REHVA
Federation of European Heating, Ventilation and Air Conditioning Associations

Model Indoor Environmental Quality regulation aligning with new provisions of the 2024 EPBD recast

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Model Indoor Environmental Quality regulation aligning with new provisions of the 2024 EPBD recast

The 2024 recast of the Energy Performance of Buildings Directive (EPBD) introduces new provisions for indoor environmental quality (IEQ) which implementation in national regulations may require substantial effort. These include:

- **New definition for IEQ** in Article 2(66) according to which a minimum scope of IEQ addresses thermal comfort and ventilation/indoor air quality domains.
- New principle of **optimal indoor environmental quality**. When setting minimum energy performance requirements, Article 5 states that "those requirements shall take account of optimal indoor environmental quality, in order to avoid possible negative effects such as inadequate ventilation…". Revised Articles 7 and 8 for new and existing buildings stress IEQ for both new buildings and major renovations by stating that the issues of optimal indoor environmental quality shall be addressed.
- Article 13 calls to establish national IEQ requirements: "Member States shall set requirements for the implementation of **adequate indoor environmental quality standards** in buildings in order **to maintain a healthy indoor climate**." These requirements may be referred when recommendations to improve IEQ are provided in EPC-s which is new provision in Article 19(5).
- Article 13 also requires that new non-residential ZEBs must be equipped with **IAQ monitoring and regulation** devices.
- Article 19 requires that the **energy performance certificates** include recommendations for the improvement of IEQ.

To support harmonised national implementation, a model regulatory text has been developed from EPBD provisions and by setting requirements with measurable indicators outlined in Level(s), the European framework for sustainable buildings[1]. Level(s) defines IEQ indicators in User Manual 3, under Macro-Objective 4: Healthy and comfortable spaces, with indicators 4.1 to 4.4 for IAQ, thermal comfort, lighting and acoustics. Regarding to numeric values, Level(s) 4.1[2] IAQ and 4.2[3] thermal comfort indicators refer to EN 16798-1:2019, and some other relevant standards are also utilised.

Proposed text is expected to serve as a practical example of evidence based IEQ useful minimum implementation. All numeric values included serve as examples, following the Commission guidance[4] recommendation to use Category II specified in EN 16798-1:2019 (medium occupant expectation), whose values ensure avoiding adverse health effects, and comfort and well-being of occupants.

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[1] https://environment.ec.europa.eu/topics/circular-economy/levels_en

[2] Dodd N., Donatello S. & Cordella.M., 2021. Level(s) indicator 4.1: Indoor air quality user manual: introductory briefing, instructions and guidance (Publication version 1.1)

[3] Dodd N., Donatello S., & Cordella M., 2021. Level(s) indicator 4.2: Time outside of thermal comfort range user manual: introductory briefing, instructions and guidance (Publication version 1.1)

[4] Draft guidance, Article 13, 23, 24, Technical Building Systems, Indoor Environmental Quality and Inspections, European Commision November 2024

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Model Indoor Environmental Quality regulation

1. Subject matter

1.1 This model regulation specifies minimum requirements for thermal comfort, indoor air quality (IAQ) and noise from building services compliant with 2024 EPBD for new buildings and major renovations with necessary considerations for residential and non-residential buildings.

1.2 Requirements apply for design and operation of buildings, including monitoring and long-term assessment of indoor conditions.

1.3 Commissioning of technical buildings systems which includes test procedures and measurement methods to hand over, and regular inspection of heating, ventilation and air conditioning systems are not included in this document.

1.4 Indoor environmental quality (IEQ) requirements follow the EPBD minimum scope that is limited to thermal comfort and IAQ. Lighting and acoustics, other than the noise of building services, are not included in this document.

2. Definitions

2.1 'indoor environmental quality[5]' means the result of an assessment of the conditions inside a building that influence the health and wellbeing of its occupants, based upon parameters such as those relating to the temperature, humidity, ventilation rate and presence of contaminants.

3. Design values and requirements for thermal comfort

3.1 In continuously occupied spaces general thermal comfort shall be maintained and local thermal discomfort avoided.

3.2 Room temperature[7] comfort ranges for sedentary activities (1.2 met) specified in Table 1 shall be maintained in the occupied zone[6].

Table 1. Room temperature[7] acceptable comfort ranges in the occupied zone[8].

Building Category	Heating season, (1.0 clo) °C	Cooling season, (0.5 clo) °C
Non-residential buildings	20.0 - 24.0	23.0 - 26.0
Residential buildings	20.0 - 25.0	22.0 - 26.0

[5] EPBD Article 2(66)

[6] Occupied zone may be defined as in EN 16798-3

[7] In EN 16798-1:2019 room temperature is specified as operative temperature that is calculated as the weighted average of the air temperature and the mean radiant temperature. The weighting coefficients are the convective and radiative heat transfer coefficients, respectively.

[8] Values are from IEQ category II of EN 16798-1:2019 that is default category for new buildings. They should be applied together with design outdoor temperature and a weather file for indoor climate and energy simulations which typically already exist.

3.3 The values for dimensioning of the heating system shall be the lower values of the comfort range during heating season (Table 1) and values for dimensioning cooling systems shall be the upper values of the comfort range during cooling season.

3.4 Heating season is defined when the outside running mean temperature is below 10 °C and cooling season when it is above 15 °C. Between 10 °C and 15 °C running mean temperature, room temperature may lie in between the lower heating season and the higher cooling season value.

3.5 To avoid local thermal discomfort[9], draught[10], radiant temperature asymmetry, vertical air temperature difference and floor surface temperature shall be considered when designing buildings and HVAC systems.

3.6 Long term performance of a building to maintain room temperatures in the range specified in Table 1 during occupancy[11] can be evaluated with dynamic temperature simulations. Temperature simulations are not necessary in the case of heating and cooling systems where temperature control is implemented with room thermostats and heating and cooling powers are sufficient. For other systems, and particularly when using building thermal mass as a capacity to react to external signals[12], acceptable deviation from the specified range in Table 1 is maximum 5% of the occupancy time. In residential buildings, 150 Kh (Kelvin hours) above 26 °C is an acceptable excess[13].

4. Design values and requirements for indoor air quality

4.1 General

4.1.1 Indoor air quality shall be controlled by source control (pollutant sources), ventilation, and filtration of outdoor air where relevant.

4.1.2 Source control must be applied for pollutants emitted from building materials and interior design through the use of low polluting building materials[14], and with the use of local exhausts where relevant.

4.1.3 To maintain an acceptable level of pollutants in the indoor environment, minimum outdoor air ventilation requirements given in 4.2 and 4.3 shall be used to dimension the ventilation system.

4.1.4 To control the entry of outdoor particulate matter, outdoor air filters[15] in the ventilation system may be used. In zones where outdoor air intake without outdoor air filters is used, the particulate matter PM2.5 cannot be higher[16] than 10 μg/m³.

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[9] For more detailed specification, see Table A.3 and B.3 in EN 16798-1:2019.

[10] Draught rate or corresponding local mean air velocity is one of the most important parameters in ventilation and air conditioning systems design. Target values are specified in ISO 7730:2005.

[11] Occupancy schedules are usually specified in energy regulation. They are also available in EN 16798-1:2019 Annex C.

[12] EPBD Article 11(1)

[13] National weather files should be available for temperature simulations. Typical meteorological year or more severe climate may be used. For instance, an hourly values of 28.3 °C and 27.4 °C provide 3.7 Kh.

[14] Low polluting building materials are defined in EN 16798-1:2019. Values for very low-polluting materials can be used only in the case of labelled/certified materials.

[15] For non-residential buildings filters are specified in EN 16798-3. Adequate filters protect both the occupants and the ventilation equipment.

[16] At a higher concentration, outdoor openings must be closed and IAQ maintained with other ventilation or air cleaning measures. WHO Global Air Quality Guidelines 2021 specify PM2.5 thresholds as an annual mean of 5-10 μg/m³ and a 24-hour mean of 15-25 μg/m³.

4.2 Ventilation in non-residential buildings

4.2.1 In indoor spaces where the criteria for indoor environments are set by human occupancy and where the production or process does not have a significant impact on the indoor environment, the required outdoor air ventilation rate shall be calculated as follows:

$$q_s = Nq_p + A_R q_B \qquad (1)$$

where[17]

q_s design outdoor air ventilation rate, L/s (1 L/s = 3.6 m^3/h)

N design value for the number of persons in the room,

q_p ventilation rate for occupancy per person, 7 L/(s person)

A_R room floor area, m^2

q_B ventilation rate for emissions from building, default value 0.7 L/(s m^2) assuming low polluting materials. When very low-polluting building materials (certified by national material emission control/labelling systems) are used, q_B = 0.35 L/(s m^2).

4.2.2 In indoor spaces with other pollution sources, in addition to human occupancy and emissions from building, the sufficiency of ventilation rates provided by Equation 1 shall be checked and ventilation rates increased where relevant.

4.3 Ventilation in residential buildings

4.3.1 In residential buildings the total ventilation of a whole residence shall be at least 0.42 L/(s m^2) [18]. Room specific minimum ventilation requirements are given in Table 2.

Table 2. Minimum design airflow rates in residences[19].

	Supply airflow rate L/s	Extract airflow rate L/s
Living rooms[1] >15 m^2	8+0.27 L/(s·m^2)	
Master bedroom and bedrooms >15 m^2	14	
Living rooms and bedrooms 11-15 m^2	12	
Bedrooms <11 m^2, 3rd and successive bedrooms in large apartments	8	
WC		10
Bathroom		15
Bathroom in one room apartment		10
Utility room		8
Wardrobe and storage room		6
Kitchen[2]		8
Kitchen[2], one room apartment		6
Kitchen[3], cooker hood in operation		25
Average airflow rate of a whole residence L/(s m^2)	0.42	
Staircase of an apartment building, ACH	0.5	

[1] Transfer air from bedrooms can be used as a part of supply air but 12 L/s is minimum outdoor air rate
[2] Airflow rate in the kitchen when cooker hood is not in operation
[3] Fire regulations are to be followed

[17] Values of q_p and q_B are EN 16798-1:2019 IEQ category II values (default category for new buildings).

[18] EN 16798-1:2019 IEQ category II value. 0.42 L/s m^2 corresponds to 0.6 ach if the room height is 2.5 m.

[19] This table is from REHVA Guidebook 25, Residential heat recovery ventilation, REHVA 2018

4.3.2 The ventilation supply airflows to the bedrooms and living rooms are expressed in Table 2 as outdoor airflow rates which shall be supplied primarily to living rooms and bedrooms. The ventilation air for the kitchen and wet rooms such as bathrooms and toilets must be transfer air from the bedrooms and living rooms. Doors or specific openings must allow transfer air flows without significant pressure loss. From wet rooms extract airflows shall be used to remove pollutants and humidity.

5 Ventilation system requirements

5.1 General requirements

5.1.1 Ventilation system must be designed so that it enables to fulfil the requirements specified in chapter 4.

5.1.2 Ventilation system shall ensure air movement from rooms with higher air cleanliness to rooms with lower air cleanliness as specified in table 3.

Table 3. Classification of indoor air cleanliness and ventilation requirements in rooms.

Indoor air class	Pollution sources	Ventilation requirements	Room examples
1	Human occupancy and emissions from building materials.	Outdoor air according to Equation 1. Suitable for transfer air to corridors and to all rooms with extracts. Suitable for heat recovery and recirculation.	Offices, classrooms, living rooms, bedrooms and all other rooms without additional pollution sources.
2	Low intensity odours in addition to Class 1 pollution sources.	Outdoor air with airflow rates which may be higher than according to Equation 1. Suitable for heat recovery and for transfer air to Class 3 rooms. Cannot be used for recirculation.	Dining room, restaurant, café, dressing room, gym, fitness, sauna.
3	Processes, specific pollutants, humidity and intensive odours which are controlled with general ventilation.	Extract air, transfer air from Class 2 and 1 rooms and supply air if needed. Cannot be used for transfer air and recirculation air. Special requirements for heat recovery.	Toilet, bathroom, kitchens in apartments, assembly hall, laboratory, garage.
4	Pollution sources which will need local exhaust.	Local exhaust and general ventilation extract air. Cannot be used for transfer air and recirculation air. Special requirements for heat recovery.	Fume cupboard, local exhausts in laboratories and hot kitchens, rooms with chemicals, smoking room.

5.1.3 Air intakes shall be located where the outdoor air is less polluted.

5.1.4 Exhaust air shall be discharged from the building so that harmful effects in the building, to the adjacent buildings and to the occupants close to the building will not be caused.

5.1.5 To avoid cross contamination, minimum distances[20] shall be considered to find optimal locations for intake and exhaust openings.

5.2 Operation for optimal indoor air quality in non-residential buildings

5.2.1 Ventilation systems in non-residential buildings shall be controlled according to occupancy. Concentration of CO_2 can be used as a proxy for ventilation to operate ventilation system in between design and minimum ventilation rate.

5.2.2 Minimum ventilation rate shall be calculated with Equation 1 with no occupancy (n=0).

5.2.3 For CO_2 concentration setpoint[21] the total ventilation rate per person shall be calculated:

$$q_{sp} = \frac{q_s}{n} \tag{2}$$

where

q_{sp} total ventilation rate per person (L/(s person))

q_s design ventilation rate supplied by actual air distribution system, (L/s)

n number of the persons in the room corresponding to typical occupancy[22] (-)

5.2.4 CO_2 concentration setpoint above the outdoor CO_2 concentration shall be calculated from metabolic CO_2 generation and CO_2 volume balance:

$$C = \frac{q_{CO2}}{q_{sp}}\frac{1000}{3.6} \tag{3}$$

where

C CO_2 concentration setpoint value above the outdoor CO_2 concentration (ppm)

q_{CO2} CO_2 generation rate (L/(h person))

$\frac{1000}{3.6}$ 3600 and 10^6 are unit conversions from hour to second and litre to ppm

5.2.5 As an alternative to 5.2.3 and 5.2.4, the following fixed CO_2 concentration setpoint values above the outdoor CO_2 concentration may be used:

- 500 ppm in rooms where floor area is >6 m^2 per person;
- 600 ppm in classrooms;
- 800 ppm in other rooms where floor area is <3 m^2 per person.

[20] Minimum distances are specified in EN 16798-3.

[21] The procedure described in 5.2 is proposed in the ongoing revision of EN 16798-1 in CEN TC 156 WG 25.

[22] Energy calculation usage schedule values may be applied to design value for the number of persons in the room to estimate typical occupancy.

5.2.6 If ventilation is shut off for unoccupied periods, the system shall be switched on so that ventilation airflow volume corresponding to at least one volume of rooms will be delivered within 2 hours prior to occupation.

5.2.7 CO_2 setpoint values shall be used in the long-term assessment of CO_2 concentration with IAQ simulations. Acceptable deviation from these values shall be no more than 5% during occupancy hours.

5.3 Operation for optimal indoor air quality in residential buildings

5.3.1 Ventilation system shall be operated at constant air volume or as demand-controlled ventilation.

5.3.2 In the case of demand-controlled operation, ventilation system shall maintain specified IAQ and humidity levels. Ventilation system may be operated in between design, as given in 4.3, and minimum ventilation rate so that CO_2 in living rooms and bedrooms, and relative humidity in wet rooms are maintained at specified levels. Acceptable deviations may be assessed as specified in 5.2.7.

5.3.3 Minimum ventilation rate[23] shall be at least 0.15 L/(s m^2) of floor area.

5.3.4 Cooker hoods must be used in kitchens to remove cooking pollutants.

6 IAQ monitoring and regulation equipment[24] in non-residential buildings

6.1 New non-residential buildings shall be equipped with measuring and control devices as a part of a demand-controlled ventilation (DCV) system for the monitoring and regulation of IAQ.

6.2 New non-residential buildings shall be equipped with building automation and control systems[25] which provide monitoring of IAQ and temperature in continuously occupied spaces.

6.3 In major renovations 6.1 and 6.2 shall be followed as applicable.

6.4 IAQ regulation shall be applied at least in spaces that are intended for three or more persons.

6.5 IAQ regulation is not needed in spaces where ventilation requirements are determined predominately by extract air flow rates.

6.6 DCV systems should use sensors that can reliably measure parameters that are used for IAQ monitoring and regulation.

6.7 In DCV systems equipped with adequate outdoor air filters, CO_2 may be used as a parameter for IAQ monitoring and regulation. In zones where outdoor air intake without outdoor air filters is used, additionally the particulate matter PM2.5 shall be used for IAQ monitoring and regulation[26].

6.8 Monitored IAQ parameters shall be made visible in rooms for users, provided both by readings and traffic light colour type of indicators. They should also be available at least

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[23] Represents the air flow rate needed to deal with building materials emissions and humidity reduction. In residential buildings, ventilation systems have to function continuously and cannot be switched off during unoccupied periods.

[24] EPBD Article 13(5)

[25] EPBD Article 13(10). Note that article 13(9–12) provide other building automation and control requirements for systems performance and automatic lighting controls which can be addressed in energy regulation.

[26] When PM2.5 is reaching the setpoint, measures to control PM2.5 should be applied. These may include closing the outdoor openings, activating mechanical ventilation and/or air cleaning.

with hourly resolution for last 12 months in building automation and control systems for long term performance assessment and maintenance support purposes.

7 Noise from building service equipment

7.1 Building service equipment including ventilation, heating and cooling systems shall not cause disturbing noise. Indoor noise due to building service systems at design conditions shall not exceed the values specified in Table 4.

Table 4. A-weighted equivalent continuous sound pressure level, normalized with respect to reverberation time, $L_{Aeq,nT}$ [dB(A)][27] for continuous sources.

Building	Type of space	Equivalent continuous sound level $L_{Aeq,nT}$ [dB(A)]
Residential	Living room	35
	Bedrooms	30
Places of assembly	Auditoriums	28
	Libraries	30
	Cinemas	28
	Museums	32
Commercial	Retail Stores	40
	Department stores, Supermarkets	45
Hospitals	Bedrooms	30
	Wards	36
	Operating theatres	40
Hotels	Hotel rooms	30
	Reception, Lobbies	35
Offices	Small offices	35
	Landscaped offices	40
	Conference rooms	35
Restaurants	Cafeterias	40
	Bars, Dining rooms	36
	Kitchens	50
Schools	Classrooms	34
	Gymnasiums	40
Sport	Covered sport facilities	40
General	Service rooms, Corridors	40
	Toilets	45

7.2 The values in Table 4 can be exceeded by maximum 5 dB (A) for a short-term period if the occupants can control the operation of the equipment.

[27] $L_{Aeq,nT}$ is defined in EN ISO 16032 and EN ISO 10052. Calculation methods and guidance for the evaluation of noise at the design stage is found in EN 12354–5.

8 Capacity to react to external signals and adapt energy use, generation or storage[28]

8.1 A capacity to react to external signals shall be implemented so that thermal comfort and IAQ are not compromised. Acceptable deviations may be assessed as specified in 3.6, 5.2.7 and 5.3.2.

[28] EPBD Article 11(1) and 13(11). Requirements on how buildings shall be react to external signals can be addressed in energy regulation.

1 IEQ parameters throughout the construction process

Indoor environmental quality covers four domains, namely indoor air quality (IAQ), thermal comfort, lighting, and acoustic. For the first two domains, the EPBD explicitly mandates to set minimum requirements in the national regulation or building code for new buildings and major renovations. It can be practical to set these requirements according to measurable indicators based on to those of the Level(s) framework. Level(s) is European framework for sustainable buildings[29], providing IEQ indicators in User Manual 3, under Macro-Objective 4: Healthy and comfortable spaces, where indicators 4.1 to 4.4 can be found for IAQ, thermal comfort, lighting and acoustics. Regarding to numeric values, Level(s) indicators 4.1[30] and 4.2[31] (IAQ and thermal comfort) refer to EN 16798-1:2019 standard which uses Categories I to IV to describe IEQ level. As EPBD refers to 'healthy indoor climate' and 'optimal indoor environmental quality', it can be recommended to use the normal level of Category II specified in EN 16798-1:2019 which values will not only ensure avoiding adverse health effects but also ensure comfort and well-being of occupants.

When setting minimum requirements (design), conducting commissioning (handing over) and continuous monitoring in operation, and inspection (regular check), relevant IEQ parameters are different as illustrated in Table 5.

[29] https://environment.ec.europa.eu/topics/circular-economy/levels_en

[30] Dodd N., Donatello S. & Cordella.M., 2021. Level(s) indicator 4.1: Indoor air quality user manual: introductory briefing, instructions and guidance (Publication version 1.1)

[31] Dodd N., Donatello S., & Cordella M., 2021. Level(s) indicator 4.2: Time outside of thermal comfort range user manual: introductory briefing, instructions and guidance (Publication version 1.1)

Table 5. An example of most important IEQ parameters. Minimum requirements specify design targets which compliance can be assessed with commissioning procedures. IEQ and energy performance can be assessed with continuous monitoring and inspection.

		Design	Commissioning	Monitoring[1)]	Inspection	Comment
Thermal	Operative temperature	x				At representative points in the occupied zone to ensure occupant comfort
	Air velocity	x				At representative points in the occupied zone to ensure design and control of HVAC system for occupant comfort
	Air temperature			x		At 1.1 m above the floor in occupied zones
	Relative humidity			x		At 1.1 m above the floor in occupied zones
Acoustic	Sound pressure (A- and C-weighted)	x	x			Equivalent continuous sound pressure level (A- and C-weighted) at representative points in the occupied zone
	Sound reverberation time	x	x			Evaluation of noise at the design stage is found in EN 12354–5. Sound insulation parameters are not included in this document
Indoor air quality	Carbon dioxide	x		x		At 1.1 m above the floor in occupied zones, in the extract air
	PM2.5	x[2)]		x[3)]		At 1.1 m above the floor in occupied zones
	Formaldehyde				x	Near potential sources such as furniture and flooring
	Nitrogen dioxide				x	Near potential sources like kitchens and garages
	Carbon monoxide				x	Alarm sensors in buildings with combustion sources
	Radon	x			x	In the lowest occupied level of the building
	Ventilation rate	x	x		x	Outdoor airflow rate supplied and extracted from rooms, typically measured from supply and extract terminals
Light	Daylight provision	x				Daylight can be evaluated in accordance with EN 17037
	Glare probability	x				At workstations and near windows (EN 17037)
	Illuminance	x	x			The quality of lighting can be evaluated in accordance with EN 12464–1

1) *In addition to indoor values, monitoring of outdoor values for air temperature, humidity, CO_2 and PM2.5 is needed. The importance for IAQ is the difference of indoor-outdoor CO_2 and PM2.5.*
2) *For non-residential buildings filters are specified in EN 16798-3.*
3) *PM2.5 continuous monitoring is not needed if particulate matter is controlled with filters in ventilation system, and there is no significant infiltration through building envelope.*

2 Thermal comfort

Indoor environmental parameters for thermal comfort are specified in EN 16798-1:2019 standard. These include parameters for general thermal comfort and local thermal discomfort (draught, radiant temperature asymmetry, floor temperatures, vertical air temperature differences). The minimum requirements in the regulation shall include at least room temperature[32] ranges for sedentary activities (1.2 met). Requirements may be split between non-residential and residential buildings where higher adaptation is possible. An example is shown in Table 6.

Table 6. Room temperature requirements in the occupied zone, an example following Category II values.

Building Category	Heating season, (1.0 clo) °C	Cooling season, (0.5 clo) °C
Non-residential buildings	20.0 - 24.0	23.0 - 26.0
Residential buildings	20.0 - 25.0	22.0 - 26.0

Values in Table 6 serve to establish design values for dimensioning of heating and cooling systems. The lower value of heating season for the heating system and the upper value of cooling season for the cooling system shall be used. Heating season is defined when the outside running mean temperature is below 10 °C and cooling season when it is above 15 °C. Between 10 °C and 15 °C running mean temperature, room temperature may lie in between the heating and cooling season values.

Acceptable deviation from the specified range in Table 6 during occupancy is maximum 5% of the occupancy time. In residential buildings, an additional adaptation such as 150 Kh (Kelvin hours) above 26 °C may be used as acceptable excess.

3 Humidity

For relative humidity (RH) in buildings with no other humidity requirements than human occupancy (e.g. offices, schools and residential buildings), EN 16798-1:2019 states that humidification or dehumidification of room air is usually not required. Example of recommended design criteria for the humidity in occupied spaces are given if the humidification and dehumidification systems[33] are installed. This illustrates the complexity of regulating RH values because the humidity criteria depend on many factors: health, thermal comfort, indoor air quality, condensation, mould growth etc. Poor ventilation and excess humidity can create ideal conditions for microbial growth especially in kitchen and bathrooms as well on surfaces cooled by thermal bridges. Microbial growth, in turn, can provoke respiratory or allergenic health issues, while very low RH (< 20%) can cause irritation

[32] In EN 16798-1:2019 room temperature is specified as operative temperature that is calculated based on air temperature, mean radiant temperature and air velocity. In new and deeply renovated buildings, the operative temperature is almost equal to the air temperature.

[33] In the case of air conditioning systems with non-condensing room conditioning units (chilled beams, radiant panels) supply air in AHUs is typically dehumidified to avoid condensation in these units. This is system specific design requirement to ensure cooling capacity, not indoor climate requirement.

of the eyes, nose and throat[34]. It is also recommended to avoid RH below 20% because respiratory track and mucous membranes are then more sensitive to infections[35].

Thus, there are two possible options to deal with RH requirements, either not to set at all or to set a lower limit following Level(s) or EN 16798-1 values. The upper limit can be relevant in summer in southern humid climates where a requirement can be set following EN 16798-1 values. If requirements leading to humidification are used it should be noted that the humidifier itself can be a source of pollution (microbial and chemical) if not properly maintained. If the lower limit requirements of RH are set, they should be specified depending on the building category.

4 Indoor air quality (IAQ)

IAQ is affected by chemical, biological and physical hazards/parameters. Indoor air pollution originates from indoor and outdoor sources, and from the interaction of pollutants and oxidants from both of these[36]. Indoor sources are building materials or cleaning products emitting volatile organic compounds[37], and respiratory effluents and body odours emitted by humans themselves, but also combustion, cooking, products with fragrances and resuspending floor dust[38]. Outdoor sources are particulate matter and gas phase pollutants originating from transport, combustion and other processes. It has been shown that the most harmful contaminants in dwellings are PM2.5, PM10, NO_2, formaldehyde, radon, and ozone[39]. Good IAQ requires controlling of indoor emission sources and concurrently reducing the entry of outdoor pollutants indoors which can be done by filtering of outdoor air pollutants and reducing infiltration. The remaining pollutants indoors must be ventilated out. Multiple origin of indoor air pollutants makes IAQ monitoring complicated. Monitoring for all six pollutants included in WHO AQG[40] has shown to be infeasible because of the cost and complexity of compliance monitors to be deployed to all indoor spaces[41]. In addition to pollutants in WHO AQG many other harmful pollutants are common in the indoor air. Low-cost sensors for routine IAQ monitoring are available for CO_2, RH, particulate matter PM2.5, and CO that originates from combustion.

Direct measurement of all indoor air pollutants is impossible in practice because it generally requires sampling and subsequent chemical analysis. However, CO_2 concentration can be continuously monitored to inform about the adequacy of the ventilation rate which is an important factor for good IAQ. With PM2.5 monitoring it can be ensured that outdoor air for ventilation is clean or adequately filtered and indoor sources such as cooking are properly extracted. In the design of buildings, control of pollutant

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[34] Dodd N., Donatello S. & Cordella.M., 2021. Level(s) indicator 4.1: Indoor air quality user manual: introductory briefing, instructions and guidance (Publication version 1.1)

[35] Kurnitski J, Wargocki P, Aganovic A. Relative humidity effects on viruses and human responses. REHVA Journal, December 2021 https://www.rehva.eu/rehva-journal/chapter/relative-humidity-effects-on-viruses-and-human-responses

[36] Weschler, C. Chemistry in indoor environments: 20 years of research. Indoor Air 2011;21:205-218

[37] Harrison, P.; Crump, D.; Kephalopoulos, S.; Yu, C.; Däumling, C.; Rousselle, C. Harmonised regulation and labelling of product emissions–a new initiative by the european commission. Indoor and Built Environment 2011;20:581-583

[38] Qian, J.; Peccia, J.; Ferro, A.R. Walking-induced particle resuspension in indoor environments. Atmospheric Environment 2014;89:464-481

[39] Morantes, Giobertti and Jones, Benjamin and Molina, Constanza and Sherman, Max Howard, Harm from Indoor Air Contaminants. Available at SSRN: https://ssrn.com/abstract=4409736 or http://dx.doi.org/10.2139/ssrn.4409736

[40] WHO Global Air Quality Guidelines: particulate matter (PM2.5 and PM10), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide. World Health Organization. Geneva, Europe; 2021c

[41] Salthammer, T. TVOC-revisited. Environment International 2022:107440

sources and ventilation requirements must be applied for good IAQ. To control particulate matter from outdoor sources, air filtration requirements are also needed. The following minimum requirements can be recommended to be established to control IAQ:

1. Source control must be applied for pollution sources from building materials and interior design through the use of low polluting building materials as defined in EN 16798-1:2019, which means that the values for very low-polluting materials can be used only in the case of labelled/certified materials;
2. Ventilation rates to maintain an acceptable level of pollutants in the indoor environment are to be specified according to EN 16798-1:2019 requirements;
3. To control particulate matter, ventilation with filters is one way of meeting the requirements in areas where the WHO limits for outdoor air are exceeded. To be effective, building envelope needs to be airtight. For non-residential buildings filters are specified in EN 16798-3.

As EPBD requires in Article 13 the installation of measuring and control devices for the monitoring and regulation of IAQ in non-residential buildings this requirement shall be included in national regulation. This requirement means that minimum requirements of ventilation rates should be treated as design (nominal) ventilation rates. Regulation of IAQ means, that during operation, ventilation rates should be controlled according to occupancy to maintain CO_2 and temperature setpoints.

IAQ monitoring means continuous measuring of parameters in spaces designed for human occupancy, such as classrooms, offices, meeting rooms, restaurants, kitchens, shops, gyms, etc., at relevant unit level. It can be implemented with the capacity of integrated controls of ventilation devises, which include sensors in rooms, or through centralised Building Automation and Control Systems (BACS). BACS is particularly relevant for large buildings. The parameters to be monitored are CO_2, temperature and relative humidity. If outdoor air intakes without filters are used in the ventilation system, also PM2.5 needs to be monitored and to be used to control the operation of the ventilation system.

In residential buildings, monitoring and regulation of all IAQ parameters is not economically feasible. If the requirement is extended to cover residential buildings (EPBD does not require the monitoring and regulation of IAQ in residential buildings) it would be meaningful to monitor CO_2 in living rooms and bedrooms, and relative humidity in wet rooms such as toilets and bathrooms.

4.1 Indoor air quality and ventilation in non-residential buildings

To set ventilation airflow rate requirements as outdoor air flow rates, the first method (6.3.2.2 Method 1) in EN 16798-1:2019 based on perceived air quality can be used. This method is applicable to indoor spaces where the criteria for indoor environments are set by human occupancy and where the production or process does not have a significant impact on the indoor environment. In non-residential buildings, ventilation rates in occupied rooms are calculated based on perceived air quality by the visitors (unadapted persons) depending on the emissions from humans and building materials. The required outdoor air ventilation rate is:

$$q_{tot} = Nq_p + A_R q_B \qquad (4)$$

where

q_{tot} total outdoor air ventilation rate for the breathing zone, L/s (1 L/s = 3.6 m^3/h)

N design value for the number of persons in the room,

q_p ventilation rate for occupancy per person, 7 L/(s person)

A_R room floor area, m^2

q_B ventilation rate for emissions from building, default value 0.7 L/(s m^2) assuming low polluting materials. When very low-polluting building materials (certified by national material emission control/labelling systems) are used, q_B = 0.35 L/(s m^2), and in the case of non-low-polluting building materials q_B = 1.4 L/(s m^2).

Ventilation rate supplied by air distribution system deviating from fully mixing can be calculated:

$$q_s = \frac{q_{tot}}{\varepsilon_v} \qquad (5)$$

where

q_s design ventilation rate supplied by actual air distribution system, l/s

ε_v ventilation effectiveness as defined in EN 16798-3:2017 (contaminant removal effectiveness with distributed source), -

It should be noted that Equation 4 with provided L/s per person and L/s per floor area values can be set as ventilation requirement in the regulation, but the numeric values will depend on occupant density. Thus, it can be recommended to refer to standards or guidelines where default occupant density values can be found for straightforward and transparent application.

In the case of specific pollutants, the design ventilation rates shall be calculated based on a mass balance equation for the substance concentration in the space, considering the outdoor concentration (6.3.2.3 Method 2 using criteria for individual substances). This method is not discussed in this document because it is used only very rarely as the data on emission rate of pollutants is usually not available.

As an alternative to ventilation airflow rates, IAQ and ventilation requirements can be set with CO_2 values. Threshold CO_2 concentrations can be calculated with ventilation rates defined by Equation 4 and metabolic CO_2 generation (typically 20 L/(h person)) from CO_2 volume balance.

As these CO_2 concentration values depend considerably on the occupant density, it is an option to use in the regulation the following values where occupancy is fixed (absolute values, outdoor concentration 400 ppm):

- 900 ppm in rooms where floor area is >6 m^2 per person;
- 1000 ppm in classrooms;
- 1200 ppm in other rooms where floor area is <3 m^2 per person.

From these values, 900 ppm and occupant density >6 m^2 per person refers to typical offices. If occupant density is higher (i.e., <3 m^2 per person, that is the situation for instance in meeting rooms, auditoriums and restaurants), per floor area component in Equation 1 provides smaller addition to total airflow rate calculated per person, that increases CO_2

value. Classrooms belong to spaces with high occupant density (typically 2 m^2 per person), but the lower CO_2 generation rate of 18 L/(h person) reduces CO_2 value to 1000 ppm.

It should be noted that CO_2 values provided represent steady state (long term occupancy) and in the ventilation control, lower values must be used as setpoints because it takes some time while the concentration builds up. During occupied hours, minimum ventilation rate cannot be smaller than needed to remove emissions from building. These technical details should be provided either in regulatory or in technical guidance documents.

The above CO_2 values may be used also in the monitoring of IAQ by continuous measurement. In the assessment of compliance with IAQ requirements, acceptable deviation from these values shall be no more than 5% during occupancy hours.

4.2 Ventilation and IAQ in residential buildings

Ventilation requirements for residential buildings may be set by following B.3.2.2 in EN 16798-1:2019 which specifies 0.42 L/s m^2 (0.6 ach) total ventilation of a whole residence and 7 L/s per person supply air flow requirements. These general requirements are developed further in REHVA Guidebook GB 25, shown in Table 7. Typical number of occupants and are used, also distinction has been made between supply and extract air flow rates.

Table 7. Minimum airflow rates in residences.

	Supply airflow rate L/s	Extract airflow rate L/s
Living rooms[1] >15 m^2	8+0.27 L/(s·m^2)	
Master bedroom and bedrooms >15 m^2	14	
Living rooms and bedrooms 11-15 m^2	12	
Bedrooms <11 m^2, 3rd and successive bedrooms in large apartments	8	
WC		10
Bathroom		15
Bathroom in one room apartment		10
Utility room		8
Wardrobe and storage room		6
Kitchen[2]		8
Kitchen[2], one room apartment		6
Kitchen[3], cooker hood in operation		25
Average airflow rate of a whole residence L/(s m^2)	0.42	
Staircase of an apartment building, ACH	0.5	

[1] Transfer air from bedrooms can be used as a part of supply air but 12 L/s is minimum outdoor air rate
[2] Airflow rate in the kitchen when cooker hood is not in operation
[3] Requirements of fire regulations are to be followed

The ventilation supply airflows to the bedrooms and living rooms are expressed as an outdoor airflow rates which shall be supplied primarily to living rooms and bedrooms. The ventilation air for the kitchen, bathroom and toilet must be transfer air from the bedrooms and living rooms. Doors or specific openings must allow transfer air flows without significant pressure loss. From wet rooms extract airflows shall be used to remove pollutants and humidity.

In residential buildings, monitoring and regulation of all IAQ parameters is not economically feasible. The parameters that should be monitored and controlled are CO_2 in living rooms and bedrooms, and relative humidity in wet rooms[42]. Demand controlled ventilation systems regulating the air flow to maintain acceptable CO_2 and humidity levels are recommended. It is possible to locate CO_2 and relative humidity sensors in the rooms or alternatively, inside the ventilation unit or extract ductwork. The latter option enables to detect occupancy and for instance to operate ventilation unit in 'at home'/'out of the home' mode.

5 IAQ monitoring and regulation equipment

According to Article 13(5), Member States shall require the installation of measuring and control devices for the monitoring and regulation of IAQ in new and deeply renovated non-residential buildings and may promote this measure in residential buildings.

"Member States shall require non-residential zero-emission buildings to be equipped with measuring and control devices for the monitoring and regulation of indoor air quality. In existing non-residential buildings, the installation of such devices shall be required, where technically and economically feasible, when a building undergoes a major renovation. Member States may require the installation of such devices in residential buildings."

The aim of this article is to ensure the optimal operation of technical building systems to maintain IAQ with the lowest possible energy use by continuously adjusting ventilation airflow rates to correspond to the demand. Monitoring stresses the importance of being capable to follow the performance of technical buildings systems and to make IAQ visible for users.

5.1 Technical solutions for Article 13(5)

Article 13(5) calls to use a demand-controlled ventilation systems (DCV) that are capable to adjust the ventilation according to the IAQ needs. DCV systems can in principle be mechanical, hybrid or natural ventilation system equipped both with control and monitoring functions. "*equipped with measuring and control devices"* provides an indication that simple time schedule and switching the system on/off is not enough to fulfil Article 13(5) requirements, because even if such systems are complemented with measuring devices, they would not be capable to regulate IAQ on demand which will lead to not optimal IEQ. Importance of addressing optimal IEQ is stressed in EPBD Articles 5 and 7.

DCV technical solutions exist for a long time and have been offered as dedicated ventilation and air conditioning systems especially for non-residential buildings. Air handling unit, ventilation system components, control manufacturers, and to some extent BACS software and hardware providers offer components and software for these systems. Notwithstanding, these smart systems need also careful design, commissioning and maintenance to work properly that would be an important issue to consider when regulatory requirements will make these systems mandatory. To support regulation, technical guidelines and training should be made available to maintain good indoor climate conditions for occupants in buildings where ventilation supply and exhaust airflow rates are dynamically controlled depending on occupancy, pollution load and thermal load.

DCV systems may also be called variable air volume (VAV) systems, however VAV systems historically have been developed to increase the supply airflow to manage a cooling load in all-air type of ventilation and air conditioning system. Thus, the principal difference is that

[42] More guidance is provided in EN 15665 :2024.

DCV system reduces ventilation from nominal to less fresh air flow rates when IAQ sensors allow to do so.

Most of DCV systems are used together with hydronic or direct expansion (DX) heating and cooling. In this case the DCV control can solely focus to maintaining IAQ, while the dedicated heating and cooling systems can address thermal comfort. Furthermore, DCV systems often form a part of HVAC system, which uses hydronic or DX heating and cooling terminal units that may be combined with ventilation. For instance, active chilled beams and fan coils can provide ventilation, cooling and heating. If combined with radiant panels or passive chilled beams, ventilation will be organised with separate supply air devices. Hybrid ventilation system additionally include buoyancy or wind driven ventilation so that mechanical ventilation does not need to be operated when conditions are favourable for natural ventilation. In typical DCV systems, the airflow rate is based on occupancy and excess cooling/heating demand is mainly covered with hydronic or DX system. Compared to constant air volume (CAV) ventilation systems which operate all the time at nominal speed, DCV systems save considerable amounts of fan electricity as well as heating and cooling energy.

To be capable of regulating of indoor air quality as required by Article 13(5), ventilation airflow rates in DCV system should be controlled based on indoor air quality sensors. While direct measurement of IAQ is not possible with low-cost sensors, CO_2 sensors are commonly used as a proxy of IAQ. In small rooms with few persons, occupancy sensors detecting a presence of occupants are also commonly used for DCV control. In many systems, multisensors including also temperature are used to control ventilation and heating or cooling at the same time. Sensors make it possible to control supply airflow rates in zones or terminal units by modulating between minimum and maximum airflow rates, based on continuous or step control with specified airflow steps or on/off control with boost/normal airflow rates. Control of airflow rates in DCV systems can be designed for individual rooms, larger zones or specific modules in open areas like landscape offices. There are many technical solutions how the control can be implemented. For instance, DCV guidebook[43] lists six principal DCV control solutions typically used in non-residential buildings. These may be classified as pressure-independent and pressure-dependent systems with subcategories. One of the typical control principles is shown in Figure 1.

[43] SINTEF Research 24. Mads Mysen, Peter G. Schild and Axel Cablé, Demand-controlled ventilation requirements and commissioning, Guidebook on well-functioning and energy-optimal DCV. SINTEF Academic Press 2014.

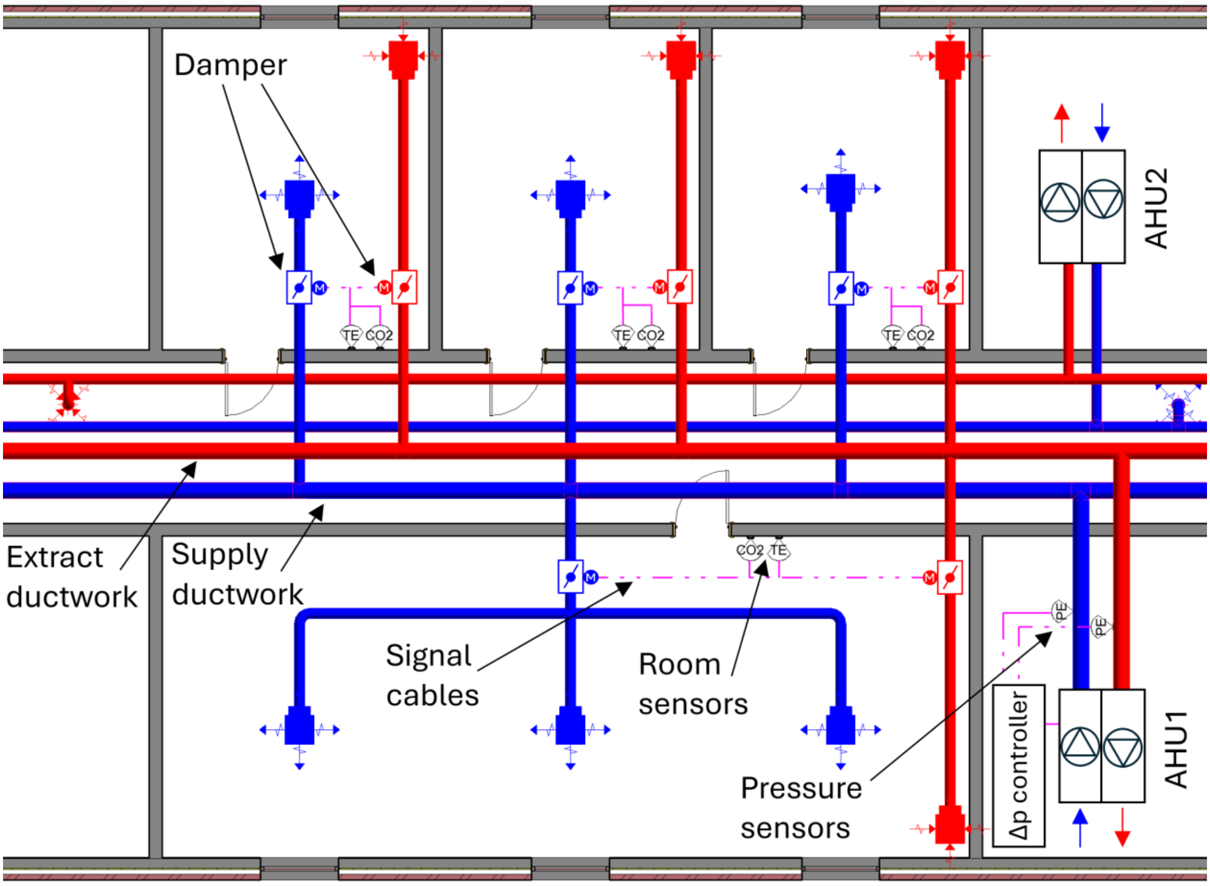

Figure 1. In pressure independent DCV system with the constant pressure control (AHU1), the fan speed is controlled to keep constant static pressure in the main ventilation duct, at the location of the pressure sensor. Dampers in each zone branch or diffuser adjust the air flow rates based on the room sensors CO_2 (and temperature) readings. Dampers may have continuous or stepwise control that should keep supply and extract air flows in balance with reasonable accuracy. AHU2 (CAV) with time control but not DCV serves toilets and corridors.

In DCV systems such as in Figure 1, supply air diffusers should manage a wide range of airflow rates so that air distribution patterns will not change too much, and draught will not be generated. For instance, active diffusers which have motorized parts for air throw length control can be used. Another option is to design the DCV system with on-off dampers so that all diffusers will have constant airflow rates. In such system the control will be less dedicated as based on switching on or off ductwork branches, Figure 2.

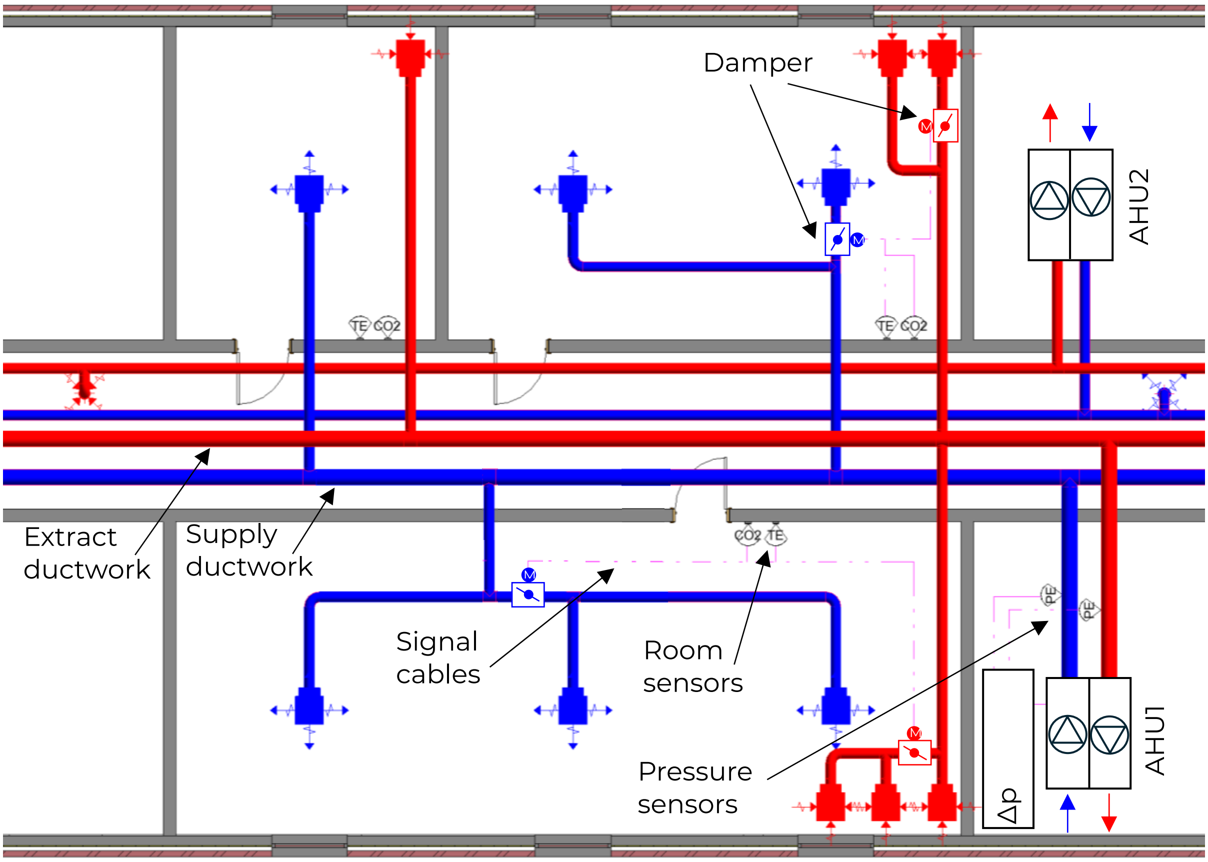

Figure 2. Pressure independent DCV system implemented with on-off dampers in larger rooms. Smaller rooms with one diffuser have constant airflow rates (CAV). Low-pressure design is recommended for main ducts that helps to keep a constant static pressure (AHU 1). The control itself is as robust as possible, room branch dampers are just opened or closed based on the local room sensors CO_2 and temperature readings. AHU2 (CAV) with time control but not DCV serves toilets and corridors.

5.2 DCV systems in residential buildings

DCV systems in apartment buildings can control ventilation airflow rates at the apartment level. This is typically done by switching to low airflow rate when the apartment is empty and by having boost airflow mode when the kitchen hood is used. Additional kitchen hood exhaust air should be properly balanced by controlling the supply airflow rate in the DCV system. In small apartments, this can be done by borrowing airflow rates from other apartments, but the balancing of airflow rates should be done carefully when several apartments are boosting at the same time. Similarly to non-residential buildings there are many DCV system configurations and control logics available in the markets. It should be noted that Article 13(5) is mandatory for non-residential buildings only. While ventilation system maintenance practices are typically less developed in residential buildings, the issue of potential residential DCV requirements should be carefully considered. It is evident that smart systems will need proper maintenance to work in practice.

5.3 Addressing Article 13(5) requirements in the regulation

To address Article 13(5) requirement on the regulation of IAQ, the following essential issues can be recommended to consider:

- To specify at which unit/zone level or in which space categories[44] DCV is required to ensure cost effectiveness of equipment
- To ensure that the sensors used in DCV systems are capable to maintain adequate IAQ
- To specify IAQ proxies limit values according to which DCV systems should be controlled and operated to ensure maintaining optimal IAQ

There are several possible options how these essential requirements can be implemented. From a regulatory point of view, technical implementation details of DCV control are not important, but what rather needs to be regulated is at which unit level IAQ monitoring and regulation should be applied. To be cost effective, each sensor, controller and damper/actuator shall operate with enough high airflow rate. This is evident in large spaces such as open plan offices, classrooms, meeting rooms, corridors, but not necessarily for instance in a small 10 m^2 single person office. In single person office, the airflow rate and savings from IAQ control are so small that CAV system may be relevant. Therefore, it can be recommended that regulation should determine space categories where IAQ monitoring and regulation is required. For instance, it may be reasonable to specify that IAQ regulation is needed in spaces intended for three or more persons, or alternatively in rooms where supply airflow rates are higher than 50 L/s. Spaces where ventilation requirements are determined predominantly by extract air flow rates (toilets, other wet and special rooms) should be left out from IAQ regulation requirement. It is also possible to leave more flexibility to be decided in the design just by specifying that IAQ regulation is needed at relevant unit level.

Another important question is that DCV systems must be sensitive enough and capable to react to changes in IAQ. It is essential that regulation specifies threshold values for CO_2 concentration. This allows to set technology neutral requirement mandating that DCV systems should use sensors which can reliably measure IAQ parameters for which minimum requirements are established in the regulation. In such a case, technical guidance documents can further provide recommendations which sensor types are suitable for which space categories. The most robust sensors commonly used in practice are room air CO_2 and occupancy (motion) sensors. VOC sensors which are typically metal oxide sensors measuring some ranges of VOCs have also been used but the accuracy as a CO_2 predictor is not well documented. These sensors may also perform in practice as an occupancy detector that may not be optimal in all spaces. While sensors develop continuously, a technology neutral and performance-based regulation would be a preferred option compared to the list of acceptable sensor types. All sensors need re-commissioning and calibration. It can be recommended that the accuracy of CO_2 sensors is tested in re-commissioning by using additional reference sensor for comparison and to find malfunctioning sensors.

If a DCV system is equipped with adequate outdoor air filters, CO_2 as a parameter can be seen enough for IAQ monitoring and regulation. In the case of the hybrid/natural operation modes, particulate matter indoors can exceed limit values, indicating a need for particle filtering. In such systems IAQ monitoring and regulation should include PM2.5 sensors. When PM2.5 limit value is exceeded, system operation mode can be changed so that it starts to use outdoor air filters or air cleaners in the rooms may be activated.

Article 13(5) includes IAQ monitoring requirement. Monitoring is important to make IAQ visible for users for which purpose a traffic light scale can be used to explain the meaning of readings. Another aspect is that well implemented monitoring can indicate and lead

[44] Some examples are listed in Tables B.3 and B.4 of EN ISO 52000-1.

attention to possible problems in DCV system operation. Monitoring is also important to ensure the proper enforcement of IAQ regulations and will allow to know if requirements are complied with.

For IAQ monitoring requirement it may be recommended that monitored IAQ parameters should be made visible in rooms, provided both by readings and traffic light colours. They should also be available in BACS for long term performance assessment, maintenance support and fault detection purposes.

5.4 Commissioning and inspection

DCV system have been used for a long time, but so are many problems reported from real buildings. DCV systems are obviously more complex, they need more knowledge and include more sensors and actuators than ventilation systems with constant airflow rate. It has been reported that there is not enough knowledge and skills of installation and maintenance staff to manage these systems. Problems have appeared at all stages of the building process: design, installation, commissioning and operation[45]. It has been common that the commissioning of DCV system was not properly done, and ventilation airflow rates did not match the design values. If actuators and control sensors are installed in the wrong places and some electrical and data cables are not connected, the system evidently cannot operate properly. To ensure reliable and well-performing DCV systems the following items are to be considered:

- Proper design with updated and building-specific documents;
- Commissioning tests must be conducted before the building is occupied/handed over;
- Well-designed utilization of BACS for continuous monitoring;
- Regular inspections and retro-commissioning.

It may be expected that when taken more widely into use, DCV system solutions itself will be developed by manufacturers to be more robust and reliable, and skills will develop too. Depending on national situation with ventilation systems design, installation and maintenance practices, some actions beyond regulatory requirements may be needed to ensure quality and proper operation. It can be recommended to make available a guidance for thorough commissioning test procedures of DCV systems; one good example successfully tested in practice is a SINTEF procedure[46]. The main difference compared with the commissioning of the ventilation system with constant airflow rates, including a test of only one operation mode, is to test typical operating modes of the DCV system and the need to consider different control zones in parallel.

Inspection issues are dealt in EPBD Articles 23-25. So far very few countries have implemented regular inspection schemes for ventilation systems. One example is Sweden with mandatory regular ventilation system inspections[47] and significantly fewer reported problems with DCV systems. This would be one important action to be considered also in other countries with a specific focus on the inspection of DCV system operation.

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[45] Demand Controlled Ventilation – Current situation, challenges, and needed remedies, Nordic Ventilation Group 3.3.2023. http://www.scanvac.eu/demand-controlled-ventilation.html

[46] SINTEF Research 24. Mads Mysen, Peter G. Schild and Axel Cablé, Demand-controlled ventilation requirements and commissioning, Guidebook on well-functioning and energy-optimal DCV. SINTEF Academic Press 2014.

[47] OVK – Obligatory Ventilation Control https://www.boverket.se/en/start/building-in-sweden/swedish-market/laws-and-regulations/national-regulations/obligatory-ventilation-control/

6 Building automation and control systems (BACS)

Control and automation are typically implemented so that technical building systems or system components have either an own control system or are controlled by BACS. In the case of an own control system typical for AHUs, heat pumps, chillers etc. these control systems are still connected to BACS so that the main parameters can be monitored, setpoints changed, runtime and other necessary control commands given through the BACS. In small housing units (single-family), control systems of the main system components such as heat pumps, ventilation and cooling units are often sufficient, and BACS systems seldom used.

EPBD specifies BACS requirements in Article 13(9–12). Also, the ZEB requirement to have a capacity to react to external signals in Article 11(1) can be implemented with technical solutions which are controlled through BACS or some other service. BACS requirements include many system performance and energy efficiency requirements which are suitable to be addressed for instance in energy regulation and are not dealt in this document focusing to IEQ.

Article 13(9) provides a requirement of monitoring of indoor environmental quality by 29 May 2026 that is closely connected with the equipment dealt in section 5. This requirement may be addressed by requiring that new non-residential buildings shall be equipped with building automation and control systems which provide monitoring of IAQ and temperature in continuously occupied spaces.

Article 13(12) requires to equip non-residential buildings with automatic lighting controls with specified deadlines. It is said that the automatic lighting controls shall be suitably zoned and capable of occupancy detection that provides flexibility for implementation. Lighting controls are well available in the markets and have been successfully used for a long time. Compared to IAQ regulation, lighting control represents much lower cost solution. Furthermore, the same sensors can be used for both systems. In continuously occupied spaces, dimmable lighting fixtures and controls utilising daylight is the most energy efficient solution. In rooms visited just occasionally, motion detectors (IR sensors) maybe a feasible solution.

7 Rating the smart readiness of buildings

The equipment described in section 5 and BACS will considerably impact the rating the smart readiness of buildings provided in EPBD Article 15. The Commission is preparing delegated acts on an optional common Union scheme for the smart readiness rating which will include the definition of the smart readiness indicator (SRI) and the assessment methodology as specified in EPBD Annex IV. By 30 June 2027 the Commission shall adopt an implementing act detailing the technical arrangements for the effective implementation of the application of the scheme in non-residential buildings with an effective rated output of over 290 kW. These developments will refine SRI technical framework that has been in voluntary use. Existing SRI methodology includes:

- The Smart Readiness Indicator (SRI) is assessed for a building (or building unit) capacity to meet **3 key functionalities**, further detailed into 7 impact criteria. *Particularly relevant in relation to EPBD Article 13(5):* ***Response to User Needs****, detailed into information to occupants, health, well-being and accessibility, convenience, and comfort.*
- The SRI calculation is based on the assessment of smart-ready services that are present or planned at design stage and those considered relevant for the building or unit. These

relevant services are included in a smart-ready service catalogue and are grouped into **9 technical domains**. *Particularly relevant in relation to EPBD Article 13(5): ventilation.*

- The calculation considers various functionality levels for each smart-ready service, and weighting factors are applied to aggregate the evaluation of all services.
- Member States have the prerogative to determine which technical domains are mandatory in the SRI assessment. They must also provide at least one smart-ready service catalogue, detailing the services included in the assessment. Additional catalogues may be created, for example, for different building types. Furthermore, Member States must define the respective weighting factors for the impact criteria and technical domains in relation to each impact criterion.
- To support national implementation, the European Commission has developed a **default technical framework** that includes a catalogue of smart-ready services, their corresponding functionality levels, and weighting factors. *For the ventilation technical domain, this include the following service groups: air flow control, air temperature control, free cooling, and information to occupants and facility managers.*

Figure 3 provides an example of smart readiness indicator SRI on ventilation depending on the air flow control referring to four control types specified in EN ISO 52120-1:2021.

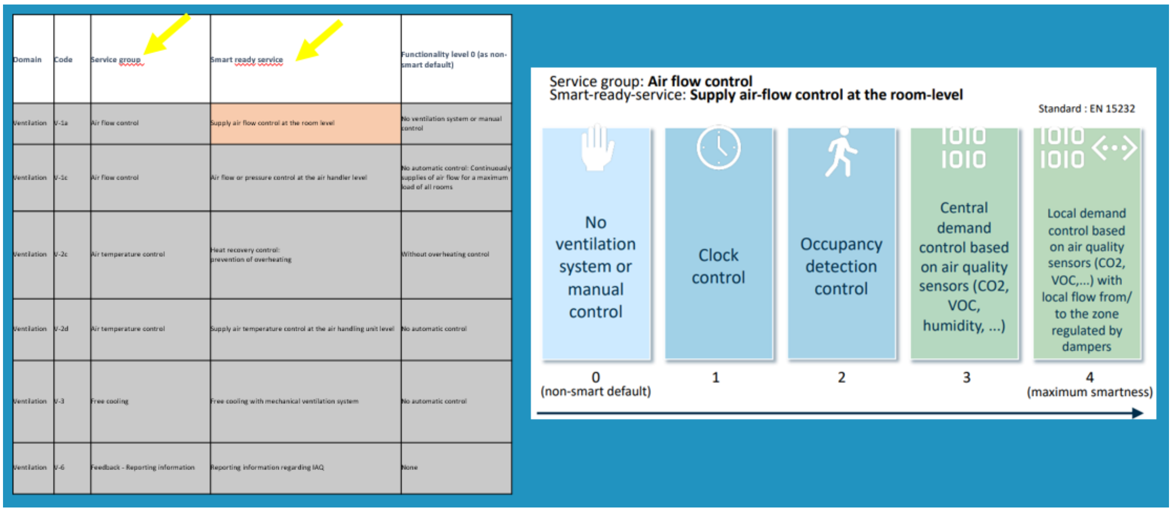

Figure 3. Smart readiness assessment of ventilation. IAQ monitoring and regulation equipment dealt in section 5 leads to the highest or close to the highest score.

8 IEQ rating and labelling

It is possible to make IEQ visible using indicators and scales that are similar to energy performance certificate scale. Four categories, thermal, IAQ, light and acoustics, are needed to cover IEQ and these cannot be combined, because for instance more light cannot compensate poor ventilation and vice versa. One possible IEQ rating and labelling scheme is TAIL[48] that was developed in EU ALDREN project. TAIL rating can be based either on measured or IEQ simulation[49] data. TAIL IAQ ranges are shown in Table 8. To measure TAIL indicators, a measurement protocol is provided, Table 9.

[48] TAIL, a new scheme for rating indoor environmental quality in offices and hotels undergoing deep energy renovation (EU ALDREN project) https://doi.org/10.1016/j.enbuild.2021.111029

[49] PredicTAIL, a prediction method for indoor environmental quality in buildings undergoing deep energy renovation based on the TAIL rating scheme https://doi.org/10.1016/j.enbuild.2022.111839

Table 8. Ranges of TAIL indoor air quality indicators.

Quality of indoor air quality (I)	Green TAIL rating	Yellow TAIL rating	Orange (TAIL rating	Red (TAIL rating)
Carbon dioxide (concentration above outdoors)[1,2]	≤550 ppm	≤800 ppm	≤1350 ppm	If other quality levels cannot be achieved
Ventilation rate[3,7]	≥(10 L/s/p + 2.0 L/s/m²floor)	≥(7 L/s/p + 1.4 L/s/m²floor) and <(10 L/s/p + 2.0 L/s/m²floor)	≥(4 L/s/p + 0.8 L/s/m²floor) and <(7 L/s/p + 1.4 L/s/m²floor)	If other quality levels cannot be achieved
Relative humidity offices[2,4] hotel rooms[2,4,5]	≥30% ≤50% ≥30% and ≤50%	≥25% ≤60% ≥25% and ≤60%	≥20% ≤70% ≥20% and ≤60%	If other quality levels cannot be achieved
Visible mold[6,7]	No visible mold	Minor moisture damage, minor areas with visible mold (< 400 cm²)	Damaged interior structural component, larger areas with visible mold (< 2500 cm²)	Large areas with visible mold (≥ 2500 cm²)
Benzene[7]	< 2 μg/m³	≥2 μg/m³	no criteria	≥ 5 μg/m³
Formaldehyde[7]	< 30 μg/m³	≥30 μg/m³	no criteria	≥ 100 μg/m³
Particles $PM_{2.5}$ (gravimetric)[7]	< 10 μg/m³	≥10 μg/m³	no criteria	≥ 25 μg/m³
Particles $PM_{2.5}$ (optical)	<10 μg/m³	≥10 μg/m³	no criteria	≥ 25 μg/m³
Radon[7,8]	< 100 Bq/m³	≥100 Bq/m³	no criteria	≥ 300 Bq/m³

[1] Outdoor CO_2 should be measured or assumed using https://www.co2.earth/
[2] To be classified in each quality level, the measurements shall not exceed the range defined by the indicated quality level and the subsequent quality level by no more than 5% of time, and the range defined by the subsequent quality level and the next lower quality level by no more than 1% of the time
[3] For non-low polluting buildings according to EN 16798-1 (2019) because no information on pollution load; the measured ventilation rates (average values of the two measurements) shall be compared with the nominal ventilation rate for that area according to design
[4] The levels match EN 16798-1 regarding humidification requirements
[5] The higher levels selected to avoid house dust mite infestation (survival and reproduction)
[6] According to Nordic classification system and Level(s); observations in the instrumented rooms should be supplemented by locations where the risk of mold is likely (e.g., using simulations of surface relative humidity)
[7] The permissible levels that cannot be exceeded
[8] Thirty-day average value measured in winter

Table 9. Measurement protocol of TAIL thermal and IAQ indicators.

Indicator	Measurements
Air temperature	Online measurements. Calibrated sensors with accuracy of at least 0.5 °C shall log temperatures. Measurement duration: one month. Time-interval: from 1 min to 10 min.
Ventilation rate	Two measurements shall be performed at the onset and towards the end of continuous measurements carried out for other parameters in buildings with mechanical supply and/or exhaust. No measurements are to be performed in naturally ventilated buildings. Calibrated differential pressure meter or flow hood (capture hood) shall be used to measure airflow on all inlets and exhausts in the rooms selected for measurements.
Carbon dioxide concentration	Online measurements. Calibrated Fourier Transform infrared (FTIR) sensors with accuracy of at least ±50 ppm of reading shall log carbon dioxide. Measuring period from Monday to Friday in offices and 7 consecutive days in hotels. Time-interval: from 1 min to 10 min. An additional measurement of CO_2 concentration outdoors is recommended both in offices and hotels; else 400 ppm can be considered.
Formaldehyde concentration	Passive measurements from Monday to Friday in offices and 7 consecutive days in hotels. To be representative it is recommended (not compulsory) that measurements are carried out twice in the most critical periods of the year with respect to outdoor temperatures, i.e. in winter and in summer. In this case, the average concentration is used for the ranking. Measurements must comply with ISO 16000-4:2011 (Indoor air -- Part 4: Determination of formaldehyde -- Diffusive sampling method).
Particle ($PM_{2.5}$) concentration	Gravimetric (preferable) or measurements with calibrated optical counters shall be performed. Measurements must be performed from Monday to Friday in offices and 7 consecutive days in hotels. An additional measurement of outdoor concentration is recommended; the data from the nearby ambient air quality monitoring station can be used instead. To be representative it is recommended (not compulsory) that measurements are carried out twice in the most critical periods of the year with respect to outdoor temperatures, i.e. in winter and in summer. In this case, the average concentration is used for the ranking. Gravimetric measurements must comply with standard CEN - EN 12341:2014 (Ambient air - Standard gravimetric measurement method for the determination of the PM10 or PM2,5 mass concentration of suspended particulate matter).
Air relative humidity	Online measurements. Calibrated sensors with accuracy of at least 5% shall log indoor air relative humidity. Measuring one month in case of temperature monitoring with the same instrument, otherwise measurement period from Monday to Friday in offices and 7 consecutive days in hotels. Time-interval: from 1 min to 10 min. An additional measurement of outdoor relative humidity is recommended both in offices and hotels; the hourly data from the near ambient measuring station can be used instead.

TAIL rating scheme provides a label using traffic light colours for each IEQ category and the total IEQ rating that represents the lowest rating of any category, Figure 4. An ongoing EU

Smart Living EPC project[50] has further developed the labelling scale to follow the same A-G categories as used in energy performance certificates, Figure 5.

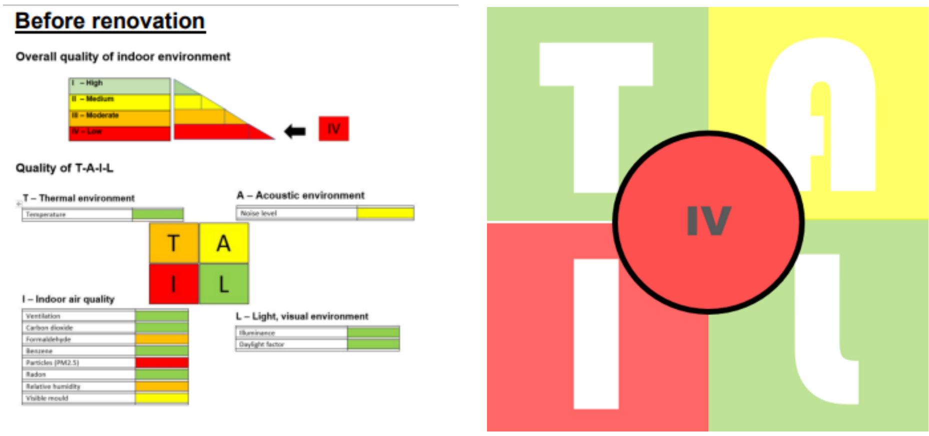

Figure 4. An example of TAIL rating. In this case, thermal and light are in the highest category I, acoustics in the moderate II and IAQ in the lowest category IV. The building rating follows the lowest rating of a single category and is in this case IV.

Classification \ Categories	Energy	Life Cycle Cost	IAQ	Thermal comfort	Virus risk	Occupancy feedback
A	☐	☐	☐	☐	☐	☐
B	☐	☐	☐	☐	☐	☐
C	☐	☐	☐	☐	☐	☑
D	☐	☐	☑	☐	☑	☐
E	☐	☐	☐	☑	☐	☐
F	☐	☐	☐	☐	☐	☐
G	☐	☐	☐	☐	☐	☐
OUTSIDE		☐	☐	☐	☐	☐

Figure 5. IEQ rating using EPC scale of A-G developed in EU Smart Living EPC project.

TAIL rating scheme provides recommendations for the improvement of indoor environmental quality that are required by Art 19 (5) in the energy performance certificate. An example of TAIL recommendations is shown in Table 10.

[50] https://www.smartlivingepc.eu/en

Table 10. An example of TAIL recommendations applicable for energy performance certificates.

TAIL component	Indicator	Possible influence of renovation operations
Thermal environment (T)	Air temperature	(1) Thermal rehabilitation (insulation) of an envelope, roof, ground floor, etc. (2) New low-energy windows (3) Installation of low-temperature heating and high-temperature cooling hydronic systems (4) Air-based cooling and heating systems (5) Improved control of heating/cooling systems (6) Installation of sunscreens
Acoustic environment (A)	Sound pressure level	(1) New windows (2) Tightening of the envelope and thermal rehabilitation of envelope
Indoor air quality (I)	Ventilation rate	(1) New ventilation system
	Carbon dioxide concentration	(1) New ventilation system (2) Tightening of the envelope
	Formaldehyde concentration	(1) New ventilation system (2) Tightening of the envelope (3) New materials

Colophon

This document was prepared by the Nordic Ventilation Group and REHVA Technology and Research Committee, EPBD Implementation Guidance Task Force, and was reviewed by Eurovent association.

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Nordic Ventilation Group

http://www.scanvac.eu

Nordic Ventilation Group is a group of academics sharing the same interest and concerns regarding the indoor climate and ventilation. The group works independently under the umbrella of SCANVAC. The objective of the Nordic Ventilation Group (NVG) is to develop ventilation technologies and services for good and healthy indoor environment with an energy efficient and environmentally friendly way. The work is 100% voluntary and free from commercial interest. Possible outcomes of the work can be published through various channels with the common agreement of the group.

REHVA, Federation of European Heating, Ventilation and Air Conditioning Associations

https://www.rehva.eu/

REHVA, founded in 1963, is a European professional federation that joins national associations of building services engineers. Today REHVA represents more than 120.000 HVAC designers, engineers, technicians, and experts from 26 European countries. REHVA is dedicated to the improvement of health, comfort, energy efficiency in all buildings and communities. REHVA provides its members with a platform for international networking and knowledge exchange, contributes to technical and professional development, follows EU policy developments, and represents the interests of its members in Europe and in the world. REHVA's mission is to promote energy efficient, safe and healthy technologies for mechanical services of buildings by disseminating knowledge among professionals and practitioners in Europe and beyond.

Eurovent, the European Industry Association

https://eurovent.eu/

Eurovent is Europe's Industry Association for Indoor Climate (HVAC), Process Cooling, and Food Cold Chain Technologies. Its members from throughout Europe represent more than 1.000 companies, the majority small and medium-sized manufacturers. Based on objective and verifiable data, these account for a combined annual turnover of more than 30bn EUR, employing around 150.000 people within the association's geographic area. This makes Eurovent one of the largest cross-regional industry committees of its kind. The organisation's activities are based on highly valued democratic decision-making principles, ensuring a level playing field for the entire industry independent from organisation sizes or membership fees.