Article information

Article title
Indoor flow datasets of two-layered cross-ventilation models by particle image velocimetry and hot wire anemometry

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Keywords
Two velocity components, Approaching flow, Incidental flow, PIV, HWA, Wind-tunnel experiment, CFD validation

Abstract
This data article provides temporally and spatially high-resolution datasets of the indoor velocity fields for cross-ventilation models of two-layered simplified buildings separated by a second floor at the middle height with an opening using wind-tunnel experiments. The datasets are based on the research article entitled “Quantifying natural cross-ventilation flow of a two-layered model used for terraced houses in tropical zones by particle image velocimetry” by Ali et al. [1]. Two cases are considered based on the positions of the inlet and outlet openings on each floor. The measurements were conducted using hot-wire anemometry (HWA) with 10,000Hz and particle image velocimetry (PIV) with 1000Hz for a sufficiently long period to determine reliable statistics of the mean, variances, and covariances. In addition, the article provides the instantaneous datasets of two velocity components determined by PIV for the cross-ventilation models. The datasets can be used for both computational fluid dynamics (CFD) validation and further investigation of turbulent flow nature of the multi-layer cross ventilation flow.

Specifications table

<table>
<thead>
<tr>
<th>Subject</th>
<th>Engineering, Environmental Engineering</th>
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<tbody>
<tr>
<td>Specific subject area</td>
<td>Cross Ventilation, Wind Induced Ventilation, Indoor Air Quality</td>
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</table>
| Type of data | Table  
|             | Graph  
|             | Binary |
|-------------|--------

| How the data were acquired | For hot-wire anemometry (HWA), an x-type hot-wire probe (0249R-T5, KANOMAX JAPAN, INC.), constant temperature amplifier unit (MODEL 1011, KANOMAX JAPAN, INC) were employed.  
For particle image velocimetry (PIV), a high-speed camera (Phantom T1340, Nobby Tech. Ltd.), double-pulse laser device (Tolar-527-20, Beamtech Optronics Co, Ltd.), seeding device (CTS-1000, SEIKA Digital Image Corporation) were employed. The particle images were analyzed by a PIV postprocessing software, Koncerto-II (SEIKA Digital Image Corporation). |
| Data format | Raw  
|             | Analyzed |

| Description of data collection | For HWA, the sampling period and frequency are 180s and 10,000Hz, respectively.  
For PIV, the sampling period and frame rates are 11s and 2,000fps using a double pulse layer. The sampling frequency of the analyzed velocity data is 1000Hz. The measurements were repeated three times for each condition. |
Data source location
Institution: Tokyo Polytechnic University
City/Town/Region: Atsugi, Kanagawa
Country: Japan

Data accessibility
With the article
Repository name: Mendeley Data
Data identification number:
Direct URL to data:
https://data.mendeley.com/datasets/bmf5kf273b/1

Related research article
Quantifying natural cross-ventilation flow of a two-layered terraced house used for terraced houses in in tropical zones by particle image velocimetry, Building and Environment 244, 110829,
https://doi.org/10.1016/j.buildenv.2023.110829

Value of the data
- The temporally and spatially high-resolution datasets enable to develop evaluation procedures of indoor air quality and effective ventilation for cross-ventilation flow of a multi-layered simplified building [1].
- The statistical velocity datasets can be used by researchers and engineers to validate CFD simulations for a simplified multi-layer indoor ventilation flow [2].
The datasets can be used as a benchmark case for cross-ventilation flow of a multi-layer simplified building to develop CFD techniques such as numerical settings and turbulence models [2,3].

The instantaneous velocity datasets can be utilized for developing a new validation process of unsteady CFDs by determining probability density, power spectrum, and low-occurrence velocity events [4-8].

The statistical and instantaneous velocity datasets can be employed as an input and output data of inductive approaches such as regression analysis and machine learning method to predict indoor velocity distributions.

Objective
The high-resolution velocity datasets of indoor cross-ventilation flow are required for both CFD validations and further evaluation of indoor air quality. Due to the complex flow distributions within a cross-ventilation model, the datasets need to be statistically reliable and spatially well-resolved. This data article can provide both statistical datasets and highly resolved instantaneous velocity datasets for simplified multi-layered buildings obtained by both PIV and HWA. The statistical data can be used as a benchmark case to conduct sensitivity studies of CFD simulations for the simplified multi-layered building for both steady-state and unsteady simulations. In addition, the instantaneous datasets enable further investigations on the evaluation method of indoor ventilation performance and the turbulent nature of the cross-ventilation flow. The data article facilitates using these datasets for understanding the characteristics of the cross-ventilation flow and quantifying the ventilation performance of multi-layer buildings.

1. Data description
There are three Excel files and eight binary files following netCDF format. For the definition of the variable and coordinate system, please refer to Section 2. The model case names, U2D1 and U1D2 are explained in Section 2.2.

1) Approaching and incidental wind profiles (prof01-inflow.xlsx)
The Excel file is the list of the temporally averaged streamwise velocity component, variances and covariance of the streamwise and vertical velocity component. The Excel file has two sheets for the data at the approaching flow position (“ApproachingFlow”) and incidental flow position (“IncidentalFlow”). See Fig. 3 for the definition of the positions. The graphs of the data are also included in each sheet. The coordinates and velocity are normalized by $H$ and $u_H$, respectively, where $H = 200mm$ is the model height and $u_H$ is the mean streamwise velocity component at the building height of the incidental flow.

2) Velocity component profiles for the model U2D1 (prof02-U2D1.xlsx)
The Excel file is the list of the temporally averaged streamwise velocity component, variances of the streamwise and vertical velocity components at several measurement locations. The definition of the measurement locations is explained in Fig. 3. The file has two sheets for the HWA (“HWA”) and PIV (“PIV”). The graphs of the data are also included in each sheet.

3) Velocity component profiles for the model U1D2 (prof03-U1D2.xlsx)
The same format data as prof02-U2D1.xlsx but for the model U1D2.
4) Two-dimensional datasets of the velocity component statistics by PIV (U2D1.stat.nc)
   The binary file follows the netCDF format. It includes the temporally averaged streamwise velocity component, wind speed in a vertical plan, variances and covariance of the streamwise and spanwise velocity components for the model U2D1 obtained by PIV.

5) Two-dimensional datasets of the velocity component statistics by PIV (U1D2.stat.nc)
   The same format data as U2D1.stat.nc but for the model U2D1.

6) Two-dimensional instantaneous datasets of the two velocity components (U1D2-T1.nc, U1D2-T2.nc, U1D2-T3.nc)
   The binary file follows the netCDF format. It includes the instantaneous streamwise and vertical velocity components for the model U1D2 by PIV. The three files with T1, T2 and T3 indicate three different trials. The time in the datasets is normalized by $H/u_H$.

7) Two dimensional instantaneous datasets of the two velocity components (U2D1-T1.nc, U2D1-T2.nc, U2D1-T3.nc)
   The same format data as U1D2-T1.nc, U1D2-T2.nc, U1D2-T3.nc but for the model U2D1.

2. Experimental design, materials and methods

2.1 Experimental setups

   The experiments were performed using a wind tunnel at Tokyo Polytechnic University (TPU), Japan. The streamwise length of the test section is 19 m and the cross-section is 2.2 m spanwise and 1.8 m in the vertical direction. The definition of the coordinates and velocity components are shown in Fig. 1 (a). The origin of the coordinate system is defined as 5$H$ downstream from the approaching flow position and at the spanwise center. The reference wind speed is measured using a Pitot static tube as shown in Fig. 1 (a) at $z/H = 6$. The reference wind speed was used to derive the streamwise velocity component at the block height, $u_H$, based on the vertical profile of the incidental flow. Throughout the datasets, $u_H$ is used as a scaling velocity. The variation of $u_H$ among experiments are less than 0.4%. The Reynolds number defined by $H$ and $u_H$ is approximately $8.6 \times 10^4$. The approaching flow was generated to follow the power law for the streamwise velocity component with the power index of 0.25 and the exponential equations for the turbulent kinetic energy (Tominaga and Blocken (2015)) using roughness, spires, and a barrier in the upstream region of the test section (Fig. 1 (a)).

2.2 Ventilation model design

   Fig. 1 (b) shows the isometric view of the ventilation model. The detailed dimensions of each face are illustrated in Fig. 2. The external dimensions of the model height, length, and width are 200 mm, 320 mm, and 150 mm. The wall thickness is 2mm. There is a divider with an opening of 70 mm × 70 mm at the streamwise and spanwise centers at the middle height of the model. The inlet and outlet openings are the dimensions of 75 mm × 40 mm. Using the same ventilation models, the datasets provide two conditions: the inlet and outlet openings were positioned at the second and first layers, and vice versa (U2D1 and U1D2, respectively).
2.3 Data acquisition

The vertical profiles of the approaching flow (at $x/H = -5$ and $y/H = 0$), incidental flow (at $x/H = 0$ and $y/H = 0$ without the model), and five locations near the model were obtained using an x-type HWA. A probe calibrator (MODEL 1065, KANOMAX) was used to determine the wire angle in advance for each probe. The fixed wire angles were used for each probe, while the calibration coefficients of the HWA probe were determined each day of the experiments. Fig. 3 shows the measurement positions of the approaching flow, incidental flow, and vertical profiles near the model. The filled circles in Fig. 3 represents the measurement locations. The approaching and incidental profiles were measured at 21 vertical points between $z/H = 0.1$ and 6.0. The velocity profiles around the model were determined at five streamwise positions between $z/H = 0.1$ and 2.0. The measurement period and sampling frequency are 180 s and 10,000Hz, respectively.

The shaded areas in Fig. 3 shows the region captured by PIV (1.4H in streamwise, and 1.45H vertically). The two velocity components in the xz-plane (namely, $u$ and $w$) were determined at the spanwise center, $y/H = 0$. A double pulse laser device (Tolar-527-20, Beamtech Optronics Co, Ltd.) was installed at $x/H = 3.5$ (approximately, 3.2 m downstream from the downmost face of the model). The interval of double-pulse laser was 200 $\mu$s, and the frame rate was set as 2000 fps. A high-speed camera (Phantom T1340, Nobby Tech. Ltd.) was installed at approximately 1 m from the model on the side. The measurement area in a xz plane was captured with a resolution of 1024 $\times$ 1024 pixel. The measurement period of each trial is 11s and was repeated three times. Therefore, the total sampling duration is 33 s. The expected variations in the mean and standard deviation over 30 s were 1% and 2%, respectively (Ikegaya et al. [9])

After obtaining raw images, the velocity components in a xz plane were determined by image preprocessing using a PIV software, Koncerto-II (Seika Digital Image Corporation). After subtracting the minimum brightness distributions from the original images, a three-time multi-pass correlation method with a least-squares Gauss-fit sub-pixel analysis was employed to determine the velocity distribution. The output grid resolution was 16 pixels corresponding to a resolution of approximately 6 mm (The interrogation window size was 32 $\times$ 32 pixel with a 50% overlap.).

2.4 Data calculation

The time series data with the sampling period $T$ were used to calculate the mean, variances, and covariance.

$$\bar{u} = \frac{1}{T} \int_{T} u(t) dt$$

(1)

$$\sigma_u^2 = \frac{1}{T} \int_{T} (u(t) - \bar{u})^2 dt$$

(2)

$$\sigma_w^2 = \frac{1}{T} \int_{T} (w(t) - \bar{w})^2 dt$$

(3)

$$\bar{uw} = \frac{1}{T} \int_{T} (u(t) - \bar{u})(w(t) - \bar{w}) dt$$

(4)

When measurements were repeated $N$ times, the ensemble average of each statistics $\phi_i$ was calculated as follows.

$$\langle \phi \rangle = \frac{1}{N} \sum_{i=1}^{N} \phi_i$$

(5)

Therefore, the statistical datasets provided by HWA is $\bar{u}$, $\sigma_u^2$, $\sigma_w^2$, $\bar{uw}$, and those by PIV are $\langle \bar{u} \rangle$, $\langle \sigma_u^2 \rangle$, $\langle \sigma_w^2 \rangle$, $\langle \bar{uw} \rangle$, respectively. All the velocity data, coordinates, and time in the datasets are normalized using $H$ and $U_H$. 

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Fig. 1 (a) Experimental settings of the turbulence generators (spires, barrier and roughness) and ventilation model and (b) ventilation model (modified from Ali et al. [1])

Fig. 2 Detailed dimensions of the ventilation model (unit in mm). The front and back views indicate the windward and leeward faces of U2D1, and vice versa for U1D2.
Fig. 3 Measurement locations. The filled circles indicate the measurement locations of HWA. The blue shaded area indicates the regions measured by PIV. The model U2D1 is shown in the schematics, but the measurement positions are identical for U1D2. The horizontal and vertical axes were normalized by $H$.

**Ethics statements**
There is no ethical issue in this paper.

**CRediT author statement**
C. Hirose: Conceptualization, Investigation, Funding acquisition
W. Wang: Software, Investigation, Formal analysis
M.F. Mohamad: Conceptualization, Funding acquisition, Supervision
N. Ikegaya: Conceptualization, Writing – Original draft, Writing – Reviewing, Funding acquisition, Supervision

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Declaration of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References