Parameter study for risk assessment in internal spaces regarding aerosols loaded with virus

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Introduction

Based on the current knowledge aerosols are one important way of transmission of SARS-CoV-2-viruses [1]. In previous studies the emission rate during breathing, speaking, coughing [2] as well as singing [3] has been measured. On the basis on these results a risk assessment for internal spaces has been performed [4,5].
A defined rate of one virus per aerosol and a critical dose of 3,000 viruses has been used in these investigations. The influence of the survival time of the viruses, the number of viruses per aerosol and the critical dose should be varied and their influence on the results should be shown.

Background

The concentration of aerosols has been calculated regarding equation (1), like it is explained in detail in [5]. In addition, an equation for the number of viruses dying regarding equation (2) and equation (3) has been established. The exact course of this process of viruses dying is unknown. Therefore, it has been assumed, that at the beginning few viruses have died and while the time is increasing the percentage has increased. Furthermore, it has been assumed that all investigated aerosols have carried a virus at the beginning (i_{max}=1). The course can be seen in Figure 1.

$$\Delta c_{particle,oz}(t) = \frac{f \cdot \big((s)(1-e)+(1-s)\big) \cdot \dot{V}_{so,particle,mouth/nose} - \dot{V}_{i,V}}{\dot{V} \cdot \varepsilon^{c}_{oz,particle}} \cdot \left(1 - e^{-(nt-SR)}\right) + \Delta c_{particle,oz}(t-1) \cdot e^{-(nt-SR)} \quad (1)$$

with:
$\Delta c_{particle,oz}(t)$…concentration of aerosols in the occupied zone at time t
f…number of infected persons in the room
s…ratio of persons, who are wearing face masks
e… efficiency of the cloth face mask
$\dot{V}_{so,particle,mouth/nose}$… emission rate of the persons through mouth and nose in particle/s
$\dot{V}_{i,V}$… volume flow of the virus dying in V/s
$\dot{V}$…volume flow in m³/h
$\varepsilon^{c}_{oz,particle}$… ventilation effectiveness in the occupied zone
n…air change in 1/h
t…time in h
SR…rate of deposition

$$\dot{V}_{IV} = \sum_{t^*=0}^{t_{st}} \left(i(t^*-1) - i(t^*)\right) \cdot f \cdot \left((s)(1-e) + (1-s)\right) \cdot \dot{V}_{so,particle,mouth/nose} \cdot e^{-(nt^*-SR)} \quad (2)$$

$$i(t) = -\frac{i_{max}}{{t_{st}}^2} x^2 + i_{max} \quad (3)$$

with:
i(t)… infectivity at time t
i_{max}… infectivity at the beginning
t_{st}…survival time of the virus in h

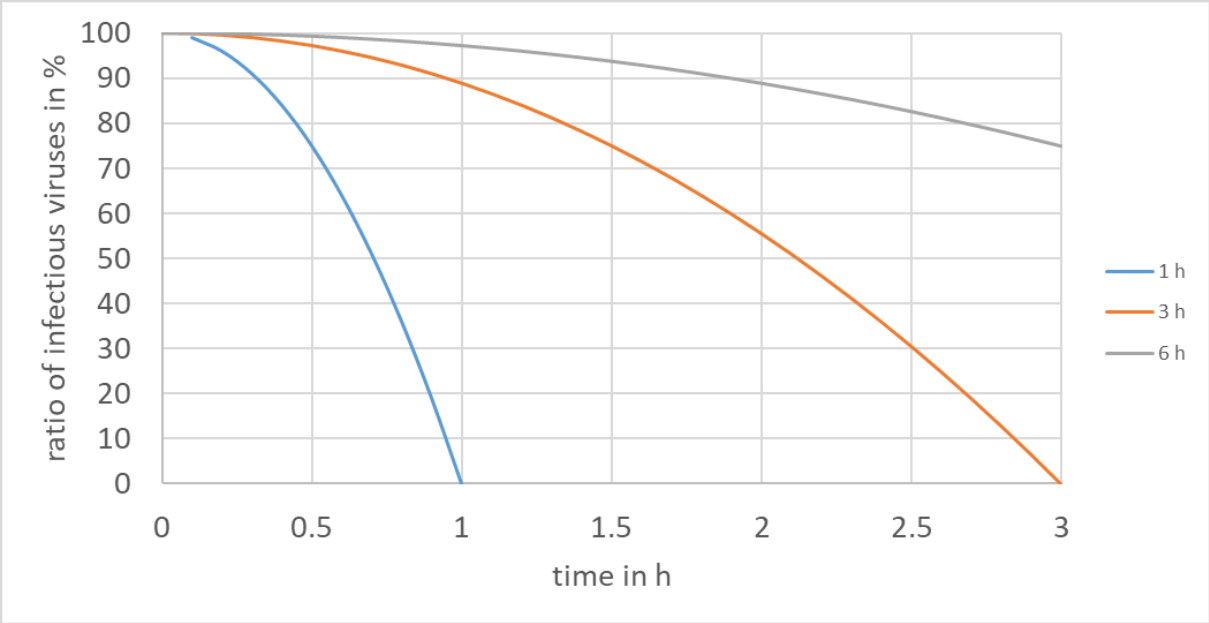

Figure 1: assumed course of the infectivity for different survival times

Application – example 1

To investigate the influence of the survival time of the viruses an application example has been defined. The following boundary conditions has been fixed:

- 2-person-office with 60m³
- one infected person f=1
- no masks s=0
- ideal mixing ventilation $\varepsilon^c_{oz,particle} = 1$
- no deposition SR=0

The following parameters has been varied in the shown limits:

- survival time t_{st}=1 to 6h
- air change n=0.1 to 5 1/h

The course of the concentration of potentially infectious viruses is shown in Figure 2. In Figure 2 the emission rate has been fixed to be 300 V/s and it can be seen that the survival time of the virus is only playing an important role, if the air change rate is low (dotted lines). In case of a high air change rate (dashed lines) only little differences have been found.

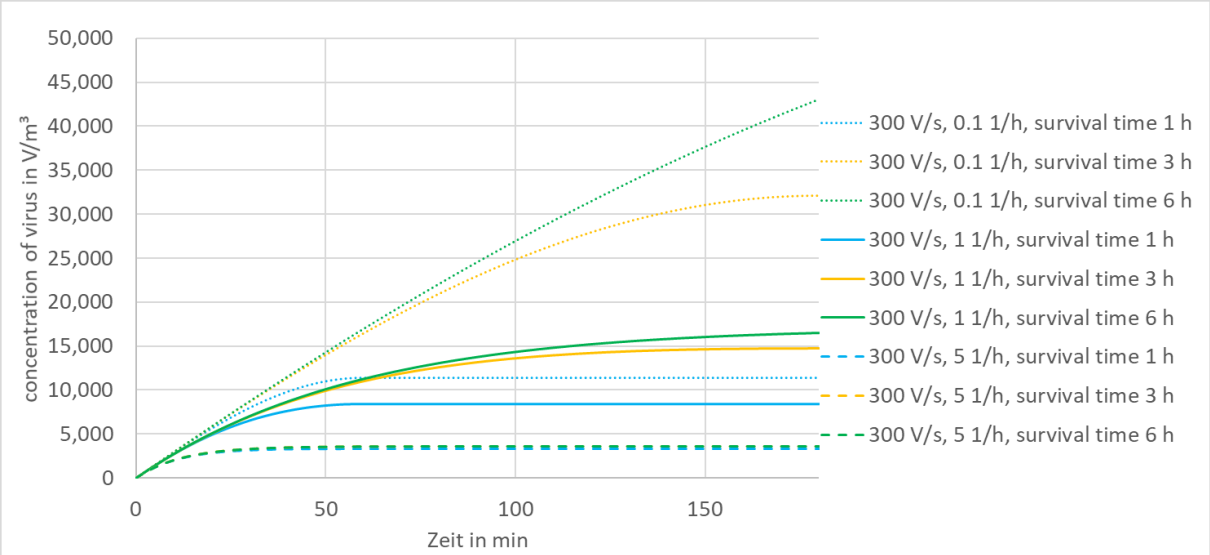

Figure 2: Influence of the survival time of the virus and the air change rate on the course of the concentration

Application – example 2

Because of the little influence of the survival time of the virus the survival time has been neglected in the following investigations. The following parameters has been fixed in this case:

- survival time of the viruses $t_{st}>t_{occupation}$ and is therefore neglected
- one infected person f=1
- no masks s=0
- ideal mixing ventilation $\varepsilon^{c}_{oz,particle} = 1$
- no deposition SR=0
- $\dot{V}_{so,particle,mouth/nose} = 300P/s$

Variations has been performed for the following parameters:

- type of room:
  - 2-person-office (V=60 m³)
  - open-plan office (V=300 m³, normal occupancy 16 persons, current occupancy 8 persons)
  - classroom (V=250 m³, normal occupancy 28 pupils + 1 teacher, current occupancy 14 pupils + 1 teacher)
- air change rate n=0.1 to 1 1/h
- virus per aerosol 0.1 to 1 as well as 10-fold virus emission during the infection
- critical dose of virus 300 to 10.000 viruses

The results can be seen in Figure 3 to 11.
If a classroom with a low air change rate (Figure 9) has been considered a reduction of the number of viruses per aerosol from one virus on each emitted aerosol to one virus on every second aerosol have led to an increase of the possible time of stay from 36 min to 51 min for a critical dose of 300 viruses and from 223 min to 324 min for a critical dose of 10,000 viruses, which means an increase of 40 – 45 % depending on the critical dose.
For an increase of the critical dose from 300 viruses to 3,000 viruses the maximum time of stay has been raised from 118 min to 406 min for one virus on every tenth aerosol and from

36 min to 118 min for one virus on every aerosol. This means an increase about factor 3.3 nearly independent of the number of virus per aerosol.
For the other two room types with low air change rates, similar results have been found.

In case of a high air change rate (Figure 11) the extension of the time of stay, because of a decrease of the number of virus per aerosol from one on every aerosol to one on every second aerosol has been found to be between 48 % (critical dose 300 viruses, from 40 min to 59 min) and 88 % (critical dose 10,000 virus, from 430 min to 807 min). The time of stay has been found to extend from 167 min for 0.1 viruses/aerosol with a critical dose of 300 viruses to more than 10 h for a critical dose of more than 3,000 viruses.
For a tenfold increase of the virus emission during the infection the time of stay has been calculated to be 11 min for a critical dose of 300 viruses and 81 min for a critical dose of 10,000 viruses.
Here a clear effect of the room size can be recognized. While in a 2-person-office even with an increase of the critical dose from 300 to 3,000 viruses with an air change rate of 1 1/h and 0.1 viruses/aerosol, the time of stay has been increased from 66 min to 326 min (about factor 5), for an open-plan office the time has been found to increase from 191 min to more than 10 h. With a high emission of viruses (tenfold increase during the infection) the factor is about 3.6 for all three room types and the maximum time of stay has been found to be pretty low (little more than 90 min) for the larger rooms and with 35 min even smaller in the 2-person-office.

Summary and Discussion

In addition to the previous analytical investigations it has been shown, that depending on the critical dose as well as the virus emission rate the importance of the ventilation can be different. Whereas with a high emission rate, typical air change rates have just little influence on the maximum time of stay, for low emission rates even little supply of fresh air could have a significant influence. Furthermore, the air volume in the room has been seen to be important. The larger the air volume of the room, the longer the possible time of stay. The survival time of viruses just played an important role if the aerosols stayed in the room air for a long time the air change rate has therefore been low.

It has been shown, that the limitation of these parameters (critical dose as well as number of virus per aerosol) from a virological point of view has an important influence on the approach of the ventilation system. Solely the survival time of viruses for normal times of stay has been shown to play an important role just in cases without ventilation (neither ventilation through windows nor mechanical ventilation, air change rate 0.1 1/h) and can therefore be neglected in most cases. It has to be kept in mind that the aerosol concentration increases fast and closed windows should not be an option anyway.
Current studies offer guidance as well as a methodology, but the results may differ significantly from reality.

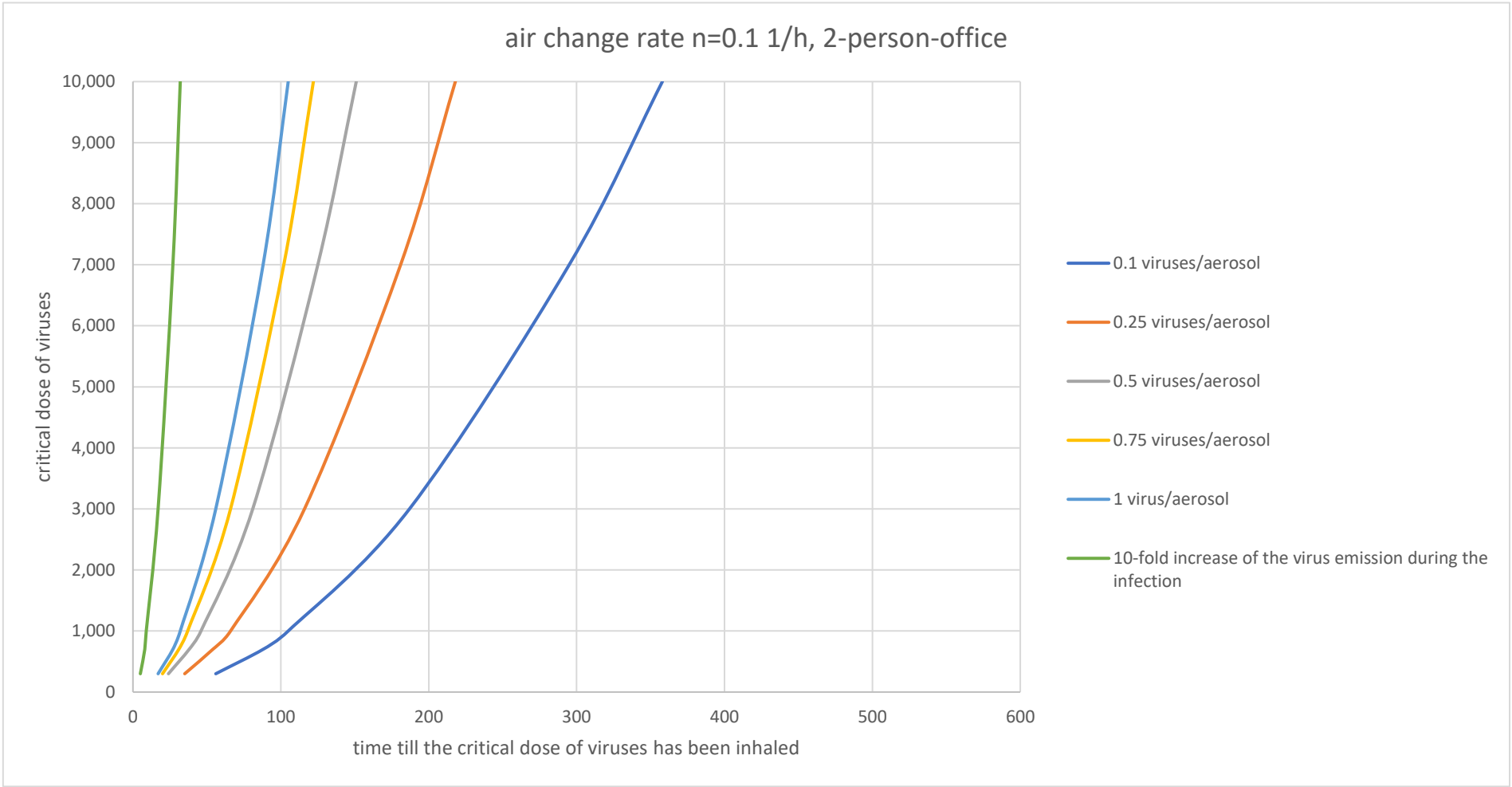

Figure 3: influence of the number of viruses per aerosol as well as the critical dose of viruses on the maximum time of stay, air change rate 0.1 1/h, 2-person-office

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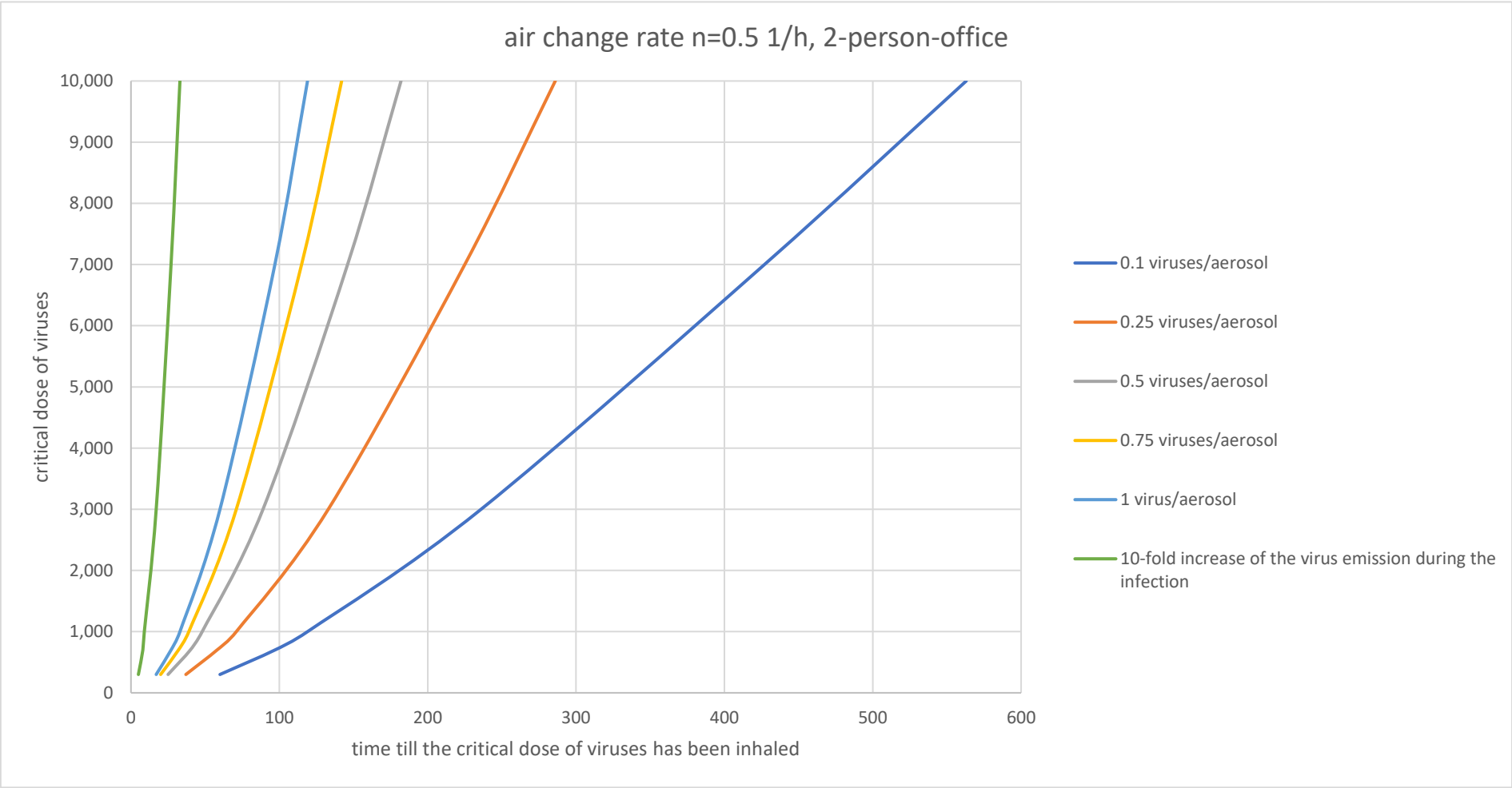

Figure 4: influence of the number of viruses per aerosol as well as the critical dose of viruses on the maximum time of stay, air change rate 0.5 1/h, 2-person-office

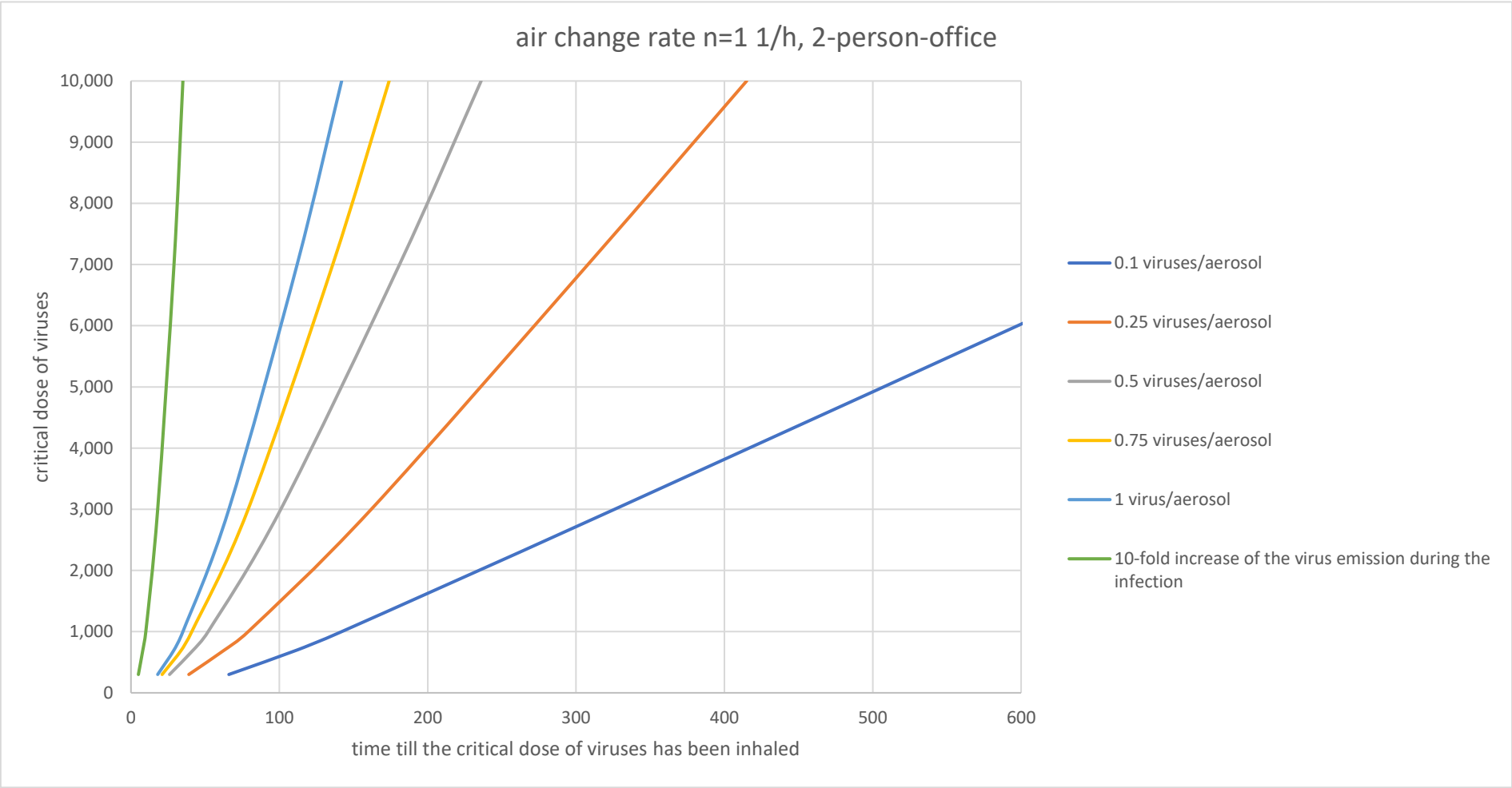

Figure 5: influence of the number of viruses per aerosol as well as the critical dose of viruses on the maximum time of stay, air change rate 1 1/h, 2-person-office

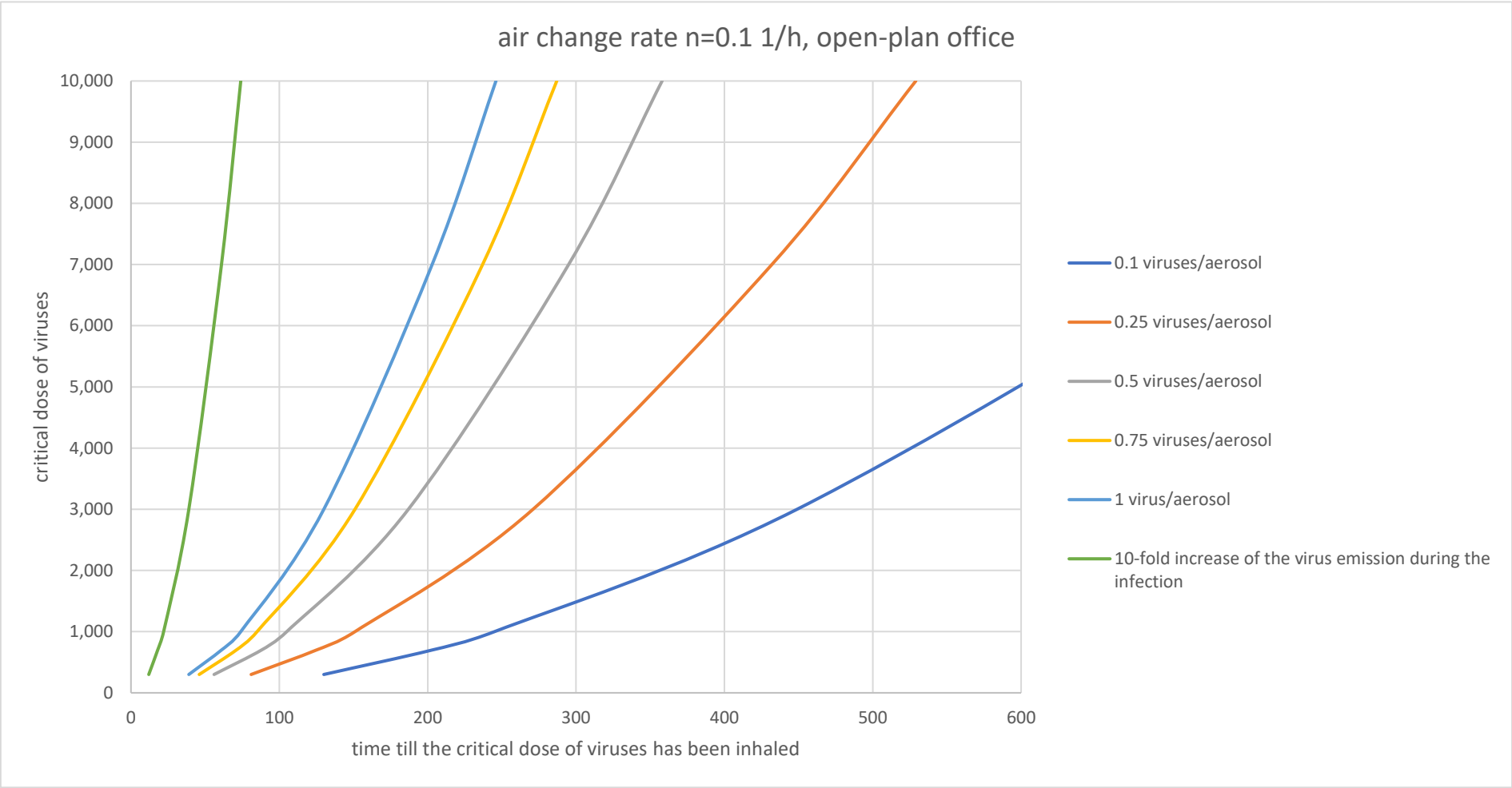

Figure 6: influence of the number of viruses per aerosol as well as the critical dose of viruses on the maximum time of stay, air change rate 0.1 1/h, open-plan office

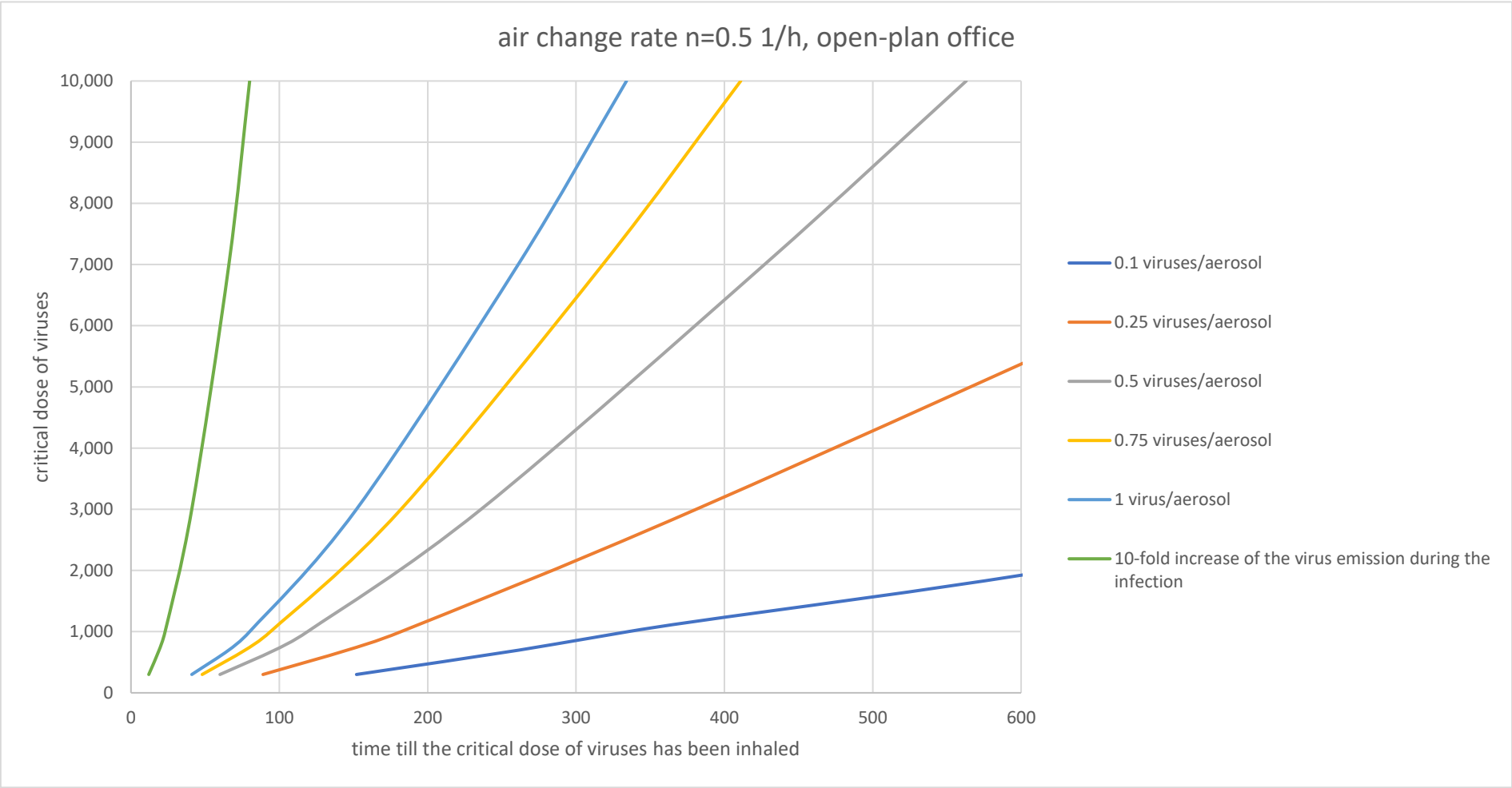

Figure 7: influence of the number of viruses per aerosol as well as the critical dose of viruses on the maximum time of stay, air change rate 0.5 1/h, open-plan office

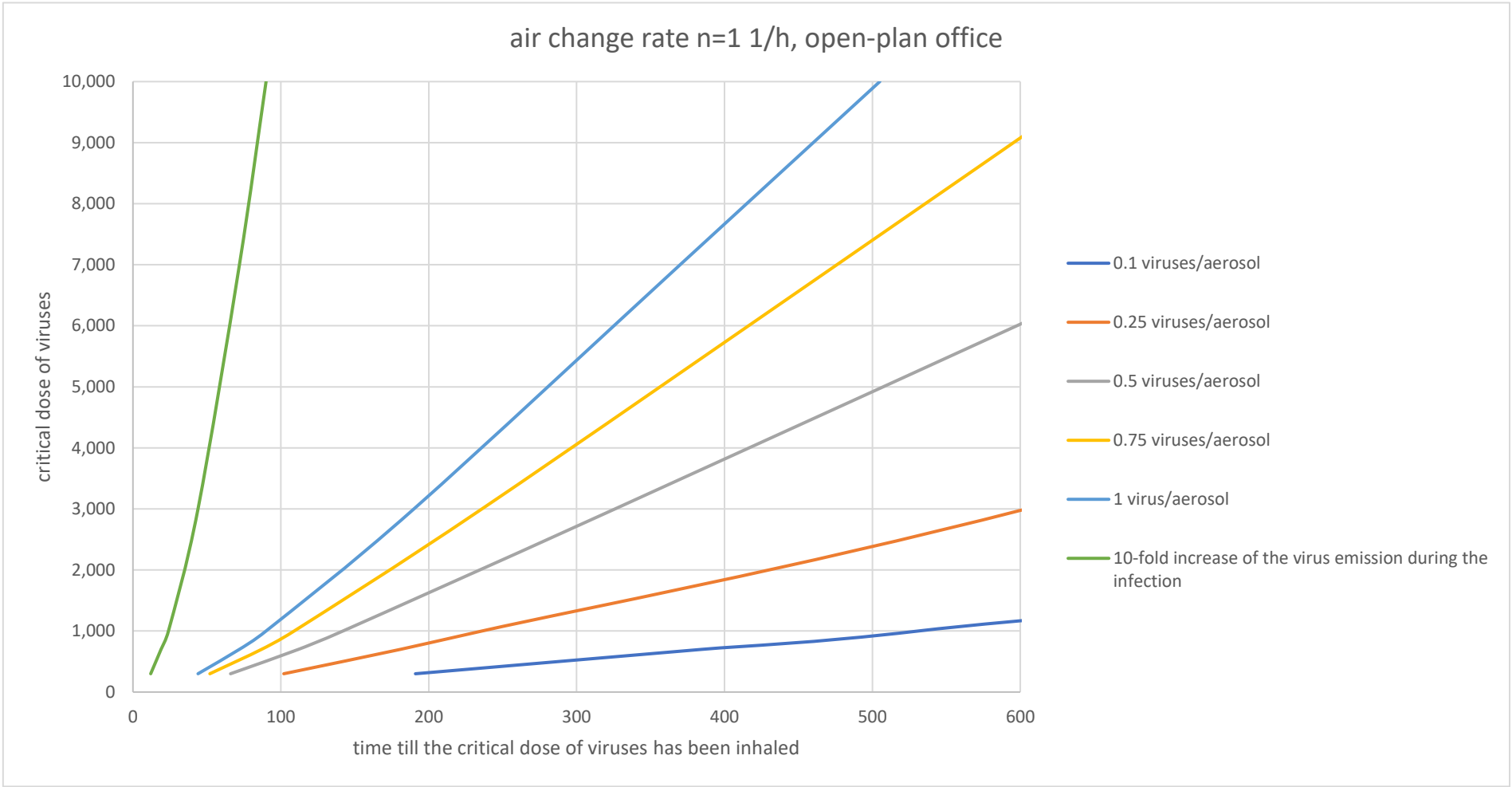

Figure 8: influence of the number of viruses per aerosol as well as the critical dose of viruses on the maximum time of stay, air change rate 1 1/h, open-plan office

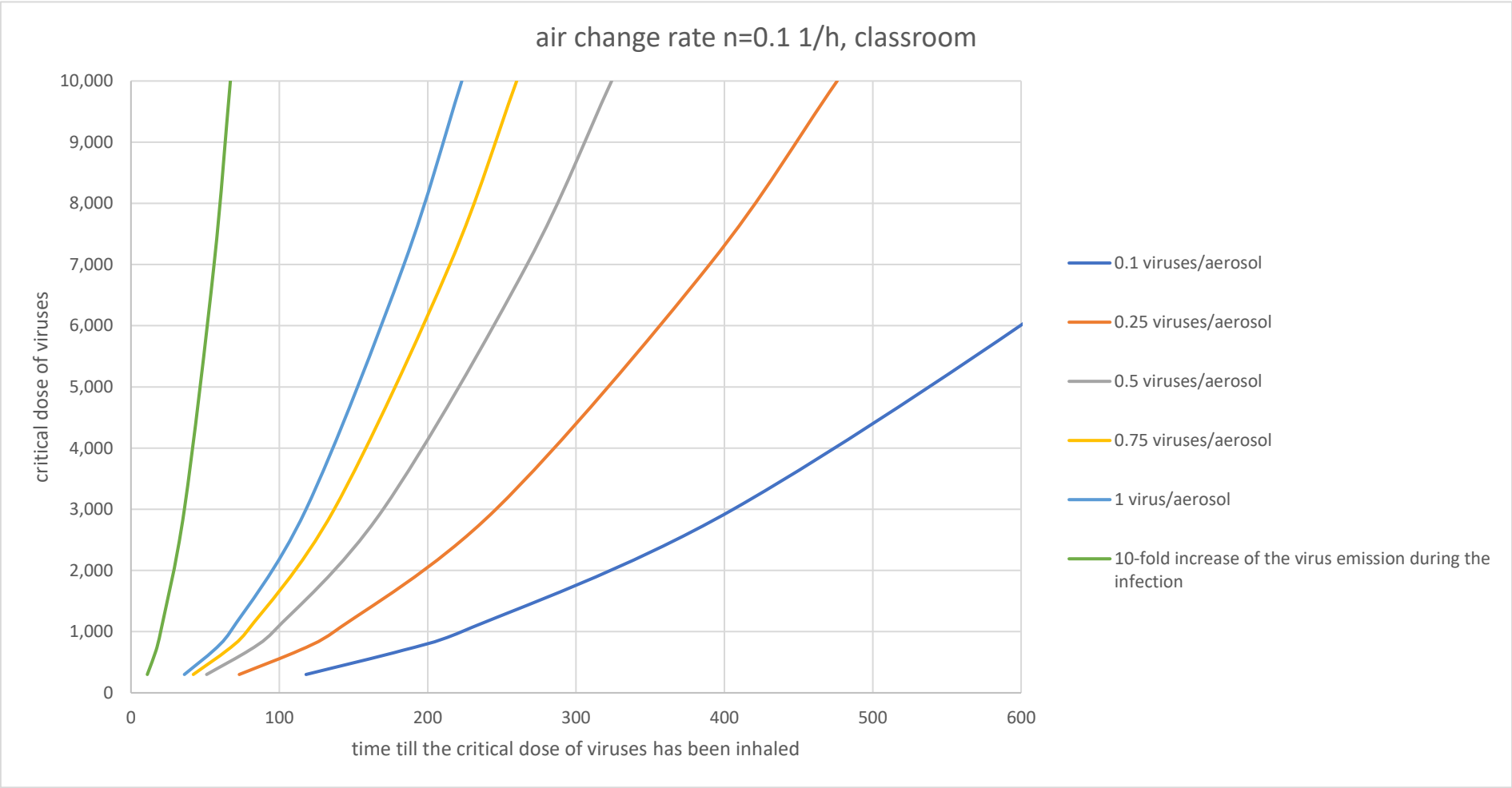

Figure 9: influence of the number of viruses per aerosol as well as the critical dose of viruses on the maximum time of stay, air change rate 0.1 1/h, classroom

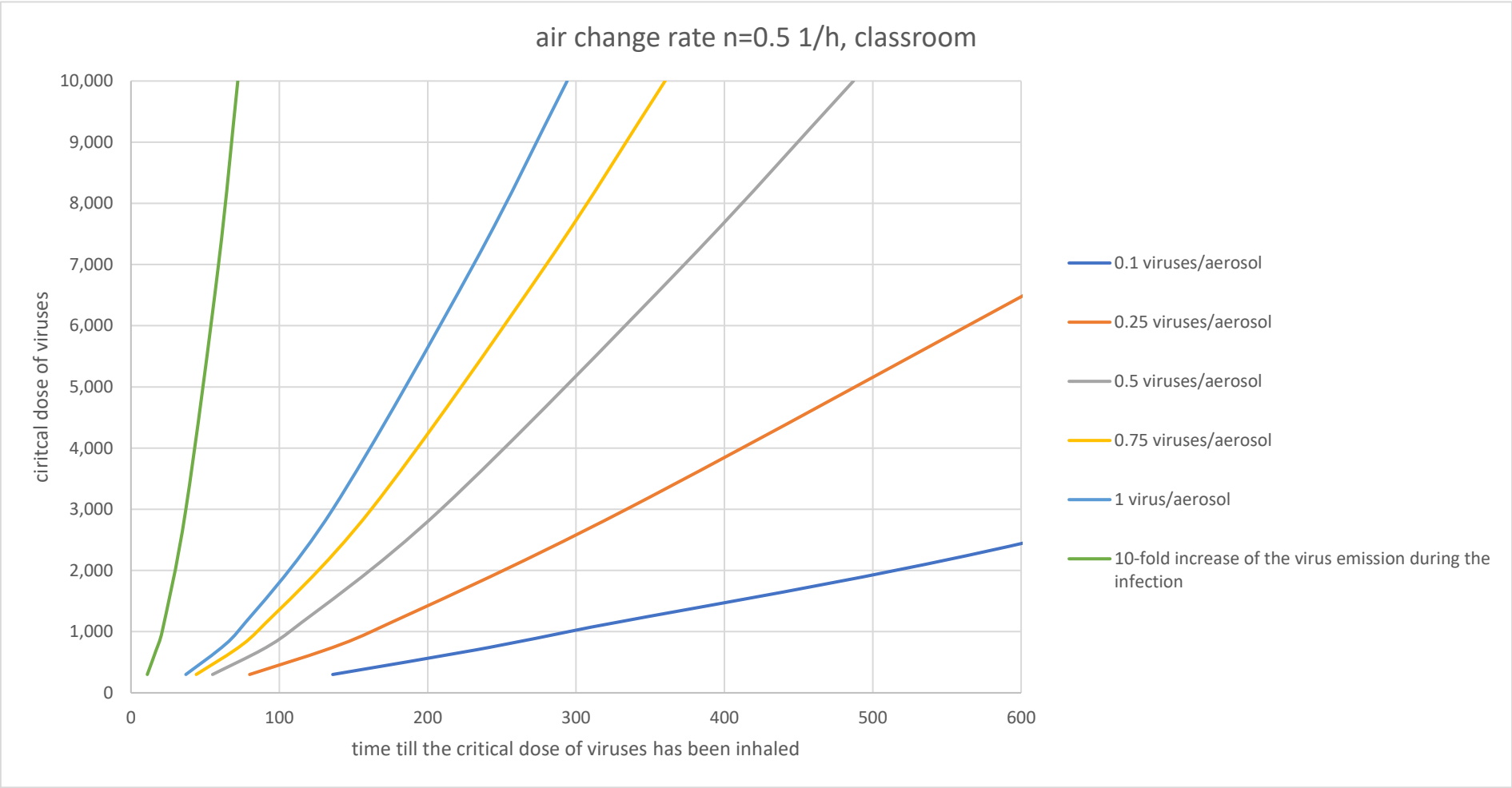

Figure 10: influence of the number of viruses per aerosol as well as the critical dose of viruses on the maximum time of stay, air change rate 0.5 1/h, classroom

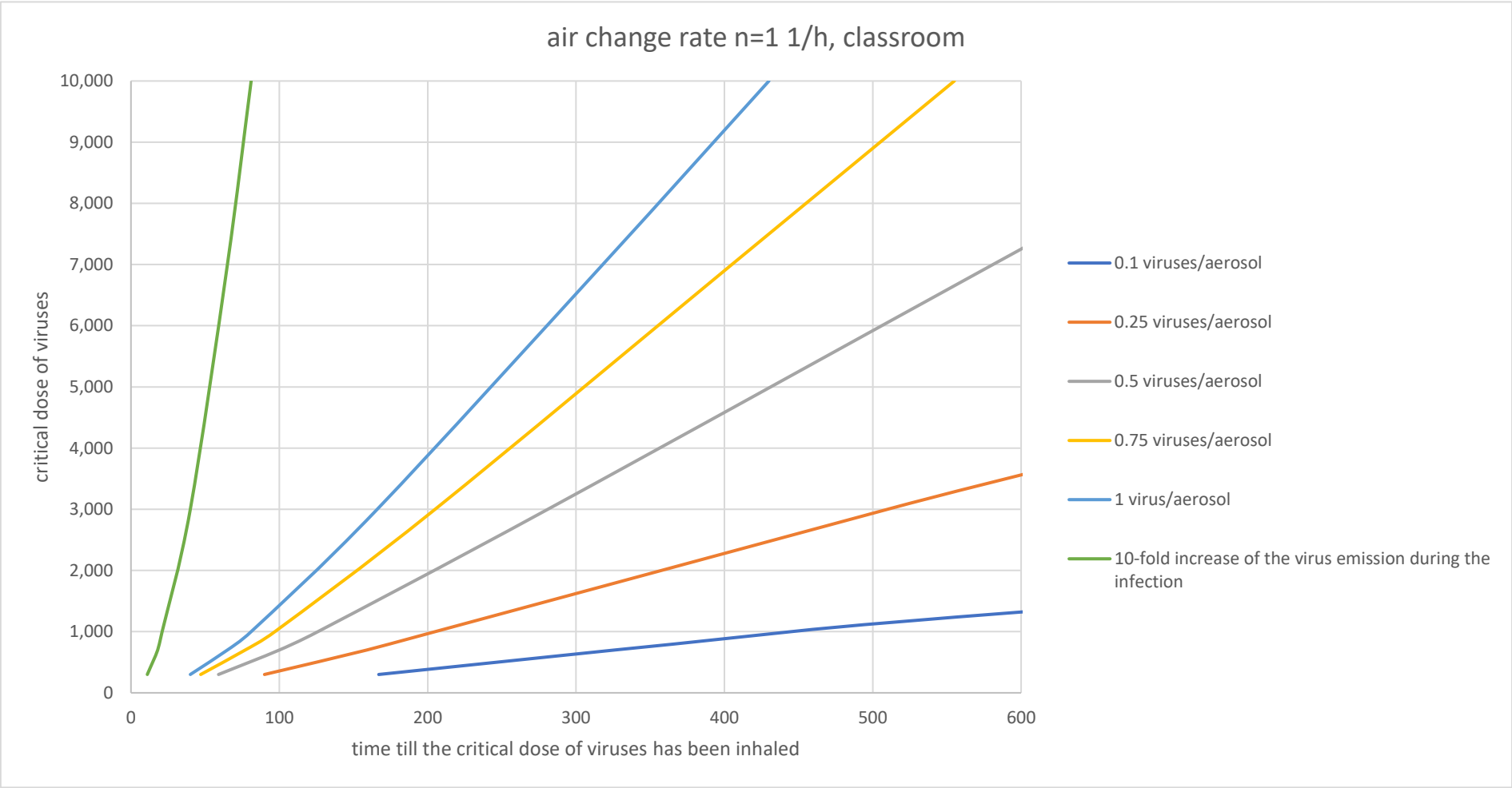

Figure 11: influence of the number of viruses per aerosol as well as the critical dose of viruses on the maximum time of stay, air change rate 1 1/h, classroom

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