CFD Analysis of a small social gathering (COVID-19)

December 2020

Introduction & Objectives

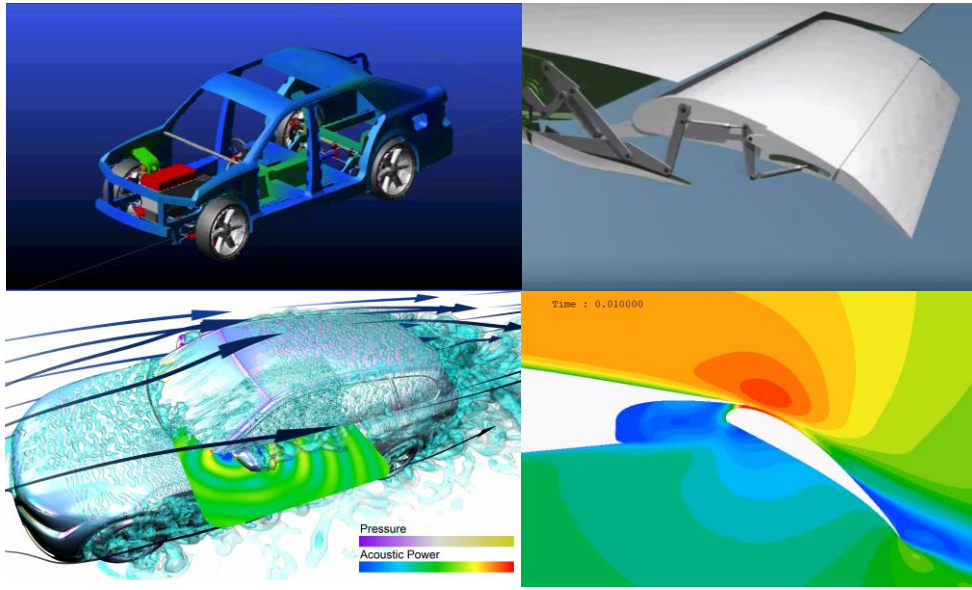
- Hexagon develops software technologies in the area of **Computational Aided Engineering** (CAE) used by leading **industrial companies** in automotive, aerospace, electronics, consumer goods, medical equipment & more

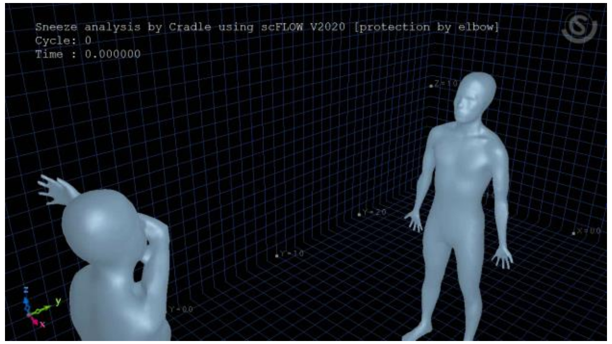
- CAE is used to **predict the effect of complex physical phenomena** and covers all engineering disciplines such as structural analysis, electromagnetics, acoustics, **fluid mechanics**, among others

- The discipline of simulating fluid phenomena and thermal effects is named **Computational Fluid Dynamics** (CFD).

- The goal of this simulation is to apply CFD technologies to better understand the **effect of thermal airflows** within domestic social gathering and how it could affect the **spread of airborne contagions** in expelled droplets.

- The objective of the authors of this work is to **assist the authorities and the public with their understanding** of risk and **show researchers how visualisation can help them communicate their work to non-experts**





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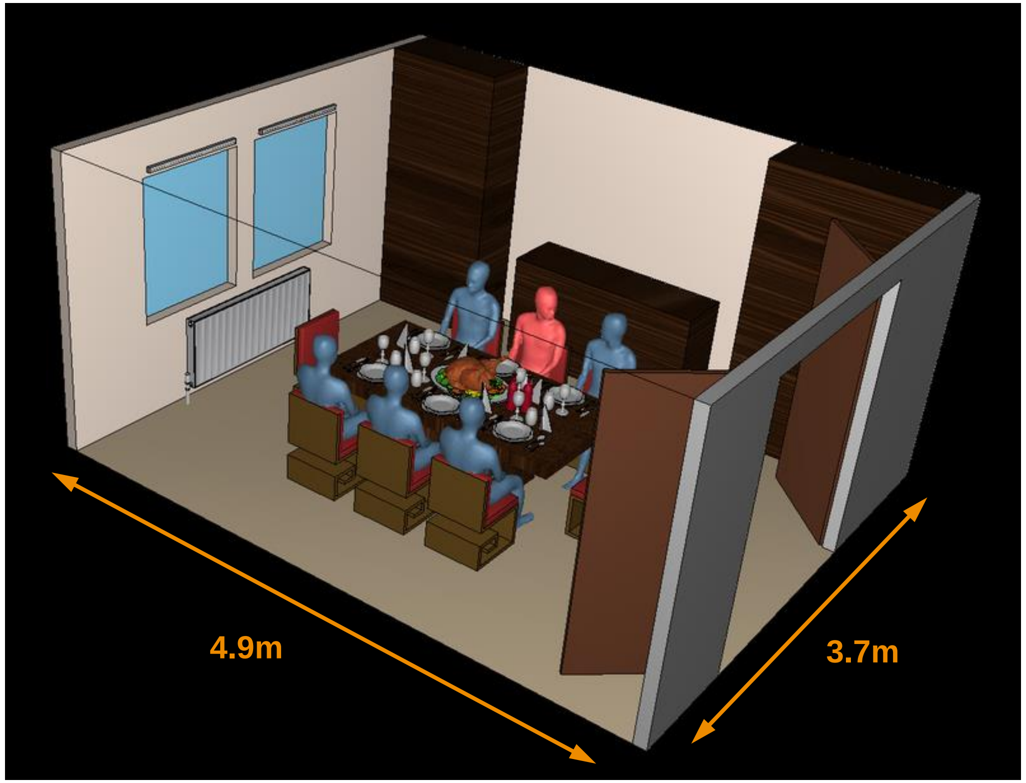
Simulation Scenario: Person Breathing & Speaking in Dining Room

<u>Global</u>

- A generic dining room with six guests, a heater, top-vented windows and doors
- Persons sitting next to each other are 0.6m apart, those opposite 1.8m apart
- One person emits droplets and is assumed to be speaking (red) to the adjacent person
- All the other passengers are assumed to breathe through their noses
- Simulated physical time is 10 minutes (600s) seconds (while the Emitter speaks)

<u>Cases</u>:

- Case #1 The doors and windows are closed
- Case #2 The doors and windows are open



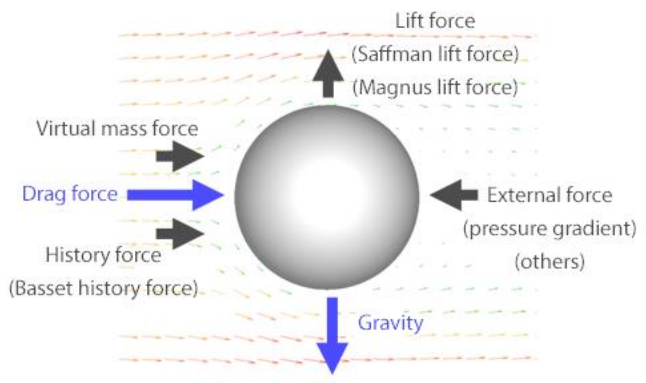
General simulation set-up

<u>Software:</u>

- The CFD solver used to perform this work is [Cradle CFD (scFlow v2021)] from Hexagon
- More information and validation examples are available upon request

<u>Droplet physics:</u>

- A simple approach called ‘particle tracking’ (diluted droplet into air) is used to model the droplets which accounts for:
  - Take drag force, gravity, and turbulent diffusion in consideration
  - No evaporation, no break-up/collapse of droplets
  - No interaction between particles (droplets)
- No consideration of virus behavior, **only air-flow and water droplets (particles) movement**
- When particles meet objects, they are arrested
- Particles were counted on the hands and faces of persons



<u>Turbulence</u>:

- The SST k-omega model was used

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Approximation of breathing cycles

CFD boundary conditions on persons

Person Breathing boundary condition according to the graph to the top right

- Breathing rate (c-rate) of 5 sec [1]
- Flow pattern approximated by figure 1 presented by Gupta et. al. [2]
- Flow rate of 600ml/stroke for European individual derived by 1.2 times 500ml/stroke for Japanese individual [1]

Person Speaking boundary condition according to the graph to the bottom right

- Maximum exhalation rate of 5.e-4 m^3/s [2] (figure 9c in reference)
- Breathing rate depend on language. Same breathing rate as for breathing was assumed
- To approximate longer exhales during speaking exhaling was extended to 3.5s and inhale to 1.5s
- Air flux rate per stroke was balances so inhale and exhale is same volume

Both the speaking and breathing case resulting flow velocity of 0.5m/s and 0.34m/s roughly agrees with data summarized by Zhang et al [3]

Table for Breathing (m^3/s - sec)

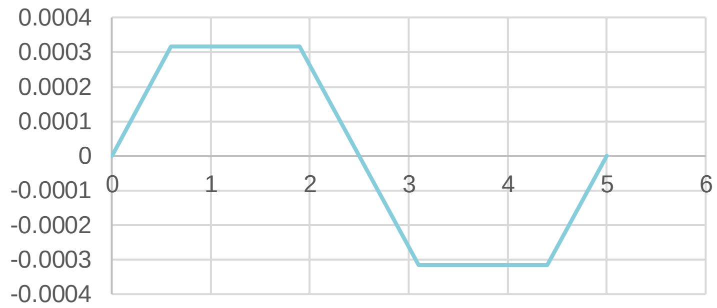
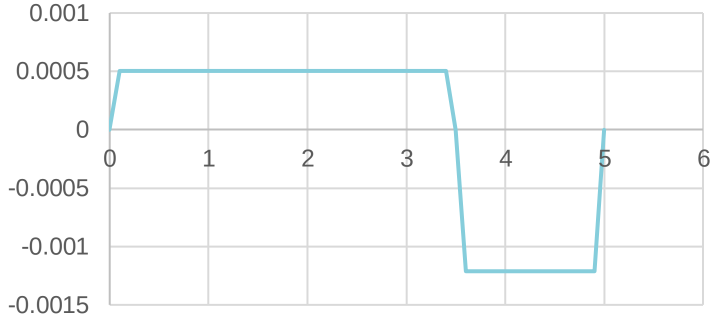


Table for Speaking (m^3/s - sec)



Breathing model references:

[1] *Breathing reference numbers and formulas*, Kyoto Prefectural University of Medicine, 30 April 2020 (Japanese) access reference here

[2] *Gupta J. K. et. al., 2010, "Characterizing Exhaled Airflow from Breathing and Talking", Indoor Air, 20, pp. 31-39* access reference here

[3] Zhang H. et. al., 2015, "Documentary Research of Human Respiratory Droplet Characteristics", Procedia Engineering, vol. 121, pp.1365-1374 access reference here

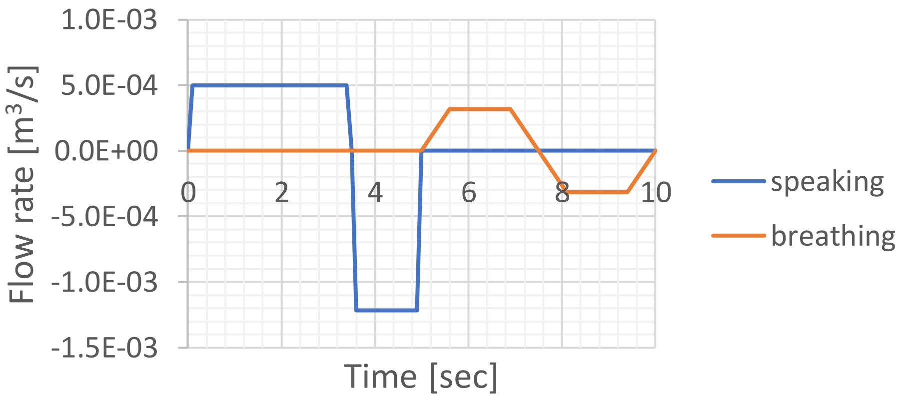
Approximation of conversation

CFD boundary conditions on persons

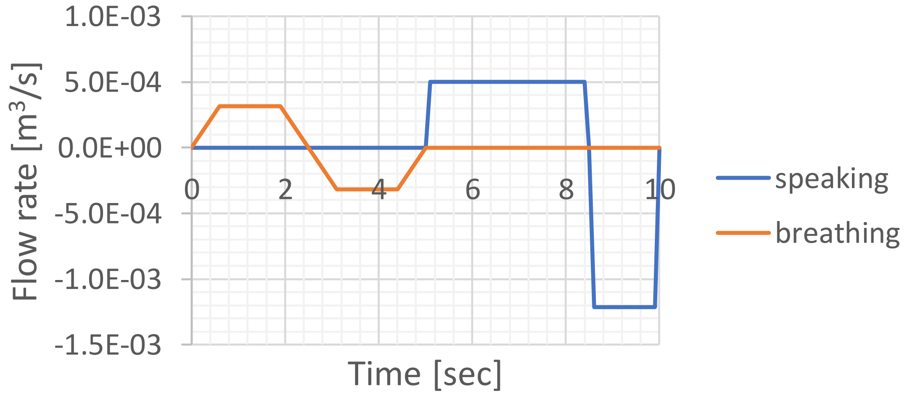
Conversation:

- According to the flow pattern introduced in page 6, a red person and the person sitting next to them are assumed to be having a conversation
- A person is assumed to breathe from their nose while the other person speaks

Flow pattern of the red person [m^3/s - s]



Flow pattern of the partner [m^3/s - s]



Approximation of droplet generation

CFD boundary conditions on emitter

Droplet Generation when Breathing:

- This boundary condition is only applied to the speaker
- Droplets are modelled as particles that are interacting with surrounding air
- Droplet Distribution:
  - Droplet (”particle”) diameter distribution were approximated by a Nukiyama-Tanasawa distribution to approximate distribution found in figure 7a presented by Xie et. al. [1]
    - Droplet mean diameter of 40 micrometer, density same as water and 1000 droplets were generated per breathing stroke with a mass of 3.35e-8 kg
  - Note that the large droplets were under-estimated by the distribution, but as they are heavy they will fall down quicker, so the distribution was tuned to agreeing with smaller sized droplets according to [1].
- Droplet spray while speaking:
  - The droplet spray was estimated based on results presented by Gupta et. al. [2], see figure 6 in reference.
  - A fan shaped spray with spread angles of 5 degrees and length of 0.03m (long axis) and 15 degrees with length 0.015 m (short axis)

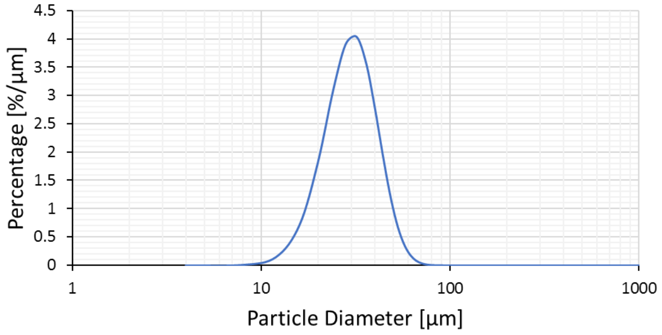
Droplet References:

[1] Xie, *X. et. al., 2009, “Exhaled droplets due to talking and coughing”, J. R. Soc. Interface 6, pp.* 703-714 access reference here

[2] *Gupta J. K. et. al., 2010, “Characterizing Exhaled Airflow from Breathing and Talking”, Indoor Air, 20, pp. 31-39* access reference here

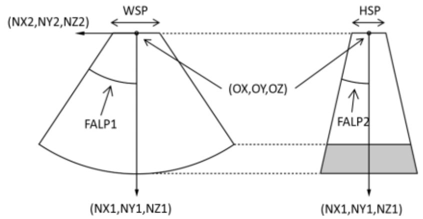
Droplet distribution

Nukiyama Tanasawa distribution with mean=40µm, a=10 & b=1



Spray model

Top view *Side view*



Approximation of droplet generation

CFD boundary conditions on emitter

<u>**Droplet Generation when Breathing:**</u>

- This boundary condition only applies to the emitter's nose
- Droplets is modelled as particles that are interacting with surrounding air
- Droplet Distribution:
  - Droplet ("particle") diameter distribution were approximated by a Nukiyama-Tanasawa distribution to approximate distribution found in figure 3 presented by Morawska et. al. [3]
    - Droplet mean diameter of 1.1 micrometer, density same as water and 30 droplets were generated per breathing stroke with a mass of 2.09e-14 kg

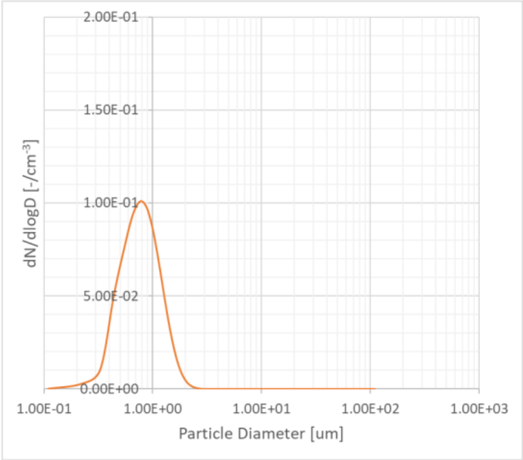
- Droplet spray while speaking:
  - Droplet spray were estimated by results presented by Gupta et. al. [2], see figure 4 in reference.
  - A fan-shaped spray with spread angles of 21degree and length of 0.01m (long axis) and 11.5degree and length 0.005 m (short axis)

- Droplet References:

[3] *Morawska, L. et. al., 2009, "*Size distribution and sites of origin of droplets expelled from the human respiratory tract during expiratory activities*", J. of. Aerosol Sci., Vol. 40 Issue 3, pp. 256-269*
access reference here

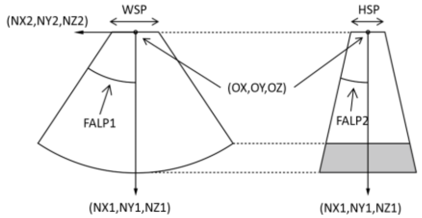
Droplet distribution

Nukiyama Tanasawa distribution with Sauter mean=1.1µm, a=4 & b=1

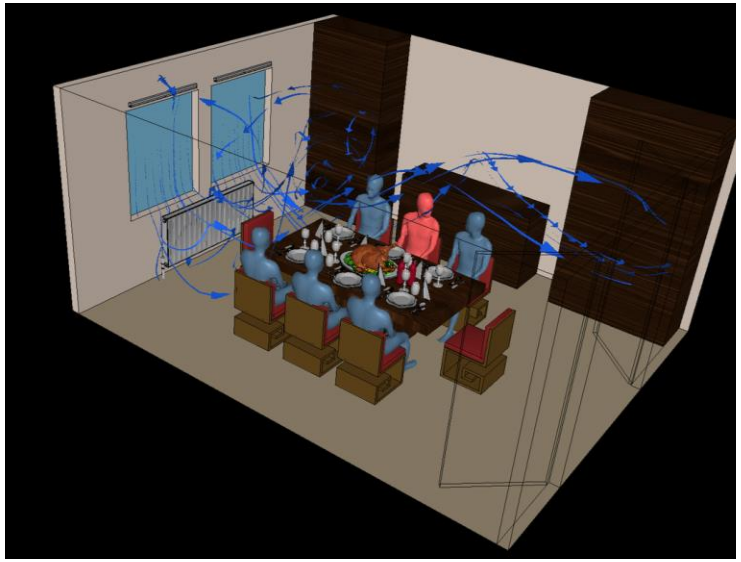


Spray model

Top view *Side view*

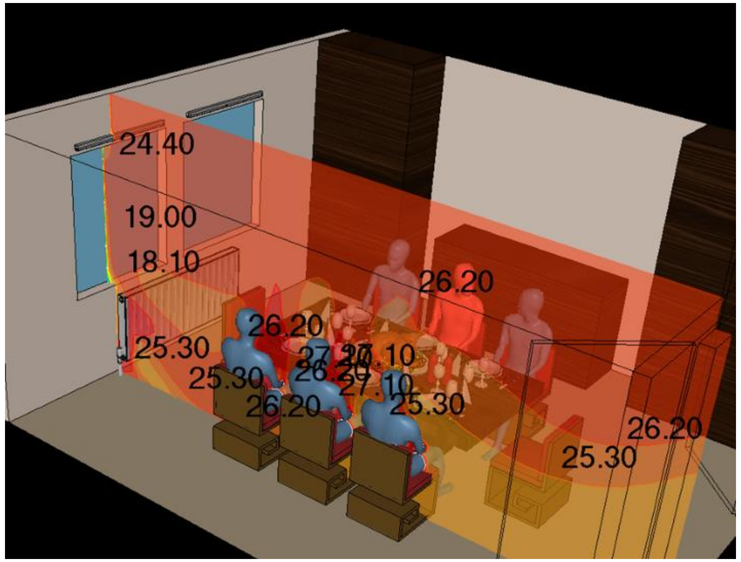


Behind the simulation's thermal, fluid dynamics



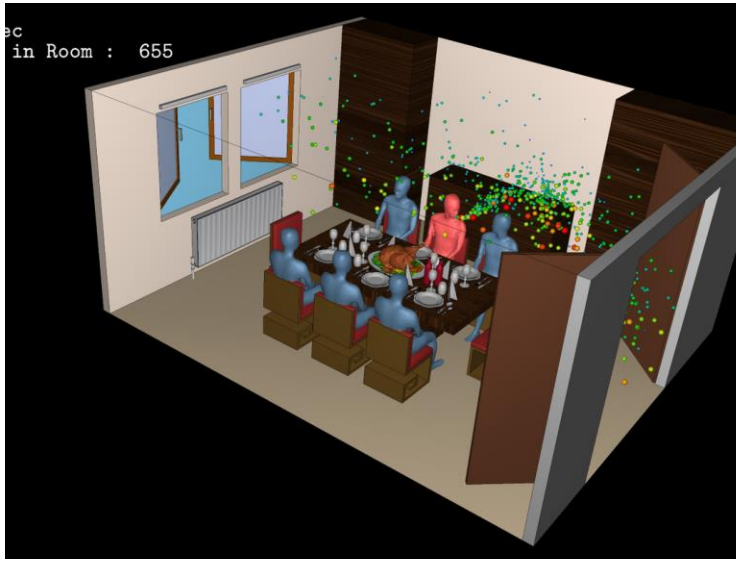
The heater stimulates natural convection in the room, with some air influx from vents above the window panes.

The arrows visualize the airflow that creates a vortex (spinning air) that transports the droplets from the Emitter and around the room.

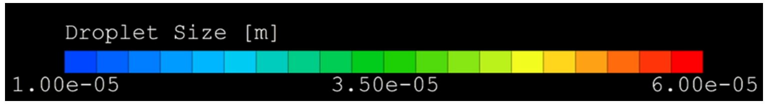


The heat in the room is represented with isotherms, showing the increase above the guests and the meal that is served.

The heater (radiator) output is 70 W/m^2 and the heat from each person is modelled using the JOS human body model. It is 5º C outside.



The size or particles is indicated by colour, with larger (red) particles more likely to settle and the lightest (blue) particles remaining airborne longest.



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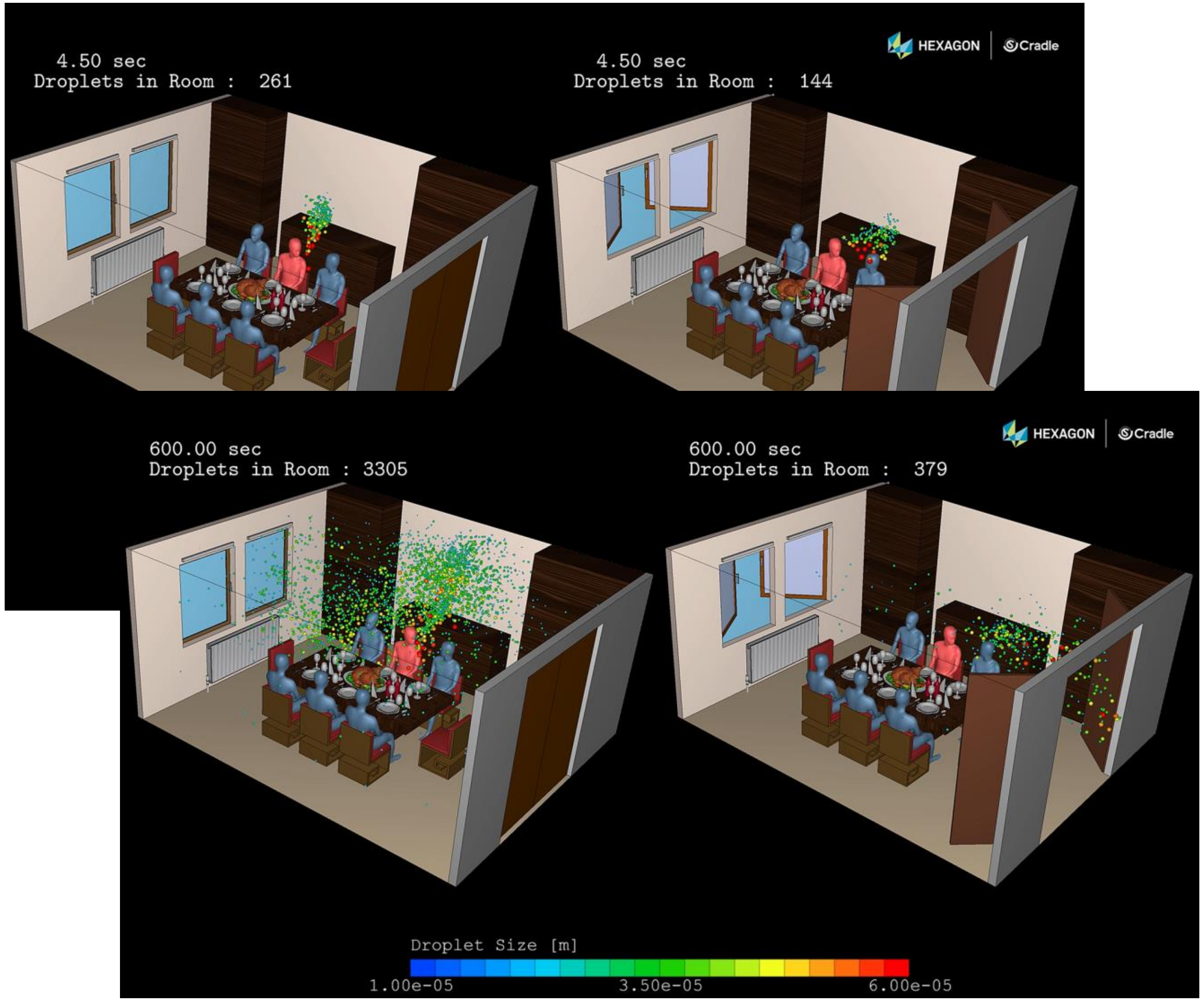
Observations



We show up to the full 10 minute (600s) duration (final frame), focussing the video on the first seconds up to 3 minutes simulation time where the initial particle emissions and dissipation occurs (top image).

What it shows

- The room with open windows and door reaches a steady state, clearly showing that ventilation disperses the particles that could be inhaled, up to a peak of around 400 particles.
- The room with no ventilation continues to accumulate particles, shown by a final count > 3000. Larger particles (red) will begin to settle on surfaces while lighter (blue) particles circulate around the room due to the heat from the heater, guests and hot meal (turkey).

It suggests

- That social distancing significantly reduces exposure.
- Sitting opposite may help, but also not sitting too close – without a mask, people project their voices and also droplets.
- Ventilation significantly reduces the concentration of droplets in the room.