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# Experimental study for wind pressure loss rate through exterior venetian blind in cross ventilation

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ABSTRACT

Exterior venetian blinds (EVBs) are widely used in commercial and residential buildings, and show a high performance level for both shading and lighting purposes. However, an EVB installed over an open window also influences natural ventilation rates. In this study, applying the pressure loss rate of an EVB to wind-driven natural ventilation rates was proposed. A mock-up building was set that the EVB was installed on the front opening. Wind generator was installed toward the front opening in order to describe wind-driven cross ventilation in a single zone. To investigate wind pressure changes through the EVB plane, 16 pressure measuring taps were installed on each of the front and back side of the EVB plane. Various wind speeds were induced toward the front opening so as to derive the pressure loss rate for the four EVB slat angle cases (0°, 45°, 90°, and no shading). The pressure loss rates for each case were derived from the field measurements. The results show that the pressure loss rates have a range of 0.22 to 0.90. In addition, the measurement results indicated that an EVB can change the air velocity by about 50% based on the slat angle. Therefore, when an EVB is installed on a window opening, the effect of the EVB on wind-driven cross ventilation rate should be taken into account.

## 1. Introduction

Natural ventilation in buildings has been discussed as an important issue for improving indoor air quality and providing comfortable air temperatures. A low ventilation rate in a building can cause irritation, discomfort, or even the onset of disease in the occupants, and the choice of a ventilation strategy can significantly affect the building's energy consumption. It has been determined that natural ventilation can save about 40% in energy costs compared to air-conditioned buildings [1–4]. An orifice used for natural ventilation is glazed and is the weakest area in terms of protecting the indoor space from solar radiation. Therefore, shading devices are usually installed in hot regions to improve the level of shading. A shading device installed over an outer window has the best performance in protecting the indoor area from solar heat gain [5], and a movable shading device can efficiently control the solar heat gain based on occupant need [6]. Therefore, exterior venetian blinds (EVBs) are widely used in residential and office buildings. EVBs have the greatest performance in terms of thermal and lighting conditions by allowing the slat angle to be controlled, thereby allowing outside daylight to enter an indoor area while shading the building from solar radiation.

Existing studies have indicated that adjacent obstacles and buildings have a shelter effect on outdoor air flow, and significantly affect the cross ventilation in naturally ventilated buildings [7,8]. Exterior shading devices can be left close while still allowing the building to be naturally ventilated whereas interior shading devices should be opened when the window is opened. Thus, exterior shading devices can also influence the natural ventilation by reducing wind pressure entering the opening on the facade. Existing studies on cross-ventilation have mainly used computational fluid dynamics (CFD) and wind tunnel tests. Focusing on pressure loss coefficient, Karava et al. [9] reviewed these studies and discussed about the parameters affecting the pressure loss coefficient, called 'discharge coefficient', for wind-driven cross ventilation such as opening area, wind speed, wind direction, location of the opening on the façade, and internal partitions. By comparing various studies, Karava et al. mentioned that the constant values should be used within the limits of their applicability. Studies dealing with the orifice size and building form have mainly discussed the changes in pressure coefficient ($C_p$) in naturally ventilated

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buildings according to the size and/or location of the windward/leeward openings and the length and height of the building form [10–23]. The changes of natural ventilation rate when partitions or obstacles are placed in a single zone [24–29] and estimations of the natural ventilation rate in multiple zones have been discussed [30,31]. These studies have mainly dealt with the effects of orifice size, building form, and multiple zones on the pressure coefficient, discharge coefficient and the natural ventilation rate in various buildings.

Dynamic changes in the shape of an exterior movable shading device can significantly influence the wind pressure toward the windward opening of a building. Gandhi et al. [32] used CFD and derived the drag coefficient and pressure loss coefficient values for 12 different body shapes, including rectangular, square, and circular shapes, and it was revealed that the wind pressure coefficient can be reduced to around 40% according to the changes in body shape. Zuo et al. [33] and Hajj et al. [34] used wind tunnel tests and derived drag coefficient values for a tilted louver, and it was found that a louver has about a 40% lower drag coefficient than a solid panel. Mara et al. [35] conducted wind tunnel tests and derived drag coefficient values for generic lattice frame geometries based on 37 different solidity ratios. Sharifian et al. [36] conducted wind tunnel tests for three plain-square type woven metal screens with different porosities to derive their drag coefficient. The studies in both [35,36] indicate that the types of panel, lattice, or square metal have a significant influence on the pressure change throughout the layer.

There are several case studies applying various shading devices to the naturally ventilated buildings [37–40]. Hien et al. [37] conducted CFD for a building with three types of horizontal shading devices installed, and it was found that the shading devices can have an effect on reducing both the inlet and outlet air flow. Zeng et al. [38] and Xu et al. [39] conducted a mock-up test and CFD for a naturally ventilated double-skin façade with a venetian blind. The studies showed that a venetian blind has an influence on the air speed within a cavity space. In order to calculate the ventilation rates in the exterior shading device installed buildings, it is necessary to find the pressure loss rates according to the applications of various exterior shading devices to the window openings. Argiriou et al. [40] conducted an experimental study for exterior shading devices. In this study, the impact of exterior shading devices (awning, horizontal louvers, vertical fins, and roll blind) on the airflow across large openings during single-sided natural ventilation was investigated through an experimental study. Argiriou et al. found loss factors of shading devices that can be applied on airflow calculations. Regarding the limitations of the applicability in the constant values such as pressure coefficient and discharge coefficient [9], the impact of exterior shading devices on the pressure loss have rarely been discussed in natural ventilation of the buildings. Therefore, it is needed to investigate the pressure loss rate of wind-driven cross ventilation in a building with exterior shading devices.

This paper focused on pressure loss rates in a building with wind-driven cross ventilation caused by two window openings where an exterior venetian blind is installed on the front opening. The changes in slat angle of the EVB can provide resistance to the wind pressure or speed toward the opening of a naturally ventilated building. Therefore, the amount of air flow through an EVB-installed building can be affected by the EVB movement. In this study, an EVB-installed mock-up building was set up and wind generator was installed in order to describe wind-driven cross ventilation in a single zone. An experimental study was conducted to derive the pressure loss rate according to the EVB movement. Pressure loss rates for the four EVB slat angle cases (0°, 45°, 90°, and no shading) were presented in this paper, and the limitations of the applicability were discussed.

## 2. Effect of exterior venetian blinds on cross ventilation

The natural ventilation in buildings consists mainly of single-side ventilation, in which air moves through a single opening, and cross ventilation, in which air moves through multiple openings located on different sides of a building. From the efficiency aspect of natural ventilation, cross ventilation is a more effective natural ventilation method than single-sided ventilation [41]. This study was conducted to examine ventilation rate changes in the case of venetian blinds installed on the exterior of an opened window, with respect to cross ventilation. As shown in Fig. 1(A), when wind blows on one side of a building that has openings on both sides, the cross ventilation varies depending on the inlet and outlet sizes of the openings on both sides and the pressure coefficient of the envelope. According to the formula proposed by the British Standards method (BS 5925) [42] for cross ventilation, shown in Eq. (1), the air flow for cross ventilation in a single space where there is no indoor partition is a function of the discharge coefficient $C_d$, the area of the opening $A_w$, the reference wind speed $V$, and the pressure coefficient $\Delta C_p$. The area of the opening and the pressure coefficient are obtained from Eqs. (2) and (3), respectively.

$$Q_w = C_d A_w V \Delta C_p^{1/2} \tag{1}$$

$$\frac{1}{A_w^2} = \frac{1}{A_1^2} + \frac{1}{A_2^2} \tag{2}$$

$$\Delta C_p = \left| C_{p1} - C_{p2} \right| \tag{3}$$

In Eq. (2), $A_1$ is the area of the front opening and $A_2$ is the area of the rear opening. $C_d$ varies depending on the Reynolds number, and in general, has a value of 0.60–0.65 at sharp-edged openings [43–45]. $\Delta C_p$ is calculated from the difference between the pressure coefficients of the front and rear openings, $C_{p1}$ and $C_{p2}$. $C_{p1}$ and $C_{p2}$ vary mainly according to the shape of the building, the elevation, the wind speed, and the wind direction, among other factors [9].

When an exterior venetian blind (EVB) is installed on the exterior of building, the cross ventilation of the building can vary depending on the cross-sectional shape of the EVB slats (see Fig. 1(B)). The pressure at the front opening, where wind blows in, is different on the front side and the back side of the EVB plane, depending on the tilt angle of the EVB. In calculating the air flow of the cross ventilation in a single space of a building with an EVB installed, the pressure change used should reflect the tilt angle of the slats. Fig. 1(B) illustrates how the wind pressure on both sides of the EVB is determined by dividing the wind pressure into $P_{w1}$ and $P_{w2}$ depending on the pressure loss of the wind passing through the EVB.

The value of $P_{w1}$ on the front side of the EVB is not affected by the tilt angle of the slats, but the value of $P_{w2}$ on the back side of the EVB is affected by the tilt angle of the slats. Therefore, when the pressure on the front side of the EVB is $P_1$, the pressure on the back side is $P_2$, and the wind pressure at a place where there is no effect of external wind is $P_0$, the pressure loss rate $F_{\mathrm{evb}(\theta)}$, which changes depending on the slat tilt angle $\theta$, can be expressed as shown in the following equation:

$$F_{\mathrm{evb}}\left(\theta\right) = \frac{P_2 - P_0}{P_1 - P_0} = \frac{P_{w2}}{P_{w1}} \tag{4}$$

Under natural ventilation conditions, if there is no air density difference between the front and back sides of a blind plane, the velocity ($V$) of the wind entering an opening by passing through a venetian blind installed outside a building is affected by the pressure loss rate of the EVB. Therefore, when the wind velocity loss rate ${F_{\mathrm{evb}(\theta)}}^{1/2}$ for the EVB is applied to the calculation of the cross ventilation air flow. According to the British Standards method (See