Tool for determining the required ventilation and/or air cleaning capacity for low aerosol particle concentrations in indoor environments during the COVID-19 pandemic

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Objective and scope: This document presents an easy-to-use practical tool to determine the required total room ventilation rate and/or total room air cleaning rate as a function of the important parameters that govern the indoor concentration of saliva aerosol particles: the floor area, the room height, the maximum allowed number of people present, the required clean air delivery rate per person and the deposition rate of saliva aerosol particles. Conversely, this tool can also be used for determine how many people can be present given the floor area, the room height, the total room ventilation rate and/or total room air cleaning rate, the required clean air delivery rate per person and the deposition rate of saliva aerosol particles. Typically, the required ventilation flow rate per person is determined by international, national or local regulations or guidelines. For example, the pre-COVID-19 era Guidebook Sports Accommodations in the Netherlands (Ariëns et al., 2008) recommends 11.1 dm^3/s per person. ASHRAE (2019) recommends 10 dm^2/s per person. The draft European guideline for safe exercising in fitness centers during COVID-19 advises 20 dm^3/s per person. These are values that often significantly exceed the minimum requirements of building codes. Application of these higher values does not provide a zero percent risk for aerosol COVID-19 transmission but is expected substantially reduce the risk of this type of transmission. In view of limiting COVID-19 transmission, it should be noted that ventilation and air cleaning only reduce the risk of transmission via saliva aerosol particles, not the transmission via large droplet spray and contact routes (Blocken et al., 2021). Therefore, social distancing, face masks and surface disinfection remain important, in addition to ventilation and air cleaning.

Symbols:

10N/A	maximum number of persons present per 10 m^2
A	floor area (m^2)
H	room height (m)
Q	required ventilation flow rate per person (dm^3/s)
E_C	zone air distribution effectiveness (-)
n_V	total room ventilation rate (h^{-1})
n_{AC}	total room air cleaning rate (h^{-1})
K	deposition loss rate (= 0.7 h^{-1})

Procedure towards the required total room ventilation flow rate and/or total room air cleaning rate n_{AC}:

- Step 1: Use Table 1 to determine value of E_C for ventilation system currently present in the room.
- Step 2: With Q and 10N/A, use Figure 1 to determine the value of the product "($E_C\,n_V + n_{AC} + K$)H"
- Step 3: With H, determine the value of the sum "$E_C\,n_V + n_{AC} + K$"
- Step 4: With E_C and K, check whether the calculated value of the sum "$E_C\,n_V + n_{AC} + K$" is obtained by the current ventilation system and/or air cleaning units in the room. If not, ventilation and/or air cleaning should be upgraded and/or engaged until the calculated value of "$E_C\,n_V + n_{AC} + K$" is obtained or exceeded.

Disclaimer:
Application of this tool does not provide a zero percent risk for aerosol COVID-19 transmission but is expected to substantially reduce the risk of this type of transmission. In view of limiting COVID-19 transmission, it should be noted that ventilation and air cleaning only reduce the risk of transmission via saliva aerosol particles, not the transmission via large droplets and contact routes. Therefore, social distancing, face masks and surface disinfection remain important, in addition to ventilation and air cleaning.

Comments:
This simplified tool is based on the well-mixed assumption, implying that the concentration is uniform across the room. Non-uniform distribution of ventilation air can partly be taken into account by application of the factor E_C. The well-mixed assumption will be closest to reality as more intensive ventilation and air cleaning is engaged and when the room geometry is not excessively long or narrow. In such cases, it is advised to divide the room volume in several parts of simpler geometry and apply the above-mentioned procedure for every part separately.

Upgrading existing mechanical ventilation systems to (much) higher ventilation rates might be very costly and might also be less effective. Note that Table 1 shows that several ventilation systems have values of E_C below unity and that common system in fitness rooms, classrooms etc have values of 0.5 or 0.8. Adding mobile stand-alone air cleaning units will generally be cheaper but might also be more effective than adding ventilation. The study by Blocken et al. (2021) showed that the ventilation E_C for a gym with large height and multiple supply openings was only about 0.5 while air cleaning units were substantially more effective. Air cleaning alone (without ventilation) should not be employed. Air cleaners often do not remove CO_2. The total room air ventilation rate should at least adhere to national standards. Ventilation alone (without air cleaning) should also not be employed because of the high installation costs but also the high energy costs in heating, cooling and/or (de)humidifying incoming outdoor air. Therefore, in view of reducing aerosol COVID-19 transmission, a combination of ventilation and air cleaning is advised.

Table 1: Zone air distribution effectiveness for well-mixed air distribution configurations (Source: ASHRAE)

Ceiling supply of cool air	1.0
Ceiling supply of warm air and floor return	1.0
Ceiling supply of warm air (8 °C) or more above space temperature and ceiling return	0.8
Ceiling supply of warm air less than 8°C above average space temperature where the supply air-jet velocity is less than 0.8 m/s within 1.4 m of the floor and ceiling return	0.8
Ceiling supply of warm air less than 8°C above average space temperature where the supply air-jet velocity is equal to or greater than 0.8 m/s within 1.4 m of the floor and ceiling return	1.0
Floor supply of warm air and floor return	1.0
Floor supply of warm air and ceiling return	0.7
Makeup supply outlet located more than half the length of the space from the exhaust, return, or both	0.8
Makeup supply outlet located less than half the length of the space from the exhaust, return, or both	0.5

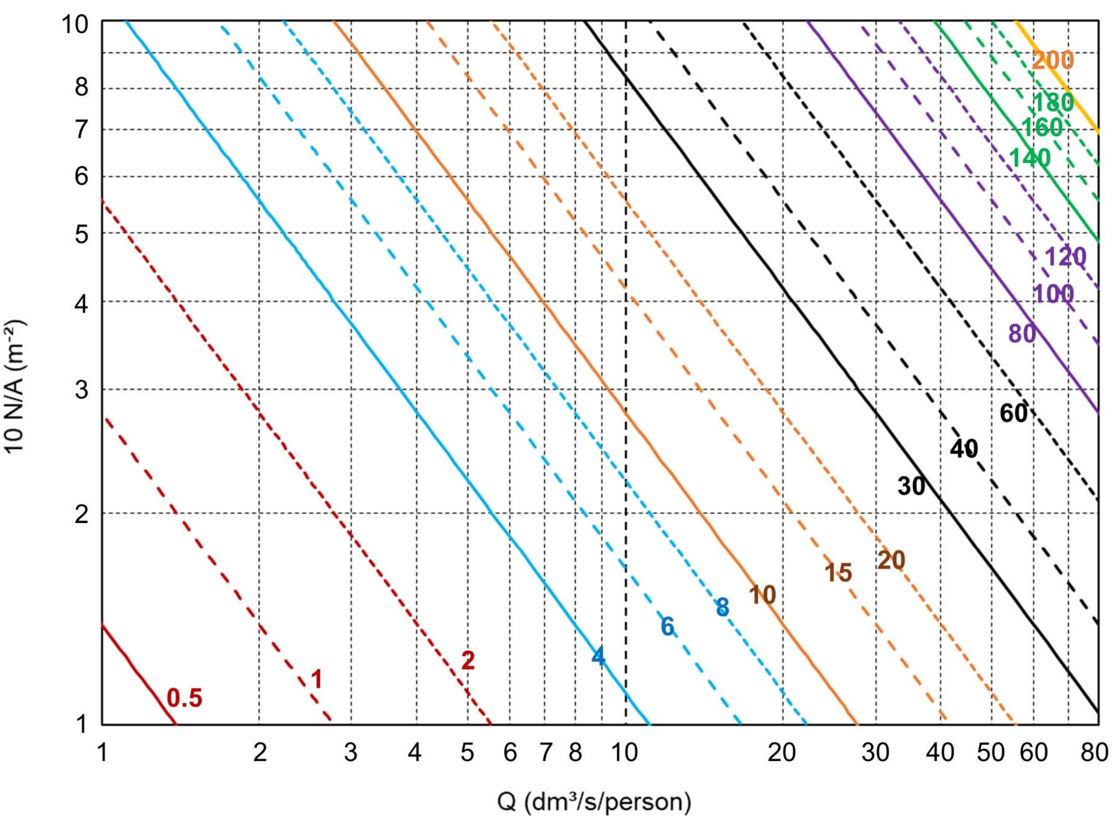

Figure 1: Nomogram expressing the maximum number of persons allowed per 10 m² floor area, as a function of the required ventilation flow rate per person. The parameter in the nomogram is the product "($E_C n_V + n_{AC} + K$)H". Source: this document (Eindhoven University of Technology)

Source documents:

Blocken B, Ricci A, Xia L, et al. 2021. Some practical tools towards limiting indoor saliva aerosol particle concentrations in indoor environments in the COVID-19 pandemic. Preprint.

Blocken B, van Druenen T, Ricci A, et al. 2021. Ventilation and air cleaning to limit aerosol particle concentrations in a gym during the COVID-19 pandemic. Building and Environment 193: Art. Nr. 107659.

References:

ASHRAE. 2019. Ventilation for acceptable indoor air quality, ANSI/ASHRAE Standard 62.

Blocken B, van Druenen T, Ricci A, et al. 2021. Ventilation and air cleaning to limit aerosol particle concentrations in a gym during the COVID-19 pandemic. Building and Environment 193: Art. Nr. 107659.

Ariëns JPE, Joosten TA, Schriemer W, et al. 2008. Guidebook sports accommodations (in Dutch), Handboek Sportaccommodaties. ISA Sport, NOC*NSF, Arko Sports Media BV.