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The mutual influence of two buildings on their wind-driven rain exposure and comments on the obstruction factor

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ABSTRACT

Wind-driven rain (WDR) deposition on a two-building configuration is studied with Computational Fluid Dynamics (CFD). The configuration consists of a high-rise building screened by a low-rise building. Validation of the wind-flow simulations is performed with Particle Image Velocimetry (PIV) measurements in a wind tunnel. Raindrop motion is simulated by Lagrangian particle tracking in the mean wind-flow pattern with a reference wind speed $U_{10} = 10$ m/s. Horizontal rainfall intensities $R_h = 5$ and 30 mm/h are considered. Simulations of WDR are performed for the two-building configuration and for each building separately, to analyse the mutual influence of the buildings on their WDR deposition pattern. The simulation results indicate that this influence is very pronounced and that it is to some extent opposite to what might be expected. The low-rise building influences the deposition on the high-rise building (downstream disturbance), not by partly shielding it from wind and WDR, but by increasing the strength of the standing vortex between the two buildings. This locally increases WDR intensities on the high-rise building facade by more than a factor 2 for both $R_h = 5$ and 30 mm/h. On the other hand, the high-rise building influences deposition on the low-rise building facade (upstream disturbance) by the wind-blocking effect. This effect yields a reduction in WDR deposition on the low-rise building facade by up to about 25% for both $R_h = 5$ and 30 mm/h. In the European standard draft for WDR assessment, the mutual influence can only be taken into account by a simplified reduction factor, called the obstruction factor. It only considers downstream disturbances, and does not consider the possibility of increased WDR deposition due to neighbouring buildings. Care should therefore be exercised when using the current version of the obstruction factor to determine WDR exposure.

1. Introduction

The deposition of wind-driven rain (WDR) on buildings is of concern because it is one of the most important moisture sources affecting the hygrothermal behaviour and durability of building facades. Three categories of methods exist to assess the amount of WDR that is deposited on building facades: experimental, semi-empirical and numerical methods (Blocken and Carmeliet, 2004). The introduction of numerical methods (Computational Fluid Dynamics; CFD) in WDR research has provided the capability to meticulously study the complex interaction between WDR and buildings. The CFD numerical simulation technique for WDR was developed by Choi (1991, 1993, 1994) and extended in the time domain by Blocken and Carmeliet (2002, 2007a). The steady-state simulation technique by Choi allows determining the spatial distribution of WDR on buildings under steady-state conditions of wind and rain, i.e. for fixed, static values of wind speed, wind direction and horizontal rainfall intensity (i.e. the rainfall intensity falling through a horizontal plane). This technique has been adopted by a large number of researchers for their WDR analyses. Validation studies of the steady-state simulation technique were performed by e.g. Hangan (1999) and van Mook (2002). The extension of this technique in the time domain allowed the numerical determination of both the spatial and temporal distribution of WDR on buildings. Validation studies for a low-rise building and for different rain events have indicated that this extended numerical method can provide quite accurate predictions of the WDR amount and the WDR deposition pattern on the building facade (Blocken and Carmeliet, 2002, 2006, 2007b). Recently, additional validation studies, based on the extended numerical method, were made for two rather complex high-rise buildings and for a simple rectangular test building, showing a satisfactory agreement between simulations and measurements (Tang and Davidson, 2004; Abuku et al., 2009;

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Nomenclature

B_1, L_1, H_1	width, length, height of the low-rise building (m)
B_2, L_2, H_2	width, length, height of the high-rise building (m)
$C_{1\varepsilon}$, $C_{2\varepsilon}$	turbulence model constants (dimensionless)
C_μ	turbulence model constant, variable in realizable k–ε model
C_{1PS}, C_{2PS}, $C_{1'PS}$, $C_{2'PS}$	turbulence model constants—linear pressure strain model
C_s	roughness constant in the standard wall function modified-for-roughness (dimensionless)
d	raindrop diameter (mm)
$f(d)$	probability-density function of raindrop size in a volume of air (m^{-1})
$f_h(d)$	probability-density function of raindrop size falling through a horizontal plane (m^{-1})
k	turbulent kinetic energy ($m^2\,s^{-2}$)
k_S	equivalent sand-grain roughness height (m)
Re	Reynolds number (dimensionless)
R_h	horizontal rainfall intensity, i.e. through a horizontal plane ($Lm^{-2}\,h^{-1}$ or $mm\,h^{-1}$)
R_{wdr}	wind-driven rain intensity ($Lm^{-2}\,h^{-1}$ or $mm\,h^{-1}$)
t	time (s)
u^*	friction velocity associated with the inlet profiles of U, k and ε (ms^{-1})
U	streamwise horizontal component of the mean wind-velocity vector (ms^{-1})
U_{10}	reference wind speed at 10 m height in the upstream undisturbed flow (ms^{-1})
U_{ref}	reference wind speed at $y/H_2 = 1.5$ (ms^{-1})
V	vertical component of the mean wind-velocity vector (ms^{-1})
x, z	streamwise and spanwise co-ordinate (m)
y	vertical co-ordinate (m)
y_0	aerodynamic roughness length (m)
Δt	time delay between two laser pulses (s)
ε	turbulence dissipation rate ($m^2\,s^{-3}$)
η_d	specific catch ratio (dimensionless)
η	catch ratio (dimensionless)
κ	von Karman constant ($\approx$0.42)
σ_k, σ_ε	turbulent Prandtl numbers for k and ε (dimensionless)
σ_v, σ_w	standard deviation of turbulent fluctuations in vertical and lateral direction (m/s)
φ_{10}	wind direction at 10 m height in the upstream undisturbed flow (degrees from north)
CFD	Computational Fluid Dynamics
ESD	European standard draft
RANS	Reynolds-averaged Navier–Stokes
WDR	wind-driven rain

Briggen et al., 2009). Abuku et al. (2009) specifically focused on validation for oblique wind directions.

In spite of the large amount of research work done in the past, there are important topics in CFD studies of WDR on buildings that have not yet or hardly been addressed. Two of these are mentioned here because they are part of this paper. (1) Up to now, almost all CFD WDR studies were conducted for isolated (single-standing) buildings. In reality however, buildings seldom stand alone. To the knowledge of the authors, there is only one publication in which a preliminary CFD study was made of WDR on a combination of two high-rise buildings (Karagiozis et al., 1997). More research on the influence of surrounding buildings on the WDR exposure of building facades is needed. (2) The CFD simulation technique allows a detailed determination of the spatial and temporal distribution of WDR on building facades. However, this technique is often too complex and time-consuming for practical WDR assessment. On the other hand, the semi-empirical European standard draft (ESD) prEN ISO 15927-3 (CEN, 2006) is fast and easy to use, but it cannot provide such detailed information. The mutual influence of buildings, for example, can only be taken into account by a simplified reduction factor, called the "obstruction factor". The power of CFD can be used to study the accuracy of the European standard draft procedure and, eventually, to provide some improvements to this procedure.

In this paper, CFD simulations of WDR on a two-building configuration are presented. The configuration consists of a high-rise building ($L_2 \times B_2 \times H_2 = 50 \times 12.5 \times 50\,m^3$) screened by a low-rise building ($L_1 \times B_1 \times H_1 = 50 \times 12.5 \times 12.5\,m^3$) (Fig. 1). The distance between both buildings is 25 m. Wind direction is perpendicular to the building facades. This particular configuration is chosen because it has been one of the common configurations studied in earlier work on building aerodynamics in which the interaction effect of both buildings on the flow pattern has been described (Wise et al., 1965; Sexton, 1968; Wise, 1970; Penwarden and Wise, 1975). The mutual influence of the two buildings on their WDR exposure is investigated in the present paper by performing simulations, not only for the two-building configuration, but also for each building separately. The CFD results will also be used to discuss the performance of the ESD obstruction factor. In Section 2, the definitions and

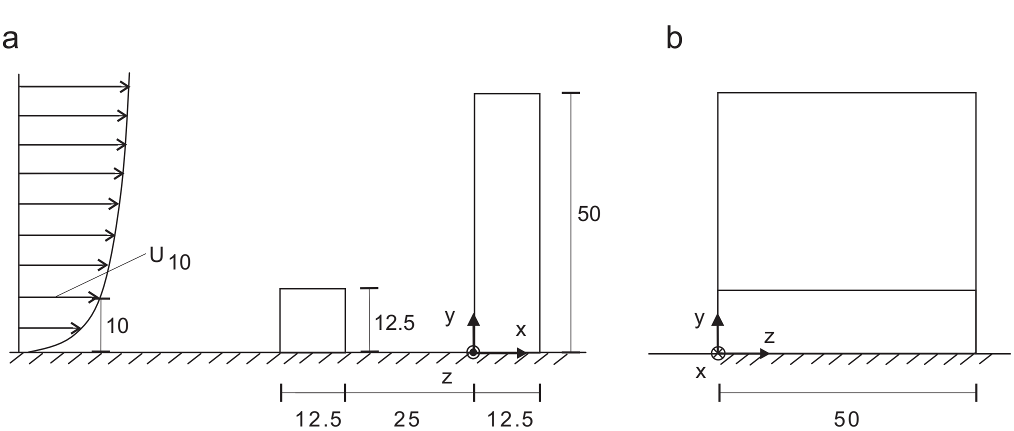

Fig. 1. Geometry of the two-building configuration: high-rise building screened by a low-rise building: (a) side view; (b) front view. Dimensions in m.