and chronic effects (low concentration, long-time); this approach is used merely for classification and some health agencies suggest that they need to be considered separately. This is a significant drawback of the method. It can be noticed that nearly all compounds identified by WHO and the INDEX project are also included on the list with compounds proposed by the French Observatory.

5.3. Pollutants identified by LBNL and AIVC

Lawrence Berkeley National Labs (Logue et al. (2011a)) compiled results of measurements of chemical pollutants in residences in the USA and in countries with similar lifestyles published in 77 studies; the results were also published in the Technical Note 68 (Borsboom et al., 2016) by the Air Infiltration and Ventilation Centre (AIVC). They identified nine pollutants of concern by comparing measured concentrations with the respective ELVs. These were acetaldehyde, acrolein, benzene, 1,3-butadiene, 1,4-dichlorobenzene, formaldehyde, naphthalene, nitrogen dioxide and $PM_{2.5}$. Logue et al. (2011b) estimated additionally the population-averaged annual cost, of **chronic** air pollutant inhalation in U.S. residences; for that purpose they used lost Disability Adjusted Life Years (DALYs). Figure 21 presents the results for the 12 pollutants with the highest median DALY loss estimates. These are $PM_{2.5}$, SHS (Second-hand tobacco smoke), radon, formaldehyde, acrolein and to a lower extent ozone, NO_2, ammonia, acetaldehyde, crotonaldehyde, 1,1-dichloroethene, styrene, carbon tetrachloride, 1,4-dichlorobenzene and chromium.

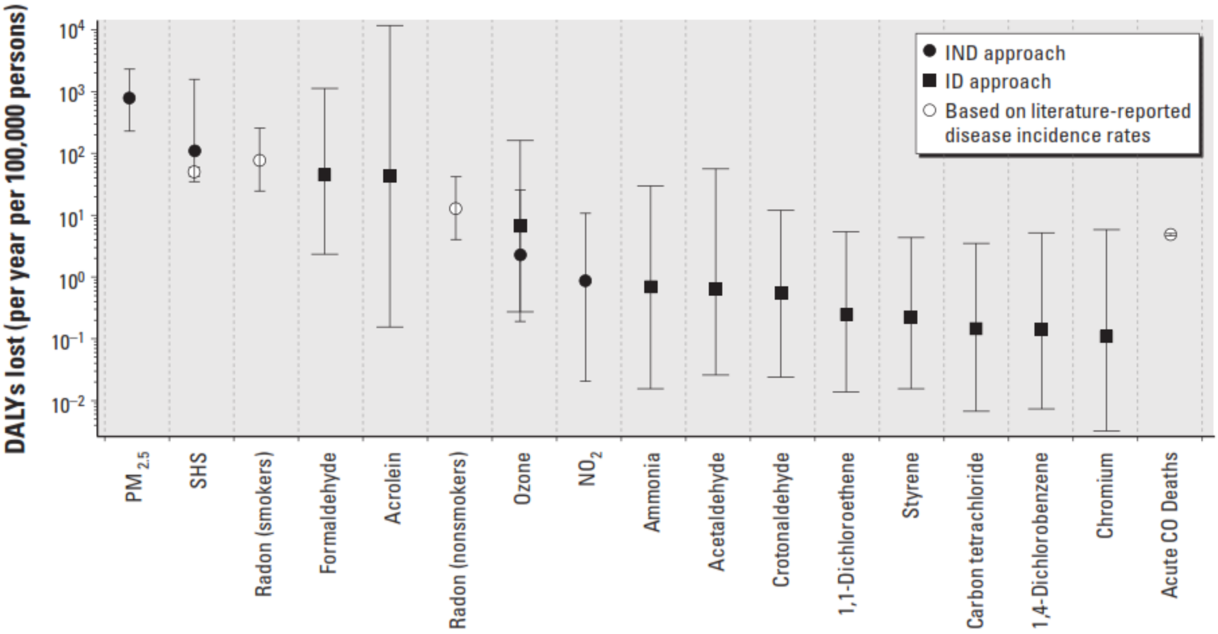
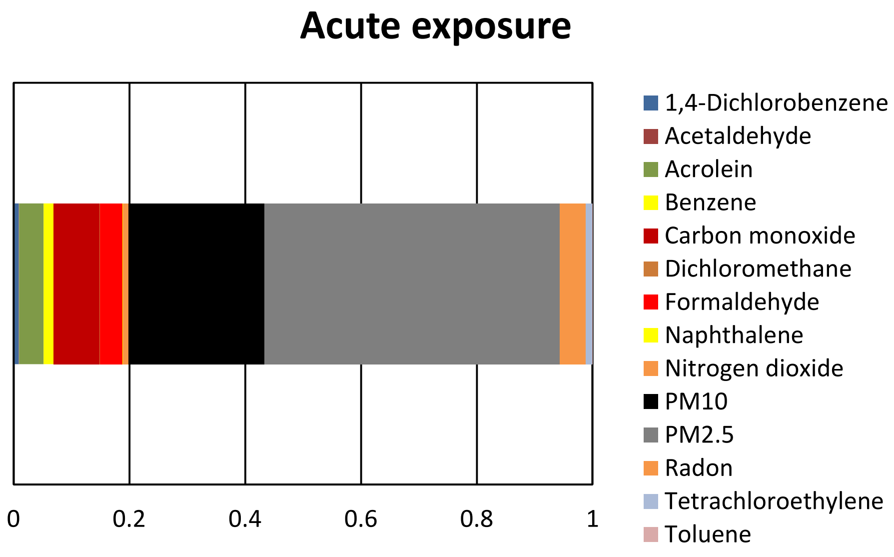


Figure 21: Estimated population-averaged annual cost, in DALYs lost, of chronic air pollutant inhalation in U.S. residences (Logue et al., 2011b). Results for the 12 pollutants with highest median DALY loss estimates. IND and ID approaches are two different DALY calculations (see section 7.2 on IAQ indices for additional information).

5.4. Pollutants selected by Djouad et al. (2015)

In the search for target indoor environment pollutants, Djouad et al. (2015) produced two lists of pollutants relevant for residential buildings by considering chronic and acute exposures separately. They also established a list of target pollutants for office buildings and hospitals using the most recent pollutant reference values and concentrations measured in-situ and reported in the peer-reviewed literature (Djouad et al., 2015). The methodology consists firstly of calculating sub-indices for each pollutant by dividing the pollutant concentration by the respective ELV and secondly by dividing them by the sum of all sub-indices in order to evaluate the share of each pollutant in the total exposure risk. In this approach, annual mean and maximum concentrations and ELVs are used to evaluate long-term and short-term effects. Figure 22 presents the list of pollutants relevant for residential buildings established using the Djouad et al. methodology and the data of the national survey in French dwellings. Based on this approach PM10 and PM2.5 are clearly the most important pollutants to be considered for the acute health effects (inferred to be responsible for 75% of all acute effects). Carbon monoxide, acrolein, formaldehyde, and radon should also be taken into account. The result for chronic exposures is slightly different - The share of PM10 and PM2,5 in chronic effects is 35% and formaldehyde, acrolein, and nitrogen dioxide have each about 20% contribution each . Benzene and radon also play a notable role.



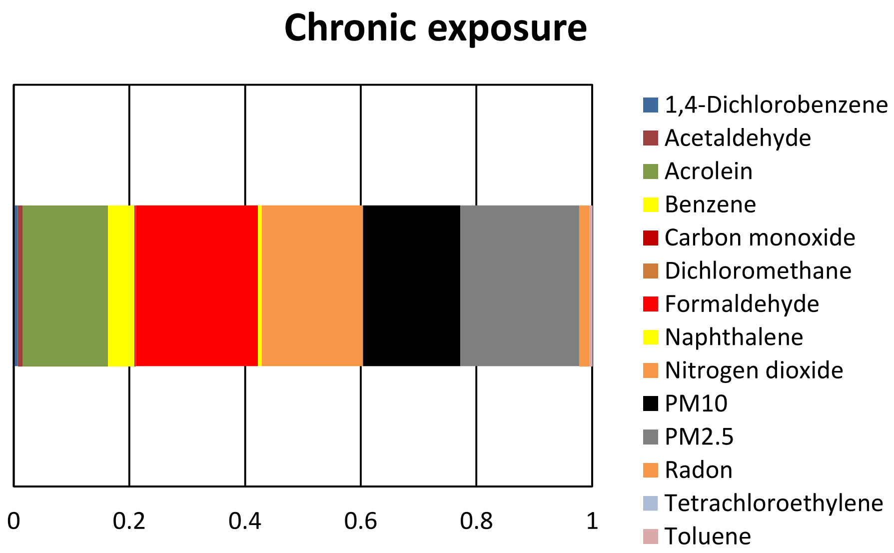


Figure 22: Relative importance of indoor pollutants for residential building sector (top: acute exposure, bottom: chronic exposure); the data are based on the study by Djouad et al. (2015). Interpretation of these graphs: the importance of a pollutant is given by the width of the bar. For example, in the upper graph, PM10 spans from 0.2 to 0.42 giving 0.22 (or 22%) value of the total considering all listed pollutant (1 or 100%). Some pollutants from the list may not be visible as their relative importance is very small.

6. Defining the list of pollutants of concern for Annex 68

Using the reported measured concentrations (section **Error! Reference source not found.**) and he exposure limit levels for chronic and acute effects (section 4), this chapter aims to select the pollutants that should be included in the list of pollutants of concern for the purpose of Annex 68. The methodology applied for selection was as follows:

- For each pollutant, all data compiled in section **Error! Reference source not found.** was sed to calculate the annual minimum, 1st and 3rd quartiles, median, maximum and the average concentrations of pollutants in low-energy buildings.
- For each pollutant, the minimum value of all available ELVs was used; these ELVs are listed in Table 7.
- The 3rd quartile (75% percentile) concentration was compared with ELV. The pollutants with ratios higher or close to 0.1 were considered to be pollutants with the potential risk for health and relevant to Annex 68. Although ratios lower than 1.0 should mean no harm, it was decided to use a safety factor of 10 (this is why the ratio of 0.1 was used). For the same reason it was decided to use 75% percentile concentration rather than the median or mean.

Table 7. The list of the long-term and short-term ELVs used to select pollutants relevant for Annex 68.

	Long-term ELV*	Short-term ELV*
Acetaldehyde	48	4600
Acrolein	0.35	6.9
Acrylonitrile	5	-
α-pinene	200	-
Ammonia	70	3200
Benzene	0.2	110
Carbon dioxide	-	1250
Carbon disulfide	800	6200
Carbon monoxide	-	100
Carbon tetrachloride	40	1900

Chlorobenzene	1000	-
Chloroform	300	150
Dichloromethane	200	-
Ethylbenzene	-	3800
Formaldehyde	9	123
Methyl ethyl ketone	-	13000
Naphthalene	2	-
Nitrogen dioxide	20	470
Ozone	-	180
Pentachlorophenol	100	-
PM10	20	50
PM2.5	10	25
Radon	200	400
Styrene	30	21000
Sulfur dioxide	-	660
Tetrachloroethylene	100	1380
Toluene	250	37000
Trichloroethylene	2	-
TVOC	-	600
Vinyl chloride	-	180000
Xylene	200	22000

* ELV concentration in µg/m^3 except for carbon dioxide in ppm and radon in Bq/m^3

Figure 23 and Figure 24 present the ratio of pollutant concentration to the respective ELV for the long-term exposure; the ratios were calculated using both the measured concentrations in the non-low-energy and low-energy buildings. In the case of non-low-energy buildings, the following 15 pollutants had ratios higher than 0.1: acetaldehyde, acrolein, α-pinene, ammonia, benzene, formaldehyde, naphthalene, nitrogen dioxide, PM10, PM2.5, radon, styrene, toluene, trichloroethylene and xylene. In the case of low-energy buildings, the following 12 pollutants had ratios higher than 0.1: acetaldehyde, α-pinene, benzene, formaldehyde, naphthalene, nitrogen dioxide, PM10, PM2.5, radon, styrene, toluene and trichloroethylene.

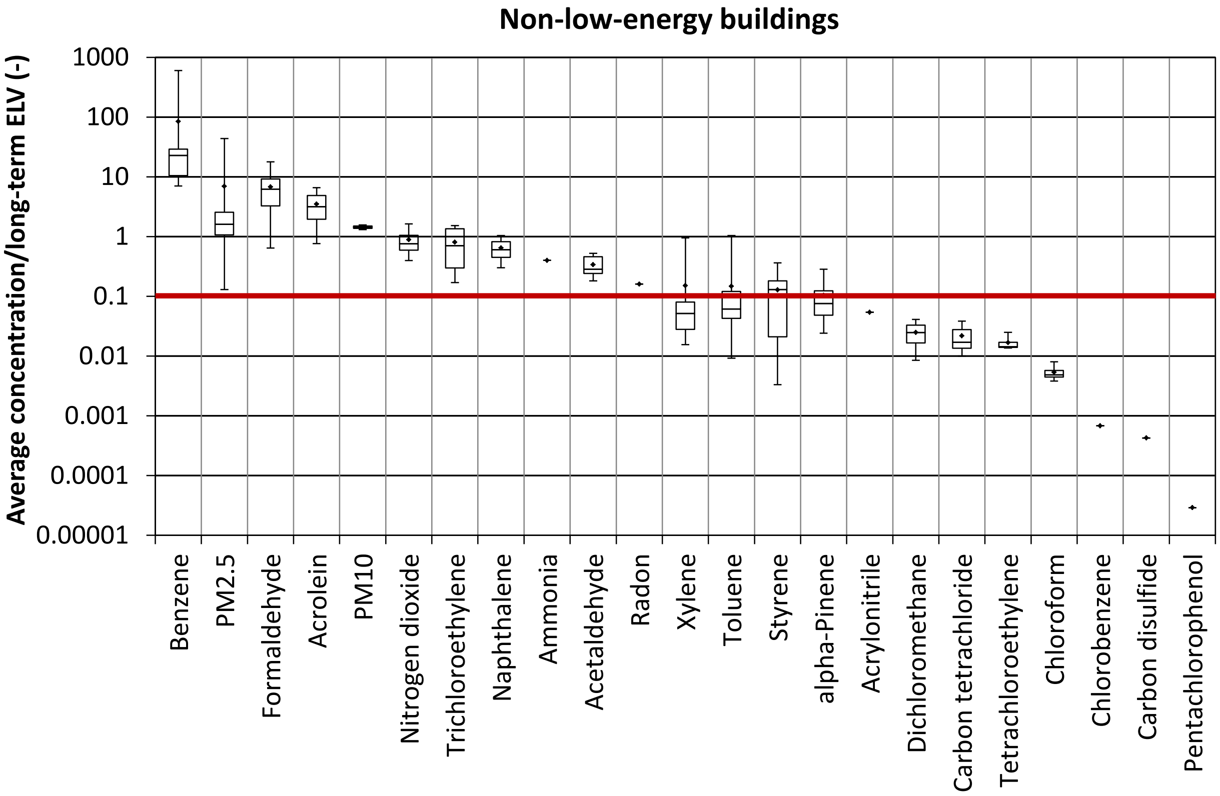


Figure 23: The ratio of annual average concentration measured in <u>non-low-energy buildings</u> to their respective ELVs for long-term exposures

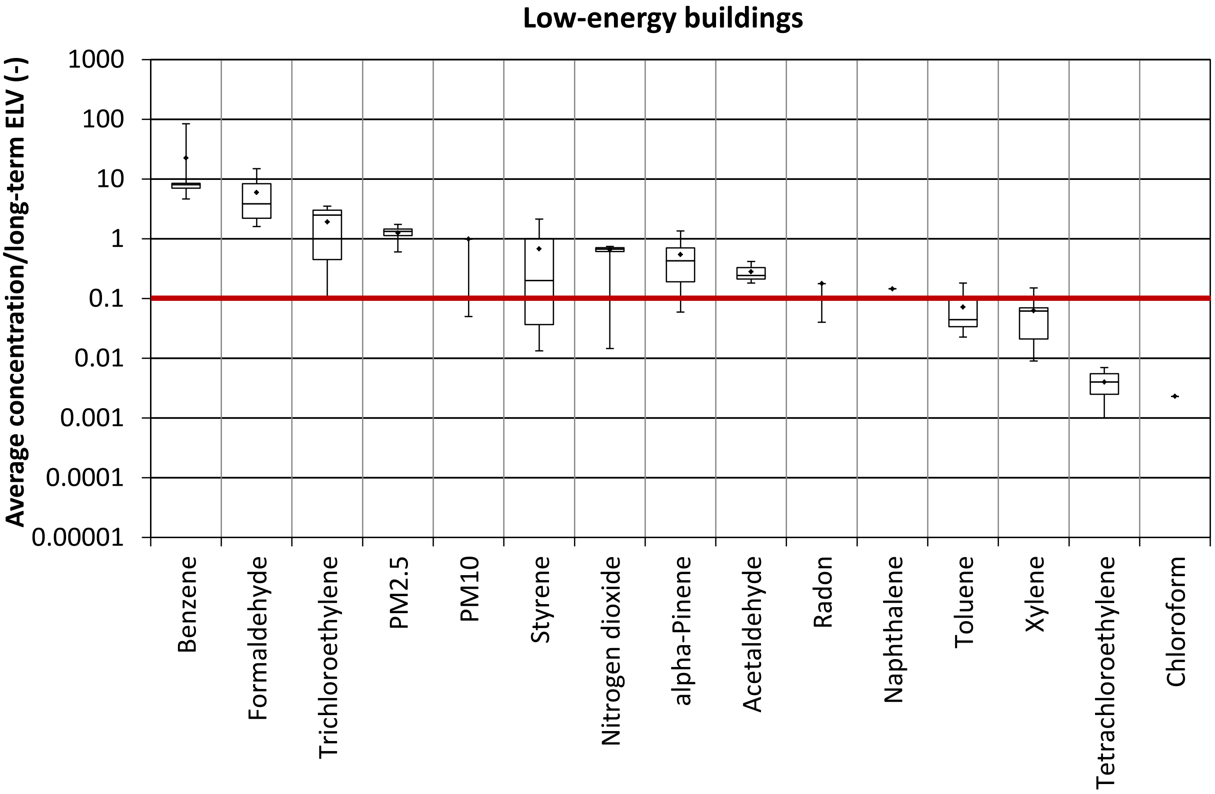


Figure 24: The ratio of annual average concentration measured in low-energy buildings to their respective ELVs for long-term exposures.

There are only three substances (acrolein, ammonia and xylene) that are present on the list of the compounds measured in the non-low-energy buildings with ratio higher than 0.1. Ammonia and acrolein were actually not measured in low-energy buildings (section 3) and xylene was measured at very low concentration. Nevertheless it was decided to include acrolein in the list of compounds relevant for exposures in low-energy buildings, because it was considered to be an important pollutant by other classifications of the type made here (Logue et al., 2011a and Kirchner et al., 2006a).

Figure 25 and Figure 26 present the ratio of maximum pollutant concentration to the respective ELV for short-term exposure respectively for the non-low-energy buildings and the low-energy ones. The compounds with the ratio higher than 0.1 in the non-low-energy buildings were the following: acetaldehyde, α-pinene, benzene, formaldehyde, naphthalene, nitrogen dioxide, PM10, PM2.5, radon, styrene, toluene and trichloroethylene. The compounds with the ration higher than 0.1 in the low-energy buildings were: carbon dioxide, formaldehyde, nitrogen dioxide, PM10, PM2.5, radon and TVOC. The list for low-energy buildings is different from list for non-low-energy buildings mainly because the peak concentrations of many compounds are lower in the low-energy buildings (see 3.8). Acrolein was included in the list for low-energy buildings on the same rationale as in case of the chronic exposures. Carbon dioxide was included not as a pollutant but the marker of the efficiency of ventilation and air quality in case people are present in the buildings.

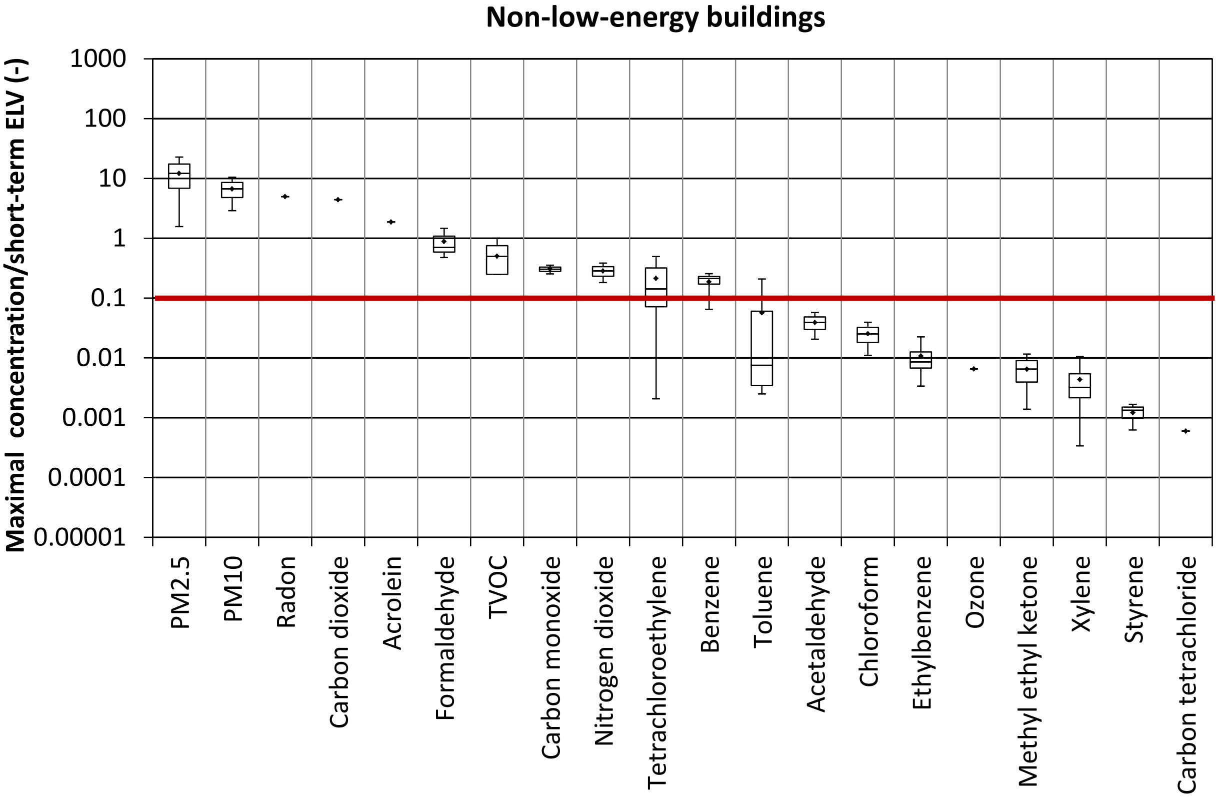


Figure 25: The ratio of annual maximum concentration measured in non-low-energy buildings to their respective ELVs for short term exposure.

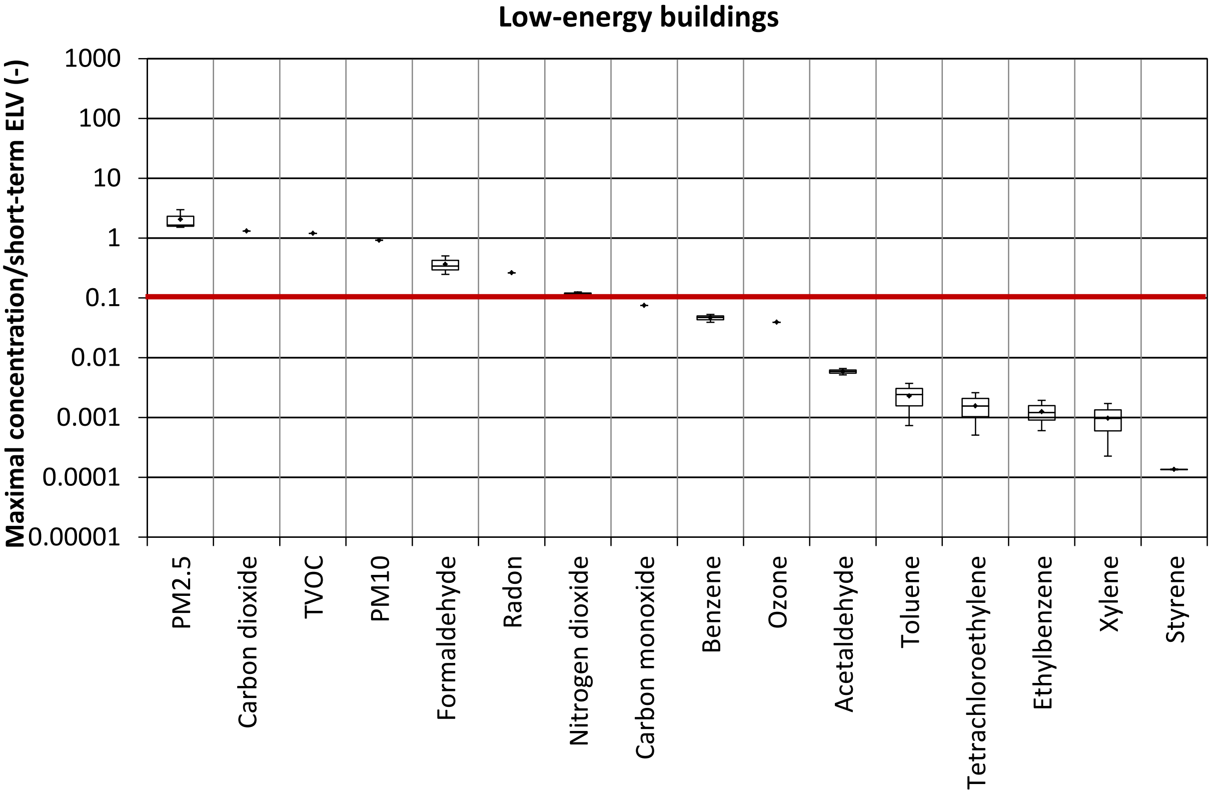


Figure 26: The ratio of annual maximum concentration measured in low-energy buildings to their respective ELVs for short-term exposures

Table 8 shows the final list of pollutants considered to be relevant in the context of the objectives of Annex 68 i.e. definition of pollutants present in residential low-energy buildings, to which exposure potentially creates the health risk. The pathogens and allergens are not considered in the present report and are not mentioned in Table 8 although they do create the health risk. Carbon dioxide is not a pollutant as well, although listed in Table 8. It is included in the list as a surrogate for the adequacy of ventilation in relation to human occupation.

Table 8. List of selected target pollutants for Annex 68 with their respective exposure limits.

	Long-term Exposure			Short-term Exposure		
	ELV*	Averaging period	Source	ELV*	Averaging period	Source
Acetaldehyde	48	1 year	Japan	-	-	-
Acrolein	0.35	1 year	USA-California	6.9	1 h	France
α-Pinene	200	1 year	Germany	-	-	-
Benzene	0.2	whole life (carcinogenic risk level: 10^{-6})	France	-	-	-
Formaldehyde	9	1 year	USA-California	123	1 h	Canada
Naphthalene	2	1 year	Germany	-	-	-
Nitrogen dioxide	20	1 year	France	470	1 h	USA-California
PM10	20	1 year	WHO	50	24 h	WHO
PM2.5	10	1 year	WHO	25	24 h	WHO
Radon	200	1 year	Austria, Canada	400	8 h	Austria, China, Portugal
Styrene	30	1 year	Germany	-	-	-
Toluene	250	1 year	Portugal	-	-	-
Trichloroethylene	2	whole life (carcinogenic risk level: 10^{-6})	France	-	-	-
TVOC	-	-		400	8 h	Japan, Korea
Mold	200	1 year	EU	-	-	-
Carbon dioxide	-	-	-	*1000*	*8 h*	*Hong-Kong, Korea*

* ELV concentration in µg/m^3 except for carbon dioxide in ppm, radon in Bq/m^3 and mold in CFU/m^3

7. A survey of indices proposed for the purpose of evaluating IAQ

In section 6, the list of target pollutants was created. This section describes an attempt to define metrics that can be used to evaluate IAQ.

According to Sofuoglu and Moschandreas (2003), an index of IAQ should have specific properties. It should communicate indoor air pollution levels to a non-scientific audience, should be correlated to symptoms experienced and reported by the occupants and should be used as a management tool to improve effectively air quality.

Two approaches were used in the literature to calculate IAQ indices. The first one builds on the comparison of typical exposure concentrations with the existing exposure limits i.e. the Exposure Limit Values (ELV) as defined and used in the previous sections. The second evaluates the direct health impacts of the pollution by estimation of the Disability-Adjusted Life Years (DALYs).

7.1. Indices based on ELVs

A literature review of existing indoor environmental quality indices has been recently carried out by Kirchner et al. (2006b). They concluded that previous IAQ indices considered different pollutants, exposure limits and different aggregations methods of effects. Based on Kirchner et al. (2006b), the different indices can be divided into four categories as shown in Table 9 and described below.

7.1.1. Category I: One index per single pollutant

A dimensionless index is defined by dividing the measured/calculated concentration by a reference value (see e.g. chapter 6). The reference value usually refers to health risks (accounting for chronic or acute effects), but other metrics can also be used (e.g., odour or irritation threshold). A value higher than one, i.e. a concentration higher than the reference value indicates a potential IAQ problem or risk. For each single pollutant, one index is calculated and it is specific only for this pollutant. Teichman et al. (2016) used this approach and proposed a graphical representation to characterize the IAQ performance (Figure 27). Rojas et al. (2016) used the relative threshold deviation for CO_2 and TVOC by integrating over the time the difference between the pollutant concentration and a lower ELV based on German and Austrian guideline values, and dividing by the difference between the lower and upper ELV (Figure 28).

7.1.2. Category II: Simple aggregation

A unique index is calculated by aggregating all sub-indices derived for single pollutants (as described in the case of Category I); aggregation can be made by addition or by taking the maximum value or by other methods. This approach was used by Cohas (1996), who defined a global index representing the worst situation by using the maximal value of the indices evaluated for each single pollutant. Gadeau (1996) and Castanet (1998) used on the other hand a simple algebraic sum to establish one index. In the definition of an Indoor Environment Index (IEI), Chiang and Lai (2002) calculated an IAQ sub-index based on an arbitrary scale for each pollutant concentration.

7.1.3. Category III: Aggregation according to the sources of pollutants and/or types of pollutants

The French project QUAD-BBC (2012) used the simple aggregation principle arranging the measured concentrations in four groups related to the pollutant sources or types (Figure 29): human presence (A), cooking activity (B), potential sources of gaseous pollutant in the studied room (C) and particles (D). The indices obtained for different ventilation configurations are represented in a radar graph. *A, B, C* and *D* are IAQ indices and *En* is the energy index.

Table 9. Previously proposed approaches to define an IAQ index.

Cat.	Reference	Pollutant	Equation
I	All references from this table. Used as sub-indices	Any	$I_i = \frac{C_i}{ELV_i}$ (2) where C_i is the concentration of pollutant *i* and ELV_i its exposure limit value.
II	Rojas et al. (2016)	CO2, TVOC	$I_i = \frac{\int_0^T (C_i(t) - ELV_{lower})dt}{ELV_{upper} - ELV_{lower}}$ (3) where $C_i(t)$ is the concentration of pollutant I, ELV_{lower} and ELV_{upper} are the lower and upper exposure limit values, *t* is the time and *T* is the occupancy period.
	Cohas (1996)	Any	$I_{BILGA} = \begin{cases} \max\left(\frac{E^P_{mean} - ELVc^P_T}{ELVa^P_T - ELV^P_T}\right) si\ E^P_{moy} > ELVc^P_T \\ \max\left(\frac{E^P_{mean} - ELVc^P_T}{ELVc^P_T}\right) si\ E^P_{moy} \leq ELVc^P_T \end{cases}$ (4) where E^P_{mean} is the mean exposure to pollutant p over the period of time T and $ELVc^P_T$ and $ELVa^P_T$ are the Exposure Limit Values for chronic and acute effects.
	Gadeau (1996)	CO, CO2, NO2, formaldehyde	$I_{CLIM2000} = \frac{1}{4}\left(\frac{[CO]}{30} + \frac{[CO2]}{4500} + \frac{[NO2]}{0,4} + \frac{[HCHO]}{0,06}\right)$ (5) where concentrations are in mg/m^3.
	Castanet (1998)	CO, CO2, bacteria	$I_{LHVP} = \frac{[CO]}{5} + \frac{[CO2]}{1000} + \frac{[Bacteria]}{1000}$ (6) where *[CO]* and *[CO2]* are carbon monoxide and dioxide concentration (ppm) and *[Bacteria]* is the bacteria concentration (cfu/m^3).
	Chiang and Lai (2002)	CO, CO2, formaldehyde, TVOC, PM10	$I_{IEI\_IAQ} = \frac{1}{p}\sum_{i=1}^{p} Grade_i$ if $all\ \ Grade_i \geq 60\ (good\ IAQ)$

			$I_{IEI\_IAQ} = \min\left(Grade_i\right) if\ not$ (7) Where *Gradeᵢ* is 20, 40, 60, 80 or 100 depending on the pollutant concentration values. Example for CO_2: $Grade_i = 20$ if [CO2] > 2500 ppm, $Grade_i = 40$ if 2500 ppm > [CO2] > 1000 ppm…
III	QUAD-BBC (2012)	Group A: CO2 Group B: NO2, SO2, O3 Group C: CO, formaldehyde, acetaldehyde, ethylbenzene, styrene, toluene, o-xylene, acetone Group D: PM2.5, PM10	$I_{QUAD-BBC} = \sum_{i=1}^{p} \frac{C_{obs}}{ELV}$ (8) where *p* is the number of pollutants in the group and *obs* is the measured concentration.
IV	Sofuoglu and Moschandreas (2003)	Formaldehyde, TVOC, CO, CO_2, PM2.5, PM10, fungi, bacteria	$I_{IAPI} = \frac{1}{I}\sum_{i=1}^{I}\frac{1}{J}\sum_{j=1}^{J}\frac{1}{K}\sum_{k=1}^{K}10\times\left[1-\frac{C_{i,j,k}^{\max}-C_{i,j,k}^{obs}}{C_{i,j,k}^{\max}-C_{i,j,k}^{\min}}\left(\frac{ELV_{i,j,k}-C_{i,j,k}^{obs}}{ELV_{i,j,k}}\right)\right]$ (9) where *I* is the number of level-3 groups, *J*, the number of level-2 groups in each level-3 group, *K*, the number of level-1 pollutant variables in each level-2 group and *max* and *min* are the measured maximum and minimum concentrations of the BASE study (Girman et al., 1995), respectively.

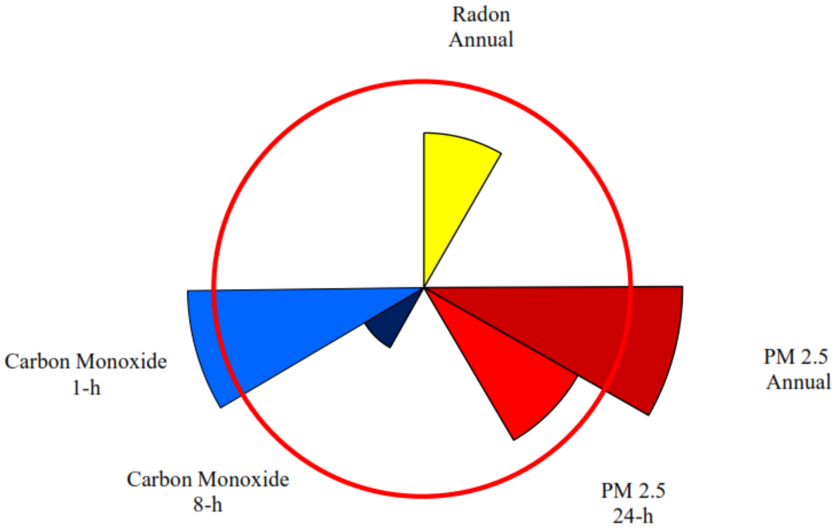


Figure 27: Graphical representation of IAQ performance using one index per single pollutant (Teichman et al, 2016). The outer red circle represents the threshold limit (ELVs) for each pollutant.

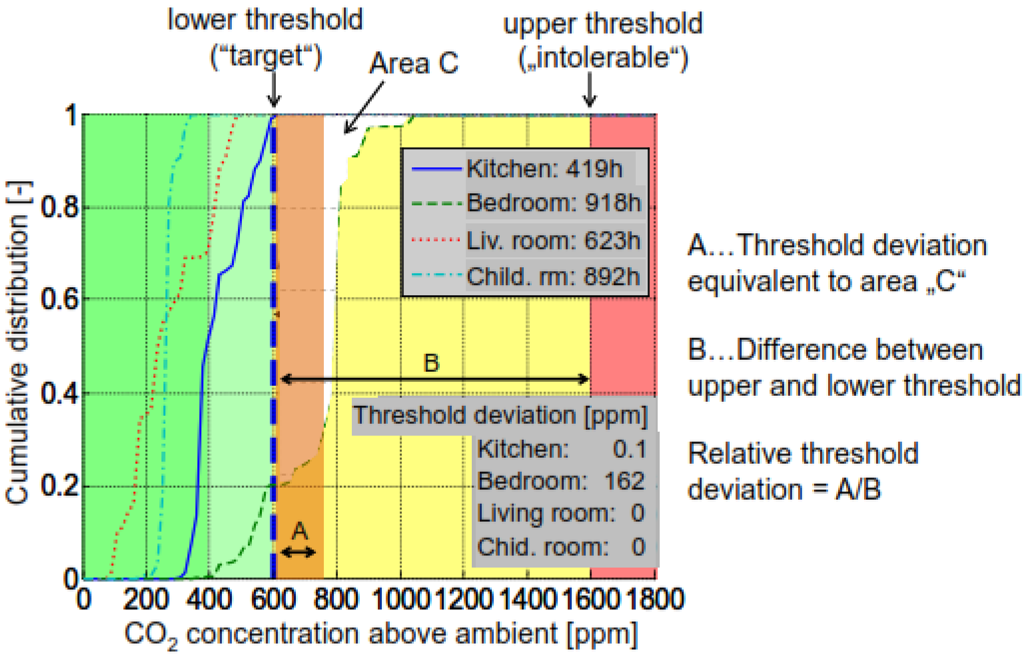
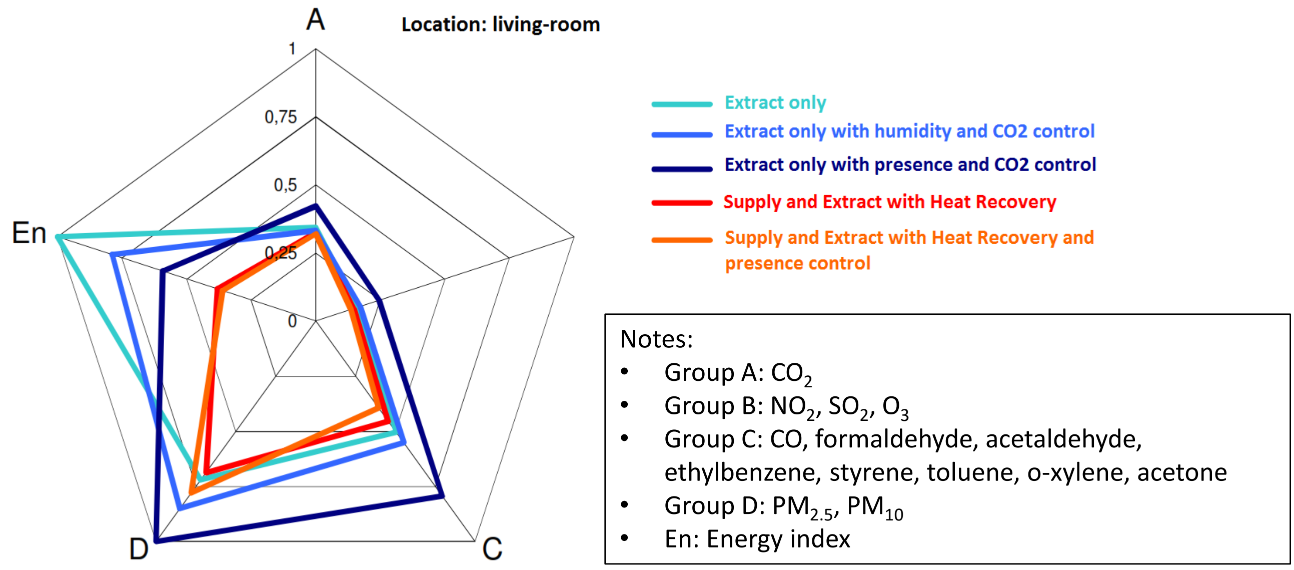


Figure 28: Principle for determination of the relative threshold deviation (Rojas et al, 2016).



Notes:

- Group A: CO_2
- Group B: NO_2, SO_2, O_3
- Group C: CO, formaldehyde, acetaldehyde, ethylbenzene, styrene, toluene, o-xylene, acetone
- Group D: $PM_{2.5}$, PM_{10}
- En: Energy index

Figure 29: Representation of Indoor Air Pollution. *A, B, C and D* are IAQ indices and *En* is the energy index, 0 is the best situation for IAQ and energy (QUAD-BBC, 2012).

7.1.4. Category IV: Aggregation accounting for the IAQ in the building stock

The Indoor Air Pollution Index (IAPI) developed by Sofuoglu and Moschandreas (2003) is derived using the average concentration of eight pollutants: VOCs (formaldehyde and TVOC), inorganic gases (CO and CO2), particulate matter (PM2.5 and PM10) and biological particles (bacteria and fungi). The main feature that makes IAPI different from the previous indices is that it includes in its definition the minimum and maximum concentration from the reference database. Sofuoglu and Moschandreas (2003) used the data from the Building Assessment Survey and Evaluation (BASE) project (Girman et al., 1995) that was focused on office buildings as their reference database compared the measurements against these data. This feature allows an easy comparison of the IAQ of a particular building (Building X in Figure 30) with the typical levels measured in building stock but no valuation is made of the potential risk.

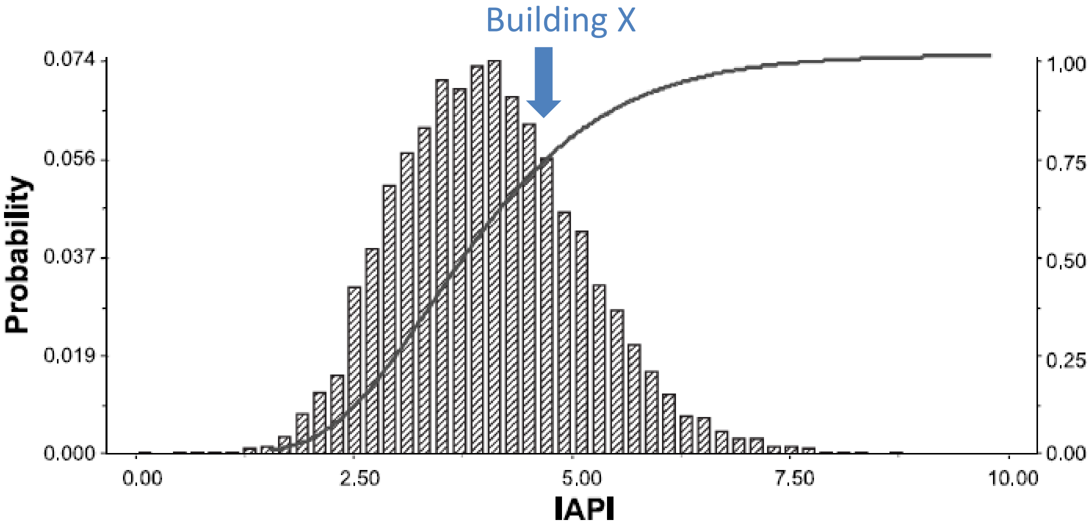


Figure 30: Frequency distribution and fitted lognormal cumulative distribution for simulated IAPI values using the BASE project database (Sofuoglu and Moschandreas, 2003).

7.1.5. *Aggregation of indices for deriving a multipollutant index*

Most of the indices presented earlier derive indices using the respective ELVs and then use the specific aggregation function. This process is illustrated in Figure 31. The point of discussion is aggregation and how it should be made to derive the comprehensive multipollutant index.

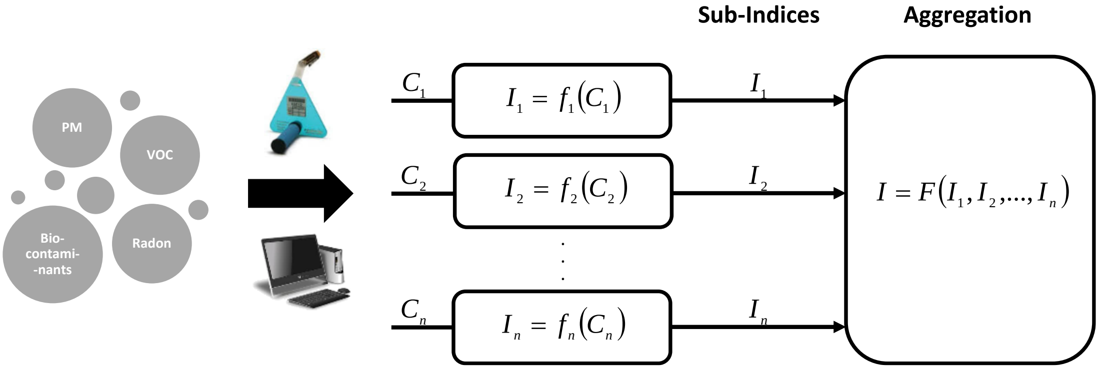


Figure 31: Derivation of a multipollutant index.

There are two important properties to be considered when aggregating sub-indices: ambiguity and eclipsing. They were introduced and discussed in the study regarding the definition of the Indian Outdoor Air Quality Index by Sharma and Bhattacharya (2012); Figure 32 illustrates the two issues.

Ambiguity is creating the false alarm. As shown in Figure 31, if I is considered as the multipollutant index defined as the sum of the 2 sub-indices I_1 and I_2, $I > 1$ indicates that the concentration of each pollutant is greater than the recommended level. However it is possible to have combinations of $I_1 < 1$ and $I_2 < 1$ such that $I > 1$ i.e. the condition when the aggregation is causing the in the false alarm; red triangle in Figure 32 left is demonstrating such case and is called an ambiguous region.

Eclipsing is underestimating the effect. As shown in Figure 31 if I is considered as the average of the 2 sub-indices I_1 and I_2, one of them can be higher than 1 and aggregated I can be below I even though one of the indices suggests the risk (as shown by the red triangle in Figure 31 right).

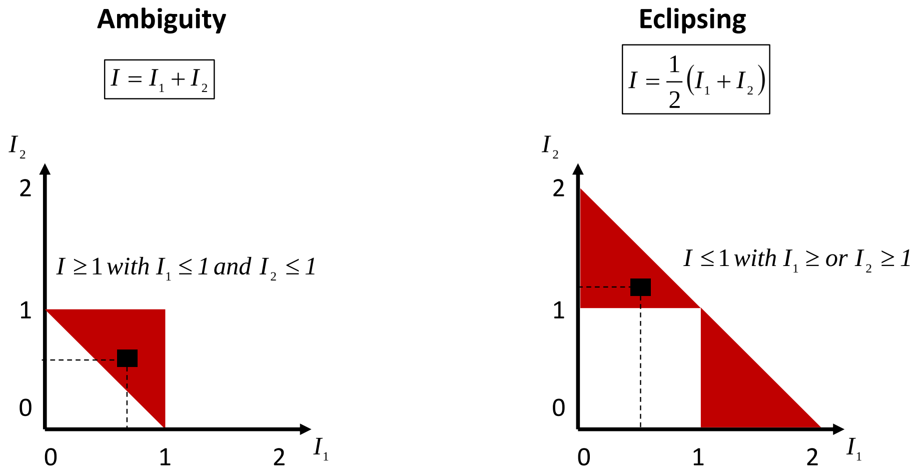


Figure 32: Problems related to the aggregation of sub-indices adapted from Sharma and Bhattacharya (2012): ambiguity (left) and eclipsing (right); explanation of red triangles is provided in the text

Ambiguity and eclipsing are important problems of additive and multiplicative indices. The only way to avoid ambiguity and eclipsing is to use the maximum values of all individual sub-indices. The maximum operator is currently used around the world to calculate the Air Quality Index (AQI) for ambient air that is based on the maximum value of sub-indices related to outdoor pollutants such as PM, SO_2, NO_x, etc. (EPA, 2016).

From the indices for IAQ collected in this project, the only one that applies the maximum operator is the BILGA index (Cohas, 1996). All the other indices have in their definition the possibility of giving the false alarm (ambiguity) or of eclipsing the health issues. An example which further illustrates ambiguity and eclipsing using actual data is shown in Appendix C.

7.2. DALY approach

The DALY metric quantifies Disability-Adjusted Life Years (DALY) due to exposure to a chemical substance. As defined by WHO (2016), *one DALY can be thought of as one lost year of "healthy"* *life. The sum of these DALYs across the population, or the burden of disease, can be thought of as a measurement of the gap between current health status and an ideal health situation where the entire population lives to an advanced age, free of disease and disability*. The main advantage of DALY is that it allows quantifying and comparing the health impact from various pollutants, including the various types of disease induced. For each disease, the DALYs lost per incidence are calculated using the following equation (Logue et al., 2011b):

$$\mathrm{DALY}_{\mathrm{disease}} = \mathrm{YLL}_{\mathrm{disease}} + \mathrm{YLD}_{\mathrm{disease}} \tag{10}$$

where $\mathrm{YLL}_{\mathrm{disease}}$ are Years of Life Lost due to premature death from the disease and $\mathrm{YLD}_{\mathrm{disease}}$ are Years of Life Disability, weighted from 0 to 1 depending on disease severity.

Equation (10) can be rewritten as:

$$DALYs = \frac{\partial DALY}{\partial disease\ incidence} \times disease\ incidence \tag{11}$$

Which is equivalent to:

$$DALYs = DALY\ factor \times disease\ incidence \tag{12}$$

According to Logue et al. (2011b), there are two different ways of estimating DALYs lost for indoor air pollutants health impact. An intake-incidence-DALY (IND) approach is based on epidemiological data to quantify disease incidence. If these data are not available, it is yet possible to use animal toxicity literature in order to calculate health impact via an intake-DALY (ID) method. Both ID and IND methods are accepted health impact models and, for both of them, only the annual average value of pollutant concentration is needed to estimate the population long-term impact.

7.2.1. DALY IND method based on the epidemiological data

The disease incidence is calculated by application of the following concentration-response (C-R) function.

$$\Delta incidence = population \times y_0 \times (1 - e^{-\beta \times \Delta C_{exposure}}) \tag{13}$$

where $population$ (-) is the number of persons exposed (it is often set to 100,000 to obtain a DALY lost per 100,000 persons), y_0 is the baseline prevalence of illness per year (-), β is the coefficient of the concentration change (natural logarithm of the relative risk divided by the change in mean/median exposure) and $\Delta C_{exposure}$ is the exposure-related concentration (µg/m^3).

The exposure-related concentration is calculated by considering the inhalation of indoor polluted air of mean concentration C_{indoor} relative to a pollutant-free indoor air. Logue et al. (2011b) considered that, in the US, people spend 70% of their time in residential buildings so that:

$$\Delta C_{exposure} = 0.7 \times C_{indoor} \tag{14}$$

where C_{indoor} is the indoor mean concentration of pollutant *(*µg/m^3*)*.

The second step is to estimate the DALY losses using equation (12). The available DALY factors for each pollutant have been compiled by Logue et al. (2011b) from literature. If the DALY factor is not available then the ID approach should be used instead.

7.2.2. DALY ID method based on animal toxicity data

This method to estimate the DALYs lost due to exposure to a chemical substance is less accurate than the previous one. Yet, it allows estimating DALY for non-criteria pollutants and results remain coherent with the pollutant ranking.

In this method equation (10) has to be rewritten as follows:

$$DALYs = \left(\frac{\partial DALY}{\partial disease\ incidence} \times \frac{\partial disease\ incidence}{\partial intake}\right) \times intake \tag{15}$$

Which is equivalent to:

$$DALYs = \frac{\partial DALY}{\partial intake} \times intake \tag{16}$$

Where $intake$ is the mass of pollutant (µg) that an individual inhales over a given time period.

The first term of the right member of Equation 16 is split into two categories for cancer and non-cancer effects:

$$\frac{\partial DALY}{\partial intake} = \left(\frac{\partial DALY}{\partial intake}\right)_{cancer} \times ADAF + \left(\frac{\partial DALY}{\partial intake}\right)_{non-cancer} \tag{17}$$

Where $\left(\frac{\partial DALY}{\partial intake}\right)_{cancer}$ and $\left(\frac{\partial DALY}{\partial intake}\right)_{non-cancer}$ are DALYs lost per unit of *intake* from carcinogenic and non-carcinogenic causes for each pollutant (DALY/µg) and $ADAF$ is the Age-Dependent Adjustment Factor (-). All required data are available in Huijbregts et al. (2005).

The mass of pollutant that an individual inhales over a given time period in an indoor space can be evaluated by:

$$intake = Q_{intake} \times C_{indoor} \times \Delta t \tag{18}$$

Where Q_{intake} is the volume rate of air intake (m^3/day), C_{indoor} is indoor concentration (µg/m^3), Δt is the considered period of time (day), usually taken to 365 to estimate the DALYs lost per year.

Figure 33 and Figure 34 present the results obtained by Logue et al. (2011b) using the two approaches with Monte-Carlo sampling to account for confidence intervals. As it can be seen in these figures and also as commented by the authors, there is actually a large uncertainty in the number of DALY losses estimated for each pollutant by the IND and ID models but it is the only scientifically-based method available to evaluate and compare the health impacts of the exposure to different pollutants.

In case of DALYs there is no problem of agglomeration and the direct summation of DALYs for all studied pollutants can be done to evaluate the overall health effect. In this way, Logue et al. (2011b) estimated the total annual health impact of inhaling indoor air pollutants in U.S. residences, excluding radon and Second Hand Smoke Exposure (SHS), to 1,100 DALY losses per 100,000 persons.

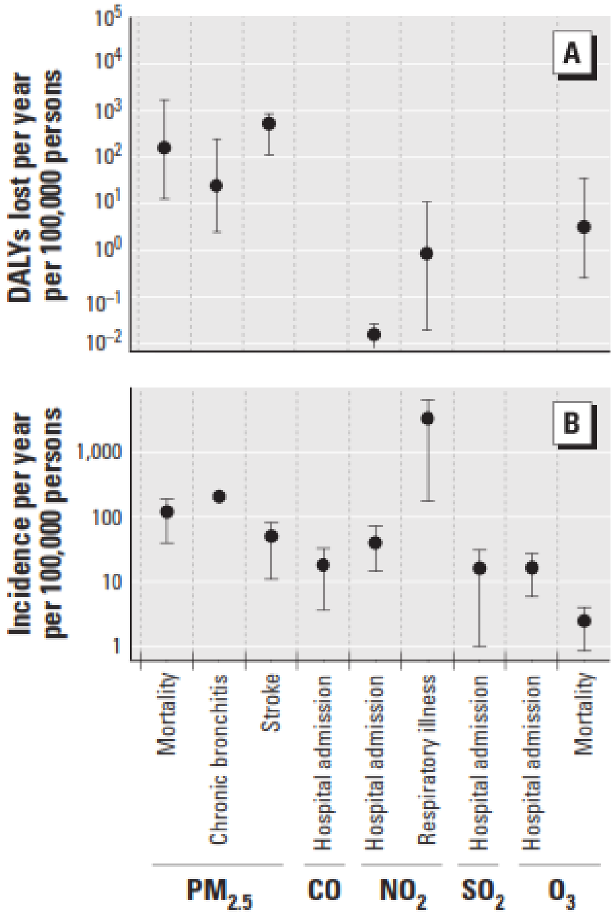


Figure 33: DALYs lost per year per 100,000 persons evaluated using the IND method (Logue et al., 2011b).

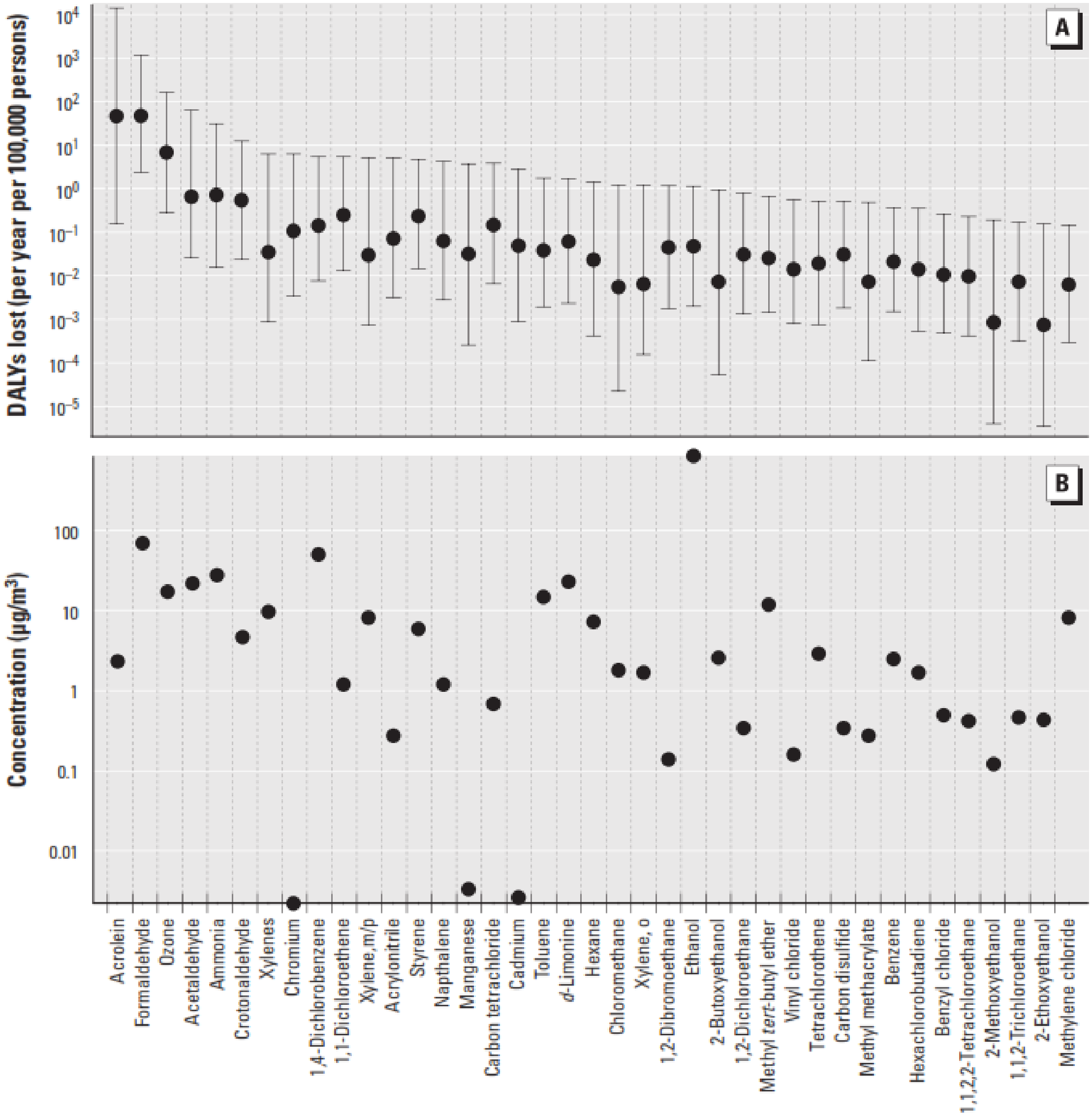


Figure 34: DALYs lost per year per 100,000 persons evaluated using the ID method (Logue et al., 2011b).

8. IAQ metrics suggested for use in Annex 68

The purpose of the present section is to define metrics to be used by Annex 68 and the ELVs needed to properly evaluate the impact of IAQ. The results presented in this section on IAQ synthesize the different elements described in previous sections. The last part of the section presents the relationship between IAQ and energy and how it has been addressed in past studies.

It has been assumed that Annex 68 will only use the **pollutants listed in** Table 8. The impact of the long- and short- term exposures are to be considered **separately**, **pollutant by pollutant** (by evaluating sub-indices for each pollutant) and a **unique multipollutant** (aggregated) index is evaluated according to the calculations described in the subsequent sections.

8.1. IAQ Indices

8.1.1. Long-term exposure (chronic effects)

For each pollutant two indices are proposed, one based on ELV and one on DALY approaches (see sections 7.1 and 7.2) because they provide different information regarding IAQ and are differently aggregated. The ELV-based method compares the pollutant concentration to an exposure limit and thus indicates if the concentration is above (>1) or below (<1) the exposure limit. This approach simply detects the potential risk and is easy to follow by designers. This approach does not however inform about the burden of the effects on health. This is why DALY approach is proposed as well which is evaluating the number of years of healthy life lost because of a given exposure. The DALY approach communicates thus better to policy/decision makers as it provides the information on which efforts should be made and for which pollutants to achieve the largest effects on the population health. Table 10 shows the ELV and DALY approaches applied for the target pollutants in Annex 68 (see section 6).

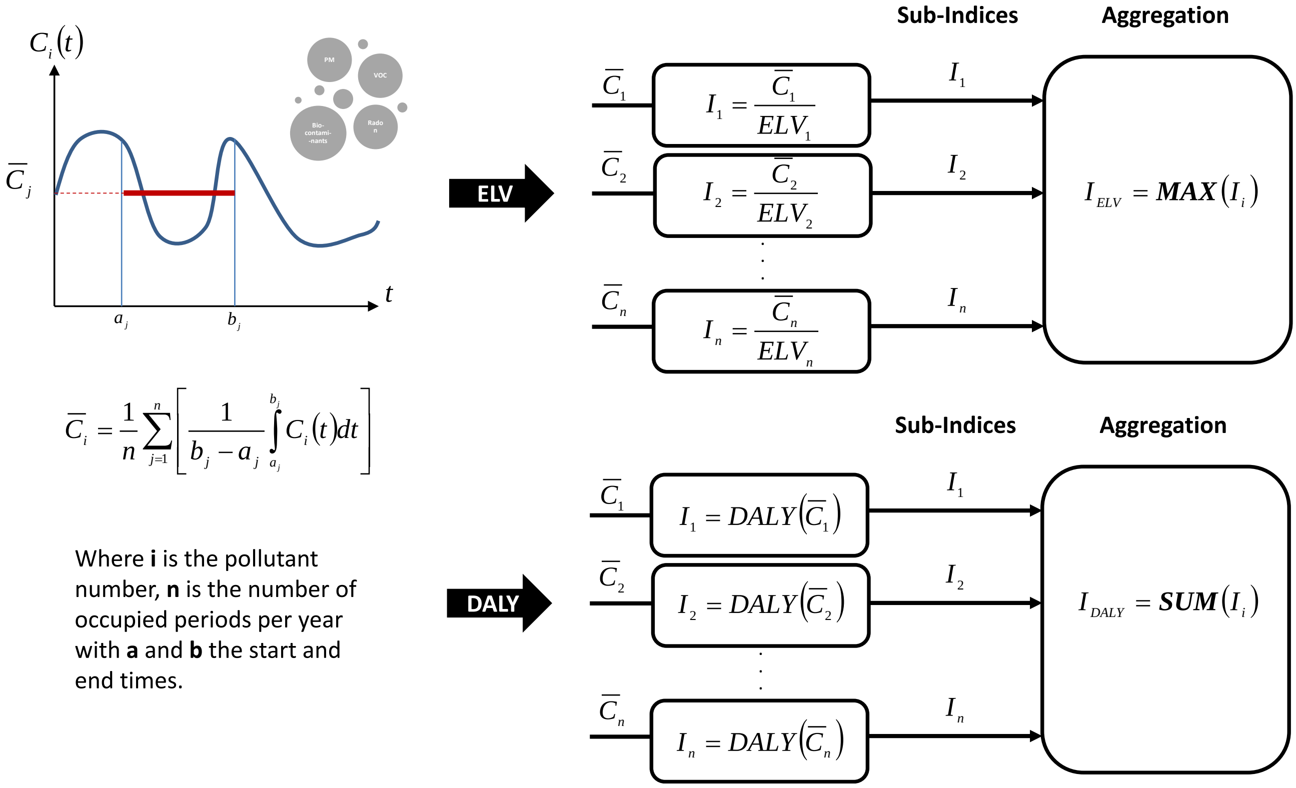
ELV and DALY approaches require a pollutant concentration which is relevant for a long-term exposure. The reference period is in this case set to one year. Consequently, the concentration is calculated as the mean annual concentration during occupation. This period can possibly be estimated by short 1-2 week measuring campaigns in different seasons as pollutant emissions may depend on indoor temperature. Additional information about indoor air pollutant measurements and sampling protocols can be found in various Guidelines (ASHRAE, 2009) and Standards (ISO 16000 series, 2006).

Figure 35 presents the process used to evaluate IAQ considering the long-term exposure (with the ELV or DALY approaches) that results into index defined as the maximum value of indices calculated for individual pollutants using the ELV approach and as the sum of DALYS for individual pollutants using the DALY approach. Figure 36 and Figure 37 illustrate a possible graphical representation of the two approaches when comparison between two cases has to be done. In this illustrative example, the data from Kirchner et al. (2006a) for the non-low-energy buildings and Derbez et al. (2015) for the low-energy buildings in France are used. The comparison illustrated in these figures shows that both approaches lead to more or less similar conclusion: the IAQ in the low-energy buildings is better because the multipollutant indices are lower than the indices calculated for the exposure in the non-low-energy buildings. This example also shows the limitations of the method. Not all data for all pollutants are available. For example, no data was available for mold and acrolein was measured during the measurements in the low-energy buildings.

Table 10. Input values for ELV and DALY method to estimate the index describing the long-term exposure and the risk for chronic effects.

	ELV*	DALY method
Acetaldehyde	48	ID
Acrolein	0.35	ID
α-pinene	200	Not available
Benzene	0.2	ID
Formaldehyde	9	ID
Naphthalene	2	Not available
Nitrogen dioxide	20	IND
PM10	20	Not available
PM2.5	10	IND
Radon	200	Not available
Styrene	30	ID
Toluene	250	ID
Trichloroethylene	2	ID
Mold	200	Not available

* ELV concentration in µg/m^3 except for radon in Bq/m^3 and mold in CFU/m^3



$$\overline{C}_i = \frac{1}{n}\sum_{j=1}^{n}\left[\frac{1}{b_j - a_j}\int_{a_j}^{b_j} C_i(t)dt\right]$$

Where **i** is the pollutant number, **n** is the number of occupied periods per year with **a** and **b** the start and end times.

Figure 35: Aggregation of indices for individual compounds in case of ELV method (maximum index) and DALY method (addition of DALYs) when the long-term exposure effects are considered.

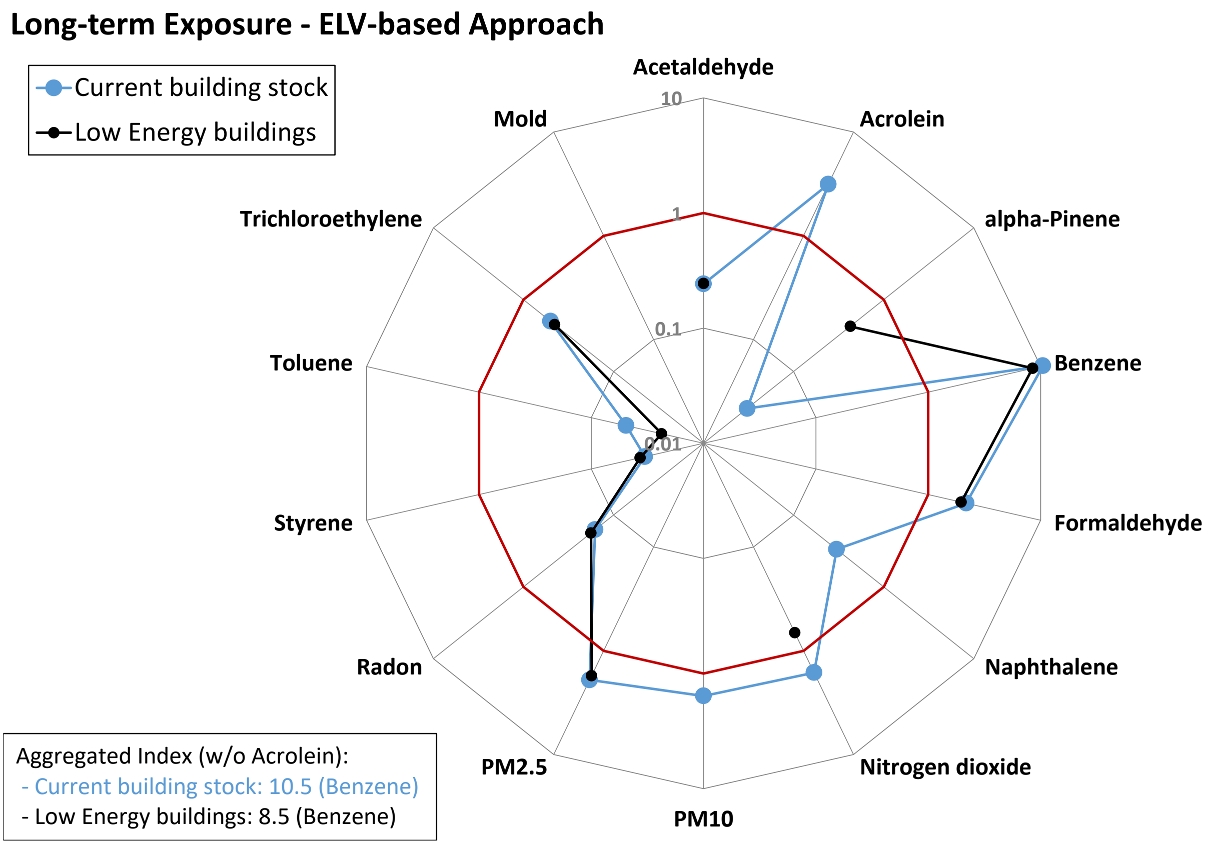


Figure 36: Comparison of indices for target pollutants estimated using ELV approach in the French non-low-energy and low-energy buildings. The outer red circle represents the threshold limit (ELVs) for each pollutant.

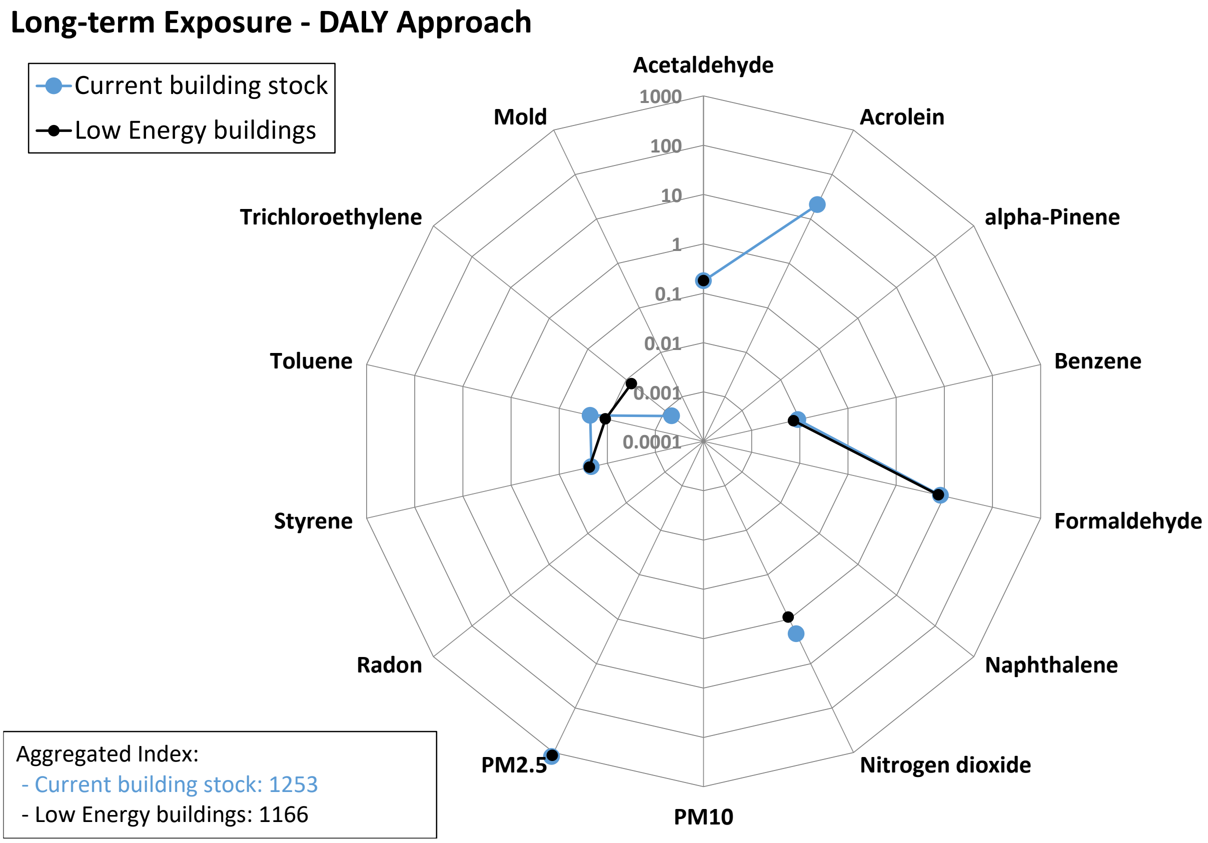


Figure 37: Comparison of indices for target pollutants estimated using DALY approach in the French non-low-energy and low-energy buildings. Y-axis are DALYs lost per year, per 100,000 persons.

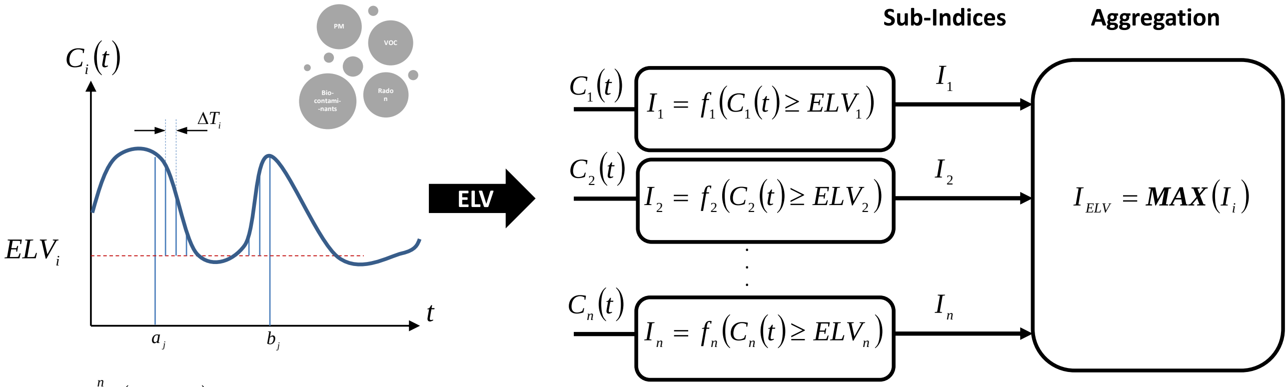
8.1.2. Short-term exposure (acute effects)

Table 11 gives the ELV together with the averaging time required to evaluate the effects of short-term exposure to target pollutants. Compared to the effects of long-term exposure, short-term exposures are more difficult to evaluate as they require the knowledge of the variation of pollutant concentration with time at a time step determined by the averaging period i.e. ≤1h for most of the pollutants. If the period of occupancy is taken into account, then the index can be calculated as the frequency of exceedance over allowable ELV and the averaging time for each pollutant. An aggregated index is derived in a similar way to that for long-term exposure, i.e. as the maximum of the frequency per pollutant. The derivation process is illustrated in Figure 38.

Table 11. Input values for short-term exposure.

	ELV*	Averaging period
Acrolein	6.9	1 h
Carbon dioxide	1250	8 h
Formaldehyde	123	1 h
Nitrogen dioxide	470	1 h
PM10	50	24 h
PM2.5	25	24 h
Radon	400	8 h
TVOC	600	8 h

* ELV concentration in µg/m^3 except for carbon dioxide in ppm and radon in Bq/m^3



$$I_i = \frac{\sum_{j=1}^{n} (b_j - a_j) \times f_j(C_i(t) \geq ELV_i \ over \ \Delta t_i)}{\sum_{j=1}^{n} (b_j - a_j)}$$

Where **i** is the pollutant number, **n** is the number of occupied periods per year with **a** and **b** the start and end times. The **f** function is the frequency of exceedance of ELV over the [a;b] period of time.

Figure 38: Aggregation of indices for individual compounds in case the short-term exposure effects are taken into account.

8.2. Indoor Air Quality and Energy

Measures to reduce pollutant concentrations in indoor spaces that require use of energy comprise increasing the rate of outdoor air supplied to spaces and/or use of air cleaners, as well as pollutant entrapment with hoods or exhausts. Pollution source control will not increase operational costs for energy and can even reduce this cost, but may not always be feasible during renovations.

Increasing outdoor air supply rate will increase energy needed to condition the outdoor air i.e. heat, cool, humidify or dehumidify. Considering ventilation system with heat recovery typically found in low-energy buildings in moderate and cold climates, the energy demand for the air supply to spaces can be approximately calculated as follows:

$$Q_{load} = \rho \times c_p \times Q_v \times (1 - \varepsilon_x) \times (T_{in} - T_{out}) \tag{19}$$

where Q_{load} is the energy demand (W), ρ is the air density (kg/m^3), c_p is the air heat capacity (J./(kg.K)), Q_v is the volumetric air flow rate (m^3/s), ε_x is the heat exchanger efficiency (-) and T_{in} and T_{out} are the indoor and outdoor temperatures (K), respectively.

Increasing the outdoor air supply rate or using air cleaners in the ventilation system such as additional or more efficient particle/gas filters (resulting in a pressure loss increase), will have a direct effect on the electricity consumption by the fan. The fan electric power can be expressed as follow:

$$P_{fan} = \frac{Q_v \times \Delta p_{fan}}{\varepsilon_{fan}} \quad \text{or} \quad P_{fan} = \frac{Z}{\varepsilon_{fan}} Q_v^{\,3} \tag{20}$$

where P_{fan} is the electric power used by the (W), Δp_{fan} is the fan total pressure difference (Pa), ε_{fan} is the fan overall efficiency (-) and Z is overall pressure loss coefficient (kg/m^7).

Electrical energy is also used by active air cleaning devices that employ techniques such as electrostatic precipitation, plasma or photocatalytic oxidation.

Final energy can be evaluated once the duration of using the ventilation system is known. The total energy can then be evaluated after conversion to primary energy consumption.

As an example, the primary energy consumption in a low-energy residential building was calculated when two IAQ solutions are employed: increasing outdoor air supply rate and increased filtration (Table 12). Simulations were made during the QUAD-BBC project (2012). The building was located in France. They were equipped with a conventional balanced system with heat recovery and heated by electric devices. The total primary energy consumption (heating + fan electricity consumption) increased by 59% and 35% respectively for a 50% increase of the outdoor air supply rate and when a F7 filter was added in the system. This simple example shows that improving IAQ can have an important impact on energy consumption.

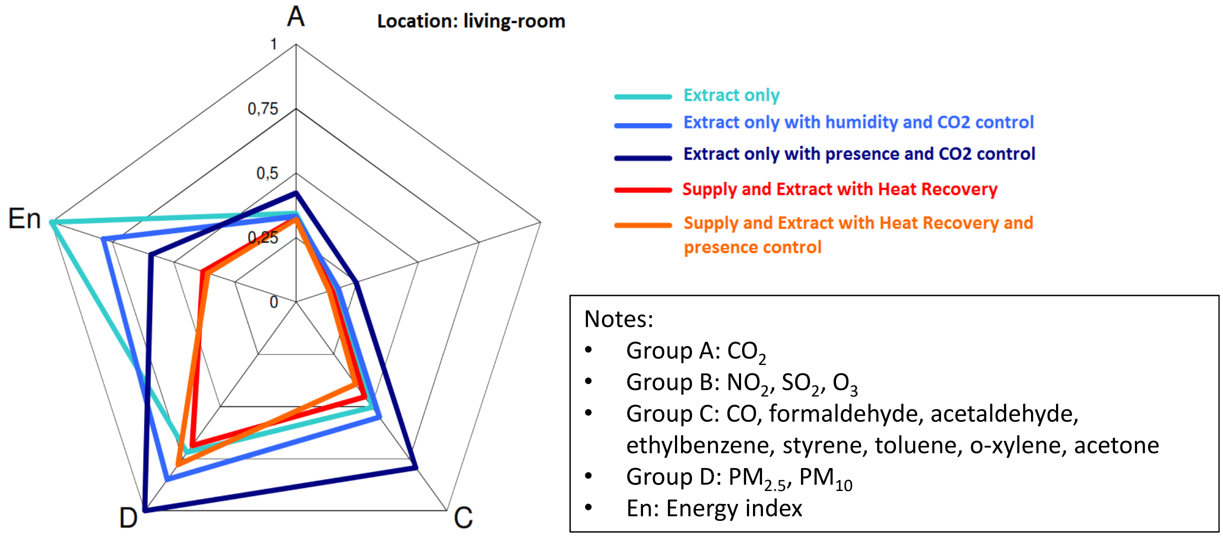
Table 12. Simulation of the potential energy costs related with improved IAQ in a low-energy dwelling.

Energy consumption for heating (kWh_{pe}/m^2.year)	Envelope	Ventilation	Fan	Total	Increase
Reference	17	8	6.1	31.1	
Increasing outdoor air supply rate by 1.5*	17	12	20.6	49.6	59%
Increasing filter efficiency (G4 to G4/F7)*	17	8	17.1	42.1	35%

*exchanger nominal efficiency = 0.85, constant fan efficiency, G4 to G4/F7 pressure loss increase = 100 Pa (initial pressure loss = 125 Pa)

The real energy consequences of an IAQ measure will depend on the whole ventilation system (fan control, fan type, age of filters, system design (e.g. duct sizing), etc.). Building Energy Simulations (BES) are necessary to model all heat transfers that take place in a building (through its envelope and its systems) during the whole year. An investigation made by Stephens et al. (2010) shows that upgrading ventilation system to a higher level of filtration cause higher or lower energy consumption (likely to be small in residential buildings) depending on the rest of the return side of the system, the system fan curve, the fan-efficiency curve and the location of the intersection of the fan and duct curves.

Coupling BES and Indoor Air Quality models is the additional step needed to evaluate the energy performance of a building (or building strategies) in relation to its IAQ performance. Some previous studies included energy use (for ventilation and space heating) modeling in their evaluation of solutions to improve the air quality of indoor spaces (QUAD-BBC, 2012; Tourreilles et al., 2015). In the QUAD-BBC project (2012), IAQ indices and energy use were considered separately (Figure 39). The energy index (*En*) is dimensionless and obtained by dividing the primary energy consumption of the considered configuration by the energy-related worst case configuration. In this example, a balanced system with heat recovery and occupancy-based airflow rate is clearly the best solution in terms of IAQ performance and energy consumption.



Notes:

- Group A: CO_2
- Group B: NO_2, SO_2, O_3
- Group C: CO, formaldehyde, acetaldehyde, ethylbenzene, styrene, toluene, o-xylene, acetone
- Group D: $PM_{2.5}$, PM_{10}
- En: Energy index

Figure 39: Representation of Indoor Air Pollution. *A, B, C and D* are IAQ indices and *En* is the energy index, 0 is the best situation for IAQ and energy (QUAD-BBC, 2012).

Tourreilles (2015) used a unique index to compare the different solutions. This index is defined as the ratio of an IAQ index using the considered case and the worst one in terms of IAQ (0 being bad, 1 being good) to an energy one (0 being the solution with the lowest additional energy consumption). The best solution in terms of IAQ/energy use has the index with the highest value. In the example shown in Figure 40, the electronic filter is clearly the best choice for PM but is the worst one for formaldehyde (no effect on formaldehyde concentration). The "F7+Carbon Filter" and "doubling the fresh air rates" solutions are equivalent to treat both formaldehyde and PM while the two other solutions induce too high energy consumption so the index defining their performance is low. The main drawback of this index is that it equally weights the IAQ and energy performance.

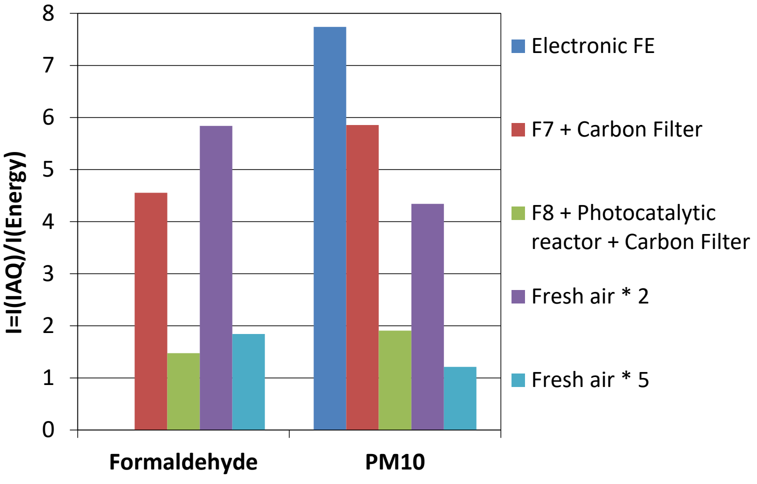


Figure 40: Accounting for energy consumption in IAQ evaluation (the index aggregates IAQ and energy, 0 is the worst situation because of bad IAQ, high energy consumption or both).

In conclusion, aggregating energy and IAQ indices in the examples presented requires that both are measured on the same absolute scale – and they are not. Therefore, in the future monetizing the effects of IAQ (using e.g. DALYs) and energy would be the way to bring both indices to the same scale. Such approach was used to estimate socio-economic costs of IAQ in France (ANSES, 2014). There are currently too few data to extend this approach to all the pollutants listed in Annex 68. So, it has been decided to **considerer energy consumption separately from the IAQ indices**.

8.3. Graphical presentation

Figure 41 illustrates a possible graphical presentation of IAQ indices along with energy consumption (for ventilation and space heating and cooling i.e. excluding domestic hot water, lighting and generation by photovoltaic cells). All indices for single pollutants are shown for long-term (chronic) and short-term (acute) effects using ELV and DALY approaches. Energy consumption is displayed in the lower right corner. This representation makes possible visual and quantitative comparison among a reference IAQ/Energy situation and possible air cleaning solutions. Figure 41 provides an example of the possible approach for labeling indoor environments as regards IAQ and energy performance.

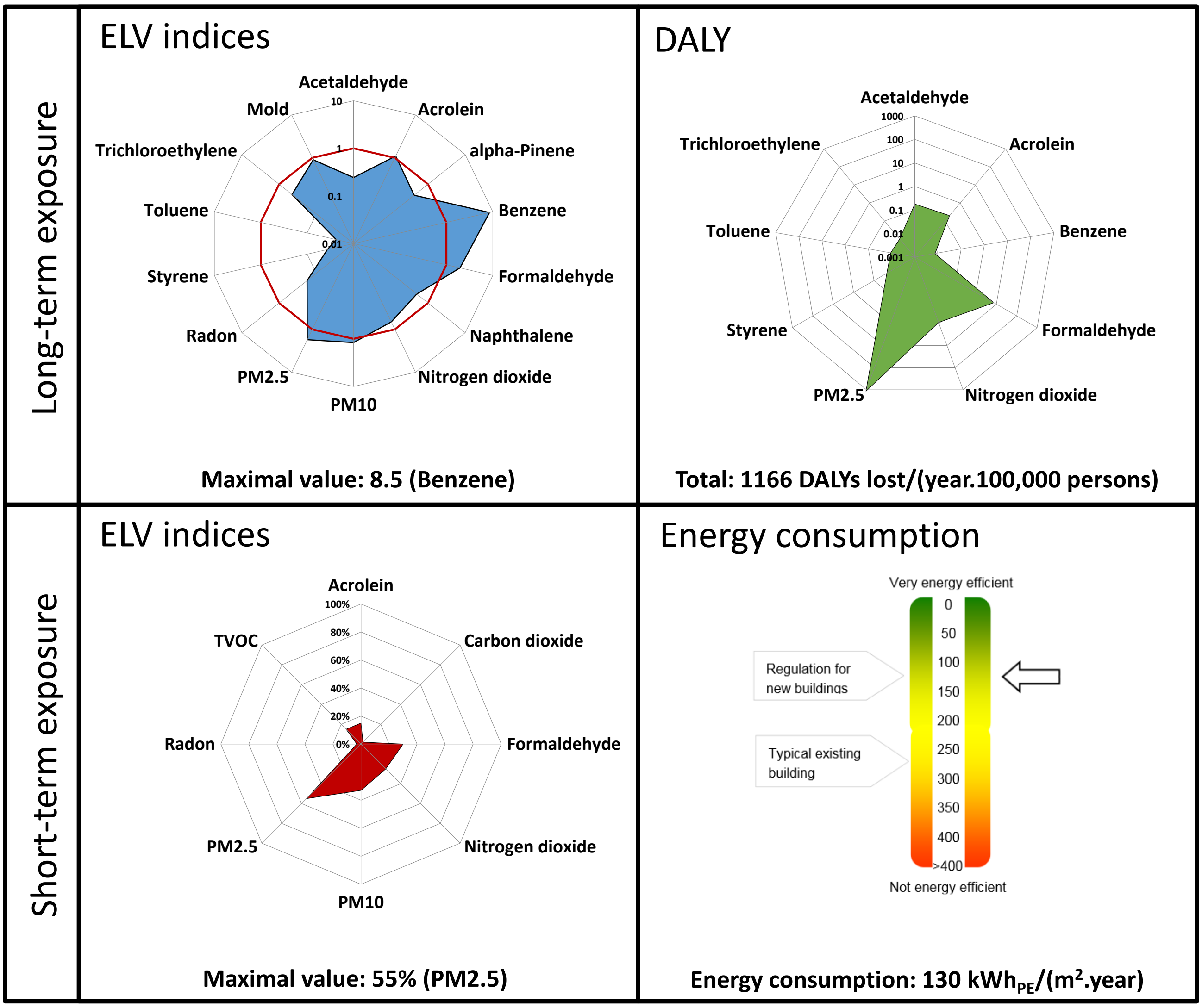


Figure 41: An example of IAQ/Energy signature for low-energy residential buildings (data represented here are just for display and do not represent actual situation).

9. Conclusions

This report proposed the target pollutants and the metrics needed to evaluate IAQ in in low-energy residential buildings in relation to energy consumption.

Comparisons between the non-low-energy and low-energy residential buildings were made based on the data from Australia, Belgium, China, France, Japan and USA. The data presented in the report originate from the following six studies in about 3000 low-energy residential buildings in total: Park and Ikeda (2006), Cheng et al. (2010), Stranger et al. (2012), Du et al. (2014b), Derbez et al. (2015), Logue et al. (2011a). The measurement results were compared with the concentration levels measured in about 5000 non-low-energy residential buildings. These comparisons showed generally lower concentrations describing long-term exposures of pollutants in the low-energy buildings. A few pollutants still had high concentrations, specifically benzene, formaldehyde, nitrogen dioxide, PM2.5, styrene, trichloroethylene. In the case of the same comparisons in China and Japan, higher concentrations of formaldehyde, α-pinene, decane, dodecane, propanal, crotonaldehyde, trichloroethylene and pentanal were found in the low-energy buildings. There were generally lower concentrations in low-energy buildings that are representative for short-term exposures.

Sixteen target pollutants were proposed to assess the likelihood of health risks in low-energy residential buildings both as regards the short-term and the long-term exposures and effects. These are: acetaldehyde, acrolein, α-pinene, benzene, carbon dioxide, formaldehyde, naphthalene, nitrogen dioxide, PM10, PM2.5, radon, styrene, toluene, trichloroethylene, TVOC and mold.

Two approaches to define the metric for assessing the importance of measured concentrations of pollutants were selected. One approach compares measured concentrations with the existing exposure limits (Exposure Limit Values, ELVs). In this approach the unbiased aggregation of indices for specific pollutants is achieved by selecting the maximum index among them to avoid false response (ambiguity) and lack of action (eclipsing); aggregating by averaging, adding or multiplying is not recommended. This approach is communicative to building designers as it clearly defines concentration level limits for the selected pollutants to avoid the health risk. The second approach evaluates the direct health impacts of the pollutants through the estimation of Disability-Adjusted Life Years (DALYs) lost. In this approach the DALYs for individual pollutants are added to estimate the total burden of disease. This approach is more communicative to policy and decision makers.

As the effects of changing IAQ on energy and IAQ effects are measured on different scale, it is proposed that they are monetized so that they can be compared. Energy consumption, expressed in kWh/(m^2.year) should be consequently considered separately from the IAQ indices.

The present report of Subtask 1 represents the one-year study dedicated to define the Annex 68 metrics. The main limitation of this work clearly lies in the too limited data regarding the levels of pollutants and actual exposures in low-energy residential buildings. Another limitation is that the available data presented average levels (mostly) and no details for individual buildings were achievable. Consequently the information on the concentration levels in the low-energy buildings and their distributions should be considered with caution. Finally, the available ELVs are only for cases when the pollutants in question occur and act individually on the body organ. They exclude the potential adjuvant or synergistic or additive effects of multipollutant mixtures which need to be examined in the future.

10. Acknowledgments

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12. Appendix A: Indoor Air Guideline Value (IAGV) by organization or country

This appendix provides the initial data used in the project to define the Exposure Limit Values (ELV). They are mainly Indoor Air Guideline Values defined by different supra-state or country health organizations.

12.1. World Health Organization

NAME	CAS	IAGV	UNIT	EXPOSURE	AVERAGING PERIOD	Note
Benzene	71-43-2	0	µg/m³	LONG-TERM		carcinogen 1
Carbon monoxide	630-08-0	7	mg/m³	SHORT-TERM	24 h	
Carbon monoxide	630-08-0	10	mg/m³	SHORT-TERM	8 h	
Carbon monoxide	630-08-0	35	mg/m³	SHORT-TERM	1 h	
Carbon monoxide	630-08-0	100	mg/m³	SHORT-TERM	15 min	
Formaldehyde	50-00-0	100	µg/m³	SHORT-TERM	30 min	
HAP	-	0	µg/m³	LONG-TERM		Marker benzo(a)pyrène (50-32-8)
Naphthalene	91-20-3	10	µg/m³	LONG-TERM	>1 year	
Nitrogen dioxide	10102-44-0	200	µg/m³	SHORT-TERM	1 h	
Nitrogen dioxide	10102-44-0	40	µg/m³	LONG-TERM	>1 year	
Ozone	10028-15-6	100	µg/m³	SHORT-TERM	8 h	Outdoor Air
PM10	-	50	µg/m³	SHORT-TERM	24 h	Outdoor Air
PM10	-	20	µg/m³	LONG-TERM		Outdoor Air
PM2.5	-	25	µg/m³	SHORT-TERM	24 h	Outdoor Air
PM2.5	-	10	µg/m³	LONG-TERM		Outdoor Air
Sulfur dioxide	7446-09-5	500	µg/m³	SHORT-TERM	10 min	Outdoor Air
Sulfur dioxide	7446-09-5	20	µg/m³	SHORT-TERM	24 h	Outdoor Air

Tetrachloroethylene	127-18-4	250	µg/m^3	LONG-TERM	>1 year	
Trichloroethylene	79-01-6	0	µg/m^3	LONG-TERM		suspected carcinogen

Figure 42: Indoor Air Guideline Values – WHO (References: WHO. 2010. WHO guidelines for indoor air quality: selected pollutants. World Health Organization Regional Office for Europe, Bonn, Germany / WHO. 2006. WHO Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide: Global Update. World Health Organization Report, 22p.)

12.2. Europe

NAME	CAS	IAGV	UNIT	EXPOSURE	AVERAGING PERIOD	Note
Acetaldehyde	75-07-0	200	µg/m^3	LONG-TERM	>1 year	
Ammonia	7664-41-7	100	µg/m^3	SHORT-TERM	1 h	
Ammonia	7664-41-7	70	µg/m^3	LONG-TERM	>1 year	
Benzene	71-43-2	0	µg/m^3	LONG-TERM		carcinogen 1
Carbon monoxide	630-08-0	10	mg/m^3	SHORT-TERM	8 h	
Carbon monoxide	630-08-0	30	mg/m^3	SHORT-TERM	1 h	
Formaldehyde	50-00-0	30	µg/m^3	SHORT-TERM	30 min	carcinogen 1
Naphthalene	91-20-3	10	µg/m^3	LONG-TERM	>1 year	
Nitrogen dioxide	10102-44-0	200	µg/m^3	SHORT-TERM	1 h	
Nitrogen dioxide	10102-44-0	40	µg/m^3	SHORT-TERM	week	
Styrene	100-42-5	250	µg/m^3	LONG-TERM	>1 year	
Xylene	1330-20-7	200	µg/m^3	LONG-TERM	>1 year	

Figure 43: Indoor Air Guideline Values – Europe (References: INDEX. 2005. The INDEX project: Critical Appraisal of the Setting and Implementation of Indoor exposure Limits in the EU. European Commission, Joint Research Centre, Institute for Health and Consumer Protection, Physical and Chemical Exposure Unit, Ispra, Italy (JRC/IHCP/PCE), Report, 338 pages.)

12.3. Austria

NAME	CAS	IAGV	UNIT	EXPOSURE	AVERAGING PERIOD	Note
Acetaldehyde	75-07-0	100	µg/m^3	SHORT-TERM	1 h	
Benzene	71-43-2	2.5	µg/m^3	LONG-TERM		
Benzene	71-43-2	10	µg/m^3	INTERMEDIATE		
Formaldehyde	50-00-0	60	µg/m^3	SHORT-TERM	24 h	
Formaldehyde	50-00-0	100	µg/m^3	SHORT-TERM	30 min	
n-Hexane	110-54-3	200	µg/m^3	SHORT-TERM	24 h	
Radon	10043-92-2	200	Bq/m^3	LONG-TERM		
Radon	10043-92-2	400	Bq/m^3	INTERMEDIATE		
Styrene	100-42-5	40	µg/m^3	INTERMEDIATE	7 days	
Tetrachloroethylene	127-18-4	250	µg/m^3	INTERMEDIATE	7 days	
Toluene	108-88-3	75	µg/m^3	SHORT-TERM	1 h	
Xylene	1330-20-7	350	µg/m^3	SHORT-TERM	24 h	

Figure 44: Indoor Air Guideline Values – Austria (References: Baldinger, Silvia et al. 2011. Richtlinie zur Bewertung der Innenraumluft (Guideline for evaluation of indoor air). www.lebensministerium.at/umwelt/luft-laerm-verkehr/luft/innenraumluft/richtlinie_innenraum.html. / Akademie der Wissenschaften. 1997. Flüchtige Kohlenwasserstoffe in der Atmosphäre – Luftqualitätskriterien VOC, Band 2, Hrsg. Bundesministerium für Umwelt, Jugend und Familie, www.oeaw.ac.at/krl/publikation/documents/VOC.pdf)

12.4. Belgium

NAME	CAS	IAGV	UNIT	EXPOSURE	AVERAGING PERIOD	Note
Acetaldehyde	75-07-0	4600	µg/m^3	SHORT-TERM		
Aldéhyde (total)	-	20	µg/m^3	LONG-TERM		
Asbestos	-	0.1	fib./cm^3	LONG-TERM		
Benzene	71-43-2	2	µg/m^3	LONG-TERM		
Formaldehyde	50-00-0	10	µg/m^3	LONG-TERM		
Carbon monoxide	630-08-0	5.7	mg/m^3	SHORT-TERM	30 min	
Carbon dioxide	124-38-9	900	mg/m^3	SHORT-TERM		
Ozone	10028-15-6	110	µg/m^3	SHORT-TERM	8 h	
Nitrogen dioxide	10102-44-0	135	µg/m^3	SHORT-TERM	1 h	
Tetrachloroethylene	127-18-4	100	µg/m^3	LONG-TERM		
Toluene	108-88-3	260	µg/m^3	LONG-TERM		
Trichloroethylene	79-01-6	200	µg/m^3	LONG-TERM		
TVOC	-	200	µg/m^3	SHORT-TERM		

PM10	-	40	µg/m^3	LONG-TERM	year	
PM2.5	-	15	µg/m^3	SHORT-TERM	24 h	
Micro-organism	-	500	CFU/m^3	LONG-TERM		
Mold	-	200	CFU/m^3	LONG-TERM		

Figure 45: Indoor Air Guideline Values – Belgium (References: Decree of The Flemish Government of 11 June 2004 providing for measures aiming at controlling health risks caused by indoor pollution (2004), Belgian Official Journal, 19/10/2004)

12.5. USA – California

NAME	CAS	IAGV	UNIT	EXPOSURE	AVERAGING PERIOD	Note
Acetaldehyde	75-07-0	470	µg/m^3	SHORT-TERM	1 h	
Acetaldehyde	75-07-0	300	µg/m^3	SHORT-TERM	8 h	
Acetaldehyde	75-07-0	140	µg/m^3	LONG-TERM		
Acrolein	107-02-8	2.5	µg/m^3	SHORT-TERM	1 h	
Acrolein	107-02-8	0.7	µg/m^3	SHORT-TERM	8 h	
Acrolein	107-02-8	0.35	µg/m^3	LONG-TERM		
Acrylic Acid	79-10-7	6000	µg/m^3	SHORT-TERM	1 h	
Acrylonitrile	107-13-1	5	µg/m^3	LONG-TERM		
Ammonia	7664-41-7	3200	µg/m^3	SHORT-TERM	1 h	
Arsenic & inorganic arsenic compounds (including arsine)	7440-38-2	0.2	µg/m^3	SHORT-TERM	1 h	
Arsenic & inorganic arsenic compounds (including arsine)	7440-38-2	0.15	µg/m^3	SHORT-TERM	8 h	
Arsenic & inorganic arsenic compounds (including arsine)	7440-38-2	0.15	µg/m^3	LONG-TERM		
Benzene	71-43-2	27	µg/m^3	SHORT-TERM	1 h	
Benzene	71-43-2	3	µg/m^3	SHORT-TERM	8 h	
Benzene	71-43-2	3	µg/m^3	LONG-TERM		

Benzyl Chloride	100-44-7	240	µg/m³	SHORT-TERM	1 h	
Beryllium& beryllium compounds	7440-41-7	0.007	µg/m³	LONG-TERM		
Butadiene	106-99-0	660	µg/m³	SHORT-TERM	1 h	
Butadiene	106-99-0	9	µg/m³	SHORT-TERM	8 h	
Butadiene	106-99-0	2	µg/m³	LONG-TERM		
Cadmium & cadmium compounds	7440-43-9	0.02	µg/m³	LONG-TERM		
Carbon disulfide	75-15-0	6200	µg/m³	SHORT-TERM	1 h	
Carbon disulfide	75-15-0	800	µg/m³	LONG-TERM		
Carbon monoxide	630-08-0	23	mg/m³	SHORT-TERM	1 h	
Caprolactam	105-60-2	50	µg/m³	SHORT-TERM	1 h	
Caprolactam	105-60-2	7	µg/m³	SHORT-TERM	8 h	
Caprolactam	105-60-2	2.2	µg/m³	LONG-TERM		
Carbon tetrachloride	56-23-5	1900	µg/m³	SHORT-TERM	1 h	
Carbon tetrachloride	56-23-5	40	µg/m³	LONG-TERM		
Chlorinated dibenzo-p dioxins and dibenzofurans	-	0.00004	µg/m³	LONG-TERM		
Chlorine	7782-50-5	210	µg/m³	SHORT-TERM	1 h	
Chlorine	7782-50-5	0.2	µg/m³	LONG-TERM		
Chlorine dioxide	10049-04-4	0.6	µg/m³	LONG-TERM		
Chlorobenzene	108-90-7	1000	µg/m³	LONG-TERM		
Chloroform	67-66-3	150	µg/m³	SHORT-TERM	1 h	
Chloroform	67-66-3	300	µg/m³	LONG-TERM		
Chloropicrin	76-06-2	29	µg/m³	SHORT-TERM	1 h	
Chloropicrin	76-06-2	0.4	µg/m³	LONG-TERM		
Chromic trioxide (as chromic acid mist)	-	0.002	µg/m³	LONG-TERM		

Chromium (hexavalent) (18540-29-9) & soluble hexavalent chromium compounds (except chromic trioxide)	-	0.2	µg/m^3	LONG-TERM		
Copper and compounds	-	100	µg/m^3	SHORT-TERM	1 h	
Cresol mixtures	1319-77-3	600	µg/m^3	LONG-TERM		
Dichlorobenzene (1,4-)	106-46-7	800	µg/m^3	LONG-TERM		
Dichloroethylene (1,1)	75-35-4	70	µg/m^3	LONG-TERM		
Diesel Exhaust	-	5	µg/m^3	LONG-TERM		
Diethanolamine	111-42-2	3	µg/m^3	LONG-TERM		
Dimethylformamide (N,N-)	68-12-2	80	µg/m^3	LONG-TERM		
Dioxane (1,4-)	123-91-1	3000	µg/m^3	SHORT-TERM	1 h	
Dioxane (1,4-)	123-91-1	3000	µg/m^3	LONG-TERM		
Epichlorohydrin	106-89-8	1300	µg/m^3	SHORT-TERM	1 h	
Epichlorohydrin	106-89-8	3	µg/m^3	LONG-TERM		
Epoxybutane (1,2-)	106-88-7	20	µg/m^3	LONG-TERM		
Ethylbenzene	100-41-4	2000	µg/m^3	SHORT-TERM		
Ethyl chloride	75-00-3	30000	µg/m^3	LONG-TERM		
Ethylene dibromide	106-93-4	0.8	µg/m^3	LONG-TERM		
Ethylene dichloride	107-06-2	400	µg/m^3	LONG-TERM		
Ethylene glycol	107-21-1	400	µg/m^3	LONG-TERM		
Ethylene glycol monobutyl ether	111-76-2	14000	µg/m^3	SHORT-TERM	1 h	
Ethylene glycol monoethyl ether	110-80-5	370	µg/m^3	SHORT-TERM	1 h	
Ethylene glycol monoethyl ether	110-80-5	70	µg/m^3	LONG-TERM		
Ethylene glycol monoethyl ether acetate	111-15-9	140	µg/m^3	SHORT-TERM	1 h	
Ethylene glycol monoethyl ether acetate	111-15-9	300	µg/m^3	LONG-TERM		

Ethylene glycol monomethyl ether	109-86-4	93	µg/m^3	SHORT-TERM	1 h	
Ethylene glycol monomethyl ether	109-86-4	60	µg/m^3	LONG-TERM		
Ethylene glycol monomethyl ether acetate	110-49-6	90	µg/m^3	LONG-TERM		
Ethylene oxide	75-21-8	30	µg/m^3	LONG-TERM		
Fluorides (except Hydrogen Fluoride - listed below separately)	-	13	µg/m^3	LONG-TERM		
Formaldehyde	50-00-0	55	µg/m^3	SHORT-TERM	1 h	
Formaldehyde	50-00-0	9	µg/m^3	SHORT-TERM	8 h	
Formaldehyde	50-00-0	9	µg/m^3	LONG-TERM		
Glutaraldehyde	111-30-8	0.08	µg/m^3	LONG-TERM		
Hexane (n-)	110-54-3	7000	µg/m^3	SHORT-TERM		
Hydrazine	302-01-2	0.2	µg/m^3	LONG-TERM		
Hydrogen chloride	7647-01-0	2100	µg/m^3	SHORT-TERM	1 h	
Hydrogen chloride	7647-01-0	9	µg/m^3	LONG-TERM		
Hydrogen cyanide	74-90-8	340	µg/m^3	SHORT-TERM	1 h	
Hydrogen cyanide	74-90-8	9	µg/m^3	LONG-TERM		
Hydrogen fluoride	7664-39-3	240	µg/m^3	SHORT-TERM	1 h	
Hydrogen fluoride	7664-39-3	14	µg/m^3	LONG-TERM		
Hydrogen selenide	7783-07-5	5	µg/m^3	SHORT-TERM	1 h	
Hydrogen sulfide	7783-06-4	42	µg/m^3	SHORT-TERM	1 h	
Hydrogen sulfide	7783-06-4	10	µg/m^3	LONG-TERM		
Isophorone	78-59-1	2000	µg/m^3	LONG-TERM		
Isopropanol	67-63-0	3200	µg/m^3	SHORT-TERM	1 h	
Isopropanol	67-63-0	7000	µg/m^3	LONG-TERM		
Maleic anhydride	108-31-6	0.7	µg/m^3	LONG-TERM		

Manganese (7439-96-5) & manganese compounds	7439-96-5	0.17	µg/m^3	SHORT-TERM	8 h	
Manganese (7439-96-5) & manganese compounds	7439-96-5	0.09	µg/m^3	LONG-TERM		
Mercury (7439-97-6) & inorganic mercury compounds	7439-97-6	0.6	µg/m^3	SHORT-TERM	1 h	
Mercury (7439-97-6) & inorganic mercury compounds	7439-97-6	0.06	µg/m^3	SHORT-TERM	8 h	
Mercury (7439-97-6) & inorganic mercury compounds	7439-97-6	0.03	µg/m^3	LONG-TERM		
Methanol	67-56-1	28000	µg/m^3	SHORT-TERM	1 h	
Methanol	67-56-1	4000	µg/m^3	SHORT-TERM		
Methyl bromide	74-83-9	3900	µg/m^3	SHORT-TERM	1 h	
Methyl bromide	74-83-9	5	µg/m^3	LONG-TERM		
Methyl chloroform	71-55-6	68000	µg/m^3	SHORT-TERM	1 h	
Methyl chloroform	71-55-6	1000	µg/m^3	LONG-TERM		
Methylene chloride	75-09-2	14000	µg/m^3	SHORT-TERM	1 h	
Methylene chloride	75-09-2	400	µg/m^3	LONG-TERM		
Methylene dianiline (4,4'-)	101-77-9	20	µg/m^3	LONG-TERM		
Methylene diphenyl diisocyanate (101-68-8) and polymeric methylene diphenyl diisocyanate (9016-87-9)	101-68-8	12	µg/m^3	SHORT-TERM	1 h	
Methylene diphenyl diisocyanate (101-68-8) and polymeric methylene diphenyl diisocyanate (9016-87-9)	101-68-8	0.16	µg/m^3	SHORT-TERM	8 h	
Methylene diphenyl diisocyanate (101-68-8) and polymeric methylene diphenyl diisocyanate (9016-87-9)	101-68-8	0.08	µg/m^3	LONG-TERM		
Methyl ethyl ketone	78-93-3	13000	µg/m^3	SHORT-TERM	1 h	
Methyl isocyanate	624-83-9	1	µg/m^3	LONG-TERM		
Methyl t-butyl ether	1634-04-4	8000	µg/m^3	LONG-TERM		

Naphthalene	91-20-3	9	µg/m^3	LONG-TERM		
Nickel & nickel compounds (except nickel oxide for chronic inhalation exposures) (Inhalation concentrations as µg Ni/m3: oral dose as µg Ni/kg-day)	-	0.2	µg/m^3	SHORT-TERM	1 h	
Nickel & nickel compounds (except nickel oxide for chronic inhalation exposures) (Inhalation concentrations as µg Ni/m3: oral dose as µg Ni/kg-day)	-	0.06	µg/m^3	SHORT-TERM	8 h	
Nickel & nickel compounds (except nickel oxide for chronic inhalation exposures) (Inhalation concentrations as µg Ni/m3: oral dose as µg Ni/kg-day)	-	0.014	µg/m^3	LONG-TERM		
Nickel oxide (1313-99-1) (Inhalation concentration as µg Ni/m3: oral dose as µg Ni/kg-day)	-	0.02	µg/m^3	LONG-TERM		
Nitric acid	7697-37-2	86	µg/m^3	SHORT-TERM	1 h	
Nitrogen dioxide	10102-44-0	470	µg/m^3	SHORT-TERM	1 h	
Ozone	10028-15-6	180	µg/m^3	SHORT-TERM	1 h	
Perchloroethylene (syn. Tetrachloroethylene)	127-18-4	20000	µg/m^3	SHORT-TERM	1 h	
Perchloroethylene (syn. Tetrachloroethylene)	127-18-4	35	µg/m^3	LONG-TERM		
Phenol	108-95-2	5800	µg/m^3	SHORT-TERM	1 h	
Phenol	108-95-2	200	µg/m^3	LONG-TERM		
Phosgene	75-44-5	4	µg/m^3	SHORT-TERM	1 h	
Phosphine	7803-51-2	0.8	µg/m^3	LONG-TERM		
Phosphoric acid	7664-38-2	7	µg/m^3	LONG-TERM		
Polychlorinated biphenyls (PCBs)	-	0	µg/m^3	LONG-TERM		
Phthalic anhydride	85-44-9	20	µg/m^3	LONG-TERM		
Propylene	115-07-1	3000	µg/m^3	LONG-TERM		

Propylene glycol monomethyl ether	107-98-2	7000	µg/m^3	LONG-TERM		
Propylene oxide	75-56-9	3100	µg/m^3	SHORT-TERM	1 h	
Propylene oxide	75-56-9	30	µg/m^3	LONG-TERM		
Selenium and selenium compounds (other than hydrogen selenide)	-	20	µg/m^3	LONG-TERM		
Silica (crystalline, respirable)	-	3	µg/m^3	LONG-TERM		
Sodium hydroxide	1310-93-2	8	µg/m^3	SHORT-TERM	1 h	
Styrene	100-42-5	21000	µg/m^3	SHORT-TERM		
Styrene	100-42-5	900	µg/m^3	LONG-TERM		
Sulfates	-	120	µg/m^3	SHORT-TERM		
Sulfur dioxide	7446-09-5	660	µg/m^3	SHORT-TERM	1 h	
Sulfuric acid (7664-93-9) [& oleum, acute only]	7664-93-9	120	µg/m^3	SHORT-TERM	1 h	
Sulfuric acid (7664-93-9) [& oleum, acute only]	7664-93-9	1	µg/m^3	LONG-TERM		
Toluene	108-88-3	37000	µg/m^3	SHORT-TERM	1 h	
Toluene	108-88-3	300	µg/m^3	LONG-TERM		
Toluene diisocyanates: 2,4- (584-84-9) and 2,6- (91-08-7) isomers and mixed isomers (26471-62-5)	584-84-9	2	µg/m^3	SHORT-TERM	1 h	
Toluene diisocyanates: 2,4- (584-84-9) and 2,6- (91-08-7) isomers and mixed isomers (26471-62-5)	584-84-9	0.015	µg/m^3	SHORT-TERM	8 h	
Toluene diisocyanates: 2,4- (584-84-9) and 2,6- (91-08-7) isomers and mixed isomers (26471-62-5)	584-84-9	0.008	µg/m^3	LONG-TERM		
Trichloroethylene	79-01-6	600	µg/m^3	LONG-TERM		
Triethylamine	121-44-8	2800	µg/m^3	SHORT-TERM	1 h	
Triethylamine	121-44-8	200	µg/m^3	LONG-TERM		
Vanadium pentoxide	1314-62-1	30	µg/m^3	SHORT-TERM	1 h	

Vinyl acetate	108-05-4	200	µg/m³	LONG-TERM		
Vinyl chloride	75-01-4	180000	µg/m³	SHORT-TERM	1 h	
Xylenes: technical mixture (1330-20-7) and o-xylene (95-47-6), m-xylene (108-38-3) and p-xylene (106-42-3) isomers.	1330-20-7	22000	µg/m³	SHORT-TERM	1 h	
Xylenes: technical mixture (1330-20-7) and o-xylene (95-47-6), m-xylene (108-38-3) and p-xylene (106-42-3) isomers.	1330-20-7	700	µg/m³	LONG-TERM		

Figure 46: Indoor Air Guideline Values – USA – California (References: Office of Environmental Health Hazard Assessment (OEHHA). 2016. Acute, 8-hour and Chronic Reference Exposure Levels (chRELs), www.oehha.ca.gov/air/allrels.html.)

12.6. Canada – Residential buildings

NAME	CAS	IAGV	UNIT	EXPOSURE	AVERAGING PERIOD	Note
Benzene	71-43-2		µg/m³	LONG-TERM		as low as possible
Carbon monoxide	630-08-0	11.5	mg/m³	SHORT-TERM	24 h	
Carbon monoxide	630-08-0	28.6	mg/m³	SHORT-TERM	1 h	
Formaldehyde	50-00-0	123	µg/m³	SHORT-TERM	1 h	
Formaldehyde	50-00-0	50	µg/m³	LONG-TERM	8 h	
Naphthalene	91-20-3	10	µg/m³	LONG-TERM	24 h	
Nitrogen dioxide	10102-44-0	170	µg/m³	SHORT-TERM	1 h	
Nitrogen dioxide	10102-44-0	20	µg/m³	SHORT-TERM	24 h	
PM2.5	-	-	µg/m³	LONG-TERM		as low as possible
Ozone	10028-15-6	40	µg/m³	SHORT-TERM	8 h	
Toluene	108-88-3	2300	µg/m³	SHORT-TERM	24 h	
Toluene	108-88-3	15000	µg/m³	SHORT-TERM	8 h	
Radon	10043-92-2	200	Bq/m³	LONG-TERM		

Figure 47: Indoor Air Guideline Values – Canada (References: Government of Canada. 2016. Residential Indoor Air Quality Guidelines. www.healthycanadians.gc.ca/healthy-living-vie-saine/environment-environnement/air/guidelines-lignes-directrices-eng.php)

12.7. China

NAME	CAS	IAGV	UNIT	EXPOSURE	AVERAGING PERIOD	Note

Ammonia	7664-41-7	200	µg/m^3	SHORT-TERM	1 h	
Benzene	71-43-2	110	µg/m^3	SHORT-TERM	1 h	
Carbon dioxide	124-38-9	1962	mg/m^3	SHORT-TERM		
Carbon monoxide	630-08-0	10	mg/m^3	SHORT-TERM	1 h	
Formaldehyde	50-00-0	100	µg/m^3	SHORT-TERM	1 h	
HAP	-	1000	µg/m^3	SHORT-TERM	24 h	Marker benzo(a)pyrène (50-32-8)
Micro-organism	-	2500	CFU/m^3	LONG-TERM		
Nitrogen dioxide	10102-44-0	240	µg/m^3	SHORT-TERM	1 h	
Ozone	10028-15-6	160	µg/m^3	SHORT-TERM	1 h	
PM10	-	150	µg/m^3	SHORT-TERM	24 h	
Radon	10043-92-2	400	Bq/m^3	LONG-TERM	>1 year	
Sulfur dioxide	7446-09-5	500	µg/m^3	SHORT-TERM	1 h	
Toluene	108-88-3	200	µg/m^3	SHORT-TERM	1 h	
TVOC	-	600	µg/m^3	SHORT-TERM	24 h	
Xylene	1330-20-7	200	µg/m^3	SHORT-TERM	1 h	
Xylene	1330-20-7	200	µg/m^3	SHORT-TERM	1 h	

Figure 48: Indoor Air Guideline Values – China (References: Chinese code GB/T 18883-2002. 2002. Indoor air quality standard. Ministry of Health)

12.8. France

NAME	CAS	IAGV	UNIT	EXPOSURE	AVERAGING PERIOD	Note
Acetaldehyde	75-07-0	3000	µg/m^3	SHORT-TERM	1 h	
Acetaldehyde	75-07-0	160	µg/m^3	LONG-TERM	>1 year	
Acrolein	107-02-8	6.9	µg/m^3	SHORT-TERM	1 h	
Acrolein	107-02-8	0.8	µg/m^3	LONG-TERM	>1 year	
Benzene	71-43-2	30	µg/m^3	SHORT-TERM	<14 days	
Benzene	71-43-2	20	µg/m^3	INTERMEDIATE	<1 year	

Benzene	71-43-2	10	µg/m^3	LONG-TERM	>1 year	non carcinogenic
Benzene	71-43-2	0.2	µg/m^3	LONG-TERM	whole life	carcinogenic risk level:10^{-6}
Benzene	71-43-2	2	µg/m^3	LONG-TERM	whole life	carcinogenic risk level:10^{-5}
Carbon monoxide	630-08-0	10	mg/m^3	SHORT-TERM	8 h	
Carbon monoxide	630-08-0	30	mg/m^3	SHORT-TERM	1 h	
Carbon monoxide	630-08-0	60	mg/m^3	SHORT-TERM	30 min	
Carbon monoxide	630-08-0	100	mg/m^3	SHORT-TERM	15 min	
Formaldehyde	50-00-0	50	µg/m^3	SHORT-TERM	2 h	
Formaldehyde	50-00-0	10	µg/m^3	LONG-TERM	>1 year	
Naphthalene	91-20-3	10	µg/m^3	LONG-TERM	>1 year	
Nitrogen dioxide	10102-44-0	200	µg/m^3	SHORT-TERM	2 h	
Nitrogen dioxide	10102-44-0	20	µg/m^3	LONG-TERM	>1 year	
Tetrachloroethylene	127-18-4	1380	µg/m^3	SHORT-TERM	<14 days	
Tetrachloroethylene	127-18-4	250	µg/m^3	LONG-TERM	>1 year	
Trichloroethylene	79-01-6	800	µg/m^3	INTERMEDIATE	<1 year; >14 days	
Trichloroethylene	79-01-6	2	µg/m^3	LONG-TERM	whole life	carcinogenic risk level:10^{-6}
Trichloroethylene	79-01-6	20	µg/m^3	LONG-TERM	whole life	carcinogenic risk level:10^{-5}

Figure 49: Indoor Air Guideline Values – France (References: ANSES. 2016. Valeurs Guides de qualité d'Air Intérieur (VGAI), https://www.anses.fr/fr/content/valeurs-guides-de-qualit%C3%A9-d%E2%80%99air-int%C3%A9rieur-vgai)

12.9. Germany

NAME	CAS	IAGV	UNIT	EXPOSURE	AVERAGING PERIOD	Note
1-Butanol	71-36-3	700	µg/m^3	LONG-TERM		
2-Butanonoxime	96-29-7	20	µg/m^3	LONG-TERM		
2-Chloropropane	75-29-6	800	µg/m^3	LONG-TERM		
2-Ethyl-1-hexanol	104-76-7	100	µg/m^3	LONG-TERM		
2-Propyleneglycol-1-ethylether	1569-02-04	300	µg/m^3	LONG-TERM		
2-Propyleneglycol-1-tertbutylether	57017-52-7	300	µg/m^3	LONG-TERM		
Acetaldehyde	75-07-0	100	µg/m^3	LONG-TERM		
aliphatic hydrocarbons	-	200	µg/m^3	LONG-TERM		
alpha-Pinene	80-56-8	200	µg/m^3	LONG-TERM		
Benzaldehyde	100-52-7	20	µg/m^3	LONG-TERM		
Benzyl alcohol	100-51-6	400	µg/m^3	LONG-TERM		

Carbon monoxide	630-08-0	6	mg/m^3	SHORT-TERM	30 min	
Carbon monoxide	630-08-0	1.5	mg/m^3	SHORT-TERM	8 h	
Cresol mixtures	1319-77-3	5	µg/m^3	LONG-TERM		
Dichloromethane	75-09-2	200	µg/m^3	LONG-TERM		
Diethylene glycol dimethyl ether(1-Methoxy-2-(2-methoxy-ethoxy)-ethan)	111-96-6	30	µg/m^3	LONG-TERM		
Diethylene glycol monoethyl ether (2-(2-ethoxyethoxy)ethanol)	111-90-0	700	µg/m^3	LONG-TERM		
Diethylene glycol-monobutylether	112-34-5	400	µg/m^3	LONG-TERM		
Diethyleneglycolmethylether	111-77-3	2000	µg/m^3	LONG-TERM		
Dipropylene glycol monomethyl ether	34590-94-8	2000	µg/m^3	LONG-TERM		
Ethyl acetate	141-78-6	600	µg/m^3	LONG-TERM		
Ethylbenzene	100-41-4	200	µg/m^3	LONG-TERM		
Ethylene glycol monobutyl ether	111-76-2	100	µg/m^3	LONG-TERM		
Ethylene glycol monoethyl ether	110-80-5	100	µg/m^3	LONG-TERM		
Ethylene glycol monoethyl ether acetate	111-15-9	200	µg/m^3	LONG-TERM		
Ethylene glycol monomethyl ether	109-86-4	20	µg/m^3	LONG-TERM		
Ethylene glycol n-hexyl ether (2-Hexoxyethanol)	112-25-4	100	µg/m^3	LONG-TERM		
Ethylenglykolbutyletheracetat (2-Butoxyethyl acetate)	112-07-2	200	µg/m^3	LONG-TERM		
Furfural	98-01-1	10	µg/m^3	LONG-TERM		
Limonene	138-86-3	1000	µg/m^3	LONG-TERM		
Methylisobutylketone	108-10-1	100	µg/m^3	LONG-TERM		
Naphthalene	91-20-3	10	µg/m^3	LONG-TERM		
Nitrogen dioxide	10102-44-0	350	µg/m^3	SHORT-TERM	30 min	
Nitrogen dioxide	10102-44-0	60	µg/m^3	SHORT-TERM	1 week	
N-methyl-2-pyrrolidon	872-50-4	100	µg/m^3	LONG-TERM		
Pentachlorophenol	87-86-5	100	µg/m^3	LONG-TERM		
Phenol	108-95-2	20	µg/m^3	LONG-TERM		
Propylene glycol monomethyl ether	107-98-2	1000	µg/m^3	LONG-TERM		
Styrene	100-42-5	30	µg/m^3	LONG-TERM		
Toluene	108-88-3	300	µg/m^3	LONG-TERM		
Tris(2-chloroethyl) phosphate	115-96-8	5	µg/m^3	LONG-TERM		
Xylene	1330-20-7	100	µg/m^3	LONG-TERM		

Figure 50: Indoor Air Guideline Values – Germany (References: German Federal Environment Agency. 2016. Guide values I and II. German Committee on Indoor Guide Values,

www.umweltbundesamt.de/en/topics/health/commissions-working-groups/german-committee-on-indoor-guide-values)

12.10. Hong-Kong

NAME	CAS	IAGV	UNIT	EXPOSURE	AVERAGING PERIOD	Note
Benzene	71-43-2	16.1	µg/m³	SHORT-TERM	8 h	
Carbon dioxide	124-38-9	1000	ppm	SHORT-TERM	8 h	
Carbon monoxide	630-08-0	10	mg/m³	SHORT-TERM	8 h	
Ethylbenzene	100-41-4	1447	µg/m³	SHORT-TERM	8 h	
Formaldehyde	50-00-0	100	µg/m³	SHORT-TERM	8 h	
Micro-organism	-	1000	CFU/m³	SHORT-TERM	8 h	
Nitrogen dioxide	10102-44-0	100	µg/m³	SHORT-TERM	8 h	
Ozone	10028-15-6	120	µg/m³	SHORT-TERM	8 h	
PM10	-	180	µg/m³	SHORT-TERM	8 h	
Radon	10043-92-2	200	Bq/m³	SHORT-TERM	8 h	
Toluene	108-88-3	1092	µg/m³	SHORT-TERM	8 h	
TVOC	-	600	µg/m³	SHORT-TERM	8 h	
Xylene	1330-20-7	1447	µg/m³	SHORT-TERM	8 h	

Figure 51: Indoor Air Guideline Values – Hong-Kong (References: Hong Kong HKSAR (The Government of the Hong Kong Special Administrative Region) Indoor Air Quality Management Group. 2003. Guidance Notes for the Management of Indoor Air Quality in Offices and Public Spaces)

12.11. Japan

NAME	CAS	IAGV	UNIT	EXPOSURE	AVERAGING PERIOD	Note
Acetaldehyde	75-07-0	48	µg/m³	LONG-TERM		
Chlorpyriphos	2921-88-2	1	µg/m³	LONG-TERM		
di-2-ethylhexylphthalate	84-66-2	120	µg/m³	LONG-TERM		
Diazinone	33-41-5	0.29	µg/m³	LONG-TERM		
Dichlorobenzene (1,4-)	106-46-7	240	µg/m³	LONG-TERM		

di-n-butylphthalate	84-74-2	220	µg/m^3	LONG-TERM		
Ethylbenzene	100-41-4	3800	µg/m^3	SHORT-TERM		
Fenobucarb	3766-81-2	33	µg/m^3	LONG-TERM		
Formaldehyde	50-00-0	100	µg/m^3	SHORT-TERM	30min	
Nonanal	124-19-6	41	µg/m^3	LONG-TERM		
Styrene	100-42-5	220	µg/m^3	LONG-TERM		
Tetradecane	629-59-4	330	µg/m^3	LONG-TERM		
Toluene	108-88-3	260	µg/m^3	LONG-TERM		
TVOC	-	400	µg/m^3	SHORT-TERM		
Xylene	1330-20-7	870	µg/m^3	LONG-TERM		

Figure 52: Indoor Air Guideline Values – Japan (References: Japanese Ministry of Health, Labor and Welfare. Committee on Sick House Syndrome: Indoor Air Pollution, Progress Report No. 4; Summary of Discussions from the 8th to 9th Meetings. Available online: www.nihs.go.jp/mhlw/chemical/situnai/kentoukai/rep-eng4.pdf.)

12.12. Korea

NAME	CAS	IAGV	UNIT	EXPOSURE	AVERAGING PERIOD	Note
Carbon dioxide	124-38-9	1000	ppm	SHORT-TERM		
Carbon monoxide	630-08-0	12.3	mg/m^3	SHORT-TERM		
Formaldehyde	50-00-0	100	µg/m^3	SHORT-TERM		
Micro-organism	-	800	CFU/m^3	LONG-TERM		
Nitrogen dioxide	10102-44-0	100	µg/m^3	SHORT-TERM		
Ozone	10028-15-6	127	µg/m^3	SHORT-TERM		
PM10	-	100	µg/m^3	SHORT-TERM		
Radon	10043-92-2	148	Bq/m^3	SHORT-TERM		
TVOC	-	400	µg/m^3	SHORT-TERM		

Figure 53: Indoor Air Guideline Values – Korea (References: Korea ministry of Environment: Indoor air quality control in public use facilities. Act; Amended by Act No. 10789; 2011)

12.13. Portugal

NAME	CAS	IAGV	UNIT	EXPOSURE	AVERAGING PERIOD	Note
Benzene	71-43-2	5	µg/m^3	LONG-TERM		
Carbon dioxide	124-38-9	1250	ppm	SHORT-TERM	8 h	
Carbon monoxide	630-08-0	10	mg/m^3	SHORT-TERM		
Formaldehyde	50-00-0	100	µg/m^3	SHORT-TERM		
Micro-organism	-	Coutdoor + 350	CFU/m^3	LONG-TERM		
Mold	-	Coutdoor	CFU/m^3	LONG-TERM		
PM10	-	50	µg/m^3	LONG-TERM		
PM2.5	-	25	µg/m^3	SHORT-TERM		
Radon	10043-92-2	400	Bq/m^3	SHORT-TERM		
Styrene	100-42-5	260	µg/m^3	LONG-TERM		
Tetrachloroethylene	127-18-4	250	µg/m^3	LONG-TERM		
Toluene	108-88-3	250	µg/m^3	LONG-TERM		
Trichloroethylene	79-01-6	25	µg/m^3	LONG-TERM		
TVOC	-	600	µg/m^3	SHORT-TERM		

Figure 54: Indoor Air Guideline Values – Portugal (References: Portuguese Standard. 2013. Decreto-Lei nº 118/2013 & Portaria n°353-A/2013 (JO du 4/12/2013) and Portaria n.º 353-A/2013. D.R. n.º 235, Suplemento, Série I de 2013-12-04)

12.14. United Kingdom - Dwellings

NAME	CAS	IAGV	UNIT	EXPOSURE	AVERAGING PERIOD	Note
Carbon monoxide	630-08-0	10	mg/m^3	SHORT-TERM	8 h	
Carbon monoxide	630-08-0	30	mg/m^3	SHORT-TERM	1 h	
Carbon monoxide	630-08-0	60	mg/m^3	SHORT-TERM	30 min	
Carbon monoxide	630-08-0	100	mg/m^3	SHORT-TERM	15 min	
Nitrogen dioxide	10102-44-0	288	µg/m^3	SHORT-TERM	1h	
Nitrogen dioxide	10102-44-0	40	µg/m^3	LONG-TERM		
TVOC	-	300	µg/m^3	SHORT-TERM	8 h	

Figure 55: Indoor Air Guideline Values – United Kingdom (References: UK Building Regulations. 2010. F1: Means of Ventilation - Appendix A: Performance-based ventilation, HM Government)

13. Appendix B: Lowest Concentration of Interest (EU-LCI)

This present appendix presents the Lowest Concentration of Interest (EU-LCI) from European Union.

NAME	CASN	EU-LCI (µg/m^3)
2-Methoxy-1-methylethyl acetate	108-65-6	2700
1,1-Dichloroethylene	75-35-4	-
1,2-Diethoxyethane	629-14-1	-
1,2-Dimethoxyethan	110-71-4	-
1,2-Propylene glycol n-butylether	5131-66-8 / 29387-86-8 / 15821-83-7 / 63716-40-5	-
1,2-Propylene glycol n-propylether	1569-01-3 / 30136-13-1	-
1,4-Butylene glycol (1,4-Butandiol)	110-63-4	2000
1,4-Dichlorobenzene	106-46-7	150
1.2.3-Trimethylbenzene	526-73-8	450
1.2.4.5-Tetramethyl benzene	95-93-2	500
1.2.4-Trimethylbenzene	95-63-6	450
1.2.-Propylene glycol-dimethyl ether	7777-85-0	-
1.3.5-Trimethylbenzene	108-67-8	450
1.3-Diisopropylbenzene	99-62-7	750
1.4-Diisopropylbenzene	100-18-5	750
1.4-Dioxan	123-91-1	-
1-Butanol	71-36-3	3000
1-Butyl acetate	123-86-4	4800
1-Hexanol	111-27-3	2100
1-Hydroxyacetone (2 Propanone, 1-hydrocx-)	116-09-6	-
1-Isopropyl-2-methylbenzene (o-cymene)	527-84-4	1000
1-Isopropyl-3-methylbenzene (m-cymene)	535-77-3	1000
1-Isopropyl-4-methylbenzene (p-cymene)	99-87-6	1000
1-Methyl-2-propylbenzene	1074-17-5	-
1-Methyl-3-propylbenzene	1074-43-7	-
1-Octanol	111-87-5	1100
1-Phenyl undecane and isomers	6742-54-7	-
1-Phenyldecane and isomers	104-72-3	-
1-Propenyl benzene (ß-methyl styrene)	637-50-3	-

1-Propylene glycol 2-methyl ether (2-Methoxy-1-propanol)	1589-47-5	19
1-Propylene glycol 2-methyl ether acetate (2-Methoxy-1-propyl acetate)	70657-70-4	28
2,2,4-Trimethylpentanediol diisobutyrate (TXIB)	6846-50-0	450
2,2-Dimethylpropanoic acid (pivalic acid)	75-98-9	-
2.2.4-Trimethyl-1.3-pentane diol, monoisobutyrate (Texanol®)	25265-77-4	600
2-Butanonoxime	96-29-7	-
2-Butenal (Crotonaldehyd)	4170-30-3 / 123-73-9 / 15798-64-8	-
2-Decenal	3913-71-1 / 2497-25-8 / 3913-81-3	-
2-Ethyl-1-hexanol	104-76-7	300
2-Ethyl-hexanal	123-05-7	900
2-Ethylhexanoic acid	149-57-5	150
2-Ethylhexyl acetate	103-09-3	-
2-Ethylhexyl acrylate	103-11-7	380
2-Ethyltoluene	611-14-3	-
2-Heptenal	2463-63-0 / 18829-55-5 / 57266-86-1 / 29381-66-6	-
2-Methyl-1-propanol	78-83-1	-
2-Methyl-4-isothiazolin-3-one	2682-20-4	100
2-Methylcyclohexanone	583-60-8	2300
2-Methylcyclopentanone	1120-72-5	-
2-Nonenal	2463-53-8 / 18829-56-6 / 60784-31-8	-
2-Octenal	2363-89-5 / 2548-87-0 / 25447-69-2 / 20664-46-4	-
2-Pentenal	1576-87-0 / 764-39-6 / 31424-04-1	-
2-Phenoxyethanol	122-99-6	1100
2-Phenylpropene (α-Methylstyrene)	98-83-9	-
2-Undecenal	2463-77-6 / 53448-07-0 / 1337-83-3	-
3-Carene	498-15-7	1500
3-Methoxy-1-butanol	2517-43-3	-
3-Methylbutanone-2	563-80-4	7000
4-Hydroxy-4-methyl-pentane-2-on (diacetone alcohol)	123-42-2	960
4-Phenyl cyclohexene (4-PCH)	4994-16-5	-
5-Chloro-2-methyl-2H-isothiazol-3-one (CIT)	26172-55-4	1
Acetaldehyde (VVOC)	75-07-0	1200
Acetic acid	64-19-7	-
Acetone (VVOC)	67-64-1	-
Acetophenone	98-86-2	490

Benzaldehyde	100-52-7	-
Benzene	71-43-2	1 (carcinogen)
Benzyl alcohol	100-51-6	440
Butanal (VVOC)	123-72-8	650
Butyl glycolate	7397-62-8	-
Butylated hydroxytoluene	128-37-0	100
Butyric acid	107-92-6	-
Butyrolactone	96-48-0	-
Caprolactam	105-60-2	300
Chlorobenzene	108-90-7	-
Chloroform	67-66-3	-
Cyclohexane	110-82-7	6000
Cyclohexanol	108-93-0	2000
Cyclohexanone	108-94-1	410
Cyclopentanone	120-92-3	900
Decahydronaphthalene	91-17-8	-
Decamethylcyclopentasiloxane (D5)	541-02-6	-
Decanal	112-31-2	900
Dibutyl fumarate	105-75-9	50
Dichloromethane (Methylenchloride)	75-09-2	-
Diethylene glycol	111-46-6	440
Diethylene glycol dimethyl ether(1-Methoxy-2-(2-methoxy-ethoxy)-ethan)	111-96-6	28
Diethylene glycol monoethyl ether (2-(2-ethoxyethoxy)ethanol)	111-90-0	350
Diethylene glycol monomethyl ether acetate (2-(2-butoxyethoxy) ethyl acetate)	124-17-4	850
Diethylene glycol n-hexyl ether (2-(2-Hexoxyethoxy)-ethanol)	112-59-4	-
Diethylene glycol phenylether	104-68-7	-
Diethylene glycol-monobutylether	112-34-5	670
Diisobutyl glutarate	71195-64-7	-
Diisobutyl succinate	925-06-4	-
Dimethyl adipate	627-93-0	50
Dimethyl glutarate	1119-40-0	50
Dimethyl succinate	106-65-0	50
Dimethylformamide	68-12-2	-
Dipropylene glycol	110-98-5 / 25265-71-8	670
Dipropylene glycol dimethyl ether	63019-84-1 / 89399-28-0 / 111109-77-4	1300

Dipropylene glycol monomethyl ether	34590-94-8	3100
Dipropylene glycol-monomethyl ether acetate	88917-22-0	-
Dipropylene glycol-mono-n-(t-)butylether	29911-28-2 / 35884-42-5 / 132739-31-2	-
Dipropylene glycol-mono-n-propylether	29911-27-1	-
Dodecamethylcyclohexa-siloxane (D6)	540-97-6	-
Ethyl acrylate	140-88-5	200
Ethyl benzene	100-41-4	850
Ethylene carbonate	96-49-1	-
Ethylene glycol (Ethandiol)	107-21-1	-
Ethylene glycol isopropylether (2-Methylethoxyethanol)	109-59-1	220
Ethylene glycol monoethyl ether (2-Ethoxyethanol)	110-80-5	-
Ethylene glycol monoethyl ether acetate (2-Ethoxyethyl acetat)	111-15-9	-
Ethylene glycol monoisopropyl ether (2-Propoxyethanol)	2807-30-9	860
Ethylene glycol monomethyl ether (2-Methoxyethanol)	109-86-4	-
Ethylene glycol monomethyl ether acetate (2-Methoxyethyl acetate)	110-49-6	-
Ethylene glycol n-hexyl ether (2-Hexoxyethanol)	112-25-4	-
Ethylene glycol-monobutylether (2-butoxyethanol)	111-76-2	1100
Ethylenglykolbutyletheracetat (2-Butoxyethyl acetate)	112-07-2	-
Ethylmethylketone	78-93-3	5000
Furfural	98-01-1	-
Glutaraldehyde	111-30-8	-
Heptanal	111-71-7	900
Hexamethylene diacrylate	13048-33-4	10
Hexamethylenetetramine	100-97-0	30
Hexanal	66-25-1	900
Hexenal	6728-26-3 / 505-57-7 / 16635-54-4 / 1335-39-3 / 73543-95-0	-
Hexylene glycol (2-methyl-2,4-pentanediol)	107-41-5	-
Indene	95-13-6	-
Isobutyl acetate	110-19-0	4800
Isobutyric acid	79-31-2	-
Isophorone	78-59-1	-
Isopropanol	67-63-0	-
Isopropylacetat	108-21-4	-
Isopropylbenzene (Cumene)	98-82-8	-
Limonene	138-86-3	5000

Linalool acetate	115-95-7	-
Maleic acid dibutylester	105-76-0	50
Methyl acrylate	96-33-3	180
Methyl cyclohexane	108-87-2	8100
Methyl methacrylate	80-62-6	-
Methylchloroform	71-55-6	-
Methylformiate	107-31-3	1200
Methylisobutylketone	108-10-1	-
m-Xylene	108-38-3	500
Naphthalene	91-20-3	10
n-Butyl acrylate	141-32-2	110
n-Butyl benzene	104-51-8	1100
n-Butyl formiate	592-84-7	-
Neopentyl glycol	126-30-7	-
N-ethyl-2-pyrrolidon	2687-91-4	-
n-Heptane	142-82-5	-
n-Heptanoic acid	111-14-8	-
n-Hexane	110-54-3	-
n-Hexanoic acid (n-caproic acid)	142-62-1	-
N-methyl-2-pyrrolidon	872-50-4	~~400~~
n-Octanoic acid	124-07-2	-
Nonanal	124-19-6	900
n-Pentanoic acid (n-valeric acid)	109-52-4	-
n-Propyl benzene	103-65-1	950
Octamethylcyclotetra-siloxane (D4)	556-67-2	1200
Octanal	124-13-0	900
Other acrylates (acrylic acid esters)	0	110
Other alkylbenzenes, as long as indiv. isomers have not to be evaluated differently	0	-
other C4 - C10 and C11 - C13 saturated alcohols	0	-
Other methacrylates	0	-
Other terpene hydrocarbons	0	1400
o-Xylene	95-47-6	500
Pentanal	110-62-3	800
Pentanol (all isomers)		730
Phenol	108-95-2	-
Phenyl acetylene	536-74-3	-

Phenyl octane and isomers	2189-60-8	1100
Propanal (VVOC)	123-38-6	-
Propionic acid	79-09-4	310
Propyl acetate	109-60-4	4200
Propylene carbonate	108-32-7	-
Propylene glycol (1,2-Dihydroxypropane)	57-55-6	-
Propylene glycol diacetat	623-84-7	-
Propylene glycol monomethyl ether (1-Methoxy-2-propanol)	107-98-2	-
p-Xylene	106-42-3	500
saturated aliphatic hydrocarbons C9 til C16	0	6000
saturated aliphatic hydrocarbons until C8	0	-
ß-Pinene	127-91-3	1400
Styrene	100-42-5	250
Tert-butanol, 2-methylpropanol-2	75-65-0	620
Tetraamethylcyclohexa-siloxane (D7)	107-50-6	-
Tetrachloroethene (Tetrachloroethylene)	127-18-4	-
Tetrachloromethane	56-23-5	-
Tetrahydrofuran	109-99-9	-
Toluene	108-88-3	2900
Tributyl phosphate	126-73-8	-
Trichloroethene	79-01-6	-
Triethyl phosphate	78-40-0	-
Triethylamine	121-44-8	-
Triethylene glycol-dimethyl ether	112-49-2	-
Tripropylene glycol-mono-methylether	20324-33-8 / 25498-49-1	-
Vinyl toluene (all isomers: o-,m-,p-methyl styrenes)	25013-15-4	-
Xylene, mix of o-, m- and p-xylene isomers	1330-20-7	500
α-Pinene	80-56-8	2500

Figure 56: Lowest Concentration of Interest (EU-LCI) from European Union (References: European collaborative action. 2013. Harmonisation framework for health based evaluation of indoor emissions from construction products in the European Union using the EU-LCI concept, Report n°29, 192p.)

14. Appendix C: Illustration of ambiguity and eclipsing

ELV-based sub-indices and the IAPI multipollutant index (Sofuoglu and Moschandreas, 2003) were calculated using the data of the French survey from 567 houses and apartments (Kirchner et al., 2006a). Figure 57 represents the relationship between the ELV-based maximum sub-index (MAX) and the IAPI. It can be noticed that the overall trend is in line with expectations as the IAPI increases according to the MAX. However, there is statistically no correlation between the two indices and the dispersion is so high that IAPI is not able to distinguish the level of IAQ as shown by the green region of equal MAX and IAPI ranging from 4 to 10 and the orange region where IAPI predicts the same level of IAQ with a MAX ranging from 1 to 30. Another illustrative example of eclipsing is given by Figure 58 where ELV-based sub-indices were averaged is used instead of the IAPI (using the same data). The correlation factor is in this case very good so one can deduce that both approaches are similar. However, averaging sub-indices tends to overestimate the real pollution level for the points located in the green square.

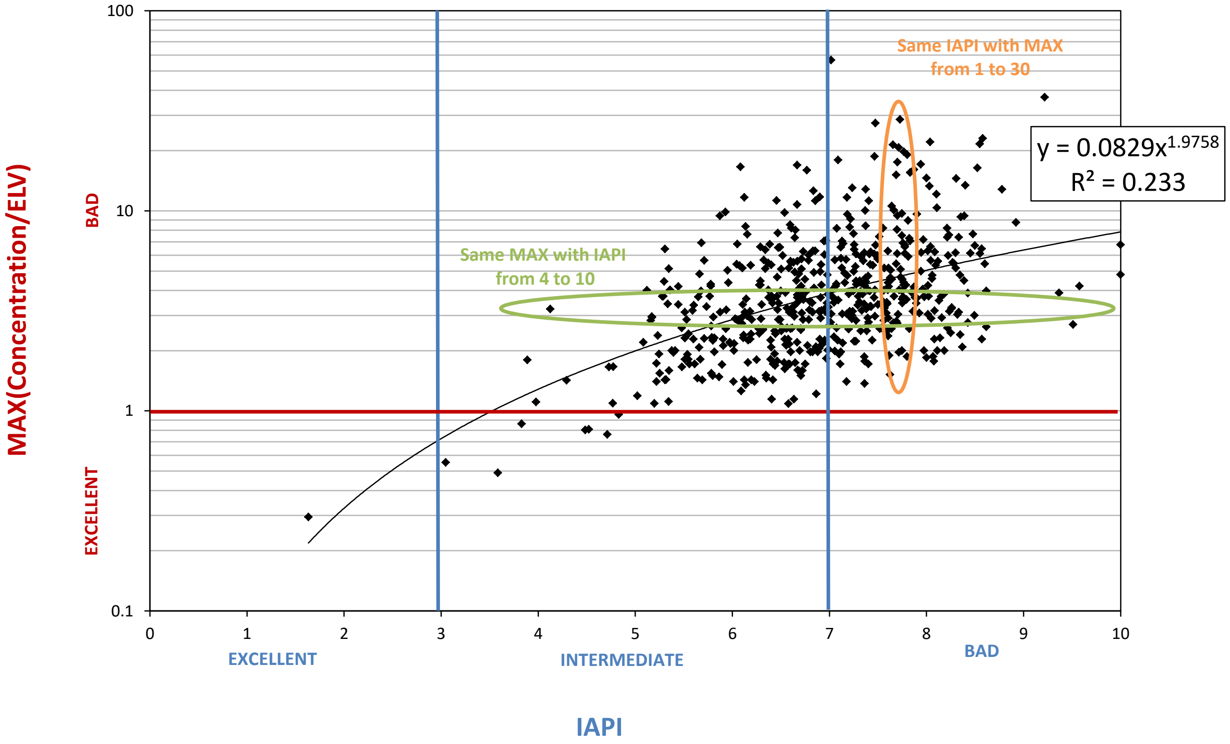

Figure 57: Correlation between the IAPI and MAX(C/ELV) indices. Each point represents the IAQ of a house/apartment from the French survey according to the two approaches.

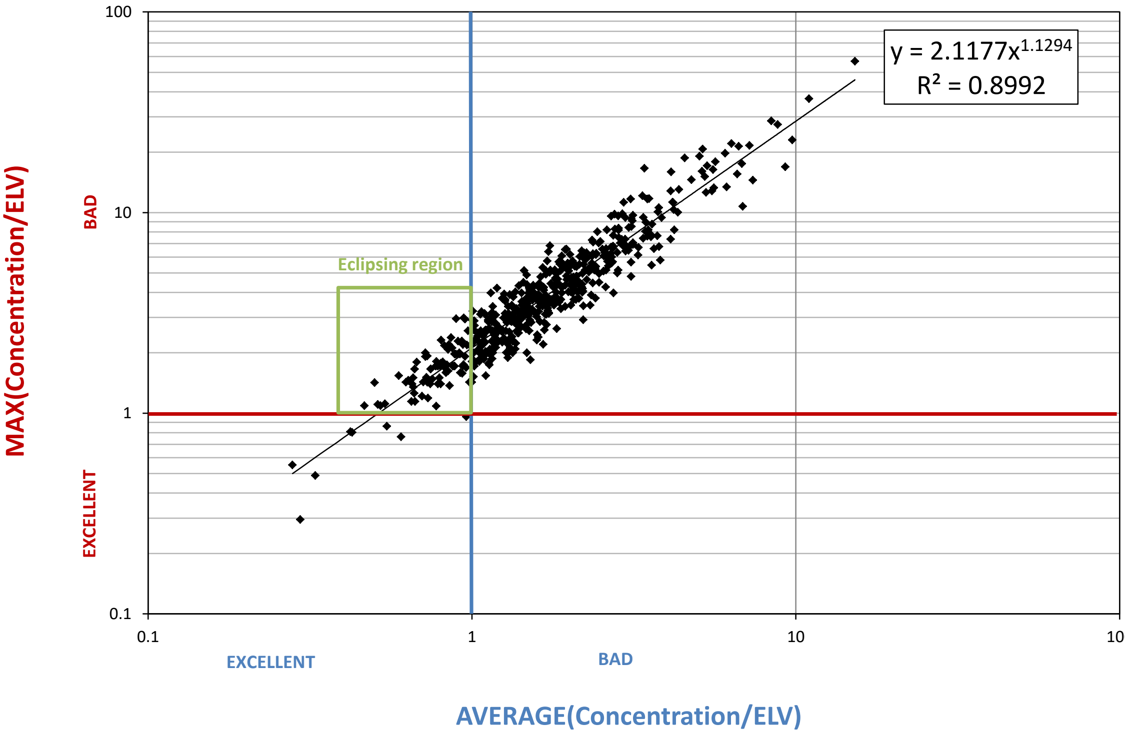

Figure 58: Correlation between the AVERAGE(C/ELV) and MAX(C/ELV) indices. Each point represents the IAQ of a house/apartment from the French survey according to the two approaches.

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