Editorial to Virtual Special Issue:

CFD simulation of micro-scale pollutant dispersion in the built environment

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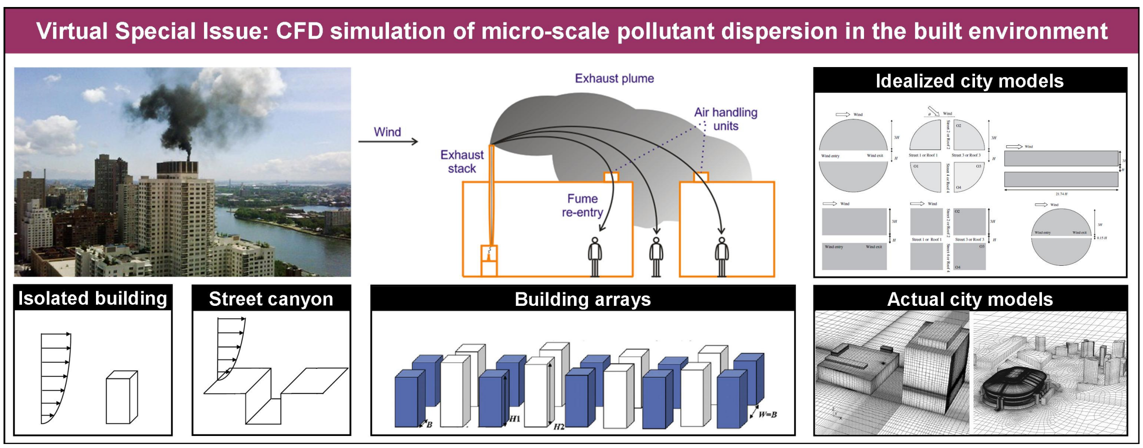
Graphical abstract:



Research highlights:

- Outdoor air quality is one of the major environmental problems today
- Micro-scale pollutant dispersion covers the building scale and the meteorological micro-scale
- Computational Fluid Dynamics (CFD) is increasingly used for micro-scale dispersion studies
- Virtual Special Issue groups papers published previously on this topic in Building & Environment
- Some trends and directions for future research are outlined

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1. Context, aim and scope of Virtual Special Issue

1.1. Context

Outdoor air pollution is one of the major environmental problems today. It is associated with a broad spectrum of acute and chronic health effects [1]. The pollutants that are brought into the atmosphere by various sources are dispersed (advected and diffused) over a wide range of horizontal length scales (L). Concerning outdoor pollutant dispersion, a distinction can be made between global or macro-scale dispersion (L > 6500 km), meso-scale dispersion (10 km < L < 6500 km) and micro-scale dispersion (L < 10 km). In the built environment, both the outdoor exposure of pedestrians and the indoor exposure of building inhabitants are of concern. Also building components and building materials play an important role, and finally the pollutants can be responsible for human morbidity and mortality. Pollutant dispersion in the built environment is therefore intrinsically a multi-scale and multi-disciplinary problem. The relevant spatial scales, ranging from global scale to material/human scale, are schematically depicted in Figure 1.

Figure 1: Schematic representation of relevant spatial scales in pollutant dispersion.

Outdoor and indoor air pollution are a main concern of building and air-conditioning engineers that design the ventilation inlets and outlets on building facades or roofs [2-5]. Indoor air pollution by outdoor air pollutants can be caused by the re-ingestion of the contaminated exhaust air by the same building [6] or by the intake of exhaust from other sources such as nearby buildings, street traffic, vehicle parking lots and loading docks, emergency generators and cooling towers (Figure 2) [7-11].

The precise prediction of pollutant concentration distributions on and near buildings is important for building design and evaluation. The prediction of such concentrations however is a difficult task, especially in the built environment. It does not only require the knowledge of air pollution meteorology and dispersion, it also requires knowledge of building aerodynamics because wind and buildings can strongly affect plume behaviour. Important parameters for dispersion around buildings are building geometry and environment topography, wind speed, wind direction, turbulence, atmospheric stability, temperature, humidity and solar radiation.

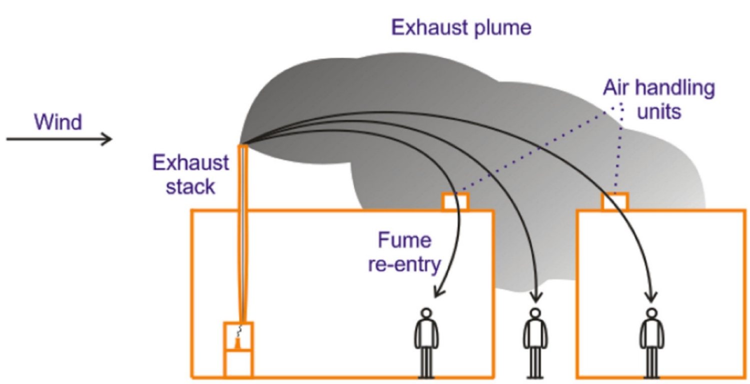

Figure 2: Schematic representation of re-ingestion of exhaust air by the same building and of contamination of neighbouring building and street (modified from [11]).

Micro-scale pollutant dispersion in the built environment can be assessed by field measurements, wind-tunnel testing and numerical simulation with Computational Fluid Dynamics (CFD). Field measurements offer the advantage that the real situation is studied and the full complexity of the problem is taken into account. However, field measurements are usually only performed in a limited number of points in space. In addition, there is no or only limited control over the boundary conditions. Reduced-scale wind-tunnel testing allows a strong degree of control over the boundary conditions, however at the expense of – sometimes incompatible – similarity requirements. Furthermore, wind-tunnel measurements are usually also only performed in a limited number of points in space. CFD on the other hand provides whole-flow field data, i.e. data on the relevant parameters in all points of the computational domain. Unlike wind-tunnel testing, CFD does not suffer from potentially incompatible similarity requirements because simulations can be conducted at full scale. In addition, CFD simulations easily allow parametric studies to evaluate alternative design configurations, especially when the different configurations are all a priori embedded within the same computational domain and grid. However, the accuracy and reliability of CFD are of concern, and solution verification and validation studies are imperative. Validation studies in turn require experimental data that have to satisfy important quality criteria. These can be field data or wind tunnel data. The use of CFD for pollutant dispersion studies has received strong support from initiatives focused on the establishment of best practice guidelines. Such documents provide guidance on the large number of choices to be made and actions to be performed by the user of a CFD code. These are either comprehensive guidelines that cover many aspects of a CFD simulation [12-16] or more specific guidelines addressing only one or a few aspects in detail (e.g. [17-22]).

Micro-scale pollutant dispersion in actual urban areas is very complex. Due to this complexity, many basic studies of micro-scale pollutant dispersion around buildings in wind tunnels and with CFD have focused on two generic and idealised configurations: the isolated building and the isolated street canyon (Figure 3). While both configurations are strong simplifications of reality, the flow and dispersion processes involved are very complex and contain most of the salient features that are also present in the complex urban environment. Other generic configurations that have been considered consist of arrays of buildings or building blocks.

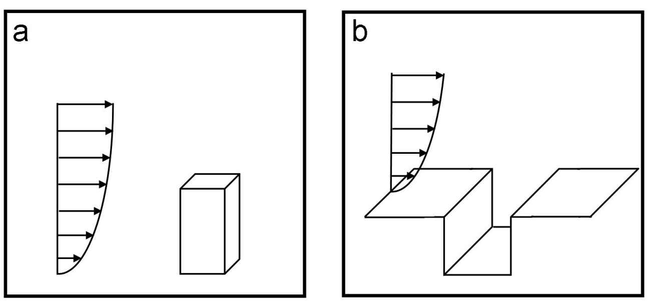

Figure 3: Schematic representation of (a) isolated building and (b) isolated street canyon.

1.2. Aim and scope

A Virtual Special Issue (VSI) is a Special Issue that consists of previously published papers in a given journal. The aim of a VSI is to identify and group a coherent set of such papers and to provide some post-publication perspectives. The present VSI is stimulated by the increasing environmental concerns about outdoor air quality in the built environment and by the increasing use of CFD for pollutant dispersion modelling. The aim of this VSI is therefore to identify and group a number of papers reporting CFD simulations of micro-scale pollutant dispersion in the built environment published in Building & Environment.

The intention of the VSI is neither to be complete, nor to provide an overview of such studies over a wider range of journals. In the recent past, several reviews on micro-scale pollutant dispersion were provided. Meroney [23] compiled a very comprehensive review of wind tunnel and CFD studies of micro-scale pollutant dispersion in the larger framework of hybrid wind tunnel – CFD modelling, and Canepa [24] reviewed a large number of models for stack and building wake downwash.

The VSI is focused on micro-scale pollutant dispersion. While micro-scale dispersion is strongly connected to processes acting at the global scale and the meteorological meso-scale, these are not the subject of the present VSI. Micro-scale pollutant dispersion is also strongly connected to building ventilation. Building ventilation is also not included in this VSI. Comprehensive reviews on building ventilation research have been provided by Awbi [25], Etheridge and Sandberg [26] and Chen [27]. Reviews on natural ventilation can be found in, e.g. [28-30].

While the VSI focuses on CFD, also field measurements and wind-tunnel testing are included when they serve CFD validation. Given the complexity of micro-scale dispersion, many studies have focused on two generic configurations: the isolated building and the isolated street canyon (Figure 3). However, the VSI also includes studies on other generic configurations such as arrays of block-type buildings and on applied configurations such as parts of actual cities.

2. Contents of Virtual Special Issue

This VSI consists of 16 papers, all of which have their focus on CFD simulation of micro-scale pollutant dispersion. Section 2.1 summarizes these papers in an overview table along with the main characteristics of their CFD simulations. Section 2.2 briefly highlights the main contribution by each of these 16 papers. Papers focusing on the wider topic of urban microclimate, in which pollutant dispersion is only one of many processes, are not included.

2.1. Overview table

Table 1 provides an overview of the 16 papers, listed in chronological order. The table entries are:
- the author last names and year of publication;
- the reference number (as cited in the reference list of this editorial)
- the type of study / geometrical configuration: generic or applied. While generic studies can provide more general information that can more easily be extrapolated to practical situations, applied studies offer the advantage that they generally consider a larger degree of geometrical complexity.
- the configuration: 2D or 3D, street canyon, isolated building, array of buildings or part of a real city;
- the turbulence modelling approach: Reynolds-Averaged Navier-Stokes (RANS) or Large Eddy Simulation (LES). While RANS generally refers to the solution of the steady RANS equations, LES provides time-dependent information and information on peak values, which can be of prime importance.
- whether or not a validation study was performed, and if so, based on what type of data (wind tunnel or full scale).
- whether or not a sensitivity study was performed, and if so, for which parameters.

Although this table is not complete, it does provide a first overview of some main characteristics of the CFD simulations reported in these papers. Based on this table, the following general observations can be made:
- Each one of the 16 papers reports a sensitivity analysis of some or a few computational parameters. This could be expected, given the large number of computational parameters that have to be chosen by the user of a CFD code.
- 14 out of the 16 papers focus on pollutant dispersion in the outdoor environment around buildings, without connection to dispersion in the indoor environment. Two exceptions to this are the papers by Gao et al. (Article d in Table 1) and van Hooff and Blocken (Article p in Table 1), where both outdoor and indoor dispersion are modelled in a coupled approach, i.e. within the same computational domain.
- 14 out of the 16 papers report simulations that are based on the RANS equations. The two exceptions are the papers by Gu et al. (Article m in Table 1) and Gallagher et al. (Article n in Table 1) that only report LES results. 4 out of the 16 papers report LES results. 2 papers report both RANS and LES results: that by Tominaga and Stathopoulos (Article k in Table 1) and that by Salim et al. (Article *l* in Table1). Out of the 16 RANS papers, 13 use a k-ε turbulence model for closure, 8 of which use the standard k--ε turbulence model.
- 13 out of the 16 papers have been published in the past 5 years. The three exceptions are the papers by Qin & Kot in 1990 (Article a in Table 1) and the two papers by Xie et al. in 2005 and 2006 (Articles b and c in Table 1).
- 13 out of the 16 papers focus on generic building or street canyon configurations. The three exceptions are the paper by Qin & Kot (Article a in Table 1)that focuses on a two-building configuration in Shenzhen, China, the paper by Lateb et al. (Article j in Table 1) that focuses on a two-building configuration in downtown Montreal and the paper by van Hooff and Blocken (Article p in Table 1) that includes a group of buildings in a small part of Amsterdam.
- 13 out of the 16 papers report 3D simulations. The three exceptions are the papers by Xie al. (Articles b and c in Table 1) and Huang et al. (Article i in Table 1) that all consider a 2D street canyon.
- 12 out of the 16 papers include a validation study by comparison of the CFD results with either field data or wind-tunnel data, or both.

Note that the first paper on CFD simulation of micro-scale pollutant dispersion published in Building & Environment is the paper by Kot [32] in 1989. However, this paper is not included in the VSI as it provides a valuable discussion of different CFD modelling approaches but no actual application of one or more of these approaches.

2.2. Paper contributions

The main contribution by each paper is briefly highlighted in chronological order of publication.

In 1990, Qin and Kot (Article a in Table 1) provided one of the first publications on CFD simulation of pollutant dispersion around buildings including a comparison with on-site measurements. They analysed wind flow and dispersion of NO_x from vehicle emissions in a street between a two-building configuration in the city of Shenzhen. The main part of the study was focused on the north wind direction with the tower building (90 m) directly upstream of the lower building (30 m). Turbulent momentum and mass diffusivities were taken as constants or based on the mixing-length hypothesis and this assumption was subjected to a sensitivity analysis. The paper reports a close agreement between the CFD simulations and field measurements of NO_x concentration, with a maximum error of only 25% for north wind, in spite of the simple expressions for momentum and mass diffusivities. This wind direction is reported to yield an extreme case of vehicular exhaust pollutant accumulation, due to the wake effect of the tower building.

Xie et al. (Article b in Table 1) investigated the impact of solar radiation and street layout on pollutant dispersion in a generic 2D street canyon. The analysis was focused on the vortical structures and the resulting pollutant concentrations in the canyon. For isothermal conditions, a step-up notch was found to decrease pollutant levels, while a step-down notch was found to increase them. For the wind speed and temperature differences considered, adding solar radiation on the windward side of the step-up notch was found to increase pollution levels in the canyon. A step-down notch with solar radiation on the windward side of the building and ground would decrease pollution levels, while solar radiation on the leeward side would increase them.

Later, Xie et al. (Article c in Table 1) extended the isothermal part of their earlier study by investigating the vortical structures and pollutant concentration levels in generic 2D street canyons for a wide range of aspect ratios (i.e. building height divided by street width). They identified different flow regimes and the most favourable configurations in terms of pollutant dispersion.

Gao et al. (Article d in Table 1) analysed the transmission of tracer gas between flats in high-rise residential buildings in the framework of airborne transmission of infection. Their coupled outdoor-indoor simulations highlighted that the transmission between single-sided ventilated flats at different floors should be taken into account in infection control.

Bady et al. (Article e in Table 1) suggested the use of three indoor ventilation efficiency indices to evaluate the air quality of urban areas: the purging flow rate (PFR: the effective airflow rate required to purge pollutants from the domain), the visitation frequency (VF: the number of times a pollutant enters the domain and passes through it) and the residence time (TP: the time a pollutant takes from once entering or being generated in the domain until its leaving). They also applied these indices for two examples, hereby demonstrating that these indices are able to describe the pollutant behaviour within the domain, which is very important for achieving a complete assessment of the wind ventilation performance within urban domains.

Bu et al. (Article f in Table 1) developed two new criteria for the assessment of local wind environment at pedestrian level based on exceedance probability analysis. These criteria are based on the local air change rate and the local kinetic energy, respectively. The practicability and effectiveness of these criteria was demonstrated for a street canyon model exposed to the Tokyo wind conditions.

Hefny and Ooka (Article g in Table 1) analysed the effect of grid typology – and more specifically: cell geometry – on the related numerical error for pollutant dispersion around buildings. The effect was found to be large: the hexahedral-based mesh was observed to have Grid Convergence Index (GCI) values [17] that were an order of magnitude below the tetrahedral-based mesh values for all resolutions considered, even in the very fine tetrahedral-based mesh. In addition, the GCI value remained high compared to conventional hexahedral meshes.

Hang et al. (Article h in Table 1) evaluated three idealised city models in terms of the local mean age of air and the air exchange efficiency. The city models included a round city model, a square city model and a long rectangular city with one main street parallel to the approaching wind or with two crossing streets.

Huang et al. (Article i in Table 1)extended the studies by Xie et al. (Articles b and c in Table 1)by investigating the effect of wedge-shaped roofs – rather than only flat roofs – on velocity vector and pollutant concentration fields. The effects of these geometrical modifications are significant, and as in (Article b in Table 1), the pollutant concentrations are much higher in the “step-down” canyons compared to the “level” or “step-up” canyons.

Lateb et al. (Article j in Table 1) performed CFD simulations of a two-building configuration in Montreal, with the tall building (45 m; excluding rooftop structures) upstream of the low-rise BE building (12.5 m;

excluding rooftop structures). As in the study by Qin and Kot (Article a in Table 1), this combination of configuration and wind direction was also here considered as most problematic in terms of pollutant dispersion. Note however that the exhaust in this study is not at street level, but from a stack on top of the BE building. The results from the CFD simulations were compared with results from both detailed wind-tunnel tests and elaborate field experiments, allowing a comprehensive analysis of the errors and uncertainties involved in RANS modelling with the realisable k-ε model.

Tominaga and Stathopoulos (Article k in Table 1) provided a detailed comparison of LES, RANS and wind-tunnel data of both wind velocity and pollutant concentration for the case of an isolated building. The RANS simulations were performed with the Renormalisation Group (RNG) k-ε model for closure. Although the differences in velocity between LES and RANS were not large, LES clearly outperformed RANS for pollutant concentration, because the horizontal diffusion was well reproduced by LES and not by RANS. This study therefore confirmed the accuracy of LES in modelling for plume dispersion near and around an isolated building model and identified the reason for the discrepancies obtained by RANS modelling.

Salim et al. (Article *l* in Table 1) numerically reproduced the wind-tunnel experiments of traffic pollutant dispersion in a street canyon with and without trees from the CODASC database [31] with RANS (standard k-ε and Reynolds Stress Model) and LES. For the street canyon without trees, the LES simulations show a very close agreement with the wind tunnel (WT) data for the concentrations at the leeward and windward canyon walls. For the street canyons with trees however, the agreement between LES and WT remains very close for the leeward wall, while it deteriorates substantially for the windward wall. In fact, for the windward wall and with trees present, the agreement between RANS and WT is much better than between LES and WT. Although not mentioned by the authors, this suggests some discrepancies in modelling the aerodynamic effect of the trees in LES.

Gu et al. (Article m in Table 1) extended the work by Xie et al. (Articles b and c in Table 1)and Huang et al. (Article i in Table 1)by focusing on non-uniform street canyons, where higher and lower buildings are positioned in a 3D staggered arrangement. For this more complicated geometry, LES was applied. The simulations indicated that at the pedestrian level, the concentrations of simulated pollutants (e.g., the mean and maximum concentrations) in the non-uniform street canyons are lower than those in the uniform one, suggesting that uneven building layouts are capable of improving the dispersion of pollutants in urban area.

Gallagher et al. (Article n in Table 1) analysed the effect of passive controls in the form of a low boundary wall (LBW) on pedestrian-level pollution in idealised asymmetric street canyons. The LBWs were found to yield a local increase or decrease of concentration, depending on the side and geometrical conditions.

Hang et al. (Article o in Table 1) extended the study by Gu et al. (Article m in Table 1)by analysing the influence of building height variability on pollutant dispersion and pedestrian ventilation in idealised arrays of high-rise buildings. Larger standard deviations of building heights were found to induce better pedestrian ventilation.

Van Hooff and Blocken (Article p in Table 1) investigated the dispersion of indoor CO_2 from a semi-enclosed stadium due to wind and buoyancy. Unsteady RANS simulations with the realisable k-ε model were found capable of reproducing the wind velocity in the main ventilation openings and the CO_2 concentration decay in the geometrically complex stadium.

3. Some trends and directions for future research and publications

Based on the information provided in section 2, some (non-exhaustive) trends and directions for future research and publications can be outlined:

- Increased application of the ventilation indices PGR, VF and TP, potentially in an exceedance probability framework.
- Increased use of LES, especially for more complex urban configurations and when peak concentration values are required.
- Increased and improved integration of additional processes in the CFD simulations of pollutant dispersion, such as chemical reactions and the aerodynamic effect of trees and other vegetative features.
- Increased combination of coupled outdoor and indoor dispersion studies.

In the past 5 years, the number of publications on CFD simulation of micro-scale dispersion in Building & Environment have increased substantially. Given the importance of this topic and the advances in computational modelling and computational resources, this trend is expected to continue in the future.

Acknowledgements

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PAPERS IN VIRTUAL SPECIAL ISSUE WITH HYPERLINKS TO SCIENCE DIRECT:

Article a: Validation of computer modelling of vehicular exhaust dispersion near a tower block Original Research Article
Building and Environment, *Volume 25, Issue 2*, *1990*, *Pages 125-131*
Y. Qin, S.C. Kot

Article b: The impact of solar radiation and street layout on pollutant dispersion in street canyon Original Research Article
Building and Environment, *Volume 40, Issue 2*, *February 2005*, *Pages 201-212*
Xiaomin Xie, Zhen Huang, Jiasong Wang, Zheng Xie

Article c: The impact of urban street layout on local atmospheric environment Original Research Article
Building and Environment, *Volume 41, Issue 10*, *October 2006*, *Pages 1352-1363*
Xie Xiaomin, Huang Zhen, Wang Jiasong

Article d: The airborne transmission of infection between flats in high-rise residential buildings: Particle simulation Original Research Article
Building and Environment, *Volume 44, Issue 2*, *February 2009*, *Pages 402-410*
N.P. Gao, J.L. Niu, M. Perino, P. Heiselberg

Article e: Towards the application of indoor ventilation efficiency indices to evaluate the air quality of urban areas Original Research Article
Building and Environment, *Volume 43, Issue 12*, *December 2008*, *Pages 1991-2004*
Mahmoud Bady, Shinsuke Kato, Hong Huang

Article f: New criteria for assessing local wind environment at pedestrian level based on exceedance probability analysis Original Research Article
Building and Environment, *Volume 44, Issue 7*, *July 2009*, *Pages 1501-1508*
Zhen Bu, Shinsuke Kato, Yoshihiro Ishida, Hong Huang

Article g: CFD analysis of pollutant dispersion around buildings: Effect of cell geometry Original Research Article
Building and Environment, *Volume 44, Issue 8*, *August 2009*, *Pages 1699-1706*
Mohamed M. Hefny, Ryozo Ooka

Article h: Age of air and air exchange efficiency in idealized city models Original Research Article
Building and Environment, *Volume 44, Issue 8*, *August 2009*, *Pages 1714-1723*
Jian Hang, Mats Sandberg, Yuguo Li

Article i: Impact of wedge-shaped roofs on airflow and pollutant dispersion inside urban street canyons Original Research Article
Building and Environment, *Volume 44, Issue 12*, *December 2009*, *Pages 2335-2347*
Yuandong Huang, Xiaonan Hu, Ningbin Zeng

Article j: Numerical simulation of pollutant dispersion around a building complex Original Research Article
Building and Environment, *Volume 45, Issue 8*, *August 2010*, *Pages 1788-1798*
Mohamed Lateb, Christian Masson, Ted Stathopoulos, Claude Bédard

Article k: Numerical simulation of dispersion around an isolated cubic building: Model evaluation of RANS and LES Original Research Article
Building and Environment, *Volume 45, Issue 10*, *October 2010*, *Pages 2231-2239*
Yoshihide Tominaga, Ted Stathopoulos

Article *l*: Numerical simulation of dispersion in urban street canyons with avenue-like tree plantings: Comparison between RANS and LES Original Research Article
Building and Environment, *Volume 46, Issue 9*, *September 2011*, *Pages 1735-1746*
Salim Mohamed Salim, Siew Cheong Cheah, Andrew Chan

Article m: Effect of uneven building layout on air flow and pollutant dispersion in non-uniform street canyons Original Research Article
Building and Environment, *Volume 46, Issue 12*, *December 2011*, *Pages 2657-2665*
Zhao-Lin Gu, Yun-Wei Zhang, Yan Cheng, Shun-Cheng Lee

Article n: Numerical modelling of the passive control of air pollution in asymmetrical urban street canyons using refined mesh discretization schemes Original Research Article
Building and Environment, *Volume 56*, *October 2012*, *Pages 232-240*
J. Gallagher, L.W. Gill, A. McNabola

Article o: The influence of building height variability on pollutant dispersion and pedestrian ventilation in idealized high-rise urban areas Original Research Article
Building and Environment, *Volume 56*, *October 2012*, *Pages 346-360*
Jian Hang, Yuguo Li, Mats Sandberg, Riccardo Buccolieri, Silvana Di Sabatino

Article p: CFD evaluation of natural ventilation of indoor environments by the concentration decay method: CO2 gas dispersion from a semi-enclosed stadium Original Research Article
Building and Environment, *Volume 61*, *March 2013*, *Pages 1-17*
T. van Hooff, B. Blocken

Table 1. Overview of CFD studies on micro-scale pollutant dispersion in the built environment published previously in Building & Environment

Authors (year)	Ref.	Study	Configuration	Turbulence modelling	Assessment method	Validation	Sensitivity analysis
Qin & Kot (1990)	a	Applied	3D/2-building([a])	RANS (ML)	AD/$Dt_{,i}$ = cons.	Y (FS-c)	$D_{t,i}$ ([b])
Xie et al. (2005)	b	Generic	2D/Street canyon	RANS (SKE)	NP	Y (WT-v)	Canygeom./Solrad./Wsp.
Xie et al. (2006)	c	Generic	2D/Street canyon	RANS (SKE)	AD/Sc_t = NP	Y (WT-c)	Canygeom./Gridres.
Gao et al. (2008)	d	Generic	3D/Isolated	RANS (RNG)	NP	Y(WT-v)	Wsp.
Bady et al. (2008)	e	Generic	3D/2-building([c]) 3D/Arrays([d])	RANS (SKE)	AD/Sc_t = cons.([e])	N	Canygeom./Buildgeom./ Wdir.([f])
Bu et al. (2009)	f	Generic	3D/Street canyon	RANS (SKE)	AD/Sc_t = NP	N	Canygeom./Orientation
Hefny & Ooka (2009)	g	Generic	3D/Isolated	RANS (CKE)	NP	Y (WT-v)	Gridtyp./Gridres.
Hang et al. (2009)	h	Generic	3D/3 idealized city models([g])	RANS (SKE, RNG)	AD/Sc_t = NP([e])	N	City geom./Wdir.
Huang et al. (2009)	i	Generic	2D/Street canyon	RANS (SKE)	AD/Sc_t = 0.7	Y (WT-c)	Canygeom.
Lateb et al. (2010)	j	Applied	3D/ City part([h])	RANS (RLZ)	AD/Sc_t = 0.7	Y (WT-c,FS-c)	Geom.scale/Momratio/Stack height([i])
Tominaga & Stathopoulos (2010)	k	Generic	3D/Isolated	RANS (RNG), LES	AD/Sc_t = 0.7/ $Sc_{t,SGS}$ = 0.5	Y (WT-v,c)	Turb.mod.
Salim et al. (2011)	l	Generic	3D/Street canyon	RANS (SKE,RSM), LES	AD/Sc_t = 0.7/ $Sc_{t,SGS}$ = 0.7	Y (WT-c)	Turb. mod./Trees([j])
Gu et al. (2011)	m	Generic	3D/Street canyon	LES	AD/$Sc_{t,SGS}$ = 1	Y (WT-v)	Canygeom.
Gallagher et al. (2012)	n	Generic	3D/Street canyon	LES	NP	N	Canygeom./Gridres./Pass.([k])
Hang et al. (2012)	o	Generic	3D/Arrays	RANS (SKE, RNG)	AD/Sc_t = 0.4/0.7	Y (WT-v)([l])	Array geom.([m])/Sc_t
van Hooff & Blocken (2013)	p	Applied	3D/City part([n])	RANS (RLZ)	AD/Sc_t = 0.7	Y (FS-c)	Gridres.

Table legend: RANS = Reynolds-averaged Navier-Stokes; ML = Mixing-length turbulence model; SKE = Standard k-ε model; CKE = non-linear Cubic k-ε model; RNG = Renormalization Group k-ε model; RLZ = Realizable k-ε model; RSM = Reynolds stress model; LES = Large eddy simulation; AD = advection-diffusion equation; NP = not provided; $D_{t,i}$ = turbulent diffusivity in i-direction; Sc_t = turbulent Schmidt number; $Sc_{t,SGS}$ = subgrid-scale turbulent Schmidt number; cons. = constant value; Y = yes; N = no; FS-c = full-scale concentration data; WT-v = wind-tunnel velocity data; WT-c = wind-tunnel concentration data; Canygeom. = street canyon geometry; Buildgeom. = building geometry; Momratio = momentum ratio; Gridtyp. = grid typology; Gridres. = grid resolution; Turb.mod. = Turbulence model; Wsp. = wind speed; Wdir. = wind direction; Solrad. = solar radiation; ([a]) Isolated 2-building configuration; ([b]) Detailed results of sensitivity study not provided; ([c]) Isolated 2-building configuration with variable street width and building height; ([d]) Both aligned and staggered; ([e]) Constant value is used but actual value not provided; ([f]) For 2-building configuration, only wind direction perpendicular to canyon; for building arrays both 0° and 45°; ([g]) Round, square and long rectangular city model. One main street parallel to the approaching wind or two crossing streets; ([h]) 2-

building model as part of an actual urban geometry in Montreal; ([i]) Simulations are made at FS and at WT scale (1:200). Mom.ratio varies between 2.3 and 4.9 for FS and between 2.2 and 5.0 for WT scale. Stack height is 1 or 3 m at both FS and WT scale; ([j]) With and without trees and with varying tree crown porosity; ([k]) Passive air pollution control measure in the form of a low boundary wall; [(l)] Both mean wind speed and turbulent kinetic energy are validated; ([m]) Arrays have regular horizontal spacing but differ from each other in street width and building height; ([n]) Small part of Amsterdam.