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The Effect of Wind Incidence Angle on Wind-Driven Natural Ventilation of Airport Terminals

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SUMMARY
The wind-driven natural ventilation of airport terminals is a promising solution for reducing energy demand and improving indoor air quality. This study focuses on the effects of wind incidence angles on the wind-driven natural ventilation of a generic airport terminal building equipped with four roof-mounted windows. Small-scale model experiments were performed in a boundary layer wind tunnel. Ventilation performance was quantified using the tracer gas method to determine the air change rate ACH. Vertical flow velocity component near the roof openings was measured using hot-wire sensors. Measurements were performed at the mean freestream flow velocity u = 7 m/s for the flow incidence angles in the 0° < β < 360° range. The results show that the optimal ventilation occurs at β = 180° and 330°, while the minimum ventilation performance is achieved at β = 90°.

Keywords: Wind-driven natural ventilation, Airport terminal buildings, Air change rate, Wind-tunnel experiments

1. INTRODUCTION

Wind-driven ventilation is a passive ventilation approach that does not rely on mechanical devices, making it energy efficient and capable of reducing operational costs in buildings. In large occupant-dense spaces such as airport terminals, maintaining adequate indoor air quality is particularly important for human health. Natural ventilation can contribute to reducing the risk of airborne virus transmission and respiratory issues (Chua et al., 2013).

Wind-driven natural ventilation has been extensively studied, predominantly in simplified configurations such as single-sided ventilation (involving a single opening) and cross-ventilation (with several openings on opposing walls). In contrast, the present study investigates a more complex ventilation approach featuring roof-mounted windows. In this study, the effect of wind incidence angle on natural ventilation performance is studied to improve the understanding of airflow characteristics and support engineering applications. Experiments were performed on a generic airport terminal model in a boundary layer wind tunnel (BLWT).

2. EXPERIMENTS

Measurements were performed in a BLWT at the Institute of Fluid Mechanics and Heat Transfer, Graz University of Technology, Austria. The test section is 8 m long, with a rectangular 2 m wide and 1 m high cross-section. A turntable is placed at the end of the test section, allowing for the rotation of structural models to investigate the effects of the flow incidence angle. The maximum flow velocity in the wind tunnel is 31 m/s. The atmospheric boundary layer (ABL) flow was simulated using horizontal rods and a serrated wall barrier downstream of the nozzle.

The flow characteristics of the modelled ABL-type flow were measured using a constant temperature hot-wire anemometry (CTA) system in combination with a traverse system. Measurements were performed in 47 points at the middle plane of the wind-tunnel test section. In each point, the data was recorded for 120 s at the sampling rate of 10 kHz.

The air change rate (ACH) was determined using the tracer gas decay method. The internal volume of the airport terminal model was initially filled with carbon dioxide (CO_2) to achieve a uniform concentration. Once a homogeneous mixture was established, the openings were exposed to the external flow for $\Delta t = 3$ s to allow ventilation. By measuring the CO_2 concentration before and after the ventilation period, the air exchange rate is quantified and subsequently presented as the ACH. The calculation procedure is based on Eq. (1):

$$ACH = \frac{\dot{V}}{V} = \frac{1}{\Delta t} \ln \frac{\Delta C\ (t)}{\Delta C\ (t+\Delta t)}. \tag{1}$$

In Eq. (1), $\dot{V}$ represents the volumetric air flow rate and V is the internal building volume. Δc is the carbon dioxide (CO_2) concentration excess.

To provide insight into the airflow characteristics in the airport terminal model, hot-wire anemometers were employed. Four sensors were positioned centrally below each window opening to measure the vertical velocity component, i.e., the velocity perpendicular to the window opening surface. The data was recorded for 60 s at the sampling rate of 20 Hz.

Measurements of the ACH and vertical air velocity component were conducted on a simplified airport terminal model, Figure 1. The model is $H = 150$ mm high, $W = 250$ mm wide, and $L = 300$ mm long. Four skylight openings are symmetrically positioned on the roof, each with a lateral opening mechanism (w_1, w_2, w_3 and w_4). The dimensions of each opening are 60 mm × 40 mm.

The airport terminal building model has six simplified passenger tunnels with a rectangular cross-section. They are located on three terminal façades. These internal volumes of passenger tunnels are sealed, i.e., they are not ventilated, but still included to offer a realistic aerodynamics of the airport terminal model.

3. RESULTS

The flow characteristics of the modelled ABL-type flow exhibit good agreement with the rural-type ABL flow (e.g., Miše et al., 2024; Jelašić et al., 2026). The results indicate a pronounced effect of the flow incidence angle on the ACH, Figure 2. The maximum ACH is at $\beta = 180°$ and $\beta = 330°$, while the minimum ACH is at $\beta = 90°$. In general, the ventilation performance is enhanced when the openings are aligned, or nearly aligned, with the incoming flow, allowing more efficient air exchange through the building model. In contrast, at $\beta = 90°$, the openings are unfavorably oriented relative to the wind direction, yielding lower ventilation efficiency.

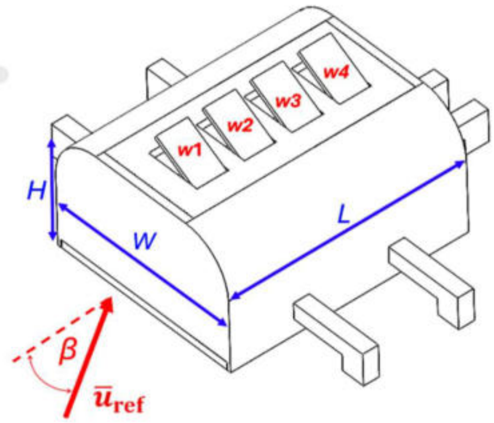

Figure 1. Airport terminal building model.

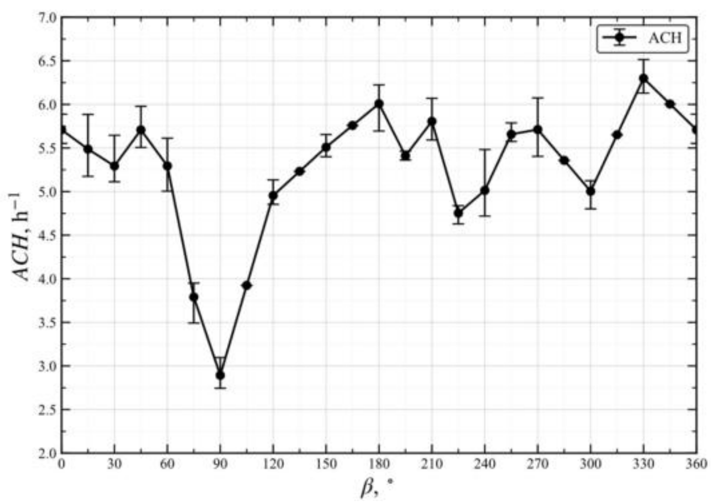

Figure 2. ACH of the airport terminal building model with measurement uncertainty

Velocity measurements provide insight into the airflow characteristics at each window. Figure 3b presents the temporal variation of the vertical velocity component at β = 180° over 60 s, where the strong fluctuations of the turbulent flow are observed. The results indicate that the velocity amplitudes vary with changes in the flow incidence angle. For β = 180°, the maximum mean vertical velocity is at the first window w_1, followed by the second window w_2.

In contrast, at β = 90°, all windows exhibit nearly the same mean vertical velocity, Figure 3a. This is expected, as the openings are at similar relative distances with respect to the incoming flow, resulting in a more uniform velocity distribution. The mean flow velocity is larger for β = 180° than for β = 90°.

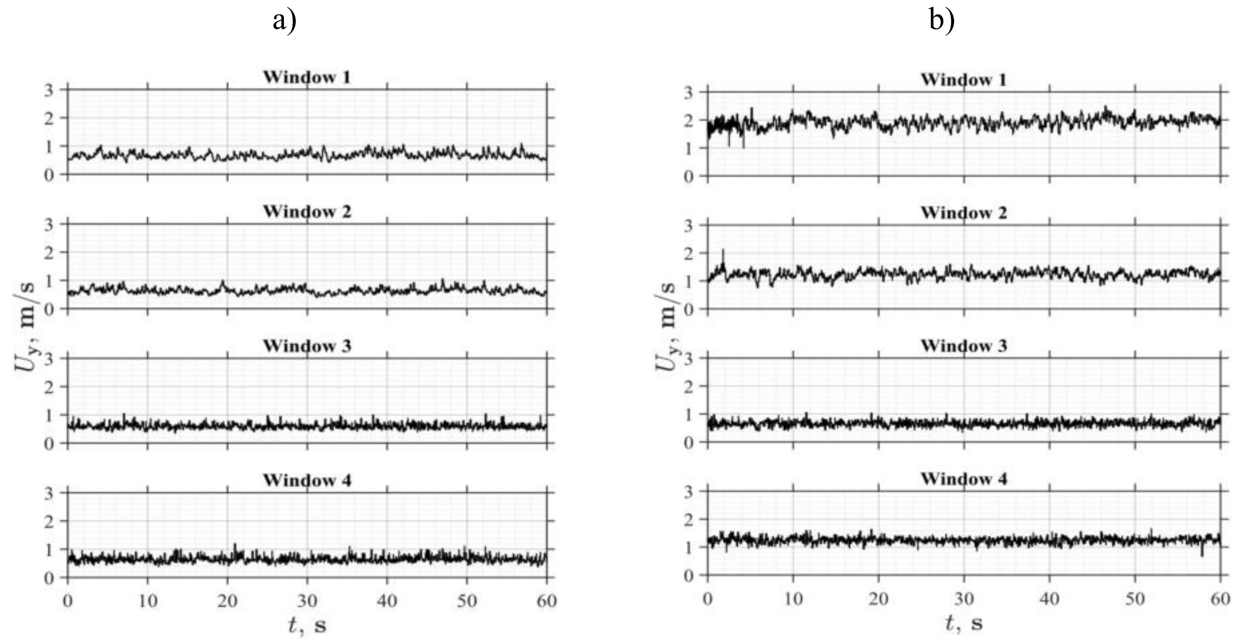

Figure 3. Vertical flow velocity at the windows of the airport terminal building model: a) β = 90°, b) β = 180°.

4. CONCLUDING REMARKS

Wind-driven natural ventilation was experimentally studied on a small-scale airport terminal building model. The experiments were performed in a boundary layer wind tunnel. Ventilation was quantified using the tracer gas method, whereas airflow characteristics were further examined based on velocity measurements obtained using air velocity transducers, providing insight into the internal flow characteristics. The results show that the maximum ACH is at β = 330° and 180°, while the minimum is at β = 90°. These findings exhibit the substantial effects of the wind incidence angle on the wind-driven natural ventilation of airport terminal buildings. Further flow velocity measurements are required to achieve a more comprehensive understanding of the airflows in the airport terminals.

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