ANALYSIS OF THE EXCHANGE OF POLLUTANT AND MOMENTUM BETWEEN OUTDOOR AND INDOOR ENVIRONMENTS. THE CASE OF A CLASSROOM IN THE FRAMEWORK OF THE VIEPI PROJECT

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DICEA - DIPARTIMENTO DI INGEGNERIA CIVILE, EDILE ED AMBIENTALE

1 GOALS

- ✓ Investigation of the physical mechanism governing the exchanges between indoor and outdoor
- ✓ Evaluation of indoor airflow and particulate matter concentrations through field campaigns
- ✓ Modelling of indoor fluid dynamics in different conditions
- ✓ Investigation of the role played by the external boundary conditions
- ✓ Evaluation of indoor pollution by means of high-resolution computational fluid dynamics (CFD)
- ✓ Comparison between numerical results and experimental data collected during the field campaigns

2 INTRODUCTION

In last decades, indoor air pollution has been recognised as a topic of primary importance in that population live mainly in indoor environments within which it is exposed to different kinds of pollutants, in particular fine and ultrafine particulate matter which affect human health.

Indoor concentration peaks and exposure of these substances depend on several factors, e.g. indoor and outdoor sources, particle size distributions, ventilation and outdoor fluid dynamics (Chen and Zhao, 2011). The last two factors, in particular, are fundamental in evaluating outdoor-indoor exchanges of pollutant and momentum, both in case of large openings, i.e. windows and doors, and through leakages.

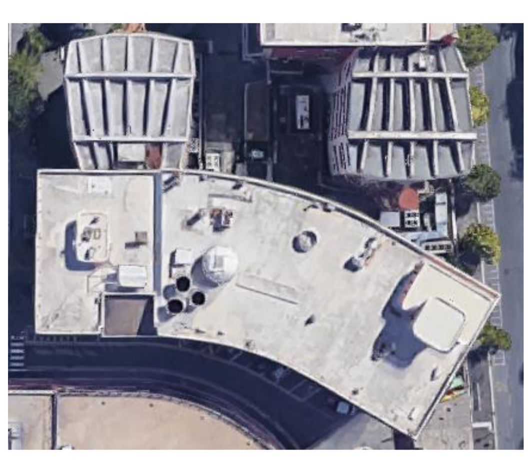
Outdoor concentrations depend mainly by the source characteristics and building geometry (see e.g. Amicarelli et al., 2012; Leuzzi et al. 2012; Badas et al., 2017; Garau et al., 2018). The investigation of indoor particle dispersion usually presents difficulties related to the geometry. High-resolution Computational Fluid Dynamics (CFD) modelling is a useful tool for evaluating indoor particulate matter dispersion and indoor-outdoor interaction (Blocken, 2015). Such models require detailed input data to obtain physically based results and to validate the results as well.

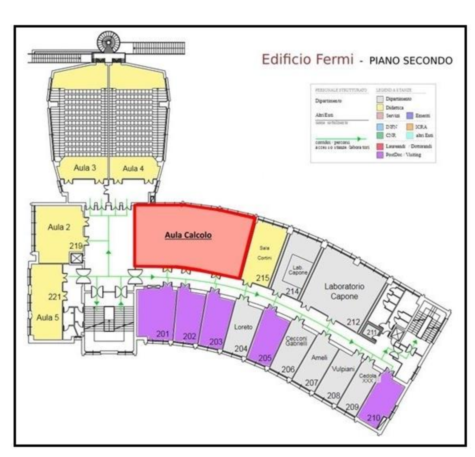
In this work, which is part of the **VIEPI** (*Integrated Evaluation of Indoor Particulate Exposure*) project, numerical simulations of flow and particle concentration fields within a confined real environment were carried out. Experimental data, i.e. concentrations of fine and ultrafine particles and fluid dynamic quantities collected outdoor and indoor, were used both as input data and for comparison with the numerical results.

3 MATERIALS AND METHODS

❖ STUDY AREA

- Classroom of the University of Rome "La Sapienza"





❖ FIELD CAMPAIGNS

- Long-term campaigns
- Short-term campaigns (Intensive Operating Periods, IOPs)

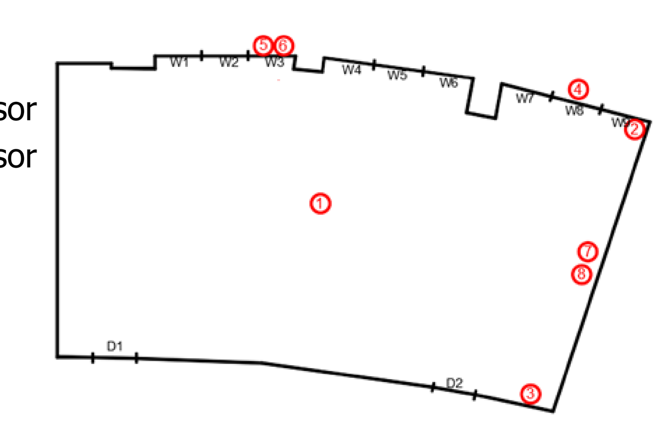
IOP#1: 21st April 2018
- From 5:00 to 17:00 ➡ evaluation of I/O exchange mechanism
- From 9:50 to 11:50 ➡ numerical simulations

❖ DATA

- The differential pressure (ΔP) sensors measure the difference in pressure between the external and internal environment
- The anemometers provide the Cartesian components of the velocity field U, V and W, pressure, temperature and relative humidity
- The condensation particle counter (CPC) and the optical particle sizer (OPS) measure concentration in number of fine (<10 μm) and ultrafine (<1 μm) particles

❖ INSTRUMENTS

1. Ultrasonic anemometer
2. Differential pressure sensor
3. Differential pressure sensor
4. Ultrasonic anemometer
5. CPC-OUT
6. OPS-OUT
7. CPC-IN
8. OPS-IN

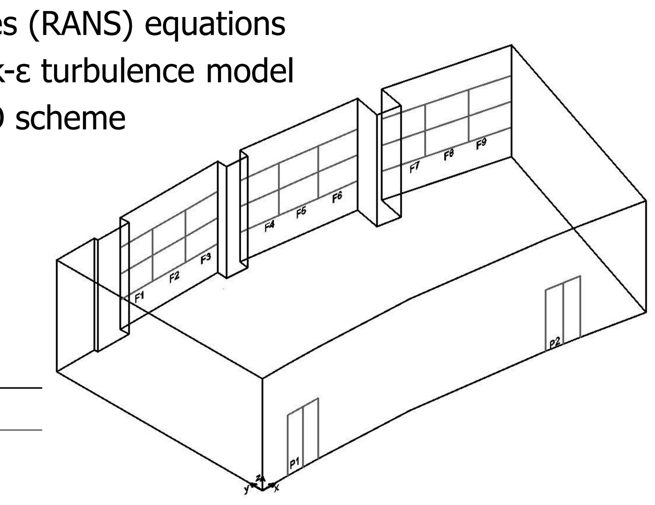


❖ CFD MODELLING

- Reynolds-Averaged Navier-Stokes (RANS) equations
- RNG (Re-Normalization Group) k-ε turbulence model
- Boussinesq's approach and PISO scheme

Domain
- ➢ Surface: ≈ 133.26 m^2
- ➢ Height: 3.85 m
- ➢ Volume: ≈ 513.05 m^3

	Mesh
Mesh interval size (m)	0.075
Number of cells	1227978
Number of nodes	≈1200000

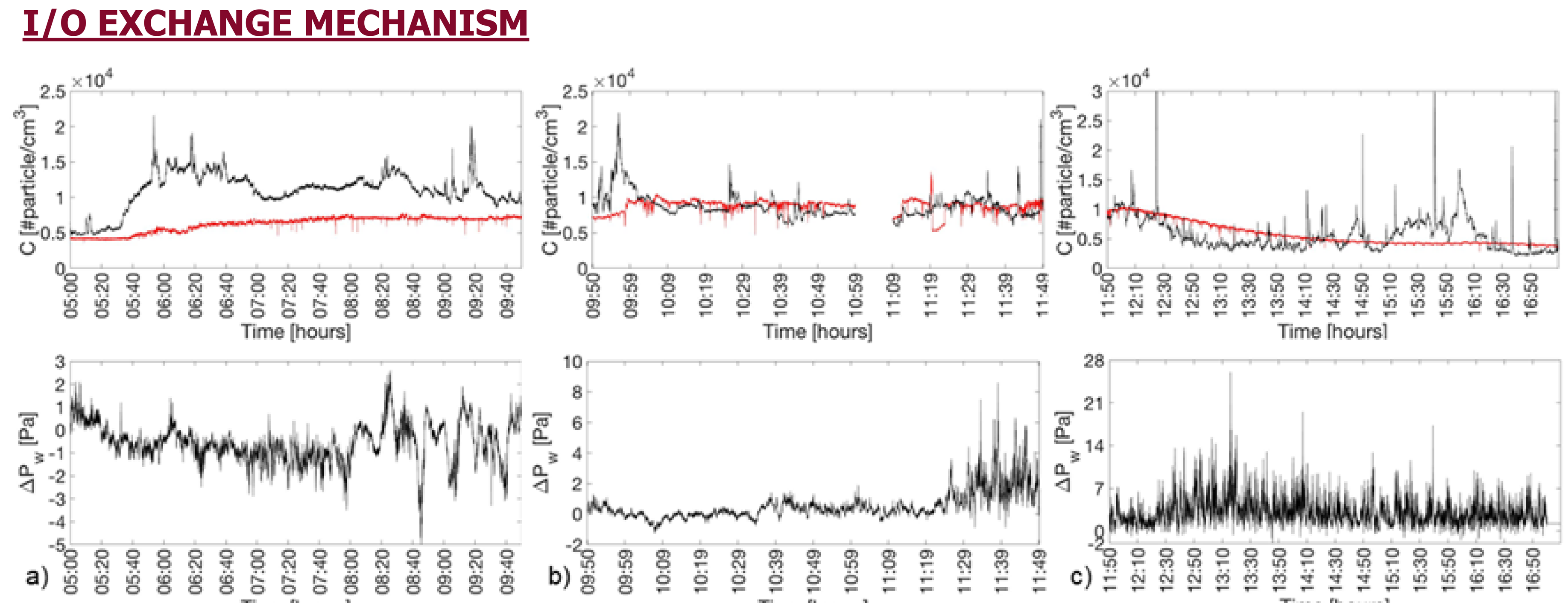


- DPM (Discrete Phase Model)
- Unsteady particle tracking

Particle time step (s)	1
Particle diameter (m)	10^{-6}
Particle velocity (m/s)	0.3
Mass flow rate (kg/s)	$5.1 \cdot 10^{-9}$

4 RESULTS

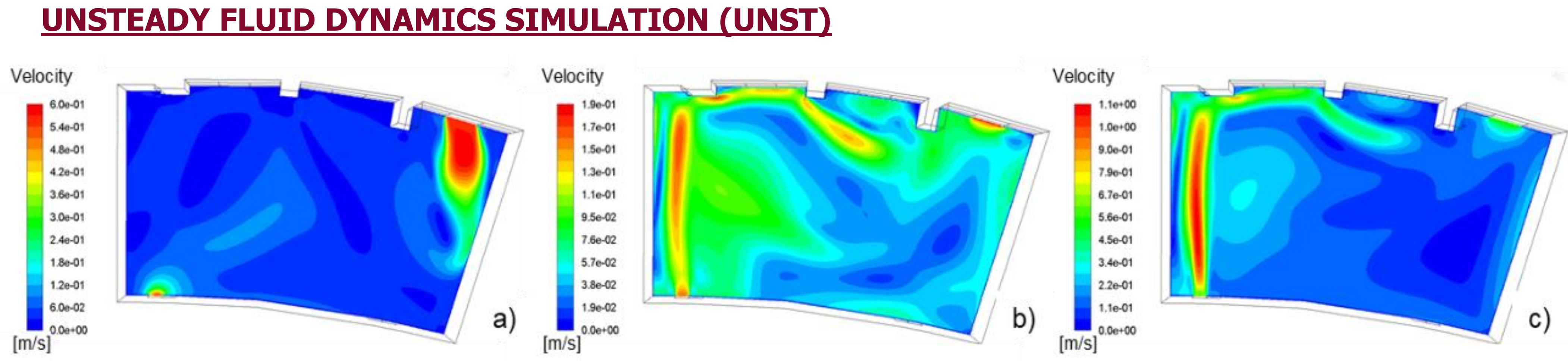
I/O EXCHANGE MECHANISM



Indoor (red lines) and outdoor (black lines) particle concentration (top panel) and differential pressure, $\Delta P_w = P_{ind} - P_{out}$, (bottom panel) measured at the window for different time intervals for IOP#1:

a) From 5:00 to 9:50	$\Delta P_w < 0$	Doors and windows closed Room pressure lower then outside The indoor concentration, C_{ind}, tends to increase probably due to the infiltrations through the leakages of outdoor air with greater concentration
b) From 9:50 to 11:50	$\Delta P_w \to 0$	Doors and windows opened I/O particle concentrations are nearly the same after about 10 min
c) From 11:50 to 17:00	$\Delta P_w > 0$	Doors and windows closed Room pressure greater then outside This condition contributes to outward filtration and infiltration from the corridor, phenomena that determine the observed C_{ind} decrease

UNSTEADY FLUID DYNAMICS SIMULATION (UNST)



Maps of the velocity fields computed along the horizontal plane at 1.5 m above the floor in unsteady conditions at (a) 900 s, (b) 5400 s and (c) 7200 s.

Experimental data concerning the outdoor velocity field, i.e. wind velocity and direction measured by the ultrasonic anemometer, were used as input data.

Simulations reproduce the two hours in which the window and the door were opened during IOP#1 test.

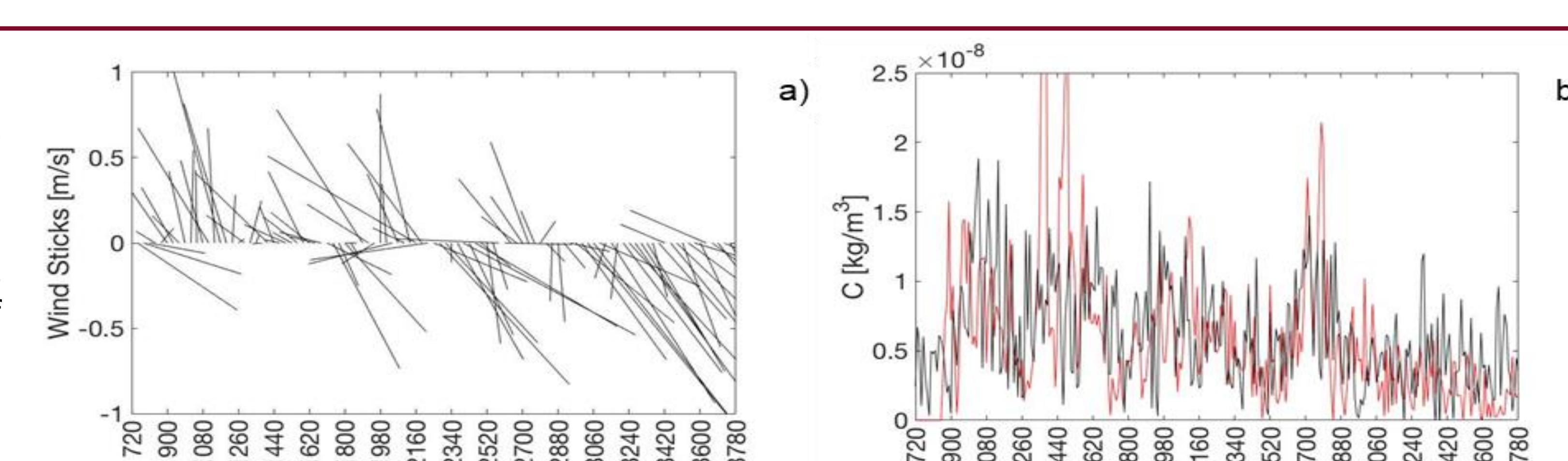
The results show the strong flow inhomogeneity and highlight the need to have high frequency measured data to proper set boundary conditions and hence to obtain physically-based numerical results.

PARTICLE DISPERSION

Stick plot of the external wind (a) and comparison between measured (black line) and computed (red line) indoor concentrations for IOP#1 (b).

The computed concentrations compare well with the measured ones when the airflow enters through the window, i.e. from 0 s up to 1700 s. In contrast, when the direction of the external wind rotates, i.e. from 1800s up to 4000s, there is no airflow entering the window while air enters through the door. As no injection of pollutant was set at this opening, the computed concentration decreases faster than the measured one.

This fact confirms the need to model properly also airflow and pollutant concentration in the hallway.



5 CONCLUSIONS

Airflow and particulate matter concentration within an indoor environment have been investigated by means of a series of field campaigns and numerical simulations.

The main objective was the analysis of indoor-outdoor exchanges of mass and momentum.

The results show the need to have detailed indoor-outdoor boundary conditions as well as information on flow and concentration field also in correspondence of the other indoor environments, if any, constituting the building.

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