Wind Engineering Joint Usage/Research Center
FY2023 Research Result Report

Research Field: Indoor environment.
Research Year: FY2023
Research Number:
Research Theme: Study on ventilation airflow properties under unsteady conditions in complex housing.

Representative Researcher: Takashi Kurabuchi (Tokyo University of Science)

Budget [FY2021]: 420,000 Yen

*There is no limitation of the number of pages of this report.
*Figures can be included to the report, and they can also be colored.
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1. Research Aim

Although the analysis of airflow properties around buildings is typically conducted under steady-state conditions, the actual airflow properties within and outside buildings are believed to differ from the analysis results under steady-state conditions due to the variability of outdoor wind direction and speed over time. Consequently, in this study, actual measurements were conducted in an apartment block with the objective of elucidating the indoor and outdoor ventilation airflow properties under external wind conditions that fluctuate over time, and to reproduce them in a CFD analysis.

2. Research Method

2.1 Outline of actual measurements

The actual measurements were conducted in a single room of the M complex in Atsugi, Kanagawa Prefecture, Japan. In this room, the rooftop anemometer, opening anemometer, indoor anemometer, and pressure difference were measured. The outdoor wind was gauged by installing an ultrasonic anemometer at a height of 5 m above the roof of the building to be measured. The opening anemometer was installed in the center of the opening and measured the opening anemometer. Indoor anemometers were installed in the target dwelling at 17 locations as illustrated in Fig. 1, with the objective of measuring the indoor anemometer velocity. Wind pressure was gauged using a digital differential pressure gauge with a pressure tap on the outdoor wall in close proximity to each opening, with the pressure near the indoor ceiling serving as the reference (Fig. 1). In addition, pressure taps were installed on the glass surface of window 3 in order to assess the wind catcher effect. The cases under investigation are presented in Table 1. Each case was monitored for a period of three hours.

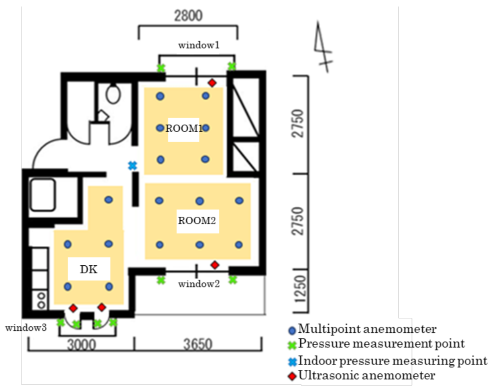


Fig. 1 Equipment installation locations

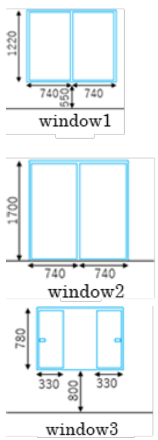
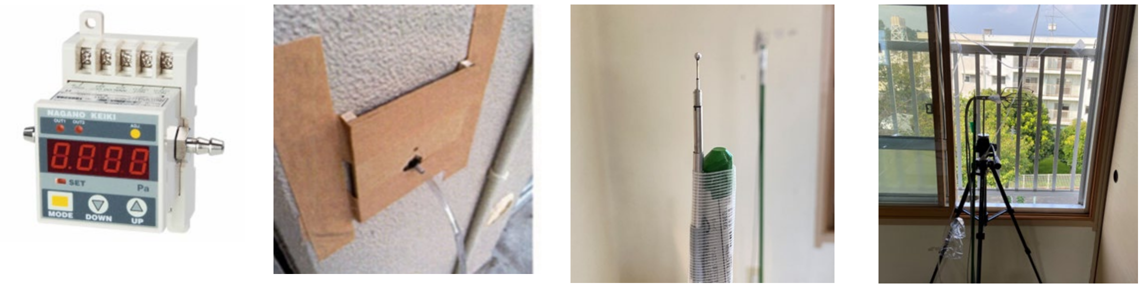


Fig. 2 Apertures.



Digital differential pressure gauge | Pressure tap | Multipoint anemometer | ultrasonic anemometer

Fig. 3 Equipment used.

Table 1 Study cases

Case	Opening case	Measurement period
case1	window1.2	9/20,9/22
case2	window1.3	9/23,9/25,9/26(AM)
case3	window3	9/26(PM)

Table 2 Measurement intervals

Appliance name	measurement interval[s]
ultrasonic anemometer	0.02
Multipoint anemometer	0.2
Digital differential pressure gauge	0.02

2.2 CFD overview

In order to obtain a more detailed understanding of the airflow properties inside and outside the building under non-steady state conditions, an attempt was made to reproduce the measured airflow properties using CFD. The analysis model is shown in Fig. The model was developed for the surrounding city block center on the building under study. The analysis was turned around for 100 s, where the rooftop wind direction changed from a stable point to a stable point at a different angle based on the actual measurements. As the unsteady analysis requires the wind to be grown in advance, the inlet values of the 0s for 300s were input and analyzed before running the 100s analysis. LES and DES are often used for unsteady state turbulence models, but these require a small mesh spacing and therefore a small-time step. On the other hand, as the evaluation time of ventilation indoors is from one minute to one hour, the Realizable k-ε model was used as the turbulence model in this study with the aim of enabling practical ventilation evaluation. The wind direction measured as an outdoor condition was at the rooftop of the building under study, but because there are buildings around the building under study, the wind direction under the inflow boundary condition and the wind direction at the rooftop of the building under study do not necessarily match. Therefore, in order to understand the wind direction of the inflow boundary condition that should be given to reproduce the wind direction on the rooftop of the building under study, the relationship between the wind direction in the inflow boundary condition and the wind direction on the rooftop of the building under study was investigated. The results are shown in Figure 5. The rooftop wind direction and inlet wind direction in the range compared to the present measurements were almost linear. The analysis conditions are shown in Table 3. The convergence criterion is to proceed to the next step when each residual falls to 1.0E-4 or when the internal iteration is 150 times.

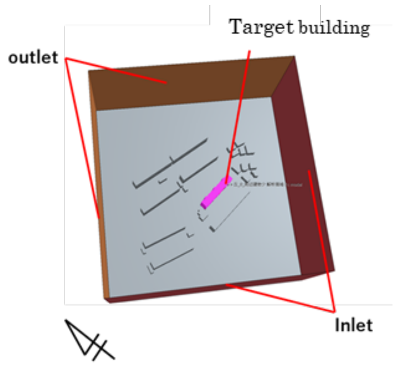


Fig. 4 Analysis model

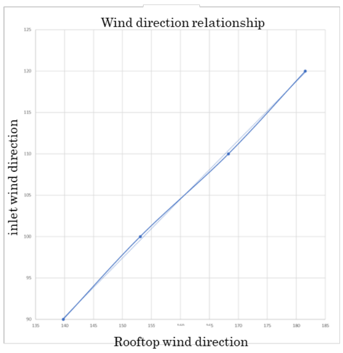


Fig 5 Wind direction relationship

Table 3 CFD analysis conditions

Software used	Simecenter STAR-CCM+(2310.0001)
Turbulence model	Realizable K- ε
Time step	1s
Analysis method	Implicit non-stationary analysis
Number of meshes	41720

Boundary	Boundary condition	
inlet	inlet	Profile based on 1/4 power law Eaves height 15.0
outlet	outlet	exit
top side	symmetry	Free slip
ground	wall	Wall functions based on the general logarithmic side

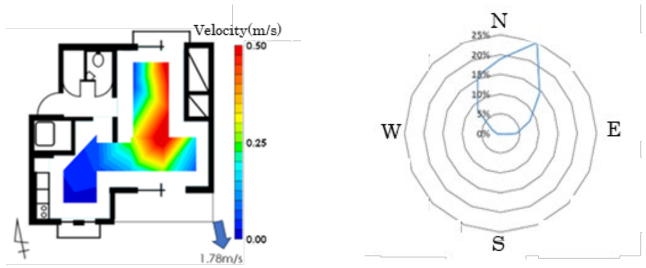
3. Research Result

3.1 Actual measurement results

The rooftop wind direction at the time of measurement was 0° to the north, 90° to the east, 180° to the south, and 270° to the west. The wind direction on the rooftop was from the north, and the wind speed inside the room increased from window 1 to window 2, but there was no significant change in the wind speed at DK. The results of Case 3 are shown in Fig. 8.

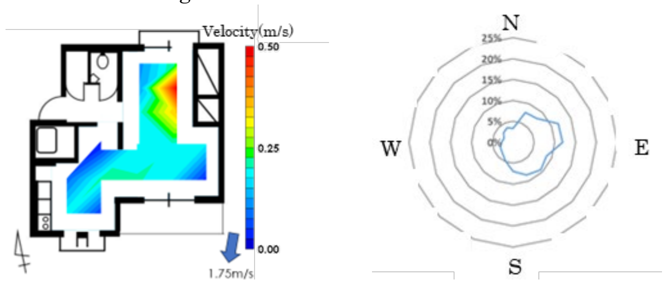
The wind direction on the rooftop was from the southwest, and although wind was entering the room near window 3, there was no ventilation to rooms 1 and 2. In Case 1, the indoor wind velocity distribution when the outdoor wind direction is stable and steady, and the indoor wind velocity distribution when the average outdoor wind direction is the same but the outdoor wind direction varies from time to time (non-steady state) are shown in Fig. 8.

Figure 9 compares the indoor wind velocity distribution in Case 1 when the outdoor wind direction is stable and can be regarded as steady state and the indoor wind velocity distribution in Case 2 when the outdoor wind direction is different from time to time (non-steady state), although the average wind direction is the same. In addition, the outdoor wind speed transition and wind distribution maps for the non-steady state are shown in Figure 10. The outdoor wind direction and wind speed are the same when averaged, but the indoor wind speed distribution differs between the two, suggesting that it is preferable to evaluate the indoor wind speed distribution in real space under the non-steady state.



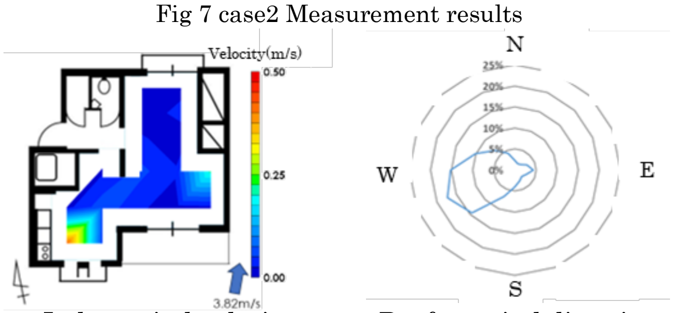
Indoor wind velocity distribution
Rooftop wind direction

Fig 6 case1 Measurement results



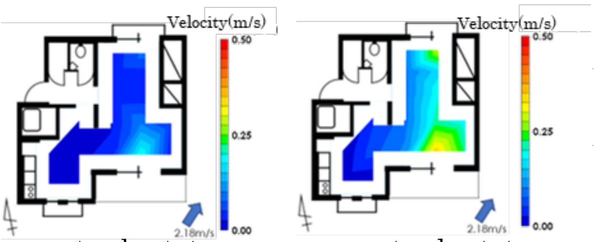
Indoor wind velocity distribution
Rooftop wind direction

Fig 7 case2 Measurement results



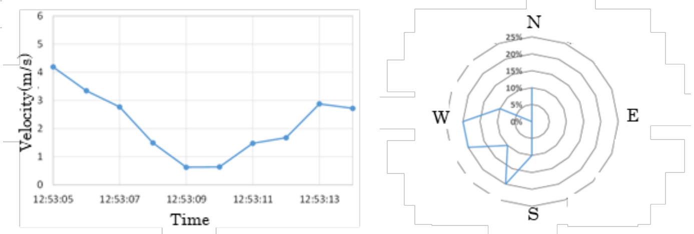
Indoor wind velocity distribution
Rooftop wind direction

Fig 8 case3 Measurement results



steady state　unsteady state

Fig.9 Comparison of indoor wind velocity



Rooftop wind velocity　Rooftop wind direction

Fig. 10 Actual measurement results (unsteady state 10s)

3.2 CFD Analysis Results

The pressure was compared at the same point taken by the pressure tap measured in the actual measurement. the CFD analysis results also show the differential pressure with the chamber pressure as in the actual measurement. (Fig. 11) First, a comparison of the results of the solution turned in the steady-state analysis for 0s and the results of the unsteady analysis turned for 100s with an inlet of 0s is shown in Fig. 12. The pressure was compared at the same point taken by the pressure tap that was measured in the actual measurement. From these results, the rooftop wind speed, pressure, and wind vector distribution were equal.

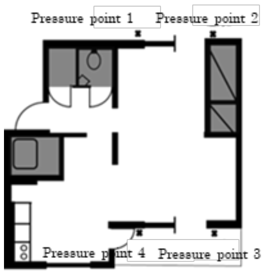
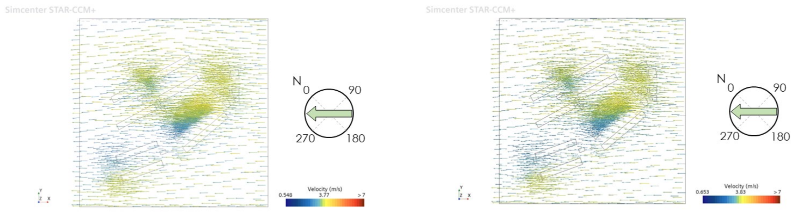


Fig 11 Pressure Comparison Points

	Steady state 0s	Unsteady state 0s
Rooftop wind direction	137	137
Rooftop wind velocity	3.428	3.412
Pressure point 1	-1.064879	-1.06529
Pressure point 2	-0.954634	-0.95503
Pressure point 3	-0.012636	-0.01254
Pressure point 4	0.976712	0.976989



Numerical Comparison　Wind velocity vector distribution (steady)　Wind velocity vector distribution (unsteady)

Fig 12 Comparison of steady-state analysis 0s and unsteady-state analysis 0s

Figures 13 and 14 show a comparison of the wind direction and wind speed on the rooftop for the next 100 s with the actual measurements. The wind direction was almost the same and the wind speed was almost the same as the actual measurement, but the wind velocity at the timing when the wind direction switched at 60s was significantly different from the actual measurement. The graph comparing the pressure at each point is shown in Fig. 14. 100s, when the inlets are changed, the CFD result is too large compared to the actual measurement, and the order is not correct. Figure 15 shows the wind velocity vector distribution for the 59s, where the wind velocity is larger than the actual measurement. The results show that the flow is unnatural.

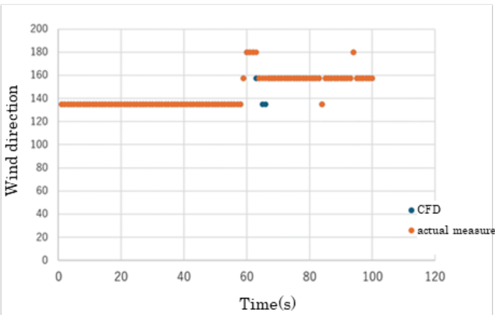


Fig 13Comparison of rooftop wind direction

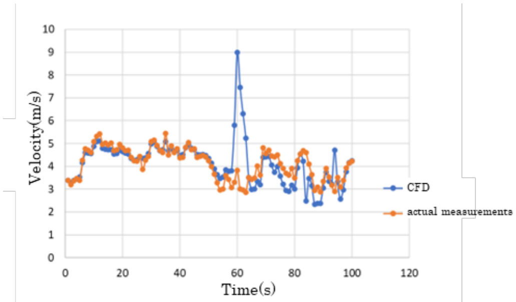


Fig 14 Comparison of rooftop wind velocity

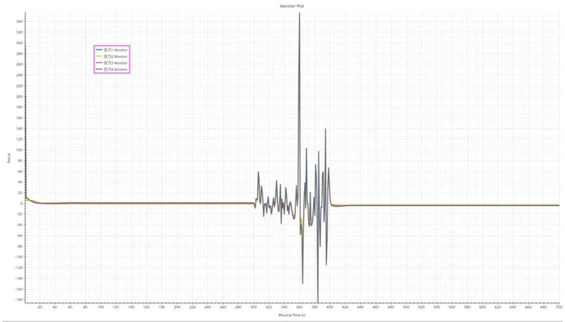


Figure 15 Pressure Comparison

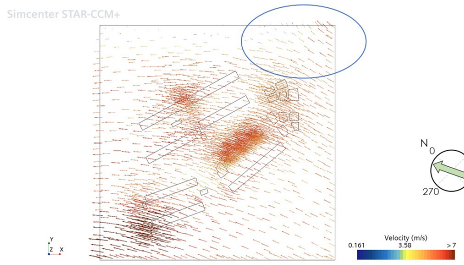
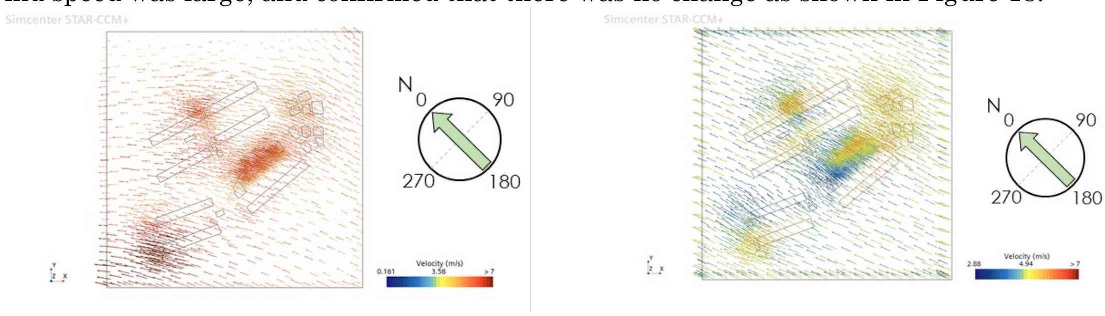


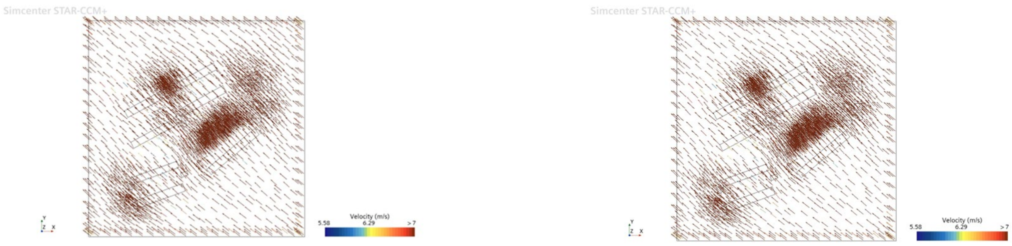
Fig 16 Wind velocity vector distribution (59s)

Therefore, the analysis was changed from a 2-plane inlet 2-plane outlet to a 4-plane inlet. The analysis conditions and convergence criteria were left unchanged. The wind velocity vector distribution is shown in Figure 17. As a result, the unnatural flow observed in the case of the 2-plane inlets and 2-plane outlets has been improved. Rooftop wind speed and pressure were almost the same as in Figures 13, 14, and 15. We also checked whether there was any change by making the timestep finer in the section from 59s to 60s, where the wind speed was large, and confirmed that there was no change as shown in Figure 18.



2-sided inlet2-sided outlet 4-sided inlet

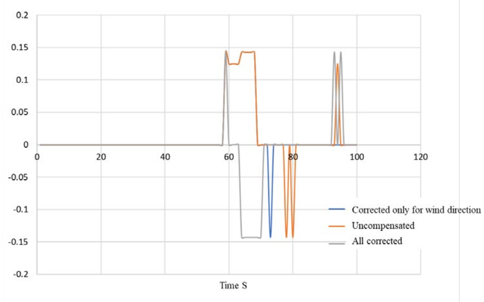
Fig 17 Wind velocity vector distribution 59s

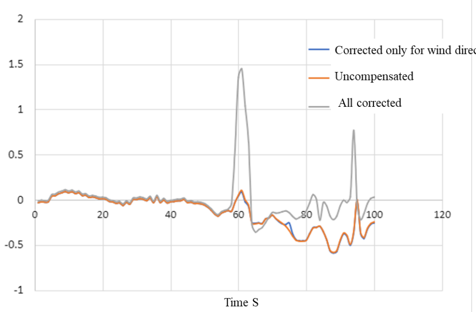


Timestep0.01s Timestep1s

Fig 18 Wind velocity vector distribution 60s

The results of this analysis show that the inlets were created based on the results of the steady-state analysis, but two cases were verified and compared: a case with no correction (the measured rooftop wind direction and wind speed are included in the inlets as they are) and a case with correction only for wind direction (only the measured rooftop wind speed is included in the inlets as they are). The two cases were verified and compared. Figure 19 shows a graph comparing the difference between the actual measured values of rooftop wind direction and wind speed. In this graph, the closer the vertical axis is to 0, the more the value is the same as the actual measurement. From this result, it can be seen that the case with wind direction correction is the closest to the actual measurement, while the case with wind speed correction is a very good system except for the outliers. From this result, it can be said that the inlets should be corrected in the steady-state analysis when the wind direction is stable and should not be corrected in the steady-state analysis when the wind direction changes.

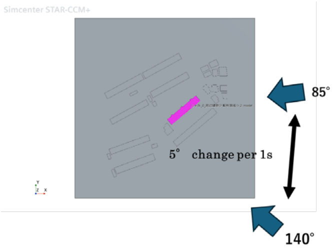


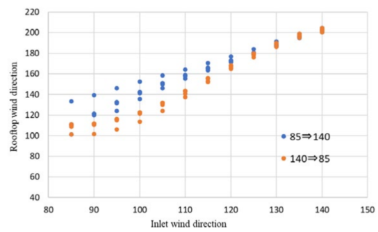


Rooftop wind direction　　　　　　　　　Rooftop wind velocity

Fig19 Comparison of the difference between the actual measured values of the three cases

In order to reexamine the INLET for the timing of the wind direction changeover, we examined how the rooftop wind speed changes when the wind direction changes every 5 degrees in 1s in a full surface INLET unsteady analysis. (5 round trips) Inlets were placed so that 5 m/s at the reference height (H=15.5). (Figure 20)The relationship between the inlet wind direction, rooftop wind direction, and wind speed is shown in Figure 21. From this, it can be seen that both wind direction and wind speed are affected by the wind in front of the building, so different values are obtained when 85° →140° and when 140° → 85° so, it is necessary to create an inlet that takes these factors into account as well.





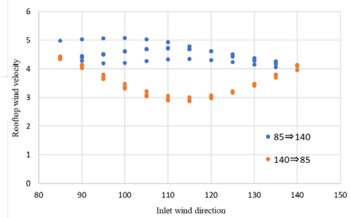


Fig. 20 Analysis model

Rooftop wind direction　　　Rooftop wind velocity

Figure 21 Relationship between inlet wind direction at unsteady

3.3 Summary

The following findings were obtained from this study.

1) In actual measurements, the indoor airflow properties are significantly different between the steady state and non-steady state conditions.
2) The steady state solution is the same as the unsteady state solution when the same inlet is used, and the analysis is run for a certain period.
3) The unnatural airflow was eliminated by using a 4-sided inlet. The analysis also rotates with a 4-sided inlet.
4) There is almost no change by timestep.
5) It is better to create inlets with steady correction for areas where the wind direction is stable, but if steady correction is used for areas where the wind direction switches, there will be a large difference from the actual measurement.
6) The unsteady inlets are strongly affected by the previous wind, so it is necessary to separate the cases when making corrections.

Based on the results of our research, we will improve the inlet correction to reproduce the wind speed and direction on rooftops and will work on indoor analysis in the future.

4. Published Paper etc.

[Underline the representative researcher and collaborate researchers]

[Published papers]

1.

2.

[Presentations at academic societies]

1. Study on ventilation airflow properties under unsteady conditions in complex housing. Akito Kono, Takashi Kurabuchi, Toshihiro Nonaka, Jeongil Kim, Koichiro Saito. Summaries of technical papers of Annual Meeting, Architectural Institute of Japan (scheduled for 2024.8).
2. Study on ventilation airflow properties under unsteady conditions in complex housing. Akito Kono, Takashi Kurabuchi, Toshihiro Nonaka, Jeongil Kim, Koichiro Saito. Technical Papers of annual meeting, the Society of Heating, Air-Conditioning and Sanitary Engineers of Japan (scheduled for 2024.9).

[Published books]

1.
2.

[Other]

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5. Research Group

1. Representative Researcher

Takashi Kurabuchi	Professor, Tokyo University of Science

2. Collaborate Researchers

1.	Mitsuru Takuwa	Graduate Student, Tokyo University of Science
2.	Akito Kono	Graduate Student, Tokyo University of Science
3.	Akie Sugeno	Graduate Student, Tokyo University of Science
4.	Toshihiro Nonaka	Professor, Tokyo University of Science
5.	Jeongil Kim	Assistant Professor, Tokyo University of Science
6.	Yosihide Yamamoto	Professor, Tokyo Polytechnic University

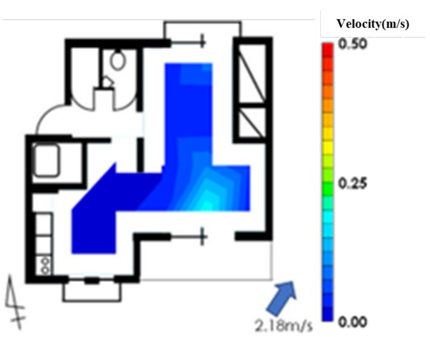
6. Abstract (half page)

Research Theme: Study on ventilation airflow properties under unsteady conditions in complex housing.

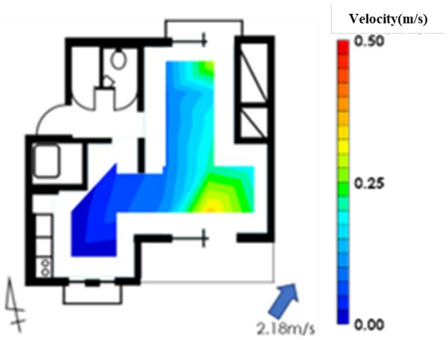
Representative Researcher (Affiliation): Takashi Kurabuchi (Tokyo University of Science)

Summary・Figures

We measured the indoor and outdoor ventilation airflow characteristics in an apartment building under constantly changing external wind conditions and attempted to reproduce them in a CFD analysis. In the CFD analysis, it is better to create inlets with steady-state correction for the areas where the wind direction is stable in the four-plane inlets, but it was found that the correction for the areas where the wind direction changes with the steady-state correction results in a large difference from the actual measurement. However, it was found that the steady-state wind direction correction also differed significantly from the actual measurement. In addition, when creating unsteady inlet, it is necessary to take into account the strong influence of the wind of a few seconds ago when making the correction.

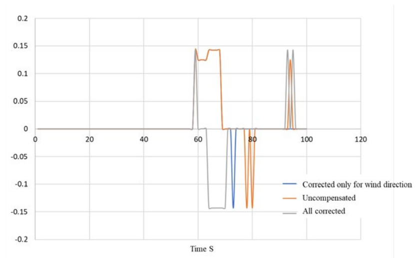


steady state

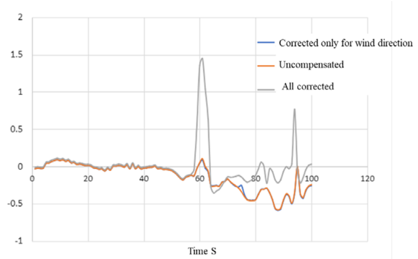


unsteady state

Comparison of measured indoor wind velocity

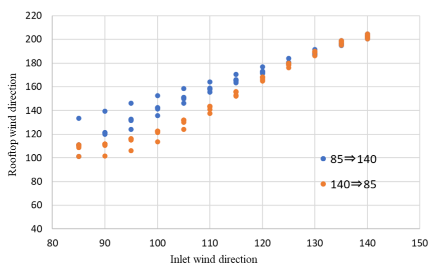


Rooftop wind direction

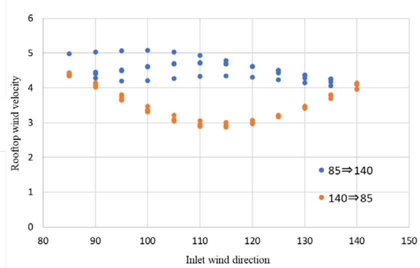


Rooftop wind velocity

Comparison of the difference between the measured values of the three cases and the actual values



Rooftop wind direction



Rooftop wind velocity

Relationship with inlet wind direction at unsteady