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Towards a Comprehensive Urban Air Quality Modelling and Population Exposure Assessment: Relationship Between Outdoor Pollutant Concentration in Sidewalks and Indoor Pollution Inside Buildings

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Introduction

- **Impact of Air Pollution on Human Health**
- Air Pollution → largest environmental health risk in Europe (EEA, 2017)

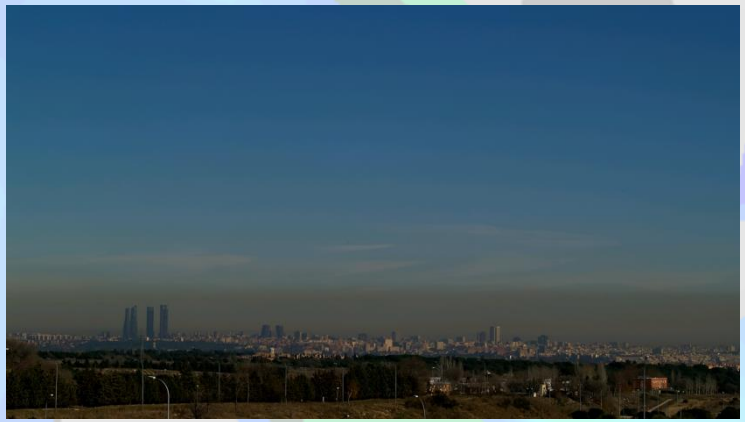
Urban Environment

1) High percentage of population lives in cities (e.g. > 70% in Europe)

2) Reduced ventilation and traffic emissions in urban environments → High pollution in cities (NO_2, PM_{10},…).

Population are exposed to pollutant concentrations exceeding the AQ standards → Impact on human health

How can the concentration representative of the amount of pollutant to which people are exposed be estimated ?

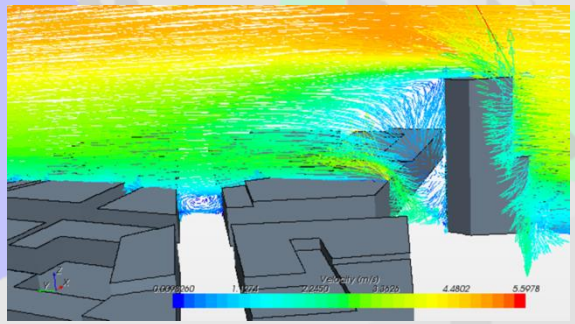


Introduction

Air Pollution in Urban Environments

1) Complex **Atmosphere – Urban Surfaces Interactions**
2) Reduced **Street Ventilation**
3) Complex temporal and spatial **variability of traffic emissions**

High pollutant concentration and **strong gradient of concentration** (spatial and temporal)



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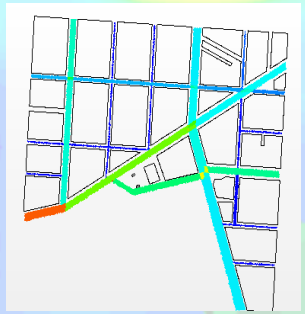
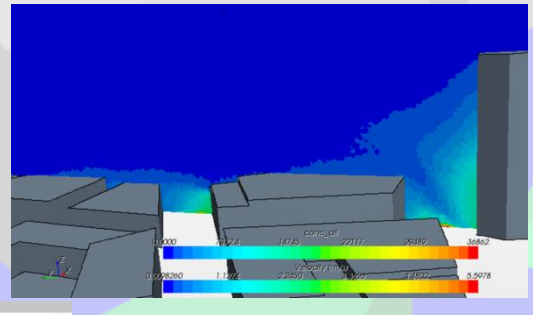
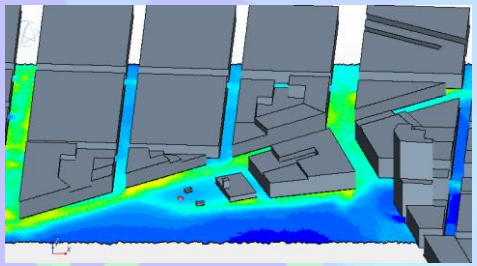






Street Scale

High Spatial Resolution Needed

Introduction

Indoor concentration

People spend the most time inside building

Necessary:

1) Indoor Concentration

2) Concentration in the streets

Street Scale and outdoor-indoor pollutant exchange

Modelling at High Spatial Resolution Needed

Main Objective

Objective

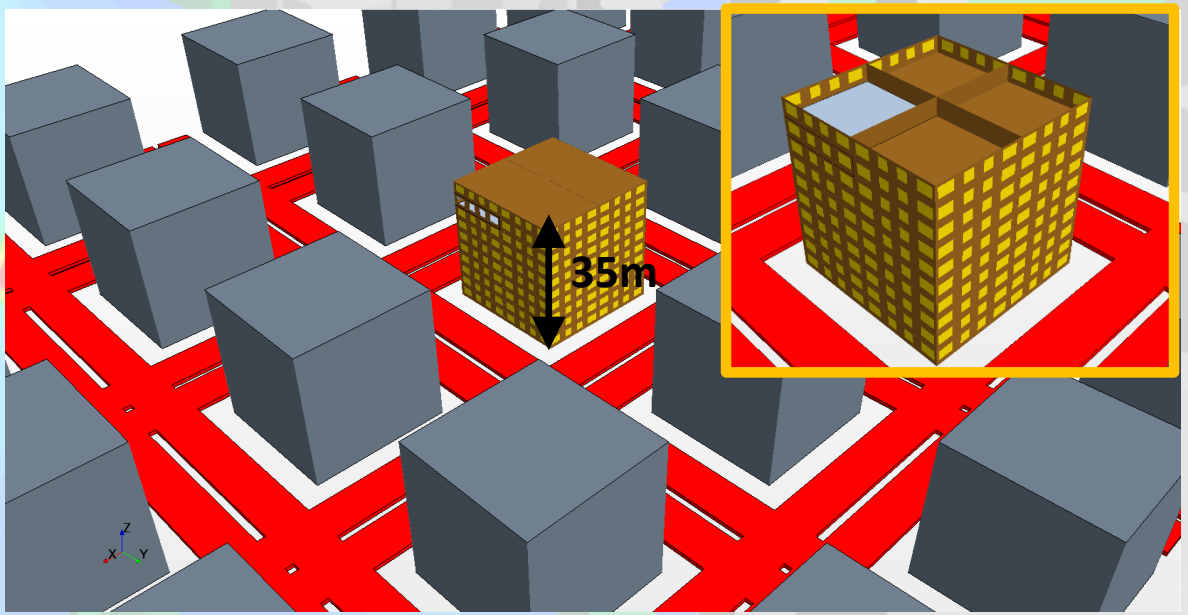
To investigate the relationship between concentration of traffic-related pollutant at pedestrian level and indoor concentration inside a standard building of apartments in an urban environment.

Study focused on:

- Traffic-related pollutants
- Natural ventilation of the rooms

Methodology

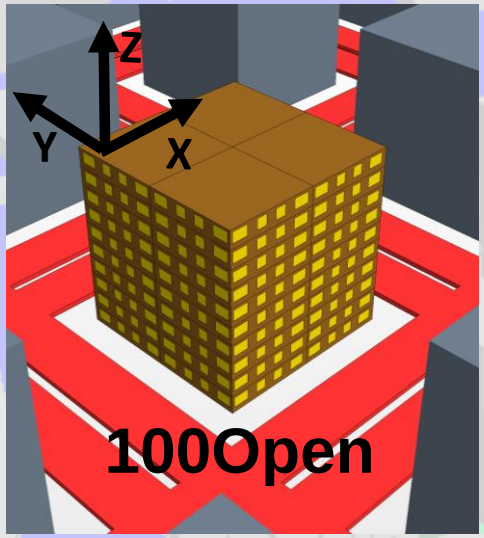
CFD modelling covers the whole urban environment around the building and the indoor of the target building.

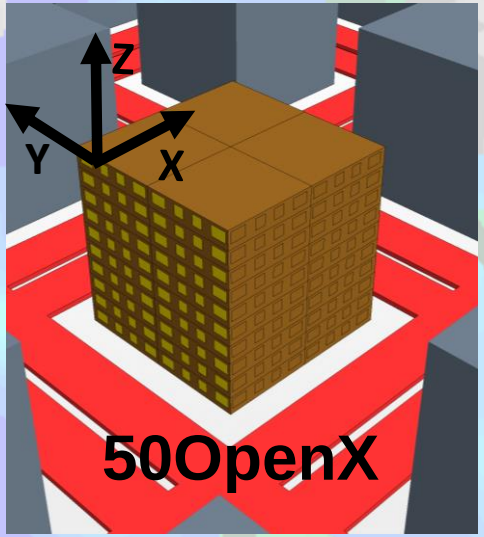


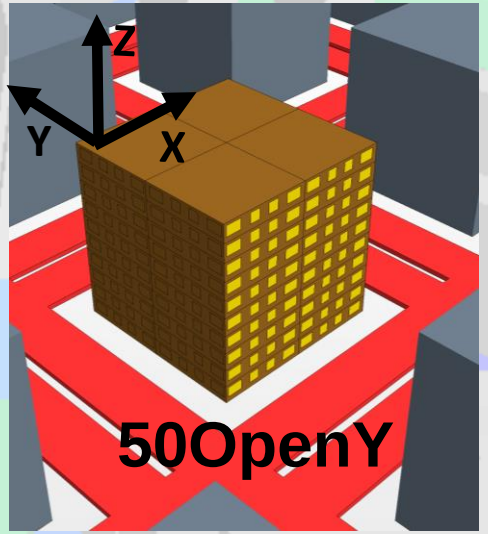
- Array of building: **Height=35m (10 floors)**; Street width= 35m
- **Interior of target building**:
  - **Four indoor rooms** at each floor with windows in the facades.
  - Percentage of **windows=30%**
- **Traffic emissions** (in red)

Description of Scenarios

Configuration of open windows





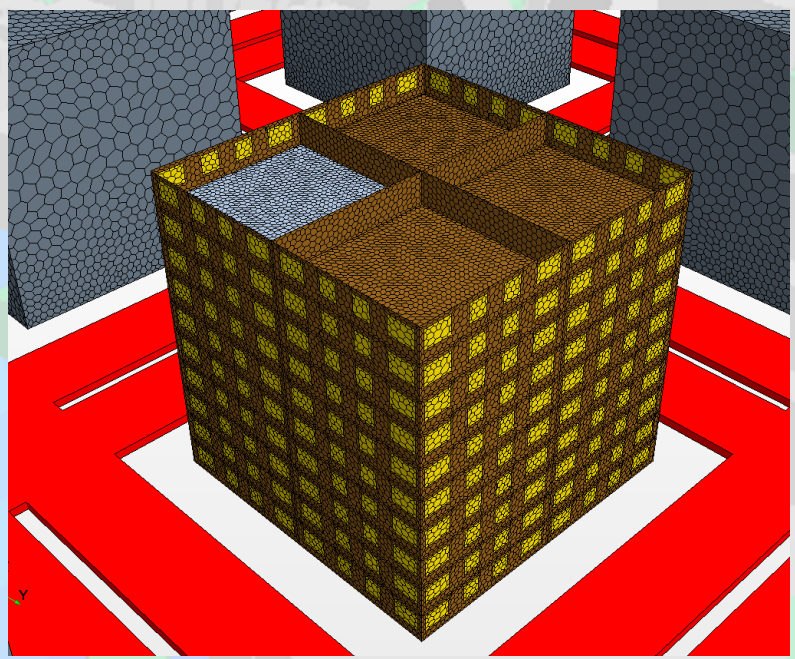


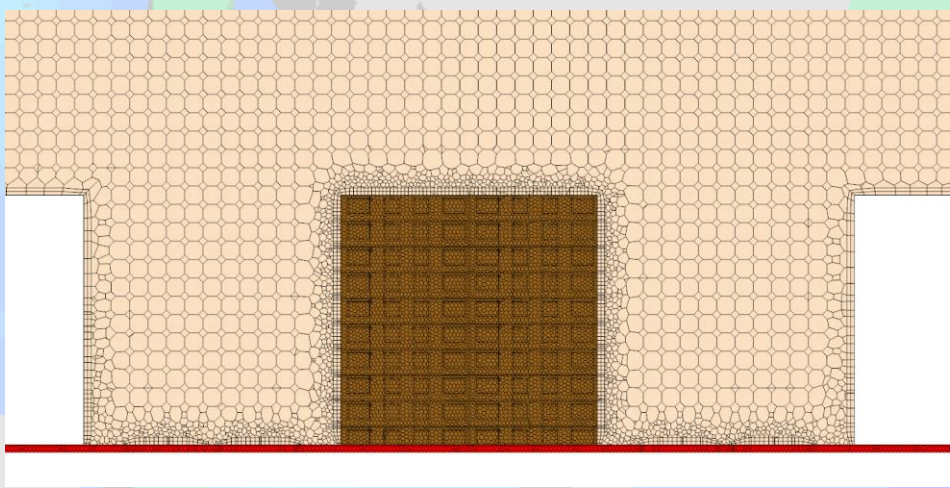
- **Configuration 1**: All the windows closed (***Closed***)
- **Configuration 2**: All the windows open (***100Open***)
- **Configuration 3**: Only windows of the X-facade open (***50OpenX***)
- **Configuration 4**: Only windows of the Y-facade open (***50OpenY***)

Assumption: No infiltration of pollutants through closed windows

Model Description

- CFD model: RANS with Realizable k-ε
- Non-reactive pollutant. Only traffic emissions considered.
- Domain following best practice guidelines.
- Mesh: 12.3 x 10^6 cells with refinements 0.5 m. A grid sensitivity test was performed.
- Unsteady simulations of 1 hour
- Neutral inlet vertical profiles for wind flow
- Two wind directions
- Flow around building for closed windows scenarios evaluated by using wind-tunnel measurements





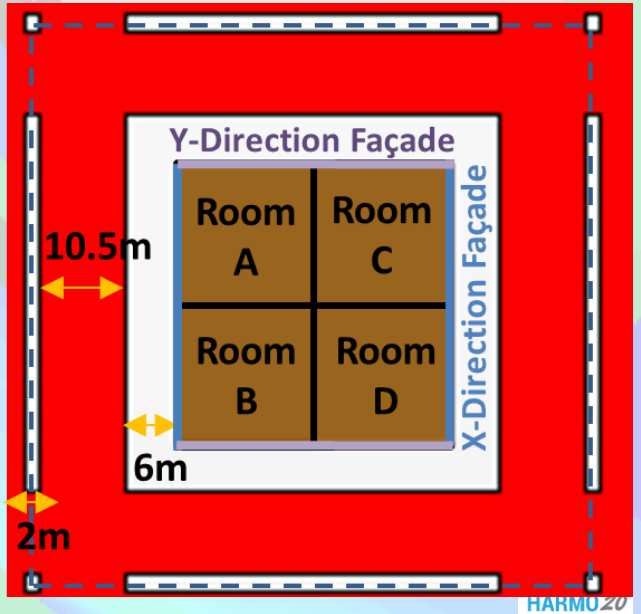
Results

How much would the indoor concentration be (something that we normally do not know) compared to ground-level concentration outside (something it is usually estimated)?

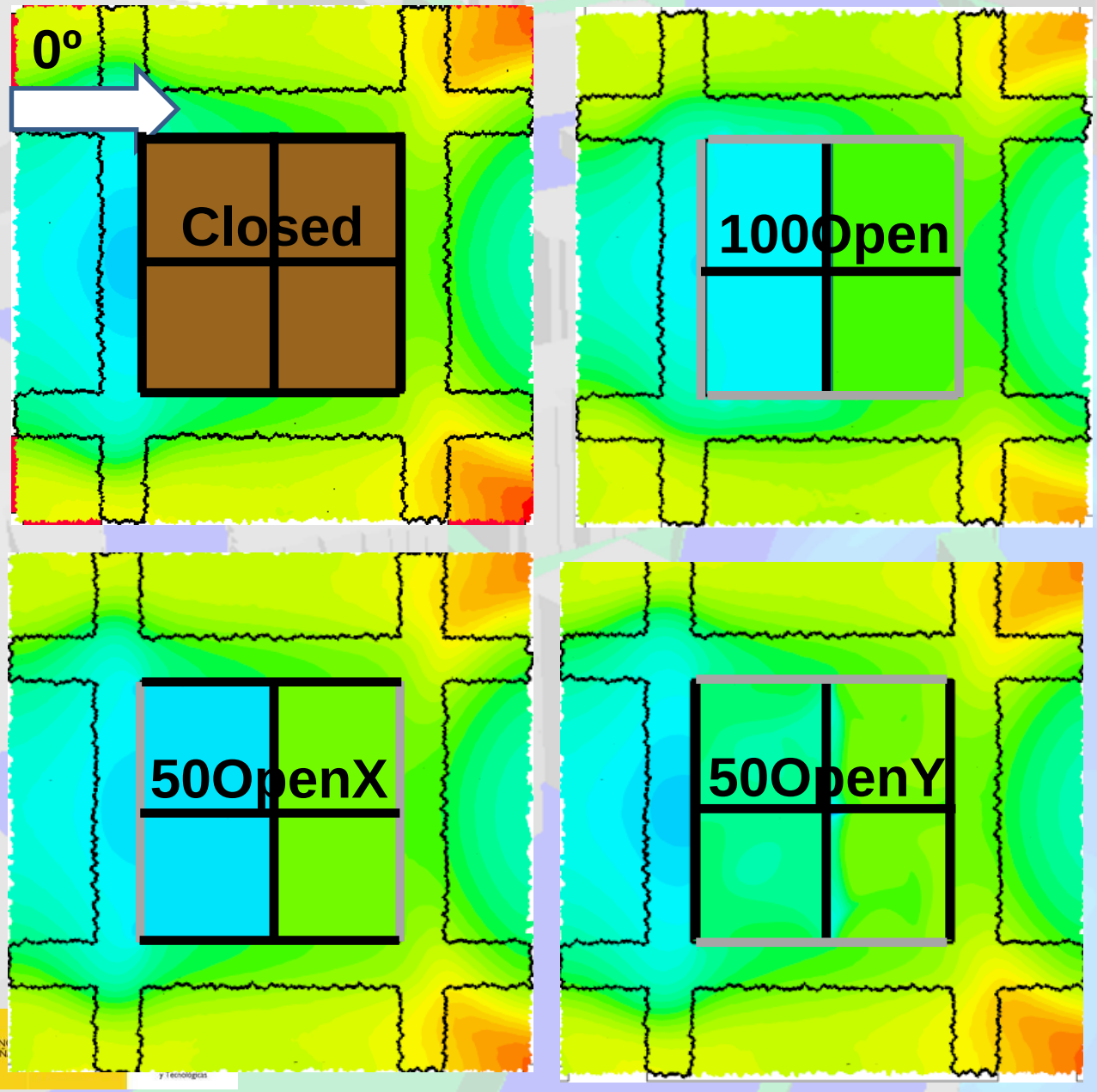
Average concentration of traffic-related pollutants in the street at pedestrian level

Average indoor concentration in different rooms of different floor of a standard building of apartments in an urban environment

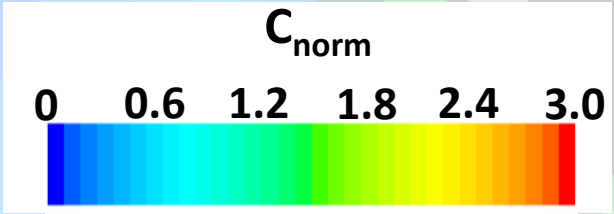
- **Two wind directions and 4 window configurations**
- **<u>Assumptions</u>:**
  - **Traffic-related pollutants**
  - Only **wind-driven ventilation across the windows** is considered (No infiltration of pollutants through closed windows)



Perpendicular Wind Scenarios



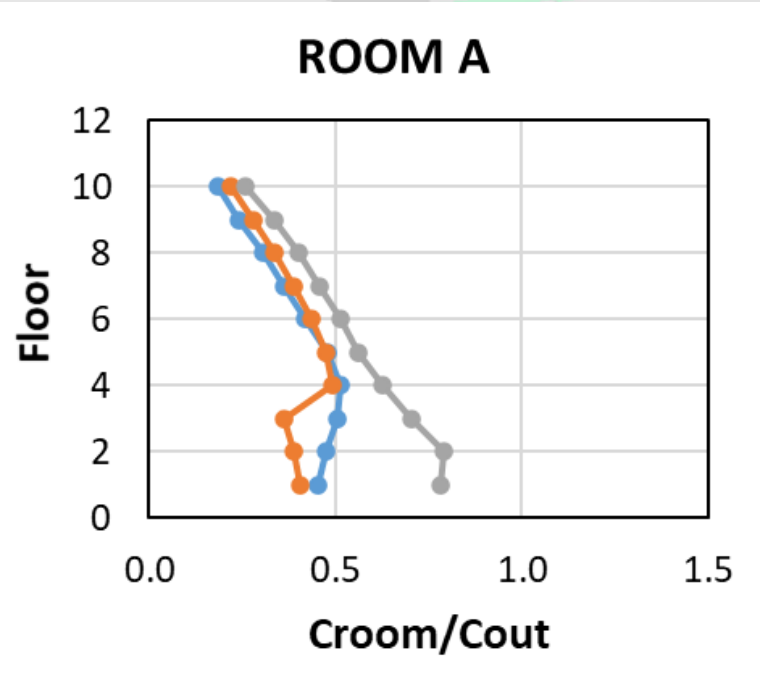
- Concentration of traffic-related pollutants in the street at pedestrian level is NOT affected by the opening of windows.
- Rooms receive pollutants from outdoor through the open windows → **indoor concentration depends on flow through open windows** and **concentration close to them**.
- **Highest indoor concentrations** are obtained:
  1) **high concentration in at least one façade** of the room with open windows.
  2) The **wind-induced flow across the open windows enters the room from highly-polluted façades**.

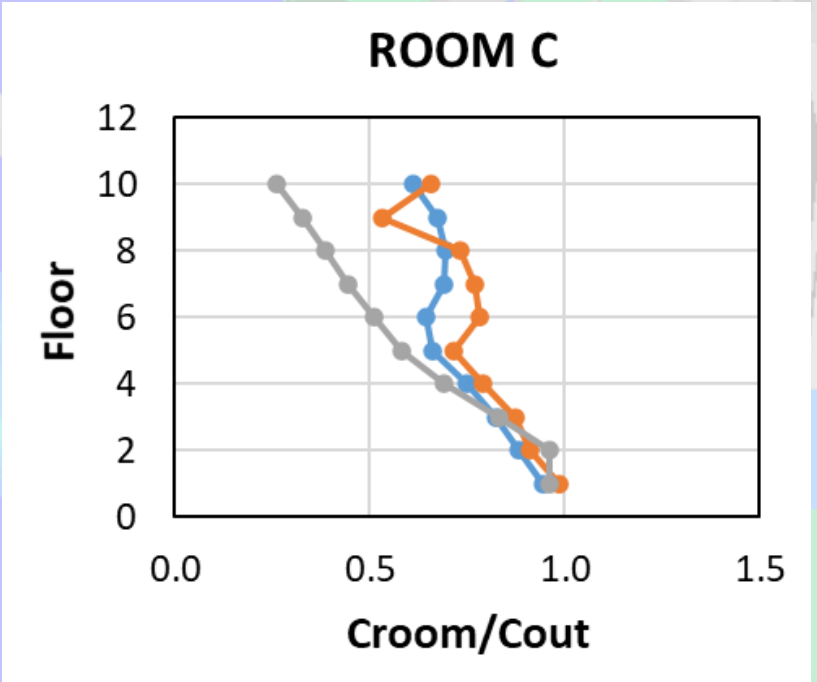


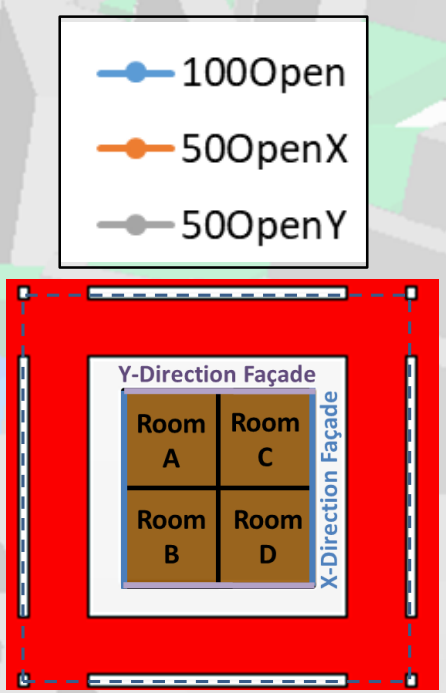
$$C_{norm} = \frac{Cu_* A_{em}}{Q}$$

Normalized concentration at pedestrian level (1st floor in the buildings)

Perpendicular Wind Scenarios

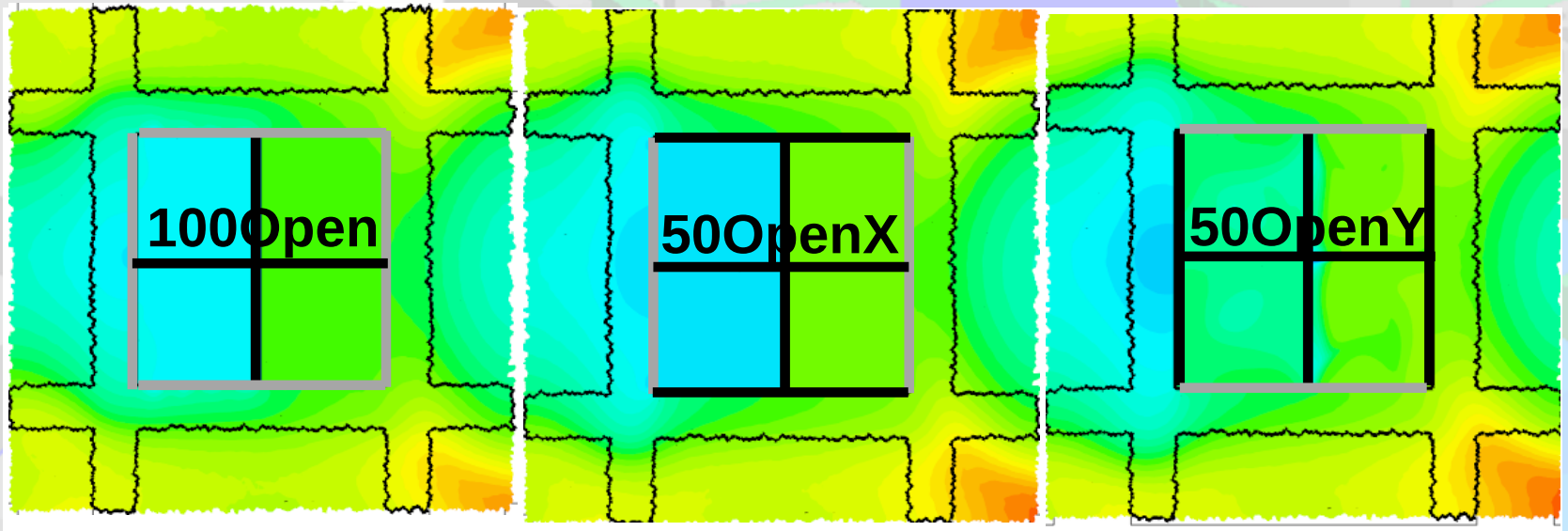


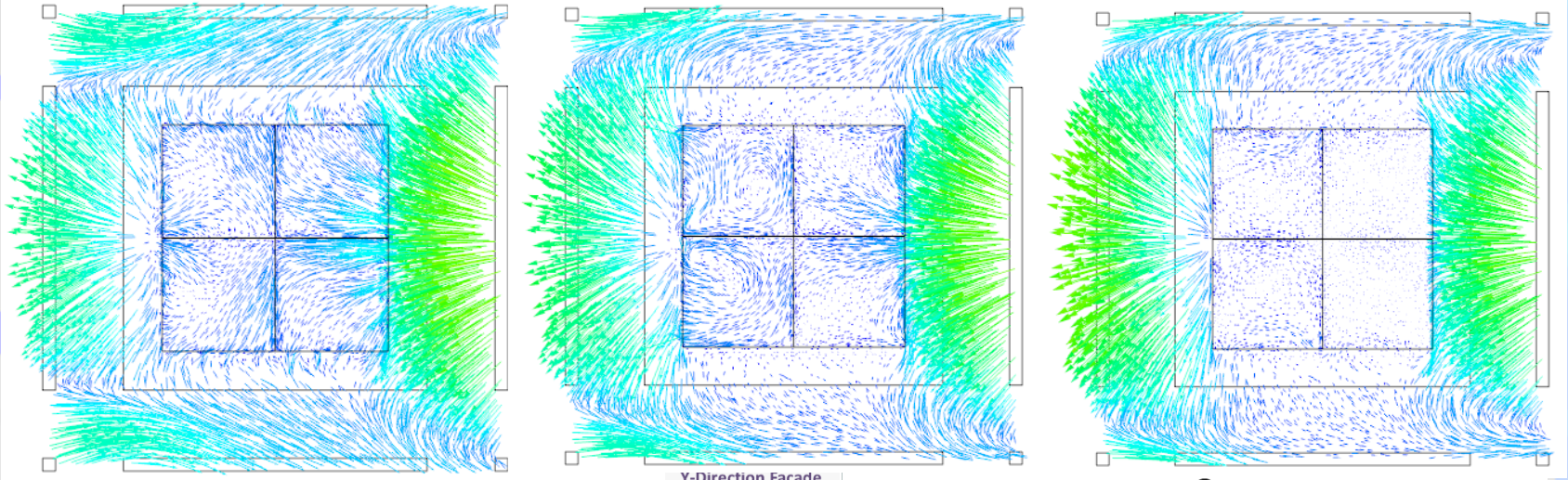




- **Cout**: spatially-averaged concentration in the street at pedestrian level.
- **Croom**: concentration inside each room.
- **Croom/Cout decreases with height.**
- **Indoor concentrations depend on the room location and the arrangement of open/closed windows.**
- **Lower concentrations are found in rooms located at windward facades.**

Wind Flow and Indoor Concentration (0º)

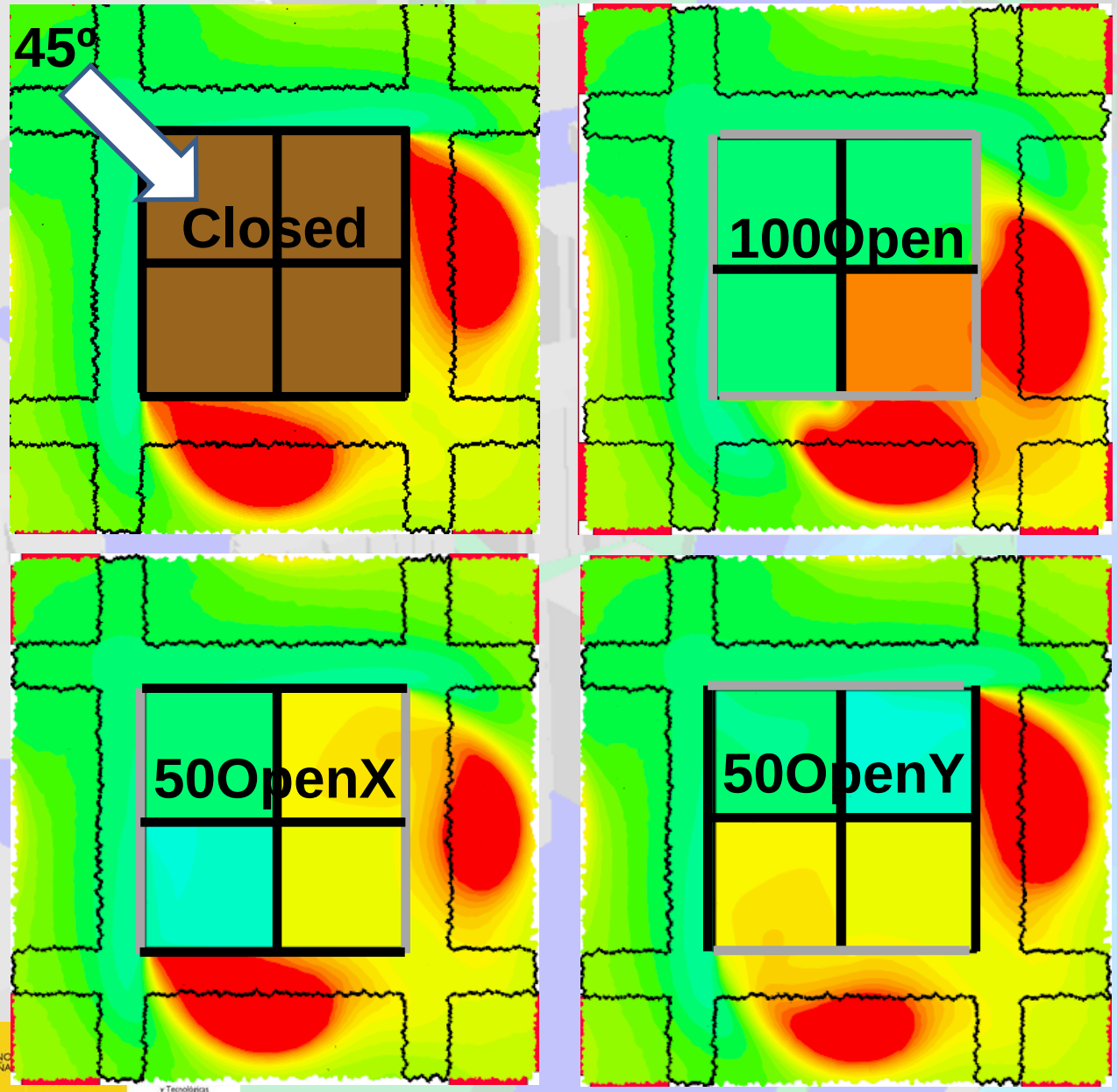




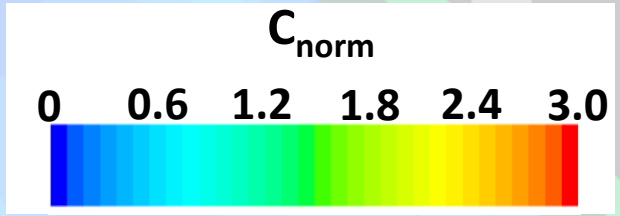
Pedestrian level (1st floor in the buildings)

- Flow patterns → Pollutant distribution
- High concentration NOT in facades → Croom/Cout < 1
- Higher Croom for leeward rooms.
- **Room A**: Concentration Y-façade > Concentration X-façade.
  - **100Open**: air mainly enters across X-façade and flows out across Y-façade
  - **50OpenX** and **50OpenY**: air flows in and out across windows of the same façade.
  - Then, **highest Croom** for **50OpenY**
- **Room C**: Pollutant concentration similar in both facades → Indoor concentration similar in all configurations.

45º Wind Direction Scenarios



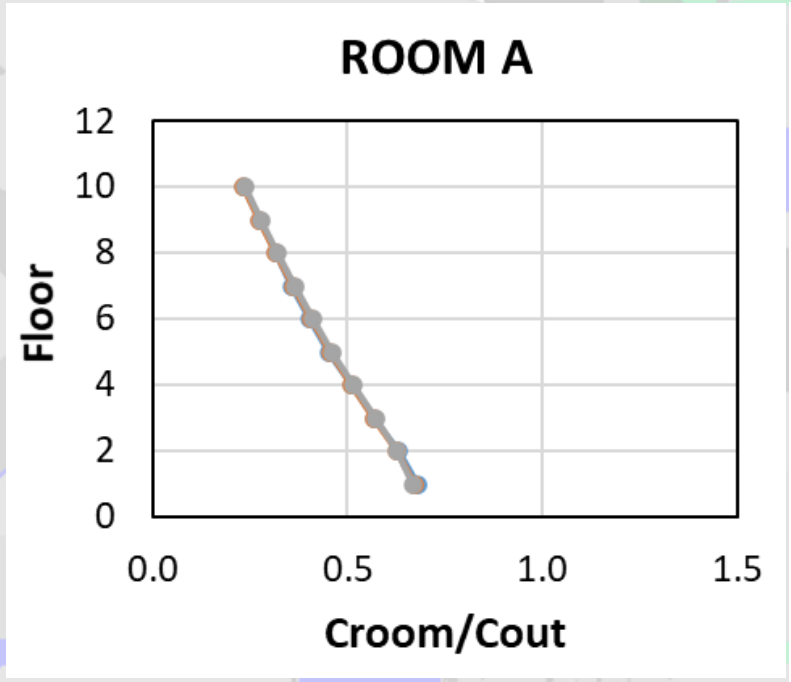
- Rooms receive pollutants from outdoor through the open windows → **indoor concentration depends on flow through open windows** and **concentration close to them**.
- **Large differences in comparison with 0º** due to:
  - **Differences** of the **wind flow patterns around the building** and **air flow across the windows**
  - **Differences in the distribution of traffic-related pollutants around the target building**.

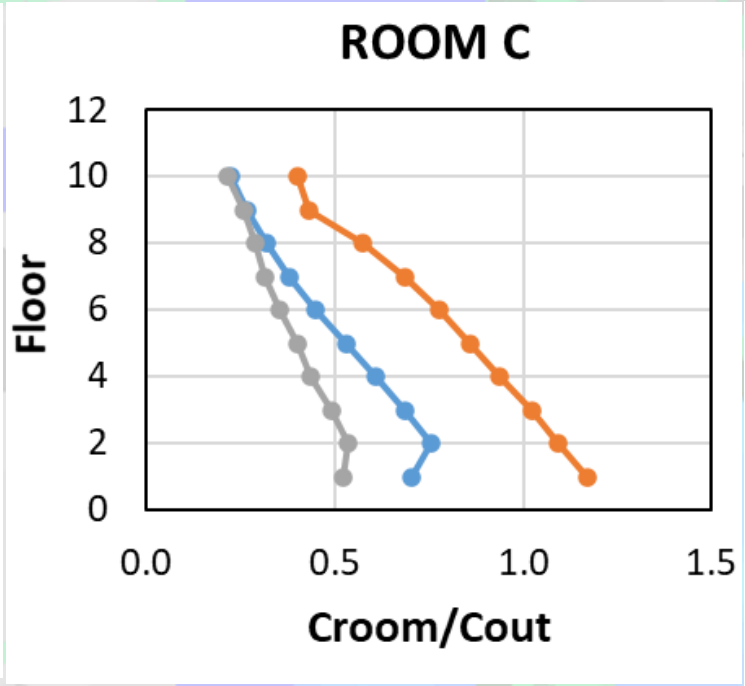


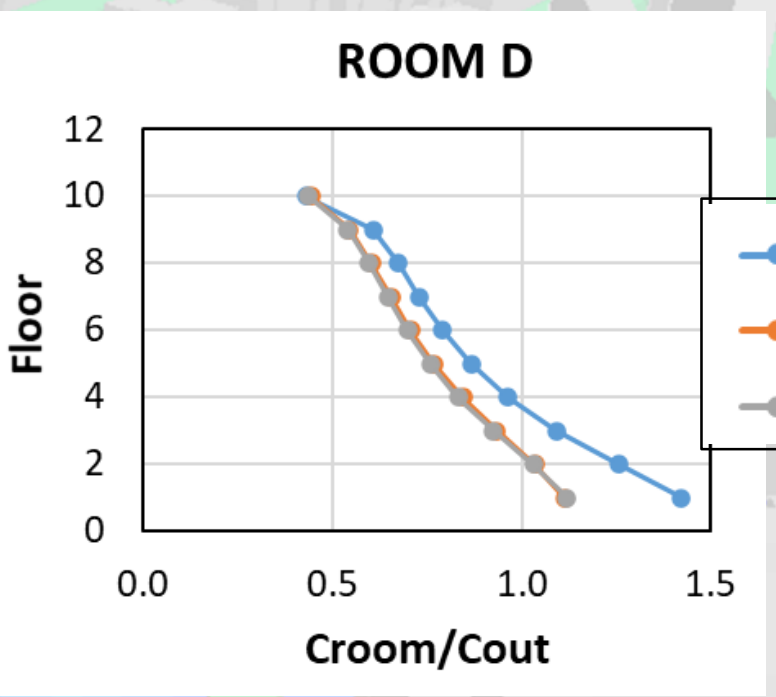
$$C_{norm} = \frac{Cu_* A_{em}}{Q}$$

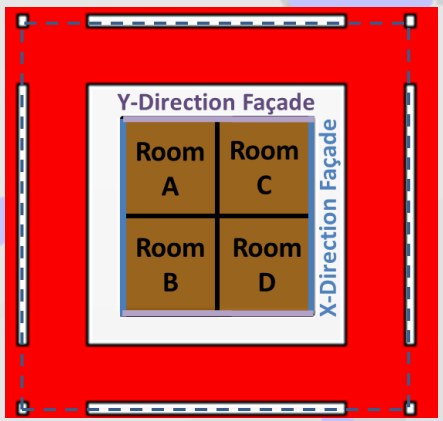
Normalized concentration at pedestrian level (1st floor in the buildings)

45º Wind Direction Scenarios



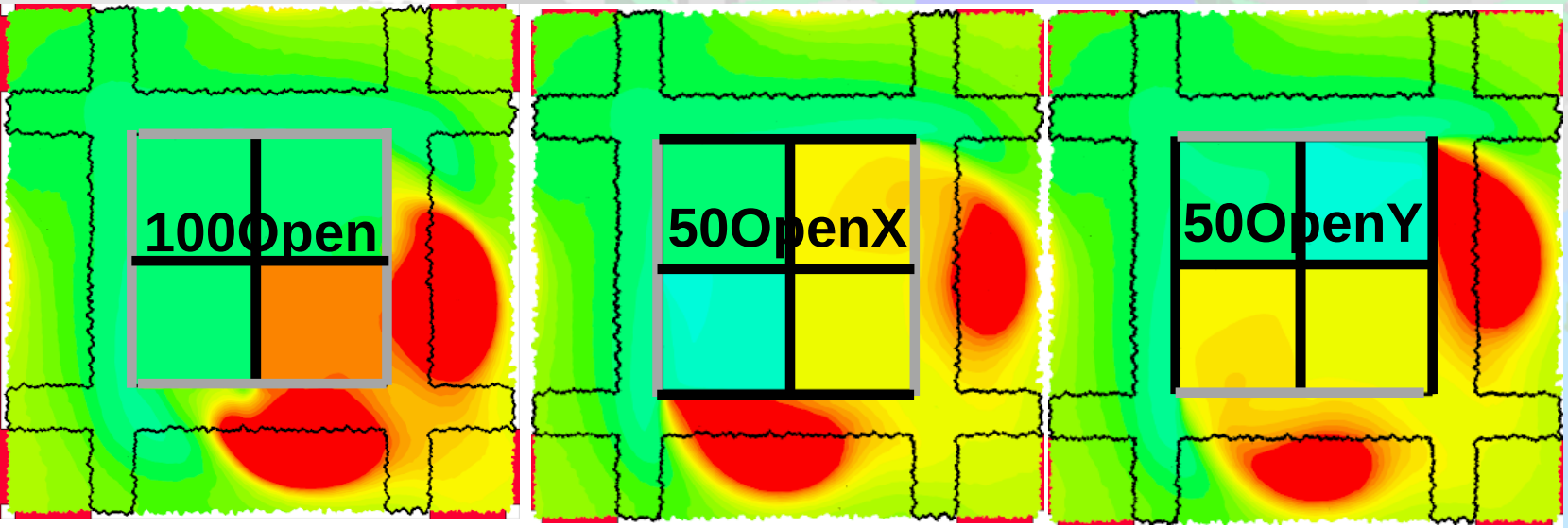


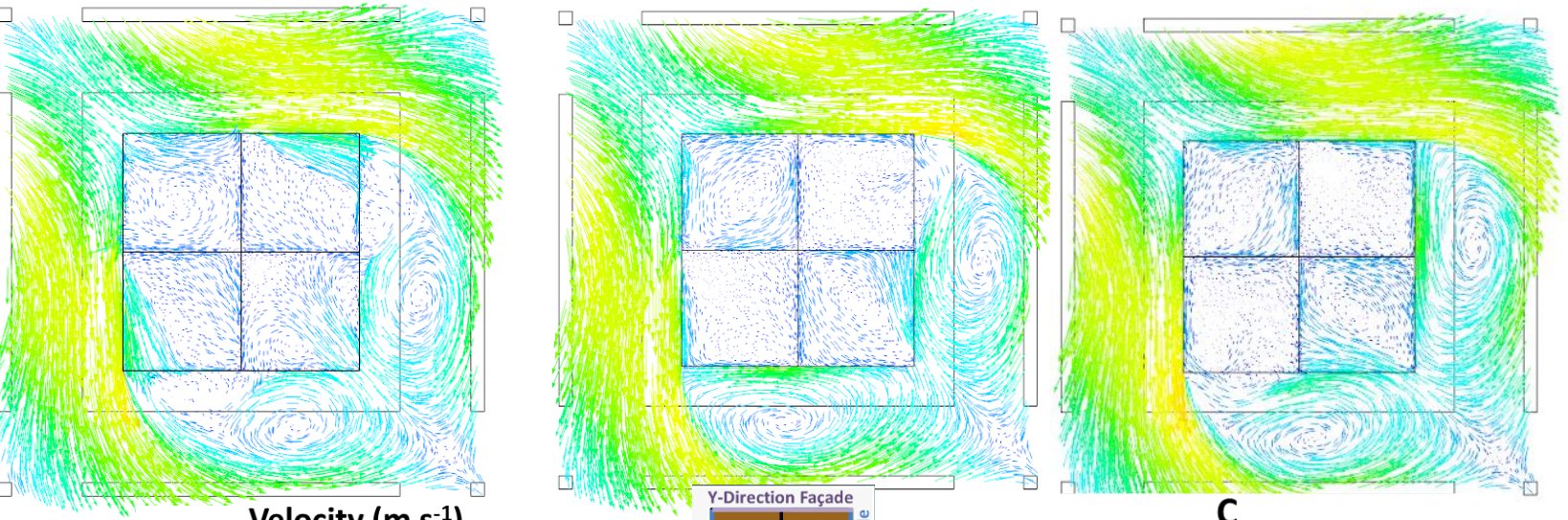




- **Croom/Cout decreases with height.**
- **Indoor concentrations depend on the room location and the arrangement of open/closed windows.**
- **Croom/Cout > 1 is found for some rooms of the first floor for 45º wind direction** (e.g. Room D for the three configurations of open windows or Room C for 50OpenX). Note that Croom is higher than the spatially-averaged concentration at pedestrian level in the street. Cases with high concentration close to open windows and wind flow enters inside the room across the windows of high-polluted façade.

Wind Flow and Indoor Concentration (45º)





Pedestrian level (1st floor in the buildings)

- Flow patterns → Pollutant distribution
- High concentration in facades → Croom/Cout > 1 → Higher indoor concentration than the average concentration in street at pedestrian level.
- **Room A**: **Croom/Cout < 1**. Similar concentration for all window configurations
- **Room C**: Conc. X-façade > Conc. Y-facade
  - **50OpenX** and **50OpenY**: air flows in and out across windows of the same façade.
  - **100Open**: Cross ventilation → air enters across Y-façade and flows out across X-façade
  - Then, **Croom/Cout > 1** for **50OpenX**
- **Room D**: **Croom/Cout > 1**. The **largest concentration for 100Open** due to air enters the room across windows of both façades.

Disscusion and Conclusions

- Research is focused to **improve the estimation of pollutant concentration people are exposed to.**
- **Spatially-averaged concentration of traffic-related pollutant at pedestrian level in the street** is related to **concentration inside different rooms of different floors of a standard building of apartments in an urban environment.**
- **Modelling approach**: **CFD** simulations that **cover the whole urban environment and the interior of a standard building of apartments**
- **Croom/Cout depends** on:
  - **floor and room location at each floor**
  - **wind direction**
  - **the arrangement of open/closed windows**.
  - **concentration close to the corresponding façade**

Disscusion and Conclusions

- **Croom/Cout**:
  - General view, **Croom/Cout** is averaged for all scenarios and rooms → an **average indoor-outdoor ratio of 0.6** with a standard deviation of **±0.2** (in agreement with previous studies in real buildings).
  - **Decreases as room floor increases**.
  - **For some cases, Croom/Cout > 1 → high concentration** is accumulated **in at least one façade** of the room and the **open windows induce** that **air flow enters the room from highly-polluted façades**.
- **Detailed and specific studies** are **needed → ventilation patterns** for a given building configuration **may substantially change indoor exposure for the same outdoor pollution** level.
- We can conclude that **indoor air quality** is **important for the assessment of total exposure** and **this research contributes to a more comprehensive knowledge to the methodologies for the assessment of the total population exposure**.

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Thank you for your attention
Questions?

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