Risk assessment for internal spaces regarding aerosols loaded with virus

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Introduction:

Regarding the currently available knowledge, aerosols are one of the main transmission ways of SARS-CoV-2 [1]. During breathing, speaking and coughing every person emits particles [2], which are distributed with the air in the whole room. If one of the persons in the room is infected this aerosols may transport virus. With increasing time of stay in the room, the aerosols will be concentrated (see Figure 1) and reach critical values for an infection.

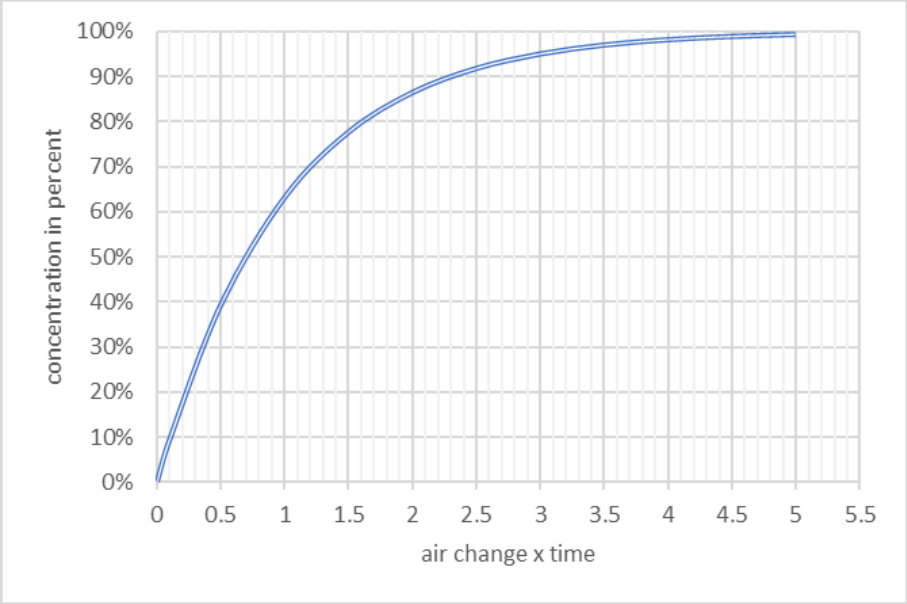

Figure 1: Relative concentration related with the air change and the time

Background and methods

It has been assumed, that an inhalation of 3,000 virus may lead to an infection [3]. If furthermore, it has been supposed that each aerosol carried one virus [4], it can be calculated how long persons may stay in a room with an infected person until they have inhaled 3,000 virus. Infection transmission via other mucous membranes (e.g. eyes) has not been taken into consideration.

Based on the known equations (1) and (2) for the calculation for concentration of contaminations in rooms under the influence of different air change rates an analytical risk assessment for different scenarios have been performed. For all equations it has been assumed that the contaminant have been evenly distributed in the room.

$$\Delta c_{unsteady} = \frac{Q - \dot{V}_a \cdot \Delta c_0}{\dot{V}_a} \cdot (1 - \mathrm{e}^{-nt}) \quad (1)$$

$$\Delta c_{steady} = \frac{Q}{\dot{V}_a} \quad (2)$$

with:
Δc…elevation of the concentration of the contaminant above the supply air
Q…released volume flow of contaminant in Partikel/h
$\dot{V}_a$…volume flow, which is supplied to the room in m³/h
Δc_0… concentration of contaminant above the outdoor level at time t=0
n…air change in 1/h ($n = \frac{\dot{V}_a}{V_R}$)
V_R…room volume in m³
t…time in h

It has to be kept in mind that depending on the way of air supply the concentration of the contaminant in the occupied zone may be higher or lower. A parameter to characterize this is the ventilation effectiveness, which estimated how good contaminants can be exhausted from the room air. The definition of the ventilation effectiveness can be seen in equation (3).

$$\varepsilon_{oz}^{c} = \frac{\Delta c_{exh}}{\Delta c_{oz}} \quad (3)$$

ε_{oz}^{c}…ventilation effectiveness in the occupied zone
Δc_{exh}…concentration of contaminant above outdoor level in the exhaust air
Δc_{oz}… concentration of contaminant above outdoor level in the occupied zone

For an ideal mixing ventilation, the ventilation effectiveness is therefore 1.0 (the concentration of contaminant is the same for every point in the room). Typical ranges for the ventilation effectiveness in other cases can be found in table 1.

Table 1: limits of the ventilation effectiveness

upper limit	∞	source of contamination directly next to the exhaust air outlet
ideal mixing ventilation	1	complete mixing in the room
lower limit	0	source of contamination in a recirculation area

To determine the number of inhaled virus equation (4) has been used.

$$c_{inhal.} = \int c_R \cdot \dot{V}_{inhal.} \quad (4)$$

The required volume flow for breathing, depending on the activity, can be found in table 2.

Table 2: required volume flow for breathing for different activities

Activity	degree of activity	required volume flow for breathing in m³/h
reading or writing	I	0.375
extremely easy physical activity (standing or sitting)	II	0.575
physical activity	III	0.75

If the concentration of virus in the room with just outdoor air supply has been investigated, it can be assumed that $c_{sup} = 0$. If equation (1) has been substituted into equation (4) equation (5) for the maximal time of stay can be established. For the following investigation a concentration limit of $c_{inhal.} = 3{,}000$ has been applied.

$$c_{inhal.,instationär} = \left(\frac{Q - \dot{V}_a \cdot \Delta c_0}{\dot{V}_a} t - \frac{Q - \dot{V}_a \cdot \Delta c_0}{n \cdot \dot{V}_a} \cdot (1 - \mathrm{e}^{-nt})\right) \cdot \dot{V}_{inhal} \quad (5)$$

Results of the analytical investigation

For the analytical investigation the following parameters have been varied:

- room volume: 30 m³ to 300 m³
- air change: 0.05 1/h to 4 1/h

Furthermore, it has been assumed that an infected person has entered the room at time t = 0 s and a normal speaking situation, e.g. in offices, with an emission rate of 300 P/s = 300 virus/s and a degree of activity I regarding table 2 has occurred. In addition, ideal mixing ventilation with a ventilation effectiveness of 1.0 has been presumed.
The results can be found in Figure 2.

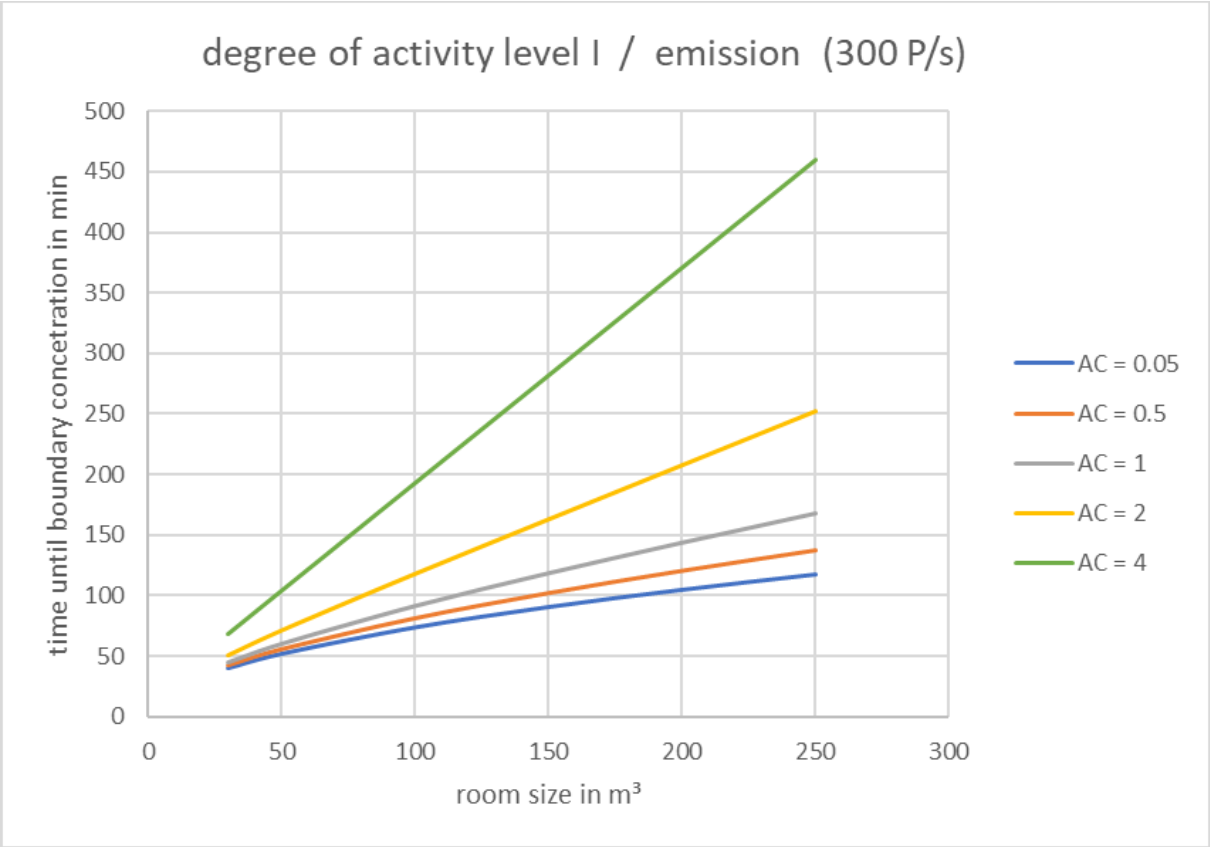

Figure 2: time in minutes until the number of inhaled virus exceeds 3,000 virus depending on the room volume and the air change

In Figure 2, it can be seen how long a healthy person together with an infected person could stay in a room until the critical number of 3,000 virus has been inhaled.
It is obvious, that for smaller rooms, smaller influence of the air change on the potential risk of infection can be found than for larger rooms. If a 2-person-office with an area of 20 m², a height of 3 m and a typical air change of 2 1/h has been investigated, the maximum duration of stay after the entrance of the infected person can be seen to be about 80 minutes.
Otherwise, if a 10-person office, with an area of 100 m², a height of 3 m and an air change rate of 1 1/h has been taken the maximum duration of stay can be found to be little more than 3 hours.

Summary and discussion:
With the simplified assumptions, simple analytical equations have been used for an investigation of the risk of infection in internal spaces. In detail and in specific situations the ventilation effectiveness has to be taken into consideration as well. Furthermore, the statements cannot be applied to the field near the face, were the concentration of aerosols is much higher (direct influence of the exhaled air). The number of virus per aerosol as well as the critical number of virus for an infection can be seen as uncertain parameter. A cumulative load (low number of virus per breath over a long time) may not have the same influence as a high number of virus per breath over a short time. Finally, it also has to be kept in mind, that the vitality of the virus decreases with time, which is also influenced by the air temperature and the humidity [5].

Literature:

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