20th International Conference on
Harmonisation within Atmospheric Dispersion Modelling for Regulatory Purposes
14-18 June 2020, Tartu, Estonia

PRELIMINARY STUDY OF NATURAL VENTILATION IN INDOOR/SEMI-INDOOR TERRACES

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Key words: *CFD, Natural ventilation, Indoor/semi-indoor, air quality,* CO_2

INTRODUCTION

Bioaerosols are solid or liquid particles whose size ranges from 0.1 nm to 100 µm, containing smaller particles from biological origin (Baron and Willeke, 2001). Depending on their size, they can remain suspended in a gas from hours (lighter bioaerosols) to seconds (heavier bioaerosols). Today, it is well known that bioaerosols play an essential role in the transmission of respiratory diseases, such as SARS-COV 2.

Europeans spend, on average, between 85% and 90% of their daily time in closed spaces or indoor environments according to a report published by the EC (Eurostat, 2004). The risk of contagion of airborne diseases in these environments is greater than in open spaces or outdoor environments (Nishiura et al., 2020). Natural ventilation dilutes and removes the indoor bioaerosols by providing fresh air. For this reason, the WHO recommends improving the natural ventilation in indoor environments as a risk reduction measure (World Health Organization, 2020).

In order to evaluate natural ventilation in indoor/semi-indoor environments, both experimental and theoretical tests can be used. Theoretical tests require using numerical models able to simulate bioaerosols behaviour in real scenarios. In this sense, CFD models are a useful tool (Peng et al., 2020). Although the application of CFD models to study ventilation in real indoor environments has been already addressed in the literature (Vuorinen et al., 2020; Li et al., 2020; Borro et al., 2020; Hasan 2020), natural ventilation has not been investigated in depth. In order to reduce the risk of SARS-COV 2 transmission, it is usually recommended that the human activities like dinning in a restaurant would be carry out at outdoor. However, not all outdoor conditions are equal, and this issue has not been studied in depth. For instance, the ventilation in a restaurant terrace is different depending on the meteorological conditions and the structure of the terraces (some of them have usually outfitted their setting with walls and even roofs).

The objective of this work is to study the natural ventilation in a set of virtual indoor/semi-indoor scenarios representing enclosed terraces and semi-enclosed terraces under certain outdoor meteorological conditions. Since indoor CO_2 concentrations can be used as indirect measurements of the risk of breathing infectious bioaerosols exhaled from another person (Rudnick and Milton, 2003; Emmerich and Persily, 2003; Peng and Jimenez, 2020; Schade et al., 2021), indoor CO_2 concentrations are simulated in these scenarios. For that, an URANS turbulence approach is used to simulate air flows, and passive scalars to simulate people CO_2 emissions.

The work outline is the following: firstly, CFD model is described (geometry, mesh, main hypotheses as well as the simulations methodology), secondly, the obtained numerical results are shown and discussed and finaly, the main conclusions are presented.

CFD MODEL

A 3D geometric model of a real terrace in an urban environment has been done. People inside the terrace are sitting and talking, as shown in Figure 1. The total number of persons is equal to the maximum terrace capacity and interpersonal distance between non-partners is greater than 2 m.

The meshing is made by polyhedral cells which typical sizes range from 0.5 m at outdoor up to 0.1 m at indoor and 0.02 m around the people (see Figure 2). The total number of cells is $1.286 \cdot 10^6$.

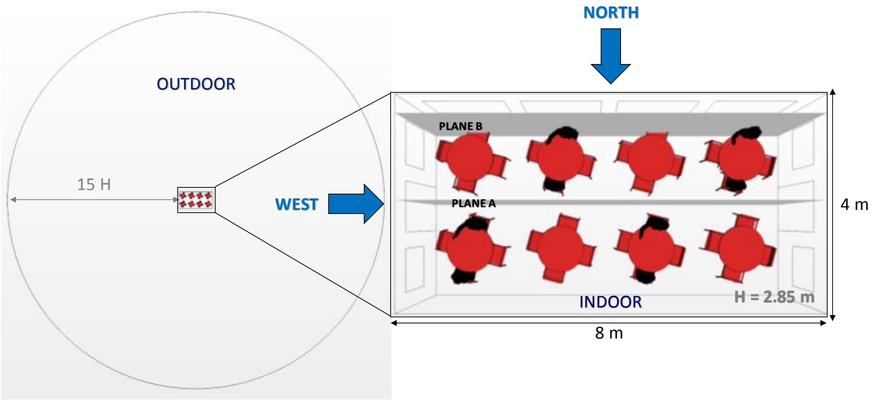

Figure 1. Geometric model: global and local dimensiones (Ordenanza, 2013) and layout of the people inside the terrace.

Regarding to the physical model, unsteady simulations have been done with a time-step 0.1 s and 3 inner iterations per time step, using the Realizable K-ε Two-Layer turbulence model. Air has been assumed to behave as an ideal gas. Exhaled CO_2 by each person has been simulated as a tracer gas, assuming that 5 % by volume of exhaled air is CO_2 and it is emitted through the mouth at 37º C and 0.375 m/s (Zhang et al., 2015).

The boundary conditions have been:

- at the outdoor, a logarithmic profile for the wind speed, the typical forms for turbulent kinetic energy and dissipation rate and a neutral profile. The considered meteorological conditions have been: 1.6 $m \cdot s^{-1}$ at 10 m high and 7 ºC. At the ground, a roughness and adiabatic specification.
- at the indoor, smooth and adiabatic surfaces except for the people, who have been assumed to be at 23 ºC. This condition is equivalent to assuming an average CLO of 0.7 (*Clothing insulation*, ASHRAE 2005) and an average MET of 1.5 (*Metabolic rate*, Ainsworth et al., 2011).

The simulated scenarios are summarized in Figure 2 as function of the enclosures condition.

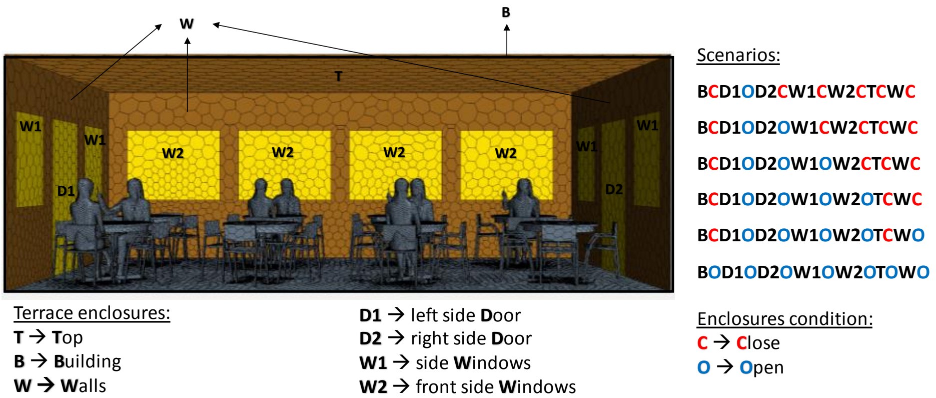

Figure 2. Meshing on indoor surfaces and set of virtual scenarios.

The methodology followed in simulations is the following: firstly, free stream is initialized and secondly, people's CO_2 emissions are run. In this way, at t_0 the volume average ΔCO_2 concentration in each scenario is null. In this work, two wind direction have been considered: West and North (see Figure 1).

RESULTS

In Figure 3, time evolution of volume average ΔCO_2 concentration in each scenario is shown for both wind direction. Each scenario has been classified according to its ACH (*Air Change per Hour*) during the steady state. ACH is a parameter communly used to study the indoor air quality.

As can be seen, in general, volume average ΔCO_2 concentration increase as ACH decrease: since ΔCO_2=[2-3] ppm in the best ventilated scenarios (ACH > 444) up to ΔCO_2=211 ppm and ΔCO_2=278 in the worst ventilated scenarios (ACH < 7).

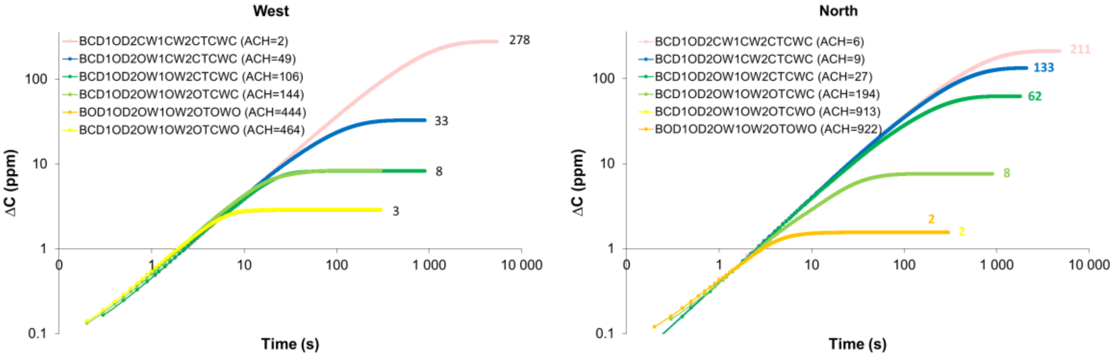

Figure 3. Time evolution of volume average ΔCO_2 concentration for different values of ACH for: left) West wind direction and right) North wind direction.

As expected, wind direction has a low impact on the extreme cases: ACH < 6 and ACH > 144.
Regarding these extreme cases, it is worth mentioning that:

- for the best ventilated scenarios, despite ΔCO_2 is low on volume average, ΔCO_2 is locally high, as it is shown in Figure 4 left) as an example. This is the reason why it is recommended to maintain interpersonal distance even in outdoor enviroments
- for the worst ventilated scenarios, in people breathing zone, surface average ΔCO_2 is always equal or greater than volume average ΔCO_2, as can be appreciated in Figure 4 right). That is why it is encouraged to increase the ventilation of these places.

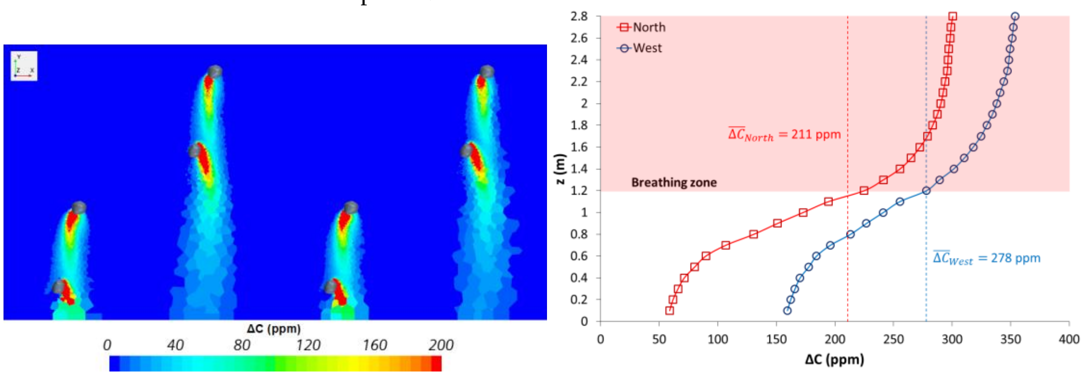

Figure 4. Left) ΔCO_2 high resolution map at 1.2 m heith (onset of breathing zone). Right) ΔCO_2 surface average profiles during the steady state for both wind directions.

However, for the intermediate cases (6 < ACH < 144) the wind direction has some impact.
For example, in BCD1OD2OW1CW2CTCWC scenario, while for West wind direction ΔCO_2 = 33 ppm for North wind direction ΔCO_2 = 133 ppm. That is, in the firt case the ventilation is better than in the second case: $ACH_W > ACH_N$.
This is because in the first case, the wind flow is perpendicular to the terrace doors, see Figure 5 left), which favors the exhaled CO_2 horizontal transport from indoor to outdoor. This configuration is commonly known as *cross ventilation* and is characterized by a well-directed air current from the the left side door to the right side door and relatively high indoor velocities, see Figure 5 left). Whereas in the second case, the flow is parallel to the terrace doors, see Figure 5 right), which favors indoor bioaerosols stagnation. This configuration is characterized by air currents flowing in and out of both doors and relatively low indoor velocities, Figure 5 left).

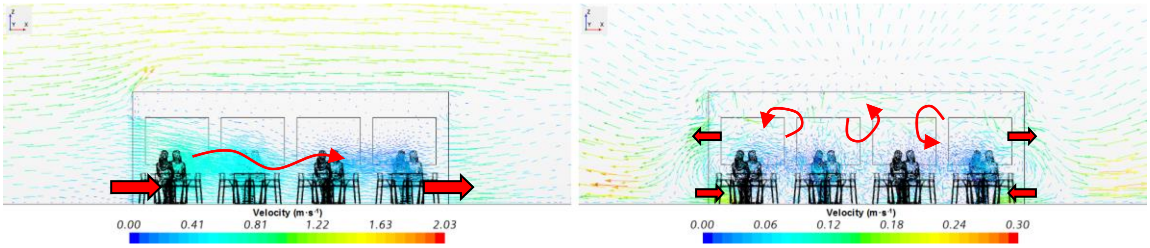

Figure 5. Tangential component of the velocity field on plane A in BCD1OD2OW1CW2CTCWC scenario for: left) West wind direction and right) North wind direction.

Finally, for West wind direction, BCD1OD2OW1OW2CTCWC and BCD1OD2OW1OW2OTCWC scenarios deserve special attention, not so much for their impact, but for their behavior, since in both cases ΔCO_2 = 8 ppm but $ACH_{BCD1OD2OW1OW2CTCWC} < ACH_{BCD1OD2OW1OW2OTCWC}$.

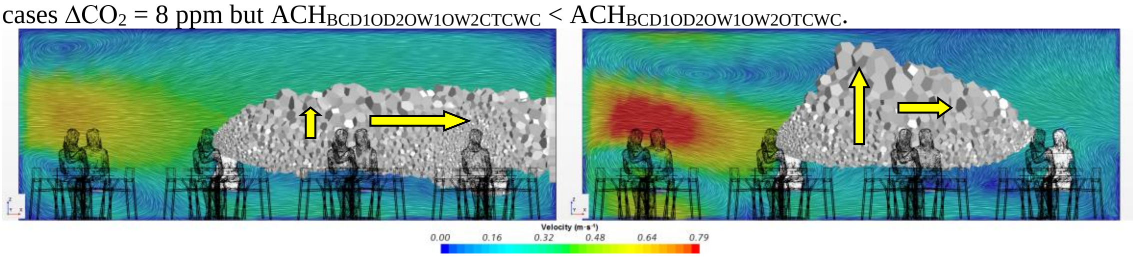

Figure 6. Line integral convolution of tangential component of velocity field on plane B and recreation of exhaled CO_2 by one of the people (cells in gray color) for West wind direction in: left) BCD1OD2OW1OW2CTCWC scenario and right) BCD1OD2OW1OW2OTCWC scenario.

In these scenarios, ΔCO_2 has been calculated also at outlets, being $\Delta CO_{2,\ out,\ BCD1OD2OW1OW2CTCWC}$ = 16 ppm and $\Delta CO_{2,\ out,\ BCD1OD2OW1OW2OTCWC}$ = 11 ppm. Therefore, from the *CO_2 removal effectiveness* point of view, BCD1OD2OW1OW2CTCWC scenario is more efficient than BCD1OD2OW1OW2OTCWC scenario (Goodfellow and Tahti, 2001).
This is because, like in scenario BCD1OD2OW1OW2CTCWC, the exhaled CO_2 is rapidly removed by the generated flow pattern between side doors and windows (cross ventilation), Figure 6 left), in scenario BCD1OD2OW1OW2OTCWC, exhaled CO_2, especially by people near the front side windows, remains indoors, i.e. the CO_2 *mean age* in scenario BCD1OD2OW1OW2CTCWC is lesser than in scenario BCD1OD2OW1OW2OTCWC (Goodfellow and Tahti, 2001).
In last configuration, Figure 6 right), the streamlines curve from the left side towards the front side, generating a vortex in the upper left half of the terrace and a low speed zone close to people located near to front side windows. The generated flow pattern weakens the exhaled CO_2 horizontal transport and thus the effective cross ventilation.

CONCLUSIONS

- CFD methodology seems suitable to study the natural ventilation in indoor/semi-indoor enviroments.
- The results show the relationship beetwen indoor CO_2 concentrations and flow patterns and how meteorological conditions influences on flow patterns.
- In general, in the simulated natural ventilation scenarios, increasing ACH decreases volume average ΔCO_2 concentration, but in some cases it is not fulfilled (e.g. BCD1OD2OW1OW2OTCWC scenario).
- To study indoor air quality, besides ACH, it is necessary to take into account CO_2 *mean age*.
- These preliminary results lay the foundation for an in-depth future work about natural ventilation and relative risk of SARS-COV 2 transmission by aerosols is these kind of scenarios.

ACKNOWLEDGEMENTS

The authors acknowledge AIRTEC-CM (S2018/EMT-4329) and RETOS-AIRE (RTI2018-099138-B-I00) Projects for the support.

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