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Wind Velocity Reduction with Igune as Traditional Homestead Trees in Osaki Koudo, Japan

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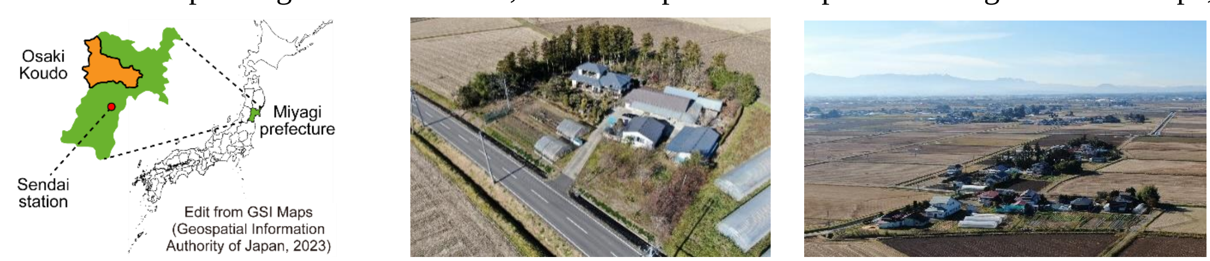
SUMMARY:
Traditional homestead trees are groups of trees surrounding houses that are maintained for various housing and human life functions in Japan. Windbreaks are essential for controlling the outdoor environment. In this study, large-eddy simulations (LESs) were conducted to investigate the wind velocity reduction effects of Igune as traditional homestead trees; the study focused on a rural dwelling in Osaki Koudo, Japan. Igune consist of shrubs and trees. The trees are approximately 16 meter tall and planted orthogonal to the prevailing wind direction in winter, while shrubs are planted under the crowns of the trees. The aerodynamic effects of Igune were reproduced using a vegetation canopy model. The calculation was conducted for a case reproducing the current situation with shrubs and tall trees, cases only with shrubs, and only tall trees as comparison cases. The mean wind velocity around the dwelling surrounded by an Igune was 1/3 smaller than that outside the site. The streamwise component of instantaneous wind velocity at twice the height of the leeward side of the Igune quantitatively corresponded with the previous field observation, as the tall trees prevented reverse flow.

Keywords: Large-eddy simulation, Homestead trees, Windbreak effects

1. INTRODUCTION

Traditional homestead trees are groups of trees surrounding houses that have been maintained for various housing and human life functions in Japan. For example, homestead trees control outdoor environments by providing windbreaks and solar radiation shielding. In addition, wood from the trees is used as a building material and their fallen leaves are used as fuel. Homestead trees have been widely used alongside houses in the past. For this reason, homestead trees, referred to by various names depending on their location, have been present in Japan for a long time. In Europe,



(1) Location of Osaki Koudo. (2) Homestead trees called Igune. (3) Rural landscape.

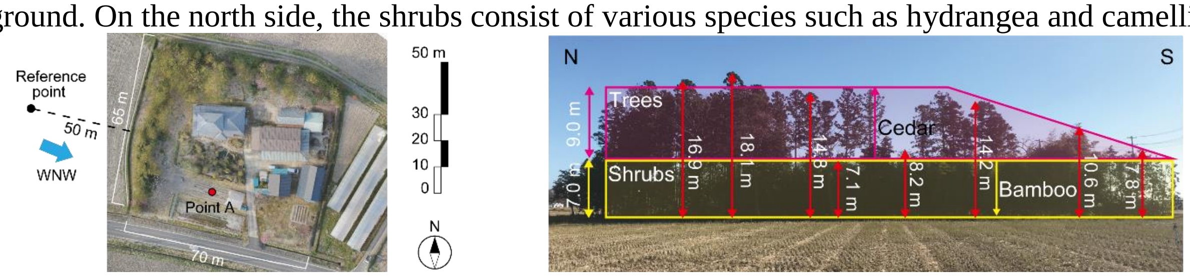
Figure 1. Outline of Osaki Koudo and Igune.

Hedgerow planted in agricultural fields (Pollard et al., 1974) are a similar example of homestead trees. However, due to urbanization and lifestyle changes, the number of homestead trees has been decreasing.

In contrast, Igune, homestead trees in Osaki Koudo in the north of Miyagi Prefecture, (see Fig. 1 (1), (2)) are still present in approximately 40% (24,300 households) of local households (Osaki City, 2023). The characteristic rural landscape is formed by Igune (Fig. 1 (3)). However, in recent years, there have been cases of Igune cutting because they are difficult to maintain. Hence, clarifying their value, in particular, their windbreak effects, which is still one of their most important roles, is needed. The authors investigated the windbreak effect of Igune with the computational fluid dynamics (CFD) simulations by reproducing the flow fields with and without Igune (Minami et al., 2022a). This study analyzes the characteristic of flow fields behind Igune by changing the composition of shrubs and trees of Igune based on CFD simulations.

2. CHARACTERISTICS OF IGUNE ON THE SUBJECT SITE

Figure 2 (1) shows an aerial photograph of the subject site. The simulated site is a scattered village-style house where a single house and compound trees and shrubs have separate locations. Igune are located on the west and north sides of the site to protect the living space from strong winds from the west-northwest direction, which is the prevailing wind direction in winter. Figure 2 (2) shows the distribution of Igune heights on west of site. The tall trees were all cedars. The shrubs on the west side, bamboo was densely distributed in the Igune up to approximately 7 m from the ground. On the north side, the shrubs consist of various species such as hydrangea and camellia.



(1) Aerial photograph. (2) Distribution of Igune heights on west of site.

Figure 2. Outline of subject site.

3. ANALYSIS OF WINDBREAK EFFECTS LEEWARD OF IGUNE

3.1. Numerical settings

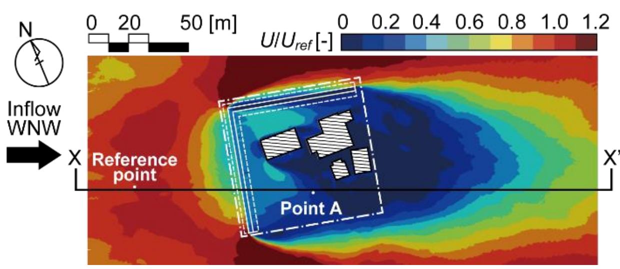
Large-eddy simulations (LESs) were conducted to investigate the windbreak effects of Igune. Three simulations were performed: case reproducing current situation with shrubs and tall trees (Case-ST), an Igune with only shrubs (Case-OS), and an Igune with only tall trees (Case-OT). The wind direction was set to west-northwest, which is the prevailing wind direction during winter. The shape of the houses and Igune were reproduced based on a 3D-CAD constructed from a digital surface model, which was calculated from drone photographs of 182 locations on March 29, 2021. The Igune was simplified to a polygon shape, as shown in Figure 2 (2). The maximum height on the west side of the Igune h_{max} was set as 16 m, and the minimum height h_{min} was 7 m. The height of the Igune on the north side of the site was set as h_{max}. The computational domain was 200 × 400 × 100 m. The total mesh number was approximately 1.3 million with polyhedral meshes. The open-source CFD code OpenFOAM-v2006 (ESI Group, 2023) was used for the LES. The Smagorinsky model (Smagorinsky, 1963) with the Smagorinsky constant, 0.12, was used as the subgrid scale turbulence model. In the Igune area, a drag force term based on the vegetation canopy model was added to the filtered Navier–Stokes equations as shown in Eq. (1). $\overline{F}_i$ is the drag force term expressed in Eq. (2). C_f is a model coefficient related to the drag force acting on the leaves, a is the leaf area density, and $\sqrt{(\overline{u}_\alpha)^2}$ is the magnitude of the wind velocity. The parameters were set as C_f = 0.5 and a = 6.0 m^2/m^3 (Kamiyama et al., 2004) for the shrubs and C_f = 0.5 and a = 0.5 m^2/m^3 (Nakai et al., 2009) for the trees. For the advection term, the second-order linear interpolation scheme was combined with the first-order upwind interpolation scheme with specific blending ratios of 5% to avoid numerical oscillations. The main calculation time was 600 s after a 200-s spin-up calculation. The inflow turbulence satisfied the vertical profiles of mean wind velocity and turbulence intensity of the Roughness Category II in the Architectural Institute of Japan recommendations for loads on buildings (Architectural Institute of Japan, 2015).

$$\frac{\partial \overline{u}_i}{\partial t} + \overline{u}_j \frac{\partial \overline{u}_i}{\partial x_j} = -\frac{\partial \overline{p}}{\partial x_i} + \frac{\partial}{\partial x_j}\left\{(\nu + \nu_{SGS})\left(\frac{\partial \overline{u}_i}{\partial x_j} + \frac{\partial \overline{u}_j}{\partial x_i}\right)\right\} - \overline{F}_i \quad (1)$$

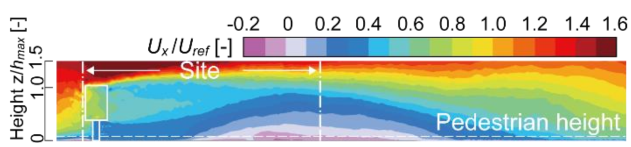
$$\overline{F}_i = C_f a \overline{u}_i \sqrt{(\overline{u}_\alpha)^2} \quad (2)$$

3.2. Results

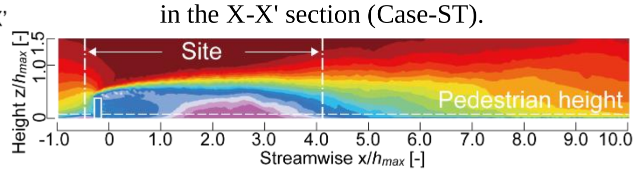
Figure 3 (1) shows the horizontal distribution of mean wind velocity at a height of 1.5 m, the pedestrian height, for Case-ST. The single dotted line in the figure is the site boundary, the solid lines represent the cross-section of shrubs, and the dotted lines represent the locations of tall trees. For the validation of the simulation, a field observation with a 3D ultrasonic anemometer (CYG-81000; R. M. Young Company, United States) was conducted from 17:00 on April 12 to 15:00 on April 13, 2022 (Minami et al., 2022b). The measurement points are shown in Figure 3 (1) as the Reference point, 50 m windward from the Igune, and Point A, approximately 2 h_{max} leeward from the Igune. The wind velocity was normalized with the mean wind velocity at reference point U_{ref}. The mean wind velocity at the site was generally less than 0.3 and was reduced to 1/3 of the mean wind velocity by the Igune. This tendency corresponded with the previous field observation. Figure 3 (2), (3) shows the distribution of the streamwise component of the mean wind velocity in the X- X' section. In Case-ST in Figure 3 (2), a weak region behind the Igune was formed up to



(1) Horizontal distribution of mean wind velocity at 1.5 m height (Case-ST).



(2) Streamwise component of the mean wind velocity in the X-X' section (Case-ST).



(3) Streamwise component of the mean wind velocity in the X-X' section (Case-OS).

Figure 3. Distribution of mean wind velocity.

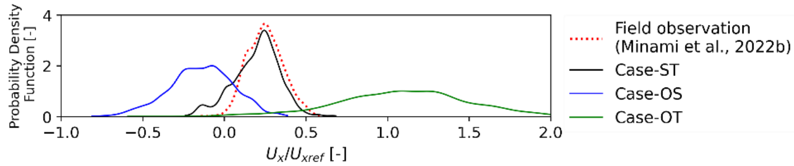


Figure 4. Probability density function of the streamwise component of instantaneous wind velocity at Point A.

approximately 10 h_{max} leeward of the Igune. In contrast, in Case-OS in Figure 3 (3), the weak region was 1/2 the length in Case-ST. In contrast, a reverse flow area with a normalized wind velocity of approximately −0.2 was formed in the center of the courtyard.

Figure 4 shows the probability density function of the streamwise component of the instantaneous wind velocity at Point A. In Case-ST, the wind velocity agreed well with field observation. In contrast, in Case-OS, the distribution pattern was mostly negative, indicating reverse flow. The range of the wind velocity distribution was larger than that in Case-ST. In Case-OT, the distribution was heavily biased toward the high wind velocity side owing to the contraction flow under the canopy.

4. CONCLUSIONS

LESs were conducted to investigate the windbreak effects of Igune as an example of a flow field around an existing house in Osaki Koudo, Miyagi Prefecture, Japan. The mean wind velocity within the site was reduced by 1/3 owing to the windbreak effects of Igune, and the length of the weak region of the case with shrubs and trees was approximately twice that of the case with only shrubs. In addition, reverse flow occurred for the case with only shrubs and reverse flow did not occur for a current situation Igune. These findings indicate that the combination of shrubs and trees in Igune contributes to calm wind conditions around the house surrounded by Igune.

ACKNOWLEDGMENTS

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