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Level(s) indicator 4.1: Indoor air quality

User manual: introductory briefing, instructions and guidance
(Publication version 1.1)

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Title
Level(s) indicator 4.1: Indoor air quality user manual: introductory briefing, instructions and guidance (Publication version 1.1)

Abstract

Developed as a common EU framework of core indicators for assessing the sustainability of office and residential buildings, Level(s) can be applied from the very earliest stages of conceptual design through to the projected end of life of the building. As well as environmental performance, which is the main focus, it also enables other important related performance aspects to be assessed using indicators and tools for health and comfort, life cycle cost and potential future risks to performance.

Level(s) aims to provide a common language of sustainability for buildings. This common language should enable actions to be taken at building level that can make a clear contribution to broader European environmental policy objectives. It is structured as follows:

1. Macro-objectives: An overarching set of 6 macro-objectives for the Level(s) framework that contribute to EU and Member State policy objectives in areas such as energy, material use, waste management, water and indoor air quality.
2. Core Indicators: A set of 16 common indicators, together with a simplified Life Cycle Assessment (LCA) methodology, that can be used to measure the performance of buildings and their contribution to each macro-objective.

In addition, the Level(s) framework aims to promote life cycle thinking. It guides users from an initial focus on individual aspects of building performance towards a more holistic perspective, with the aim of wider European use of Life Cycle Assessment (LCA) and Life Cycle Cost Assessment (LCCA) methods.

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The Level(s) documentation structure

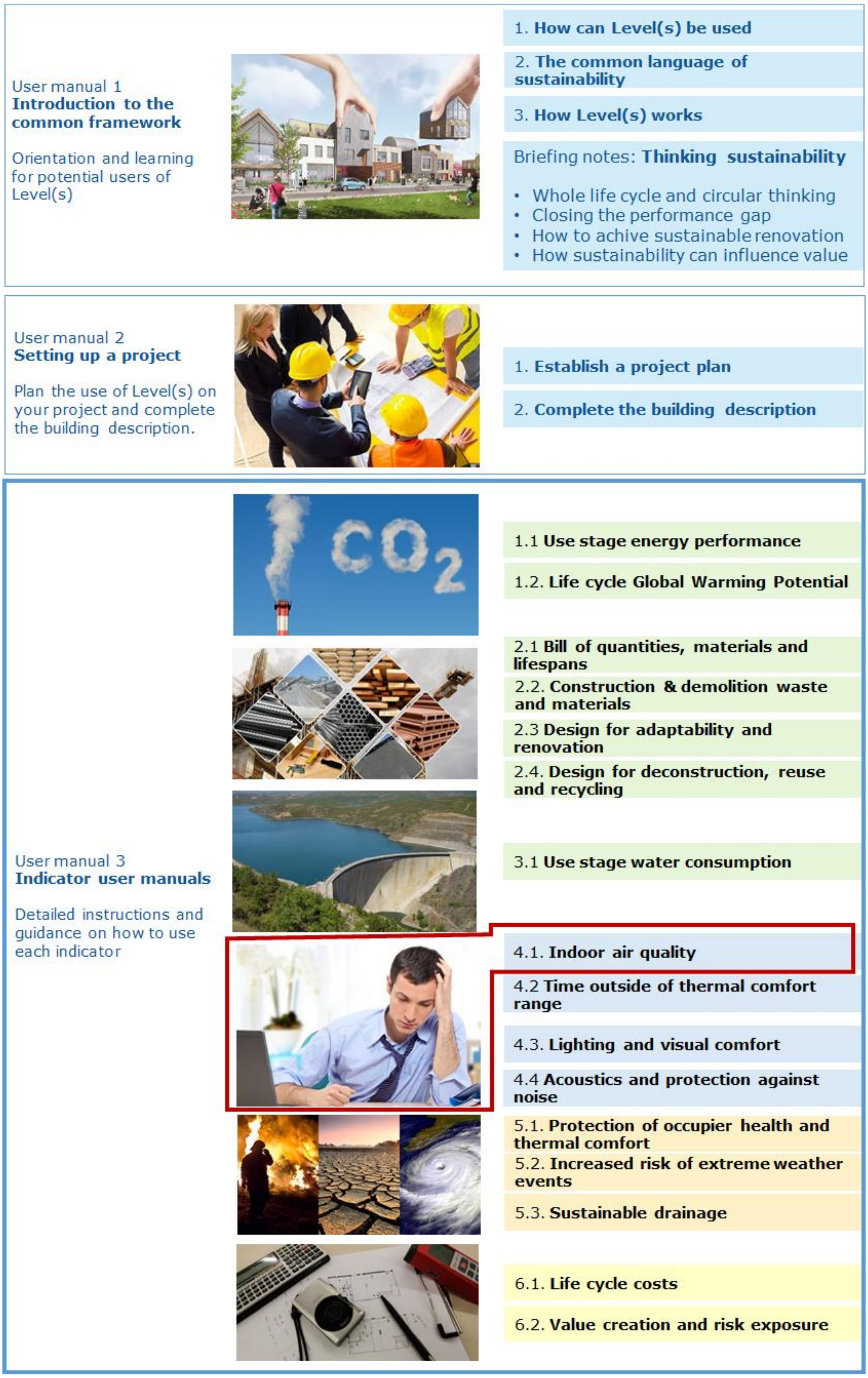

Figure 1. The Level(s) document structure

How this indicator user manual works

Level(s) is a framework of core indicators of sustainability that can be applied to building projects in order to report on and improve their performance. The supporting documentation has been designed to be accessible to all the actors that may be involved in this process.

If you are new to the assessment of building sustainability, we recommend reading the **first part of the Level(s) user manual**. This will provide you with an introduction to the basic concepts behind Level(s) and how you can apply it to a building project.

If you haven't yet set up your building project to use Level(s), including completing the project plan and the building description, then we recommend reading the **second part of the Level(s) user manual**.

This indicator user manual forms part of the third part of the Level(s) user manual where you will find instructions on how to use the indicators themselves. It is designed to help you apply your chosen indicator to a building project. It will help you to do this in the following way:

- **Introductory briefing:** This section provides an overview of the indicator, including:
  - ✓ why you may wish to measure performance with it,
  - ✓ what it measures,
  - ✓ at which stages in a project it can be used,
  - ✓ the unit of measurement, and
  - ✓ the relevant calculation method and reference standards.
- **Instructions on how to use the indicators at each level**: This section provides:
  - ✓ step by step instructions for each level,
  - ✓ what is needed to make an assessment,
  - ✓ a design concept checklist (at Level 1), and
  - ✓ the reporting formats.

  The instructions often refer to the guidance and further information section, which can be found after the instructions.
- **Guidance and further information for using the indicator**: This section provides more background information and guidance to support you in following specific steps in the instructions, including the design concepts introduced at Level 1 and the practical steps to calculate or measure performance at Levels 2 and 3. They are all cross-referenced to specific instruction steps at either level 1, 2 or 3.

This indicator user manual is structured so that once you are familiar with using the indicator and you know how to work with it, you may no longer need to refer to the guidance and background information, but only work directly with the instructions at the level of your choice.

Technical terms and definitions used

Term	Definition
Bio-effluents	A variety of pollutants produced during metabolic processes that take place within the human body[1]. These pollutants generally include CO2, ammonia, hydrocarbons, alcohols, ketones and aldehydes and their increase in concentration is associated with a decrease in perceived indoor air quality. CO2 would normally be used as a "marker" for bio-effluents.
Design ventilation airflow rate	According to EN 16798-1, it is the ventilation rate that the ventilation system is able to provide in design conditions (including boost, weather and loads).
LCI	According to EN 16516, LCI is the Lowest Concentration of Interest, which is a substance-specific value and is quoted in terms of mass concentration in the air of the reference room, for health-related evaluation of emission levels from construction products.
$PM_{2.5}$ or PM_{10}	According to EN 16890-1, particulate matter which passes through a size-selective inlet with a 50% efficiency cut-off at 10 or 2.5µm aerodynamic diameter.
Mechanical ventilation	According to EN 16798-1, a ventilation system where air is supplied or extracted from the building or both by a fan using air terminal devices, ducts and roof/wall devices
Natural ventilation	According to EN 16798-1, where ventilation is provided by thermal, wind, or diffusion effects through doors, windows, or other intentional devices in the building designed for ventilation. Natural ventilation may be manually or automatically controlled.
R value	According to EN 16516, the R value is the sum of all R_i values obtained during a given test. The R_i value is the ratio of C_i / LCI_i, where C_i is the mass concentration in the air of the reference room and LCI_i is the LCI value of compound i.
Total Volatile Organic Compounds (TVOCs)	According to EN 16516, TVOC is the sum of the concentrations of the identified and unidentified volatile organic compounds as defined in 3.1.3.11 (of EN 16516), calculated by summing the reference room concentrations of every individual compound (target and non-target, identified and unidentified) eluting between n-hexane and n-hexadecane inclusively using the specified column, and calculated using the TIC response factor for toluene after subtracting the blank values and after excluding compounds calculated to be below 5 µg/m^3 in the air of the reference room using the TIC response factor for toluene, additionally all compounds listed in Annex G (of EN 16516) are included even if they elute after n-hexadecane or before n-hexane under the specific test conditions.
Ventilation	According to EN 16798-1, ventilation is the process of providing outdoor air by natural or mechanical means to a space or building.
Ventilation rate	According to EN 16798-1, the ventilation rate is the magnitude of outdoor air flow to a room or building through the ventilation system or device.
Ventilation system	According to EN 16798-1, a ventilation system is a combination of appliances or building components designed to supply indoor spaces with outdoor air and/or to extract polluted indoor air. The system may be mechanical (e.g. using a combination of air handling units, ducts and terminals), natural (e.g. achieving air flow via temperature differences and wind via façade grills) or a hybrid combination of both mechanical and natural aspects.

[1] Zhang X., Wargocki P., Lian Z., Xie J., Liu J., 2017. Responses to human bioeffluents at levels recommended by ventilation standards. Procedia Engineering, 205, p. 609-614.

Introductory briefing

Why measure performance with this indicator?

Clean indoor air is a highly important influence on human health. Many Europeans spend more than 90% of their time inside buildings[2] and most of the >10 000 litres of air they breathe each day will be indoor air. Time spent indoors may increase even further in the future due to the conveniences or necessities of internet shopping and working from home, which reduce the need for transit.

The human health impacts of indoor air quality (IAQ) depend on multiple variables but are closely related to pollutant levels (e.g. dust, Volatile Organic Compounds (VOCs) etc.) and air conditions (e.g. CO_2 and humidity). Consequently, this indicator aims to provide an approach to ensuring suitable IAQ by addressing a number of different performance aspects, namely:

- Ventilation strategy to control air changes, CO_2 and humidity.
- Source control of pollutants from fit-out materials.
- Filter specification for intakes of outdoor air.
- Risk assessments for radon and mould.
- In-situ monitoring of ventilation system performance and pollutant levels.
- Occupant surveys of indoor conditions.

The principal purpose of the ventilation strategy is to provide occupants with a healthy supply of air. This involves filtering out harmful pollutants that could enter via intakes of outdoor air. It also involves the provision of a minimum air exchange rate to prevent levels of CO_2, humidity and pollutants arising from indoor materials or activities reaching uncomfortable or harmful levels. Coupled with this, a focus on the selection of materials and finishes to minimise of avoid at source harmful emissions into the indoor air is also important.

The level of relative humidity is an important influencing factor on occupant comfort. Excessively high humidity (> 90%) increases the intensity of hot or cold temperatures, while excessively low humidity (< 20%) can cause irritation of the eyes, nose and throat. Poor control of humidity from outdoor air or from kitchen and bathroom areas can create ideal conditions for mould growth, which in turn can provoke respiratory or allergenic health issues. Studies relating to homes suggested that around 17% of the EU population (approximately 80 million people) live in homes in which damp and associated mould growth may provoke health effects[3].

The choice of renovation materials and furnishings can also have significant effects on IAQ. When the purpose of renovation is to improve energy performance, this normally results in more airtight living spaces. More airtight spaces mean the correct design and functioning of the ventilation system becomes more critical for achieving suitable IAQ. Good design for IAQ is fundamental, but actual occupation rates and activities also have a significant influence and may deviate from design assumptions. Consequently, in-situ monitoring and occupant surveys, which cannot be undertaken until after the building project is completed, are also important.

What does it measure?

A number of parameters can be measured under indicator 4.1, which can be broadly split into "*air quality conditions*" and "*target pollutants*".

Table 1. Parameters covered by indicator 4.1.

4.1.1 Indoor air quality conditions		**4.1.2 Target pollutants**			
		Mainly from indoor sources[4]		**Mainly from outdoor sources**	
Parameter	**Unit**	**Parameter**	**Unit**	**Parameter**	**Unit**
Ventilation rate (air flow)	$L/s/m^2$	Total VOCs	$\mu g/m^3$	Benzene	$\mu g/m^3$

[2] WHO, 2014. World Health Organisation (2014) Combined or Multiple Exposure to Health Stressors in Indoor Built Environments

[3] Grun G., Urlaub S., Foldbjerg P., Towards an identification of European indoor environments' impact on health and performance – Mould and dampness. Frauhofer-Institut fur Bauphysik IBP

[4] For example, paints and varnishes, textile furnishings, wooden floor coverings, adhesives, sealants and wood-based panels used in fit out materials.

4.1.1 Indoor air quality conditions		4.1.2 Target pollutants			
		Mainly from indoor sources[4]		Mainly from outdoor sources	
Parameter	Unit	Parameter	Unit	Parameter	Unit
CO2	ppm	CMR VOCs*	µg/m³	Radon	Bq/m³
Relative humidity	%	R value	Decimal ratio	Particulate matter <2,5 µm	µg/m³
Occupant survey	Not defined	Formaldehyde	µg/m³	Particulate matter <10 µm	µg/m³

** VOCs classified as Carcinogenic, Mutagenic or toxic for Reproduction according to Regulation (EC) No 1272/2008[5]*

At what stage of a project?

Level	Activities related to indicator 4.1
1. Conceptual design	✓ Design of the building fabric and ventilation systems to meet target ventilation rates ✓ Control of potential sources of humidity by ventilation design ✓ Inspection of properties to be renovated in order to identify any problems relating to damp and mould. ✓ Design solutions for identified areas of cold bridging and damage from humidity in renovated properties ✓ Source control of target pollutants by selection of construction products/materials according to their tested emissions.
2. Detailed design and construction (based on as-built drawings)	✓ Verification that as-built and installed building fabric and services reflect those as designed.
3. As built performance	✓ In-situ measurement of the indoor concentration of target pollutants after completion and handover but prior to occupation. ✓ Functional performance testing of ventilation filters and their suitability for the building location.
3. In-use performance (testing after occupant entry and furnishing)	✓ In-situ measurement of the indoor concentration of target pollutants during occupation. ✓ In-situ measurement of the CO2 and relative humidity levels.

Unit of measurement

There a number of units of measurement that can apply, which depend on the IAQ parameter in question. The main units of measurement can be seen above, in the "*What does it measure?*" section. One additional consideration is that ventilation rates can also be expressed on a per person basis, which is important when planning for temporarily high occupation rates.

System boundary

In terms of energy consumption of any mechanical ventilation system, the indicator is related to the B6 stage (operational energy use) of the building life cycle, as per EN 15978. The assessment boundary is the useful conditioned floor area and the related indoor air conditions, as experienced by occupants of a building during normal activities within those zones of the building.

Scope

5 Regulation (EC) No 1272/2008 of the European Parliament and of the Council of 16 December 2008 on classification, labelling and packaging of substances and mixtures, amending and repealing Directives 67/548/EEC and 1999/45/EC, and amending Regulation (EC) No 1907/2006

The minimum scope for monitoring of IAQ is defined according to the parameters listed above in the "*What does it measure?*" section. In terms of limiting VOC emissions at source, users should focus efforts on the following construction products and materials:

- Ceiling tiles
- Paints and varnishes, including those applied to stairs, doors and windows
- Textile floor and wall coverings
- Laminate and flexible floor coverings
- Wooden floor coverings
- Associated adhesives and sealants

Internal insulation products and any special interior surface treatments (e.g. damp-proof courses) shall be included within the scope too.

Calculation method and reference standards

Each of the different parameters listed above that relate to IAQ have their own calculation method and reference standards. Measuring one aspect in isolation is not recommended, due to the interdependence between ventilation performance and emission rates from materials/building activities and any parameters measured to assess IAQ.

- Specifications for ventilation systems and target CO_2 and relative humidity levels follow EN 15251 and EN 16798.
- The main standard for running simulations of building ventilation is EN 16798-7.
- The choice of filter specification for air intakes (based on outdoor air quality and target IAQ) should be in line with EN 13779.
- Regarding construction products/materials as potential sources of indoor air pollutants (i.e. VOCs), EN 16516 is the main standard for reporting emission data.
- Risk assessments for mould and radon shall be carried out as and when deemed necessary by relevant experts. Standardised semi-quantitative risk assessments methods may be used.
- The main reference standards for post occupancy surveys of indoor environments and user perceptions of comfort and wellbeing are ISO 10551 and ISO 28802.

Instructions on how to use the indicators at each level

Instructions for Level 1

L1.1. The purpose of Level 1

The focus of Level 1 is to make the user aware of three highly relevant design aspects that represent the main factors that influence IAQ and contribute to optimising the ventilation strategy for a building. Users should briefly describe how these Level 1 aspects were considered (or not) during discussions and decision-making at the concept design stage in a summary table provided in L1.5.

L1.2. Step-by step instructions

These instructions should be read in conjunction with the accompanying Level 1 technical guidance and supporting information (see page 18).

1. Consult the checklist under L1.4 of IAQ and ventilation concepts and read the background descriptions in the Level 1 technical guidance.
2. Within the design team, review and identify how IAQ and ventilation design concepts can be introduced into the design process.
3. Once the design concept is finalised with the client, record the IAQ and ventilation design concepts that were taken into account using the L1 reporting format.

L1.3. Who should be involved and when?

At the concept design stage (Level 1), the main actors would be the concept architect, the prospective building owner or investor and, for office buildings, possibly also representatives of the workforce that will occupy the building.

The ventilation strategy and IAQ concepts can be translated into detailed designs for Level 2 when professionals such as service engineers and ventilation consultants become involved. The correct installation of the ventilation system, intake filters and materials that may contribute to the release of pollutants indoors will be the responsibility of the contractor, who should check with the designers that the design specifications have been met.

Post-completion and post-occupation monitoring will require in-situ testing (or sample collection followed by laboratory testing) by trained professionals or in-house staff. All building occupants could potentially be involved in post-occupation surveys. The correct maintenance of the ventilation system is ultimately the responsibility of the building owner.

L1.4. Checklist of relevant design concepts

The following indoor air quality-related design concepts have been identified from best practice and literature reviewed by the Joint Research Centre.

Level 1 design concept	Brief description
1. Consider how the building will be used and the expectations level of the future occupants	The expected use patterns for the building should be considered in order to identify how much ventilation needs may vary during the day or week. According to the EN 16798-1 category system, there are four expectation levels about indoor environmental quality (I, II, III and IV, with category I being highest expectations and IV being the lowest). Higher expectations translate into better control of IAQ and lower levels of pollutants but also generally higher energy consumption.
2. A basic understanding of the main pollutants in indoor air, their sources and how they might be minimised.	Try to minimise the indoor generation of air pollutants (e.g. off-gassing of VOCs from fit out materials or insulation) by the choice of low-emission materials. Assess the outdoor air quality and the potential intake of particulate and gaseous pollutants to the ventilation system. Carefully plan the building project to address any identified existing problems relating to air quality in the case of a renovation project. During construction the ingress of damp into the building fabric should be controlled and a drying out period allowed for.

Level 1 design concept	Brief description
3. Preferred ventilation strategy (in the context of planned use of different building zones).	Consider if a natural, mechanical or hybrid ventilation system is necessary to meet IAQ needs, taking into account the anticipated occupation patterns and densities in different parts of the building. These choices will also affect the heating and cooling strategy associated with indicator 4.2. Consider how to control when the ventilation system is on and off and, when on, at what % of maximum capacity.
4. Localised ventilation strategies to control point sources in parts of the building.	Consider specific areas where IAQ can be most compromised (e.g. cooking areas, bathrooms, smoking areas, low-ceiling meeting rooms with occasionally high occupation densities, printing rooms etc.) and whether running a separate exhaust, for defined time periods, with a high specific ventilation rate would be desirable. The purpose of separate (and higher) ventilation rates should be defined (e.g. to limit CO2 increases, to minimise risk of mould growth or to minimise negative occupant perception).
5. The importance of in-situ monitoring	Will the ventilation strategy be linked to real-life monitoring of IAQ and the ventilation rate? For example, with real time monitoring of duct flow, of CO_2 or relative humidity in office spaces? Will periodic monitoring of VOC and particulate emissions be undertaken? If so, consider the most representative locations to install sensors/take measurements.

L1.5. Reporting format

IAQ design concept	Addressed? *(yes/no)*	How has it been incorporated into the building project? *(provide a brief description)*
1. Consider how the building will be used and the expectation levels of the occupants	Yes	The office will be open Monday to Friday between 08:00 and 20:00 (peak hours expected to be 10:00 to 13:00 and 14:00 to 17:00). Staff may obtain access with management permission out of these hours and during weekends or national holidays. During peak hours, occupant density will be around 10-15 m^2/person. A medium expectation level of indoor environmental quality is assumed (category II according to EN 16798-1).
2. Source control of pollutants and related considerations.	Yes	The indoor generation of air pollutants (e.g. off-gassing of VOCs from fit out materials or insulation) will be minimised by the choice of low-emission materials. The intake of outdoor air pollutants (e.g. fine dust and benzene) will be minimised by placing the ground level intakes on the side of the building that is exposed to the car-park and not the main road and by the sheltering of ground-level air intakes by a row of densely planted fir trees. The HVAC system will provide for dehumidification and so mould risk assessment is not necessary. The building is not located in a radon risk area but passive ventilation features should be incorporated into the underground car park.
3. Preferred ventilation strategy in the context of desired ventilation rates in different zones of the building.	Yes	A hybrid ventilation system is foreseen where natural ventilation provides sufficient air change rates for emissions from building components and occupants during low occupation periods and mechanical ventilation can be used during periods of normal and high occupation, to manage CO2 and relative humidity to within acceptable limits. Higher specific ventilation rates are foreseen in the bathroom and changing room areas. For meeting rooms, the mechanical part of the ventilation system will be programmed to start one hour before planned occupation periods and to shut-down one hour after occupation periods, in

IAQ design concept	Addressed? *(yes/no)*	How has it been incorporated into the building project? ***(provide a brief description)***
		order to provide a safety margin against the build-up of VOCs from fit-out materials/furnishings and against the remaining of bio-effluents in indoor air.
4. Control system.	Possibly yes.	A building energy management system will be installed for HVAC equipment that allows for temperature control of individual building zones via a computer interface that users can access. If possible, the ventilation rate for individual offices will also be adjustable via the same interface, within preset ranges, and according to user preference. Otherwise, a timer controlled system will be used.
5. In-situ monitoring	Yes	CO2 will be monitored in the main meeting rooms and high values will automatically trigger a higher ventilation rate. Sampling of indoor air pollutants will be contracted out once per year during peak occupation periods in the winter season.

Instructions for Level 2

L2.1. The purpose of Level 2

Building upon Level 1, Level 2 is for users who are working on the detailed design of the ventilation system, the specification of indoor fit-out materials and, in the case of major renovations, the design of insulation and other design improvements to the air tightness and integrity of the building fabric.

This level will inform decisions on the methodological approach to quantify the ventilation rates needed in different zones of the building. At the same time, potential influences on the quality of outdoor air (e.g. proximity of roads, traffic volume etc.) and on the quality of indoor air (e.g. emissions from materials, bio-effluents, point sources of humidity etc.) need to be factored into the design.

It is also intended to inform ventilation system specifications. The difference in quality between outdoor air entering the system and the desired quality of the air to be supplied indoors will directly influence the filter specification, which in turn will influence the sizing of the system and its energy performance.

L2.2. Step-by-step instructions

These instructions should be read in conjunction with the accompanying Level 2 technical guidance and supporting information (see page 26).

1. Decide on which EN 16798-1 method to quantify the needed ventilation rates: Method 1-based on perceived air quality; Method 2-based on limit values of gas concentration or Method 3-based on predefined ventilation flow rates.
2. Define an occupation schedule for the main ventilated building zones and identify point sources of high humidity.
3. Define the material specifications for insulation and fit-out materials with attention to manufacturer declarations and product labels that provide information on the tested emissions of VOCs and other hazardous substances.
4. Define the outdoor air quality (ODA) for the building location.
5. Carry out design calculations taking into account steps 1-4 in order to derive the target supply air quality (SUP) for each of the main building zones. The ventilation filter(s) shall also be specified.
6. <u>*Optional step:*</u> Carry out design simulations using dynamic software and use this to derive the target supply air quality (SUP) for each of the main building zones.
7. *Renovation projects*: If deemed relevant, conduct a mould risk assessment focussing on existing signs of growth and/or material damage as well as the identification of areas of surface and interstitial condensation, as well as potential causes.
8. Compile the design documentation, stating clearly all assumptions informing the ventilation design, compiling equipment specifications and compiling product test data sources. Where carried out, the outcomes of a mould risk assessment shall also be reported.

L2.3. What do you need to make an assessment?

The main things needed are:

- ✓ Drawings of the layout of the building and the expected uses of each building zone.
- ✓ An occupation schedule for the main building zones to be ventilated.
- ✓ Access to the EN 16798 series of standards and related standards.
- ✓ A working knowledge of the design process set out by EN 16798.
- ✓ Performance data from ventilation filter suppliers.
- ✓ Product emissions test data and/or data from product emissions labelling schemes.

- ✓ *Optional:* Calculation software that can run a dynamic simulation and which is compliant with the national calculation method for the relevant Member State and/or EN ISO 52000-1.

Users should follow the methodologies provided in the cited standards and provide design documentation that clearly describes all the assumptions used for the detailed design. This way, any future performance issues with the ventilation system can be cross-checked to see if the problem is due to the design assumptions not matching real use or due to other reasons.

L2.4. Who should be involved and when?

At the detailed design stage (Level 2), the main actors would be the architects, service engineers, any specialist ventilation consultant, the building owner/investor and the main contractor. The building owner/investor will need to provide assumptions about the intended occupancy rates of different zones, the target indoor air quality category and the preferred calculation method (if any).

The consultant engineers will need to carry out the relevant calculations and simulations according to an agreed method and provide sufficient detail to the contractor for the correct installation of the system. The architect will be responsible for selecting fit-out materials, potentially with support from an environmental consultant, and for integrating passive ventilation features into the building design. The planning authority would need to check that the ventilation system complies with any relevant standards, provide input on the risk of indoor radon and input about the relevant outdoor air quality at the building site.

The ventilation strategy should be discussed together with the heating and cooling system consultants/engineers/designers as the two systems have an inter-dependent relationship, especially when the two systems are integrated – for example, when heat is to be recovered from exhaust air.

L2.5. Ensuring the comparability of results

The comparison of detailed designs of the same building can be compared in the context of a fixed target category of supplied indoor air (SUP), of outdoor air quality (ODA) and occupation schedule. Results could be influenced by changing the building layout (e.g. less/more separated zones), the specification of low-emission fit-out materials, the specification of more energy efficient ventilation systems and/or changing the relative contributions of mechanical and natural ventilation.

L2.6. Going a step further

The ventilation strategy can be dynamically simulated using more advanced software packages. At the most advanced level Computational Fluid Dynamic (CFD) techniques may additionally be used and are particularly valuable for testing passive ventilation designs.

The following steps can be taken in order to optimise the estimate of IAQ, including the potential impact on health of indoor pollutants:

- The checking of as-built specifications for the construction products and materials used against any specifications made for low VOC emission materials.
- Obtaining product emission data that, in addition to Total VOCs, includes a value for total CMR VOCs, in order to separately identify the more hazardous substances that may be emitted.

L2.7. Format for reporting the results of an assessment

The design IAQ conditions (4.1.1) and/or the product emissions data (4.1.2) for the overall specification of fit out materials shall be reported on at building level. Any significant variation in the specification in parts of the building can then optionally be reported on by building zone or by house/apartment type.

4.1.1 Indoor air quality conditions

The reporting format for design IAQ conditions below (available as an excel-based Level(s) template) is suggested for the ventilation system design. The upper part is at building level for the specified ventilation system and the lower part is for any specific representative zones of the building that the user wishes to report separately.

Design indoor air quality conditions - general building level information

Floor area (m2)	Method applied	Outdoor air quality (particulates)	Outdoor air quality (gaseous pollutants)	Supply air quality	Filter specification		
					1st	2nd	3rd
2500	Method 3 - predefined airflow rates	ODA (P) 2 - high contamination (<50% above limits)	ODA (G) 1 - clean (below limits)	SUP 2 - rooms for permanent occupation	ePM10: 85%		

Design indoor air quality conditions - specific information for defined building zones

Building zone/room	Floor area (m2)	Method applied	Ventilation performance category	Ventilation rate	Units	Design occupation rate (person/m2)	Upper CO2 limit (ppm above outdoor air)	Control range of relative humidity (%)

Figure 2. Screenshot of Level(s) reporting template for IAQ conditions for the general building (top) and for individual zones (bottom).

Entries are required in the green cells and are optional in the yellow cells. Most columns have drop-down menus to select options from. Up to three filters can be defined for the system, to allow for the different filtration needs that may occur and the different combinations that are possible to meet those needs. Further details about the reporting format for the ventilation system can be found in the Level 2 guidance (from page 26 onwards).

If reporting for specific zones, certain information should be provided depending on the calculation method chosen. For example, if EN 16798-1 method 1 is used, it should be stated if the building is to be a very low polluting (LPB-1), low polluting (LPB-2) or non-low polluting (LPB-3) building and if occupants are considered as adapted or non-adapted to bio-effluents. If EN 16798-1 method 2 is used, the design CO2 limit and assumed occupant numbers should be stated. If EN 16798-1 method 3 is used, either the floor area or the total number of occupants will suffice.

4.1.2 Target air pollutants

Regarding target air pollutants (4.1.2), the first row is again at building level and subsequent rows are for any other specific zones that the user wishes to report separately.

Target indoor air pollutants - general building level information

Floor area (m2)	Indoor radon risk assessed?	Estimated exposure (Bq/m3)	Mould risk assessed?	Conclusion about mould assessment

Target indoor air pollutants - specific construction products and materials

Construction product/material	Product type or application	Total VOCs (µg/m³)	R value	Formaldehyde (µg/m³)	Certified by labelling scheme? If so, which one?	Other relevant information? (e.g. specific limits/results for other VOCs etc.)
Ceiling tiles	All					
Paints and varnishes	walls and ceiling					
	floors and stairs					
	doors and windows					
Floor coverings	textile coverings					
	laminate and flexible coverings					
	wooden coverings					
	associated adhesives and sealants					
Renovation products	internal insulation					
	interior surface treatments (e.g. to resist damp)					
Other (please specify)	Other (please specify)					

Figure 3. Screenshot of Level(s) reporting template for target pollutants in indoor air for the general building (top) and for individual zones (bottom).

All the entries for VOC emission from specific construction products / materials are in yellow cells (optional). If more than one type of, e.g. wall paint is used, then an extra row should be inserted. The three key VOC emissions may be inserted as actual chamber air concentrations, where specific data is available. However, it is more likely that "< *X*" would be inserted, where "*X*" is a defined limit.

If the product is labelled according to a certain certification scheme, this should be mentioned. Finally, reference to other relevant information, such as other VOC limits that are respected or how much and where the product or material is used in the building, can be provided in the last column.

Instructions for Level 3

L3.1. The purpose of Level 3

The purpose of Level 3 is to allow users to assess indoor air quality (IAQ) in an objective manner based on the performance of a completed building. A two-pronged approach is recommended in Level 3. In-situ assessment of IAQ.

The first is an **objective**, quantitative approach based on air sampling and monitoring at two different stages: (i) after completion but prior to occupation and (ii) during occupation.

Testing prior to occupation allows for a direct comparison to design estimates for ventilation rates and for a baseline to be set for, CO2, humidity, VOC emissions and any pollutants from intake air. Testing during occupation captures any additional impacts on IAQ caused by the activities of occupants and the installation of furniture and equipment.

However, sampling and testing of indoor air will only provide a partial snapshot IAQ and may not correlate directly to occupant perception of IAQ. For this reason, the second approach is **subjective**, being based on occupant feedback in surveys about IAQ during occupation.

In case of unsatisfactory results, it is important that any significant differences in occupation rates and usage patterns between the design assumptions and real use are identified before taking remedial action.

L3.2. Step-by-step instructions

These instructions should be read in conjunction with the accompanying Level 3 technical guidance and supporting information (see page 33).

For in-situ monitoring (either prior to or during occupation):

1. Agree on which parameters are to be monitored (e.g. ventilation rates, relative humidity, particulate matter, CO_2, radon, VOCs etc.).
2. Identify the relevant testing standards for the parameters of interest and review the monitoring and sampling protocols.
3. Develop a plan identifying at which stages and points in time during the building project the monitoring and sampling will need to take place.
4. For each parameter, decide whether sampling and monitoring can be conducted by in-house staff (e.g. by facilities management staff), or if external experts are necessary.
5. If the monitoring and sampling is to be carried out in-house, obtain the necessary equipment.
6. Decide upon a monitoring and sampling strategy, including the locations of sampling and sensors, when the monitoring and sampling should take place and the time interval for monitoring and sampling. Some or all of these decisions may be made by consulting the protocols in relevant standards.
7. Collect samples and send them to a certified laboratory for analysis. If data is generated at the point of measurement, setup a system to log the data.

For post-occupancy surveys:

1. Decide upon the questions to ask about IAQ and which aspects to focus on (e.g. humidity, dryness, odour, stuffiness). Questions about IAQ are most likely to be included as part of a more general survey including other well-being aspects, such as thermal comfort, light levels, light quality, furniture quality, cleanliness and noise). .
2. Send out the survey to all building occupants and try to obtain as high a response rate as possible (at least 30% for results to be considered representative).

3. Gather results and compile into a report for the building manager, the building owner and (preferably) the building occupants.

L3.3. What do you need to make an assessment?

The exact requirements will depend on which parameters are to be measured and how. Generally speaking, some or all of the following will be needed for in-situ measuring of air quality and target pollutants:

- ✓ Access to the relevant testing methodology and standards document.
- ✓ Access to sampling equipment, monitoring equipment and calibration standards.
- ✓ A sampling or monitoring plan.
- ✓ Expertise to correctly implement the sampling or monitoring plan.
- ✓ (where relevant) testing of collected samples according to relevant standard(s) by a certified laboratory.
- ✓ Systems to log and store data obtained from monitoring equipment.

For the occupant survey, an appropriate survey design (structure of questions and answers) is required, which may be able to distinguish answers from different types of occupant (individual traits and nature of activities in the building). For the convenience of both the respondents and the people who need to compile answers, the survey should be carried out via an online platform.

L3.4. Who should be involved and when?

The building or facilities manager plays a central role in any in-situ monitoring of IAQ and ventilation system performance. In-house and/or specialist contractors may be used to carry out in-situ measurements depending on the level of expertise required and access to suitable testing/monitoring equipment. External laboratories may also be involved when collected samples that cannot be tested in-situ to produce a result. Data logged from monitoring equipment will need to be compiled and analysed by personnel with the appropriate expertise.

With occupant surveys, this should ideally be designed and carried out by specialists in the field of human psychology and indoor comfort factors.

L3.5. Ensuring the comparability of results

The comparison of results for different buildings or building zones can be directly compared in terms of the quantitative measurement of air quality parameters and indoor pollutants, as well as according to the project stage at which monitoring and sampling has taken place.

For a fairer comparison of occupant-related air quality parameters (humidity and CO_2 especially), buildings or building zones should also be compared in terms of the levels of occupation and the specific ventilation rates when measurements were taken.

For a fairer comparison of pollutants predominately originated from outdoor sources, buildings should be classified in the same ODA (P) and ODA (G) categories.

L3.6. Format for reporting the results of an assessment

The reporting format for Level 3 measurements for each of the selected representative building zone is shown below (available in an excel-based Level(s) template).

Level 3 - 4.1.1 IAQ conditions

Representative area tested and time/date of test	Floor area (m2)	Method applied	Ventilation performance category	Ventilation rate	Units	Occupation rate (person/m2)	CO2 (ppm above outdoor air concentration)	Control range of relative humidity (%)

Level 3 - 4.1.2 Target indoor air pollutants

		Representative area tested			Representative area tested		
Nature of IAQ parameter	**IAQ parameter**	**Design stage**	**Post completion (prior to occupation)**	**During occupation**	**Design stage**	**Post completion (prior to occupation)**	**During occupation**
Pollutants predominantly from outdoor sources	Radon (Bq/m^3)						
	$PM_{2.5}$ (µg/m^3)						
	PM_{10} (µg/m^3)						
	Ozone (µg/m^3)						
	Benzene (µg/m^3)						
Air quality aspects (from outdoor & indoor sources)	Relative humidity (%)						
	CO2 (ppm indoors)						
	CO2 (ppm outdoors)						
Pollutants predominantly from indoor sources	Total VOC (µg/m^3)	n/a			n/a		
	Total CMR VOCs (µg/m^3)	n/a			n/a		
	R-value	n/a			n/a		
	Formaldehyde (µg/m^3)	n/a			n/a		

Figure 4. Screenshot of Level(s) reporting template for comparing design, as-built and in-performance IAQ conditions for the general building (top) and for individual zones (bottom).

The description of the selected zone, the respective floor area of the building zone and the percentage of the building floor area it is representative of must be filled out (green cells).

Up to 12 different measured parameters can be reported for Level 3. It is unlikely that all parameters would be reported for any given building zone. Depending on the main concerns for the building or building zone in question, efforts might be more focussed on:

- The ingress of outdoor pollutants when the building is in industrial or heavily trafficked areas.
- Air quality aspects during periods of high occupation and/or during wet seasons.
- The emission of pollutants from indoor sources, for example when:

  (i) fit-out materials are mainly textile or wood-based;

  (ii) when walls and/or when ceilings have been recently painted or

  (iii) to simply understand the overall effect of occupation on IAQ (e.g. fit out materials, furnishings, use of kitchens and bathrooms). In the last case, a full picture could be obtained by testing prior to and during occupation.

Guidance and further information for using the indicator

For using level 1

In this section of the guidance, additional background explanations and information are provided for four key concepts that form the basis for the L1.4 adaptability design concept checklist, namely adaptation to:

- L1.4. Checklist design concept 1: in general: Considering use patterns and the expectation levels of occupants for IAQ.
- L1.4. Checklist design concept 2: Source control of air pollutants and related considerations.
- L1.4. Checklist design concept 3: Preferred ventilation strategy (in the context of planned use of different building zones).
- L1.4. Checklist design concept 4: Control system for ventilation.

L1.4. Checklist design concept 1: Building use patterns and expectation levels

When considering ventilation needs, the expected use patterns should be considered, especially if occupant densities might vary significantly from one zone to another or in the same zone, but during different times of day or week.

As per CEN/TR 16798-2, the following four categories of indoor environmental quality correspond to different expectation levels:

- Category I: high expectation of good quality (this level should be considered when occupants have special needs, for example small children, elderly people or people with disabilities).
- Category II: medium expectation of good quality (this level is the normal situation that should be applied for buildings).
- Category III: moderate expectation of good quality (while acceptable IAQ will still be delivered, there is an increased risk of IAQ affecting occupant performance sometimes).
- Category IV: low expectation of good quality (should only be considered for building areas that only occupied for short periods of time, only by a small fraction of building occupants or only during exceptional circumstances that do not occur for prolonged periods).

Indoor environmental quality is a multi-faceted consideration that includes IAQ (indicator 4.1) but also thermal comfort (indicator 4.2) and lighting (indicator 4.3). The choice of category by designers will also be influenced by possible trade-offs with these other indicators. While a higher category is generally desirable for IAQ, this would generally be associated with higher ventilation rates and/or finer filters in intakes and therefore higher energy consumption for any mechanical ventilation systems.

L1.4. Checklist design concept 2: Main sources of indoor air pollutants

Indoor air pollutants predominantly come from either indoor sources (e.g. VOCs), outdoor sources (e.g. radon and benzene) or a combination of both (e.g. particulate matter, expressed as PM_{10} or $PM_{2.5}$).

<u>*Predominantly internal pollutants: VOCs from construction products and materials*</u>

Although there are many factors that can influence the concentration of VOCs in indoor air, the specification of low-emission construction products and materials can be expected to have a positive influence on IAQ, all other factors being equal. The main question to building owners is: **How to specify low VOC emission materials?**

The obvious answer would be to look for products and materials with a low VOC emission label. However, just because a construction material does not have a low VOC emission label does not mean that it does not have low VOC emissions. Some materials, like glass, ceramic tiles, bricks, natural stone and precast concrete have inherently low VOC emissions. Other materials, such as carpets, wood-based coverings, insulation materials, paints and varnishes have inherent VOC emissions. If these latter types of material are to be used, then low VOC emission labels should be specified where possible.

The next question to ask then is: **What is meant exactly by low VOC emission?**

A range of third party verified labelling schemes for the emissions from building materials and products have emerged during the last 20 years. These have had the objective of protecting building users and occupants from health hazards by encouraging (or requiring) source control strategies that control building material emissions.

The emissions from these labelled products are (as estimated by an experienced material testing laboratory) approximately one fifth of the level they were in the early 1990's. Mature certification schemes now also provide access to many thousands of products, making them more accessible. Of the schemes available in the market, some have been developed as voluntary initiatives by industry or NGOs (e.g. GUT and EMICODE in Germany, M1 in Finland, the Indoor Climate Label in Denmark), whilst some have been mandated by regulation (e.g. the French emissions classes system, the Belgian VOC Regulation, the German AgBB). Various Type I Ecolabels certify low emission products, including the EU Ecolabel, the Blue Angel and the Nordic Swan.

A harmonised European test method for emissions of volatile organic compounds from construction products into indoor air, EN 16516, was published in 2017. This established a common method and test conditions based on a 'European reference room' in which products are to be tested. Materials to be tested are loaded in a chamber in a standard way and the concentration of the VOCs in the chamber air is measured in samples collected after a defined period (normally 3 and 28 days) under standard conditions. Verification of low emissions according to the 28 day emissions test therefore now provides a consistent basis for the selection of products.

Currently (as of October 2020) the European Commission is working on a harmonised European classification for the VOC emission from construction products and materials. In the meantime, reference can be made to different national VOC emission labels.

A brief overview of some of the labelling schemes is provided below in order to illustrate their scope and how they classify low emissions:

German (AgBB) VOC emission labelling scheme

CThe AgBB published an updated evaluation procedure for VOC emission from building products in 2018. The limits are pass or fail.

Table 2. Limit values for the German VOC testing (in µg/m³)

Parameter	3 days	28 days
Total VOC*	≤ 10 000	≤ 1 000
Category 1A and 1B carcinogens**	≤ 10	≤ 1
Total SVOC*	-	≤ 100
All VVOC*, VOC* and SVOC* with LCI value†	-	R value ≤ 1
Sum of VOC* with unknown LCI value	-	≤ 100

**VOC corresponds to compounds in the retention range C6 to C16, VVOC to compounds in the retention range <C6 and SVOC to compounds in the retention range C16 to C22.*

***Excluding formaldehyde and acetaldehyde*

†Refers to a list of VOCs maintained by AgBB and the R value is the sum of each R-value for individual VVOCs, VOCs and SVOCs.

Sensory testing of perceived odour in air samples taken after 28 days is also recommended by the AgBB but is currently a voluntary requirement. The odour testing method is based on ISO 16000-28, with some further specifications defined.

French VOC emission labelling scheme

In France, a VOC label is used for construction, decorative and furnishing products placed on the French market as per Décret no. 2011-321. The VOC label has A+, A, B and C classes, based on results from ISO 16000 chamber testing of the following VOCs. The label can be obtained for floor coverings, paints, varnishes, doors, windows, wall coverings, ceiling panels and furnishings.

Table 3. Limit values for the French VOC label in the context of EU-LCI (in µg/m³)

Substance / Emissions class	A+	A	B	C	EU-LCI
Formaldehyde	< 10	< 60	< 120	> 120	**100**
Acetaldehyde	< 200	< 300	< 400	> 400	**1200**
Toluene	< 300	< 450	< 600	> 600	**2900**
Tetrachloroethene	< 250	< 350	< 500	> 500	**80**
Xylene	< 200	< 300	< 400	> 400	**500**
1,2,4-Trimethylbenzene	< 1000	< 1500	< 2000	> 2000	**450**
1,4-Dichlorbenzene	< 60	< 90	< 120	> 120	**150**
Ethylbenzene	< 750	< 1000	< 1500	> 1500	**850**
2-Butoxyethanol	< 1000	< 1500	< 2000	> 2000	**1600**
Styrene	< 250	< 350	< 500	> 500	**250**
TVOC	< 1000	< 1500	< 2000	> 2000	-

The data in the table above show that there are some important differences between the French values and the EU-LCIs. In some cases, the EU LCI values are more stringent than the "*A*" requirement for the French VOC label (e.g. tetrachloroethene, 1,2,4-trimethylbenzene, ethylbenzene and styrene). In other cases, the EU-LCI values are less stringent than the "*C*" requirement for the French VOC label (e.g. acetaldehyde, toluene xylene and 1,4-dichlorobenzene).

Finnish VOC emission labelling scheme

In Finland, the M1 emission system sets requirements for VOC emissions from building products. The label can be applied to building and decorative materials, kitchen furniture, doors, tables shelves and chairs (including office chairs). Labelled products are listed on a public database[6]. Testing conditions have been aligned with EN 16516 and two classes are defined (M1 and M2) for VOC emissions.

Table 4. Limit values for the Finnish VOC testing (in µg/m3)

Parameter	M1 limit	M2 limit
TVOC emission rate (mg/m².h)	≤ 0,2	≤ 0,4
Individual VOC emission (µg/m³)	≤ EU-LCI	≤ EU-LCI
Formaldehyde (mg/m².h)	< 0,05	< 0,125
Ammonium (mg/m².h)	0,03	< 0,06
Category 1A and 1B carcinogens (µg/m³)*	< 1	< 1
Odour	Not odourous	

**excluding formaldehyde*

6 https://cer.rts.fi/en/m1-emission-class-for-building-material/search-m1-paastoluokiteltuja-tuotteita/

The Finnish approach sets values based on emission rates in some cases instead of chamber air concentrations. There is a requirement for odour (based on ISO 16000-28) and additionally a requirement for ammonium/ammonia.

Due to the different approaches and values specified in different countries, a harmonised European classification system will make it much simpler to make comparative assessments of different fit-out materials in buildings.

Predominantly external pollutants: Radon

As a colourless, odourless and invisible gas, radon is not perceived by occupants. Radon is a naturally occurring element that is ubiquitously present in outdoor air. It has a radioactive decay half-life of 3.8 days and is the only gaseous element in the decay chains of Uranium and Thorium. Consequently it has the potential to spread from point sources of radioactive solids in the earth's crust, through the air and into the atmosphere. Global average concentrations range from 5 to 15 Bq/m^3. In poorly ventilated indoor spaces, the concentration of radon can build up to levels that are significantly more harmful than the background concentration.

As a first step, a European map of radon exposure could be consulted to have a general idea of the seriousness of radon in indoor compared to the rest of Europe.

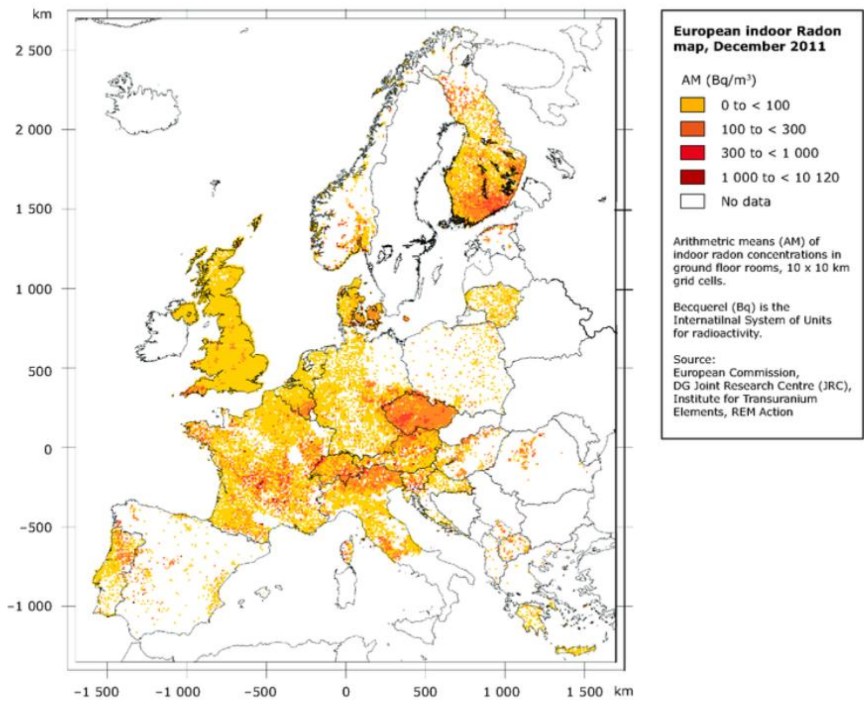

Figure 5. European indoor radon map.

Source: European Environment Agency: http://www.eea.europa.eu/data-and-maps/figures/european-indoor-radon-map-december-2011

The next step would then be to consult with regional authorities to check if there are any specific risk assessment requirements for ventilation systems for residential or office buildings.

The radioactive decay of radon (and its decay products) produces ionising radiation that causes myriad adverse effects on human health.

Exposure to radon gas is widely considered as an important risk factor in the development of lung cancer (second only to cigarette smoking). The WHO have proposed a reference level of 100 Bq/m^3 in indoor air in order to minimise the risk of human health effects. If this is not possible due to background radon levels, then a limit of 300 Bq/m^3 should be respected in all cases.

The main sources of radon to indoor air are:

- Outdoor air: radon is naturally present in outdoor air with global average concentrations of around 5 to 15 Bq/m^3. It will enter buildings via natural or mechanical ventilation intakes.
- Rocks and soil: the most significant source of radon. This source can cause elevated radon concentrations in indoor air in basements and ground floors with poor air circulation. Radon gas from underlying porous soils and fractured rock can seep up into the building.
- Building materials: radon gas may emanate from building materials due to the presence of traces of radium in granite, clays, gypsum and especially products containing secondary materials such as phosphogypsum or blast furnace slag.

The reasons for radon build-up in indoor air can be due a combination of inputs from soils and building materials and a low rate of air circulation with outdoor air, meaning that the air is not diluted to background levels. There are several measures that can be taken to reduce the risk of high levels of radon in indoor air that should be considered at the design stage:

- Sealing of surfaces in contact with soil.
- Installation of soil gas barriers.
- Design for natural (passive) ventilation of basement or other normally unoccupied ground/subterranean areas.
- Installing mechanical (active) ventilation system for basement or other normally unoccupied ground/subterranean areas.
- Active soil de-pressurisation.
- Passive soil de-pressurisation.

As a general rule, it is much more cost-effective to take measures for reducing indoor radon in the initial construction than to remediate later.

In case of any doubt, there are a number of ways in which radon levels can be monitored at the site. For further reading, users are referred to reports by the WHO[7] and the JRC[8].

Predominantly external pollutants: particulate matter and benzene

The potential of outdoor air pollutants cannot be controlled at source *per se*, but instead can be controlled by the careful placement of air intakes and the specification of filters in the intake ducts. The main outdoor pollutants to be considered that are of direct concern for indoor health are particulate matter (e.g. **PM_{10}, $PM_{2.5}$**) and **benzene**.

The abbreviation PM stands for Particulate Matter, which is the term for solid and/or liquid particles suspended in ambient air. When the term PM is accompanied by a number (e.g. PM_{10}), it means that it refers to the concentration of suspended solids and/or liquids that passes through a size-selective inlet which has a 50% efficiency cut-off at 10µm aerodynamic diameter. The same definition applies for $PM_{2.5}$ and PM_1, the only difference being that the size-selective inlet has the 50% cut-offs at 2.5µm and at 1.0µm.

These particular size cut-offs are considered to be directly relevant to potential human health effects.

7 WHO handbook on indoor radon. A public health perspective. ISBN 978 92 4 154767 3.

8 JRC, 1995. European Collaborative Action. Indoor air quality & its impact on man. Report No. 15: Radon in indoor air. ISBN 92 827 0119 0.

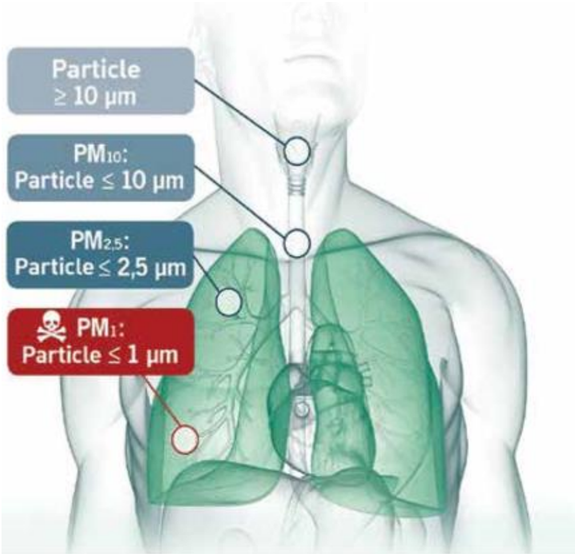

Figure 6. Potential pathways for particulate matter of different aerodynamic diameters into the human pulmonary system[9].

Broadly speaking, particles become potentially more dangerous as they become smaller. Particles ≤ 10µm can reach respiratory ducts and potentially cause decreased lung function. Particles ≤ 2.5µm can penetrate into the lungs, causing decreased lung function and possible irritation of eyes and skin. Particles ≤ 1µm can potentially enter the blood stream and may be linked to cancer, cardiovascular diseases and dementia.

Benzene originates from anthropogenic activities relating to the processing, transport and combustion of fuel. Incomplete combustion of carbon-based fuels is the main source of benzene to outdoor air. Consequently, sources in outdoor air around office and residential buildings will be dominated by the proximity of vehicular traffic. Some indoor sources may come in the form of solvent-based chemicals being used. Benzene is photo-oxidised in outdoor air and may persevere for periods ranging from 1-9 days.

As an aromatic compound, occupants would be able to smell benzene at concentrations as low as 1,5 ppm (v/v).

Related considerations: filter specification

Filters can be specified for the removal of particulate matter according to EN 16890 and, if deemed necessary, for the removal of gaseous pollutants. The specification of the filters will depend on both the outdoor air category (ODA) and the target quality of supplied ventilation air (SUP). A brief introduction to the concepts of ODA and SUP is provided below.

Outdoor air classification (ODA):

EN 16798-3 provides three levels of outdoor air quality, based on the expected levels of air pollutants compared to international, national or regional limits:

- **ODA(P)1** and **ODA(G)1** apply when outdoor air is considered as clean (i.e. **not exceeding** particulate or gaseous pollutant limits, respectively), and where excessive dust loads might only occur temporarily (e.g. due to pollen).
- **ODA(P)2** and **ODA(G)2** would apply when concentrations of dust or gaseous pollutants **exceed by up to 50%** the limits for particulates or gaseous pollutants, respectively.

[9] Eurovent, 2017. Recommendation 4/23: Selection of EN ISO 16890 rated air filter classes for general ventilation applications.

- **ODA(P)3** and **ODA(G)3** would apply when concentrations of dust or gaseous pollutants **exceed by more than 50%** the limits for particulates or gaseous pollutants, respectively.

Considering the supply air category (SUP):

At the concept design stage for the ventilation strategy, the building layout should be split into zones based on supply air (SUP) categories. The supply air quality depends on the intended use of the ventilated space. An indicative guide is provided below.

Table 5. Requirements for PM and typical applications for different SUP categories of supplied air[10]

Category	IAQ requirement compared to outdoor air	Occupation rate	Examples
SUP 1	Supplied air is < 25% of the $PM_{2.5}$ and PM_{10} limits	n/a	n/a (only for commercial/industrial applications with high hygenic demands, such as hospitals, pharmaceuticals, semi-conductor production etc.).
SUP 2	Supplied air is < 50% of the $PM_{2.5}$ and PM_{10} limits	Rooms for permanent occupation	Kindergardens, **offices,** hotels, **residential buildings**, meeting rooms, exhibition halls, conference halls, theatres, cinemas, concert halls
SUP 3	Supplied air is < 75% of the $PM_{2.5}$ and PM_{10} limits	Rooms with temporary occupation	Storage rooms, shopping centres, washing rooms, server rooms, copier rooms
SUP 4	Supplied air is < 100% of the $PM_{2.5}$ and PM_{10} limits	Rooms with short term occupation	Toilets, stairways
SUP 5	Supplied air is < 150% of the $PM_{2.5}$ and PM_{10} limits	Rooms without occupation	Garbage room, data centres, underground car parks

From the table above it is clear that SUP 2 air will be needed in any office or living spaces. Especially with offices, there is the potential for a number of different spaces that have less stringent ventilation requirements (e.g. data centres, copier rooms, stairways etc.).

L1.4. Checklist design concept 3: Preferred ventilation strategy (in the context of planned use of different building zones)

Ventilation can be achieved by natural convection, mechanically forced convection or a combination of both (a hybrid approach). The choice of ventilation strategy will be influenced by many factors. Deep building forms will be more likely to need mechanical ventilation. Buildings in noisy areas mean window-opening would result in too much noise indoors, thus favouring mechanical ventilation. Where the building is to achieve a high energy efficiency rating, and an important part of this is to have an airtight building, then mechanical ventilation will no doubt be necessary.

Anticipated use patterns of the building may dictate the need for additional mechanical ventilation in some areas compared to others, either due higher occupation densities, higher occupation rates or the nature of activities taking place in the zone (e.g. cooking areas, toilets etc.).

[10] Eurovent Recommendation 4/23 – 2018. Selection of EN ISO 16890 rated air filter classes for general ventilation applications. 2nd edition.

L1.4. Checklist concept 4: Control options for airflow rates in the ventilation system

There are number of different ways in which the control system can be controlled. The main different types are:

- **Continual operation:** very basic control, only needs to be switched off for maintenance interventions. Especially suitable for zones that are constantly occupied and/or where the continual introduction of pollutants, CO_2 or humidity would quickly compromise IAQ in the absence of mechanical ventilation.
- **Manually managed systems:** very basic control, especially useful in cases where occupation schedules are very difficult to predict. However, these systems require a responsible person to be present for switching on/off.
- **Timer controlled systems:** slightly more sophisticated control, vulnerable to the potential malfunction of the timer. Very convenient option when occupation schedules are highly predictable.
- **Presence controlled systems:** a more complex system where occupant movement would trigger infrared sensors that feedback to the control circuit. The same presence sensors could be linked to the lighting system. Care needs to be taken about the logic to trigger the start/stop of the ventilation. If it was the same logic as lighting, excessive wear could be placed on the ventilation equipment by repeated start-stop cycles. If the normal activity of occupants involves frequent movement throughout multiple zones, this could lead to excessive ventilation energy consumption during low occupation rates.
- **Demand controlled systems (based on occupant numbers):** airflow rates can be automatically staged by the assumed number of occupants in the different building zones. Accurate input data could potentially be provided by swipe card access to different zones, by detection of network activity when all occupants can be expected to be logged onto a networked device in the office or, in the cases of physical meetings, the number of registered attendees can be used.
- **Demand controlled systems (based on an air quality indicator):** airflow rates would be adjusted by real time measurement of an indicator of indoor air quality such as CO_2, humidity or VOCs. Set-points for when to adapt ventilation rates and by how much would need to be defined and these may be refined later as building management become more familiar with use patterns and system performance.

In the control systems that rely on sensor feedback, an alternative manual operation mode must also be foreseen in case of any faults with the sensor or signal transmittance infrastructure.

The provision of adaptive opportunities for occupants should be considered. For example, opportunities to adjust the fixed workplace (e.g. opening of windows or increase/decrease of ventilation rates in the individual office) or to opportunities to change workplace (e.g. move with laptop to another desk in a fresher building zone).

In terms of matching the ventilation rate to IAQ needs, variable speed drives will provide the greatest flexibility and opportunity to reach the optimum ventilation rate. Variable speed drives will tend to be more expensive to purchase but can deliver significant life cycle cost savings compared to drives with several fixed speeds or single-speed drives. The latter types of drive would normally be over-sized by design engineers since excessive ventilation is preferable to insufficient ventilation. Over-sized drives result in additional energy consumption.

For using level 2

In this section of the guidance, additional background explanations and information are provided in order to support use of the instructions for Level 2. The following steps in the instructions are specifically addressed:

- L2.2. Step 1: Decide on the EN 16798-1 method for designing ventilation rates.
- L2.2. Step 2: Define the outdoor air quality categories (ODA(P) and ODA(G)) for the building location.
- L2.2. Step 3: Define an occupation schedule for each building zone.
- L2.2. Step 4: Defining the supply air (SUP) category and filter specifications.
- L2.2. Step 5: (optional) define material specifications and VOC emissions for fit-out and insulation materials (see guidance on L1.4 concept 2).
- L2.2. Step 6: Mould risk assessment.

L2.2. Step 1: Decide on the EN 16798-1 method for design ventilation rates

As per EN 16798-1, there are three types of method that can be used for estimating design ventilation rates:

- Method 1: based on perceived air quality. This method focuses on the capability of the ventilation system to remove two types of emission (from people, bio-effluents) and from the building. In EN 16798-1, Table B6 provides reference ventilation rates (in l/s/person) to account for the removal/dilution of bio-effluents to different IAQ categories (and expected occupant dissatisfaction rates). Table B7 provides reference ventilation rates (in l/s/m^2) to account for the removal/dilution of emissions from the building to different IAQ categories. Meanwhile Table B8 provides an example of how the reference values from Tables B6 and B7 can be combined for a real example – generating design rate results in l/s, l/s/person and l/s/m^2 for the defined zone.
- Method 2: based on limit values of a substance concentration in indoor air (e.g. CO_2). This method is particularly relevant where the ventilation system is designed to respond to different occupancy rates automatically. When occupancy rates in a building zone increase and ventilation rates do not increase sufficiently, the indoor air CO_2 concentration will increase. The baseline CO_2 concentration (outdoor CO_2) can range from 350 to 500ppm. A CO_2 emission rate needs to be assumed (e.g. 20 L/h/person) and the estimated increased in CO_2 can be calculated for different design ventilation flow rates in the same zone.
- Method 3: based on predefined ventilation airflow rates. This is the simplest of the three methods. Table B10 of EN 16798-1 provides default airflow rates for the four categories of IAQ (I, II, III and IV) in both units of l/s/person and l/s/m^2. These values range from 5.5 to 20 l/s/person and from 0.55 to 2 l/s/m^2. When applied to a specific building zone situation (in terms of occupant density), the default ventilation rate units that result in the required should be used for a given category.

The most basic method is method 3, where predefined ventilation rates can be referred to, depending on the category of IAQ that is aimed for in the design. For example, in an office building, the predefined rates reproduced below (from Table B10 of EN 16798-1):

Table 6. Default predefined ventilation air flow rates for an office (from table B10 of EN 16798-1).

Category	Total design ventilation air flow rate for the room	
	l/(s per person)	l/(s.m^2)
I	20	2
II	14	1,4
III	8	0,8
IV	5,5	0,55

Table 7. Default predefined ventilation air flow rates for a residential building (from Table B11 of EN 16798-1).

Category	Total ventilation including air infiltration (1)		Supply air flow per person (2)	Supply air flow based on perceived IAQ for adapted persons (3)	
	l/(s.m²)	Ach	l/(s per person) [a]	q_p l/(s per person)	q_B l/(s.m²)
I	0,49	0,7	10	3,5	0,25
II	0,42	0,6	7	2,5	0,15
III	0,35	0,5	4	1,5	0,1
IV	0,23	0,4			
[a] Supply air flow for Method 3 is based on Formula (1) from 6.3.3.2					

The tables above show that the ventilation rate increases as the category increases (from category IV → category I). The ventilation rates between category I and category IV differ by a factor of around 4 for office buildings and by a factor of 2 for residential buildings.

L2.2. Step 2: Define the outdoor air quality (ODA) categories for the building location

The ODA categories, based on particulate and gaseous pollutants in outdoor air have been explained in guidance section L1.4 concept 2 (see page 20). These categories refer to pollutant levels relevant to unspecified limits. These limits can be set at local, regional, national or international level.

Guideline values for outdoor air pollutant concentrations were published by the WHO in 2005[11] and are expected to be updated again in 2020 or 2021. Limit values have also been set out by Directive 2008/50/EC[12]. Values are defined as time-weighted averages below.

Table 8. Guideline and limit values for dust and pollutants of indoor relevance in outdoor air.

Parameter	Concentration	Time weighting	Source
Fine particulate matter ($PM_{2.5}$)	10 µg/m³	Annual average	WHO, 2006.
	20 µg/m³	Annual average	Directive 2008/50/EC
	25 µg/m³	24 hour average	WHO, 2006.
Coarse particulate matter (PM_{10})	50 µg/m³	24 hour average	Directive 2008/50/EC
	50 µg/m³	24 hour average	WHO, 2006.
	40 µg/m³	Annual average	Directive 2008/50/EC
	20 µg/m³	Annual average	WHO, 2006.
Benzene	5 µg/m³	Annual average	Directive 2008/50/EC

Two separate ODA classifications should be set, one for particulates (ODA P) and one for gaseous pollutants (ODA G). In major cities, users can easily obtain an indication of outdoor air quality in the building location by consulting public data made available by the European Environment Agency in their "*Airbase*" portal[13].

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11 WHO, 2006. Air quality guidelines. Global Update. Particulate matter, ozone, nitrogen dioxide and sulphur dioxide. ISBN 92 890 2192 6.

12 Directive 2008/50/EC of the European Parliament and of the Council of 21 May 2008 on ambient air quality and cleaner air for Europe. OJ L 152, 11.6.2008, p.1-44.

13 https://www.eea.europa.eu/themes/air/air-quality/map/airbase

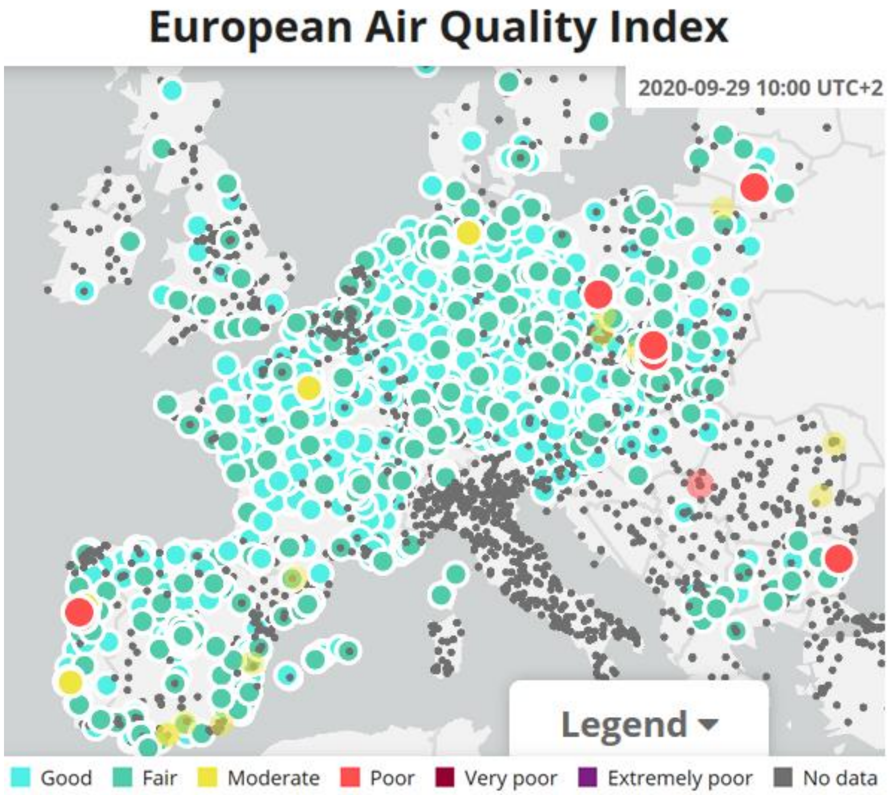

Figure 7. Example of real time data availability on EEA "airbase" website.

The map above defines a single status for each point based on combined data for 5 air pollution parameters. Zooming in and clicking on any of the sampling points provides a breakdown of how the data has been for the last year and, if applicable, which pollutant is responsible for the sampling point air not being in "*good*" status.

For sites that are remote from sampling points, reference can also be made to spatial distribution maps resulting from modelling of air quality data. These maps have been published by the European Environment Agency for air pollutant distributions during recent years.

Stricter limit values may have been set in the country or region where the building is located and limits on other pollutants, or combinations of pollutants, may have been set. In such cases, users should refer to these more locally relevant limits.

Filter specification on outdoor air intakes

With mechanical ventilation systems, filters are necessary in order to protect the HVAC equipment and ensure continued performance by providing air of a consistent quality. Filters can also improve indoor air quality by removing pollutants from outdoor air (e.g. pollen, other particulates, odours or other gaseous contaminants), thus improving IAQ.

The importance of careful placement and orientation of the air intakes to minimise the potential entrance of dust and gaseous pollutants cannot be overestimated. In general air intakes shall be located at least 20 metres from sources of poor quality air. Where this is not possible, the opening should be positioned as high above the ground as possible.

The choice of filter(s) will depend primarily on the relevant outdoor air particulate levels and the removal rate required to meet the SUP air category. However, there are also other considerations. Adding filter stages will increase pressure drops and thus energy consumption, but will provide a more robust removal of dust where a coarser first filter can protect a finer second filter.

As filters gradually clog up, the pressure drop increases and energy consumption increases. A predefined pressure drop should trigger the replacement of the filter (e.g. 150 Pa, 200 Pa or 300 Pa depending on the filter class). Even when pressure drops remain satisfactory, filters should be changed at periodic time intervals (e.g. every year or two years) for hygiene reasons. When changing filters, care must be taken to avoid release of the trapped solids into the ventilation system.

The maintenance schedule and filter specification(s) for each intake should be clearly detailed in the design documentation and should follow manufacturer recommendations.

L2.2. Step 3: Define an occupation schedule for each building zone

For office buildings, an occupation schedule will be required to help estimate the energy consumption of the ventilation system. Default occupation schedules are provided in Annex C to EN 16798-1 for different building zones such as offices, meeting rooms, kindergardens residential houses and residential apartments. These schedules are also relevant for the purposes of setting air quality objectives and calculating design air flows and air changes. Specifically relevant information for the ventilation system in the occupation schedule includes:

- Moisture production (in $g/m^2/h$).
- CO2 production (in $l/m^2/h$)
- Minimum ventilation rate (in $l/s/m^2$)
- Ventilation rate for CO2 emission (in $l/s/m^2$)
- Maximum CO2 concentration above outdoor levels (ppm)
- Minimum relative humidity (%)
- Maximum relative humidity (%)

L2.2. Step 4: Define the supply air (SUP) category for each zone and related filter specifications

The SUP categories, based on desired air quality to be supplied to the building zone have been explained in guidance section L1.4. Checklist design concept 2. The combination of SUP category and ODA category will inform designers about what filters should be specified.

Filters that can remove gaseous pollutants (e.g. ozone, benzene etc.) may be recommended or required, as per the matrix below (based on EN 16798-3):

- ODA (G)1 – gas filters **recommended** if SUP 1 air quality desired in the zone.
- ODA (G)2 – gas filters **required** for SUP 1, and **recommended** for SUP 2 and SUP 3.
- ODA (G)3 – gas filters **required** for SUP 1 and SUP 2 and **recommended** for SUP 3.

For particle removal, there are different potential configurations of filter (single stage and multi-stage) and different performance classes of filter are available. The old EN 779 standard specified particle removal by 0.4µm diameter particles. The new EN 16890 classification has replaced the EN 779 standard since mid-2018 and uses a significantly different method for assessing particle removal efficiency. The new EN 16890 standard is based on particle removal efficiency for PM_1, $PM_{2.5}$ or PM_{10}.

It should be possible to create a similar matrix between ODA (P) and SUP categories to define the filter classes needed. However, the EN 16798-1 standard still refers to the filter classes defined in EN 779, which are obsolete.

Although there is no direct or predictable relationship between particulate removal efficiency for EN 779 and EN 16890 classes, an indicative relationship is provided below.

Table 9. Indicative translation of EN 779 filter classes into EN 16890 results.

EN 779:2012	EN ISO 16890 – range of actual measured average efficiencies		
Filter classes	**ePM_1**	**$ePM_{2,5}$**	**ePM_{10}**
M5	5 – 35%	10 – 45%	40 – 70%
M6	10 – 40%	20 – 50%	60 – 80%
F7	40 – 65%	65 – 75%	80 – 90%
F8	65 – 90%	75 – 95%	90 – 100%
F9	80 – 90%	85 – 95%	90 – 100%

Until the EN 16798 standard is revised, consultation with filter manufacturers is highly recommended to ensure that the correct specifications are used in the design.

L2.2. Step 5: Specification of fit-out and insulation materials for VOC emission

Building developer and owner preferences are likely to inform the specification of fit-out materials. In cases where no preference is stated and users wish to reduce indoor VOC levels in indoor air using source control principles, it is recommended to specify low emission materials such as ceramic tile and natural stone instead of carpets, flexible or wood-based floor coverings, although labelling information can be used to select products that minimise emissions.

With a view to future European harmonisation of VOC emissions, Level 2 specifications for source control of VOC emissions relates to the following parameters:

- **Total VOCs:** Although there are reservations about this metric, because not all VOCs are equally harmful to health, it is a useful metric that can identify potential hot spots of VOC emission and can be compared to existing national schemes.
- **Total CMR VOCs**: This applies only to VOCs that have been classified as carcinogenic, mutagenic or toxic for reproduction. The serious nature of these health hazards justify the separate reporting of these substances. It excludes formaldehyde, which is reported separately.
- **R-value**: This is the main metric that links to the EU LCI values. The R value for an individual VOC is the ratio of the measured concentration to the EU-LCI value. For example, a measured concentration of 24 $\mu g/m^3$ and an EU LCI value of 200 $\mu g/m^3$ would correspond to an R value of 0.12. When more than one substance with an EU-LCI value is measured, the R values of each substance are added together.
- **Formaldehyde**: Formaldehyde was reclassified as a category 1B carcinogen and category 2 mutagen in 2015[14]. It is a commonly used resin in the surface treatment of textile fabrics, as a binder in wood-based panels and in numerous other applications. Upon contact with moisture, formaldehyde resins can break down, releasing continual small quantities of formaldehyde to the indoor air. Due to its relatively high concentrations, it is counted separately from other CMR VOCs.

With regards to the R value, it is worth referring to the considerable progress has been made in agreeing EU LCI values (Lowest Concentrations of Interest) for VOCs. As of December 2019[15], a total of 152 VOCs had been assigned

[14] Commission Regulation (EU) No 605/2014 of 5 June 2014 amending, for the purposes of introducing hazard and precautionary statements in the Croatian language and its adaptation to technical and scientific progress, Regulation (EC) No 1272/2008 of the European Parliament and of the Council on classification, labelling and packaging of substances and mixtures. OJ L 167, 6.6.2014, p.36-49.

[15] https://ec.europa.eu/docsroom/documents/39985

EU LCI values. Another 13 VOCs have EU LCI values pending assignment[16] and another 5 VOCs with more data needed prior to assigning any EU LCI[17].

L2.2 step 6 – Mould risk assessment

The World Health Organisation (WHO) has sought to address the potential health impacts from exposure to damp and mould in homes [18], emphasising that:

> *"Exposures to biological agents indoors are a significant health hazard causing a wide range of health effects. Dampness is a strong and consistent indicator of risk for asthma and respiratory symptoms related to indoor environmental conditions. Inadequate ventilation and structural failures as well as problems with thermal comfort are often to blame."*

The World Health Organisation (WHO) documented case studies of mould remediation in housing from the Germany, Finland, France, Slovakia, Sweden and the UK [19]. These provide results and recommendations that can inform both new building and major building renovation designs and ventilation strategies. The WHO has also published guidelines on dampness and mould that address the evaluation of human risk [20]. They highlight some key factors to take into account that can cause mould growth:

- Poor ventilation;
- Air leakage through structures;
- Local areas of moisture damage; and,
- Raised moisture levels in floors and walls.

Remedial actions that can be considered for major renovation projects include the sealing of air leakage paths, localised improvement of insulation, improved ventilation (including in bathrooms) and the drying of wet materials.

An expert condition inspection and survey of renovation properties is recommended to be carried out. This will provide a basis for understanding and diagnosing problems that have occurred in an existing building. Remedial steps can then be taken in the new renovation design. Mould inspections are recommended to be carried out using a structured assessment format which provides a rating. Any rating used should, as a minimum:

- reflect both the presence and severity of mould.
- identify areas of potential damage to the building envelope.

The occurrence and extent of dampness and mould shall be measured in each room and a sum of the areas used to determine the overall classification. Table 10 provides an outline of a classification system that can be used for very basic inspections.

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16 https://ec.europa.eu/docsroom/documents/38870

17 https://ec.europa.eu/docsroom/documents/38868

18 World Health Organisation, *Protecting health from home damp and mould*, European regional office, http://www.euro.who.int/en/health-topics/environment-and-health/Housing-and-health/risk-management-and-policy-options/protecting-health-from-home-damp-and-mould

19 World Health Organisation (2008) *Interventions and actions against damp and mould - a review of case studies*, WHO regional office for Europe.

20 World Health Organisation (2009) *WHO guidelines for indoor air quality – dampness and mould*, WHO regional office for Europe.

Table 10 Dampness and mould in building structures classification system

Classification criteria	Class 1	Class 2	Class 3	Class 4
Condition of the structures has been checked and the maintenance of structures and installations documented less than 5 years ago.	Yes	Yes		
Known water damages or occurrences of condensation or capillary water have been repaired.	Yes	Yes	Yes	
Visible mould in occupied spaces:	None			
- smaller areas (e.g. gasket in a window sash)		< 400 cm^2		
- minor areas show signs of mould			< 2.500 cm^2	
- larger areas show signs of mould				> 2.500 cm^2
Risks of water damage have been assessed and proactive measures taken to reduce the future risk.	Yes			
Moisture from recent construction phase (only for newly constructed buildings).	No	No	Yes	

Source: Danish Standards (2015)

A risk assessment can also be carried out on new building designs. This is recommended to focus on measures to control point sources of humidity and the avoidance of areas of cold bridging and air infiltration into the building envelope. As well as a qualitative risk assessment to identify areas of high humidity, it is necessary to ensure that there is adequate forced ventilation to control any sudden increases in humidity, technical risk assessments can be made in accordance with the following two standards:

- ISO 6946 calculation method for the thermal resistance and transmittance of building materials[21].
- ISO 13788 calculation method for the hygrothermal performance of building components and elements[22].

These standards provide a calculation method for critical surface humidity that may lead to mould growth on the internal surfaces of buildings. To carry out the risk assessment, data is required on the thermal characteristics of building products and on architectural design details, with a specific focus on thermal transmission. The latter may require calculation to provide estimates. Alternatively, performance data may be provided at national level for accredited architectural details.

[21] ISO Standards, ISO 6946: *Building components and building elements - Thermal resistance and thermal transmittance - Calculation method*.

[22] ISO Standards, *ISO 13788: Hygrothermal performance of building components and building elements -- Internal surface temperature to avoid critical surface humidity and interstitial condensation -- Calculation methods*.

For using Level 3

Additional background guidance and explanations are provided for the steps listed below in order to support the measurement of indoor air quality at Level 3.

- L3.2. Step 1a: In-situ monitoring, choice of parameters to measure
- L3.2. Step 1b: Post occupancy surveys

L3.2. Step 1: In-situ monitoring, choice of parameters to measure

Some brief points to remember about several IAQ parameters are provided below, which may help users decide which parameters they want to monitor.

<u>CO2</u>

In modern buildings, any increase in CO2 above typical background air concentrations of 350-500ppm in building spaces will be due to human respiration. Although a high CO2 level itself can cause human sensory discomfort (e.g. at levels of several thousand ppm), it is unlikely that concentrations in indoor air would be so high. To provide some context, the following effects of CO2 exposure in indoor air are generally as follows:

- 350-500ppm: typical outdoor air CO2 levels
- 1000ppm: in zones where the sole source of CO2 is human metabolic activity, CO2 levels above 1000ppm would highlight the potential significance of bio-effluents on occupant perception of IAQ (even though CO2 itself at this level is unlikely to directly affect perception).
- 2500ppm: at this level, cognitive functions of occupants may begin to be impaired[23].
- 30000ppm: The 15 minute short term exposure limit set by OSHA.
- 40000ppm: Immediately dangerous to life or health for exposures greater than 5 minutes.
- 50000ppm: the 30-minute lethal concentration for humans, causing unconsciousness.

The main reason for measuring CO2 in-situ is that it is an excellent "*marker*" of bio-effluents. Metabolic activity of respiring organisms generates bio-effluents and CO2 simultaneously, with the former being much more likely to cause adverse perception (e.g. odours). However, since bio-effluents are much more complicated to measure in-situ, it is preferred to measure CO2 instead.

Projected CO2 levels can be used to design ventilation systems and in-situ monitoring of CO2 in specific building zones can be used as a feedback signal to control ventilation rates for those same zones (e.g. in meeting rooms where CO2 levels could vary significantly).

Simple DIY kits are available for measuring CO2 concentration via colorimetric analysis, using gas detection tubes, which may cost 3-5€ per test[24]. However, these kits only provide a limited number of spot measurements. For longer term monitoring, there are numerous products available on the market which can measure CO2 in real time, and that simultaneously monitor temperature and relative humidity.

<u>$PM_{2.5}$ / PM_{10}</u>

Exposure to particulate matter, especially $PM_{2.5}$, is well known to be associated with adverse human health effects[25]. Monitoring of PM is especially desirable if there are obvious concerns about potential sources due to building activities (e.g. renovation works while the building remains open, cooking, indoor fuel combustion for

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23 Satish U., Mendell MJ., Shekhar K., Hotchi T., Sullivan D., Streufert S., Fisk WJ., 2012. Is CO2 an indoor pollutant? Direct effects of low-to-moderate concentration on human decision-making performance. Environmental Health Perspectives, 120(12).

24 See for example: https://lukeskaff.com/measure-carbon-dioxide-co2-levels-test/

25 Anderson JO., Thundiyil JG., Stolbach A., 2012. Cleaning the air: A review of the effects of particulate matter air pollution on human health. J. Med. Toxicol., 8, p.166-175.

heating/cooking, smoking, the use of aerosols, shredding paper, use of cleaning equipment, especially vacuum cleaners etc.).

Standard measurement techniques have tended to involve the pulling of controlled volumes of sample air through a standardised filter and weighing the material deposited on the filter. However, these measurements are time-consuming, relatively expensive and, depending on the time period for collecting the sample, fail to give an idea of the dynamic nature (both spatial and temporal) of PM loads in indoor air.

Equipment based on optical methods is available that is much more economical and can generate data in-situ, in real time. More expensive, research-grade instruments are available[26] as well as low-cost PM sensors[27]. The deployment of low-cost sensors, linked to wireless network reporting, can provide real time information to help pinpoint the main sources of PM in indoor air. With such precise information, the adequacy of the ventilation strategy/building activity combination can be investigated in more detail.

For context, the WELL standard sets limits of 15 $\mu g/m^3$ and 50 $\mu g/m^3$ for $PM_{2.5}$ and PM_{10}, respectively.

<u>VOCs / formaldehyde</u>

The main sources of VOC and formaldehyde to indoor air are from continual, low-level emissions from building materials and intermittent spikes from the use of chemicals (most routinely for cleaning surfaces).

Measurements of total VOC are suggested with Level(s) because it provides a complete picture of these types of compounds in indoor air. The WELL standard sets a total VOC limit of 500 $\mu g/m^3$.

Formaldehyde is also a VOC, but is generally reported separately because of its serious health risk (it is classified as carcinogenic) and because of the widespread use of formaldehyde resins in many construction materials and products. The resins in construction products themselves are not harmful. However, the gradual attack of resins in the presence of moisture results in the breakdown of small amounts of the resin, releasing small, but continual amounts of formaldehyde. The WHO have recommended indoor air limits of formaldehyde at 80ppb[28], the WELL standard sets a limit of 27ppb and France, from 2023 onwards, intends to set limits that are 10 times stricter than the WHO (8 ppb)[29].

The normal method for measuring VOC and formaldehyde is to collect a known volume of air over a period of time, passing it through an absorbing material, where the VOCs are retained. The material is then transported to a lab and the VOCs are released under controlled conditions where individual VOCs can be identified and quantified against relevant standards via chromatography techniques. However, given the importance of monitoring formaldehyde in particular, there is a need for more cost-effective monitoring techniques that can provide near real-time results[30].

High or low total VOC concentrations, while informative and especially relevant for identifying VOC hotspots or changes in background levels, should not be automatically assumed to translate to harmful or harmless concentrations. Each individual VOC has its own potential toxicity upon exposure to humans.

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26 Amaral SS., De Carvalho AJ., Costa AM., Pinheiro C., 2015. An overview of particulate matter measurement instruments. Atmosphere, 6, p.1327-1345.

27 Hegde S., Min KT., Moore J., Lundrigan P., Patwari N., Collingwood S., Balch A., Kelly KE., 2019. Indoor household particulate matter measurements using a network of low-cost sensors. Aerosol and Air Quality Research, 20(2), p.381-394.

28 WHO, 2010. WHO guidelines for indoor air quality. Selected pollutants. ISBN 9789289002141

29 Ministêre de L'Écoologie, du Développement Durable, des Transports et du LogementDécret nº 2011-1727 du 2 Décembre 2011 relatif aux valeurs-guides pour l'air intérieur pour le formaldéhyde et le benzène

30 Van den Broek J., Klein Cerrejon D., Pratsinis SE., Guntner AT., 2020. Selective formaldehyde detection at ppb in indoor air with a portable sensor. Journal of Hazardous Materials, 399.

Along these lines, the R value has been developed, trying to translate data from total VOC measurements into potential human health risks. The R value normalises each individual VOC concentration against a specific LCI (Lowest Concentration of Interest) value for that individual VOC. This creates a coefficient for each VOC and, when coefficients for individually identified VOCs in the same sample are totalled together, the overall R value can be generated. An R value >1 would then suggest that the VOC content in indoor air is a concern for human health impacts.

L3.2. Step 1: Post occupancy surveys, design of questions

Indoor air quality (IAQ) is part of the broader concept of indoor environmental quality, which also encompasses other aspects such as thermal comfort, lighting and noise. In a real-life situation, it is unlikely that any survey exercise would just focus on one of these aspects and not on others.

While many aspects of indoor air quality can be physically measured, whether or not these measurements correlate with occupant satisfaction will depend on the subjective perception of occupants.

Since the purpose of building design and of building system operation is to provide a satisfactory living or working space for occupants, surveys are highly relevant for Level 3 reporting.

ISO 28802[31] presents some basic principles for carrying out a survey relating to perceptions of the indoor environment. The survey should start with some general questions about the overall indoor environmental quality (i.e. IAQ, thermal comfort, lighting and noise combined). These general questions should make it clear that they refer to the combined perception of all of these factors (and possibly more). Any relevant underlying health conditions (in this case, asthma is an obvious one) could also be clarified in the general questions.

Questions specifically about indoor air quality should contain the following elements:

- Demographic information about the respondent (e.g. age group, gender, experience, core activity in the building, location of workstation, shift patterns etc.). If the survey is supposed to be anonymous, then only very limited demographic information should be requested.
- A closed question with limited answers about how they find the indoor air quality "*now*" (i.e. at the moment of responding to the questionnaire). Possible answers could be "*very smelly*", "*smelly*", "*slightly smelly*" and "*not smelly*".
- An open question about specific sources of pollution that negatively affect perception of air quality "*now*".
- A closed question about their general satisfaction with air quality, when only two answers are possible, one positive and one negative.
- An open question about sources of pollution from any sources that they have found to cause an adverse effect on indoor air quality in other parts of the building and during other moments.

The options for answers mean that neutral responses are not going to occur. The closest to a neutral answer can be a blank response to open questions. However, depending on how the open question is worded, a blank answer could also be considered as a positive sentiment (e.g. nothing specific or general to complain about in their own words).

The importance of gathering demographic data for respondents will help identify any possible bias in answers towards one type of sentiment (e.g. it would be worth knowing if the split between "satisfied/unsatisfied" is the same for staff on the ground floor as on the top floor. Any concentration of unsatisfied responses could help pinpoint problem areas that could be subject to repair or renovation activities for the ventilation system or simply to changing the ventilation rates in those areas.

[31] ISO 28802: Ergonomics of the physical environment – Assessment of environments by means of an environmental survey involving physical measurements of the environment and subjective responses of people.