Nordic collaboration to reduce transmission of viral disease in indoor air

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Preface

During spring 2020 Chalmers' Areas of Advance initiated a joint effort aiming at rapid actions related to the Corona crisis. The intention was to initiate short-term projects for developing new knowledge. The present project was funded by the Energy Area of Advance.

The project contributes to building up knowledge regarding how to substantially reduce risks of spreading the SARS-CoV-2 and any other pathogens in indoor environments. The project is reported in the form of a knowledge review on the topic in question and a proposal for further actions.

The project has enabled Chalmers to participate in the work of the Nordic expert group NVG (Nordic Ventilation Group). Related to the SARS-CoV-2 pandemic, the overall aim of NVG is to contribute to providing important input to any revisions of building codes, standards, guidelines, and operational procedures, to better address the preparedness for future epidemics and protection of individuals against the transmission of infectious pathogens in our societies.

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1. Background

According to the WHO, the coronavirus SARS-CoV-2 has led to over 72 million infected persons and more than 1.6 million deaths worldwide to date (mid December 2020). The health and economic effects of the pandemic pose major social challenges for practically all countries. Throughout the year (2020) governments, academy and business actors have sought ways to prevent the spread of the virus in order to avoid drastic measures such as lockdowns. Despite this, the pandemic rages at an even higher intensity by the end of the first year of the pandemic.

The main transmission route of the SARS-CoV-2 virus is typically considered to be direct human-to-human contact, in conjunction with occasions when people secrete the virus as droplets by sneezing or coughing etc. A recommendation to keep a minimum distance of 1.5-2 m (social distancing) is a commonly recommended precaution. There are authorities and other influential actors that claim that the COVID-19 disease is not transmitted by airborne virus-carrying particles, implying that ventilation is not an important factor in this context. However, the possible and potential airborne spread of the SARS-CoV-2 virus has been suggested by vast groups of researchers and trade organizations (e.g. SCANVAC, REHVA, ASHRAE). Thus, there are opposing views on this matter, among authority officials, and among scientists.

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Both in Europe and in the US actions have been recommended to prevent the spread of the virus within buildings. In the Nordic countries, SCANVAC (www.scanvac.eu), has formed a group of experts in the field of ventilation and air filtration. The group, denominated the Nordic Ventilation Group (NVG), has about 20 members (see Appendix A) of which one is Chalmers, contributing with expertise within safety ventilation and all aspects of indoor air quality.

2. Purpose and aim

The purpose of the present project is to gather information regarding methods to substantially reduce risks of spreading the SARS-CoV-2 virus in indoor environments. The intention is also to initiate Chalmers to participate in the work of the Nordic expert group NVG. The overall and long-term aim is to contribute to providing important input to any revisions of building codes, standards, guidelines, and operational procedures, to better address the preparedness for future epidemics and protection of individuals against the transmission of infectious pathogens in our societies.

3. Activities and contacts

The following activities have been carried out within the scope of the present project:

1. A signed petition for measures against airborne transmission of infectious diseases
    a. Early 2020 a group of about 20 researchers signed a petition for measures against airborne transmission of infectious diseases. (https://www.scanvac.eu/scanvac-petition.html
    b. The petition was translated to Swedish and published by the Swedish trade organization EMTF https://www.energi-miljo.se/medlemsnytt/oppet-brev-scanvac-begaran-om-atgarder-mot-luftburen-overforing-av-infektionssjukdomar).
2. The new Nordic expert group on ventilation and air cleaning (NVG) was initiated during 2020 and a digital communications platform has been established. Group meetings are being held on a regular basis and data are being shared among the members.
3. A brief literature review has been carried out with focus on airborne spread of biological pathogens.
4. A theoretical model for estimation of airborne pathogen transmission has been summarized.

This report comprises a knowledge review and a proposal for how Chalmers can and should join forces with other representatives of the academy and with organizations representing both authorities and practitioners, in order to contribute to an enhanced preparedness to prevent airborne spread of infectious disease in indoor environments.

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4. Summary and suggestions for further actions

- There is reason to harmonize the guidance from Swedish authorities related to the role of ventilation system operation. Today there are substantial differences regarding the information and guidance from the Swedish authorities.
- Consistent information and guidance are provided by European organizations within public health on one hand, and within engineering on the other. This guidance needs to be further scrutinized, developed and disseminated.
- A theoretical basis for assessing the risk of disease transmission in indoor environments is available. There is reason to develop an engineering tool with the aim to provide aid for:
    - risk assessment and analysis of existing environments
    - design of ventilation solutions for future safe indoor environments
- The expert group NVG has formed a platform for its communication
    - Work is in progress within several prioritized areas, some of which are briefly described in Appendix B
    - Publications are planned, in the first run as a special issue of the REHVA European HVAC Journal (https://www.rehva.eu/rehva-journal)
    - The development of the activities within NVG will be shared with decision makers, academies and practitioners within the participating countries. In Sweden, the suggestion is to accomplish this primarily through communication with, and publication through, the trade organization EMTF and the networks of building owners BELOK and BEBO

5. Introduction to SARS-CoV-2 transmission routes

The main transmission route of virus carrying particles (a.k.a. viral droplets) was at an early stage considered to be direct human-to-human contact, in conjunction with occasions when people sneeze or cough and thus secrete the virus as droplets. Because these droplets are large and heavy, they fall quickly to the ground and can travel short distances in the air only. The recommendation to keep a minimum distance of 1.5 m to 2 m (social distancing) is based on this assumption. However, COVID-19 outbreaks have also been recorded, where the pathogens seem to have travelled far longer distances in the air [CEBM, 2020; Chirico et al., 2020; EFFAT, 2020; Hamner et al. 2020; Lednicky et al. 2020; Qian et al. 2020; Santarpia et al., 2020a]. This has been the case especially when many people have been present in one room simultaneously (e.g. at choir rehearsals). There are also reports of so called superspreading events where the viral droplets have been transported by strong air-currents through a room, e.g. by the fan in an air-condi-

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tioning unit [Li et al., 2020; Miller et al. 2020]. Traces of the SARS-CoV-2 virus has also been found in the interior of the extract air ducts in ventilation systems, even quite far from the room where the source of the pathogen may have been located [Nissen et al., 2020; Horve et al. 2020].

Small droplets and droplet nuclei are constituents of aersosols and may remain airborne for extended periods. Larger droplets settle rapidly by gravity. The difference between small and large in this context has been debated. It has erroneously been claimed that particles smaller than 5 μm are airborne aerosol particles and particles larger than 5 μm are droplets that settle rapidly. Such misconceptions – unfortunately longstanding – is not based on aerosol science. Table 1 indicate entirely different particle size spans and also indicates that the pathway of the exposure changes with particle size.

No sharp distinction between aerosol particles and depositing particles can be made, which is illustrated in the subsequent chapter on theoretical modeling of particle transport. Instead, there is a transition zone covering quite a large particle size span [Jayaweera et al, 2020; Prather et al., 2020].

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Table 1. Terminology for particles involved in airborne disease transmission. From National Academies of Sciences, Engineering, and Medicine (2020).

Terms	Traditional Thinking (based on longstanding misconceptions, *not* informed by aerosol science)	Updated Descriptions (informed by aerosol science and exposure pathways)		
		Definition and Typical Size	Behavior in Air	Exposure Pathways
Aerosol[a]	Particle <5 µm	Stable suspension of solid and/or liquid particles in air, smaller than about 100 µm	Can remain airborne for extended time. Concentration is highest near source. Concentration decreases with distance from source but can travel farther than about 2 meters or 6 feet and build up in a room	Inhaled into respiratory system
Droplet	Particle >5 µm	Liquid particle, larger than about 100 µm	Settles quickly to the ground or on to a surface. Travels less than about 2 meters or 6 feet, except when propelled (e.g., sneezes and coughs)	Exposure via eyes, nose, or mouth at close range

[a] Aerosol is used here as a shorthand for "aerosol particle," reflecting common usage. When the physical attribute of the particle is described in this document, the term aerosol particle is used.

NOTES: The table illustrates how differences in language can contribute to confusion and prevent a shared understanding of the science. Several workshop leaders proposed terminology informed by aerosol science and emphasizing exposure path to improve communication and understanding. This table is based on concepts presented by Linsey Marr and others at the workshop.

As mentioned above, there are reports of virus transport over longer distances than a few meters from the source [Guo et al., 2020; Razzini et al. ,2020; Liu et al., 2020; Santarpia et al., 2020b; Ong et al., 2020]. Coughing, shouting, singing and speaking are activities known to produce a mix of droplets and aerosol particles [Klompas et al., 2020], i.e. a mix of particles that rapidly deposit on surfaces and particles that remain airborne for extended periods. Sometimes, it is claimed that the virus traces found far away from the source are not necessarily active and thus do not contribute to the spread of the disease. However, cultivable SARS-CoV-2 have been found airborne indoors [Lednicky et al. 2020; Santarpia et al., 2020a]. The instance the viral droplet left the source, it was apparently active. How long it remains active may depend on various factors of which two are temperature and humidity [Dietz et al., 2020]. These influencing factors are discussed in a separate section.

One reflection of the information above is that a safety distance of 1-2 m cannot be considered universally valid. The possibility of long distance SARS-CoV-2 transport must be considered, especially in indoor locations where infected and healthy people are toget-

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her for extended periods. The transmission is claimed to be particularly effective in “closed spaces”, including transmission from pre-symptomatic COVID-19 cases [Lu et al, 2020; Rothe et al., 2020; WHO 2020a]. The wording “closed spaces” is far from clear – but it indicates that it is a matter of small rooms with low ventilations rates. SARS-CoV-2 transmission has been suggested to take place in such indoor environments occupied by many people who stay for longer periods of time [Lednicky et al. 2020; Santarpia et al., 2020a]. The high occupancy density suggests that it is a matter of “short-range” aerosol transmission. The relative importance of large droplet disease transmission compared to aerosol transmission remains unclear.

6. Regulations and guidance from Swedish authorities

Two Swedish authorities issue regulations and guidance with respect to the transmission of the present corona virus disease. These are The Public Health Agency of Sweden and The Swedish Work Environment Authority. The guidance related to the context of ventilation published by these authorities are summarized below.

6.1 The Public Health Agency of Sweden

On the English version of the agency’s web-page, it is claimed (per mid December 2020) that the SARS-CoV-2 is mainly transmitted via respiratory droplets or secretions from the respiratory tract (FoHM 2020a). Such transmission happens when an infected person e.g. coughs or sneezes and the droplets reach mucous tissue in someone's eyes, nose, or mouth. It is also claimed that the droplets fall to the ground within approximately one meter from the source. It is acknowledged that the virus also can be transmitted indirectly via contaminated surfaces, but it is claimed that the risk of disease transmission by that route is considered to be very low.

The Swedish version of the agency´s web page gives a somewhat elaborated view (per mid December 2020). In addition to the statement about transmission via respiratory droplets there is a text about airborne virus disease transmission in general. The information is given that airborne disease transmission often is a matter of virus particles that reproduce in blisters on the skin and that such particles become suspended in the air. It is acknowledged that the viruses causing measles and chicken-pox can travel long distances, and that small dried droplets can cause disease if inhaled when they become sufficiently many and remain airborne. The agency informs that airborne disease transmission constitutes a smaller risk outdoors and at places with “good air change”, where the droplets quickly become diluted.

It is explicitly claimed that the Coronavirus (SARS-CoV-2) that causes Covid-19 is not transmitted as an airborne disease.

> In Swedish:
> *”Coronaviruset (SARS-CoV-2) som orsakar sjukdomen covid-19 smittar inte som luftburen smitta utan som droppsmitta”.*

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The citation in Swedish could be found on the web-page of the authority in August 2020. In mid-December the statement had been altered to *"…covid-19 räknas inte som en luftburen smitta"* (In English: covid-19 does not count as an airborne disease).

The Public Health Agency makes a statement that free-standing fans, portable air-conditioning units and other comfort-cooling systems shall be avoided in rooms occupied by more than one person. It is of special importance not to direct fans directly towards groups of people. The reason is claimed to be that there is a theoretical possibility that the fan will blow liquid droplets with viruses farther away from the source. The authority states that this may be valid also for COVID-19 even if the influence of fans on this disease, and its virus-particles, has not been studied scientifically. Thus, the authority gives the advice that fans shall not be directed towards groups of people. However, it is apparently ok to use that free-standing fans and similar devices in rooms with one person only.

Furthermore, the Agency informs that, currently, it is not clear how long the virus can survive on surfaces. The material and the surrounding humidity, temperature, and sunlight will determine how long the virus is viable. It is claimed that further studies will clarify the importance of transmission via surfaces and items for the overall spread of COVID-19.

Finally, the information is given that the risk of transmission can be decreased by keeping a distance from other people in public spaces, washing hands often with soap and warm water, avoiding touching the face, and by staying at home if feeling ill.

No guidance or other comments regarding any influence of ventilation is given (as per December 2020).

FoHM (2020a) https://www.folkhalsomyndigheten.se/the-public-health-agency-of-sweden/communicable-disease-control/covid-19/

FoHM (2020b) https://www.folkhalsomyndigheten.se/smittskydd-beredskap/utbrott/aktuella-utbrott/covid-19/om-sjukdomen-och-smittspridning/smittspridning/

6.2 The Swedish Work Environment Authority

Under the heading "Good ventilation with the new coronavirus", per mid-December, the authority makes the following statements (AV 2020a):

The new coronavirus is spread mainly by droplet infection when people are close to each other. Several organizations such as the World Health Organization, WHO, the EU's infection control authority ECDC, and others, state that infection can also be spread by droplets that remain suspended in the air. The droplets originate from infected people who sneeze, cough or talk.

Furthermore, the authority claims that ventilation normally needs to be in operation for at least one hour before the start of the working day. The authority also states that, to be on the safe side, WHO, ECDC and others recommend that ventilation be in operation

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for two hours before and two hours after the working day in order for pollutants and infectious agents to be ventilated out.

The work environment authority gives the following advice, directly related to the new coronavirus and ventilation of indoor environments: To reduce the risk of infecting others in the workplace, it is important to keep your distance. When several people work in a room with a small volume of air, the risk increases of inhaling other people's exhaled air, which may contain infectious substances. To ventilate away any infectious agents and other contaminants, the ventilation must be sufficient for the number of people working in the room. Taking frequent breaks and window airing are good ways to quickly change the air in the room and thus reduce the risks. The number of people should be limited with respect to the room volume and ventilation.

There is great variation in how well different ventilation solutions work and in how efficiently the air is exchanged. A review of the ventilation may be needed to make sure that it is working properly.

So, the Swedish Work Environment Authority acknowledges the possibility of airborne transmission and gives a set of recommendations related to ventilation system operation. However, no details are given regarding the required ventilations rates. One interpretation is that the recommendation is to ensure that the ventilation system operates properly and in accordance with general requirements and guidelines effective regardless of the present corona virus pandemic. The authority gives general information on the main risks of infection in the work environment, not specifically addressing COVID-19 (AV 2020b).

AV (2020a) https://www.av.se/inomhusmiljo/luft-och-ventilation/

AV (2020b) https://www.av.se/en/health-and-safety/diseases-infection-and-microbiological-risks/risk-of-diseases-in-the-workplace/main-risks-of-infection/

6.3 International guidance

6.3.1 Guidance from the European Centre for Disease Prevention and Control

The European Centre for Disease Prevention and Control (ECDC 2020a; ECDC 2020b) has issued guidance for public health authorities in EU/EEA countries and the UK on the ventilation of indoor spaces in the context of COVID-19. The key-messages are:

- It is now well-established that COVID-19 transmission commonly occurs in closed spaces
- If well-maintained and adapted for use in the COVID-19 pandemic, heating, ventilation and air-conditioning (HVAC) systems may have a complementary role in decreasing potential airborne transmission of SARS-CoV-2
- Four groups of non-pharmaceutical interventions (NPIs) should be considered to reduce potential airborne transmission of SARS-CoV-2 in closed spaces:
    - Control of SARS-CoV-2 sources in closed spaces

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        - Hold off persons with COVID-19 or with COVID-19-related symptoms from staying with other people in closed indoor spaces
    - Engineering controls in mechanically ventilated (by HVAC systems) and naturally ventilated closed spaces
        - Comply with best practice of maintenance and settings of HVAC systems in the context of COVID-19;
        - Ensure frequently opened windows in naturally ventilated closed spaces.
    - Administrative controls
        - Reduce occupancy of closed indoor spaces.
    - Personal protective behavior
        - Keep physical distance;
        - Practice respiratory etiquette;
        - Wear a community face mask.

Among the four groups of non-pharmaceutical interventions mentioned in the list above, one is dedicated to *Engineering controls in mechanically ventilated (by HVAC systems) and naturally ventilated closed spaces*. Guidelines and information given in this context comprise:

- Building administrators should review, maintain (including the upgrade of filters where appropriate), and monitor HVAC-systems according to the manufacturer's current instructions, particularly in relation to the cleaning and changing of filters [2]. There is no benefit or need for additional maintenance cycles in connection with COVID-19.
- The minimum number of air exchanges per hour, in accordance with the applicable building regulations, should be ensured at all times. Increasing the number of air exchanges per hour will reduce the risk of transmission in closed spaces. This may be achieved by natural or mechanical ventilation, depending on the setting [1,6,32,33,34].
- Specific recommendations for natural ventilation through opening windows and doors should be developed on an individual basis, taking into account the characteristics of the room (volume, size and function of openings, occupancy rates), the activities taking place in the room, the climatic and weather conditions, as well as energy conservation and the comfort of the users. Advice on these topics can be found in the documents referenced in this guidance [2,33,38].
- When it is not possible to measure the ventilation rate, measuring carbon dioxide air levels can be considered, especially in naturally ventilated rooms, as a surrogate of the sufficiency of ventilation. Technical guidelines recommend that the carbon dioxide concentration is kept below 800 to 1 000 ppm to ensure sufficient ventilation [2].
- Energy-saving settings, such as demand-controlled ventilation in central HVAC systems controlled by a timer or CO_2 detectors, should be assessed for their possible impact on risks of transmission. Consideration should also be given to extending the operating times of HVAC systems before and after the regular period [1,2,39].

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- Direct air flow should be diverted away from groups of individuals to avoid the dispersion of SARS-CoV-2 from infected persons and transmission to other persons. For example, in supermarkets, cashiers and customers have different levels of mobility and durations of occupancy. As a general principle, mechanical ventilation should be arranged so that it minimizes the direction of sustained air flow towards stationary persons.
- Building administrators should, with the assistance of their technical/maintenance teams, explore options to avoid the use of air recirculation as much as possible [1,2,39]. They should consider reviewing their procedures for the use of recirculation in HVAC systems based on information provided by the manufacturer or, if unavailable, seeking advice from the manufacturer.
- It is not recommended to change heating set points, cooling set points and possible humidification set points of HVAC systems as a measure to reduce potential SARS-CoV-2 transmission [2,33].
- The use of stand-alone air cleaning devices equipped with an HEPA filter or a filter with comparable efficiency level can be considered, especially in spaces in which optimal ventilation is impossible. Such 'room air cleaners', however, usually only cover small areas and need to be placed close to the people occupying the room [2]. UVGI devices, either in the ducts of HVAC systems or placed sufficiently high in rooms, can also be considered, but they should be shielded from direct vision due to the risk of causing cataracts [47]. Stand-alone air cleaning devices and UVGI devices can have a role in settings where central HVAC systems are not capable of increasing the air exchange or reducing the re-circulation of air.
- The technical specifications regarding the logistical arrangement of closed spaces, including the physical placement of HVAC systems, need to be informed by scientific evidence and technical expertise, so as to minimise the risk of transmission of SARS-CoV-2. These specifications also need to take into account the expected number of users, the different types of user, and the users' activity.

ECDC (2020a) https://www.ecdc.europa.eu/en/covid-19-pandemic

ECDC (2020b) https://www.ecdc.europa.eu/en/publications-data/heating-ventilation-air-conditioning-systems-covid-19

6.3.2 Federation of European Heating, Ventilation and Air Conditioning Associations (REHVA)

REHVA (2020) has issued a COVID-19 guidance document. The document has the title "How to operate HVAC and other building service systems to prevent the spread of the coronavirus (SARS-CoV-2) disease (COVID-19) in workplaces". The information given below relates to an update made , August 3, 2020
https://www.rehva.eu/fileadmin/user_upload/REHVA_COVID-19_guidance_document_V3_03082020.pdf

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REHVA references the ECDC-guidance as described in the previous section, and the traditional infection control hierarchy, see Figure 1. According to that hierarchy, ventilation and other HVAC-related measures (engineering) are at a higher level than application of administrative controls and personal protective equipment. REHVA claims that it therefore is very important to consider measures on ventilation and other building services systems to protect against airborne disease transmission.

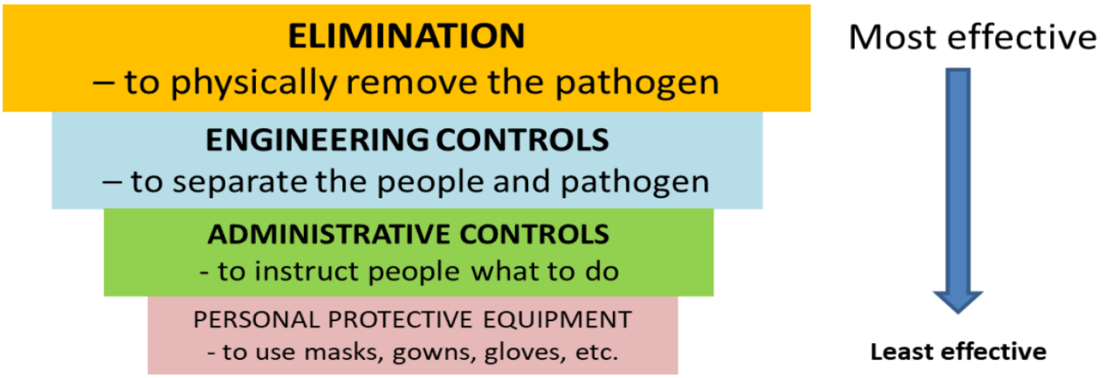

Figure 3. Traditional infection control pyramid adapted from the US Centers for Disease Control[xxiii].

Figure 1. The traditional infection control hierarchy as presented by REHVA 2020.

Briefly summarized the REHVA-guidance comprises the following practical measures for building services operation during an epidemic:

1. Provide adequate ventilation of spaces with outdoor air
2. Switch ventilation on at nominal speed at least 2 hours before the building opening time and set it to lower speed 2 hours after the building usage time
3. At nights and weekends, do not switch ventilation off, but keep systems running at a lower speed
4. Open windows regularly (even in mechanically ventilated buildings)
5. Keep toilet ventilation in operation 24/7
6. Avoid open windows in toilets to maintain the right direction of ventilation
7. Instruct building occupants to flush toilets with closed lid
8. Switch air handling units with recirculation to 100% outdoor air
9. Inspect heat recovery equipment to be sure that leakages are under control
10. Adjust fan coil settings to operate so that fans are continuously on
11. Do not change heating, cooling and possible humidification setpoints
12. Carry out scheduled duct cleaning as normal (additional cleaning is not required)
13. Replace central outdoor air and extract air filters as normal, according to the maintenance schedule
14. Regular filter replacement and maintenance works shall be performed with common protective measures including respiratory protection
15. Introduce an IAQ sensor network that allows occupants and facility managers to monitor that ventilation is operating adequately.

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6.3.3 Guidance from the Centers for Disease Control and Prevention -CDC (USA)

CDC states that COVID-19 can sometimes be spread by airborne transmission. It is explained that some infections can be spread by exposure to virus in small droplets and particles that can linger in the air for minutes to hours. Such particles may infect people who are further than 6 feet (1.8 m) away from the infected person, or even after that person has left the space.

The described spread is referred to as airborne transmission and is an important way that infections like tuberculosis, measles, and chicken pox are spread.

It is pointed out that under certain conditions airborne transmission of COVID-19 has occurred within enclosed spaces with inadequate ventilation. In some cases the transmission occurred when the infected person was breathing heavily, for example while singing or exercising. These circumstances contribute to elevated amounts of infectious smaller droplets and particles

A disclaimer is made that it likely is much more common for the SARS-CoV-2 virus to spread through close contact with an infected person than through airborne transmission. It is also claimed that COVID-19 spreads less commonly through contact with contaminated surfaces.

The CDC gives quite extensive recommendations regarding ventilation and filtration. The points given below were collected mid-December 2020 from: https://www.cdc.gov/coronavirus/2019-ncov/community/ventilation.html (CDC 2020).

Ventilation improvements may include some or all of the following considerations:

- Increase outdoor air ventilation, using caution in highly polluted areas.
- When weather conditions allow, increase fresh outdoor air by opening windows and doors. Do not open windows and doors if doing so poses a safety or health risk (e.g., risk of falling, triggering asthma symptoms) to occupants in the building.
- Use fans to increase the effectiveness of open windows. To safely achieve this, fan placement is important and will vary based on room configuration. Avoid placing fans in a way that could potentially cause contaminated air to flow directly from one person over another. One helpful strategy is to use a window fan, placed safely and securely in a window, to exhaust room air to the outdoors. This will help draw fresh air into room via other open windows and doors without generating strong room air currents.
- Decrease occupancy in areas where outdoor ventilation cannot be increased.
- Ensure ventilation systems operate properly and provide acceptable indoor air quality for the current occupancy level for each space.
- Increase airflow to occupied spaces when possible.
- Turn off any demand-controlled ventilation (DCV) controls that reduce air supply based on occupancy or temperature during occupied hours. In homes and buildings where the HVAC fan operation can be controlled at the thermostat, set the fan to the “on” position instead of “auto,” which will operate the fan continuously, even when heating or air-conditioning is not required.

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- Open outdoor air dampers beyond minimum settings to reduce or eliminate HVAC air recirculation. In mild weather, this will not affect thermal comfort or humidity. However, this may be difficult to do in cold, hot, or humid weather.
- Improve central air filtration:
  - Increase air filtration to as high as possible without significantly reducing design airflow.
  - Inspect filter housing and racks to ensure appropriate filter fit and check for ways to minimize filter bypass.
  - Check filters to ensure they are within their service life and appropriately installed.
- Ensure restroom exhaust fans are functional and operating at full capacity when the building is occupied.
- Inspect and maintain local exhaust ventilation in areas such as kitchens, cooking areas, etc. Operate these systems any time these spaces are occupied. Consider operating these systems, even when the specific space is not occupied, to increase overall ventilation within the occupied building.
- Consider portable high-efficiency particulate air (HEPA) fan/filtration systems to help enhance air cleaning (especially in higher risk areas such as a nurse's office or areas frequently inhabited by persons with higher likelihood of COVID-19 and/or increased risk of getting COVID-19).
- Generate clean-to-less-clean air movement by re-evaluating the positioning of supply and exhaust air diffusers and/or dampers (especially in higher risk areas).
- Consider using ultraviolet germicidal irradiation (UVGI) as a supplement to help inactivate SARS-CoV-2, especially if options for increasing room ventilation are limited. Upper-room UVGI systems can be used to provide air cleaning within occupied spaces, and in-duct UVGI systems can help enhance air cleaning inside central ventilation systems.

6.3.4 Guidance from the American Society of Heating Refrigerating and Air-conditioning Engineers (ASHRAE)

In April2020 ASHRAE published the following two statements regarding transmission of SARS-CoV-2 and the operation of HVAC systems during the COVID-19 pandemic: https://www.ashrae.org/about/news/2020/ashrae-issues-statements-on-relationship-between-covid-19-and-hvac-in-buildings (ASHRAE 2020a).

> *ASHRAE's statement on airborne transmission of SARS-CoV-2/COVID-19*
> Transmission of SARS-CoV-2 through the air is sufficiently likely that airborne exposure to the virus should be controlled. Changes to building operations, including the operation of heating, ventilating, and air-conditioning systems, can reduce airborne exposures.

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> *ASHRAE's statement on operation of heating, ventilating, and air-conditioning systems to reduce SARS-CoV-2/COVID-19 transmission*
> Ventilation and filtration provided by heating, ventilating, and air-conditioning systems can reduce the airborne concentration of SARS-CoV-2 and thus the risk of transmission through the air. Unconditioned spaces can cause thermal stress to people that may be directly life threatening and that may also lower resistance to infection. In general, disabling of heating, ventilating, and air-conditioning systems is not a recommended measure to reduce the transmission of the virus.

Detailed guidance is presented on the web-portal of ASHRAE: https://www.ashrae.org/technical-resources/resources (ASHRAE 2020b)

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7. Theoretical model for estimation of airborne pathogen transmission

This chapter illustrates some basics related to theoretical modeling of the spread of potentially infectious particles. First, a summary is presented regarding the removal of particles from air by deposition. Then, the theoretical approach for assessing the risk of disease transmission according to the Welles-Riley equation is summarized, together with the basic equation for air exchange and particle dilution in a ventilated room.

7.1 Particle deposition

Figure 2 shows the result from calculations of the particle settling (deposition) velocity according to the theory described in by Hinds (1999) and by Kulkarni et al. (2011). The upper curve was obtained when neglecting the drag-force that occurs at high velocities/high values of the Reynolds number. The difference is small when comparing with the case accounting for the drag at high velocities.

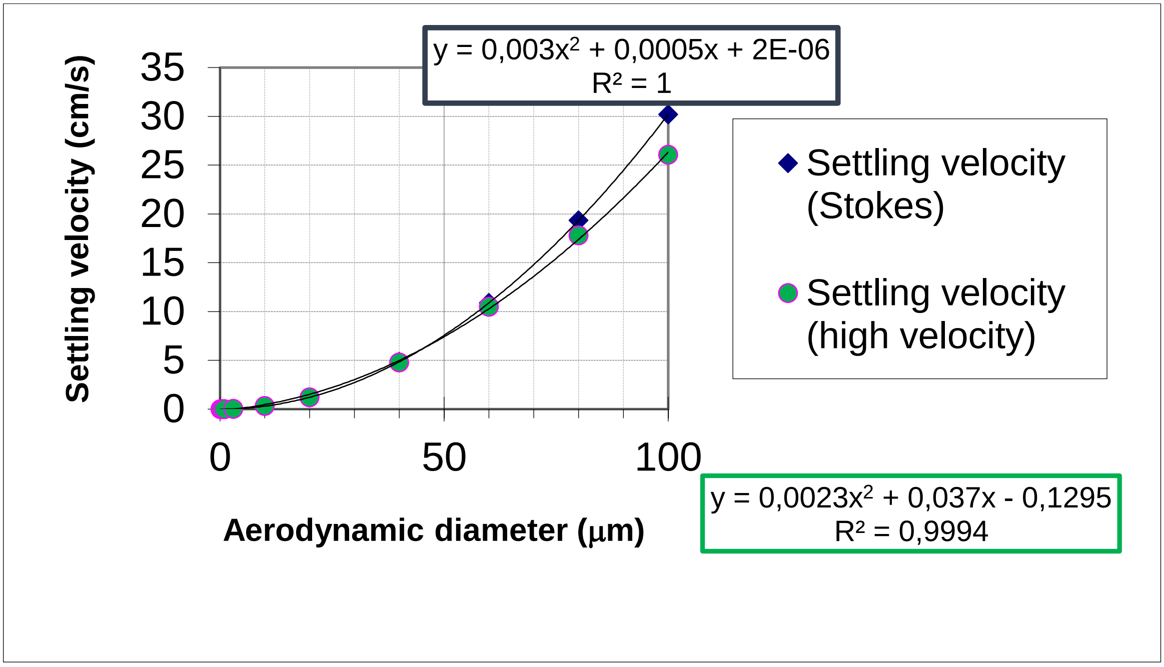

Figure 2. Particle settling velocity calculated for spherical particles of various sizes. Temperature, pressure and particle density set to 20°C, 101,3 kPa and 1 g/cm³. Theory according to Hinds (1999). Note: The regression curve (cubic polynomial) for the high velocity case (green) cannot be used for particle sizes below 30 µm due to loss of precision.

The settling velocities shown in Figure 2 was used to calculate the time it would take for the particles to settle on the floor after falling 2.0 m vertically in still air. The result is shown in Figure 3. A particle of the size 5 µm would settle from 2 m height to the floor in

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43 minutes. A 10 μm particle would settle within 10 minutes. Particles smaller than 1 μm will remain airborne for at least 8 hrs.

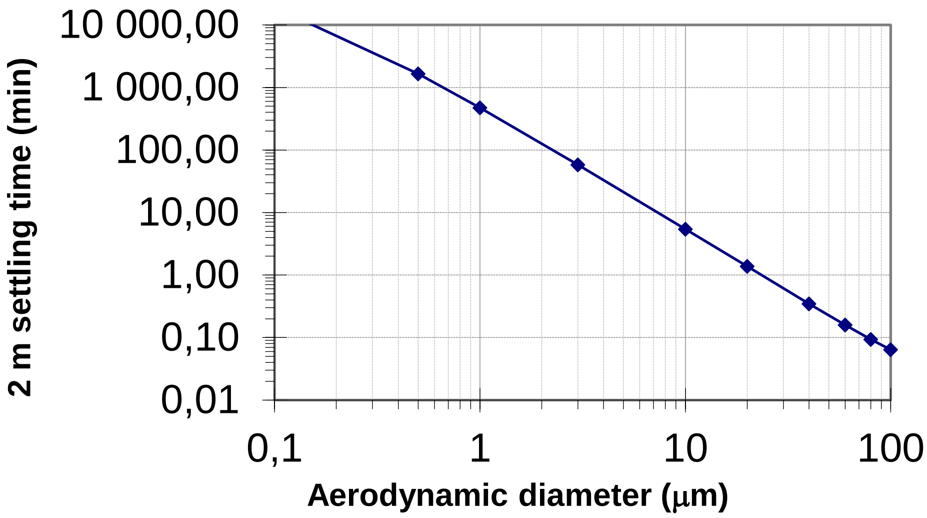

Figure 3. Settling time corresponding to the settling velocities shown in Figure 1 (data corrected for the drag at high Reynolds numbers). The calculated values represent a case where the particles fall vertically a distance of 2.0 m in still air.

Whether the settling velocities discussed above are to be considered short or long can be judged if the result is transformed to a value that can be compared to the other mechanisms of particle removal, primarily the air change rate of the room being studied. First it is suitable to calculate the magnitude of the particle removal by settling:

The removal of particles from the room air by settling can be calculated as the particle flux directed downwards due to the particle settling. The magnitude of the flux can be calculated as the product of the settling velocity and the cross-section of the room, perpendicular to the particle flux, typically the floor area. The flux will have a unit corresponding to a flow rate, and it can be transformed to e.g. m^3/h. By dividing the flux by the free air volume of the room in question we obtain the particle removal rate, which has the unit h^{-1} (the same unit as for the air change rate).

$$k_{dep} = \frac{v \times A}{V} \qquad [Eq. 1]$$

Where:

k_{dep} = particle removal rate by deposition (h^{-1})
v = particle settling velocity (m/h)
A = floor area (m^2)
V = free room volume (m^3)

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Figure 4 shows the result of calculations using Eq. 1 with settling velocities according to Figure 2 and the assumption that the ratio V/A equals 2.4 m which represents a room ceiling height of 2.4 m. Towards the low end of the particle size scale the removal rate is much lower than the removal rate that any ventilation system typically would provide. Between 1 μm and slightly larger than 10 μm the removal rate is roughly of the same magnitude as the removal by ventilation, depending on which indoor setting being considered, residential on the lower end and classrooms, laboratories etc. on the high end. Thus, for particles up to 10 to 15 μm, particle removal by ventilation will typically play an important role. For larger particles than that, the particle settling by gravity will typically dominate the total removal and, thus, ventilation will be of minor importance.

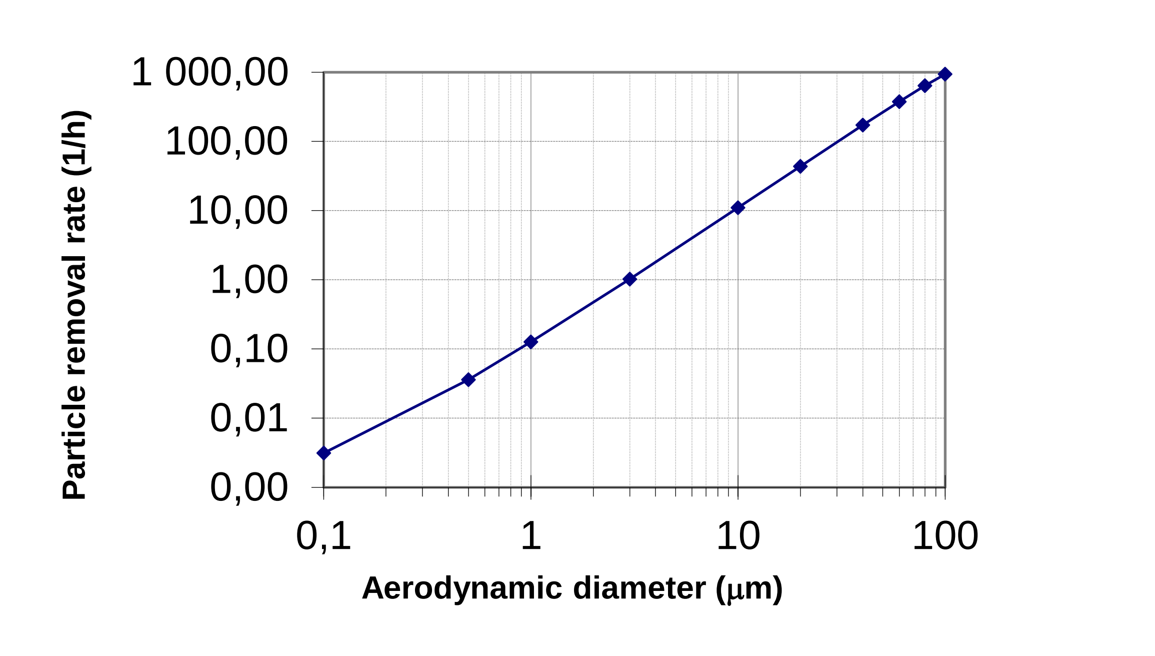

Figure 4. Particle removal rates calculated for various particle sizes. Settling velocities according to Figure 2. The V/A-ratio represents a ceiling height of 2.4 m.

Figure 5 shows the result of a simple calculation of the horizontal particle traveling distance when the particles are assumed to be released at the height 1 m above the floor with a horizontal velocity as indicated (0.1 m/s, 1.0 m/s and 3 m/s). The distances have been calculated for the particle settling velocities shown in Figure 2, and assuming that there is no other air movement in the room.

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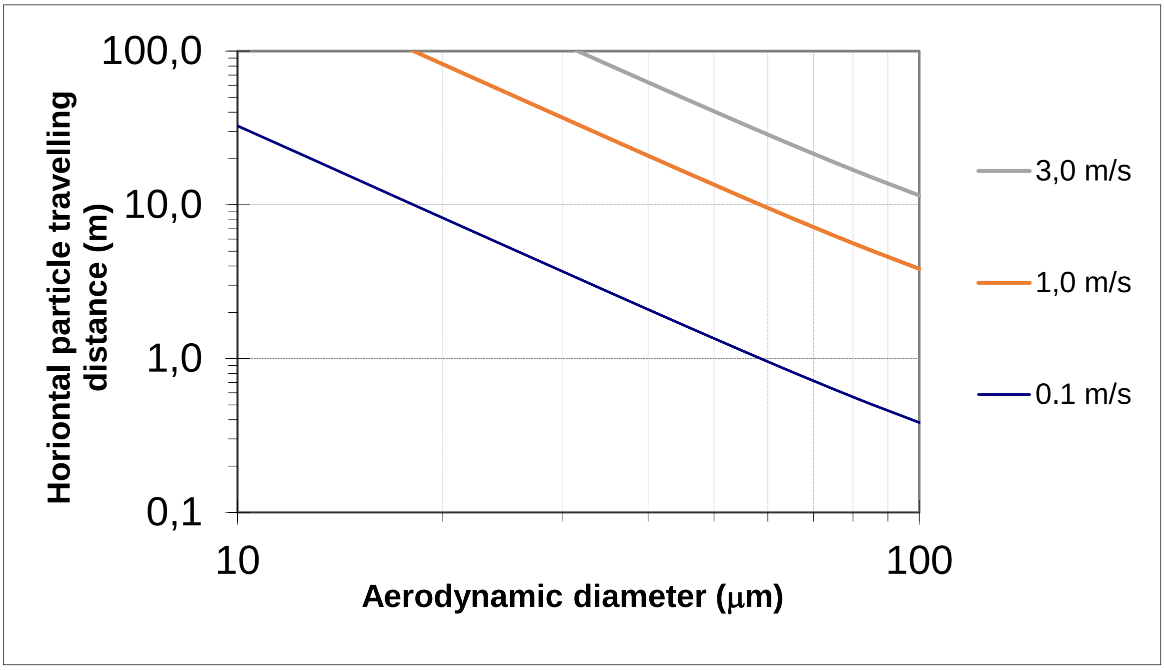

Figure 5. Horizontal particle traveling distance calculated for the particle settling velocities shown in Figure 1 for three different initial particle velocities horizontally. The particles are assumed to be released at the height 1 m above the floor with a horizontal velocity as indicated.

Examples of experimental data for comparison

Laboratory measurements by Yang et al. (2007) showed that particles produced when healthy people were coughing had a size distribution within 0.62–15.9 µm. The same publication presented data for people of various ages and for both genders. In addition data on the particle source strengths were presented.

Wang et el. (2020) studied the SARS-CoV-2 virus in human expelled particles during coughing and speaking. They reported that viruses are mostly contained in droplets larger than 10 µm and they observed virus containing particles all the way up and above 100 µm.

Dynamic modeling of transmission of SARS-CoV-2 in confined spaces carried out by Smith et al. (2020) suggests that aerosol transmission is not a very efficient route. Particularly from non-symptomatic or individuals with mild symptoms only. They concluded that highly infected people having a large viral load in their saliva and so called superspreaders producing lots of aerosols are likely far more dangerous.

Liu et al. (2016) explored a so called proximity effect of airborne exposure, which refers to a substantial increase of the concentration of airborne particles when a susceptible individual is within 1.5 m of the source patient. The effect is an additional effect to the short-range transmission of large droplets. The same publication also noted that the air speed of the exhalation or cough jets may be within 2-20 m/s, while the air movements in a room typically amounts to around 0.2–0.3 m/s.

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7.2 Airborne disease transmission

The *Wells-Riley equation* can be used for modeling airborne disease transmission in ventilated rooms. It is a general model for assessing transmission of any airborne disease. It has been used to study also transmission of the COVID-19 disease. The Wells-Riley model was originally described by Riley et al. (1978). Applications of the model have been published by Miller et al. (2020), Buonnano et al. (2020a), Buonnano et al. (2020b).

The equation is used for calculation of the average rate of infection for a given room and time period. Close contact and fomite transmission (transmission via contaminated objects) are not accounted for – only airborne transmission. Complete air mixing (equal concentration throughout the room) in one single zone is assumed. The equation is not valid close to an infected person (within 1-2 m) since the concentration of virus carrying particles will most likely be substantially higher there than in the general room air.

The concentration dynamics can be taken into account using Eq 3, the "dilution equation".

$$p = \frac{infection\ cases}{susceptibles} = 1 - e^{-\frac{E \cdot k_{br} \cdot \tau}{V \cdot \Sigma k}} \qquad \text{[Eq. 2]}$$

$$\frac{dC}{dt} = \frac{E}{V} - (k_{vent} + k_{dep} + k_{vd})C \qquad \text{[Eq. 3]}$$

Where:

E = quanta emission rate	(q/h)
k_{br} = breathing rate	(m^3/h)
τ = exposure time	(h)
V = room air volume	(m^3)
Σ_k = sum of particle (quanta) removal rates = k_{vent} + k_{dep} + k_{vd}	(h^{-1})
k_{vent} = ventilation (air change) rate	(h^{-1})
k_{dep} = particle (quanta) decay rate	(h^{-1})
k_{vd} = virus activity decay rate	(h^{-1})

Several of the input parameters are uncertain, especially the "quanta" generation rate; the source strength of pathogens/virus carrying particles. Thus, it must be acknowledged that the calculated probability of infection is uncertain, and the result should be used as a rough estimation of the order-of-magnitude. Examples of input data and calculated examples have been developed by Prof. Jarek Kurnitski and the REHVA COVID-19 Task Force; https://www.rehva.eu/covid19-ventilation-calculator

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Yet another version with suggested input data and calculated examples has been developed by Prof. Jimenez, University of Colorado-Boulder; https://tinyurl.com/covid-estimator.

One further tool, called a COVID-19 Indoor Safety Guideline, has been published by Khan, Bush, and Bazant: https://indoor-covid-safety.herokuapp.com/.

7.3 Examples of modelling results of various scenarios are presented

Below, a set of examples of calculation results based on the Welles-Riley equation are briefly summarized. Firstly, the probability of infection as a function of occupancy time for selected cases are presented according to the REHVA-model mentioned previously, see Figure 6.

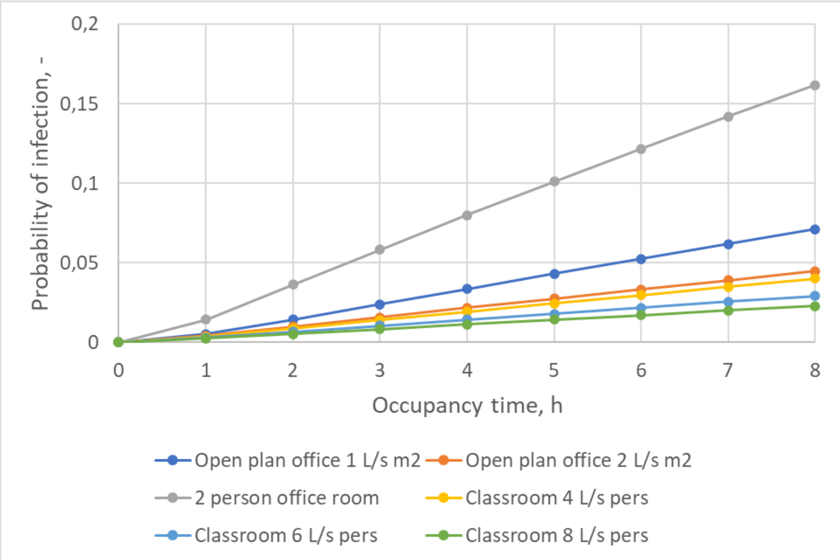

Figure 6. Probability of infection as a function of occupancy time for selected cases according to the REHVA-model (https://www.rehva.eu/covid19-ventilation-calculator).

Figures 7 and 8 presents the results from rough estimations made using Eq2. Figure 7 shows the calculated probability of infection as a function of the relative ventilation rate. Figure 8 shows the corresponding reduction of the probability of infection as a function of the relative ventilation rate. In both figures the calculations are presented for thee three risk level situations. Note that the levels are arbitrary and the celcultations are primarily made in order to explore Eq2.

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- Low risk level
    - The probability of infection is set to 1% at the nominal airflow rate having a relative value of 1.

- Intermediate risk level
    - The probability of infection is arbitrarily set to 93% at the nominal airflow rate having a relative value of 1.
    - This risk level corresponds to a situation with roughly 250 times higher quanta emission rate compared to the low risk level.

- High risk level
    - The probability of infection is arbitrarily set to 99.5% at the nominal airflow rate having a relative value of 1.
    - This risk level corresponds to a situation with roughly twice the quanta emission rate compared to the intermediate risk level.

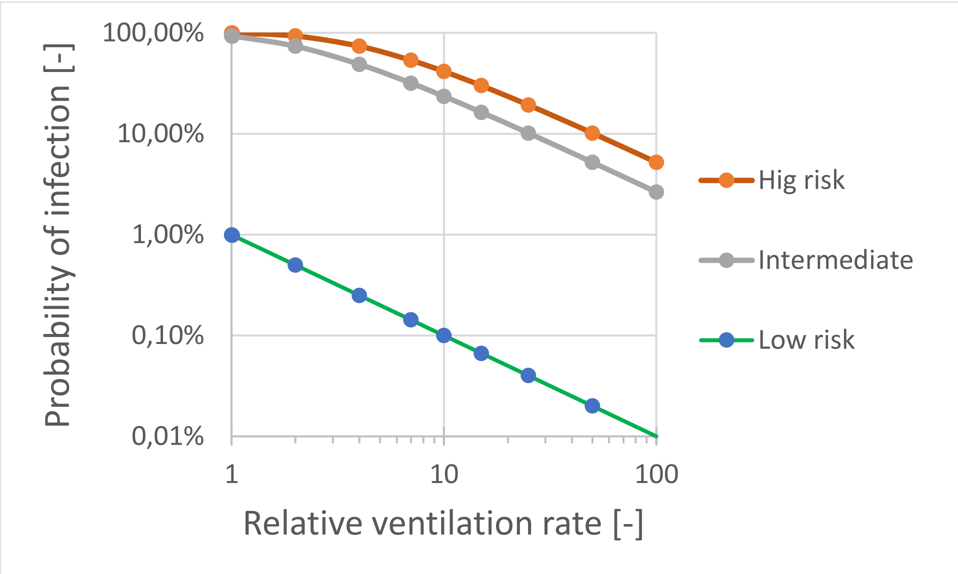

Figure 7. Probability of infection as a function of the relative ventilation rate calculated for three risk level situations using Eq 2.

As an example, in Figure 7, we can note that if the ventilation rate is increased ten times above the nominal value, the calculated probability of infection is reduced from 1% to 0.1% for the low risk case. The same ventilation rate increase in the high risk case reduces the probability of infection from close to 100% to about 40%, and to a little over 20% for the intermediate risk case.

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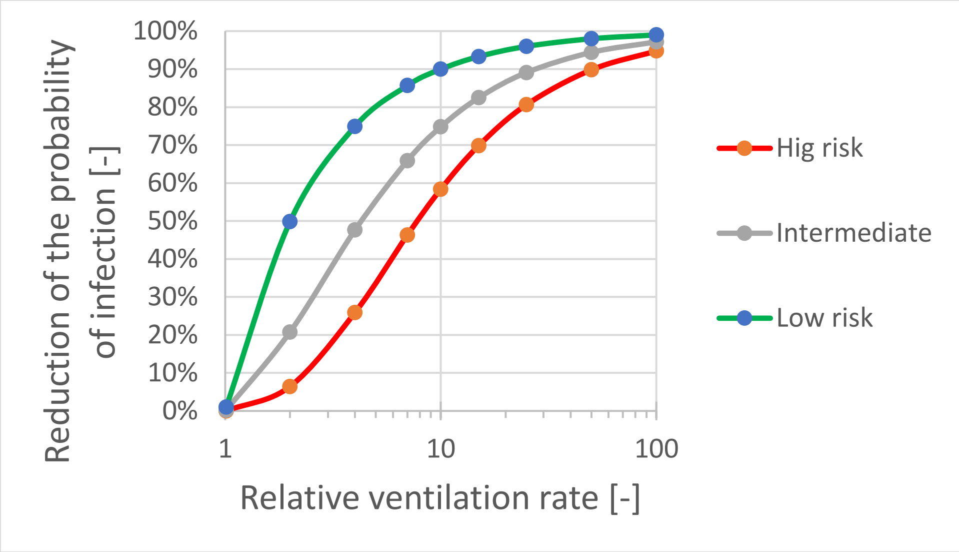

Figure 8. Reduction of the probability of infection calculated for three risk levels situations using Eq 2.

In Figure 8 the data in Figure 7 have been recalculated to the percentage the probability of infection is estimated to be reduced when the ventilation rate is increased. The calculations indicate the it may be practically impossible to obtain any substantial risk reductions by increasing the ventilation rate within realistic limits for cases represented by intermediate or high risk of infection. However, for low risk situations realistic changes of the ventilation rate appears to have a substantial influence. As indicated by Figure 9, a reduction of the ventilation rate may drastically increase the probability of infection. For example, if the ventilation rate is reduced to half its nominal value the probability of infection is doubled (shown in the diagram as a 100% negative reduction of the probability of infection).

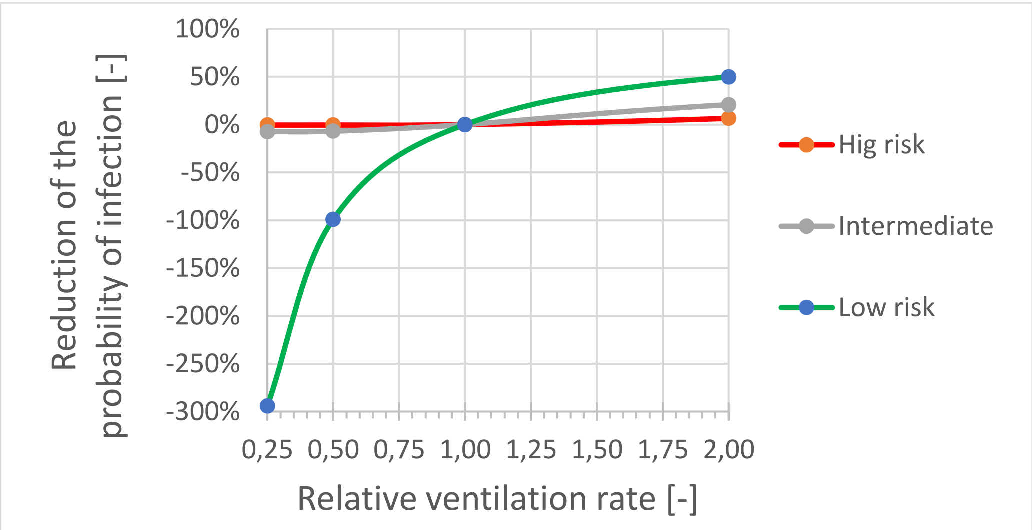

Figure 9. Reduction of the probability of infection calculated for three risk levels situations using Eq 2. The diagram shows the corresponding data as in shown in Figure 8, but for a relative ventilation rate interval around the value 1.

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8. Influence of temperature and humidity

Ahlawat et al. (2020) presented a review of ten international studies, published between 2007 and 2020, on the influence of humidity on survival, spread and infection with the pathogens of influenza and the corona viruses SARS-CoV-1, MERS and SARS-CoV-2. They concluded that a relative humidity of 40 to 60 percent could reduce the spread of the viruses. Specifically related to the present corona virus pandemic the authors interpre-ted the review to indicate that dry indoor environments (< 40% RH) increases the risk of airborne transmission of SARS-CoV-2 compared to humid environments (> 90% RH). They claimed that setting a minimum humidity standard of 40%RH for public buildings will reduce the impact of COVID-19, and it will reduce the impact of further viral outbreaks, both seasonal and novel.

A literature review by Mecenas et al. (2020) claimed that, on a low level of evidence, the spread of COVID-19 seems to be lower in warm and wet climates. They concluded that temperature and humidity alone cannot explain most of the variability of the COVID-19 outbreak.

A position document on infectious aerosols by ASHRAE (2020) state that temperature and humidity can influence transmissibility of infectious agents. With reference to Derby et al. (2016) and Taylor and Tasi (2018), ASHRAE encourages HVAC-designers to give careful consideration to temperature and relative humidity.

ASHRAE also refers to Mousavi et al. (2019) who report that the scientific literature generally reflects the most unfavorable survival for microorganisms when the relative humidity is between 40 %RH and 60 %RH

Taylor and Tasi (2018) stated that relative humidity is a significant driver of patient infections. It was shown that relative humidity values below 40%RH are associated with three factors that increase infections:

- Infectious aerosols emitted from a primary host shrink rapidly to become droplet nuclei, and these dormant yet infectious pathogens remain suspended in the air and are capable of traveling long distances.
- When pathogens encounter a hydrated secondary host, they rehydrate and are able to transmit the infection.
  - Many viruses and bacteria are resistant to dry conditions (Goffau et al. 2009; Stone et al. 2016) and actually have increased viability in low-RH conditions.
- Ambient RH below 40% impairs mucus membrane barriers and other steps in immune system protection (Kudo et al. 2019).

The ASHRAE position document on infectious aerosols (ASHRAE 2020) does not make specific recommendations on indoor temperature and humidity set points as a means to control infectious aerosol transmission. It is stated that practitioners may use the information to make building design and operation decisions on a case-by-case basis.

Effect of environmental factors on viability of corona virus has been under investigations all over the world mainly in laboratory set-ups. Models have been developed, and

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published e.g. by the Homeland Security, US https://www.dhs.gov/science-and-technology/sars-airborne-calculator . The model shows that increase of humidity, temperature, and UV-radiation will shorten the lifetime of the virus. However, it looks like the UV-radiation and temperature have greater influence than humidity.

The Nordic Ventilation Group (NVG) has initiated a sub-group addressing effects of indoor air humidity, in relation to the COVID-19 disease and other aspects. A first draft of a working document is available and a final publication may be expected during the spring of 2021.

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Appendix A. Members of NVG

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Guangyu Cao, Professor, NTNU - Norwegian university of science and technology

Lars Ekberg, Associate Professor, Chalmers University of Technology

Per Kvols Heiselberg, Professor, Aalborg University

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Appendix B. Development of the new NVG

This appendix outlines the background for the new start of the Nordic Ventilation Group. Some early ideas for a working plan and an outline of important issues are briefly summarized. The text is gathered from a rater early working document of the NVG.

B1. Background

Properly designed, maintained and operated systems for ventilation of buildings is important both for human wellbeing and for energy efficiency. Both the wellbeing and the energy aspects involve great economic values for businesses and for society. The Nordic countries have been leading in construction of energy efficient buildings with high indoor environmental quality. This knowledge must be kept updated with increasing demands of the sustainable society.

The building regulations in Nordic countries give the basic, minimum requirements for ventilation. The requirements set by the building codes and by other relevant authorities need to be complemented with voluntary guidelines. Such guidelines are needed, partly in order to meet the mandatory legislative requirements and definitely in order to meet higher level requirements – both regarding the quality of indoor environment and the energy efficiency.

Differences in regulations, classification systems and guidelines cause a need for adjustments of products and building design, which may cause extra cost challenges for companies in the common Nordic market.

As the cultural background, climate and building constructions are similar in the Nordic counties, the harmonization of ventilation guidelines would be realistic to achieve and of great value. A strong Nordic consensus regarding ventilation solutions would be a beneficial for strengthening the Nordic position as the leader of technology development and know-how. This would strengthen trade organizations, service providers and other stake-holders for a good environmental and energy efficient built environment.

B2. Objective

The objective of the Nordic Ventilation Group (NVG) is to develop Nordic ventilation technologies and services for good and healthy indoor environment with energy efficient and environmentally friendly ways of working.

B3. Organization

NVG is intended for academics sharing the same interest and concerns regarding the indoor climate and ventilation. The work is 100% voluntary and free from commercial interest. The Group does not have any specific funding, and each participant has to fund his/her own work. Possible outcomes of the work can be published through various channels with the common agreement of the group.
The current members of the group are listed in Appendix A:

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B4. Working platform

The platform for NVG is for sharing knowledge and for discussion of common problems. A platform has been established using Microsoft Teams (VVS Föreningen i Finland rf hosts the platform). Meetings are arranged using Teams to discuss and decide on topics of interest. Material and feedback are shared on the platform. In the future also face-to-face meetings and seminars can be arranged.

B5. Working plan/areas of common interest

The following summary of potential working items is based on the national inputs from Finland (Risto Kosonen), Denmark (Pawel Wargocki), Estonia (Jarek Kurnitski), Norway (Peter Schild), Sweden (Lars Ekberg) and a Teams meeting on June 8th, 2020.

Below is a rough summary of potential NVG working items. Note that it is not a final report; instead it is a rather early working document:

B5.1 Ventilation, energy and IAQ

Ventilation rates are often balanced with perceived indoor climate and energy use. How much does ventilation need energy, and how it can be reduced? A useful information would be the total share of ventilation on national energy balances and also breakdown of the ration of ventilation energy demand (heating, cooling and fan power) in different building types. A cost benefit analysis of ventilation should be updated. The analysis should include direct and indirect cost and benefits like: investment, energy, health, productivity, learning etc.

Some estimations have been presented that ventilation will contribute about 10% of national energy use? Is any analysis data published?

B5.2 Multidisciplinary IAQ work

The Corona/Covid 19 crisis has emphasized the need for multidisciplinary work. International communication during the corona pandemic has again shown the communication problems between disciplines. NVG will follow with interest the work and results of the Danish working group in this area. Could Nordic groups be again leading the international work in this area as it was during the Fanger – Lindvall – Berglund - Rodahl era.

B5.3 Ventilation rates

What is the minimum and optimal ventilation rate? All Nordic countries have mandatory minimum ventilation rates in building codes. Looks like regulation on occupational health and regulations on public health do not. Previous work in the area of ventilation has shown large variety in the regulations. This has been reported in the EU HealthVent project in mid-2010´s, as well as in the report by The Buildings Performance Institute Europe (BPIE) on Residential ventilation.

Examples of minimum ventilation rates:

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- Finland 6 l/s, person
- Norway 7,2 l/s,person
- Sweden
    - Building code: 0,35l/s,m^2 + intended use (no fixed value in the building code)
    - Healthcode: 4 l/s,person (residential),
    - Occupational health regulations: 0,35 l/s,m^2+7 l/s,person),
- Denmark?

Optimal ventilation rates (in voluntary based guidelines like Swedish R1 and Finnish Classification of Indoor Air Quality and Climate) are typically greater than minimum values when effects on the health, productivity and learning are included.

EN 16798-1:2019 has four quality levels, however, the values in standard are based on perceived air quality of non-adapted person, not health. The absolute minimum ventilation rate is 4 L/s,pers. Values in standard depend on the assume level of pollution emission of building.

Could NVG make a summary:
What are the mandatory and guideline values for ventilation rates in the Nordic countries taking in account the size, flexibility, and use of the spaces. This may affect also on the design of whole system like duct work, air handling units, zoning etc.

B5.4 IAQ standard EN 16798-1

Standard was accepted in the final voting with minimum marginal by the final votes from Nordic countries.

Some of Nordic countries think that standard should be revised. In the standard blank table Annex A has been criticized a lot. Only a few Nordic countries have made national version of Annex A like Estonia (any other country?).

Can NVG write a common draft for Nordic Annex A?

Standard 16798-1 has many new ideas which may not yet been formulated correctly in the standard and technical report. There is need to improve. Can NVG do some of this work as several of the NVG members proposed in the meeting. Some examples of the potential working items:

- occupancy schedules
- how much ventilation rates can be reduced due to the air cleaning
- criteria for localized indoor environmental control
- effect of the real use of the spaces

B5.5 Non-polluting building

EN16798-1 specifies the low pollution building based on Mid European criteria (previous version of standard EN 15251 referred to the Finnish method as an example how to specify a clean building). Is there a need to define more exactly the relation between

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"non-polluting building and ventilation"? How long a building is "non-polluting". Is this something for Nordic member of ISIAQ?

However, it is very difficult to control in at the design state the material emissions and their impact on ventilation requirements. Cleanliness and control of the construction work may also have an influence on the need of ventilation.

Is this an area NVG could do something about?

B5.6 Effect of potential cross contamination on ventilation guidelines

Increasing evidence shows that building occupants are infected by "corona virus aerosols". Aerosol infections have been recognized for long time with many other viruses. Is there enough data to modify ventilation design due to aerosol infections? Like ventilation rates, air flows in buildings, air distribution in rooms, recirculation. REHVA and other organizations have guidelines. Do we need to have some Nordic input? Many members of this group have already been involved in the international working groups in this topic area, focusing particularly on current corona virus.

B5.7 Ventilation rates and outdoor air quality

Ventilation is supposed to improve the indoor air quality, but this is not always the case. Is there a strategy to control ventilation rates by outdoor air quality? Like using more outdoor air for ventilation when the outdoor ai quality is good and less when it is bad.

Should the ventilation rates be higher in summer when the heating of the air needs less energy than in winter, and vice versa in the summer. Lower ventilation rates in winter increase the relative humidity indoor which may be beneficial.

B5.8 Residential ventilation

In general, the optimal ventilation rates as still under discussion. Ventilation may be too low in some countries and building types, especially in existing building with no designed/installed ventilations system (natural or mechanical). Nordic originating guideline value for residential ventilation 0,5 ach that been used in many counties.

Some specific problems in the area of residential ventilation were also identified:

- What is the optimal ventilation rate for bedrooms for good sleeping quality. Some new data is available.
- How to control the supply air flow rate when kitchen ventilation is used with high flow rates, typically increase from 8 to 20-30 L/s. This is a problem is recognized specifically in tight buildings.
- Can supply and exhaust opening be placed on walls in apartment buildings instead of having the exhaust on roof

B5.9 Ventilation products

Products in the market are controlled by various regulations and standards. One of most important being the regulations based on ecodesign directive. The regulations are mandatory in all EU countries without national approvement. The follow up of

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preparatory work is most important but very time consuming. NVG may not be major player in this area, but needs to work with industry when needed. The same applies to CEN standards, NVG could help in checking that CEN product standards also acknowledge the requirements for good IAQ and energy efficiency, like the leakage of heat exchangers.

One single product group brought on the table was the need to have international ISO air duct standards based on EU standards.

Another product in the discussion was residential kitchen range hoods. An international, or even Nordic, testing standard is needed. Currently Swedish SP method is widely used. Could it be the developed to a Nordic standard and further to a European standard?

Another problem is the performance criteria of commercial kitchen hood regarding the removal of particulate pollutants and odors.

The corona crisis has also emphasized the good performance of air cleaners. Common standards for performance testing of room air cleaners are also needed, specifically regarding the location the unit in the test room and room use.

B5.10 UV- air cleaning

UV- air cleaners have been promoted a lot during the corona crises. Good design and products have been emphasized. Performance of UV cleaners depends on the wavelength of the radiation, residence time of microbes in the radiation, radiation intensity and many other factors.

B5.11 Ventilation efficiency and air distribution

Many studies have shown that air distribution has an effect on exposure to pollutants, and that localized ventilation can result in many benefits. This has been known for years, but still ventilation is dimensioned based on assumption of complete mixing. What are the steps which can be taken towards wider practical applications of air distribution indices? This has been the interest area from little difference angles of several NVG members.

REHVA has two task Forces related to the topic.

Air distribution has also an effect on the air quality controlled ventilation. The assumption of complete and even distribution of pollutants and CO_2 is not necessarily true.

B5.12 Operation of ventilation

Poor operation of ventilation is a universal problem. Recent report (2019) based on Energy performance of buildings directive (EPBD) 2018 article 19a showed also a large variation on ventilation inspection within EU countries. Various guidelines and standards have been published during last decades describing how to check and improve the performance of ventilation, including the CEN standards. Sweden has had the mandatory ventilation control in practice from 1995. Can we develop a Nordic inspection and monitoring method based on Swedish instructions and experience?

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The problem with CEN standard, for example, is that it is too complex, complicated, and expensive to apply. Could we first make a summary of Swedish experience, and lean from that? This has been an interest area at least in Finland.

B5.13 Indoor air humidity

The question on correct humidity levels indoor has been on table for decades.

It is real problem in cold climate countries. Position in EN 16798-1 is very conservative. No binding values, and if you humidify or dehumidify, do not do too much.

In some countries, the position is: higher humidity in winter is beneficial but the increased energy use and risks with humidifiers are bigger than benefits. In Finland, the position is: low humidity is not a risk factor for healthy people in clean air – so no humidification is recommended. Higher humidity is beneficial for many symptomatic people. Decreasing the ventilation rates in winter will increase humidity indoors in spaces with human occupancy.

How to increase the humidity in winter with minimum energy use and risk for dampness?

B5.14 Use of ventilation during non-occupied hours

Running ventilation on full speed also during the night will consume energy but is supposed to improve the indoor air quality during daytime. In Finland parents of school children in some areas have demanded cities to run ventilation 100% full speed in schools.

Is it necessary to run ventilation also during non-occupied hours, if yes how and how much, and in which types of buildings? Does the ventilation outside the normal operation hours have also an influence on the spread of COVID-19.

All Nordic countries have requirements for minimum ventilation during nighttime use.

Finland 0,15 dm^3/m^2

Norway 0,19 dm^3/m^2

Sweden >0,1 dm^3/m^2 (for residential and only if IAQ-demands still are met). Cutoff is allowed in other building types if prestart before use secure IAQ-demands in use.

EN 16798-1:2019 gives minimum and optional run time before the use of the building

These guideline values and based on the assumption that pollutants are generated in the building also during non-occupied hours due to sorption and reemission mechanism. The balancing of ventilation system for these low ventilation rates is almost impossible in practice. Low air flow will not lead to a good air distribution either.

Questions:

- Can IAQ be improved with high nighttime ventilation?
- What is the minimum ventilation rate during nighttime?

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- What is the best way to implement the nighttime minimum ventilation without causing more problems related to pressure differences etc.

B5.15 Balancing of ventilation

How to balance the ventilation in airtight buildings, where even a small difference between supply and exhaust air flows may cause significant pressure differences over the building envelope and consequent problems. The accuracy of current air flow measurements is not good enough to do the balancing by just based on air flows measurements. The air flows and pressure differences between rooms should also be included in the balancing process. The problem has been recognized, specifically in Finland.

Question:

- What is the best procedure to balance ventilation a) based on more accurate air flow measurements b) based on pressure difference over the building envelope?

B5.16 Measurement of air flows

Measurement of air flow rates was the one of the starters of the NVG work in 80´s. Currently EN standard 16211:2015 is being revised. Any input from NVG needed?

The measurement strategy should not be limited only in air flows but include also other environmental parameters.

B5.17 Demand controlled ventilation (Load based control of ventilation)

Adjusting/controlling of ventilation rates has been for a long time a significant technology to improve energy efficiency of ventilation without deteriorating indoor air quality. The performance of these systems could have been better. Only one out of eight recently investigated systems in Finland worked as intended. Similar results are reported from other countries as well. Technology has been used and developed for years in Nordic countries, but still the shortage of performance is common.

What could this group do?

B5.18 Health care facilities

Some NVG members have been involved several initiatives on IAQ and ventilation of health care facilities, including a EU Marie Curie ITN group (has not received funding yet), CEN TC 56 WG8 for a European standard of ventilation for hospitals, REHVA COVID-19 Task force, a new Gemini centre (about Safe indoor environment in hospitals) of NTNU&SINTEF. Hopefully more participants of NVG may be interested in this Topic.

B5.19 Education

All participating countries have curricula on HVAC technology also in English.

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Could some common actions be taken to promote these programmes to attract students particularly from EU countries to these programmes. Could Scanvac help in the promotion of programmes? Could cooperation with REHVA be beneficial in this area? Maybe training of professionals could be included, too.

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Appendix C. Web-links to explore further

https://www.ncbi.nlm.nih.gov/books/NBK143281/

https://pubmed.ncbi.nlm.nih.gov/33068577/

https://pubmed.ncbi.nlm.nih.gov/33125421/

https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0241539

https://www.sciencedirect.com/science/article/pii/S0360132317305322

https://onlinelibrary.wiley.com/doi/full/10.1111/ina.12297?casa_token=HqeVVwqFrcEAAAAA%3AisXBlzrAusnK5yqP8_tZ0SiXh-_VrB-Y6fal03pHWE6q7Ot6HplxnITkVCUVjYq_tCXKtJwyxmaanQ

https://pubs.acs.org/doi/10.1021/acs.jpcb.0c05229

https://europepmc.org/article/med/32287988

https://aip.scitation.org/doi/10.1063/5.0026360

https://www.ashrae.org/file%20library/technical%20resources/ashrae%20journal/2020journaldocuments/72-74_ieq_schoen.pdf

https://docs.google.com/spreadsheets/d/1bnONMyhQpSdtIW7TAU4y08k-kuIzNxzq40t8W_0Ca3s/edit#gid=1387695036

https://www.medrxiv.org/content/10.1101/2020.11.30.20241406v1

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