AIVC April Workshop

• **Series of four webinars**
  • Organised in collaboration with IEA-EBC Annex 86 ‘Energy efficient IAQ management’
  • April 1, Building ventilation: How does it affect SARS-CoV-2 transmission?
  • April 8, IAQ and ventilation Metrics
  • April 13, Big data, IAQ and ventilation -part 1
  • April 21, Big data, IAQ and ventilation -part 2

Register at [www.aivc.org](http://www.aivc.org)

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**Introduction: context of the webinar**

• Scientific consensus that airborne transmission by aerosols plays important role in spreading COVID-19 in indoor spaces
• Many organisations are working on this topic and have produced guidelines: REHVA, ASHRAE, CIBSE, IEQ-GA, ...
• AIVC-project ‘Ventilation, airtightness and COVID-19’: collect, discuss and disseminate information about COVID-19 in relation to ventilation and airtightness
  • Newsletters
  • Webinars
  • FAQ’s
Building ventilation: How does it affect SARS-CoV-2 transmission?

Objectives:
- To address mitigating role of building ventilation in spread of pandemic,
- To discuss how ventilation affects exposure to infectious aerosols, based on knowledge developed in modelling, experiments and system design.

17:00 | Introduction, Arnold Janssens – chair of AIVC WG COVID-19, Ghent University, Belgium
17:10 | The Role of Building Ventilation in Indoor Infectious Aerosol Exposure, Andrew Persily – NIST, USA
17:25 | Modelling uncertainty in the relative risk of exposure to the SARS-CoV-2 virus by airborne aerosol transmission, Cath Noakes – University of Leeds, UK
17:40 | Questions and Answers
17:50 | Field measurements of aerosol exposure in indoor environments, Roberto Traversari – TNO, Netherlands
18:05 | Ventilation system design and the risk areas for spreading airborne contaminants in office buildings, Alireza Afshari – Aalborg University, Denmark
18:20 | Questions and Answers
18:30 | Closing & End of webinar
Building ventilation: How does it affect SARS-CoV-2 transmission?

Speakers

Andrew Persily
NIST, USA

Cath Noakes,
University of Leeds, UK

Roberto Traversari,
TNO, the Netherlands

Alireza Afshari,
Aalborg University, Denmark

Webinar management

María Kapsalaki
(INIVE, BE)

Valérie Leprince
(INIVE, BE)

How to ask questions during the webinar

Locate the Q&A box

Select All Panelists | Type your question | Click on Send

Note: Please DO NOT use the chat box to ask your questions!
**NOTES:**

- The webinar will be **recorded and published** at [www.aivc.org](http://www.aivc.org) within a couple of weeks, along with the presentation slides.
- After the end of the webinar you will be redirected to our **post event survey**. Your feedback is valuable so take some minutes of your time to fill it in.

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**Facilitated by:** [INIVE](http://www.inive.com)

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The Role of Building Ventilation in Indoor Infectious Aerosol Transport

Andrew Persily
Engineering Laboratory
National Institute of Standards and Technology
Gaithersburg, Maryland USA
andyp@nist.gov

AIVC Webinar: Building ventilation
How does it affect SARS-CoV-2 transmission?
1 April 2021

Outline
Which airflows and their magnitudes
Reducing aerosol exposure with airflow
Ventilation suggestions to reduce viral exposure
Summary
Some Key Concepts

Ventilation (ASHRAE Standard 62.1) the process of supplying air to or removing air from a space for the purpose of controlling air contaminant levels, humidity, or temperature within the space.

Every building is different

Buildings are not tight unless built that way

Air moves based on physics, not design intent

Airflow has been studied in very, very few buildings

Outdoor air isn’t necessarily fresh air

1 air change per hour does not mean all the air in a building is replaced in 1 hour

Which Airflows

VENTILATED/OCCUPIED SPACE

Outdoor air intake

Mechanical ventilation (filtration)

Infiltration

Natural ventilation (windows, designed systems)

Local filtration

Portable air cleaners

Local exhaust

Mechanical system (HVAC)
### Magnitudes

**Mechanical/Commercial**
- Outdoor air: ~1 h⁻¹, highly variable, up to ~5 h⁻¹
- Supply air: ~3 to 5 h⁻¹, higher in healthcare

**Mechanical/Residential**
- OA: ~0.1 to 0.5 h⁻¹

**Infiltration**
- ~0.1 to 1.0 h⁻¹
- ~5 to 1 variation in individual building

**Natural ventilation**
- >1 h⁻¹, hard to measure and predict

**Local exhaust**
- Residential, 25 L/s to 50 L/s, ~1/4 to 1/2 h⁻¹
- CADR ratings (~Local exhaust flows)

### Interzone airflows

**Magnitudes similar to airflows from outdoors**

**Residential**
- Crawl spaces, basements, attics, ...

**Commercial**
- Return air plenums, plumbing chases, mechanical rooms, ...
Buildings are diverse
USA: 100 million dwellings; 6 million commercial

Building systems vary and matter
Layout, design & controls, occupant activities, operation & maintenance (O&M), …

Ventilation has been studied in very few buildings
Impacts of HVAC & ventilation on aerosol transport in even less

Reducing Exposure with Airflow

Build tight, ventilate (filter) right

Overpressure buildings (careful with moisture)

Airflow/pressure from clean spaces to dirty

Commissioning, Operations & Maintenance

Ventilation limited for strong, local sources
Recommendations for Re-Opening Buildings

Ventilation

- Outdoor ventilation
- Filtration
- Relative humidity
- Toilet areas
- UV-C and air cleaners
- Maintenance personnel

Health & Safety

- CDC
- AIHA
- OSHA
- National Institute of Building Sciences
- APPA
- BOMA

Broad Issues
Increase outdoor air ventilation
- System capacity
- Outdoor air quality
- Moisture management
- Assuming good HVAC control

More efficient filtration
- System capacity
- Sealing
- Maintenance

Change relative humidity
- Do we know the right number?
- System capacity
- Condensation potential/microbial growth

Open windows
- Outdoor air quality
- Moisture, Noise, Security
- Direction, magnitude, distribution

Change air distribution
- System configuration
- Options often limited
Summary

Do no harm

Good ventilation is good practice

Excellent time to check system, review O&M practice (Schoen 2020 and ASHRAE guidance)
https://www.ashrae.org/technical-resources/resources

NIST on-line tool for comparing impacts of ventilation, filtration, etc. on indoor aerosols
https://www.nist.gov/services-resources/software/fatima

Modelling uncertainty in airborne SARS-CoV-2 risks

Professor Cath Noakes, OBE, CEng, FIMechE, FIHEEM
School of Civil Engineering, University of Leeds
C.J.Noakes@leeds.ac.uk

SARS-CoV-2 transmission routes

Airborne – via aerosols (>2m) in a shared room

Close range – via aerosols and droplets (<2m)

Surfaces - via contaminated hands
Evidence for transmission

- Relative importance of different transmission routes unclear
  - Animal studies show air and surface both possible
  - Outbreaks and contact tracing data show close proximity risk
  - Fomite evidence hard to find, but some association with hand hygiene/cleaning
  - Super-spreading can happen and is associated with higher exhalations
  - Air and surface sampling data patchy, but evidence of virus in small aerosols
  - Airborne transmission associated with poorly ventilated spaces (1-3 l/s/person) – potential for room to room
  - Little evidence for outdoor transmission – crowded/close
  - Modelling (physics, risk models) gives insights into the likely exposure

- Transmission can happen in any setting
  - Risk factors make some settings more/less risky
  - Transmission associated with a setting is not always what it seems

Respiratory aerosols

- Virus around 100nm but contained within respiratory fluids
- Johnson et al suggest 3 modes:
  - Bronchiolar fluid film burst – breathing
  - Laryngeal – voice and coughing
  - Oral – speech and coughing
- Evaporation depends on composition of fluids – salts, surfactants, proteins.
  - final diameter ~0.2-0.5 original
  - happens rapidly
Respiratory pathogens

- **Course > 5micron**
- **Fine < 5micron**

Influenza in aerosol

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**Variation with activity**

- 25%-75%
- Range within 1.5IQR
- Mean
- Outliers
- Median Line

- Sing note 70-80 dB, Mid-vocal range
- Speak "Happy Birthday" (20 s)
- Sing "Happy Birthday" (20 s)
- Breathe (out of mouth)
- Sing note 70-80 dB, Mid-vocal range
**Viral load**

- **A** Overall: 
  - Respiratory viral load (log_{10} copies/mL) over time for SARS-CoV-2, Al/H1N1, and Alm08.

- **B** Age: 
  - Density (%) of viral load for adults and pediatric patients.

- **C** Symptomatology: 
  - Density (%) of viral load for asymptomatic and symptomatic patients.

- **E** Days from post: 
  - Graph showing symptoms reported vs. symptoms not reported.

Chen P.Z. et al, 2020, pre-print

Kissler et al, 2020, pre-print

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**Exhalation physics**

- Exhaled breath similar to Gaussian plume
- Particles influenced by thermal plume
- Interaction between droplets for violent ejections – turbulent puff

Bourouiba L, JAMA Insights, 2020

Abkarian M et al, PNAS, 2020
Complexity of aerosols and droplets

Milton, 2020

Modelling aerosol exposure

- Mass balance models to estimate concentration in air with ventilation rate for given emission
- Exposure from inhalation rate and time
- Simple spaces assume fully mixed flow
- Reasonable estimate >2m from source
- Can include filtration, deposition, air cleaners
Space/flow relationships

20 people, 300 m³ (0.24-2.4 ACH)

160 people, 8750 m³ (0.06-0.65 ACH)

Estimating Relative Exposure

Relative to classroom designed to 1500 ppm CO2 standard

Depends on:
- Duration of exposure
- Ventilation
- Size of space
- Aerosol emission/vocalisation
**Linking exposure to risk of infection**

### Wells-Riley Approach

\[ N_c = S \left[ 1 - e^{\left(\frac{Iqpt}{Q}\right)} \right] \]

New infections \((N_c)\) with time \((t)\):
- \(S\) = number of susceptibles,
- \(I\) = number of infectors
- \(Q\) = room ventilation rate
- \(P\) = occupant breathing rate
- \(q\) = Quanta, number of infectious doses generated per unit time

### Dose-response Approach

![Graph showing dose-response relationship]

**Quanta values**

<table>
<thead>
<tr>
<th>Disease</th>
<th>Case</th>
<th>Quanta/h</th>
<th>Reported by</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Human to guinea pig transmission</td>
<td>0.3-44</td>
<td>Escombe et al (2007)</td>
</tr>
<tr>
<td></td>
<td>Human to guinea pig transmission (MDR-TB)</td>
<td>40,52,226</td>
<td>Escombe et al (2008)</td>
</tr>
<tr>
<td>Influenza</td>
<td>School cases in Taiwan</td>
<td>66.91 (LN*)</td>
<td>Liao et al (2005)</td>
</tr>
<tr>
<td></td>
<td>Human challenge studies</td>
<td>0.11</td>
<td>Bueno de Mesquita et al (2020)</td>
</tr>
<tr>
<td></td>
<td>Data from exhaled breath studies</td>
<td>0.17-630</td>
<td>Bueno de Mesquita et al (2020)</td>
</tr>
<tr>
<td>SARs</td>
<td>Taipei Hospital outbreak</td>
<td>28.77 (LN*)</td>
<td>Liao et al (2005)</td>
</tr>
</tbody>
</table>
Quanta for SARS-CoV-2

• Buonnano et al (2020) estimated quanta from respiratory viral load (RNA copies) and aerosol generation rate
• Range from 0.1 to 1000 quanta/hr
• Miller et al estimated ~950 quanta/hr for Skagit choir outbreak

Ventilation-risk relationships

SAGE EMG: Role of ventilation in controlling SARS-CoV-2 transmission
**Skagit Choir**

**Outbreak**
- 61 attendees (~half normal)
- 2.5 hour rehearsal
- 1 infector – mild symptom
- 53 cases, 33 with testing
- Use of sanitizer, no contact
- Distance 0.75-1.4m
- Cases dispersed throughout the room

**Model assumptions**
- Transient Wells-Riley model
- Monte-Carlo approach to estimate quanta
- 810 m³ room
- Breathing rate 10.8-23 l/min
- Ventilation rate 0.3-1.0 ACH
- Deposition 0.3-1.5, inactivation 0-0.63

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### Skagit Choir

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### Skagit Choir

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### Skagit Choir

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Relative risk

- CO2 data from 45 classrooms, 11 schools
- Hybrid ventilation with control based on temperature and CO2
- Risk modelled for 1 quanta/hr
- Airborne contribution within classroom only
Modelling masks

- Measured RNA copies in room air
- Inhaled dose for different fraction of infectious virus
- Infection risk from SARS-CoV1 & HCoV-229E dose-response

What about hands?

Depends on multiple parameters:
- Number of microorganisms on surfaces touched
- Frequency of surface touch
- Transfer efficiency from surface
- Area of contact
- Frequency of touching face
- Transfer efficiency to mucous membranes
- Area of contact
- Hand and surface cleaning frequency and efficiency
- Decay rate on surfaces and hands
Modelling contact risks

- Uncertainty in viral copies to nose over one hour following surface touch
- Depends on surface decay rate, amount on surface, transfer efficiency, face touch frequency, area of contact
- Lacking data on viral transfers for SARS-CoV-2

What can we conclude?

- Close-range carries the most virus
- Far-field aerosol is likely to matter for longer duration exposure – may be more frequent?
- Surfaces may matter when sharing a space with an infector
- Significant uncertainty - need more evidence to understand importance
  - Variation in viral load
  - Size of aerosols that contain virus and their emission rates
  - Dose-response and how it changes with route
  - Impact of different mitigation measures
Thank you

Leeds:
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Marco-Felipe King
Amir Khan
Martin Lopez-Garcia
Andy Sleigh
Richard Wood
Lee Benson
Jess Procter

Collaborators:
Ben Jones, Patrick Sharpe, Chris Iddon, Abigail Hathway, Shaun Fitzgerald, Carolanne Vouriot, Henry Burridge, Paul Linden, Amanda Wilson, Mark Weir, Kelly Reynolds, Stephanie Dancer, Shelly Miller + Skagit Choir group, All of SAGE EMG, aerosol and ventilation colleagues worldwide

Any Questions?

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@CathNoakes
DETERMINING THE EFFECT OF SCREENS IN EXPOSURE TO AEROLS IN RESTAURANTS
DR. ROBERTO TRAVERSARI

INDEX
EVALUATION OF SPREADING AEROSOLS IN RESTAURANTS

01. INTRODUCTION
02. METHOD
03. RESULTS
04. CONCLUSIONS
DISCLOSURE

Dr. Roberto Traversari

I have the following potential conflicts of interest to report:

- Consulting
- Employment in industry
- Stockholder of a healthcare company
- Owner of a healthcare company
- Other(s)

✓ I do not have any potential conflict of interest

01 April 2021 | Determining the effect of screens in exposure to aerosols in restaurants

BACKGROUND

PROBLEM

- Reference setting is social distancing at > 1.5 meter (between different households)
- Limiting the capacity of a restaurant
- Can screens help to reduce the 1.5 distance in a safe way?
- Is there a relation with the ventilation system and ventilation rate?

Main research question:

How to determine the effect of (protective) screens in a restaurant setting?

Project funded by the Dutch Ministry of Economic Affairs and Climate Policy

01 April 2021 | Determining the effect of screens in exposure to aerosols in restaurants
Method was based on the guidelines for operating rooms (e.g. ISO 14644-3, HTM-03, DIN 1946-4, VCCN guideline 7)

- Emission of aerosols (particles) and measure particle levels
- Measuring the concentration of particles with particle counters
- Using ≥ 0.5 μm as guiding particles (airborne appr. < 5 μm)
- Concentration at 1.5 meter was the reference
- With and without screens

Mock up (9 x 7 x 3 meters)

Experiments

Mock up

- Two ventilation systems
  - linear diffusers
  - swirl diffusers
- Three "ventilation" rates (air with relative low particle level)
  - Low (900 m³ h⁻¹, Dutch building act)
  - Medium (1,700 m³ h⁻¹)
  - High (2,500 m³ h⁻¹)
- Three different setups (excluding the reference setup)
**PROCEDURE**

Walking (according to protocol)

<table>
<thead>
<tr>
<th>Time (minutes)</th>
<th>5</th>
<th>10</th>
<th>15</th>
<th>20</th>
<th>25</th>
<th>30</th>
<th>35</th>
<th>40</th>
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</tr>
</tbody>
</table>

Start

Determine baseline concentration

Start

Emission

End

Emission Start Recovery

End

**REFERENCE SETUP**

No screens, 12 tables, 26 chairs and 21 restaurant guests,
SETUPS WITH SCREENS

Setup A, 6 full screens, one half screen, 13 tables, 32 chairs and 22 restaurant guests

Setup B, 5 full screens, two half screens, 13 tables, 32 chairs and 22 restaurant guests

Setup C, 5 full screens, two half screens, 15 tables, 31 chairs and 23 restaurant guests

EXAMPLE OF THE MEASURED CONCENTRATION

\[ C_t = C_0 \cdot e^{-\text{constant} / t} \]

- \( C_t \): concentration at time \( t \)
- \( C_0 \): concentration at time \( t = 0 \)

100-fold recovery time

Start

Start Emission

End Emission / Start Recovery

Time (minutes)

Particle concentration (particles/min m³)

Total exposure

01 April 2021 | Determining the effect of screens in exposure to aerosols in restaurants
RESULTS

LOW VENTILATION RATE

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RECOVERY TIME

Setup R with low ventilation
Setups R, A, B, C with medium ventilation
Setups R, A, B, C with high ventilation

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CONCLUSIONS

- The amount of ventilation is the most determining factor for the total exposure and for the 100-fold recovery time. The higher the ventilation, the lower the total exposure and the faster the 100-fold recovery.

- The medium and high ventilation quantities result in a lower total exposure than the setup with the 1.5 meter protocol with a low ventilation quantity; the total exposure is on average 44% and 63% lower for the medium and high ventilation volume respectively. In addition, the 100-fold recovery is faster with a higher amount of ventilation.

- The diffuser type (line diffusers or swirl diffusers) has no significant influence.

- With the low ventilation amount, the total exposure for the three setups with screens is lower than for the reference situation. However, this difference is not significant for setup A.
Ventilation system design and the risk areas for spreading airborne contaminants in office buildings

**Airborne transmission from room to room**

Even if buildings have well-functioning ventilation systems, which is the case in most Nordic countries, it does not mean that airborne infectious disease transmission from room to room could be avoided.
The spread of airborne pollutants depends on air movement or airflow.

Two prerequisites must be fulfilled for airflow from one room to another: a pressure difference and a leakage path.

Pressure differences in buildings can be created through wind forces, temperature differences and mechanical ventilation.

There must be a careful design of a mechanical ventilation system to accomplish directed airflows in a building, whereas the pressure differences created by wind and temperature are considered disturbances.

Depending on the balance between the supplied and exhausted airflows, a mechanical ventilation system can create a pressure difference between the room and adjoining spaces, both outside and between adjacent rooms.

The pressure difference depends on the airtightness of the building envelope and the interior walls and airflow balance.
Ventilation system design and the risk areas for spreading airborne contaminants in office buildings

Most of the new office buildings in **Nordic countries** are equipped with **balanced mechanical ventilation systems**.

The most common solutions in the office buildings are **variable-air-volume (VAV) systems**.

The ventilation systems should be able to **precisely control the indoor climate** or otherwise the target values of indoor temperature or CO$_2$ concentration may not be fulfilled.

![Photo: Lindab, Denmark](image)

**Typical Design of Swedish Office Buildings**

Transferred air is often used in Swedish offices.

The air **is supplied to the office rooms** and **transferred into the adjoining corridor** where it is exhausted.

Special air terminal devices are used to accomplish this, allowing air to pass from the room to the corridor. These devices constitute a known opening, a controlled leakage path for the air.
Ventilation system design and the risk areas for spreading airborne contaminants in office buildings

Typical Design of Danish Office Buildings

Supply and exhaust air is installed in every room. Equal volumes of air are brought into and exhausted out of the building. However, in a room, the supplied air volume is not equal to the exhausted air volume when the supply air volume varies in a variable air volume system.

Thus, a common exhaust is used, and the exhaust airflow rate from each room is an average airflow rate from several given rooms.

In Norway, the most common ventilation system in new office buildings is the balanced-room ventilation system.

In such systems, the supply and exhaust sections usually depend on each other; thus, the variation is often equal for the supply and exhaust air. This dependence cannot cause over or under pressure in the rooms.
Ventilation system design and the risk areas for spreading airborne contaminants in office buildings

Simulation study

All three zones have the same volume (27 m$^3$), but different supply ventilation rates.

The zones were modelled assuming complete mixing of air.

Bi-directional airflow between offices and the corridor was modelled using a door model with a leakage area of 0.02 m$^2$ when the door is closed.

Source of contaminant

Typical increase of PM10 in relation to CO$_2$, comparing breathing and talking, is shown in the figure, strong correlation.
Ventilation system design and the risk areas for spreading airborne contaminants in office buildings

**Simulation study**

Table shows supply and exhaust ventilation rates for each ventilation system, together with the airflow passing through the doors.

<table>
<thead>
<tr>
<th></th>
<th>Supply ventilation rate [l/s]</th>
<th>Exhaust ventilation rate [l/s]</th>
<th>Airflow through doors [l/s]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Office 1</td>
<td>Office 2</td>
<td>Corridor</td>
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<tr>
<td>Denmark</td>
<td>60</td>
<td>30</td>
<td>17</td>
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<tr>
<td>Sweden</td>
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</tr>
<tr>
<td>Norway</td>
<td>60</td>
<td>30</td>
<td>17</td>
</tr>
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</table>

**Table Pressure differences [Pa] across doors**

<table>
<thead>
<tr>
<th></th>
<th>Doors open</th>
<th>Doors closed</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Office 1 – Corridor</td>
<td>Office 2 - Corridor</td>
</tr>
<tr>
<td>Denmark</td>
<td>0.001</td>
<td>-0.001</td>
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<tr>
<td>Sweden</td>
<td>0.003</td>
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<td>Norway</td>
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Ventilation system design and the risk areas for spreading airborne contaminants in office buildings

**Denmark**

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<td>Denmark</td>
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<td></td>
<td>Door 2</td>
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**Sweden**

<table>
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<th>Exhaust ventilation rate [l/s]</th>
<th>Airflow through doors [l/s]</th>
</tr>
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Ventilation system design and the risk areas for spreading airborne contaminants in office buildings

Norway

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<table>
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<tr>
<th></th>
<th>Office 1</th>
<th>Office 2</th>
<th>Corridor</th>
<th>Office 1</th>
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<tbody>
<tr>
<td>Supply ventilation rate [l/s]</td>
<td>60</td>
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<td>17</td>
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<td>0</td>
</tr>
<tr>
<td>Exhaust ventilation rate [l/s]</td>
<td></td>
<td></td>
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<tr>
<td>Airflow through doors [l/s]</td>
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Conclusions

The existing ventilation systems of Swedish office rooms can contribute to spreading airborne contaminants from office rooms to corridors but not to adjacent rooms.

Airflows should be supplied and exhausted from each room and from each corridor to avoid spreading airborne contamination to corridors.
Ventilation system design and the risk areas for spreading airborne contaminants in office buildings

Conclusions

The existing ventilation systems of Danish office rooms can contribute to spreading airborne contaminants from room to room when the room demands are different.

The extracted airflows must be equal to the supplied airflows of each room to achieve the correct pressurization.

Ventilation system design and the risk areas for spreading airborne contaminants in office buildings

Conclusions

The existing ventilation systems of Norwegian office rooms do not spread airborne contaminants from room to room or from room to corridor, even if the room demands are different.
Ventilation system design and the risk areas for spreading airborne contaminants in office buildings

HYPOTHESIS AND THEORY ARTICLE

Ventilation System Design and the Coronavirus (COVID-19) 
version of the article will be published soon. Notify me

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Thank you for your attention