COVID-19 Evidence Summary: Aerosol transmission and mitigating strategies

20/08/2020 [REDACTED], SG C-19 SAG

This rapid evidence summary is based on a timely assessment of key sources such as the UNCOVER database of reviews, PubMed, Google and key organisations (eg WHO, SAGE, CDC, EPA, ECDC, HSE and industry organisations such as CIBSE, REHVA and ASHRAE). Any additional central papers suggested by the committee will be incorporated.

Definitions: 'aerosol' and 'airborne' transmission are used in different ways by different research communities and bodies. NERVTAG use the following definition: "Aerosol – a small respiratory particle that carries the virus and can remain in the air for a long period of time (at least 5 minutes, in many cases hours). These typically have a diameter less than 10μm."

Key points

• The data on aerosol transmission are growing but remain limited. The balance of agreement is that short range aerosol transmission is possible, but that long range aerosol transmission is not supported by current evidence. A definitive answer as to the relative role of aerosol transmission has not been reached.

• Advocacy for good ventilation (increasing the amount of outdoor air coming indoors) is at a general consensus. This may necessitate additional heating in winter.

• Air conditioning may facilitate spread of droplets excreted by infected people longer distances within indoor spaces. In addition, aerosols can spread through heating, ventilating and air conditioning (HVAC) systems and stand-alone air-conditioning units *if the air is recirculated.*

• HVAC systems may decrease transmission in indoor spaces by increasing the rate of air change, decreasing the recirculation of air, and increasing the use of outdoor air.

• There are limited COVID-19 data on HVAC systems but guidance can be found from the ECDC, CDC and industry bodies

•No data on storage heaters were found. Due to limited data, the practical implications for transmission of varying temperature within an acceptable range to people remain unclear.

• HEPA filters have theoretical efficacy to filter COVID-19 but direct studies of the ability of HEPA to filter SARS-CoV-2 or impact on transmission rates have not been conducted to date.

What's the role of aerosol transmission (as per NERVTAG)?

The role of aerosol transmission in COVID-19 has been the subject of ongoing academic debate for several months(1,2). Whilst there is increasing evidence that it is possible, a definitive answer as to the relative importance of aerosol transmission is still pending.

Recent interest

Recent interest in the topic has been fuelled by two key events in July. The first was an open letter on July 6th signed by 239 experts in the field advocating for the recognition that, in their view, "airborne transmission of COVID-19 is a real risk and that control measures…must be added to the other precautions taken, to reduce the severity of the pandemic and save lives."(3)

This was followed on July 9th by the WHO officially acknowledging that aerosol transmission is possible, whilst calling for urgent research to establish the extent of the role of this in transmission(4). This was a shift instance from the WHO which had previously discussed aerosol transmission primarily in the context of 'aerosol generating' medical procedures, such as intubation, rather than in a broader context(5). (The WHO told Nature that its position was not a result of the open letter - they had been working on the brief for a month prior to the letter's publication(6))

NERVTAG/EMG summary

NERVTAG and the EMG summarised current knowledge in the field in a paper published on July 22nd (7). Key points from this paper include:

- Recognition that aerosol transmission is possible (something they have noted since January)
- That there is a 'small amount of evidence that this could happen in an indoor environment more than 2m from an infected person.'
- That there is 'currently no evidence for long range aerosol transmission where the virus is dispersed between rooms in a building or long distances outdoors.'
- That it is possible that aerosol transmission plays a role in super spreading events.

They state that the highest risk of transmission of SARS-CoV-2 remains when within 2m of an infected individual, and that it is not possible to say whether droplets, aerosols or contaminated surfaces dominate as a transmission mode in this situation. At distances beyond 2m, they note that short range aerosol transmission is possible but will be dependent on the duration of exposure, ventilation of the air, volume of virus generated by the infected person and distance to the infected individual (with those at closest proximity to the infected individual obviously at greatest risk.)

They reaffirm that there is no evidence of long-range airborne transmission. A viewpoint from researchers at Harvard Medical School published in JAMA on July 13th also states that "the balance of currently available evidence suggests that long-range aerosol-based transmission is not the dominant mode of SARS-CoV-2 transmission."(8) Others have tried

to argue that aerosol spread (not specifically long range) is actually the dominant method of transmission, however this paper was based on an ecological design which is open to many confounding factors and alternative explanations(9).

NERVTAG/EMG data

The data for the NERVTAG/EMG paper are drawn from several different study types. They discuss ongoing studies on respiratory exhalation from the US, PHE and DCMS that "confirm the increase in aerosols with the loudness of singing and speech, and also show significant variation between people" (these ongoing studies are not referenced, but are supported by 2019 data(10)). Also mentioned is a NEJM laboratory study that demonstrated the stability of the virus in the air for 3 hours with little loss of viability(11), and another that suggested infectivity could be maintained for 16 hours in respirable aerosols(12). NERVTAG/EMG caution that this will likely depend on environmental conditions, given evidence of significant differences in virus half-life based on UV exposure(13).

Data supporting transmission of SARS-CoV-2 in the absence of direct interaction from animal studies is also mentioned, but also highlighted is that establishing the role of aerosols, rather than droplets, is not feasible because the cages were only cm apart. Data from clinical settings is reported as largely returning negative results for the presence of the virus in the air, but that some have found viral RNA in spaces such as patient rooms and staff areas. They don't reference these studies or note if any looked for infectious virus. The paper does highlight one preprint which claims to have found infectious virus in hospital rooms(14), but the evidence review says virology experts have cast doubt on the work. Another paper published since the NERVTAG/EMG review has also reported to have found viable virus in a hospital room, but again this is a preprint and consequently has not been peer reviewed(15).

Frequently cited in discussions about aerosol transmission are key outbreak events, in particular a choir(16), a restaurant(17) and a fitness centre(18). Whilst the exact routes of transmission in these examples have not been ascertained, it has been noted by both NERVTAG and other academics(19) that the events are difficult to explain without airborne transmission being involved.

In closing their discussion of the evidence base, NERVTAG/EMG reflect on the fact that there is no definitive evidence for airborne transmission of SARS-CoV-2. They balance this by pointing out that such conclusive evidence is also lacking for close-range droplet or surface contact transmission.

Additional views

Other notable organisations have also reflected on the issue of aerosol transmission, and generally agree that aerosol transmission is possible but that defining the extent of the role is difficult:

The ECDC state: "Infection is understood to be mainly transmitted via large respiratory droplets containing the SARS-CoV-2 virus. Transmission through aerosols has also been implicated but the relative role of large droplets and aerosols is still unclear."(20)

The CDC state that transmission is primarily through respiratory droplets. They go on to say that whilst "Current data do not support long range aerosol transmission….Short-range inhalation of aerosols is a possibility"(21)

The EPA have said "The relative importance of this potential route of SARS-CoV2 transmission in comparison to others (close-contact, fomites) has not been established at this point. This increasing weight of evidence supports the use of precautions against transmission of SARS-Co-V- 2 in indoor environments as an addition to other measures already known to limit it."(22) *(Note: the EPA provides an abundance of references on the subject of aerosol transmission in indoor environments)*

In a literature review published as a viewpoint in the Lancet Respiratory Medicine on 24 July, Kevin P Fennelly of the NIH argues that the traditional view of the primacy of respiratory droplets we see demonstrated by many organisations should be reviewed. This is in light of his work which found a predominance of pathogens in small particles (<5 μm) across a range of different pathogens. He noted an absence of cough or breath aerosol studies for COVID-19 to date, but suggests "Airborne infection control measures are indicated for potentially lethal respiratory pathogens such as severe acute respiratory syndrome coronavirus 2." However, this was not a systematic review and the search strategy was limited. (23)

Future work

This is an area of ongoing investigation, as outlined by the Evidence Review Team within the SG COVID-19 Modelling and Analysis Team (document supplied by SG):

"Developing the evidence base around airborne and wider transmission (including in different settings and contexts, such as when singing) features within the priority research questions being considered by selected SAGE sub-groups, such as the Environmental and Modelling Group. We understand research questions under consideration include (but are not limited to):

- The role of buildings in outbreaks, the impact of different environments and ways of preventing transmission in indoor workplaces
- The effects of aerosols mixing with other particles in the atmosphere
- The impact of open air on virus survival"

What advice should settings (and especially schools) be given about ventilation, use of air conditioning and storage heaters as we go into winter?

In their aforementioned open letter, the 239 experts advocated for three main measures to mitigate against airborne transmission of COVID-19(3):

- Provide sufficient and effective ventilation (supply clean outdoor air, minimize recirculating air) particularly in public buildings, workplace environments, schools, hospitals, and aged care homes.
- Supplement general ventilation with airborne infection controls such as local exhaust, high efficiency air filtration, and germicidal ultraviolet lights.
- Avoid overcrowding, particularly in public transport and public buildings

Ventilation and air conditioning

Poor ventilation in confined indoor spaces is associated with increased risk of COVID-19 transmission(24) and it is reasoned that increased ventilation removes 'virus-laden air'(25). Consequently, advocacy for good ventilation (increasing the amount of outdoor air coming indoors) is a mainstay in discussions of how to reduce the transmission risk of COVID-19 in indoor spaces (7,24–27) (in addition to other key measures such as physical distancing and hand hygiene).

Both the CDC and EPA encourage opening of windows, whilst noting that settings should be mindful whether doing so doing so poses a safety or health risk (e.g., children and risk of falling)(28,29). NERVTAG/EMG recognise the challenge this may pose in the winter months, given the issues of thermal comfort posed by open windows, and note that additional heating may be required to compensate for heat losses(7). This may be particularly salient for housing of vulnerable populations.

In addition to opening windows, mechanical ventilation can be deployed through dedicated fans, outdoor air units or a heating, ventilating and air conditioning (HVAC) system. Whilst there is epidemiologic evidence that HVAC systems may have contributed to COVID-19 transmission 19 in several community settings (including a restaurant, call centre and airplane) uncertainties over the mechanism of transmission in those cases remain(30). That was the finding of a rapid evidence review from Alberta Health Services published June 5th, which also stated that: "Given the complexity in the transmission modalities of SARS-CoV-2 and other similar viruses, lack of data on viable virus in air samples, and the wide variety of HVAC systems, studies have not been able to consider and evaluate all HVAC configurations and their potential to affect transmission of infection."

Thus, there is a limited evidence base with which to offer guidance on HVAC systems to settings. Nonetheless, the ECDC have provided guidance, published on June 22nd(24), including:

• There is currently no evidence of human infection with SARS-CoV-2 caused by infectious aerosols distributed through the ventilation system air ducts. The risk is rated as very low.

• Well-maintained HVAC systems, including air-conditioning units, securely filter large droplets containing SARS-CoV-2. COVID-19 aerosols can spread through HVAC systems within a building or vehicle and stand-alone air-conditioning units if the air is recirculated.

• The airflow generated by air-conditioning units may facilitate the spread of droplets excreted by infected people longer distances within indoor spaces.

• HVAC systems may have a complementary role in decreasing transmission in indoor spaces by increasing the rate of air change, decreasing the recirculation of air, and increasing the use of outdoor air.

• Building administrators should maintain heating, ventilation, and air-conditioning systems according to the manufacturer's current instructions, particularly concerning the cleaning and changing of filters. There is no benefit or need for additional maintenance cycles in connection with COVID-19.

Other points included extending operating times, increasing air exchanges per hour and avoiding both the use of recirculation and the use of energy-saving settings.

The CDC also offer practical advice to employers on how to improve ventilation(29), whilst encouraging that this be done in consultation with an HVAC professional. This is because HVAC systems are typically complex, but can be customised by an HVAC engineer with specialist knowledge of the system. Leading industry organisations such as ASHRAE(31–33) (The American Society of Heating, Refrigerating, and Air-conditioning Engineers), REHVA(34) (The Federation of European Heating, Ventilation and Air Conditioning associations) and CIBSE(35) (Chartered Institution of Building Services Engineers) have produced guidance on how to mitigate COVID-19 transmission by modifying HVAC systems.

Storage heaters

No studies on storage heaters and COVID-19 were identified. Whilst there has been much discussion of environmental weather impacts on COVID-19(36), little was found examining indoors temperature and the variation in stability that might be expected from different temperatures within a range acceptable to human habitation in a classroom or office.

One laboratory study carried out over 9 days found "surface stability of SARS-CoV-2 does not display major differences at 4°C, RT (room temperature) and 30°C" (37) However this lab based study kept humidity stable. Another found variation in stability with temperature (no significance levels stated), but the temperatures studied were not representative of a range that you might reasonably choose to vary and expect someone to work or learn in (4C, 22C, 37C)(38) Finally a preprint study of nasal mucus and sputum at 4C, 21C and 27C found "SARS-CoV-2 was generally more stable at cooler temperatures and lower RH (relative humidity), and less stable at warmer temperatures and higher RH. Nevertheless…we predicted that SARS-CoV-2 would remain infectious in nasal mucus and sputum on surfaces for >10–12 hours even in warm, humid conditions." Thus the practical implications for transmission of varying temperature within an acceptable range to people remain unclear (39).

What role might HEPA filters play in that?

High-Efficiency Particulate Air (HEPA) filters are typically created through the pleating of microfiber glass or other fibrous material made with multiple layers of randomly arranged fibres, with diameters of 2 to 500 nm. To meet the definition of HEPA grade, a filter must

remove at least 99.97% of all 0.15 to 0.2 μm particles. These are the particle sizes for which HEPA filters are *least* effective, due to the U-shaped efficiency curve of HEPA filters. Thus, HEPA filters have at least 99.97% efficiency for removing all particles, with higher efficiencies for particles both larger and smaller than 0.15 μm(40).

It's believed that most aerosols produced by a human cough are <1 μm, and the SARS-CoV-2 virion itself is thought to be 0.06-0.14 μm, which suggests theoretical efficacy for HEPA filters to remove airborne SARS-CoV-2. However, it is important to emphasize that direct studies of the ability of HEPA to filter SARS-CoV-2 have not been conducted to date(40).

Prior to COVID-19, HEPA filters were used in healthcare contexts that demanded particular protection eg operating rooms designated for orthopaedic implant procedures, or Protective Environment rooms(41). Much of the literature that does exist on HEPA filters and COVID-19 involves descriptions of their use in operating theatres (without evaluation of efficacy) eg (42).

Currently, the CDC recommends their use in certain healthcare contexts (43) and as of July 9th suggests employers beyond healthcare settings consider using portable HEPA systems to "help enhance air cleaning (especially in higher-risk areas)"(29). ASHRAE, an industry body, also advocates for the use of portable HEPA filters in classrooms, residence halls and businesses(32,33)

In addition to portable filtration systems, the EPA also reports on HEPA on HVAC systems, stating that "EPA, ASHRAE and CDC recommend upgrading air filters to the highest compatible with the system"(44). The CDC also suggest using a HEPA filter in a hoover when vacuuming in a school, business or community facility (whilst also acknowledging that there are no reported cases associated with vacuuming)(45).

In a paper from 19th May, the EMG examined air filtering approaches (amongst it some HEPA data) and COVID-19, and concluded: "Local air cleaning devices, including filter devices and UV-C devices – which may be found in combination - are unlikely to have significant benefit unless the airflow rate through the device is sufficient. There may be some poorly ventilated spaces where these may be useful."(46)

There are no data that demonstrate what the impact of HEPA filters on actual transmission rates of COVID-19 would be in community contexts. Moreover, their installation and maintenance costs can be high compared to other filter types(41), and on a practical note, McKinsey highlight that "Only some air conditioners can accommodate HEPA filters, and technicians must configure them properly and replace them regularly…. Upgrading HVAC systems by incorporating higher grade filters can be very expensive and is not always feasible."(47)

Note: Whilst researching the questions around HEPA, ventilation, storage heaters and air con, several discussions were found on UV disinfection and COVID-19:

29th June: Powell. Is air conditioning helping spread COVID in the South? The Harvard Gazette https://news.harvard.edu/gazette/story/2020/06/air-conditioning-may-be-factor-in-covid-19-spread-in-the-south/

24th June: Buonanno et al. Far-UVC light (222 nm) efficiently and safely inactivates airborne human coronaviruses. *Sci Rep* **10,** 10285 (2020) https://www.nature.com/articles/s41598-020-67211-2

27th May: Morawska et al. How can airborne transmission of COVID-19 indoors be minimised? Environ Int. 2020;142:105832. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7250761/

19th May: EMG for SAGE: UV disinfection, visible light, local air filtration and fumigation technologies https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/904656/S0440_EMG_-_Application_of_UV_disinfection_visible_light_local_air_filtration_and_fumigation.pdf

7th April: Dietz et al. 2019 Novel Coronavirus (COVID-19) Pandemic: Built Environment Considerations To Reduce Transmission mSystems. 2020;5(2):e00245-20. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7141890/

References

1. Allen J, Marr L. Re-thinking the Potential for Airborne Transmission of SARS-CoV-2. 2020 May 7 [cited 2020 Aug 19]; Available from: https://www.preprints.org/manuscript/202005.0126/v1

2. Anderson EL, Turnham P, Griffin JR, Clarke CC. Consideration of the Aerosol Transmission for COVID-19 and Public Health. Risk Anal. 2020;40(5):902–7.

3. Morawska L, Milton DK. It is Time to Address Airborne Transmission of COVID-19. Clin Infect Dis [Internet]. 2020 Jul 6 [cited 2020 Aug 19]; Available from: https://academic.oup.com/cid/advance-article/doi/10.1093/cid/ciaa939/5867798

4. WHO. Transmission of SARS-CoV-2: implications for infection prevention precautions [Internet]. 2020 [cited 2020 Aug 19]. Available from: https://www.who.int/news-room/commentaries/detail/transmission-of-sars-cov-2-implications-for-infection-prevention-precautions

5. WHO. Modes of transmission of virus causing COVID-19: implications for IPC precaution recommendations [Internet]. 2020 [cited 2020 Aug 19]. Available from:

https://www.who.int/news-room/commentaries/detail/modes-of-transmission-of-virus-causing-covid-19-implications-for-ipc-precaution-recommendations

6. Lewis D. Mounting evidence suggests coronavirus is airborne — but health advice has not caught up. Nature. 2020 Jul 8;583(7817):510–3.

7. NERVTAG/EMG: Role of aerosol transmission in COVID-19, 22 July 2020 [Internet]. GOV.UK. 2020 [cited 2020 Aug 19]. Available from: https://www.gov.uk/government/publications/nervtagemg-role-of-aerosol-transmission-in-covid-19-22-july-2020

8. Klompas M, Baker MA, Rhee C. Airborne Transmission of SARS-CoV-2: Theoretical Considerations and Available Evidence. JAMA. 2020 Jul 13;

9. Zhang R, Li Y, Zhang AL, Wang Y, Molina MJ. Identifying airborne transmission as the dominant route for the spread of COVID-19. Proc Natl Acad Sci. 2020 Jun 30;117(26):14857–63.

10. Asadi S, Wexler AS, Cappa CD, Barreda S, Bouvier NM, Ristenpart WD. Aerosol emission and superemission during human speech increase with voice loudness. Sci Rep. 2019 Feb 20;9(1):2348.

11. van Doremalen N, Bushmaker T, Morris DH, Holbrook MG, Gamble A, Williamson BN, et al. Aerosol and Surface Stability of SARS-CoV-2 as Compared with SARS-CoV-1. N Engl J Med. 2020 Apr 16;382(16):1564–7.

12. Fears AC, Klimstra WB, Duprex P, Hartman A, Weaver SC, Plante KS, et al. Early Release - Persistence of Severe Acute Respiratory Syndrome Coronavirus 2 in Aerosol Suspensions - Volume 26, Number 9—September 2020 - Emerging Infectious Diseases journal - CDC. [cited 2020 Aug 19]; Available from: https://wwwnc.cdc.gov/eid/article/26/9/20-1806_article

13. Schuit M, Ratnesar-Shumate S, Yolitz J, Williams G, Weaver W, Green B, et al. Airborne SARS-CoV-2 is Rapidly Inactivated by Simulated Sunlight. J Infect Dis [Internet]. 2020 Jun 11 [cited 2020 Aug 19]; Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7313838/

14. Santarpia JL, Herrera VL, Rivera DN, Ratnesar-Shumate S, Reid SP, Denton PW, et al. The Infectious Nature of Patient-Generated SARS-CoV-2 Aerosol. medRxiv. 2020 Jul 21;2020.07.13.20041632.

15. Lednicky JA, Lauzardo M, Fan ZH, Jutla AS, Tilly TB, Gangwar M, et al. Viable SARS-CoV-2 in the air of a hospital room with COVID-19 patients. medRxiv. 2020 Aug 4;2020.08.03.20167395.

16. Hamner L. High SARS-CoV-2 Attack Rate Following Exposure at a Choir Practice — Skagit County, Washington, March 2020. MMWR Morb Mortal Wkly Rep [Internet]. 2020 [cited 2020 Aug 19];69. Available from: https://www.cdc.gov/mmwr/volumes/69/wr/mm6919e6.htm

17. Lu J, Gu J, Li K, Xu C, Su W, Lai Z, et al. COVID-19 Outbreak Associated with Air Conditioning in Restaurant, Guangzhou, China, 2020 - Volume 26, Number 7—July 2020 - Emerging Infectious Diseases journal - CDC. [cited 2020 Aug 19]; Available from: https://wwwnc.cdc.gov/eid/article/26/7/20-0764_article

18. Jang S, Han SH, Rhee J-Y. Cluster of Coronavirus Disease Associated with Fitness Dance Classes, South Korea - Volume 26, Number 8—August 2020 - Emerging Infectious Diseases journal - CDC. [cited 2020 Aug 19]; Available from: https://wwwnc.cdc.gov/eid/article/26/8/20-0633_article

19. Mandavilli A. The Coronavirus Can Be Airborne Indoors, W.H.O. Says. The New York Times [Internet]. 2020 Jul 9 [cited 2020 Aug 19]; Available from: https://www.nytimes.com/2020/07/09/health/virus-aerosols-who.html

20. ECDC. Transmission of COVID-19 [Internet]. European Centre for Disease Prevention and Control. [cited 2020 Aug 19]. Available from: https://www.ecdc.europa.eu/en/covid-19/latest-evidence/transmission

21. CDC. Coronavirus Disease 2019 (COVID-19) [Internet]. Centers for Disease Control and Prevention. 2020 [cited 2020 Mar 20]. Available from: https://www.cdc.gov/coronavirus/2019-ncov/lab/guidelines-clinical-specimens.html

22. US EPA O. Indoor Air and COVID-19 Key References and Publications [Internet]. US EPA. 2020 [cited 2020 Aug 19]. Available from: https://www.epa.gov/coronavirus/indoor-air-and-covid-19-key-references-and-publications

23. Fennelly KP. Particle sizes of infectious aerosols: implications for infection control. Lancet Respir Med [Internet]. 2020 Jul 24 [cited 2020 Aug 19];0(0). Available from: https://www.thelancet.com/journals/lanres/article/PIIS2213-2600(20)30323-4/abstract

24. Heating, ventilation and air-conditioning systems in the context of COVID-19 [Internet]. European Centre for Disease Prevention and Control. 2020 [cited 2020 Aug 19]. Available from: https://www.ecdc.europa.eu/en/publications-data/heating-ventilation-air-conditioning-systems-covid-19

25. Morawska L, Tang JW, Bahnfleth W, Bluyssen PM, Boerstra A, Buonanno G, et al. How can airborne transmission of COVID-19 indoors be minimised? Environ Int. 2020 Sep;142:105832.

26. US EPA O. Indoor Air and Coronavirus (COVID-19) [Internet]. US EPA. 2020 [cited 2020 Aug 19]. Available from: https://www.epa.gov/coronavirus/indoor-air-and-coronavirus-covid-19

27. HSE. Air conditioning and ventilation during the coronavirus outbreak - HSE news [Internet]. 2020 [cited 2020 Aug 19]. Available from: https://www.hse.gov.uk/coronavirus/equipment-and-machinery/air-conditioning-and-ventilation.htm

28. US EPA O. Ventilation and Coronavirus (COVID-19) [Internet]. US EPA. 2020 [cited 2020 Aug 19]. Available from: https://www.epa.gov/coronavirus/ventilation-and-coronavirus-covid-19

29. CDC. Communities, Schools, Workplaces, & Events [Internet]. Centers for Disease Control and Prevention. 2020 [cited 2020 Aug 19]. Available from: https://www.cdc.gov/coronavirus/2019-ncov/community/office-buildings.html

30. Alberta Health Services. COVID-19 Scientific Advisory Group Rapid Evidence Report [Internet]. 2020 Jun. Available from: https://www.albertahealthservices.ca/assets/info/ppih/if-ppih-covid-19-sag-risk-transmission-hvac-systems-rapid-review.pdf

31. Stewart EJ, Schoen LJ, Mead K, Olmsted RN, Sekhar C, Vernon W, et al. ASHRAE Position Document on Infectious Aerosols. 2020;24.

32. ASHRAE. Commercial [Internet]. 2020 [cited 2020 Aug 20]. Available from: https://www.ashrae.org/technical-resources/commercial#general

33. ASHRAE. Reopening of Schools and Universities [Internet]. 2020 [cited 2020 Aug 20]. Available from: https://www.ashrae.org/technical-resources/reopening-of-schools-and-universities

34. REHVA. COVID-19 Guidance [Internet]. REHVA. 2020 [cited 2020 Aug 19]. Available from: https://www.rehva.eu/activities/covid-19-guidance?no_cache=1

35. CIBSE. CORONAVIRUS, SARS-COV-2, COVID-19 AND HVAC SYSTEMS [Internet]. 2020. Available from: https://www.cibse.org/coronavirus-covid-19/coronavirus-covid-19-and-hvac-systems

36. Spencer, Brassey, Jefferson, Heneghan. Environmental Weather Conditions and Influence on Transmission of SARS-CoV-2 [Internet]. CEBM. 2020 [cited 2020 Aug 19]. Available from: https://www.cebm.net/covid-19/weather-conditions-sars-cov-2/

37. Kratzel A, Steiner S, Todt D, V'kovski P, Brueggemann Y, Steinmann J, et al. Temperature-dependent surface stability of SARS-CoV-2. J Infect. 2020 Sep 1;81(3):452–82.

38. Chin AWH, Chu JTS, Perera MRA, Hui KPY, Yen H-L, Chan MCW, et al. Stability of SARS-CoV-2 in different environmental conditions. Lancet Microbe. 2020 May 1;1(1):e10.

39. Matson MJ, Yinda CK, Seifert SN, Bushmaker T, Fischer RJ, Doremalen N van, et al. Early Release - Effect of Environmental Conditions on SARS-CoV-2 Stability in Human Nasal Mucus and Sputum - Volume 26, Number 9—September 2020 - Emerging Infectious Diseases journal - CDC. [cited 2020 Aug 19]; Available from: https://wwwnc.cdc.gov/eid/article/26/9/20-2267_article

40. Christopherson DA, Yao WC, Lu M, Vijayakumar R, Sedaghat AR. High-Efficiency Particulate Air Filters in the Era of COVID-19: Function and Efficacy: Otolaryngol Neck

Surg [Internet]. 2020 Jul 14 [cited 2020 Aug 20]; Available from: https://journals.sagepub.com/doi/10.1177/0194599820941838?url_ver=Z39.88-2003&rfr_id=ori%3Arid%3Acrossref.org&rfr_dat=cr_pub++0pubmed

41. CDC. Air | Background | Environmental Guidelines | Guidelines Library | Infection Control | CDC [Internet]. 2019 [cited 2020 Aug 20]. Available from: https://www.cdc.gov/infectioncontrol/guidelines/environmental/background/air.html

42. Perrone G, Giuffrida M, Bellini V, Lo Coco A, Pattonieri V, Bonati E, et al. Operating Room Setup: How to Improve Health Care Professionals Safety During Pandemic COVID-19-A Quality Improvement Study. J Laparoendosc Adv Surg Tech A. 2020 Aug 14;

43. CDC. Interim Infection Prevention and Control Recommendations for Healthcare Personnel During the Coronavirus Disease 2019 (COVID-19) Pandemic [Internet]. Centers for Disease Control and Prevention. 2020 [cited 2020 Aug 20]. Available from: https://www.cdc.gov/coronavirus/2019-ncov/hcp/infection-control-recommendations.html

44. US EPA O. Air Cleaners, HVAC Filters, and Coronavirus (COVID-19) [Internet]. US EPA. 2020 [cited 2020 Aug 20]. Available from: https://www.epa.gov/coronavirus/air-cleaners-hvac-filters-and-coronavirus-covid-19

45. CDC. Coronavirus Disease 2019 (COVID-19) FAQs [Internet]. Centers for Disease Control and Prevention. 2020 [cited 2020 Aug 20]. Available from: https://www.cdc.gov/coronavirus/2019-ncov/faq.html

46. EMG: Application of UV disinfection, visible light, local air filtration and fumigation technologies to microbial control, 19 May 2020 [Internet]. GOV.UK. [cited 2020 Aug 20]. Available from: https://www.gov.uk/government/publications/emg-application-of-uv-disinfection-visible-light-local-air-filtration-and-fumigation-technologies-to-microbial-control-19-may-2020

47. McKinsey and Co. Can HVAC systems help prevent the transmission of COVID-19? [Internet]. 2020 Jul. Available from: https://www.mckinsey.com/~/media/McKinsey/Industries/Advanced%20Electronics/Our%20Insights/Can%20HVAC%20systems%20help%20prevent%20transmission%20of%20COVID19/Can-HVAC-systems-help-prevent-transmission-of-COVID-19-final.pdf