Fachverband Gebäude-Klima e.V.

Status Report | 52

Requirements of ventilation and air cleanliness to reduce the risk of infection by airborne transmission

Protection rules + Ventilation

1. Introduction

The primary foundation of protection against infection by airborne transmission (droplets and aerosols) is currently based on rules governing social distancing, observing hygiene and wearing a mask. There is now a consensus that reducing the number of airborne germs through ventilation with outdoor air and/or effective air purification can also significantly reduce the risk of infection (protection rules +V). In this context, the +V for "Ventilation" has not yet been given a satisfying definition.

This FGK Status Report proposes a simplified evaluation procedure based on European standards for rooms in buildings, which is intended to be used for the documentation of compliance with +V criteria in a simple, pragmatic manner. Similarly, to the other protection rules, it is important that the focus remains on achieving the greatest possible use with an acceptable degree of effort (restrictions for people, cost-effectiveness, energy requirements).

For this reason, rules will also be defined for ventilation/air cleanliness that reduce the risk of Covid-19 infection. However, similar to the other measures, they cannot offer absolute protection.

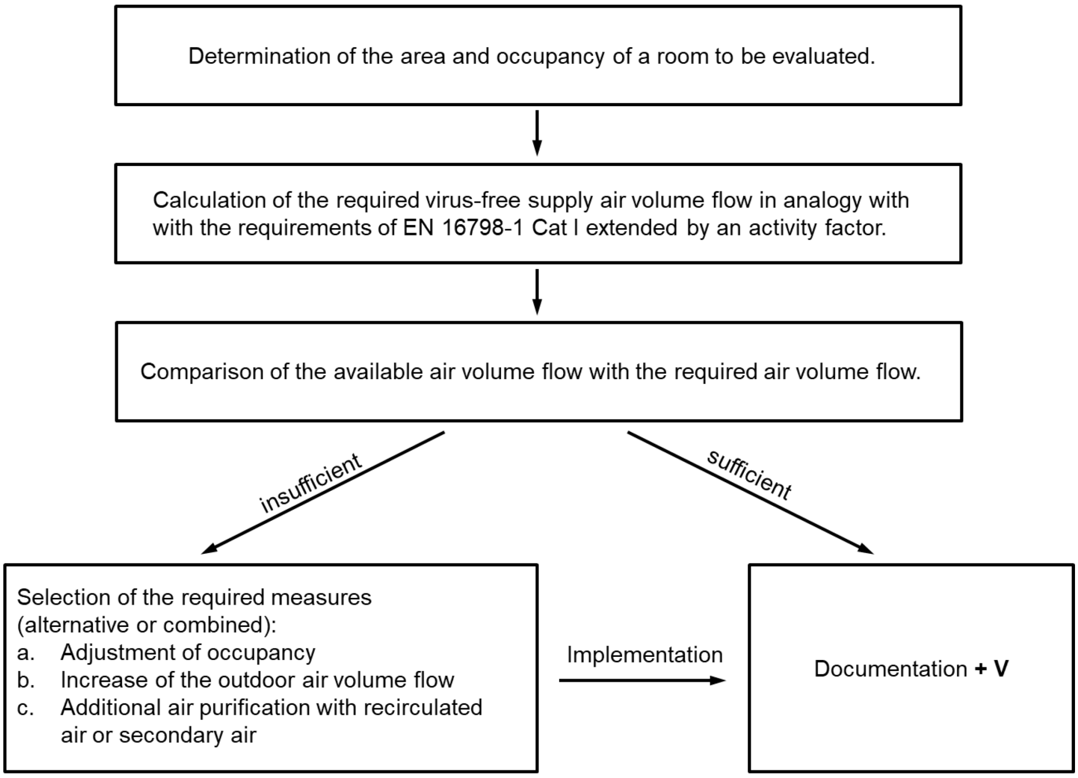
The rules described reflect the latest results of research, they are proportionate and established. Their task is to ensure existing ventilation recommendations, are user-friendly and capable of being implemented. They cannot replace individual risk analyses, but at best deliver individual components. In any case, these recommendations provide more effective evidence with regard to ventilation rates than the requirement to open windows for a certain period of time.

1.1. Objective of the procedure described

The simplified procedure described here enables evaluation of the protection against infection offered by air conditioning and ventilation systems, the aim being, to be able to continue to operate facilities with a hygiene concept, even during pandemic times, and without having to implement blanket closures. The verification process can be performed and documented by specialists in a clear and transparent way.

1.2. Brief description of the verification process

For verification of adequate ventilation **+V** in conjunction with possible aerosol transmission, the following method is proposed:



2. Nomenclature

2.1. Ventilation, outdoor air flow, fresh air flow rate

Air exchange with outdoor air, sometimes referred to as fresh air flow rate or external air flow rate.

2.2. Supply air

Prepared/treated air volume flow rate supplied to a zone. This volume flow rate can comprise various proportions of outdoor air, recirculation air and secondary air.

2.3. Recirculation air

Extract air supplied to the air treatment system from various rooms and reused as supply air for various rooms.

2.4. Secondary air

Airflow taken exclusively from one room and re-supplied to the same room after treatment.

3. Requirements for the ventilation

3.1. Outdoor air flow rates

The criteria are defined in accordance to EN 16798-1. CO_2 is assumed as a variable correlating to the aerosols emitted by people as a complete mixture (additional information on ventilation effectiveness in Section 5.2.).

To ensure adequate protection against infection by airborne transmission, the volume of virus-free air provided in the form of supply air should be equivalent to the volume of outdoor air that would be needed to keep the CO_2 values in occupied rooms under 800-1,000 ppm. In accordance with EN 16798-1, this corresponds to Category I rooms, i.e. the highest category for air quality.

The necessary outdoor air flow rate q_{tot} is calculated in accordance to EN 16798-1. This is supplemented by an activity factor f_{Act} as follows:

$$q_{tot} = (n \cdot q_P + A_R \cdot q_B) \cdot f_{Act}$$ (see also Table 1 or Table 2)

For an area larger than 20 m²/person, $q_B = 0$ should be used.

Table 1: Average occupancy of a seminar room produces the following outdoor air volume flow rates in Category I, II and III:

	Cat	No. of people	Area in m²	V m³/h per person	V m³/h per m² room	Activity factor	Outdoor air volume flow rate V m³/h	Room air change rate 1/h	**m³/h per person**
		n	A_R	q_P	q_B	f_{Act}	q_{tot}	$n = q_{tot}/(A_R \times 3m)$	q_{tot}/n
Seminar room	I	25	75	36	3.6	1.0	1,170	5.2	**47**
Seminar room	II	25	75	25	2.5	1.0	812	3.6	**33**
Seminar room	III	25	75	14	1.4	1.0	455	2	**18**

For moderate activity, a Category I outdoor air flow rate appears to be effective with respect to reducing the risk of infection.

A outdoor air flow rate of approx. 20 m³/h per person may never be undershoot, even when secondary air purification and filter units are used. This also applies under the general conditions created by opening windows. The indoor air quality (contaminants, odours, performance and perceived air quality), which is set to 20 m³/h per person per hour, is moderate and the absolute minimum. As a basic principle, higher outdoor air flow rates in accordance with applicable standards are recommended independently of infection protection.

3.2. Activity, aerosols and time dependence

The emission of aerosols is heavily dependent on breathing and vocal activity [2] and typically ranges between 50 (e.g. when breathing) and 1,000 P/s (when singing).

Increased physical activity also increases the CO_2 output of people. The outdoor air flow rates in accordance with EN 16798-1 are based on normal office work and do not take into account increased activity.

For this reason, a simplified activity factor f_{Act} is intended for rooms with increased physical or vocal activity (see 3.1.).

Table 2 Activity factors for various types of use

Activity factor in the room	Examples	f_{Act}
Moderate: People breathing normally (90 %) and only speaking occasionally (10 %),no increased physical activity	Shops, sales rooms, supermarkets, department stores	1
	Events, cinemas, theatres (spectators), theatres (foyer), conferences, trade fairs	
	Classrooms, auditoriums, lecture halls, seminars, kindergarten group rooms	
	Offices	
	Hotel bedrooms	
	Museums, exhibitions, libraries	
High: Most people speaking, physically active or breathing with increased frequency	Hairdressers, beauticians	1.3
	Restaurants, cafés, canteens	
	Conference rooms, meeting rooms	
	Gymnasiums	
	Fitness rooms, sports rooms, choir rooms	1.6
Typical room heights were partly taken into account using the activity factor.		

3.3. Secondary/recirculation air treatment

For infection protection in conjunction with Covid-19 aerosol transmission, it is irrelevant (under the condition that the minimum outdoor air volume flow rate is ensured, see Section 3.1.) whether outdoor air or purified recirculation air or secondary air is provided. For an equivalent analysis, however, recirculation air or secondary air must exhibit a purification effect of almost 100 % (> 99 %) with respect to active viruses or the size of particles with the highest penetration (MPPS, e.g. in accordance with EN 1822).

What is counted here is the total of outdoor air and purified air with a purification effect of min. 99 % (see above). If the purification/inactivation efficiency is lower, the airflow can be increased accordingly.

$$q_{V,tot,x\%} = q_{V,tot,100\%} / f_{Filter}$$

with:
- $q_{V,tot,100\%}$ Volume flow rate with an air purification effect based on the viruses/aerosols of approx. 100 %
- $q_{V,tot,x\%}$ Volume flow rate with an air purification effect based on viruses/aerosols of x %
- f_{Filter} Purification efficiency of the system based on active aerosols.

For example, the volume flow rate to be purified at a purification efficiency of 80 % increases 1.25-fold (1/0.8=1.25).

Here, it must also be taken into account that purified recirculation air or secondary air is not capable of reducing the CO_2 concentration or dissipating moisture-based or gaseous contaminants from rooms.

3.4. Method based on other procedures

More detailed designs based on scientific principles and other common standards and guidelines, e.g. to VDI 6040 (ventilation and air conditioning in schools – implementation instructions, VDI ventilation regulations, VDI school building guidelines) also fulfil **+V** if the devices and systems are dimensioned so that they never exceed a CO_2 concentration of 1,000 ppm in accordance with the respective guidelines. Corresponding purification efficiencies or transmission reductions are also demonstrated when the required minimum outdoor air flow rate is ensured.

4. Method +V verification

4.1. General conditions

The following specifications are suitable for documenting adequate ventilation, even in pandemic times, with **+V.**

- **DIN EN 16798-1 Cat I:**
  High air quality, recommended for rooms and use that should guarantee extensive ventilation with outdoor air, even in pandemic times. This category fulfils the relevant recommendations for hygiene, in pandemic times also (aerosol and droplet infection) **+V**.
- **DIN EN 16798-1 Cat II:**
  Normal air quality, recommended for rooms and for use that guarantees good air quality in normal use scenarios, but in pandemic times does **not fully meet** the relevant recommendations for hygiene in pandemics **without additional measures[1].**
- **DIN EN 16798-3 Cat III:**
  Acceptable air quality, recommended for rooms and for use that guarantees the minimum requirements of air quality in normal use scenarios, but in pandemic times does not fully meet the relevant recommendations for hygiene in pandemics **without additional measures[1].**

[1]**Additional measures** (individual or in combination):

1. Increase in the outdoor air flow rate of the ventilation and air conditioning system to achieve Category I -> **+V**.
2. **Reduction in occupancy density** to achieve Category I -> **+V**.
3. **Use additional secondary air purification systems**. With the right dimensioning, the occupancy density in Category II or III, if applicable, can be maintained -> **+V**.

The outdoor air flow rate of Category I that is calculated for use (taking into account the activity factor) is the benchmark for fulfilling the +V criterion for the ventilation system.

4.2. Adjustment of occupancy

To fulfil the +V criteria, the maximum occupancy density can always be reduced so that Cat I is achieved in accordance with DIN EN 16798-1. If this is not fully possible, additional measures can be implemented.

4.3. Secondary air purification systems

4.3.1. General requirements

For secondary air purification systems, there are still no binding standards and specifications. From today's perspective, the following systems appear to be suitable:

- Secondary air filter units with HEPA filters (H13 or H14).
- Secondary air purification units with UV-C.
- Various combinations of fine filters min. ePM 1 60 % (see also 3.3.).

Secondary air filter units must have the following basic characteristics:

- The purification method (with respect to viruses or their size) must be verified in the airflow for all devices (e.g. via tests or by the manufacturer's declaration in accordance with normative specifications (such as EN 1822 for particulate filters) and indicated for specific volume flow rates. Hazards must be excluded for users in the room for every technology.
- The electrical power consumption and the sound power level must also be specified for all devices for the specific volume flow rates. Here, the entire device (incl. the purification unit) and all installation space conditions must be taken into account.

- The sound level is the only variable that describes the noise characteristics of a unit independently of the room. Sound values must therefore always be specified as sound power as a minimum. Details on the sound pressure without additional room definition or with exclusive specification of a certain distance do not suffice as the only sound data.
- Air distribution must be designed so that the room is fully ventilated but without the use of the room being affected.

4.3.2. Consideration in the necessary outdoor air flow rate

Devices that fulfil the requirements in accordance with Section 4.3.1. can partly replace the necessary outdoor air flow rate, as long as a outdoor air flow rate of Cat II or III in accordance with DINEN 16798-1 is maintained (at any rate, min. 20 m^3/h per person).

Example of seminar room as above:

- Outdoor air flow rate 1,170 m^3/h or
- Outdoor air flow rate 455 m^3/h and secondary air flow rate 715 m^3/h

Combination of opening windows and the use of CO_2 measuring devices or ventilation lights, see Section 4.5.

4.4. Recirculation air in central ventilation and air conditioning systems

Recirculation air should be avoided as much as possible. Filtration of recirculation air can be carried out in a similar way to Section 4.3.1. and on a proportionate basis to fulfil the necessary volume flow rate, as long as the required outdoor air flow rate is fulfilled in accordance with Section 3.1.

4.5. Outdoor air flow rate when opening windows

The outdoor air flow rate that occurs when windows are manually opened cannot be quantifiably verified with simple methods and, more importantly, cannot be ensured all year round. For this reason, CO_2 measuring devices or measurement lights must be used. Observing the required ventilation rates to achieve 800-1,000 ppm CO_2 is always insufficient when there is no measuring unit and only a specification on how long the window is open. To ensure the required room air change rate under fluctuating general conditions (wind, thermal, opening time), a higher room air change rate must be accepted with the corresponding energy losses and comfort restrictions.

Secondary air purification units in accordance with 4.3.1. can also be combined with opening windows. The chargeable outdoor air flow rate in combination with CO_2 measurement is as follows:

- CO_2 concentration up to 800 ppm: allowance of a outdoor air flow rate according to Cat I
- CO_2 concentration up to 1,000 ppm: allowance of a outdoor air flow rate according to Cat II
- CO_2 concentration up to 1,500 ppm: allowance of a outdoor air flow rate according to Cat III
- Without CO_2 measurement or CO_2 concentration over 1,500 ppm, no allowance.

5. Plants

5.1. The factors of time and room volumes

As a general rule, the risk of infection increases the longer people spend in a room and the higher the number of emitting occupants [4][8]. The duration of occupancy is heavily dependent on organisational general conditions; it can change at short notice or it may not be observed. Consideration of all of these factors would go beyond the scope of this procedure and affect clarity, which is the reason it was omitted from this simplified procedure.

5.2. Ventilation effectiveness

Ventilation effectiveness ε_V describes the connection between the concentration of aerosols and air distribution in the room. However, this connection depends on a number of parameters, including source distribution, indoor airflow and thermals in the room. This is defined as follows in accordance with DIN EN 16798-3:

$$\varepsilon_V = (c_E - c_S) / (c_I - c_S)$$

ε_V: Ventilation effectiveness;

C_e: Contamination concentration of the extract air;

C_s: Contamination concentration of the supply air;

C_{ii}: Contamination concentration at breathing height.

The volume flow rates stipulated in DIN EN 16798-1 are based on a ventilation effectiveness of $\varepsilon_V = 1$. This value must always be used if the ventilation effectiveness cannot be verified for each design case (loads, temperatures, volume flow rates). If the ventilation effectiveness is known, then the most unfavorable case must be used for this verification (lowest ε_V value).

In accordance with EN 16798-3, the ventilation rate can be corrected as follows depending on the verified ventilation effectiveness:

$$q_{V,tot,\varepsilon V} = q_{V,tot} / \varepsilon_V$$

$q_{V,tot,\varepsilon V}$: Volume flow rate taking into account the verified ventilation effectiveness;

$q_{V,tot}$: Volume flow rate at $\varepsilon_V = 1$;

Note: Other instructions for ε_V are provided by CEN TR 16798-4.

6. Sources and further information

[1] FGK, BTGA, German Association of Air handling units Manufacturers: Operation of ventilation and air conditioning systems under the general conditions of the current Covid-19 pandemic 03.08.2020, Version 3.

[2] Anne Hartmann HRI, FGK Workshop 2020

[3] HRI Sample risk assessment for various day-to-day situations

[4] HRI Prof. Dr.-Ing. Martin Kriegel, 07.12.2020 (Version 4), Number of SARS-CoV-2-laden particles in room air and their inhaled quantity as well as assessment of the infection risk of contracting Covid-19

[5] Hartmann, A; Lange, J; Rotheudt, H; Kriegel, M; Emission rates and particle size of bio-aerosols when breathing, speaking and coughing, DOI: Online calculator: https://hri-pira.github.io

[6] Fitzner, K; Rietschel Volume 2: Room air and room cooling technology, ISBN 978-3-540-57011-016

[7] Kriegel, M; Buchholz, U; Gastmeier, P; Bischoff, P; Abdelgawad, I; Hartmann, A; Predicted Infection Risk for Aerosol Transmission of SARS-CoV-2; DOI: 10.1101/2020.10.08.20209106, Preprint

[8] D. Müller, K. Rewitz, D. Derwein, T. M. Burgholz, M. Schweiker, J. Bardey, P. Tappler, Assessment of the infection risk via aerosol-bound viruses in ventilated rooms, White Paper, RWTH-EBC2020-005, Aachen, 2020, DOI: 10.18154/RWTH-2020-11340
Online calculator http://risico.eonerc.rwth-aachen.de

[9] BTGA Practical guide for planning and operating ventilation and air conditioning systems with increased infection protection requirements,January 2021.

7. Examples

7.1. Seminar room or classroom

The following are examples for the procedures and variants for a seminar room or a classroom:

- Column 2: Initial state
- Column 3: Reducing the occupancy to 10 people does not lead to fulfilment of the +V criterion with the existing outdoor air volume flow rate.
- Column 4: An additional secondary air filter with min. 715 m^3/h leads to fulfilment of the +V criterion.
- Column 5: A strategy of opening windows to maximum 800 ppm with CO_2 measurement leads to fulfilment of the +V criterion (min. every 20 mins with windows wide open, draught problems and energy losses).
- Column 6: A strategy of opening windows to maximum 1,500 ppm with CO_2 measurement in combination with a secondary air filter with min. 715 m^3/h leads to fulfilment of the +V criterion.

(1)	(2)	(3)	(4)	(5)	(6)
	Initial state	**Reduce occupancy rate**	**Secondary air**	**Ventilation by opening windows**	**Windows + sec.**
Room usage	Seminar	Seminar	Seminar	Seminar	Seminar
No. of people	25	10	25	25	25
Area	75	75	75	75	75
Height	3	3	3	3	3
Room volume	225	225	225	225	225
Occupancy density m2/person	3.0	7.5	3.0	3.0	3.0
Typical occupancy density	3	3	3	3	3
Social distancing observed (informative)	1.5	1.5	1.5	1.5	1.5
Distance ^2	2.25	2.25	2.25	2.25	2.25
simplified via sq. area allocation	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
Required volume flow rate +V					
V Cat I	1170	630	1170	1170	1170
Supplement for activity	1	1	1	1	1
V + Ventilation	1170	630	1170	1170	1170
Room air change rate	5.2	2.8	5.2	5.2	5.2
Volume flow rate per person	46.8				
Chargeable volume flow rate as a result of opening windows					
CO2 measurement max.				800	1500
Chargeable volume flow rate				1170	455
Actual outdoor air flow rate from ventilation and air conditioning system					
Sizing m3/h per person	18.2				
Outdoor air flow rate from air conditioning and ventilation system	455	455	455	0	0
Chargeable outdoor air flow rate from window	0	0	0	1170	455
Total of chargeable outdoor air flow rate	455	455	455	1170	455
Min. purified volume flow rate for secondary air purification			**715**		**715**
Correction filter			H13 or H14		H13 or H14
			1		1
Min. secondary air filter with selected filter			**715**		**715**
Selected volume flow rate			750		800
+V observed	No	No	**Yes**	**Yes**	**Yes**

7.2. Office

The following is an example of the procedure and variants for an office room

- Column 2a: Initial state, sizing of the room according to DIN 16798-1 Cat I This room and the ventilation system meet the requirements of **+V**.
- Column 2b: Initial state. Same room as (2a) but sizing of ventilation system according to Cat II.This room and the ventilation system do not meet the requirements of +**V.**
- Column 3: Reducing the occupancy to 4 people leads to fulfilment of the +V criterion with the existing outdoor air flow rate.
- Column 4: An additional secondary air filter with min. 212 m^3/h leads to fulfilment of the +V criterion, even with the original occupancy of 10 people (2b).

(1)	(2a)	(2b)	(3)	(4)
	Initial state	**Initial state**	**Reduce occupancy rate**	**Secondary air**
Room usage	Open plan office	Open plan office	Open plan office	Open plan office
No. of people	10	10	4	10
Area	70	70	70 0	7
Height	3	3	3	3
Room volume	210	210	210	210
Occupancy density m2/person	7.0	7.0	17.5	7.0
Typical occupancy density	10	10	10	10
Social distancing observed (informative)	1.5	1.5	1.5	1.5
Distance ^2	2.25	2.25	2.25	2.25
simplified via sq. area allocation	**Yes**	**Yes**	**Yes**	**Yes**
Required volume flow rate +V				
V Cat I	612	612	396	612
Supplement for activity	1	1	1	1
V + Ventilation	612	612	396	612
Room air change rate	2.9	2.9	1.9	2.9
Volume flow rate per person	61.2	61.2		
Chargeable volume flow rate as a result of opening windows				
CO2 measurement max.				
Chargeable volume flow rate				
Actual outdoor air flow rate from ventilation and air conditioning system				
Sizing m3/h per person	65	40		
Outdoor air flow rate from air conditioning and ventilation system	650	400	400	400
Chargeable outdoor air flow rate from window	0	0	0	0
Total of chargeable outdoor air flow rate	650	400	400	400
Min. purified volume flow rate for secondary air purification				**212**
Correction filter				H13 or H14
				1
Min. secondary air filter with selected filter				**212**
Selected volume flow rate				250
+V observed	**Yes**	No	**Yes**	**Yes**

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