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Bio-Effluents Tracing in Ventilated Aircraft Cabins

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Outlines

- Introduction to indoor ventilation in aircraft cabin
- Modelling of studied systems by COMSOL Multiphysics
- Results & Discussion
- Conclusions

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Indoor ventilation in aircraft cabins

- The bio-effluents diffusion in indoor environments is a very actual issue of interest because of the potential risk of infections transmission between people sharing the same atmosphere.

- This issue takes top relevance when considering indoor environment characterized by very high occupant density.

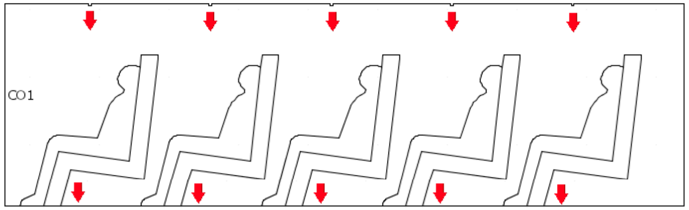
- One of the most representative of these environments is an aircraft cabin.

Indoor ventilation in aircraft cabins

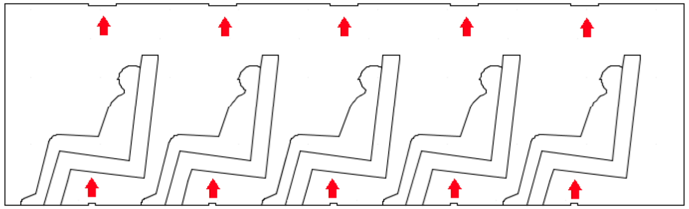
- In order to avoid high concentration regions of any air pollutant inside the cabin, environmental ventilating system is devoted to dilute the contaminant concentration by introducing fresh air inside the cabin.

- Since an aircraft cabin has a, more complex geometry and a lower outside air supply rate per person as compared to buildings, it is very challenging to design a comfortable and healthy cabin environment for commercial airplanes.

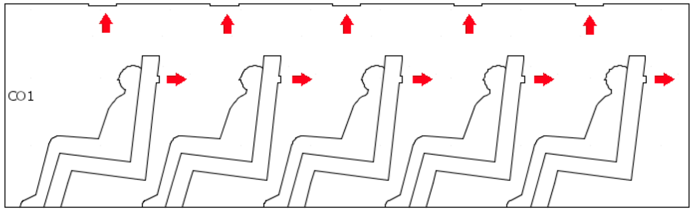
Layout of ventilating air system



Mixing Air Distribution



Under Floor Displacement

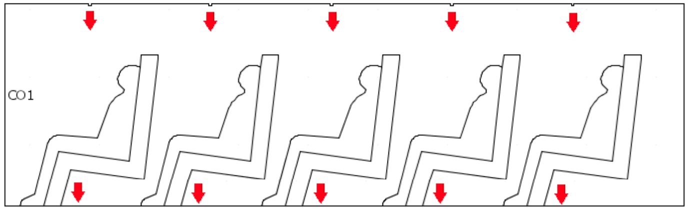


Personalized Air Distribution

Mixing Air Distribution (MAD) systems are currently used to distribute air in an aircraft cabin:

- ✓ Air is supplied at the ceiling level with a high velocity and then mixes with the air in the cabin;
- ✓ MAD system could easily spread bio-effluents from one infected passenger to other passengers because of the high velocity inlet air jets.

Layout of ventilating air system



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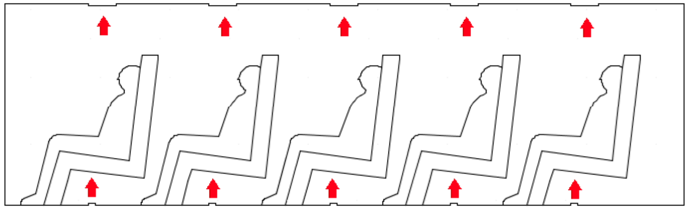

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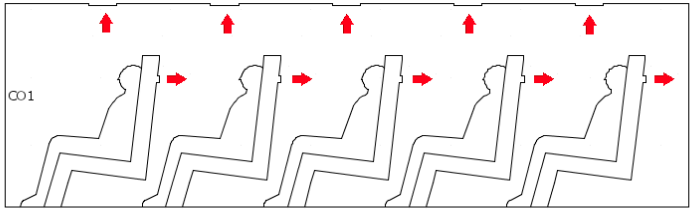
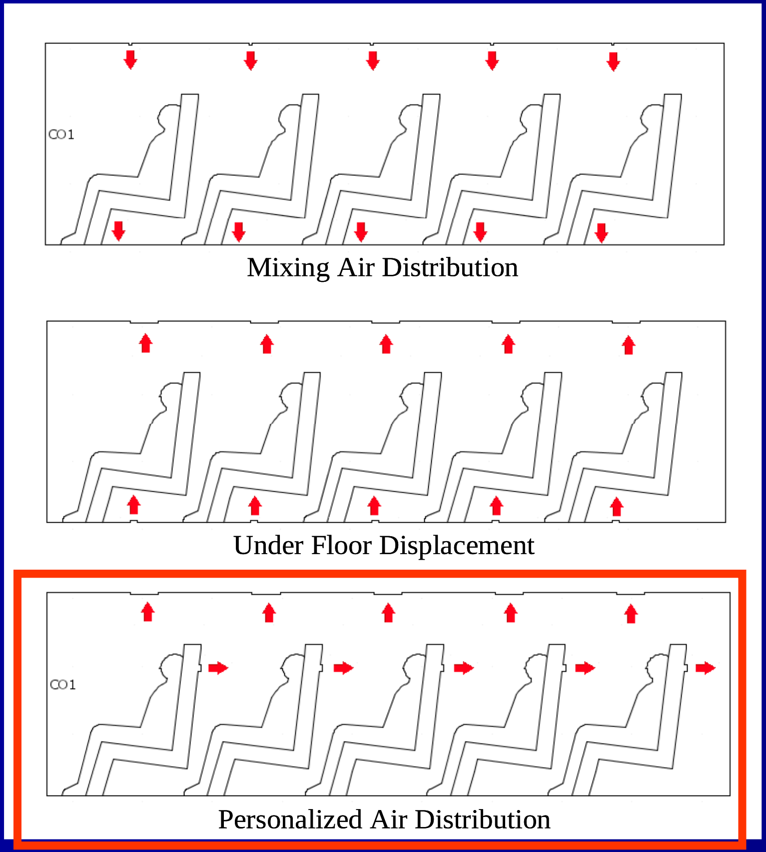


Personalized Air Distribution

Under Floor Displacement (**UFD**) air distribution systems start also to be used:

- ✓ Clean air is supplied to an indoor space from the floor;
- ✓ Then contaminated air is exhausted from the ceiling level.

Layout of ventilating air system



Mixing Air Distribution

Under Floor Displacement

Personalized Air Distribution

A new system with **Personalized Air Distribution** (**PAD**) has begun to emerge:

✓ A PAD system supplies clean air directly to the breathing area of a person;

✓ The system could create a preferred microenvironment with clean air, but it could cause a discomfort perception (draft effect) on the occupant’s face.

Purpose of the study

The present study deals with a **numerical investigation on bio-effluents transport and diffusion in ventilated aircraft cabins**:

- MAD, UFD and PAD systems are analyzed in order to strike a balance between air quality degradation and comfort conditions for passengers.

- Analyses are based on bio-effluent concentrations monitoring inside the cabin.

Outlines

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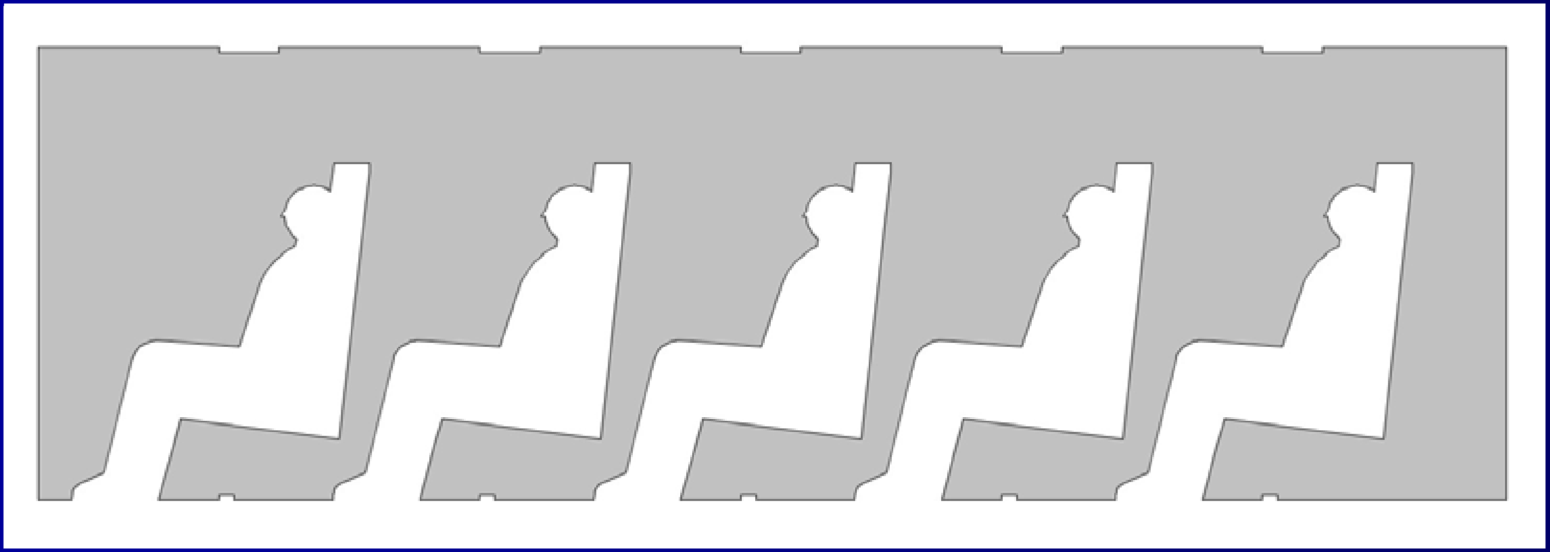
Modelling by COMSOL Multiphysics

The geometry of the considered system consists in a 2D representation of 5 rows of seats standing inside an aircraft cabin.



Modelling by COMSOL Multiphysics

Transient Navier-Stokes equations, assuming Newtonian and uncompressible fluid, are solved:

$$\rho \frac{\partial u}{\partial t} + \rho u \cdot \nabla u = \nabla \cdot \left[-pI + \eta \left(\nabla u + (\nabla u) \right)^{T} \right]$$

$$\nabla \cdot u = 0$$

Physical properties of fluid are considered constant: they are computed at atmospheric pressure (101325 Pa) and chosen ambient temperature (20 °C).

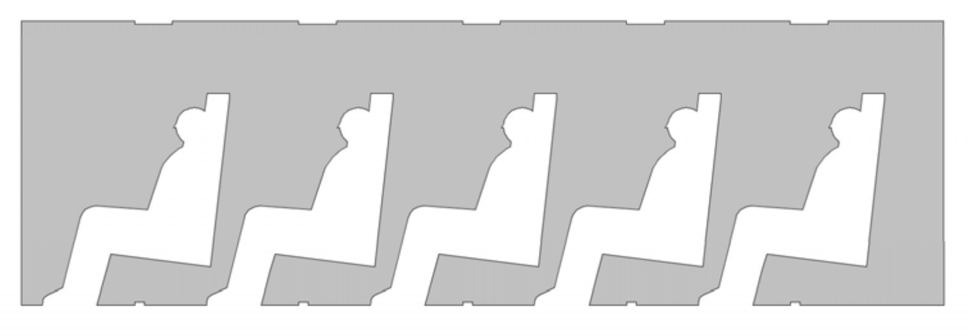
Modelling by COMSOL Multiphysics

The momentum equations are coupled with a transport-diffusion equation, based on the concentration of the carbon dioxide breathed out by the cabin occupants:

$$\frac{\partial CO_2}{\partial t} + \nabla \cdot \left(-D_{CO_2} \nabla CO_2 \right) = -u \cdot \nabla CO_2$$

Modelling by COMSOL Multiphysics

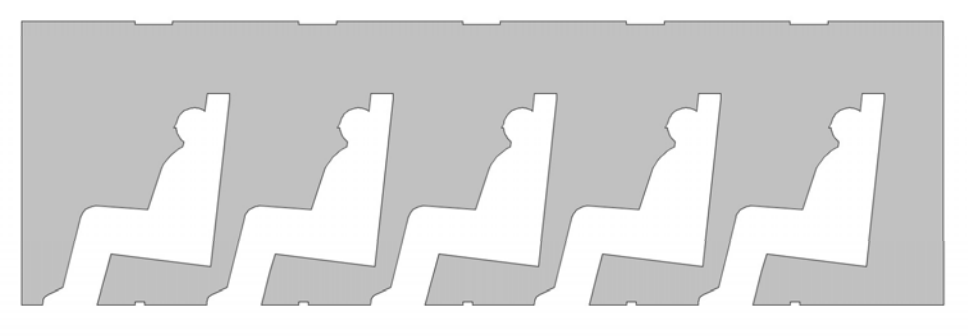
Momentum equations are solved with the following boundary conditions:



- Adherence conditions at solid walls;
- Imposed constant velocity for fresh air inlets;
- Symmetry conditions at vertical control volume confinements;
- Atmospheric pressure at recovery grids for air;
- Periodic inlet velocity function at bio-effluent inlet (nose of occupants).

Modelling by COMSOL Multiphysics

Transport-diffusion equation is solved with the following boundary conditions:



- Impermeable conditions at solid walls;
- Convective flux at recovery grids for air;
- Periodic concentration flux function at bio-effluent inlet (nose of occupants).

Modelling by COMSOL Multiphysics

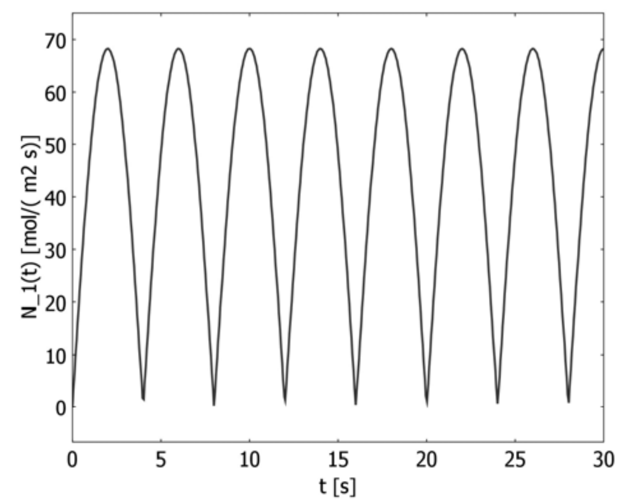
The periodic functions used as boundary conditions simulate the human breathing of occupants during time and the relative mass rate of carbon dioxide introduced in the cabin. Inlet velocity function is evaluated considering:

- The mass rate of air inhaled by a standard person every breathe;
- The air density;
- The surface of the nose holes;
- The breathing frequency.

Modelling by COMSOL Multiphysics

The carbon dioxide mass rate incoming in the control volume is as well computed following the same analytic procedure. In this case the concentration flux is evaluated by considering also:

- The CO2 molecular mass;
- The rate of CO2 contained in air breathed out.



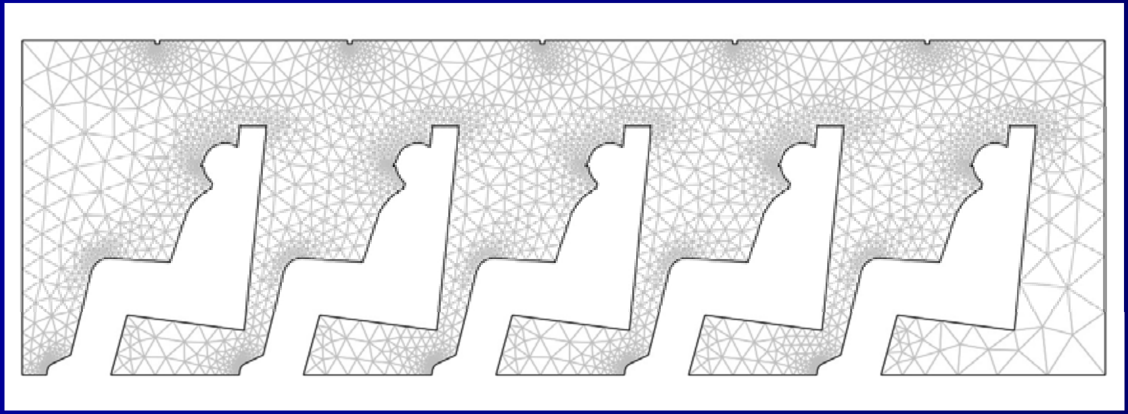
Modelling by COMSOL Multiphysics

In order to simulate more real conditions it is supposed that passengers breathe not in phase each other:

- The phase displacement is imposed in 0.2 second for each passenger.

Modelling by COMSOL Multiphysics

- ✓ Time integration lies on a BDF free time step scheme;
- ✓ Linear system are at each time step solved by a direct method;
- ✓ The time range used for computations is 120 seconds.;
- ✓ Referring to some preliminary test runs, this time range largely assures a particle introduced at time 0 to join the outlet section of the computational domain for any air distribution system studied.



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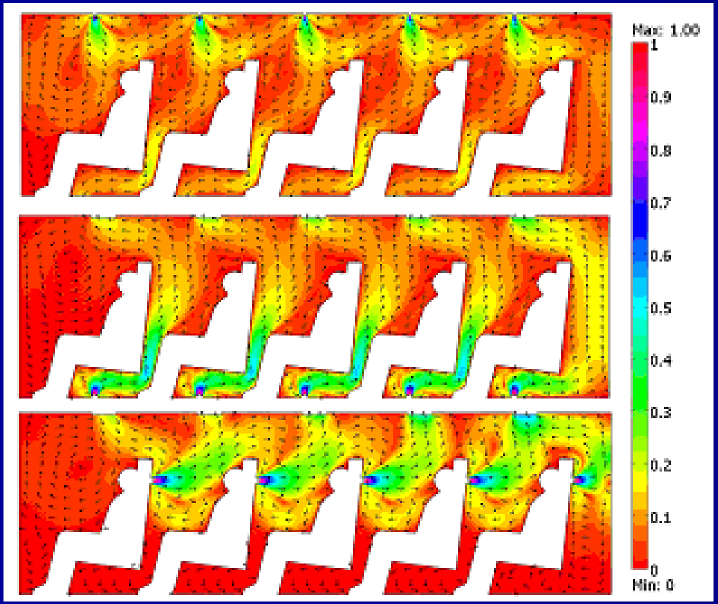
Results

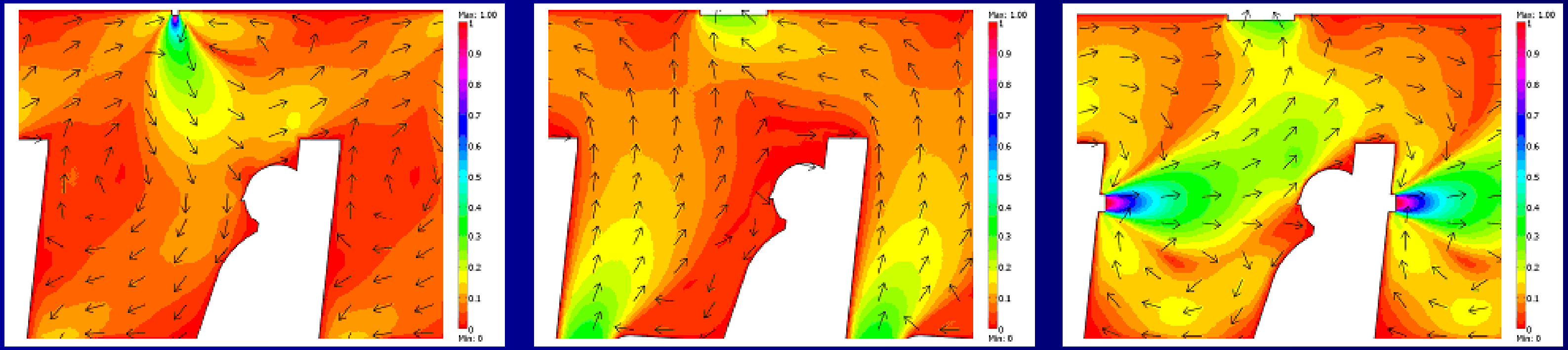
Velocity field at t=120 [s] for the MAD, UFD and PAD air distribution systems.



It is to notice as the detected motion field in proximity of the first and the last row of seats is slightly different from others. This is the effect of the control volume confinement. Anyway, it can be assumed that results referring to the intermediate rows are representative of the physical problem.

Results

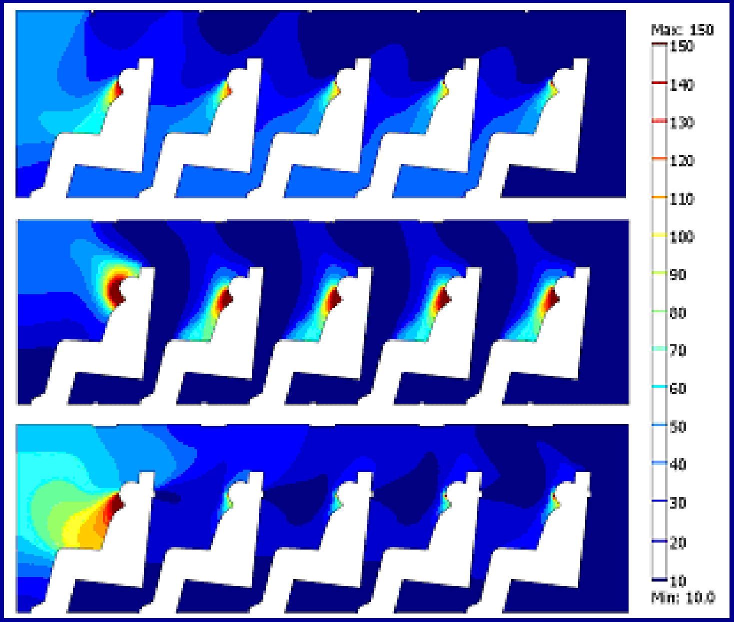
It is to remark the relative difference in the air velocity magnitude occurring close to the passenger faces. While the MAD and UFD systems assure magnitude of velocity lower than 0.15 m/s, the PAD system application determinates values comprised between 0.3-0.4 m/s.



This represents the threshold value of induced discomfort in passengers due to a potential air draft perception.

Results

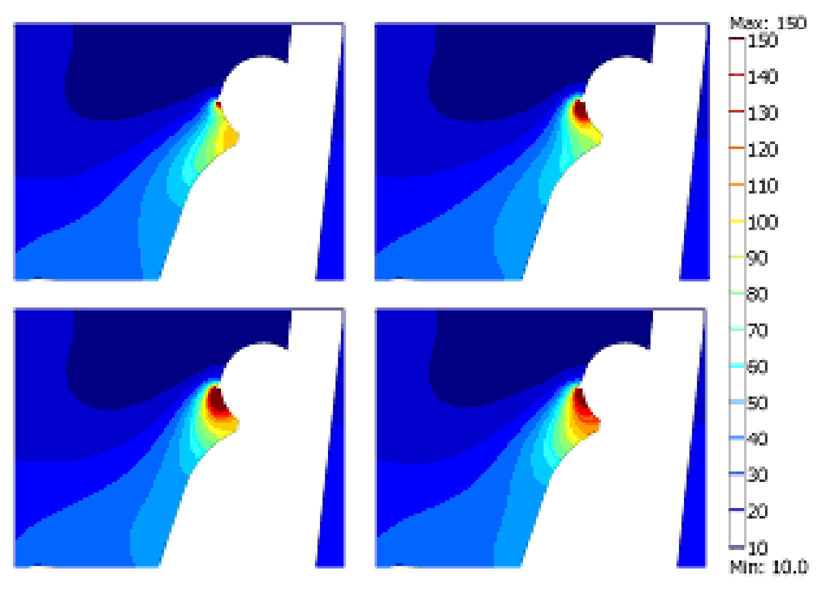
Concentration levels of carbon dioxide detected at t=120 [s].



From the air quality point of view, the best air distribution system appears the PAD one: it assures a good dilution of the bio-effluent breathed out by the passengers, determining very low concentration of it close to the occupant’s nose. UFD system is characterized by almost stagnant condition in that region, so that high levels of CO2 are detected. The MAD system determinates intermediate conditions from the previous ones.

Results

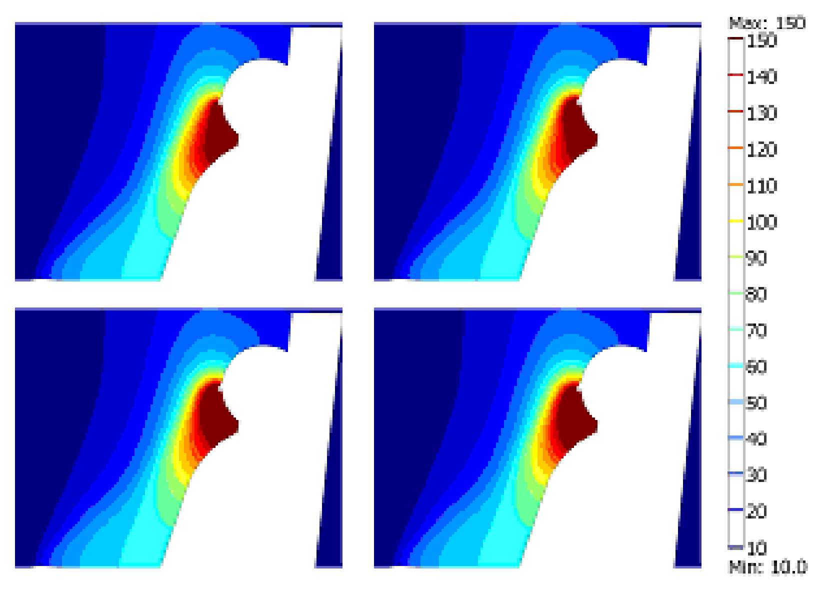
Images reporting the concentration of bio-effluent along a complete breathing act close to the passenger’s face (breathing frequency 0.25 Hz).



CO2 concentration levels [mol/m3] at t=(60; [1]; 63 [s]): enlargement close to the 3rd row of seats for MAD system.

Results

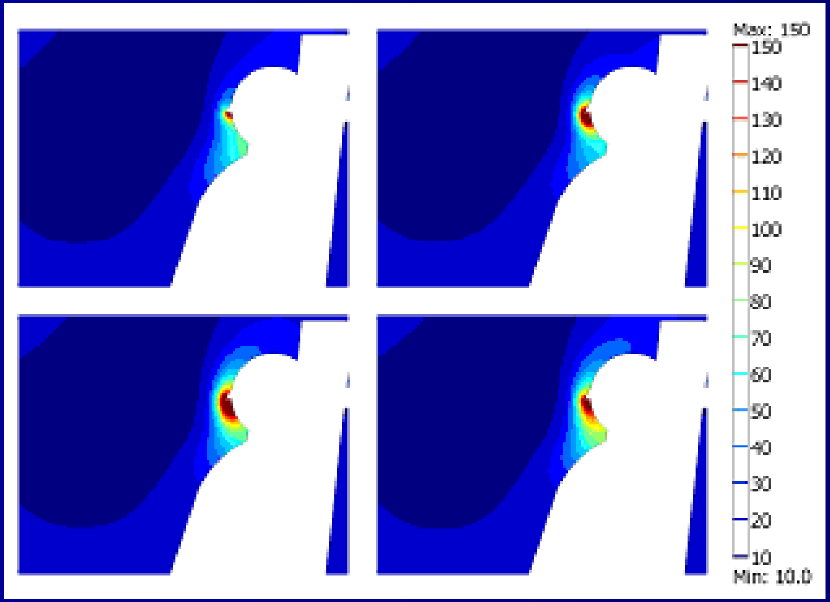
Images reporting the concentration of bio-effluent along a complete breathing act close to the passenger’s face (breathing frequency 0.25 Hz).



CO2 concentration levels [mol/m3] at t=(60; [1]; 63 [s]): enlargement close to the 3rd row of seats for UFD system.

Results

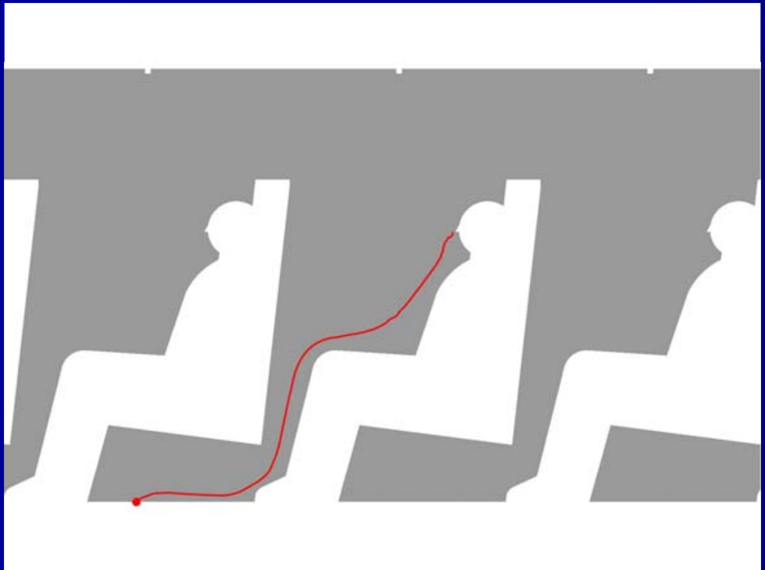
Images reporting the concentration of bio-effluent along a complete breathing act close to the passenger’s face (breathing frequency 0.25 Hz).



CO2 concentration levels [mol/m3] at t=(60; [1]; 63 [s]): enlargement close to the 3rd row of seats for PAD system.

Results

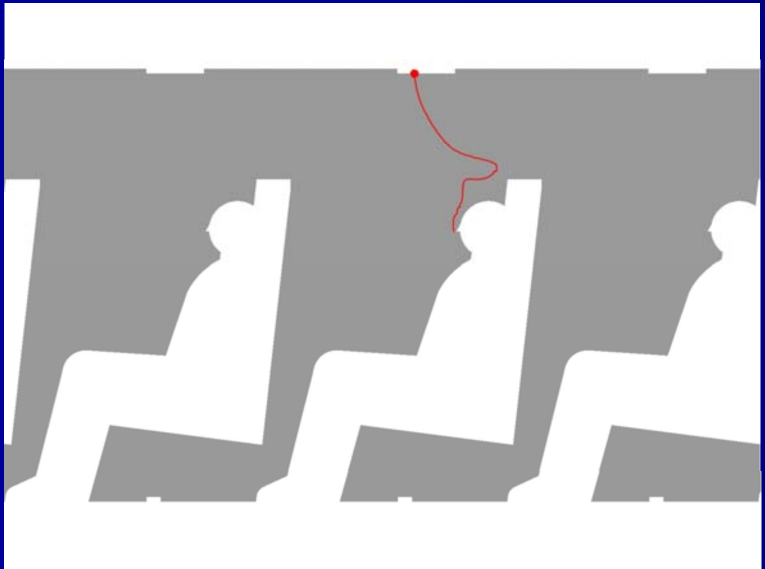
Tracing obtained by monitoring the path of a particle introduced, at the initial time of simulation, close to the nose of the passenger seated in the third row. This kind of post-processing allows to well understand the transport effect on a small mass generated by the fluid flow.



In MAD system, fresh air coming from the cabin ceiling blows the particle down as far as the recovery grids arranged on the floor. The time needed is about 23 seconds.

Results

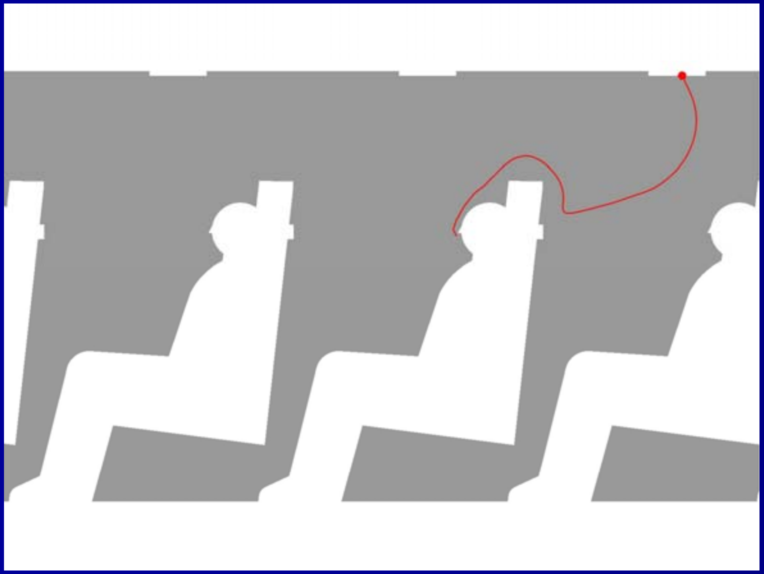
Tracing obtained by monitoring the path of a particle introduced, at the initial time of simulation, close to the nose of the passenger seated in the third row. This kind of post-processing allows to well understand the transport effect on a small mass generated by the fluid flow.



In UFD system, fresh air coming from the bottom push up the particle as far as the grids, this time located on the roof. The time needed is about 24 seconds.

Results

Tracing obtained by monitoring the path of a particle introduced, at the initial time of simulation, close to the nose of the passenger seated in the third row. This kind of post-processing allows to well understand the transport effect on a small mass generated by the fluid flow.



In the PAD system, fresh air blown by the seat in front of the breathing passenger let his bio-effluent flow toward the passenger lodged in the rear row. The particle is then blown toward the outlet section by the rear air jet. The time needed is about 10 seconds.

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Conclusions

Numerical simulations have been carried-out in order to strike a balance between air quality degradation and comfort conditions for passengers standing in an aircraft cabin potentially equipped by three kinds of air distribution system.

✓ Results mainly show as **from the comfort condition the most appropriate system is the UFD system.** In fact it assure the lower velocity level close to the passenger's face.

✓ **From the air quality point of view, the PAD system represent instead the best choice** because it allows very low level of stagnant bio-effluent close to the passenger's nose.

Conclusions

Numerical simulations have been carried-out in order to strike a balance between air quality degradation and comfort conditions for passengers standing in an aircraft cabin potentially equipped by three kinds of air distribution system.

✓ Referring to the contamination risk inside the cabin, **PAD system is detected to be the most critical because it allows particle breathed out by a passenger to be potentially inhaled by another.**

✓ Globally **it appears that in absence of relevant challenges to be pursued in the most recent UFD and PAD systems, the classical MAD represent the better compromise between opposite requirements.**

THANK YOU !!!

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