Practical guidance for ventilation of healthcare facilities

- Ventilation is important but certainly not the holy grail

ROBERTO TRAVERSARI
The Netherlands Organisation for Applied Scientific Research TNO, Delft, the Netherlands
roberto.traversari@tno.nl

ANNE BROUWER
Royal HaskoningDHV, Nijmegen, the Netherlands

FRANS SAURWALT
Association Contamination Control Netherlands, Woerden, the Netherlands

WIM MAASSEN
Royal HaskoningDHV, Rotterdam, the Netherlands, Eindhoven University of Technology, Eindhoven, the Netherlands

The Expert Panel Corona healthcare in the Netherlands, a collaboration between The Netherlands Organisation for Applied Scientific Research (TNO), Eindhoven University of Technology (EUT), Association Contamination Control Netherlands (VCCN) and Royal HaskoningDHV (RHDHV), was started in March 2020 to help healthcare facilities deal with urgent questions about technical infrastructure and HVAC systems arising because of the sudden COVID-19 pandemic. Many healthcare facilities were supported by setting up quick video calls and knowledge was shared through "FAQ & Guidance" and webinars. This article gives an overview of lessons learned, guidance, recommendations and considerations for healthcare facilities to continue safe functioning during the pandemic, with special focus on aerogenic transmission routes and the role of ventilation in risk management for SARS-CoV-2. Further information on the expert panel and its recommendations can be found in the FAQ [1].

Regular ICU and isolation room capacity cannot deal with large volumes of patients requiring specialist care for COVID-19. Accordingly, as the pandemic gathered pace, regular patient rooms had to be called into service to accommodate COVID-19 patients. These rooms had mostly not been designed to provide safe environments for care of highly infectious patients. Functional, technical and installations adjustments were called for. However, it quickly became apparent that available evidence offered no consensus either on the specific risks associated with different transmission routes, nor on which measures were likely to be effective to mitigate these risks. Around the world, healthcare organizations wrestled with the urgent question of how to prevent transmission of COVID-19 within their facilities.

Principles and approach

To help Dutch healthcare organisations take sensible and proportionate action, the Expert Panel on Corona healthcare has developed a practical guide that offers advice on short-term measures. This guidance has been based on key findings from current scientific evidence and/or literature, and has been developed around a set of pragmatic action principles.

The **key findings** from the current evidence base can be summarized as follows.

- SARS-CoV-2 is a respiratory virus in which the primary infection occurs via drip contact "coughing", [2, 3, 4]
- Secondary contamination can occur by air via aerosols, [4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16]
- On a surface, the virus can remain infectious for 2-3 days, [17, 18, 19]
- In the air, a virus can remain infectious for several hours, [17, 18]
- Infection may be caused by faecal-oral transmission, [20, 21]

Action principles shaping the practical guide developed for areas where COVID-19 suspect or COVID-19 confirmed patients reside by the Expert Panel are:

- Prevention of airflows from contaminated to non-contaminated areas. It should not be possible for air from spaces where COVID-19 (suspected) individuals are present to spread to other areas and/or parts of the facility. Organisational operational, installations-based and functional design-based measures can contribute to this goal.
- Adequate ventilation, e.g. by making sure outdoor air supply complies with applicable building codes*.
- Prevent recirculation of air in centralized systems. This helps prevent aerogenic spread and contributes to protection of vulnerable patients.
- Precautionary approach. The current evidence base has many unknowns regarding the dispersion routes of the virus and associated risk levels. Absence of evidence

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* This is based on the Dutch situation. In other countries the building codes may not be sufficient.

is not evidence of the absence of risk. A reasonable suspicion is sufficient basis to take action.
- Proportionality. The cost and side-effects of measures recommended should be proportionate to the (probable) degree of reduction of the risk of infection.

A particular objective of the guidance is to help healthcare facilities make sense of the heated scientific and media debate around the possible aerosol spread of SARS-CoV-2 and the efficacy (or not) of ventilation.

Research has found detectable amounts of virus on particles smaller than 5 µm in size. Particles of this size can remain airborne for a long time and hence cover greater distances than those generally prescribed in social distancing measures (1.5 m in the Netherlands). At the same time, media reports have suggested that ventilation measures could entirely eliminate infection risks from airborne transmission, effectively making buildings completely *corona-proof*. As a result, healthcare facilities have experienced pressure to implement rigorous and costly ventilation measures.

A closer look at the evidence, however, reveals that the evidence base for aerosol transmission through small particles is far from unequivocal. The guide accordingly tries to provide healthcare facilities with a nuanced account of sensible ventilation measures to take which reduce risks without breaking the bank on far-reaching but possibly ineffective measures.

The practical guide offers general advice and directions. Successful implementation requires that healthcare facilities contextualize this general guidance based on their own specific situation. The guide offers recommendations on how to go about this. Guidance focuses on areas in healthcare facilities where high-performance air treatment systems are not normally in place: general inpatient and treatment areas and public areas.

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To tackle contamination risk in specific departments where COVID-19 (suspect) patients or residents are present, measures on various fronts need to be taken: wearing of PPE by staff, and possibly visitors; increased supply of outside air and/or more thorough air treatment; changes to routing of air to avoid recirculation of air from potentially contaminated areas to other spaces. This is especially important for areas where activities associated with heightened aerosol emission levels take place, such as intubation/extubation, exercise tests, dental surgery, and physical examinations. Additional measures also need to be considered in spaces where care processes and/or spatial characteristics require people to be in close mutual proximity – defined as closer than the minimum required for social distancing (1.5 meter in the Netherlands).

The Corona Expert Panel advises health service providers to take only measures that are proportionate both to the known or estimated infection risk level, and to the level of risk reduction that can be achieved. Tackling ventilation issues is an important strategy for addressing COVID-19 related risks, but it is not a panacea: according to the Corona Expert Panel, good ventilation helps to reduce the risk of contamination, but will not reduce the risk of contamination to zero. This advice is based on established guidelines, recent insights from the scientific literature and its own research. [22, 23, 24]

Airborne contamination

Various studies have demonstrated that SARS-CoV-2 virus particles can move through aerosols. They have also established that the viral load of particles travelling distances of more than about 2 metres is sufficient to theoretically cause infections. [15] But the crucial questions to be answered in order to draw up are practical: what is the actual contribution of this transmission route to total risk and total number of infections; and what role do ventilation systems play in allowing or hindering dispersal of virus particles by this route? [4, 5, 14, 16, 6-13] Current research does not provide a clear answer to either of these questions.

Regardless of particle size, the concentration of virus particles will be highest close to the source, especially within the exhalation cloud. [25] However, the scientific literature offers no consensus on which sizes of particles are emitted in which numbers during various activities such as breathing, talking, singing, sneezing and coughing. This is true for the whole range of particles from small (< 5 µm) to very large (> 100 µm). What does seem clear is that the number of particles emitted depends on the noise level produced by the source. [23]

Ambient humidity strongly affects particles < 40 µm. At low relative humidity (RH), these particles will quickly decrease in size and weight, allowing them to be carried much further by air flows. On the other hand, lower RH leads to faster dispersion, dilution and dissipation of particles. There is no clear evidence of a net effect of RH on infection risk. Dilution of concentrations of smaller particles (aerosols) to reduce the risk of contamination through airborne transmission can also be achieved through providing clean outdoor air (ventilation). Overall, ventilation appears to be more effective in reducing airborne particle concentration than lowering of RH. As particle size increases, the effect of RH becomes less marked, with effects apparently negligible for particles > 80 µm. [24] Particles > 100 µm will quickly precipitate under the influence of gravity, travelling no further than about 1.3 meters.

Multi-factorial and unclear contamination causation mechanisms

Multiple factors co-determine the risk and severity of indoor air contamination. The number of (infected) persons in a room, source strength of the emittor(s), the size of the room, the susceptibility to infection of receivers (based on age, physical condition, predisposition) and the length of stay in the room are all important.

There is no consensus in the literature on what constitutes a safe threshold value for concentration of airborne virus particles. Nor is it clear what level of infection risk could be considered acceptable under different circumstances, for instance when set off against the risks of delayed diagnosis and/or treatment of other conditions. And while there is a growing body of indirect evidence, direct evidence of airborne SARS-CoV-2 transmission over greater distances has not yet been found.

In summary, neither causation mechanisms nor requisite ventilation performance levels are clear, but there is a reasonable suspicion that improving ventilation may reduce infections risks, although not to zero. Calculations done using the Wells-Riley model bear this out. The Wells-Riley model [23] estimates the probability of an individual infection occurring, taking into consideration variables such as concentration of infectious particles in the exhaled air, exposure time, and the minimum viral load required to achieve infection. Calculations using the model show that ventilation providing outdoor air change rates compliant with the Dutch building code already leads to a considerable reduction in individual infection risk compared to a baseline assuming no ventilation. The calculations also show that further improvements in ventilation lead to diminishing returns. Doubling the amount of ventilation further reduces the risk, but by less than half. Reducing risk to a level approaching zero requires unrealistically high ventilation quantities, which would essentially create an outdoor environment indoors. Even then, absolute zero risk could not be guaranteed. Creating a *corona-proof* environment through ventilation is impossible.

Given these considerations, the Expert Panel advises to at least ensure compliance of ventilation systems with requirements set out in the national building codes* and in specific guidelines and professional standards for care facilities. It should be verified under operational conditions that all ventilation systems function properly and achieve their design specification ventilation capacities.

Triage and behavioural compliance

Where no infected persons are present, no infections occur. The risk of infected persons being present in indoor healthcare environments can be very substantially reduced through thorough advance and on-site triage. Advance triage consists of behavioural protocols prescribing self-isolation and testing in the case of symptoms consistent with COVID-19. On-site triage involves encouraging or coercing individuals exhibiting behaviours that might indicate infection, such as coughing or sneezing, to leave the premises. If these measures are implemented systematically, the likelihood of infected persons being present and hence the risk of infection by air will be very low. Residual risk remains: not all individuals who are carriers of SARS-CoV-2 exhibit symptoms, so they won't be found through triage. However, the risk of such asymptomatic or presymptomatic individuals infecting others is limited, as they do not exhibit the behaviour (coughing) most associated with spread of the virus. The risk of airborne contamination through asymptomatic or presymptomatic carriers is especially low. For all eventualities, adherence to physical distancing guidelines and prevention of strong person-to-person airflows are sensible and proportional precautions. [22, 26]

Applying recirculation units

Several questions to the panel have expressed concern about the possible risks posed by recirculation units. Spreading of virus particles through indoor environments always occurs. Recirculation units accelerate this spread, potentially increasing contamination risks. On the other hand, recirculation will lead to more rapid reduction of the concentration of contaminants in the vicinity of the source, thereby reducing risks.

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Recirculation as such does not lead to dilution and discharge: this is affected by admixture of outdoor air.

Within individual rooms, application of recirculating units, for (additional) cooling and/or heating, is not a problem, provided the available ventilation provides a sufficient admixture of outdoor air to be fed into the room. Care should, however, be taken to prevent the occurrence of very powerful air flows in the room. These can cause the exhalation cloud to travel much further than normal, a so-called "extended plume". Such an extended plume could potentially infect persons over distances of more than one-and-a-half meters.

Recirculation of air across multiple rooms may be problematic if insufficient outdoor air is added. In buildings where the likelihood of infected persons being presented is high, and in facilities housing at risk populations, the safest option is to set the recirculation units to "outdoor air only" mode. In the Netherlands, systems recirculating air across multiple rooms are generally found only, and infrequently, in older buildings.

Proportional measures

The Corona Expert Panel recommends health service providers to take only measures that are proportionate to the risk of infection and the degree of risk reduction that can be achieved. This avoids expenditure on less urgent and less effective adjustments. It should be borne in mind that there is a reasonable suspicion of contamination by air, but that this transmission route has not been proven. Except under very high-risk circumstances, adherence to physical distancing and ventilation compliant with the national building code and the specific guidelines and professional standards for care building ventilation will be sufficient to reduce risks to acceptable levels. Minimalization of risks through ventilation measures is technically challenging and very costly, and elimination of risks through ventilation alone is impossible. Ventilation has a valuable contribution in reducing the risk of infections, but is not a panacea to reduce all COVID-19 infection risks. ■

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References

[1] Corona Expert Panel Healthcare – NL, FAQ, see https://www.tno.nl/nl/over-tno/nieuws/2020/3/expertpanel-corona-beantwoordt-vragen-ziekenhuizen/ OR https://www.royalhaskoningdhv.com/nl-nl/nederland/nieuws/nieuwsberichten/expertpanel-beantwoordt-vragen-ziekenhuizen-in-kader-corona/10709.

[2] World Health Orginisation (WHO). Report of the WHO-China Joint Mission on Coronavirus Disease 2019 (COVID-19). *Who*. 2020;2019(February):16-24.

[3] Offord C. How COVID-19 Is Spread. *Feb 21, 2020*. 2020;(Cdc):1-5.

[4] Kutter JS, Spronken MI, Fraaij PL, Fouchier RA, Herfst S. Transmission routes of respiratory viruses among humans. *Curr Opin Virol*. 2018;28:142-151. doi:10.1016/j.coviro.2018.01.001.

[5] Liu Y, Ning Z, Chen Y, et al. Aerodynamic Characteristics and RNA Concentration of SARS-CoV-2 Aerosol in Wuhan Hospitals during COVID-19 Outbreak. *bioRxiv*. 2020;86(21):2020.03.08.982637. doi:10.1101/2020.03.08.982637.

[6] Cowling BJ, Ip DKM, Fang VJ, et al. Aerosol transmission is an important mode of influenza A virus spread. 2013:1-12. doi:10.1038/ncomms2922.Aerosol.

[7] Tellier R. Review of aerosol transmission of influenza A virus. *Emerg Infect Dis*. 2006;12(11):1657-1662. doi:10.3201/eid1211.060426.

[8] Judson SD, Munster VJ. Nosocomial transmission of emerging viruses via aerosol-generating medical procedures. *Viruses*. 2019;11(10). doi:10.3390/v11100940.

[9] Tran K, Cimon K, Severn M, Pessoa-Silva CL, Conly J. Aerosol generating procedures and risk of transmission of acute respiratory infections to healthcare workers: A systematic review. *PLoS One*. 2012;7(4). doi:10.1371/journal.pone.0035797.

[10] Li Y, Huang X, Yu ITS, Wong TW, Qian H. Role of air distribution in SARS transmission during the largest nosocomial outbreak in Hong Kong. *Indoor Air*. 2005;15(2):83-95. doi:10.1111/j.1600-0668.2004.00317.x.

[11] Grosskopf K, Mousavi E. Bioaerosols in health-care environments. *ASHRAE J*. 2014;56(8):22-31.

[12] Lindsley WG, Blachere FM, Thewlis RE, et al. Measurements of airborne influenza virus in aerosol particles from human coughs. *PLoS One*. 2010;5(11). doi:10.1371/journal.pone.0015100.

[13] Moriyama M, Hugentobler WJ, Iwasaki A. Seasonality of Respiratory Viral Infections. *Annu Rev Virol*. 2020:1-19. doi:10.1146/annurev-virology-012420-022445.

[14] World Health Orginisation (WHO)-B. Modes of transmission of virus causing COVID-19 : implications for IPC precaution recommendations. *Sci Br 29 march 2020*. 2020;(March):1-3. doi:10.1056/NEJMoa2001316.5.

[15] Lednicky JA, Lauzardo M, Fan ZH, et al. Viable SARS-CoV-2 in the air of a hospital room with COVID-19 patients. 2020;(1):1-20.

[16] Fennelly KP. Particle sizes of infectious aerosols: implications for infection control. *Lancet Respir Med*. 2020;8(9):914-924. doi:10.1016/S2213-2600(20)30323-4.

[17] Chin A, Chu J, Perera M, et al. Stability of SARS-CoV-2 in different environmental conditions. *Lancet Infect Dis*. 2020;5247(20):2020.03.15.20036673. doi:10.1016/S2666-5247(20)30003-3.

[18] Doremalen N van, Bushmaker T, Morris DH, Holbrook MG, Gamble A, Williamson BN. corresp ondence Aerosol and Surface Stability of SARS-CoV-2 as Compared with SARS-CoV-1. *new engl J Med*. 2020:1-3. doi:10.1056/NEJMc2004973.

[19] Kampf G, Todt D, Pfaender S, Steinmann E. Persistence of coronaviruses on inanimate surfaces and its inactivation with biocidal agents. *J Hosp Infect*. 2020;104(3):246-251. doi:10.1016/j.jhin.2020.01.022.

[20] Xiao F, Tang M, Zheng X, Liu Y, Li X, Shan H. Evidence for gastrointestinal infection of SARS-CoV-2. *Gastroenterology*. 2020. doi:10.1053/j.gastro.2020.02.055.

[21] Xu Y, Li X, Zhu B, et al. Characteristics of pediatric SARS-CoV-2 infection and potential evidence for persistent fecal viral shedding. *Nat Med*. 2020. doi:10.1038/s41591-020-0817-4.

[22] RIVM. Bijlage bij LCI-richtlijn COVID-19 | versie 21 augustus 2020. https://lci.rivm.nl/ventilatie-en-covid-19.

[23] Jacobs P, Borsboom W. 2020 R11031 *Ventilatie in Gebouwen En de Invloed Op de Verspreiding van COVID-19*. Delft, The Netherlands; 2020.

[24] Kompatscher K, Traversari R. *TNO 2020 R11208 Rev. 1. Literatuurstudie Naar de Afstand Die Deeltjes (>5 µm) Afleggen Bij Verschillende Respiratoire Activiteiten*. Delft, The Netherlands; 2020.

[25] Jones NR, Qureshi ZU, Temple RJ, Larwood JPJ, Greenhalgh T. Two metres or one : what is the evidence for physical distancing in past viruses , argue Nicholas R Jones and colleagues. 2020:1-6. doi:10.1136/bmj.m3223.

[26] RIVM. COVID-19 Richtlijn. https://lci.rivm.nl/richtlijnen/covid-19.