

Introduction

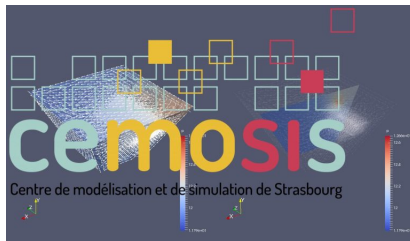
- ▶ The air quality within and around buildings.
- ▶ Responsible for 1.5 million to 2 million deaths in 2000.
- ▶ COVID-19 consequences.



Figure – Indoor air quality facts¹

1. <https://www.pinterest.fr/pin/534661787013453107/>

- ▶ Cemosis : Strasbourg Center for Modelling and Simulation .
- ▶ Cemosis² created in January 2013 by Christophe Prud'homme.



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 quality³

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 (NO_x), carbon monoxide (CO)...
 - Biological contaminants : moulds, pets , pollens ...
 - Particles and fibers : asbestos, artificial mineral fibers...

Common Indoor Air Problems



Moisture



VOCs and Chemicals



Smoking



Dust



Pet Dander

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


| | | |
|--|---|---|
| <p>1 Retrofit an Indoor Air Quality Monitoring System Analyse IAQ-Index, Thermal Comfort & CO₂</p> | <p>2 Optimise ventilation To ensure continuous fresh air supply while diluting indoor air contaminants</p> | <p>1 Maintain minimum humidity levels Optimally 50% (minimum 40%, not exceeding 60%)</p> |
|--|---|---|

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



Optimise ventilation by increasing system's volume flow rate


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

 **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

 **Adjust air volume controls**

- If available in control system, set acceptable CO₂ level recommended for your system
- Air volume = Lower, when less persons are present
→ Easier to reach desired relative humidity
- If no CO₂ controls available, keep unit running on constant airflow

 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

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 :

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

- ▶ C = concentration of airborne infectious particles ($particles/m^2$)
 t = time(s)
 ∇ = two-dimensional gradient operator
 K = isotropic eddy diffusion coefficient (turbulent diffusion)
 \vec{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

Coronavirus COVID-19

Transmission and infection

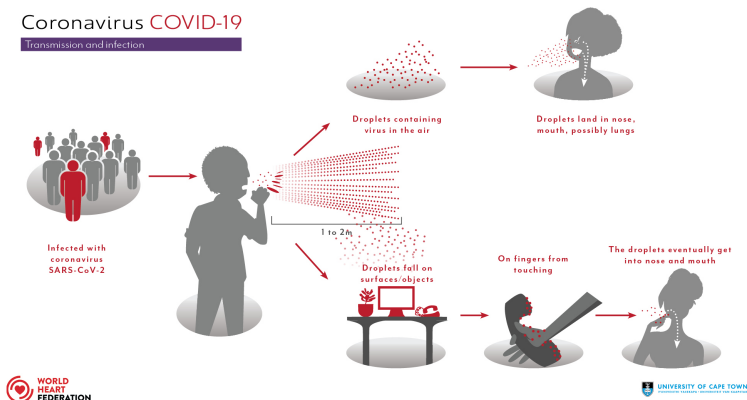


Figure – Transmission and the infection of COVID-19.⁵

5. <https://world-heart-federation.org/resource/covid-19-transmission/>

- ▶ Importance of modelling the COVID-19 transmission.
- ▶ Based on ADR equation.
- ▶ An infectious person talking or breathing with or without a mask S_{inf} .
- ▶ The room 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}).



$$\frac{\partial C}{\partial t} + \nabla \cdot (\vec{v}C) - \nabla \cdot (K \nabla C) = S_{inf} - S_{vent} - S_{deact} - S_{set}$$

- ▶ The eddy diffusion coefficient $K(m^2/s)$:

$$K = c_v Q (2c_\epsilon V N^2)^{1/3}$$

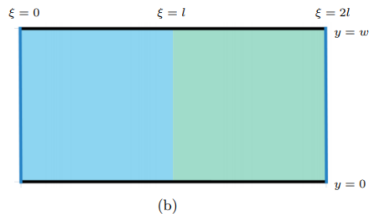
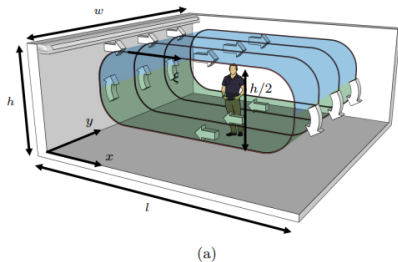
- ▶ The probability of infection :

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

with ρ the average breathing rate.

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.
- ▶ Unwrapping the loop surface of the airflow to the domain $(\xi, y) \in [0, 2l] \times [0, w]$.



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

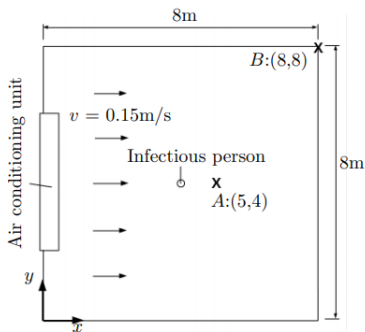


Figure – Schematic of the modelled room. One infectious person is located at the centre of the room.

Modelling environment and tools

- ▶ Using Feel++ finite library.
- ▶ Coefficient Form PDEs described by⁶

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

- ▶ 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.

6. <https://docs.feelpp.org/toolboxes/0.109/cfpdes/introduction.html>

Outputs

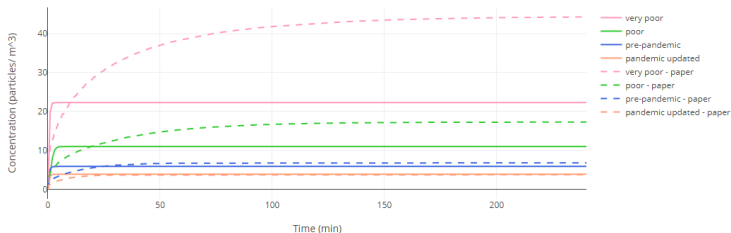


Figure – Concentration of SARS-CoV-2-carrying particles for 4 different ventilation rates at position (5,4).

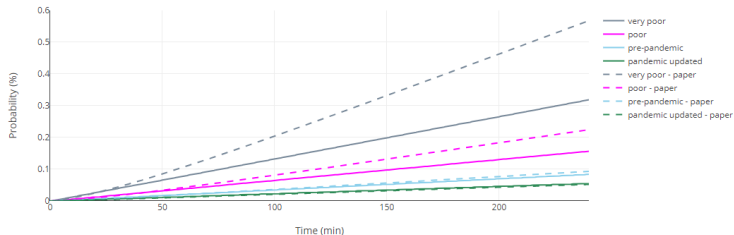


Figure – Probability of infection at position (5,4).

References

- ▶ A.P. Jones, Indoor air quality and health, Atmospheric Environment.
- ▶ D. W Pepper, D. Carrington. Modeling Indoor Air Pollution, 2009.
- ▶ COVID-19 dashboard/ <https://covid19.who.int/>
- ▶ COVID-19 transmission/ [https://en.wikipedia.org/wiki/Transmission_of_COVID-19#Respiratory_route_\(droplets_and_airborne_particles\)](https://en.wikipedia.org/wiki/Transmission_of_COVID-19#Respiratory_route_(droplets_and_airborne_particles))
- ▶ Z. Lau, K. Kaouri, I. M. Griffiths, A. English. Predicting the Spatially Varying Infection Risk in Indoor Spaces Using an Efficient Airborne Transmission Model. School of Mathematics, Cardiff University and Mathematical Institute, University of Oxford.
- ▶ F. Guo. Development of a model for controlling indoor air quality. Earth Sciences. University of Strasbourg.