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Supplementary Information

Computational and Experimental Investigation for an Optimal Design of Industrial Windows to Allow Natural Ventilation during Wind-Driven Rain. *Sustainability* 2015, *7*, 10499-10520

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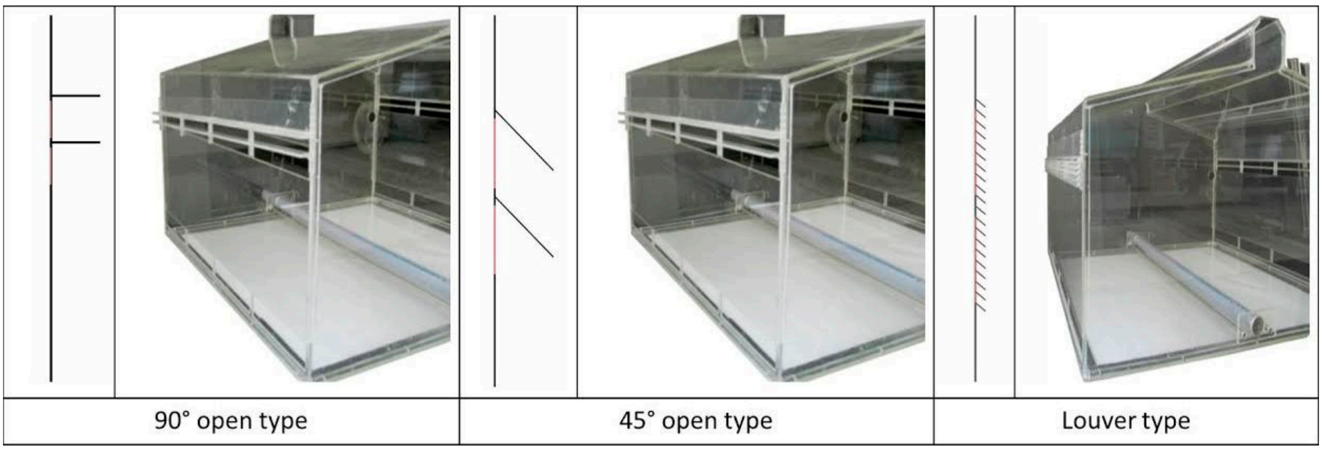

Figure S1. Reduced-scale experimental model with three basic types of windows.

Figure S2. An example (90° open type) of observing the diffusion of smoke for the visualization of airflow and observing the disappearance of smoke from the building model.

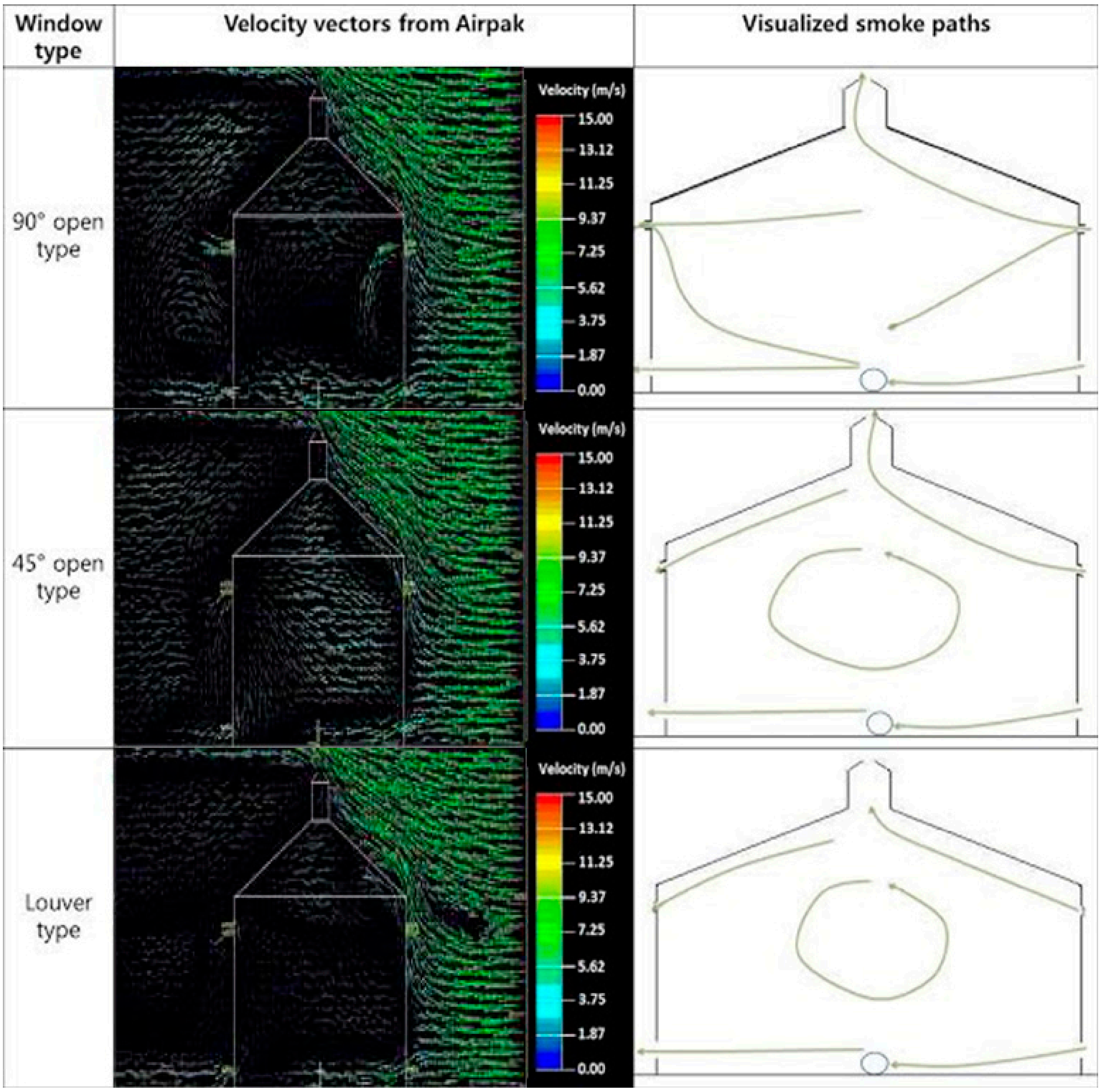

Figure S3. Comparison of the airflow paths through the diffusion of smoke and velocity vectors produced by Airpak.

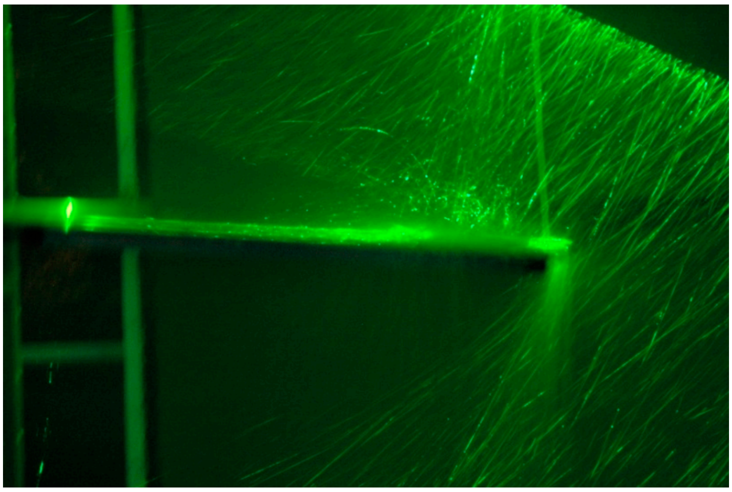

Figure S4. An example of the visualization of rainwater entry through experimental windows during wind driven rain.

Table S1. Dimensions of the windows and the specifications for supplements used in the 24 study cases.

Case Study	Total Length of Upper & Lower Window (mm)	Angle between Window & Lower Inlet	Additional Supplement (& Amount)	Angle between Window & Bended Sheet	Angle between Screen & Ground
1	800 × 800	90°	-	-	-
2	800 × 800	75°	-	-	-
3	800 × 800	60°	-	-	-
4	800 × 800	45°	-	-	-
5	800 × 800	30°	-	-	-
6	1000 × 800	90°	-	-	-
7	1000 × 1000	90°	-	-	-
8	1200 × 800	90°	-	-	-
9	1200 × 1000	90°	-	-	-
10	1200 × 800	90°	Bended sheet (2) and Gutter (2)	45°	-
11	1200 × 800	90°	Bended sheet (2) and Gutter (2)	90°	-
12	1200 × 800	90°	Bended sheet (2) and Gutter (2)	135°	-
13	1200 × 800	100°	Gutter (2)	-	-
14	1200 × 800	100°	Gutter (2) and Screen * (2)	-	90°
15	1200 × 800	100°	Gutter (2) and Screen * (2)	-	45°
16	800 × 800	80°	-	-	-
17	1000 × 800	80°	Gutter (1)	-	-
18	1000 × 1000	80°	Gutter (2)	-	-
19	1200 × 800	80°	Gutter (1)	-	-
20	1200 × 1000	80°	Gutter (2)	-	-
21	1200 × 800	90°	Cushion ** (1)	-	-
22	1200 × 800	90°	Bended sheet (2) and Gutter (2) and Cushion ** (1)	135°	-
23	1200 × 800	100°	Gutter (2) and Screen * (2) and Cushion ** (1)	-	45°
24	1200 × 1000	80°	Gutter (2) and Cushion ** (1)	-	-

* Sieve size = 1 × 1 mm^2; ** Buffer material code: JN 108.

Table S2. Different buffer materials adapted for the designed window case 13 [45].

Case Study	Buffer Material Code	Composition	File Length (mm)	Example of Usage
25	JN 108	Nylon	8	Golf course
26	JN 110	Nylon	10	
27	JN 119	Nylon	19	Outdoor tennis court
28	JNG 135	Polyester + Nylon	35	Multipurpose sport field
29	JE 160	Polyester	60	Football/baseball field

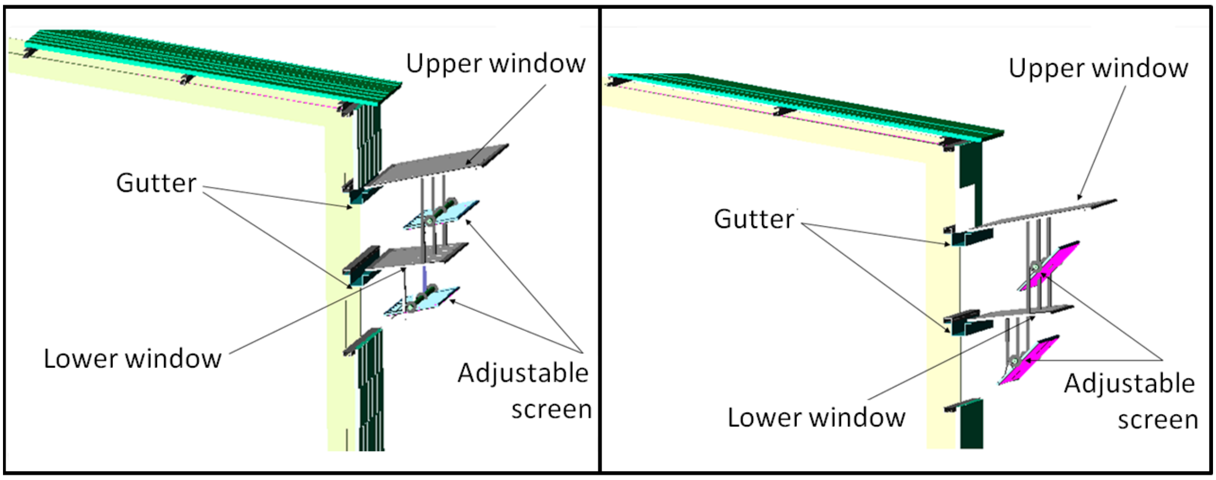

Figure S5. Experimental setup of the windows with rainwater gutters and an adjustable screen (case 15). (**Left figure**) The screen is parallel to the windowpane for no rain and causes almost no change in the ventilation efficiency. (**Right figure**) The angle of the screen is adjusted to 45° during the raining period as presented in Figure 6—case 15.

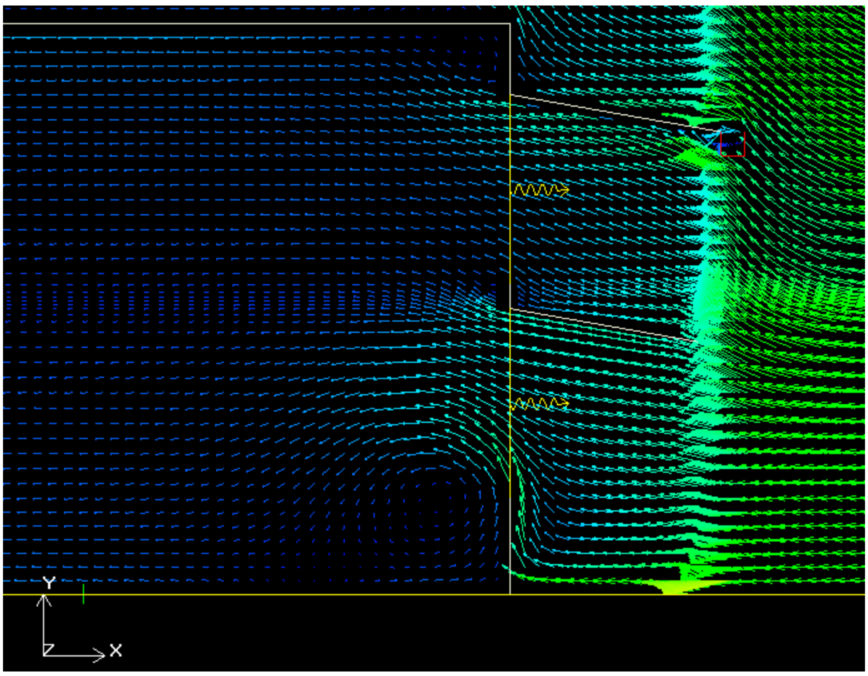

Figure S6. Velocity vector in front of the inlet of case 17 (side view) generated using post-production tools in Airpak (display options: mesh points).

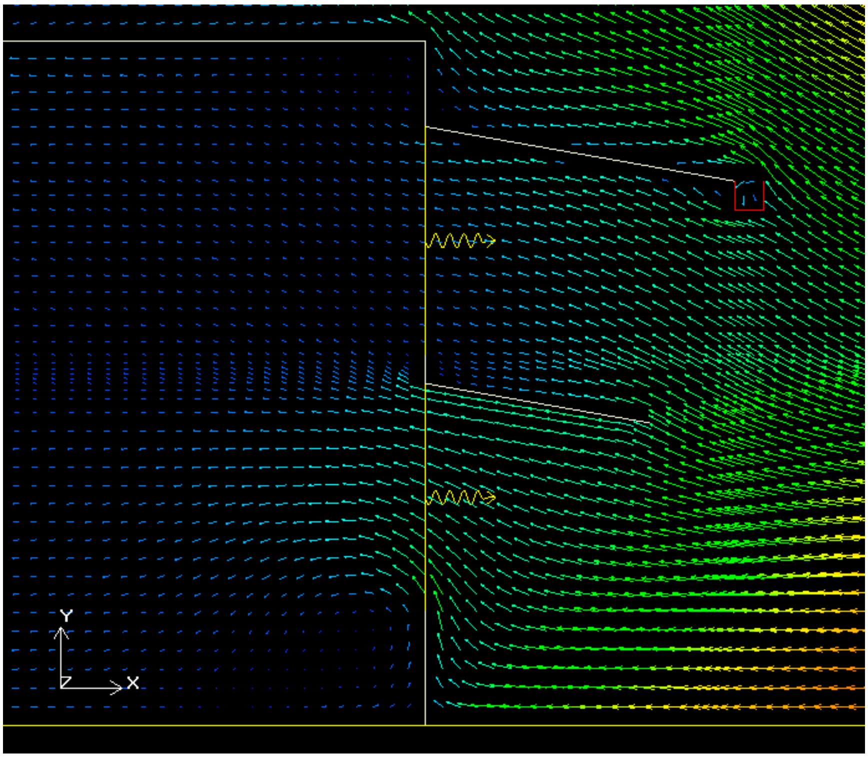

Figure S7. Velocity vector in front of the inlet of case 19 (side view) generated using post-production tools in Airpak (display options: mesh points).

Table S3. Measurement values of the average wind speed on the leeward side of the model and the measurement values of rain penetration for four different wind speeds (3, 5, 7, and 9 m/s) in the sensitivity analysis (Figure 7).

Case	**3 m/s**		**5 m/s**		**7 m/s**		**9 m/s**	
	<m>	**<r>**	**<m>**	**<r>**	**<m>**	**<r>**	**<m>**	**<r>**
C1	0.67	1.65	1.32	2.61	1.96	3.70	3.20	4.82
C2	0.65	0.53	1.29	0.84	1.85	1.20	3.01	1.57
C3	0.60	0.11	1.23	0.13	1.81	0.20	2.82	0.28
C4	0.50	0.04	1.05	0.05	1.61	0.09	2.44	0.14
C5	0.30	0.00	0.67	0.00	1.21	0.00	1.71	0.00
C6	0.65	1.43	1.30	2.25	1.95	3.31	3.15	4.39
C7	0.67	0.87	1.21	1.43	1.94	2.02	2.98	2.89
C8	0.66	0.32	1.22	0.67	1.90	0.97	2.99	1.37
C9	0.64	0.13	1.19	0.58	1.92	0.82	2.91	1.21
C10	0.69	0.07	1.10	0.14	1.89	0.21	2.84	0.31
C11	0.63	0.05	1.00	0.10	1.69	0.15	2.76	0.22
C12	0.65	0.05	1.15	0.09	1.88	0.10	2.61	0.15
C13	0.72	0.10	1.37	0.14	2.03	0.24	3.45	0.69
C14	0.32	0.01	0.70	0.02	1.34	0.04	2.05	0.09
C15	0.57	0.02	1.03	0.03	1.79	0.05	2.88	0.11
C16	0.66	0.89	1.28	1.50	1.89	2.21	3.11	2.99
C17	0.39	0.60	0.80	1.01	1.34	1.54	2.30	2.01

Table S3. *Cont.*

Case	3 m/s		5 m/s		7 m/s		9 m/s	
	<m>	<r>	<m>	<r>	<m>	<r>	<m>	<r>
C18	0.37	0.36	0.71	0.69	1.45	1.03	2.10	1.44
C19	0.55	0.01	0.99	0.03	1.78	0.06	2.40	0.13
C20	0.42	0.00	0.89	0.01	1.59	0.03	2.18	0.06
C21	0.66	0.31	1.22	0.59	1.90	0.89	2.99	1.16
C22	0.65	0.03	1.15	0.03	1.88	0.06	2.61	0.09
C23	0.57	0.01	1.03	0.03	1.79	0.04	2.88	0.06
C24	0.42	0.00	0.89	0.01	1.59	0.02	2.18	0.05
Max	0.72 (C13)	1.65 (C1)	1.37 (C13)	2.61 (C1)	2.03 (C13)	3.7 (C1)	3.45 (C13)	4.82 (C1)
Min	0.30 (C5)	0.00 (C5, 20, 24)	0.67 (C5)	0.00 (C5)	1.21 (C5)	0.00 (C5)	1.71 (C5)	0.00 (C)

C = case study, <m> = measurement value for ventilation (m/s), <r> = rain penetration (mm/h), Max = maximum value of each column, Min = minimum value of each column.

Table S4. CFD (computational fluid dynamics) simulation and measurement values of the average wind speed on the leeward side of the model and their correlations for four different wind speeds (3, 5, 7, and 9 m/s).

Case Study	3 m/s <s>	3 m/s <m>	5 m/s <s>	5 m/s <m>	7 m/s <s>	7 m/s <m>	9 m/s <s>	9 m/s <m>
C1	0.55	0.67	1.12	1.32	1.89	1.96	2.81	3.20
C2	0.54	0.65	1.05	1.29	1.72	1.85	2.51	3.01
C3	0.57	0.60	1.13	1.23	1.83	1.81	2.63	2.82
C4	0.52	0.50	0.98	1.05	1.54	1.61	2.14	2.44
C5	0.44	0.41	0.77	0.75	1.14	1.21	1.49	1.71
C6	0.55	0.65	1.13	1.30	1.88	1.95	2.81	3.15
C7	0.56	0.67	1.14	1.21	1.89	1.94	2.85	2.98
C8	0.56	0.66	1.09	1.22	1.87	1.90	2.80	2.99
C9	0.56	0.64	1.14	1.19	1.86	1.92	2.83	2.91
C10	0.55	0.69	1.12	1.10	1.85	1.89	2.73	2.84
C11	0.55	0.63	1.11	1.00	1.82	1.69	2.69	2.76
C12	0.55	0.65	1.11	1.15	1.85	1.88	2.71	2.61
C13	0.58	0.72	1.17	1.37	1.96	2.03	2.89	3.45
C14	-	-	-	-	-	-	-	-
C15	-	-	-	-	-	-	-	-
C16	0.54	0.66	1.05	1.28	1.72	1.89	2.53	3.11
C17	0.38	0.39	0.72	0.80	1.25	1.34	2.09	2.30
C18	0.39	0.37	0.79	0.71	1.38	1.45	1.98	2.10
C19	0.52	0.55	1.01	0.99	1.63	1.78	2.39	2.40
C20	0.42	0.42	0.73	0.89	1.45	1.59	2.10	2.18
Correlation		0.94		0.87		0.96		0.91

<s> = simulation (m/s), <m> = measurement (m/s).

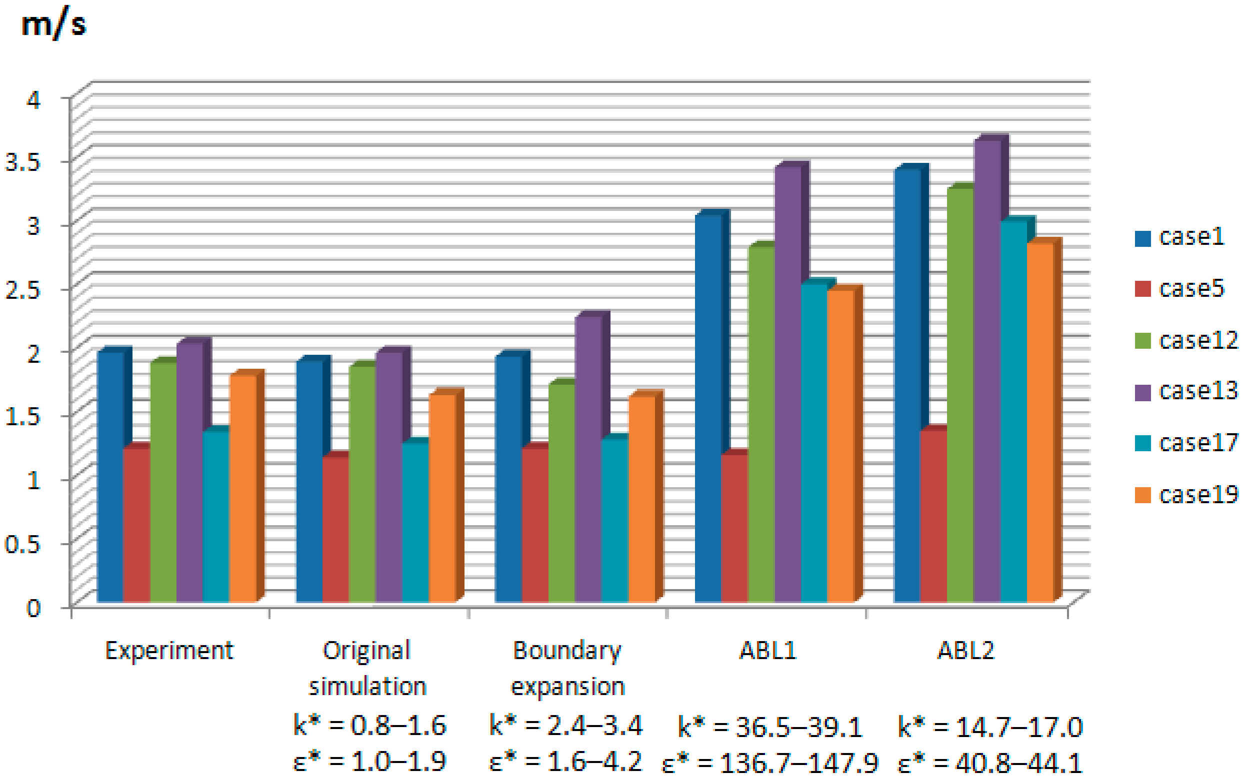

Figure S8. Sensitivity analysis for different wind profiles (for six representatives of designed windows—cases 1, 5, 12, 13, 17 and 19); Original simulation = uniform wind profile; ABL1 = ABL wind profile generated from urban, suburban, wooded areas; ABL2 = ABL wind profile generated from scattered obstacles on open terrain; k* = average turbulent kinetic energy at inlet boundary conditions (m^2/s^2); ε* = average rate of dissipation of the turbulent kinetic energy at inlet boundary conditions (m^2/s^3).