Study of influence of shading louvers on wind characteristics around buildings under different wind directions

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Abstract. In this paper, the wind characteristics on building with single-sided louvers under different wind directions were studied by using computational fluid dynamics (CFD) method. The RNG k-ε model was employed to establish the different outdoor airflow fields under different rotation angles θ of louvers. To investigate the wind pressure on facades, wind pressure coefficient Cp was introduced and average surface difference ΔCp was applied to evaluate wind-induced cross ventilation between the shaded and the opposite building surfaces. Results show that airflow pattern around the studied building is highly dependent on the building envelope under shading conditions due to obstruction and diversion of louvers. In general, the larger rotation angle of louvers contributed to more differences in average surface Cp under both normal and parallel wind directions. Shading louvers lead to an increase in ΔCp for parallel approach flow and a decrease in ΔCp for perpendicular approach flow. In simulations of this study, it could be seen that ΔCp decreases 0.01 (1.6%) for θ=0° and 0.15 (18.0%) for θ=60° under normal wind direction, while ΔCp increases 0.05 (436.1%) for θ=0° and 0.15 (1393.5%) for θ=60° under parallel wind direction. The results elucidates that a larger rotation angle can affect wind-induced cross ventilation more strongly. What’s more, the locations of minimum and maximum Cp on some facades moved obviously after shading and turning up rotation angle. This study indicates that the influence of complex building envelopes like shading louvers, should be considered in ventilation design.

Keyword: Computational Fluid Dynamics (CFD), Wind pressure coefficient, Single-sided louvers, Rotation angle, Natural ventilation.

1. Introduction

Natural ventilation is an essential factor of designing building structure and evaluating indoor environment. When airflow approaches a building, it changes the distributions of static pressure on building surfaces, which depends on incident angle, wind velocity, air density, surface orientation, and surrounding conditions [1]. In the case of building with complex components, accurate data of the wind-induced physical fields is significant to assess outdoor and indoor environment. Some structures of buildings like external shading devices and balconies have resistance and diversion effect of airflow, leading to fluctuations of wind characteristics around building facades, which can not be neglected [5]. Meanwhile, the distributions of wind pressure coefficient are sensitive to the building structure and envelopes.

In this paper, in order to investigate the wind-induced capacity of cross ventilation, wind pressure coefficient was introduced to represent the wind pressure distributions.
As a dimensionless parameter, wind pressure coefficient is almost unaffected by wind speed [6-7]. So it can be applied to evaluate the ability of wind-driven natural ventilation under various kinds of approaching airflow conditions and forecast the different wind-induced characteristics in the different wind environments.

2. Geometric model
The length, width and height of the studied building were 20m, 15m and 15m, respectively. The shading louvers were settled in front of one building facade as shown in Figure 1. Simulations were carried out for a building with and without louvers. The geometry model is showed in Figure 1. The length of louvers was the same as the building length, and \( l = 0.4 \text{m}, \ S = 0.27 \text{m}, \ d = 0.03 \text{m}. \) Simulation Cases with rotation angle \( \theta = 0^\circ \) and \( \theta = 60^\circ \) were discussed in Section 4.

![Figure 1. Geometric model (dimensions in meter). (a) Building model with louvers, and (b) details of two adjacent louvers.](image)

3. Methodology

3.1. Turbulence model in CFD
The CFD turbulence models have been widely used to perform the simulations of airflow fields around buildings. And the two-equation RANS models have a better balance between cost and a sufficient accuracy of result. The standard \( k-\epsilon \) model is one of the most popular turbulence models among CFD studies of urban microclimate [4], and some improved models, such as the RNG \( k-\epsilon \)
model and the realizable $k$-$\varepsilon$ model, can provide more realistic results because of the better simulation of turbulent swirling flows. In the present paper, the RNG $k$-$\varepsilon$ model was applied to simulate airflow fields around buildings with and without shading louvers.

3.2. Computational domain and grid resolution
The dimensions of the computational domain were chosen based on the two standards [3][8], and the size of the computational domain was $L \times W \times H = 345m \times 255m \times 135m$, resulting in a blockage ratio below 3%. The distances between the building and the boundary of the computational domain on the windward side, the leeward side, the left side are shown in Figure 1. The numbers of cells were at a range from 2,000,000 to 4,000,000 in all cases. The thicknesses of cells adjacent to the building surfaces, ground and louvers were 0.004$h_0$. After adaption of $y+$, the near-wall grids had $30 < y+ < 60$ for standard wall functions in most near-wall boundary layers. The computational domain and grid resolution are showed in Figure 2.

![Computational domain and grid resolution](image)

3.3. Boundary conditions
The inlet boundary condition was defined as velocity inlet, including wind velocity $U$, turbulent kinetic energy $k$ and turbulence dissipation rate $\varepsilon$. The vertical profile of wind velocity can be calculated by $U_h = U_0 (h/h_0)^{\alpha}$, where $U_h$ is the wind velocity at the height $h$ (m/s); $U_0$ is the wind velocity at the reference height $h_0$ (m/s), which is at the height of the studied building and $h_0 = 15m$; $\alpha$ is the
coefficient of surface roughness on the ground. In this study, the type of the ground surface was the suburban terrain as in the terrain category III [8], so the wind velocity profile exponent \( \alpha \) was 0.2.

The turbulent kinetic energy \( k(z) = 1.5[\text{U}(z)\text{g}(z)]^2 \) and the turbulent dissipation rate \( \varepsilon(z) = C_{p}^{0.75} [k(z)]^{3/2}/L, \) where \( I \) is the turbulent intensity that can be calculated by \( I = 0.1(z/z_0)^{-a_0.05} \) for \( z \leq z_0 \) and \( I = 0.1(z/z_0)^{-a_0.05} \) for \( z_0 \leq z \leq z_0. \) According to AJ, for the terrain category III, the gradient height \( z_0 \) is 450m, and \( z_0 \) is 10m. The turbulent length scale \( L = 0.07D \), where \( D \) is the characteristic length of the computational domain. The constant \( C_p \) is 0.09.

The outlet boundary condition was defined as outflow. The boundary conditions on the building surfaces, louver surfaces, and ground were defined as wall. And the standard wall functions were used in walls. Considering the terrain characteristics, the aerodynamic roughness length \( z_0 \) was 0.1m for the ground surface \((C_r=1.0)\), and for the other solid surfaces \( z_0 \) was 0m \((C_r=0.5)\) (Wieringa 1992, Blocken et al. 2007). The roughness heights of all solid surfaces \( k_s = 9.793z_0/C_r \). The boundary conditions at the top and lateral sides of the computational domain were defined as symmetry.

4. Results and discussion

In this section, the impact of shading louvers on \( C_P \) distribution was estimated. The cases with \( \theta = 0^\circ \) and \( \theta = 60^\circ \) louveres were compared to the cases without louvers under wind incident angle \( 0^\circ \) and \( 90^\circ \) approach flow. In each case, Surface-1 (S-1) was the shaded building surface; Surface-2 (S-2) was the lateral surface faced the positive direction of \( y \) axis, while Surface-3 (S-3) was the other lateral surface faced the negative direction of \( y \) axis; Surface-4 (S-4) was the roof of the building; Surface-5 (S-5) was the back surface of the building and was parallel to S-1.

The method to calculate wind pressure coefficient \( C_P \) was shown in equation (1),

\[
C_P = \frac{P - P_\infty}{\frac{1}{2} \rho U_\infty^2}
\]

where \( P \) is the local pressure on building surface, \( P_\infty \) is the static pressure at the reference height, and this height is defined as the height of the studied building. \( \rho \) represents the air density and the value is 1.225 kg/m\(^3\). \( U_\infty \) is the wind velocity at the reference height.

To evaluate the wind-induced capacity of cross ventilation, the difference \( \Delta C_P \) was introduced as equation (2),

\[
\Delta C_P = C_{P,1-mean} - C_{P,5-mean}
\]

where \( C_{P,1-mean} \) and \( C_{P,5-mean} \) represent the average surface value of \( C_P \) on S-1 and S-5, respectively.

4.1. Perpendicular approach flow

In this subsection, wind environment around the studied building with approaching flow perpendicular to the shaded surface was analyzed. The results of \( C_P \) are demonstrated in Figure 3 and Table 1, and several phenomena can be observed as follows:

Figure 3 compares distributions of \( C_P \) on S-1 and S-5 under different shading conditions. For both surfaces, the contours of \( C_P \) in three cases have similar shapes and locations. On S-1, when shading louvers are installed and the rotation angle changes from \( 0^\circ \) to \( 60^\circ \), the contours become sparser, but the locations of the maximum value are almost the same. On S-5, the location of contour center moves higher as the rotation angle turns up.

Table 1 shows average data on each building surface under different shading conditions. In addition, the degrees of increases and decreases compared to case without louvers are also shown in Table 1. It can be seen that for \( \theta = 0^\circ \), the impacts of shading louvers on average surface \( C_P \) of S-1 and S-5 are negligible. Other surfaces undergo an increase in average surface \( C_P \) for more than 20%. For \( \theta = 60^\circ \), only S-5 is basically undisturbed, while S-1 suffers from a 26.7% decrease. Meanwhile, the average surface \( C_P \) of other surfaces increases over 26%. It is also found that \( \Delta C_P \) decreases 1.6% for \( \theta = 0^\circ \) and 18.0% for \( \theta = 60^\circ \), indicated that a larger rotation angle can obstruct wind-induced cross ventilation more strongly.
Figure 3. $C_P$ distribution for perpendicular approach flow on (a) S-1 without louvers, (b) S-1 with louvers for $\theta=0^\circ$, (c) S-1 with louvers for $\theta=60^\circ$, (d) S-5 without louvers, (e) S-5 with louvers for $\theta=0^\circ$, and (f) S-5 with louvers for $\theta=60^\circ$.

Table 1. The average $C_P$ and relative difference of $C_P$ between cases with and without louvers under different shading conditions for perpendicular approach flow.

| Shaded condition | Data type       | S-1  | S-2  | S-3  | S-4  | S-5  | $\Delta C_P$ |
|------------------|-----------------|------|------|------|------|------|--------------|
| Without louvers  | Average         | 0.58 | -0.51| -0.51| -0.54| -0.26| 0.84         |
| $\theta = 0^\circ$ | Difference (value) | 0.00 | 0.12 | 0.11 | 0.14 | 0.01 | -0.01       |
|                  | Difference (percentage) | -0.6%| 23.9%| 21.2%| 26.7%| 3.8% | -1.6%       |
| $\theta = 60^\circ$ | Average        | 0.42 | -0.35| -0.37| -0.37| -0.27| 0.69         |
|                  | Difference (value) | -0.15| 0.15 | 0.13 | 0.17 | 0.00 | -0.15       |
|                  | Difference (percentage) | -26.7%| 30.2%| 26.1%| 31.0%| -1.0%| -18.0%      |

4.2. Parallel approach flow

Simulations are also performed for the approaching flow parallel to the shaded surface. The results are presented in Figure 4 and Table 2, and several phenomena can be observed as follows:

Figure 4 compares distribution of $C_P$ on S-1 and S-5 under different shading conditions. The parallel airflow patterns are much more complicated than perpendicular airflow patterns. On S-1, the $C_P$ contours become sparser when louvers are installed and $\theta=0^\circ$. For $\theta=60^\circ$, the contours dense dramatically. The diversion effect of louvers can change the location and value of minimum $C_P$ obviously. On S-5, the density of contours is lower after shading, but the impact of rotation angle is small.

Table 2 shows and compares average data and relative differences on each building surface under different shading conditions. Without louvers, wind pressure between S-1 and S-5 is negligible. After shading, for $\theta=60^\circ$, although the minimum $C_P$ on S-1 is much more than that on S-5 in absolute value, the mean $C_P$ is still larger on S-1. Meanwhile, the $\Delta C_P$ increases from 0.01 to 0.06 for $\theta=0^\circ$ and 0.16
for $\theta=60^\circ$. It can be seen that under both shading conditions, the direction of potential indoor cross ventilation is mainly from S-1 to S-5, if other surfaces have no openings.

![Figure 4. $C_p$ distribution for parallel approach flow on (a) S-1 without louvers, (b) S-1 with louvers for $\theta=0^\circ$, (c) S-1 with louvers for $\theta=60^\circ$, (d) S-5 without louvers, (e) S-5 with louvers for $\theta=0^\circ$, and (f) S-5 with louvers for $\theta=60^\circ$.](image)

### Table 2. The average $C_p$ and relative difference of $C_p$ between cases with and without louvers under different shading conditions for parallel approach flow.

| Shaded condition | Data type     | S-1 | S-2 | S-3 | S-4 | S-5 | $\Delta C_p$ |
|------------------|---------------|-----|-----|-----|-----|-----|--------------|
| Without louvers  | Surface average | -0.49 | 0.71 | -0.17 | -0.49 | -0.50 | 0.01 |
| $\theta = 0^\circ$ | Difference (value) | 0.15 | -0.12 | -0.01 | 0.11 | 0.10 | 0.05 |
|                  | Difference (percentage) | 30.2% | -17.1% | -8.1% | 22.4% | 20.2% | 436.1% |
| $\theta = 60^\circ$ | Surface average | -0.33 | 0.63 | -0.23 | -0.51 | -0.49 | 0.16 |
|                  | Difference (value) | 0.16 | -0.08 | -0.06 | -0.02 | 0.01 | 0.15 |
|                  | Difference (percentage) | 32.9% | -11.7% | -35.4% | -3.2% | 2.2% | 1393.5% |

### 5. Conclusion

In this paper, the wind characteristics on building with single-sided louvers under different wind directions were studied by using computational fluid dynamics (CFD) method. The RNG $k$-$\varepsilon$ model was employed to establish the different outdoor airflow fields with different rotation angles $\theta$ of louvers. To investigate the wind pressure on facades, wind pressure coefficient $C_p$ was introduced and average surface difference $\Delta C_p$ was applied to evaluate wind-induced cross ventilation between the shaded and the opposite building surfaces.

It is obvious that airflow pattern around the studied building is highly dependent on the building envelope under shading conditions due to obstruction and diversion of louvers. The larger rotation angle of louvers causes more differences in average surface $C_p$ under both wind directions. In general, shading louvers leads to an increase in $\Delta C_p$ for parallel approach flow and a decrease in $\Delta C_p$ for perpendicular approach flow. In simulations of this study, it could be seen that $\Delta C_p$ decreases 0.01 (1.6%) for $\theta=0^\circ$ and 0.15 (18.0%) for $\theta=60^\circ$ under normal wind direction, while $\Delta C_p$ increases 0.05 (436.1%) for $\theta=0^\circ$ and 0.15 (1393.5%) for $\theta=60^\circ$ under parallel wind direction. What’s more, the
locations of minimum and maximum $C_P$ on some facades move obviously after shading and turning up rotation angle. The results elucidates that a larger rotation angle can affect wind-induced cross ventilation more strongly. The application of $C_P$ thus can be helpful to evaluate the ability of wind-driven natural ventilation under more kinds of approaching airflow conditions and forecast the different wind-induced distributions of wind characteristics with complex building envelopes.

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