Discussion on minimum ventilation rates for infection control

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SUMMARY

There are several knowledge gaps that explains a lack of knowledge on minimum ventilation rates for intercepting airborne respiratory infection. One is a lack of unifying understanding of the roles of ventilation, filtration, settling, deactivation, and most importantly temporal and spatial variation. A recent finding on the equivalence of the occupied air volume per person and dilution and a generalized Wells-Riley equation are used to define a unified dilution air flow rate. The required threshold dilution air flow rate is not a function of the setting. I would suggest the use of the dilution air flow rate not the ventilation air flow rate for infection control.

KEYWORDS

Minimum ventilation, threshold ventilation, respiratory infection, SARS-CoV-2, risk assessment

1 A GENERALIZED WELLS-RILEY EQUATION

Consider a room with a volume V (m^3), N_σ susceptible individuals and N_I infectors. Each virus particle (virion) in the room might be inhaled by a susceptible individual and produce infection. Each point in the room is defined as $\boldsymbol{x}(x, y, z)$. Here we consider a setting where each susceptible individual ($i = 1,2, \dots, N_\sigma$) has his/her position ($\boldsymbol{x_i}$) known. Individual i arrives in space at time $t_{1,i}$ and departs at time $t_{2,i}$, and $c_{Q,i}(\boldsymbol{x_i}, t)$ is the concentration of the infectious quantum at location $\boldsymbol{x_i}$ and time t.

Following Jia et al (2022), the average infection risk of all individuals follows the generalized Wells-Riley equation.

$$\bar{p} = \frac{N_\iota}{N_\sigma} = \frac{1}{N_\sigma}\sum_{i=1}^{N_\sigma}\left(1 - e^{-\int_{t_{1,i}}^{t_{2,i}} q_{in,i}(t)c_{Q,i}(\boldsymbol{x_i},t)dt}\right) \quad (1)$$

With one infector in a space, this equation may probably be converted somehow into the classical Wells-Riley equation at ideal uniform and steady-state setting.

$$\bar{p} = \frac{N_\iota}{N_\sigma} = 1 - e^{-Q\frac{q_{in}}{q_d}\Delta t} \quad (2)$$

It is noted that the effective dilution air flow rate for each susceptible individual depends on his/her trajectory in the space. In general, we may consider that the infectious quantum emission rate Q, the inhalation rate q_{in}, the effective dilution air flow rate q_d and exposure time Δt exhibit some probability distributions. Hence there is no single threshold dilution air flow rate.

2 FOCUSING ON VENTILATION ALONE IS NOT CORRECT

The vector for respiratory infection is respiratory particles (aerosols), which can be removed not only by ventilation air as for CO_2, but also by virus deactivation, particle settling, and filtration. The particle filtration can be counted for by using the clean-air flow rate (Shaughnessy and Sextro, 2006). The effect of crowding and non-uniform distribution of air also needs to be accounted for when the concentration $c_{Q,i}(\boldsymbol{x_i}, t)$ of the infectious quantum at location $\boldsymbol{x_i}$ and time t is estimated from the mass conservation equation.

We first define a generalised *clean-air flow rate* per person q_c as the sum of the outdoor-air supply flow rate, q_v (ventilation), the equivalent clean-air flow rate due to virus deactivation, q_r, aerosol settling, q_s, and filtration, $\eta_f q_f$.

$$q_c = q_v + q_s + q_r + \eta_f q_f \tag{3}$$

We consider a typical setting with uniform concentration when infector and all susceptible individuals start to present at the same time in an indoor setting. In such situations, the concentration of the infectious quanta would build up from zero, and the individual infection risk can be written as.

$$p_i = \frac{N_\iota}{N_\sigma} = 1 - e^{-Q\frac{Qq_{in}}{q_C}\Delta t(1-C_t)}. \tag{4}$$

Where $C_t = \frac{1-e^{-n\Delta t}}{n\Delta t}$, and the dilution air change rate $n = \frac{q_C}{V}$, and is the total *clean-air flow rate* of the room.

In non-uniform setting, we may use the zone air distribution effectiveness E_z in breathing zone (ASHRAE 62.1, 2019), $E_z = \frac{c_e}{\langle c_Q(\boldsymbol{x_i})\rangle} = \frac{Q}{\langle c_Q(\boldsymbol{x_i})\rangle q_C}$, where $\langle\cdot\rangle$ indicates the average concentration. c_e is the mean concentration of infectious quantum at exhaust.

The effective dilution air flow rate per person can thus be estimated as $q_d = \frac{E_z q_c}{1-C_t}$.

3 ACKNOWLEDGEMENTS

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4 REFERENCES

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