University of Strasbourg

cemosis
Centre de modélisation et de simulation de Strasbourg

Indoor Air Quality (IAQ) modelling, application to COVID-19 transmission

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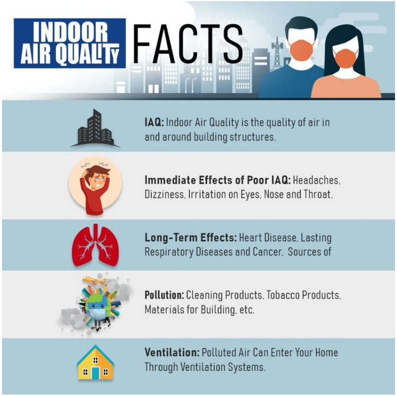
Introduction

- The air quality within and around buildings.
- Responsible for 1.5 million to 2 million deaths in 2000.
- COVID-19 consequences.



INDOOR AIR QUALITY FACTS

IAQ: Indoor Air Quality is the quality of air in and around building structures.

Immediate Effects of Poor IAQ: Headaches, Dizziness, Irritation on Eyes, Nose and Throat.

Long-Term Effects: Heart Disease, Lasting Respiratory Diseases and Cancer. Sources of

Pollution: Cleaning Products, Tobacco Products, Materials for Building, etc.

Ventilation: Polluted Air Can Enter Your Home Through Ventilation Systems.

Figure – Indoor air quality facts[1]

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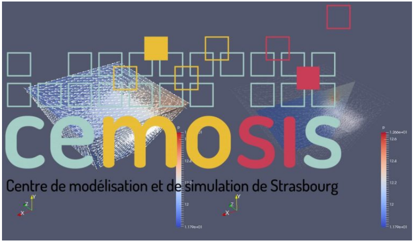
[1] https ://www.pinterest.fr/pin/534661787013453107/

Internship host

- Cemosis : Strasbourg Center for Modelling and Simulation .
- Cemosis[2] created in January 2013 by Christophe Prud'homme.



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[2] https://www.cemosis.fr/

Objectives

- State of the art of Indoor Air Quality (IAQ).
- State of the art of COVID-19 transmission.
- Modelling indoor air quality (IAQ) applied to COVID-19's transmission .
- Couple the IAQ model with the zero-equation turbulence model.

I.Indoor Air Quality (IAQ)

Figure – Indoor air quality [3]

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[3] https://catalysts.basf.com/products-and-industries/indoor-air-quality

Different pollutants and sources

- Principal pollutants of indoor air :
  - Chemical pollutants : volatile organic compounds (VOCs), nitrogen oxides (NOx), carbon monoxide (CO)...
  - Biological contaminants : moulds, pets , pollens ...
  - Particles and fibers : asbestos, artificial mineral fibers...

Effects of nefarious IAQ

- Major effects on comfort and health,
- Simple discomforts :
  - drowsiness
  - eye and skin irritation
  - lost productivity at work.
- Severe pathologies :
  - respiratory allergies,
  - asthma,
  - cancer,
  - poisoning...
- Sick Building Syndrome (SBS).
- Causes and solutions.

Recommendations to enhance IAQ

- Health problems due to IAQ, have increased the importance of IAQ measuring techniques.

The Core Recommendations

1 Retrofit an Indoor Air Quality Monitoring System
Analyse IAQ-Index,
Thermal Comfort & CO_2

2 Optimise ventilation
To ensure continuous fresh
air supply while diluting
indoor air contaminants

1 Maintain minimum humidity levels
Optimally 50% (minimum 40%,
not exceeding 60%)

Expert Advise

What can you practically do to achieve this recommendations?

Extend ventilation system's operating time, optimally run it 24/7

- Run ventilation units longer than human presence in building
- Turn on unit earlier, leave it running for extended period after occupancy

Adjust air volume controls

- If available in control system, set acceptable CO_2 level recommended for your system
- Air volume = Lower, when less persons are present → Easier to reach desired relative humidity
- If no CO_2 controls available, keep unit running on constant airflow

Optimise ventilation by increasing system's volume flow rate

- While ensuring it does not interfere with reaching recommended humidity level

Set recirculation according to operation mode

During operation hours
- Switch off recirculation

During non-operation hours
- Switch on recirculation mode → Easier to reach desired relative humidity

Maintain minimum humidity levels

During operating hours
- Maintain usual temperature setpoint
- Set relative humidity control to: Optimally 50% (minimum 40%, not exceeding 60%)
- If room temperature setpoint is high: Lower temperature setpoint
- Keep it in occupants' comfort zone to more easily reach humidity setpoint

During non-operating hours
- Consider lowering temperature setpoint further
- In case system cannot achieve recommended humidity: Consider additional system/room humidification

[4]

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4. https://iqnexus.com/solutions/indoor-air-quality

Modelling IAQ

- Three principal categories of models.
- Statistical :
  + estimate the distribution of indoor pollutant exposures,
  – less advanced,
  – can predict IAQ in an existing building.
- Mass balance :
  + estimate the impacts of sources, sinks on pollutant concentrations.
  + understand interactions of ventilation and indoor environment characteristics.
- Computational fluid dynamics (CFD) :
  + room air movement and contaminant transport application,
  – an early stage of development,
  – incompressible,inviscid,irrotational fluid.

ARD Equation

- The advection–reaction–diffusion equation :

$$\frac{\partial C}{\partial t} = \nabla.(K\nabla C) - \nabla.(\overrightarrow{v}C) + S.$$

- C = concentration of airborne infectious particles ($particles/m^2$
  t = time(s)
  ∇ = two-dimensional gradient operator
  K = isotropic eddy diffusion coefficient (turbulent diffusion)
  $\overrightarrow{v}$ = advection velocity of the air($m.s^{-1}$)
  S = sum of sources and sinks of viral particles.

II. COVID-19 transmission

- The COVID-19 virus since december 2019.
- Pandemic declared on 11th March 2020.
- Overs 209 million confirmed cases and 4.4 milion deaths.
- 81% moderate symptoms, 14% severe and 5% critical symptoms.
- 4.45 billion vaccine doses administered.

Transmission's modes

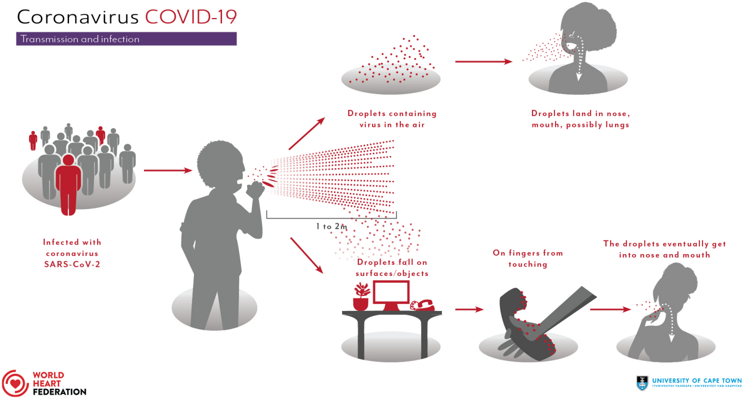

Figure – Transmission and the infection of COVID-19.[5]

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[5] https ://world-heart-federation.org/resource/covid-19-transmission/

Focus on models

- Importance of modelling the COVID-19 transmission.
- Based on ADR equation.
- An infectious person talking or breathing with or without a mask S_{inf}.
- Room of size $8m(l) \times 8m(w) \times 3m(h)$.
- Contains an air-conditioning unit.
- The airborne particles transported by advection caused by the airflow.

Model (follow-up)

- The infectious particles are removed due to three factors :
  - the ventilation system (S_{vent}),
  - biological deactivation of the virus (S_{deact}),
  - gravitational settling of the virus (S_{set}).
- $$\frac{\partial C}{\partial t} + \nabla.(\vec{v}C) - \nabla.(K\nabla C) = S_{inf} - S_{vent} - S_{deact} - S_{set}$$
- The eddy diffusion coefficient $K(m^2/s)$:

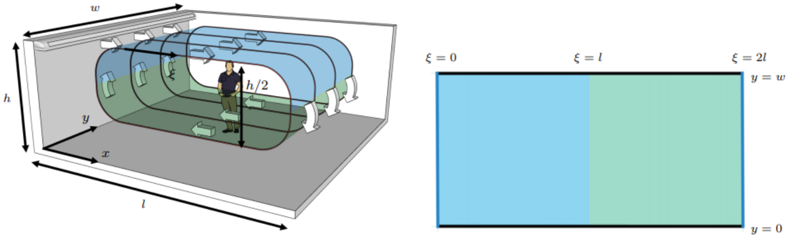
  $$K = c_v Q(2c_\epsilon VN^2)^{1/3}$$
- The probability of infection :

  $$P(x,y,t) = 1 - exp\left(- I \int_0^t \rho C(x,y,\tau)d\tau \right)$$

  with ρ, the average breathing rate and I, constant depending on the virus infectiousness.

Paper framework

- Assumptions :
  - the ADR equation governs the concentration of the virus.
  - particles released with zero initial velocity.
  - only one infectious person in the room.
- Unwraping the loop surface of the airflow to the domain $(\xi, y) \in [0, 2l] \times [0, w]$.



(a) (b)

Paper framework (follow-up)

- Boundary conditions :
  - $C(0, y, t) = C(2l, y, t)$ at the wall $\xi = 0$.
  - $\frac{\partial C}{\partial \xi}(0, y, t) = \frac{\partial C}{\partial \xi}(2l, y, t)$ at $\xi = 2l$.
  - $\frac{\partial C}{\partial y}(\xi, 0, t) = \frac{\partial C}{\partial y}(\xi, w, t) = 0$ at $y = 0, w$.

Our configuration

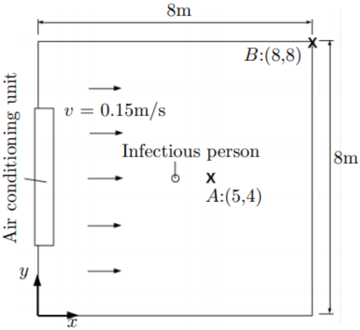


Figure – Schematic of the modelled room. One infectious person is located at the centre of the room.

Modelling environment and tools

- Using Feel++ finite library.
- Coefficient Form PDEs described by [6]

$$d\frac{\partial u}{\partial t} + \nabla \cdot (-c\nabla u - \alpha u + \gamma) + \beta \cdot \nabla u + au = f \quad in \quad \Omega$$

- d : damping or mass coefficient
- c : diffusion coefficient
- α : conservative flux convection coefficient
- γ : conservative flux source term
- β : convection coefficient
- a : absorption or reaction coefficient
- f : source term
- Creation of three main files : GEO, CFG and JSON.

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[6] `https://docs.feelpp.org/toolboxes/0.109/cfpdes/introduction.html`

Outputs

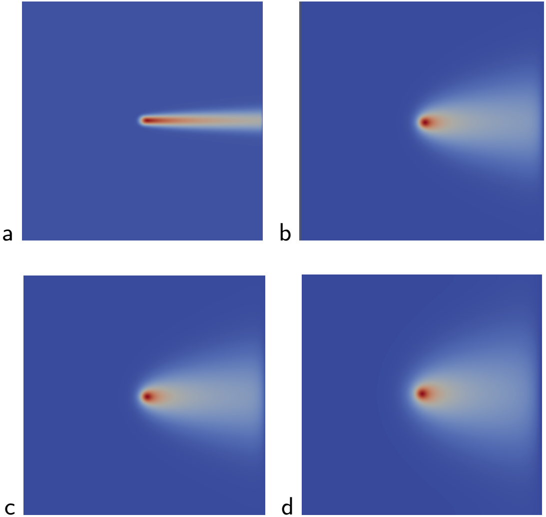

Figure – Concentration of viral particles for very poor(a), poor(b), pre-pandemic(c) and pandemic-updated(d) ventilation cases.

Outputs simile

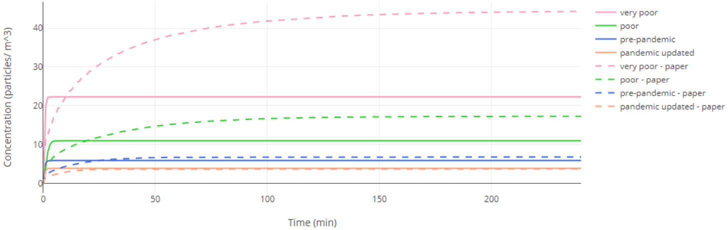

Figure – Concentration of SARS-CoV-2-carrying particles for 4 different ventilation rates at position (5,4).

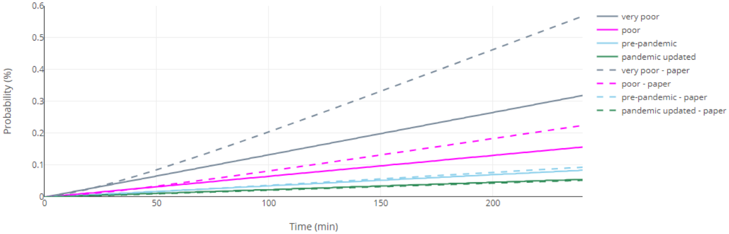

Figure – Probability of infection at position (5,4).

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