Influence of Moving Vehicles on Pollutant Dispersion in Street Canyon – A Numerical Study

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Outline

Introduction

Research methodology

- Studied cases
- Numerical models
- Model validation

Results and discussion

- General characteristics of dynamic impact
- Effects of influencing factors

Conclusion

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Introduction

- Frequently occurrence of "crazy bad" ***air pollution***
- Two main contributing factors to roadside air pollution: ***vehicular emissions*** & ***street canyon effects***
- Studies on the airflow field and the mechanisms of pollutant transport, dilution and removal in ***street canyon***

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Introduction

- The geometrical, meteorological, and *traffic related* parameters dominate the pollutant dispersion process in street canyon
- The influence of moving vehicles on the air quality in street canyon:
  - Introduce secondary airflow and additional ventilation effect
  - Break up the normal airflow pattern and pollutant distribution profile
  - Promote micro- and large-scale mixing and dispersion processes
  - Increase the complexity in predicting the pollution distribution and in the assessment of air quality
- Research Methodologies: theoretical studies, field measurements, *wind tunnel experiments*, and *CFD (computational fluid dynamics) techniques*

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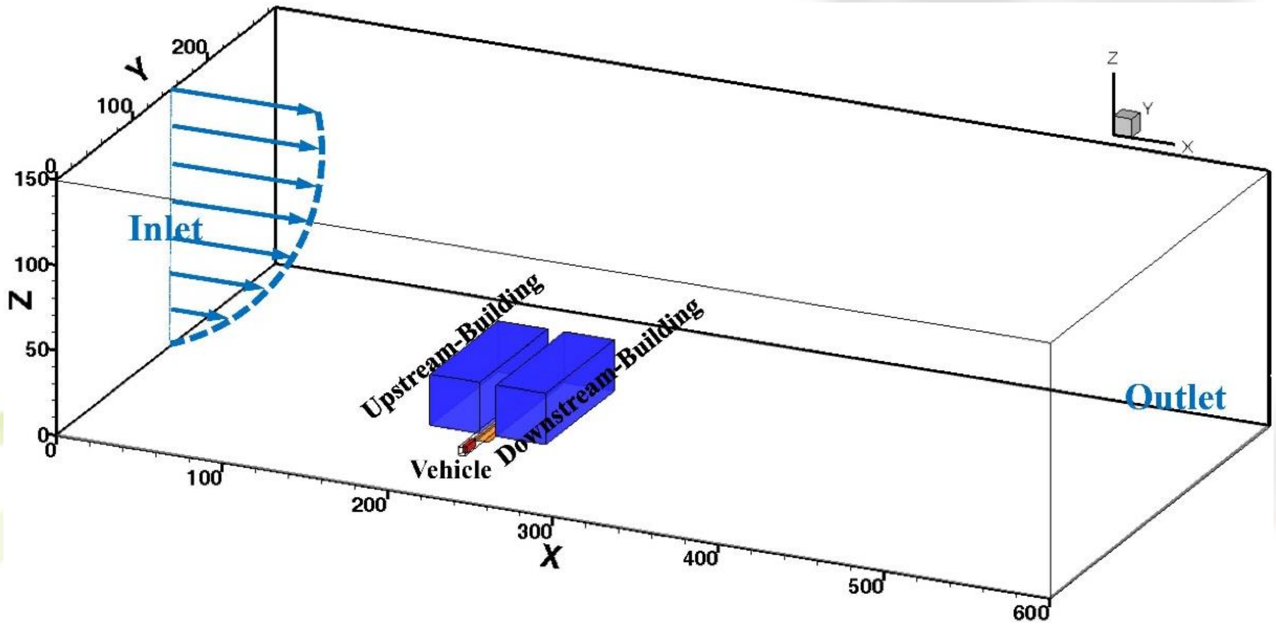
Numerical Methodology

--Studied cases

- The idealized deep canyon (H/W=3) and uniform canyon (H/W=1)
- Double decker bus with moderate speed (36 km/h)
- Traffic pollutants released from the constant traffic fleet (CO) and from the moving vehicles (NO_2)

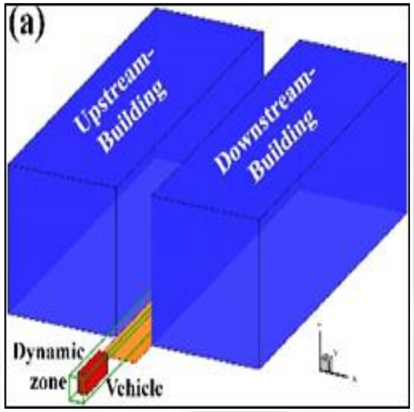


Numerical Methodology

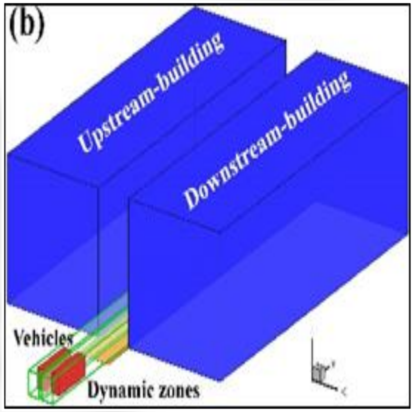
--Studied cases

- Four different scenarios:
  - *Scenario#1*—single vehicle runs on the one-lane street of the deep canyon
  - *Scenario#2*—two vehicles run in the same direction on the two-lane street of the deep canyon
  - *Scenario#3*—two vehicles run in the opposite directions on the two-lane street of the deep canyon
  - *Scenario#4*—four vehicles run on the four-lane street as the two-way traffic on the uniform canyon

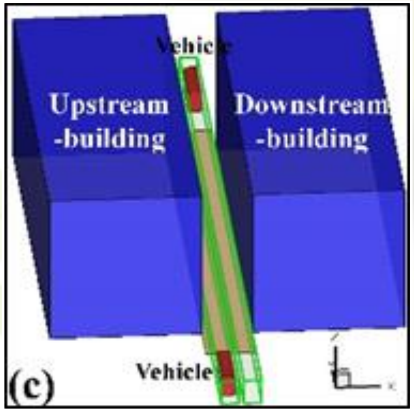
Scenario#1



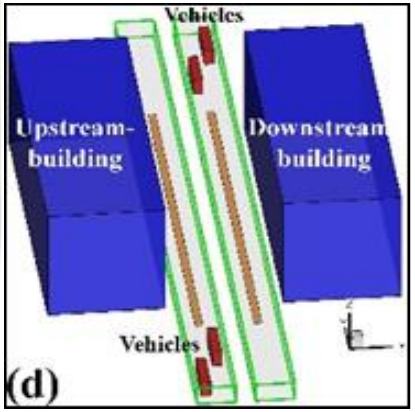
Scenario#2



Scenario#3



Scenario#4



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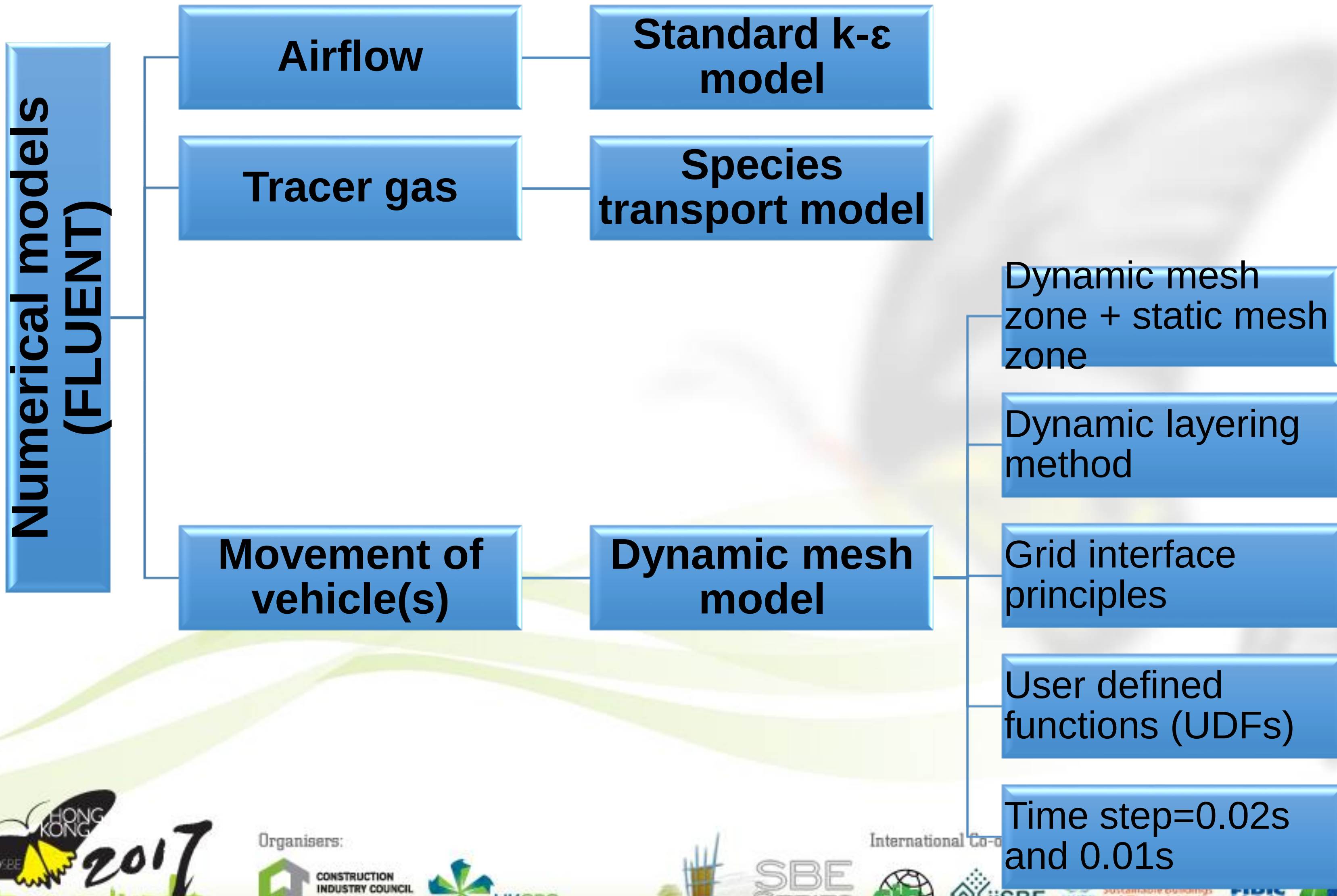
Numerical Methodology

--Numerical models



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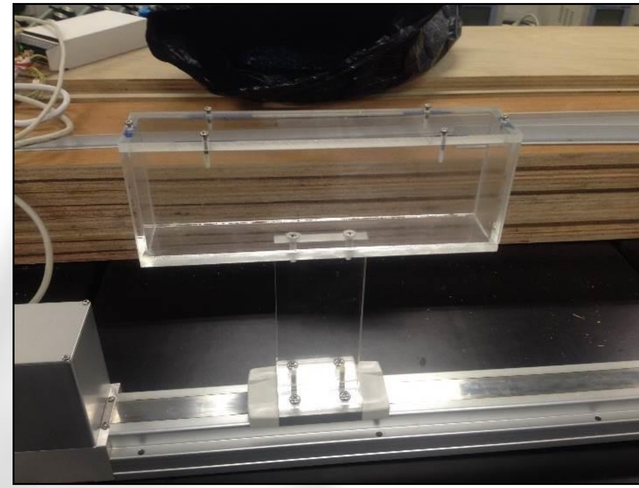
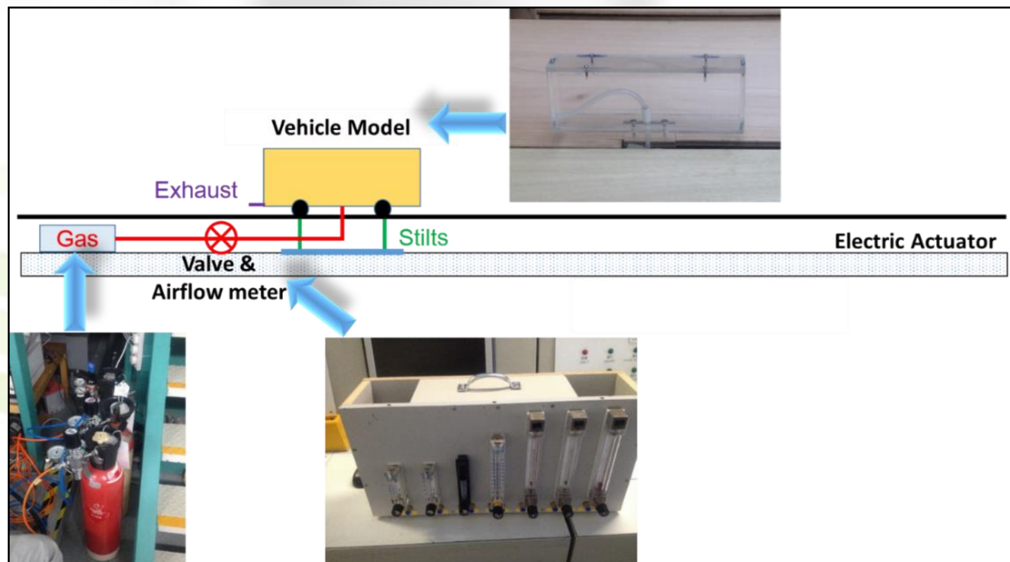
Numerical Methodology

Physical model	
Computational domain	X=600m, Y=290m, Z=150m
Buildings	L_B=90m, W_B=30m, H_B=30m
Street	Ws=10m (Deep canyon); Ws=30m (Uniform canyon)
Double decker bus	Size: Lv=12.5m, Wv=2.5m, Hv=4.5m Exhaust tail-pipe: D=0.1m Speed: 36 km/h
Approaching wind	Perpendicular; $u=2.5*(z/30)^{0.4}$;T=303.15K
Numerical method	
Boundary conditions	Velocity inlet, Outflow, Symmetry, No slip wall
Numerical iteration	The SIMPLE algorithm for the Pressure-Velocity coupling equations The second order scheme for the Pressure The second-order upwind scheme for the convection terms The central differences scheme with second order accuracy for the diffusion terms The scaled residual criteria = 10^{-5}
Total number of cells	~2 million

Numerical Methodology
--Model validation



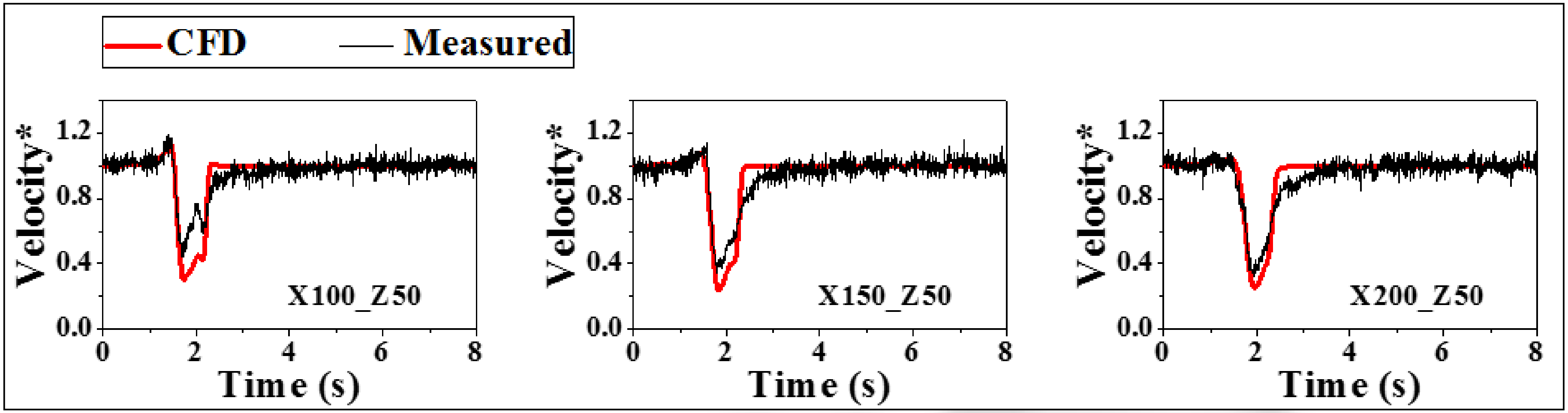
- Wind tunnel database of CODASC [1]
- Measured data from Chan et al., 2001 [2]
- Wind tunnel tests in CityU
  - Movement of vehicle(s)
  - Moving model rig with scaled bus model
  - Gas supply system
  - SWEMA03 Anemometers
  - HRF 400 fast FID system



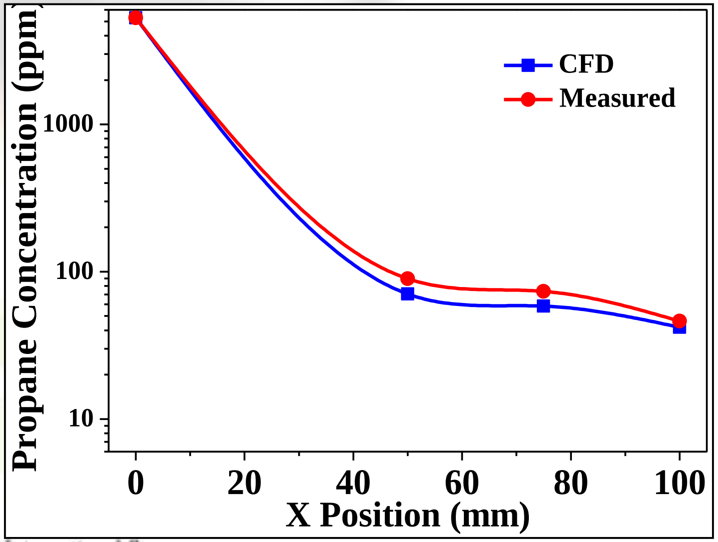
[1] Concentration Data of Street Canyons. http://www.ifh.uni-karlsruhe.de/science/aerodyn/ CODASC.htm
[2] Chan, T. L., Dong, G., Cheung, C. S., Leung, C. W., Wong, C. P. and Hung, W. T., 2001. Monte Carlo simulation of nitrogen oxides dispersion from a vehicular exhaust plume and its sensitivity studies. Atmospheric environment, 35(35), 6117-6127

Numerical Methodology

--Model validation



- Great agreements between the measured and modelled data
  - Time series of the normalized airflow velocity
  - Time-averaged peak value of the tracer gas concentration



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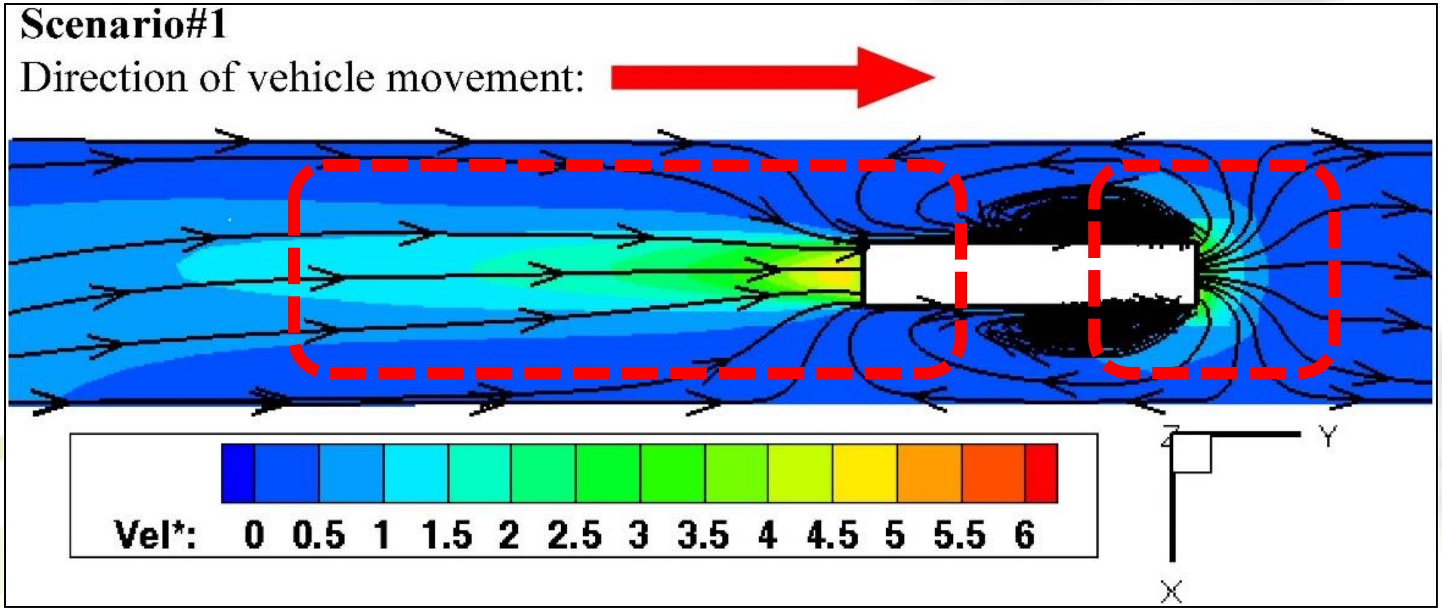
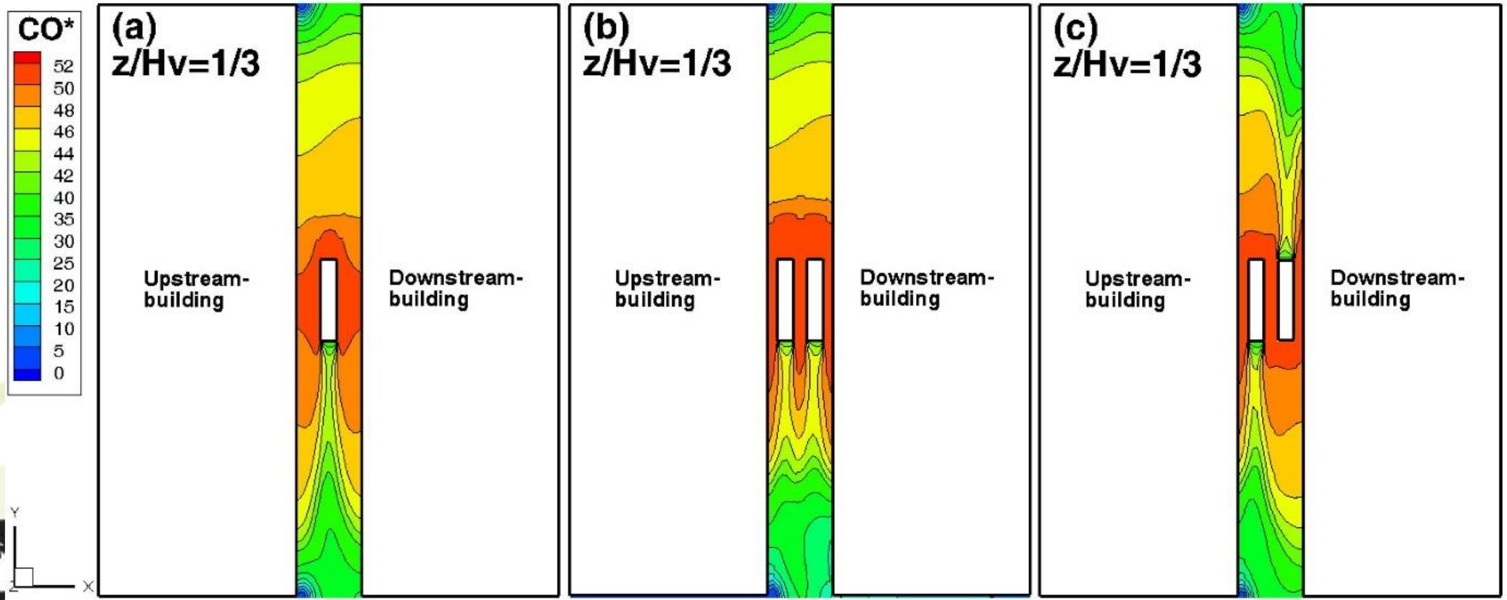
Results and discussion
--General characteristics

- "Propelling effect": a relatively high Vel* region in front of the head of the moving vehicle
- "Wake effect": a stripe of high Vel* region following the rear end of the moving vehicle
- "Piston effect" ≈ "Propelling effect" + "Wake effect"



Results and discussion
--General characteristics

- “Propelling effect”: the polluted air is pushed forward
- “Wake effect”: the clean air is entrained into the wake
- Enhanced “Piston effect”: vehicles running in the same direction (Scenario#2)
- Attenuated “Piston effect”: vehicles running in the opposite directions (Scenario#3)



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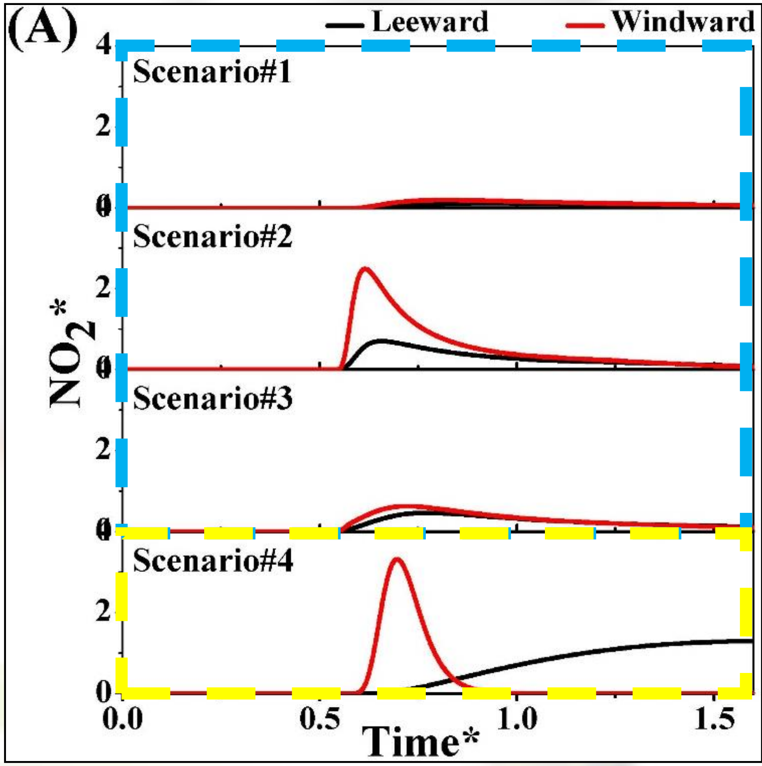
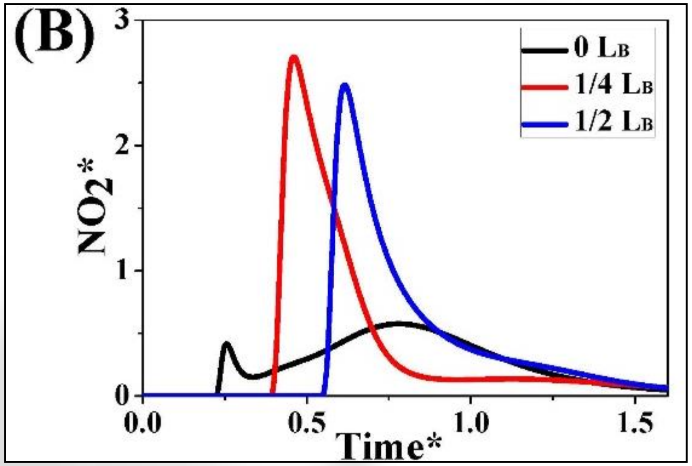
Results and discussion
--Effects of influencing factors

- The geometrical configuration of the street canyon
  - Temporal variation of NO_2*: the deep street canyon (Scenario#1~#3) is different from the uniform street canyon (Scenario#4)
  - Air ventilation effectiveness: deep canyon < uniform canyon
- The mode of vehicle motion (deep canyon)
  - The number: NO_2* in Scenario#1 << Scenario#2&3
  - The travelling direction: NO_2* in Scenario#3 < Scenario#2
- The leeward and windward wall
  - Deep canyon: similar pattern
  - Uniform canyon: long-lasting influence near leeward wall

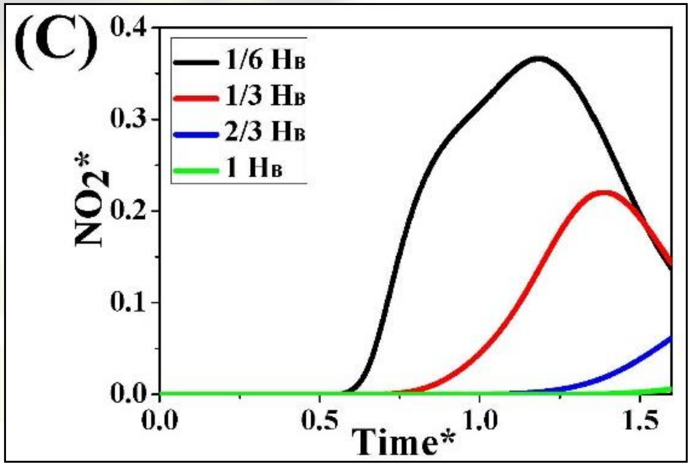


Results and discussion
--Effects of influencing factors

- The horizontal positions (windward side in Scenario#2)
  - NO_2* at the street openings (0 L_B) is lower than that in the internal space of the street canyon (1/4 L_B and 1/2 L_B)



- The vertical heights (Scenario#2)
  - NO_2*: lower level >> upper level
  - The occurrence time of NO_2* peak: lower level prior to upper level
  - Enhanced vertical dispersion by moving vehicle(s)



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Conclusion

- Moving vehicles could generate secondary airflow and hence introduce additional ventilation effects, in the form of the combined effect of “Propelling effect” and “Wake effect”. Continuous interactions between the wind flow and the vehicle wake. Enhanced mixing and transport of vehicle exhaust pollutant.
- Influencing factors: (i) the geometrical configuration of the street canyon; (ii) the mode of vehicular movements; and (iii) the position of the monitoring site.
- Unexpected exposing risks at some places (i.e. at upper level of the street canyon), which may not be predicted by the conventional steady flow simulation. More research efforts to investigate the urban air quality by dynamic simulation.

Thank you

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