Spreading distance and dynamic of aerosols in internal spaces by convection flows

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Introduction:

Based on current knowledge aerosols are one of the main transmission ways of SARS-CoV-2-viruses [1]. During breathing, speaking, coughing [2] as well as singing [3] persons are emitting particles. In general, these particles are so small, that they are ideally airborne and can therefore be called aerosols. If one of the persons in the room is infected, on the aerosols viruses may be carried. With increasing time of stay in the room, the concentration of aerosols in the room is raising and critical values for an infection can be reached [4]. Decisive for whether critical values will be reached is the air change rate, the type of supply of fresh, uncontaminated air as well as the number of infected persons in the room [4]. In the public press, it has been written several times, that "air conditioning systems" enhance the dispersion of virus loaded aerosols, because the aerosols will be transported wider with the volume flow of the air conditioning system. It strongly has to be disagreed with this statement.

Basics

Airflows in rooms are caused by convection flows. Two different types have to be distinguished: free and forced convection. Free convection is caused by density and temperature difference and forced convection through mechanical forces. In typical internal thermal buoyancy flows will be produced by heat sources e.g. person and/or radiators and therefore free convection flows occur. All system, which are operated with flow machines (e.g. fans) like ventilation systems, partial and full air conditioning systems, recirculation coolers, etc. cause a forced convection flow. Furthermore, forced flow can be split in different types of air flow: mixing ventilation and displacement ventilation [5]. In addition, different hybrid types are existing. In general, mixing as well as displacement ventilation with air supply from the floor level can be found. Just in cases with special requirements regarding the air cleanliness, laminar airflow systems (displacement ventilation system with mostly air supply through the ceiling) can be found. To assess the impact of free and forced convection flows on the dispersion of aerosols in internal spaces the order of magnitude of the volume flows, which disperse the aerosols inside the room has been compared.
For volume flow, because of thermal buoyancy equation (1) from [6] can be used, even if there are differing data [7].
z in equation (1) means the height above an virtual origin of an extended heat source like in Figure 1 according to [6], whereas the maximum case should be used for heat sources with a low temperature and the minimum case for heat sources with a high temperature [6].

$$q_{v,z} = 5 \cdot \phi^{1/3} \cdot z^{5/3} \qquad (1)$$

with:
$q_{v,z}$…volume flow above a heat source in l/s
ϕ…thermal output of the heat source in W
z…height above the virtual heat source in m

$$z_{0,max} = 2{,}3 \cdot D \tag{2}$$

$$z_{max} = z_{o,max} + h \tag{3}$$

$$z_{0,min} = 1{,}8 \cdot D \tag{4}$$

$$z_{min} = z_{o,min} + h - \frac{D}{3} \tag{5}$$

with:

z_0…position of the virtual heat source in m
D…diameter of the heat source in m
z… height above the virtual heat source in m
h…height above the cylinder in m

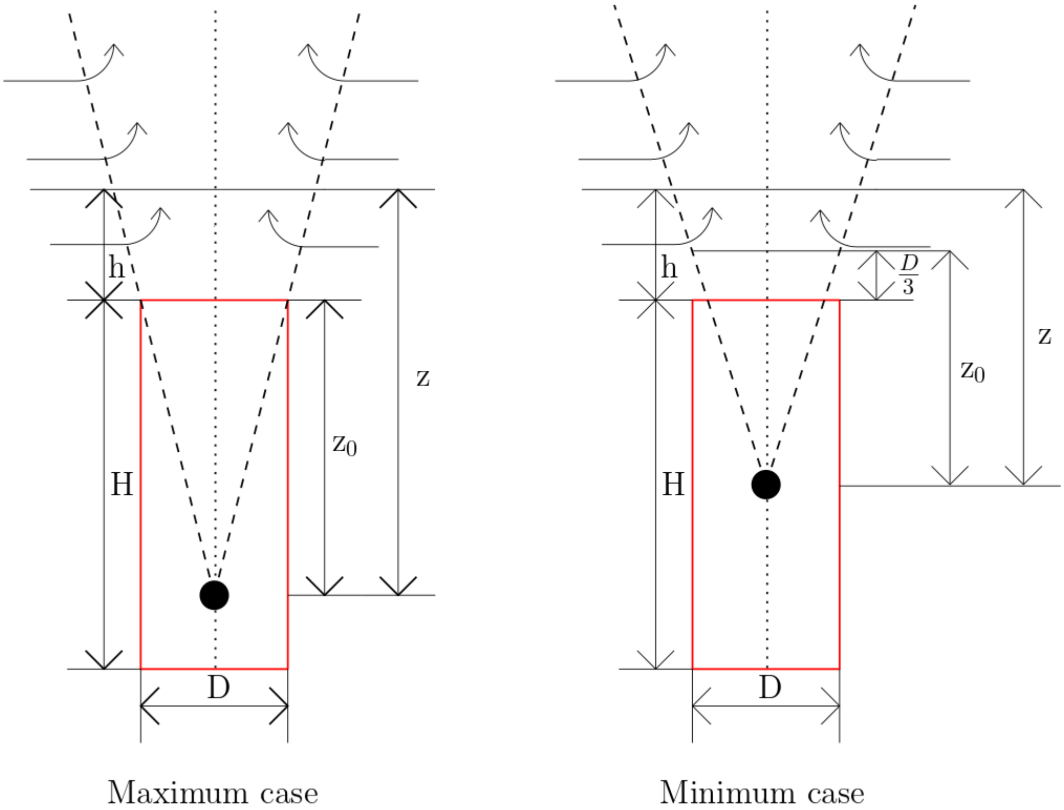

Figure 1: convection flow above a cylinder according to [6]

The order of magnitude of the forced flow can be calculated regarding the beam laws [8]. In the simplest form of an isothermal, circular free jet the volume flow can be calculated regarding equation (3) according to [8].

$$\frac{\dot{V}}{\dot{V}_0} = 2\frac{m \cdot x}{d} \tag{6}$$

with:

$\dot{V}_0$…volume flow at the air inlet
$\dot{V}$…volume flow at distance x from the inlet
x…distance from the inlet
m…mixing number
d…diameter of the open jet

Application example:
Hereafter this theoretical case has been investigated: 1 person stays in a room with a volume of 30 m³ (area 10 m², height 3 m). The corresponding airflow is 40 m³/h and will be supplied into the room by mixing ventilation. The airflows, which influence the dispersion of the aerosols, have been calculated at a distance of 1 m above the heat source and 1 m behind the air inlet regarding equation (1) and (6) and have been compared. The following assumptions has been taken:

$Q_{convectiv} = 50W$

$H_{HS} = 1{,}1m$

$D_{HS} = 0{,}3m$

$m = 0{,}2$

$d_{sup} = 0{,}2m$

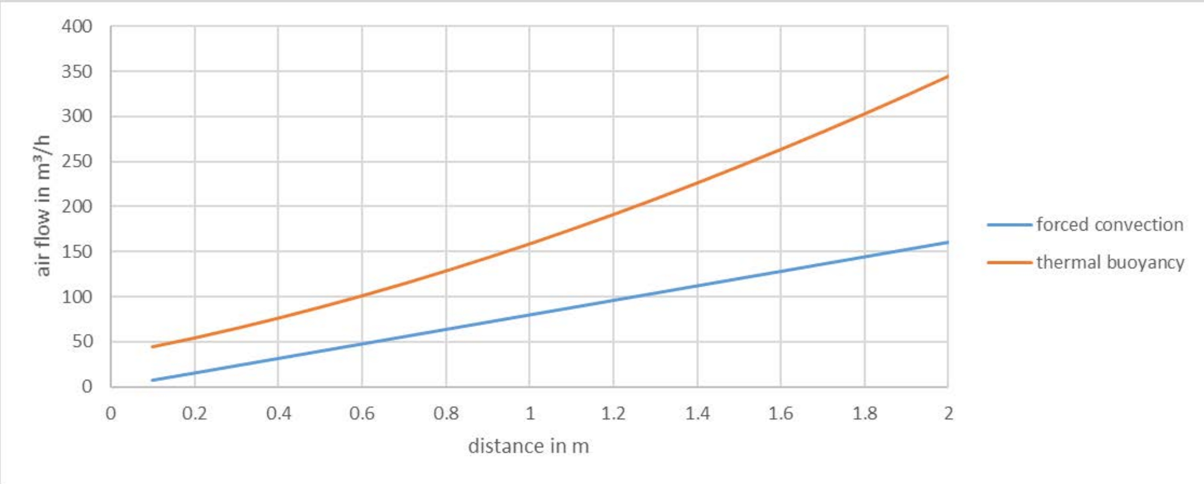

Figure 2: airflow because of forced convection and thermal buoyancy

The calculations regarding equation (1) for the free convection 1 m above the heat source have resulted in airflow of 160 m³/h. For the forced convection, a volume flow has been calculated regarding equation (6) at a distance of 1 m from the air inlet to be 80 m³/h. Solely, the comparison of the free and the forced convection flow showed, that the thermal buoyancy flow is larger. If one of them has been assumed to be the only force in the volume, aerosols would be distributed nearly evenly in the whole room, because of energy, impulse and mass transfer and the resulting turbulence structures. The velocity of the distribution would be depending on the air velocity in the room. This will be very different at the different points in the room. Outside of the primary air volume flows in rooms with just free convection flows a velocity of 0.01 to 0.05 m/s can be assumed in the investigated volume. If free and forced flows have been overlaid about 0.05 to 0.1 m/s can be assumed, which is about twice the velocity. On first sight, this seems to be low. For normal time of stay in a room of some minutes up to several hours, it relativized itself. For a distance of 1.5 m an aerosol needs between 150 s and 30 s in rooms with solely free convection and 30 s to 15 s in case of free and forced convection.

If the number of persons per m² area has been increased, also the specific (area-related) buoyancy volume flow is increased.

How fast and evenly the distribution works can be seen in the videos on [9], which are showing results of CFD simulation with and without a ventilation system.

Summary and Discussion:

With the simplified assumptions it have been shown, that even without forced convection, thus without any kind of ventilation system, aerosols will be dispersed in the whole room. The volume flows because of free convections has been found to be higher, in general. If the free and the forced convection have been applied in the same volume, the velocity of dispersion has been increased, but for normal times of stay in internal spaces, no negative consequence regarding the exposition to aerosols have been found.

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