Editorial to Virtual Special Issue:

CFD simulation of pedestrian-level wind conditions around buildings: past achievements and prospects

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1. Context of Virtual Special Issue

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. This VSI deals with papers on CFD simulation of pedestrian-level wind conditions around buildings, published in the Journal of Wind Engineering and Industrial Aerodynamics (JWEIA).

Wind comfort and wind safety for pedestrians are important requirements for urban areas. In particular near high-rise buildings, high wind velocities are often introduced at pedestrian level that can be experienced as uncomfortable or even dangerous. Uncomfortable wind conditions have proven detrimental to the success of new buildings (Durgin and Chock 1982). Wise (1970) reports about shops that are left untenanted because of the windy environment that discouraged shoppers. Lawson and Penwarden (1975) report dangerous wind conditions to be responsible for the death of two old ladies after being blown over by sudden wind gusts near a high-rise building. Many urban authorities nowadays recognize the importance of pedestrian wind comfort and wind safety and require such studies before granting building permits for new buildings or new urban areas.

Studies of wind comfort and wind safety involve combining statistical meteorological data with aerodynamic information and with wind comfort and wind safety criteria. The aerodynamic information is needed to transform the statistical meteorological data from the weather station (meteorological site) to the location of interest at the building site. At this location, the transformed statistical data are combined with the comfort and safety criteria to assess local wind comfort and safety. This procedure is schematically depicted in Figure 1. Wind statistics at the meteorological site can be expressed as potential wind speed (U_{pot}), i.e. corresponding to a terrain with aerodynamic roughness length $z_0 = 0.03$ m. The aerodynamic information usually consists of two parts: the terrain-related contribution and the design-related contribution. The terrain-related contribution represents the change in wind statistics from the meteorological site to a reference location near the building site, i.e. the transformation of U_{pot} to U_0. The design-related contribution represents the change in wind statistics due to the local urban design, i.e. the transformation of U_0 to the local wind speed U. Information on transformation procedures to determine terrain-related contributions can be found in e.g. Simiu and Scanlan (1986) and Verkaik (2006). The design-related contribution (i.e. the wind-flow conditions around the buildings at the building site) can be obtained by either wind-tunnel modelling or CFD. Wind comfort and safety criteria generally exist of a threshold value of the wind speed and an allowed exceedance probability of this threshold.

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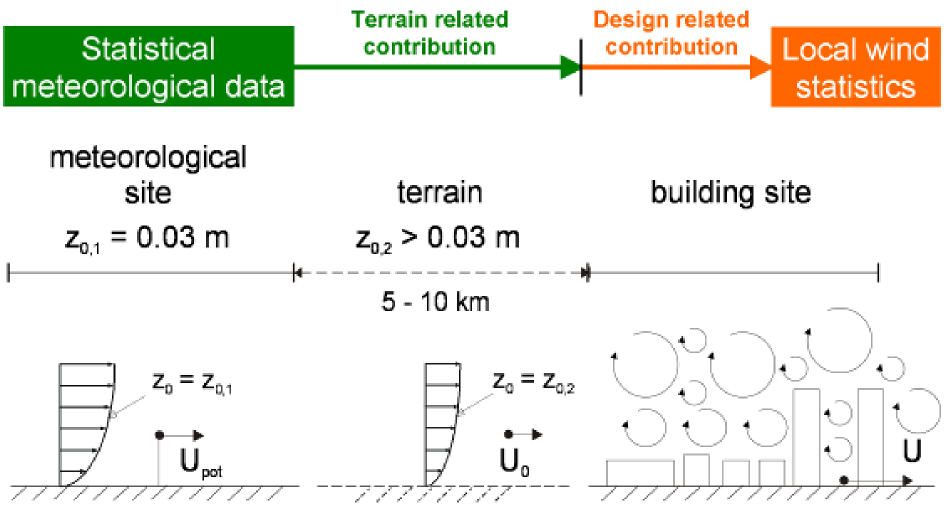

Figure 1. Schematic representation of transformation of statistical meteorological data from the meteorological site to the building site, with indication of the wind speed at the meteorological station (U_{pot}), the reference wind speed near the building site (U_0) and the wind speed at the location of interest (U). The corresponding aerodynamic roughness lengths z_0 are also indicated (from: Blocken et al. 2012).

In the Netherlands, a standard for the assessment of wind comfort and wind danger was published in 2006 (NEN 2006a) along with the Dutch Practice Guideline NRP 6097 (NEN 2006b) based on extensive research work by Verkaik (2000, 2006), Willemsen and Wisse (2002, 2007), Wisse and Willemsen (2003), Wisse et al. (2007), and others. One of the main intentions of the standard was to provide a uniform approach for wind comfort assessment in the Netherlands, concerning the use of statistical meteorological data, the acquisition and application of the aerodynamic information and the comfort criterion. This was meant to avoid different consultancy advice (in the form of different wind comfort assessment for the same building or the same urban configuration/situation) from different consultancy companies or institutes, which is clearly unwanted. The standard contains an improved and verified transformation model for the terrain-related contribution that can provide the wind statistics at every location in the Netherlands, however without including the local building aerodynamic effects, which are part of the so-called design-related contribution. A very special feature of the standard is that it allows the user to choose between wind-tunnel modelling or CFD to obtain the design-related contribution. This fact can be considered as a milestone in the acceptance process of CFD as a tool for the evaluation of pedestrian-level wind conditions, wind comfort and wind safety in urban areas. However, it does not absolve the user from providing quality assurance. The decision to treat wind-tunnel experimentation and CFD as *equals* in the Dutch standard has not been made lightly and has indeed led to the specification of quality assurance requirements in the standard, both for CFD and for wind-tunnel testing.

CFD has some important advantages compared to wind-tunnel testing. Wind-tunnel measurements are generally only performed at a few selected points in the urban model, and do not provide a whole image of the flow field. 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. This is particularly important when extensive urban areas need to be analyzed. CFD simulations also 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. Because of all these reasons, CFD is increasingly used to determine pedestrian-level wind conditions around buildings. This is one of the main reasons for the establishment of this Virtual Special Issue. It should be noted that the utilization of mean velocities to evaluate and assess comfort, as opposed to gusts, makes CFD more suitable to apply; if gust speeds are used for comfort evaluation purposes, CFD may be at a weaker position versus physical simulation in wind tunnels.

2. Aim and scope of Virtual Special Issue

2.1. Aim

The present VSI is stimulated by (1) the increasing importance of pedestrian-level wind conditions, wind comfort and wind danger in urban areas; (2) the increasing attention for pedestrian-level wind conditions, wind comfort and wind danger among building designers, architects, urban planners, researchers, consultancy companies and government authorities; and (3) the increasing use of CFD for the assessment of pedestrian-level wind conditions, wind comfort and wind danger. The aim of this VSI is therefore to identify and group a number of papers reporting CFD simulations of pedestrian-level wind conditions around buildings and published in the Journal of Wind Engineering and Industrial Aerodynamics (JWEIA).

2.2. Scope

A few specific items related to the scope of this VSI are mentioned in this subsection, which will also be referred to in the overview Table presented in section 3.

1. Review, overview and position papers
2. Generic studies versus case studies
3. Wind conditions (mean velocity and turbulence) versus wind comfort and wind danger
4. CFD validation with wind-tunnel measurements or field measurements
5. Mechanical effects versus thermal effects
6. Best practice guidelines and recommendations
7. Papers on related topics

1. The intent of this VSI is neither to be complete, nor to provide an overview of such studies over a wider range of journals. In the recent past, a number of review, overview and position papers on pedestrian-level wind conditions were provided in this and other journals (Stathopoulos 1997, 2006, Blocken and Carmeliet 2004, Mochida and Lun 2008, Blocken et al. 2011, 2012, Moonen et al. 2012). These papers are not included in the VSI, except when they address specific CFD simulations and when published in the JWEIA. An important overview document on outdoor human comfort and its assessment was prepared by a Task Committee of the Aerodynamics Committee, Aerospace Division, ASCE, Reston, VA (ASCE 2004). Important overview papers that mention pedestrian-level wind studies with CFD but however do not provide details about those CFD simulations (e.g. Laurence and Mattei 1993, Laurence 1993, Murakami 1997) are also not included in the VSI. The overview table (Table 1) in the next section will indicate which papers in the VSI are review, overview or position papers.
2. Wind flow around buildings is very complex. Due to this complexity, many basic studies of pedestrian-level wind conditions around buildings in wind tunnels and with CFD have focused on generic and idealized configurations such as isolated buildings or groups of simplified buildings (Figure 2). 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. The VSI includes studies for generic/idealized configurations such as arrays of block-type buildings as well as studies for parts of actual cities (applied studies / case studies), as indicated in Figure 2 and highlighted in Table 1.
3. The VSI explicitly indicates which CFD studies also included validation by comparison of numerical results with wind-tunnel testing and/or field measurements.
4. In the past, CFD has been frequently used to study wind speed ***conditions*** at pedestrian level in urban areas, i.e. mean velocity and turbulence intensity, but only very rarely has this information been used as part of complete ***wind comfort and wind safety*** studies. Indeed, the pedestrian-level wind speed conditions are only one part of a complete wind comfort and wind safety study, as they only provide the design-related contribution of the aerodynamic information. Complete wind comfort and wind safety studies require the combination of this aerodynamic information with statistical meteorological data and a wind comfort and/or wind danger criterion. To the best of our knowledge, wind comfort and wind safety studies based on CFD have only been published by Richards et al. (2002), Hirsch et al. (2002), Blocken et al. (2004, 2012), Blocken and Carmeliet (2008), Blocken and Persoon (2009) and Janssen et al. (2013). Table 1 will indicate which papers in the VSI only address pedestrian-level wind conditions and which also provide an assessment of wind comfort and/or wind safety.
5. Although thermal comfort is also important (e.g. Stathopoulos 2006, Metje et al. 2008, Mochida and Lun 2008, Ooka et al. 2008), wind comfort and safety generally only refer to the mechanical effects of wind on people (e.g., Lawson and Penwarden 1975, Willemsen and Wisse 2007). Table 1 will indicate which studies also address effects other than mechanical.
6. While the use of CFD for the evaluation of pedestrian-level wind conditions, wind comfort and wind danger has long been an issue of debate (e.g. Stathopoulos 2002), in the past decade, strong support for its application has been provided by the establishment of several sets of best practice guidelines (BPG). Indeed, in CFD simulations, a large number of choices have to be made by the user. It is well known that these choices can have a very large impact on the results. Several of these BPG documents were established specifically for the assessment of pedestrian-level wind conditions (Franke et al. 2004, Blocken et al. 2007, Tominaga et al. 2008, Blocken et al. 2012). Other, more general guidelines, but also of relevance to pedestrian-level wind conditions, are those by Casey and Wintergerste (2000), Jakeman et al. (2006), Franke

et al. (2007, 2011) and Blocken and Gualtieri (2012). While papers focusing on guidelines are very important, they are not included in the VSI when they do not report specific CFD simulations.

7. Papers on related and also very important topics such as urban ventilation and pedestrian-level air quality (e.g. van Hooff and Blocken 2010a, 2010b, Hang et al. 2011, Hu and Yoshie 2013), validation studies (e.g. Hertwig et al. 2012) and coupling of mesoscale and microscale modeling efforts (e.g. Liu et al. 2012) are not included in the VSI, except when they specifically include assessment of pedestrian-level wind conditions, wind comfort or wind safety. The same goes for papers that focus on the important topic of optimization techniques rather than on the CFD simulations themselves and therefore do not report turbulence modeling approach etc (e.g. Ooka et al. 2008).

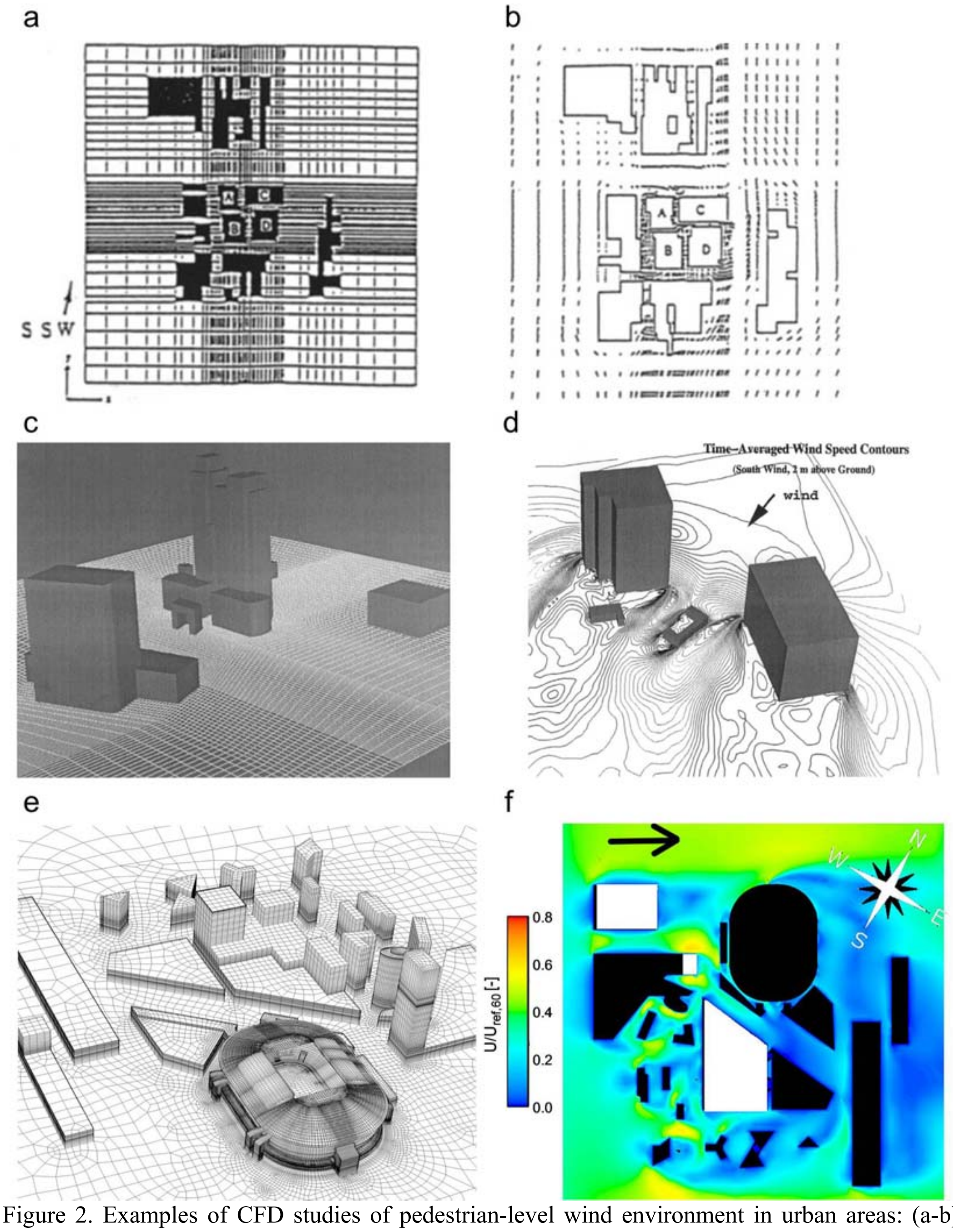

Figure 2. Examples of CFD studies of pedestrian-level wind environment in urban areas: (a-b) Grid (120120 cells) and wind-velocity vectors based on steady RANS simulations (Murakami 1990), (c-d) Grid (total cell count unknown) and wind speed contours based on LES (He and Song 1999), (e-f) Grid (2.8 million cells) and wind speed ratio contours, based on steady RANS (Blocken and Persoon, 2009).

3. Contents of Virtual Special Issue

This VSI consists of 17 papers. Section 3.1 summarizes these papers in an overview table along with the main characteristics of their CFD simulations, including the items 1-6 mentioned in section 2.2. Section 3.2 briefly highlights the main contribution by each of these 17 papers.

3.1. Overview table

Table 1 provides an overview of the 17 papers, listed in chronological order. The table entries are:

- the author last names and year of publication;
- the reference letter (by which the articles are listed below)
- the type of study / geometrical configuration: generic, applied and/or review.
- the focus of the study: pedestrian-level wind conditions (mean velocity, turbulence intensity) or also wind comfort and/or wind safety.
- turbulence modeling approach: Reynolds-Averaged Navier-Stokes (RANS) or Large Eddy Simulation (LES), and type of turbulence model.
- whether or not a validation study was performed, and if so, based on what type of data (wind-tunnel measurements or field measurements).
- whether or not thermal (T) and/or moisture (M) effects were included.
- whether or not a sensitivity analysis 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:

- 16 out of the 17 papers report simulations that are based on the RANS equations. The exception is the paper by He and Song (1999) reporting LES results. Out of the 16 RANS papers, all used a k-ε turbulence model for closure, while only 2 also applied an Algebraic Stress Model (ASM) or Differential Stress Model (DSM).
- 16 out of the 17 papers include a validation effort by comparison with measurements. 11 papers provide a comparison with wind-tunnel measurements, 6 papers provide a comparison with full-scale (field) measurements, and 1 paper includes comparisons with wind-tunnel measurements and full-scale measurements.
- Only 5 out of the 17 papers provide more information than mean velocity and turbulence: 2 papers provide estimates for the Standard Equivalent Temperature (SET or SET*), 1 paper focuses on fluxes, and only 2 papers provide information on wind comfort by means of exceedance probabilities P of a certain discomfort threshold value.
- Only 2 out of the 17 papers include thermal and/or moisture effects.
- 15 out of the 17 papers contain some type of sensitivity analysis. This could be expected, given the large number of computational parameters that have to be chosen by the user of a CFD code. Grid-sensitivity analysis however, in spite of its importance, is only explicitly reported in 3 of the 17 papers.
- 6 out of the 17 papers also provide a review.

3.2. Paper contributions

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

In his review paper on Computational Wind Engineering (CWE), Murakami (1990) describes a study of wind flow around an actual building complex. First, a preliminary study using a simplified version of the building complex was performed for validation by comparison with wind-tunnel experiments. Next, the study on the actual building complex was provided. A particularly noteworthy aspect of this case study is the focus on wind environmental conditions on the balconies, with and without windbreak. The level of detail in these simulations, already in these early years of CWE, is remarkable. It would take 23 years for the next studies of wind conditions on building balconies to be reported (Montazeri and Blocken 2013, Montazeri et al. 2013).

Bottema et al. (1992) reported a generic study focused on patterns of mean velocity and turbulent kinetic energy around generic building configurations, along with a comparison with wind-tunnel experiments by hot-wire anemometry and Laser-Doppler Anemometry (LDA).

Stathopoulos (1997) provided an extensive review on the state of CWE, including also information on the assessment of pedestrian-level wind conditions. The focus was on mean wind velocity around a group of buildings in downtown Montreal, as predicted by CFD and wind-tunnel measurements. He reported that “It is noteworthy that the maximum discrepancies between the experimental and numerical data appear in highly complex recirculating flow regions for which neither the measured nor the computed values can be considered very accurate." Stathopoulos (1997) was the first to make this observation in comparing CFD simulations and measurements. Later, similar findings were also noted by other researchers, as mentioned below.

Murakami et al. (1999) published a very comprehensive review paper entitled "CFD analysis of wind climate from human scale to urban scale". It included a study of the pedestrian-level wind conditions (in terms of mean velocity and mean pressure fields) and wind comfort (in terms of Standard Equivalent Temperature SET*). The study assessed the effects of wind speed, wind direction, and vegetation (with and without plant canopy) for an idealized building configuration.

He and Song (1999) provided – to the best of our knowledge – the first LES study of pedestrian-level wind conditions. The paper considered three different building arrangements and different wind directions.

Ferreira et al. (2002) evaluated the effect of two additional buildings to the site of the 1998 World Exposition in Lisbon, Portugal, which consisted of 7 buildings. Detailed analysis of building interference effects was supported by wind-tunnel measurements.

Blocken et al. (2004) performed a study of wind comfort in passages through three high-rise buildings in Antwerp, Belgium. For CFD validation, a preliminary study for isolated buildings with through-passages was performed, for which wind-tunnel data were available. Based on this validation study, the actual wind comfort study was conducted. Of all papers included in this VSI, this is the first one to combine the CFD results with statistical meteorological data and a comfort criterion, resulting in discomfort probabilities and allowing a complete wind comfort assessment.

Zhang et al. (2005) analyzed the effect of different building arrangements and wind directions on mean velocity patterns and compared the results with wind-tunnel measurements.

Stathopoulos (2006) provided a review on pedestrian-level winds and outdoor comfort that also contained some additional information about the CFD study for the group of buildings in downtown Montreal as reported in Stathopoulos (1997).

Li et al. (2007) computed the sheltering effects by windbreaks on mean wind velocity around idealized buildings. The geometry, porosity and position of the windbreaks were varied, and also different building heights, wind directions, turbulence models and discretization schemes were included in the analysis.

Blocken et al. (2007) simulated the wind-flow pattern in passages between parallel buildings and compared the results with wind-tunnel measurements by Stathopoulos and Storms (1986). They also indicated the importance of appropriate boundary conditions (inlet profiles and wall functions) to obtain accurate results in CFD simulations of pedestrian-level winds. Finally, also passage fluxes were analyzed to indicate that the wind-blocking effect, rather than the Venturi effect, governs the wind flow in the passages.

Yoshie et al. (2007) reported the extensive computational studies of the Architectural Institute of Japan (AIJ). These studies, for a wide range of idealized and actual building arrangements, were validated by comparison with wind-tunnel measurements and full-scale measurements and provided the basic information that would later lead to the AIJ recommendations for CFD simulation of pedestrian-level winds (Tominaga et al. 2008).

Mochida and Lun (2008) reviewed the recent developments in Computational Wind Engineering (CWE) research for predicting the pedestrian level wind and thermal environments in urban areas, primarily achieved by the researchers in the field of environmental engineering in Japan. In particular, the study included CFD simulations of pedestrian-level winds with the effects of trees and automobiles.

Mochida et al. (2008) analyzed the accuracy of tree canopy models and the effect of trees on pedestrian-level wind conditions, in which the computational results were compared with field measurements.

Lin et al. (2008) evaluated the effects of vegetation (trees, shrubs and grass) and building arrangements on outdoor thermal comfort in terms of mean velocity, air temperature, relative humidity, mean radiant temperature and SET.

Blocken and Persoon (2009) analyzed pedestrian-level wind conditions and wind comfort (in terms of exceedance probabilities of a threshold wind speed) for the deck and the surroundings of the Amsterdam ArenA football stadium in the Netherlands. The study included a grid-sensitivity analysis, the effect of two different building arrangements, the effect of local ground roughness (of streets and squares) and the effect of the accuracy with which the so-called terrain-related contribution is determined.

Finally, An et al. (2013) investigated the impact of inflow turbulence profiles on the downstream wind velocity and turbulent kinetic energy profiles within the street arrays of four different building arrangements. The study also included a fifth building arrangement for validation, which is the same arrangement as analyzed by Yoshie et al. (2007). By comparing simulated and measured wind speed ratios, An et al. (2013) arrived at a similar observation as that by Stathopoulos (1997, 2006), in that the agreement between CFD simulations and measurements is quite good for high wind speed ratios, while it severely deteriorates for low wind speed ratios. Similar observations have also been made by Blocken et al. (2011).

4. Some trends and directions for future research and publications

Based on the information provided in sections 2 and 3, some (non-exhaustive) trends and directions for future research and publications can be outlined:

- Increased focus on the assessment of pedestrian-level wind conditions (mean velocity and turbulence) by LES, especially for more complex urban configurations and for more accurate assessment of turbulence intensities/gustiness.
- Increased focus on the assessment of pedestrian-level wind comfort and wind safety instead of only on wind speed conditions (mean velocity and turbulence).
- Increased focus on a more integral assessment of outdoor comfort by including thermal and moisture effects, vegetation, etc.
- Integration of outdoor air quality into the assessment of outdoor pedestrian comfort.
- Continued sensitivity analysis, validation studies and provision of guidelines for CFD simulation of pedestrian-level wind conditions.

In the past 23 years, a considerable number of publications on CFD simulation of pedestrian-level wind conditions around building has been published in the JWEIA, indicating not only the early awareness of research community concerning the capabilities of CFD to address this problem, but also the continued importance of this topic and the ongoing research efforts towards high-quality assessment and improvement of pedestrian-level wind conditions, wind comfort and wind safety. The topic is expected to continue receiving a great deal of attention in the Computational Wind Engineering community in the future.

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Table 1. Overview of CFD studies on pedestrian-level wind conditions around buildings published previously in the Journal of Wind Engineering and Industrial Aerodynamics.

Authors (year)		Study (generic, applied, review)	PLW conditions or comfort/safety	Turbulence modeling	Validation	T/M effects	Sensitivity analysis[a]
Murakami (1990)	a	Gen./Appl./Review	Mean vel.	RANS (SKE)	Y(WT)	N	Windbreak on balcony
Bottema et al. (1992)	b	Gen.	Mean vel. + tke	RANS (SKE,ASM)[b]	Y(WT)	N	Constant C_μ in turb. model
Stathopoulos (1997)	c	Appl./Review	Mean vel.	RANS (SKE)	Y(WT)	N	-
Murakami et al. (1999)	d	Gen./Review	Mean vel. + pressure, comfort(SET*)[c]	RANS (SKE,MKE)[d]	Y(FS)[e]	Y(T,M)[f]	Wsp[g], Wdir., Veg.[h]
He & Song (1999)	e	Appl.	Mean + rms vel.	LES (SSGS)[i]	N	N	Wdir., BGeom.[j]
Ferreira et al. (2002)	f	Appl.	Mean vel.	RANS (RNG)	Y(WT)	N	Wdir., BGeom.[k]
Blocken et al. (2004)	g	Gen./Appl.	Mean vel. + comfort(P)	RANS (RLZ)	Y(WT)[l]	N	Wdir., BGeom., Gridres.
Zhang et al. (2005)	h	Appl.[m]	Mean. vel.	RANS (RNG)	Y(WT)	N	BArrang., Wdir.
Stathopoulos (2006)	i	Appl.[n]/Review	Mean vel.	RANS (SKE)	Y(WT)	N	-
Li et al. (2007)	j	Gen.	Mean vel.	RANS (SKE,RNG,TL)[o]	Y(WT)	N	Windbreaks (geom.,pos.,por.), Turb.mod., Discr.[p], Wdir., Bheight[q]
Blocken et al. (2007)	k	Gen.	Mean vel. + fluxes[r]	RANS (RLZ)	Y(WT)	N	BArrang.[s]
Yoshie et al. (2007)	l	Gen./Appl.[t]	Mean vel.	RANS (SKE,RNG,DSM)	Y(WT,FS)	N	CFDcode[u], BGeom., Comp.dom., Gridres., Gridtyp.[v], Turb.mod., Discr.[w]
Mochida & Lun (2008)	m	Appl.[x]/Review	Mean vel. + tke	RANS (MKE)	Y(FS)[y]	Y	Trees, Automobiles[z]
Mochida et al. (2008)	n	Gen./Appl.[α]/Review	Mean vel. + tke	RANS (MKE)[β]	Y(FS)	N	Tree canopy models[γ]
Lin et al. (2008)	o	Appl.	Mean vel., T_{air}, RH, MRT, Comfort(SET)	RANS (SKE)	Y(FS) [δ]	Y(T,M)	Veg.[ε], BArrang.
Blocken & Persoon (2009)	p	Appl.	Mean vel. + comfort(P)	RANS (RLZ)	Y(FS)	N	Wdir., Gridres., BArrang., Loc.rough.[ς], Terrain.contr.[η]
An et al. (2013)	q	Gen./Appl.	Mean vel. + tke	RANS (RLZ)	Y(WT)	N	BArrang., Inlet.tke

Table legend:

RANS = Reynolds-Averaged Navier-Stokes; SKE = Standard k-ε model; RNG = Renormalization Group k-ε model; RLZ = Realizable k-ε model; MKE = Modified k-ε model; ASM = Algebraic stress model; LES = Large eddy simulation; MRT = Mean Radiant Temperature; P = probability; SET = Standard Equivalent Temperature; TL = Two-layer k-ε; Y = yes; N = no; T = thermal; M = moisture; WT = wind tunnel; FS = full scale; tke = turbulent kinetic energy, rms = root mean square; BGeom. = building geometry; BArrang. = building arrangement; BHeight = building height; Comp.dom. = computational domain; Discr. = discretization scheme; Gridres. = grid resolution; Gridtyp. = grid typology; Geom. = geometry, Pos. = position; Por. = porosity; Turb.mod. = Turbulence model; Veg. = vegetation; Wsp. = wind speed; Wdir. = wind direction; ([a]) Only related to CFD simulation parameters (not wind comfort/danger);

([b]) Simulations with Algebraic Stress Model mentioned but not presented; ([c]) Comfort index: SET* = Standard Effective Temperature proposed by Gagge et al. (1986); ([d]) Modified k-e model, with some modifications added to the Launder-Kato model; ([e]) Field measurements of ground surface temperatures; ([f]) Heat and moisture transport equations included; ([g]) Wind speed zero or non-zero; ([h]) With and without plant canopy and its effect on momentum, heat and moisture transfer; ([i]) Value of Smagorinsky constant C_s not provided in paper; ([j]) Different configurations of buildings; ([k]) With two new buildings present or not; ([l]) Parametric study for validation: building height, passage width; validation only for generic study, not for applied study; ([m]) Residential zone in South China represented by idealized building shapes; ([n]) Generic study reported is that by the same author, while the review contains several other studies, the details of which are not included in this table; ([o]) Two-layer k-ε model where k-ε model is only used in fully turbulent region and near-wall viscosity-affected layer is resolved with a one-equation model; ([p]) HYBRID scheme, QUICK scheme and SMART scheme; ([q]) Variation of building height was tested; ([r]) Analysis of fluxes to indicate to what extent Venturi effect is present; ([s]) Range of different passage widths is analyzed, resulting in three flow categories: resistance flow, interaction flow and isolated flow; ([t]) Very extensive study by AIJ (Architectural Institute of Japan) for two types of single generic high-rise buildings, two generic urban areas, and two types of building configurations in actual urban areas; ([u]) Three different CFD codes included in comparison study; ([v]) Analysis of single structured grid system (orthogonal grid), overlapping structured grid system and unstructured grid system; ([w]) Schemes for advection term: Third-order upwind, QUICK, MUSCL; ([x]) Case study previously reported in more detail in (Mochida et al. 2006 and Hataya et al. 2006). The next columns in the table pertain to this case study, not to the other studies described in this extensive review paper. ([y]) Validation based on value for turbulent kinetic energy; ([z]) Effects of trees and automobiles are taken into account by source terms in the governing equations (momentum, tke, tdr); ([α]) Effects of trees are taken into account by source terms in the governing equations (momentum, tke, tdr); ([β]) Revised k-ε model based on a "mixed time scale" concept (Nagano and Hattori 2003); ([γ]) Application to an apple and cherry orchard and comparison with full-scale measurements; ([δ]) Validation reported in previous study (Lin et al. 2005a, 2005b); ([ε]) Three vegetation patterns including tree, grass and shrub; ([ς]) local aerodynamic roughness length of the streets and squares; ([η]) terrain-related contribution in wind comfort assessment.