

# A Study on the Application of Small Wind Power System with Combined Ventilator in Super High-Rise Apartment

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## Abstract

This is an elementary study on the application of small-sized exhaust wind power generation to exhausters on the rooftop of high-rise apartment buildings. Here, CFD (Computational Fluid Dynamics) simulation is performed to determine the effect of multi-diffusers for exhaust wind velocity amplification and external wind attraction; the experiments are conducted using miniatures and actual mock-ups. The results of the study are summarized as follows. From the simulation of multi-diffusers for exhaust and ventilation, the wind velocity increased with a greater number of installations of devices, where up to eight was possible and about six was found to be appropriate. In simulation of exhaust effect, an increase in the external wind velocity leads augmentation in the exhauster wind velocity; in particular, it was confirmed that even when there was no exhaust wind (0m/s), there was an exhaust air rise effect due to inflow of the external wind, itself. In the results of experiments with miniatures and mock-ups, the exhauster discharge wind velocity increased due to the external air inflow in the apartment building exhauster, confirming the existence of an exhaust effect. The wind velocity increase rate was greater at the upper part than at the lower part, leading to the prediction that it would be possible to secure over 3m/s, the initial operation wind velocity of small wind power.

**Keywords:** super high-rise apartment; small wind power system; combined ventilator (out air + shift on duct air)

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## 1. Introduction

### 1.1 Study background and objective

Recently, due to global greenhouse gas reduction policies, energy savings in buildings have been increasingly emphasized. Currently, Apartment houses represent more than 50% of residential buildings in Korea. Due to the over-densification of cities and reduction of land areas, the construction of high-rise apartment houses is rapidly increasing. High-rise buildings, however, have the shortfall of large energy consumption due to their structure. And particularly a lack of ventilation compared to low-rise buildings. In recent studies, small-sized wind power generation has been applied for energy savings in high-rise buildings (Hyun-Do Chun, Dong-Yun Lee *et al.*). On the other hand, in urban areas, it is difficult to stably secure a wind environment of 3 m/s, the initial operation power of wind power generation for high-rise buildings.

It has been demonstrated that an exhaust duct wind of 0.5 m/s ~ 1.5 m/s can be secured in high-rise

apartment buildings. Therefore, for the application of small-sized wind power system to these buildings, it has been determined that the development of devices that use external wind and exhaust wind at the same time will be necessary to resolve the lack of wind environment.

In this study, a multi-diffuser mixing external air and exhaust air at the end of a rooftop exhauster was developed for high-rise apartments. In order to apply small-sized wind power generation to high-rise apartment buildings, this elementary study aimed to determine the amplification and induction effect of external wind velocity through simulation and experiments.

### 1.2 Study methods

The methods used in this study were as follows.

1) Through resource analysis, a combined ventilator and multi-diffuser were designed and produced to secure the operation power of the small-sized wind power generation at the rooftop of a high-rise apartment building.

2) Using air current analysis simulation (STAR-CCM+), the amplification and induction effect of the exhaust wind velocity was analyzed according to the number of installations of multi-diffusers for exhaust and ventilation.

3) Along with the production of the multi-diffuser for exhaust and ventilation, in order to determine the

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amplification and induction effect for wind velocity in an actual wind environment, miniature and mock-up experiments were conducted.

## 2. Theoretical Considerations

In this section, precedent research on the application of small-sized wind power generation to high-rise apartment houses and the use of exhaust air in high-rise apartment buildings are considered.

### 2.1 Precedent studies on the application of small-sized wind power generation to high-rise apartment buildings

Domestically, research on the application of small-sized wind power generation to high-rise apartment houses is still in the elementary stage. In a study by H.D. Chun (2010), the air current pattern was analyzed according to the form of the high-rise building to propose an elementary direction for a small-sized wind power generation system; furthermore, D.Y. Lee (2011), conducted a study on the installation plan of roof and side surfaces of high-rise apartment houses according to the building type. In H.J. Chang's (2012) study, a certification system for the application of wind power generation to high-rise apartment buildings was analyzed and an application process was proposed. Moreover, in a study by L. Ganmbrota (2007), a horizontal-type module was produced to apply the small-sized wind power generation system to high-rise buildings, and results were obtained whereby the system could be operated at 2 m/s and produce 131 kWh yearly at a wind velocity of 5 m/s. In addition, W. Becker's (2009) research assessed the applicability of a small-sized and aerofoil-shaped wind power system combined PV (Photovoltaic). The domestic studies conducted so far were mostly intended to analyze the air current of high-rise apartments and use of small-sized wind power generator in the area with the best wind environment; on the other hand, in studies conducted in other countries, various types of wind power generation systems have been designed to use appropriate small-sized wind power generation for high-rise buildings, There has not yet been enough research on application of wind power generation using exhaust gas in high-rise apartment building.

### 2.2 Precedent studies regarding the use of vertical shafts for exhaust in high-rise apartment buildings

In a study by C. Tong (2011), it was found that a discharge wind velocity of 1.6 ~ 1.8 m/s at a cooling tower could be used to produce electricity of 43.8 MWh yearly per unit. Furthermore, S.Y. Kim (2011), analyzed nine cases of domestic high-rise apartment houses, as a result, the vertical shaft spaces for exhaust in high-rise buildings were largely divided into common ducts (kitchen, bathroom) and vents (boiler, generator); their sizes and characteristics varied depending on the type or use of the vertical space for exhaust.

While it differed slightly depending on the hood operation rate within the household, the wind velocity within the vertical shaft space of a high-rise apartment building was generally 0.5 m/s ~ 1.5 m/s, therefore small-sized wind power generation using only wind within vertical exhaust ducts would be difficult in general. Therefore, a plan that strengthens the wind velocity of the exhauster by the stack effect and the induction of external wind is necessary for the operation of small-sized wind power generation in high-rise apartment buildings.

## 3. The Design and Production of a Multi-Diffuser for Exhaust and Ventilation

The multi-diffuser for exhaust and ventilation designed and produced in this study is a device that installs a small-sized wind power generator of 300W~1kW at the end of the roof exhauster to produce electricity and obtain an exhaust effect at the same time. (see Fig.1.)

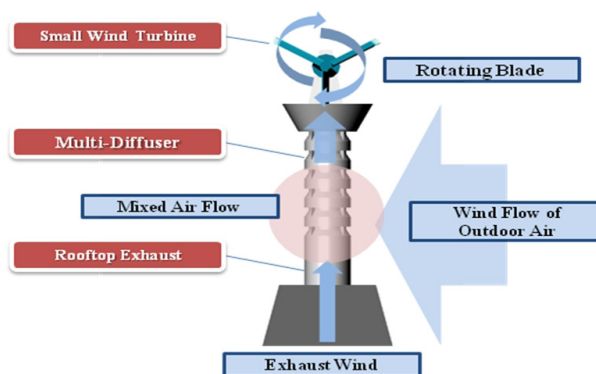


Fig.1. Concept of the Multi-Diffuser

This device changes the external wind direction to match the exhauster direction so as to generate wind as much as possible in the blade installation location, and at the same time, generate negative pressure at the exhauster as the diffused external wind increases, inducing exhaust effect. In addition, it is unified so that multiple devices can be installed to adjust the height according to the conditions of the building rooftop or the exhauster where the device is installed (see Fig.2.). The detailed characteristics of the device are listed in Table 1.

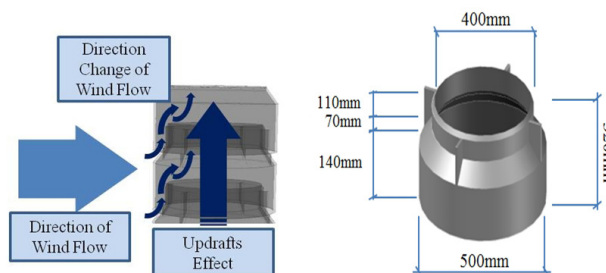


Fig.2. Features of the Multi-Diffuser

Table 1. Specifications of the Multi-Diffuser

Item	Description
Size / Material	500 x 320 (a single unit) / Stainless Steel
Installation Location	On top of the exhaust on the roof, 500 mm in diameter
Use	1) To create a wind environment for generating with small wind turbine and obtaining better exhaust 2) Uses in number of units (up to eight units)

**4. Simulation**

**4.1 CFD simulation according to the number of installations of multi-diffusers**

The multi-diffuser for exhaust and ventilation first had to be reviewed for the wind velocity amplification effect according to the number of unit installations. Especially with a small number of unit installations, the wind velocity amplification effect decreases; however, an increased number of installations does not always lead to an increase in the wind velocity. In addition, it is harder to manage a larger number of installations, and the installation costs also increase, so the number of installations should be minimized if at all possible. Therefore, the optimal number of units was investigated through simulation by determining the wind velocity amplification effect according to the number of unit installations. The external air velocity set for the simulation was 3m/s, and the wind velocity discharged from the exhauster was assumed to be 0 m/s. The simulation was conducted for the following numbers of units; 2, 4, 6, 8, and 10. The simulation analysis conditions are shown in Table 2.

Table 2. Boundary Condition of Simulation

Item	CFD condition
Category of Analysis	3-D steady state flow analysis
Boundary condition of analysis	Three dimension
Space	Stationary
Motion	Steady
Time	Turbulent
Viscous regime	K-ε turbulence
Equation	gas
Material	

For the wind velocity measurement, the average wind velocity must be taken at five points in the upper part where the blade is installed. The simulation result is given in Table 3. and Fig.3.

Table 3. Simulation Results according to the Number of Installations of the Multi-Diffuser (Unit: m/s)

	#1	#2	#3	#4	#5	Average
2 units	1.80	1.70	1.87	1.84	1.76	1.79
4 units	1.94	1.63	2.13	2.12	1.90	1.94
6 units	2.01	1.74	2.24	2.30	1.98	2.06
8 units	1.97	1.71	2.34	2.36	2.03	2.08
10 units	1.94	1.66	2.35	2.36	2.06	2.07

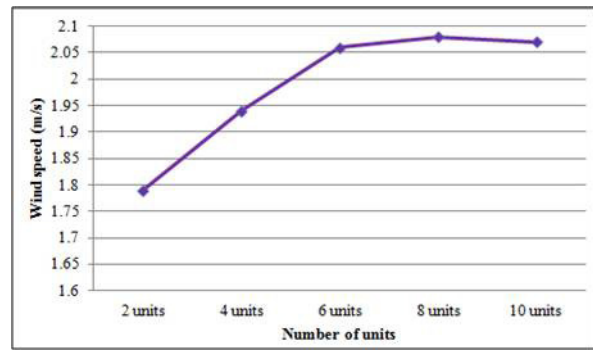


Fig.3. Variations in Wind Velocity According to the Number of Installations of Multi-Diffusers

As a result of the simulation, when two multi-diffusers were installed, the average wind velocity at the blade installation location was 1.79 m/s; as the number of installations of multi-diffusers increased, the wind velocity at the blade installation location also increased, but the wind velocity increase rate for over six installations grew gradually slower, and the wind velocity was found to be largest at 2.08 m/s for 8 installations. It was judged that there was no longer increases of wind speed over 2.08m/s for more than 8 units when external wind speed was 3m/s. As a result, it was found that eight units secured the highest wind velocity from the simulation, therefore representing the ideal number, but six units could also be used.

**4.2 Simulation according to the change in external and exhaust wind velocity**

In this section, the inhalation effect of the exhaust wind by external wind within the multi-diffuser and the wind velocity at the blade installation location were examined through simulation. The simulation analysis conditions are shown in Table 1. in section 4.1.

**(1) Inhalation Effect of the Induction of External Wind Without Exhaust Wind**

The wind velocity of the exhaust wind was found 0 m/s, when the external wind were 1 m/s, 3 m/s, and 5 m/s respectively. Here, the wind velocity was calculated for the upper part and the lower part of the exhauster. The wind velocity measured at the lower part represented the exhaust wind velocity generated by the induction. The results are given in Table 4. and Fig.4.

Table 4. Simulation Results without Exhaust Wind (Unit: m/s)

	Wind Velocity of Outdoor Air Flow			
	0m/s	1m/s	3m/s	5m/s
Top	0	0.68	2.06	3.44
Bottom	0	0.48	1.28	2.14

First, as the result of the simulation without exhaust wind, the wind velocity at the upper part was found to be 0.68 ~ 3.44m/s, while it was 0.48 ~ 2.14m/s at the lower part. That is, as the external wind velocity increased, the wind velocity at the lower and upper parts also increased. This confirmed the exhaust

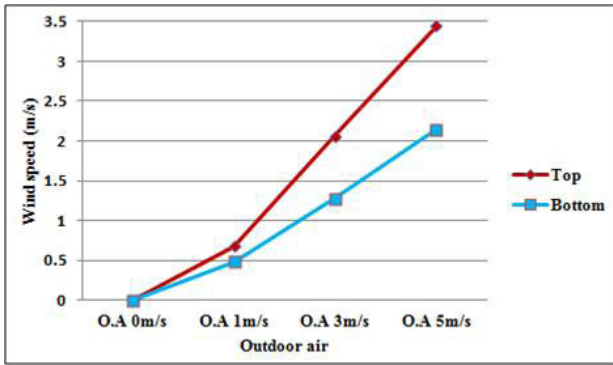


Fig.4. Variations of Wind Velocity with No Exhaust Air

increase effect with only the inflow of external wind, even when there was no exhaust wind (0 m/s) at the rooftop exhauster. At this time, it was also confirmed that the external wind velocity must be 5 m/s in order to maintain 3 m/s which is the minimal wind velocity for small-sized wind power generation in an urban building.

(2) The Wind Velocity Amplification Effect According to the Change in the Exhaust Wind

The external and exhaust wind changed to 1 m/s, 3 m/s, and 5 m/s respectively for calculation. The results are shown in Table 5. and 6. and Figs.5. and 6.

Table 5. Wind Velocity at the Bottom According to the Change in Exhaust Wind (Unit: m/s)

Wind velocity of exhaust air	Wind velocity at the Bottom		
	O.A 1m/s	O.A 3m/s	O.A 5m/s
1m/s	1.18	1.18	1.18
3m/s	3.54	3.54	3.54
5m/s	5.9	5.9	5.9

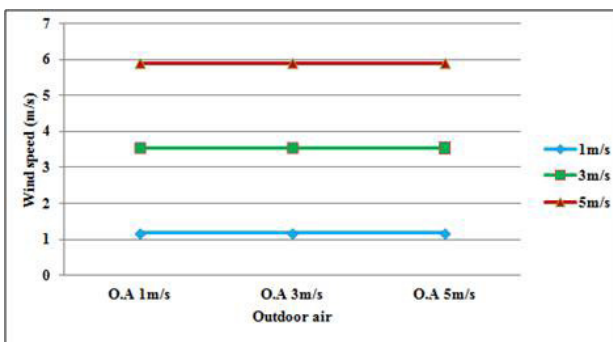


Fig.5. Variations in Wind Velocity at the Bottom According to Changes in Exhaust Air

Table 6. Wind Velocity at the Top According to Changes in Exhaust Air (Unit: m/s)

Wind velocity of Exhaust air	Wind velocity at the top		
	O.A 1m/s	O.A 3m/s	O.A 5m/s
1m/s	1.60	1.99	2.55
3m/s	4.72	4.79	4.97
5m/s	7.76	8.00	8.00

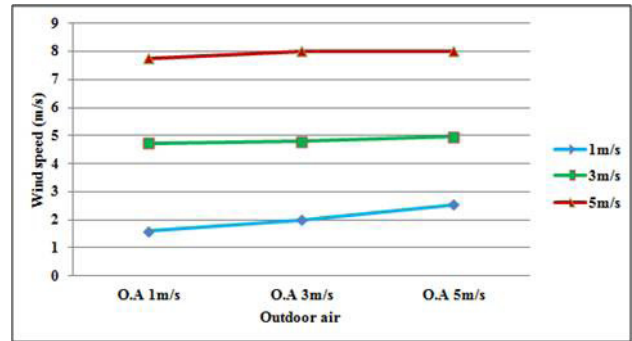


Fig.6. Variations of Wind Velocity at the Top According to Changes in Exhaust Air

The simulation demonstrated that if the exhaust wind velocity was below 1m/s at the upper and lower parts, there was no increasing effect of the exhaust wind even if the external wind velocity increased. For an exhaust wind of 3m/s or greater, however, it was shown that the exhaust wind also gradually increased according to the augmentation of the external wind.

It was judged that even if the external wind velocity is weak in high-rise apartment buildings, the minimum average wind velocity for small-sized wind power generation (3 m/s) can be secured if the exhaust wind velocity is secured.

5. Miniature and Mock-Up Experiments

5.1 Miniature experiment

In the simulation above, the exhaust effect of multi-diffusers for exhaust and ventilation was checked, but the effect in the mock-up model was subject to some error with respect to the simulation. Thus, in order to reduce the error prior to the mock-up production, a half-sized miniature was produced as in Fig.7., and a simple wind velocity measurement experiment was conducted. The material used in the production was FOAMEX.

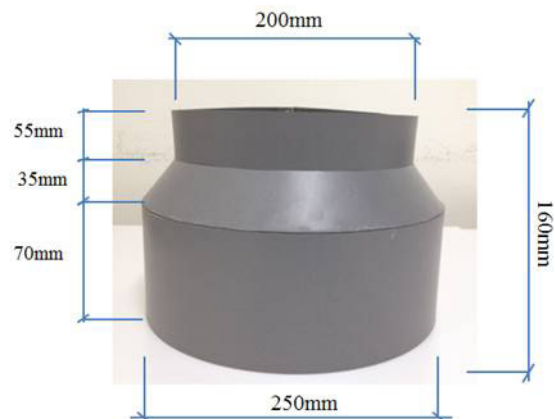


Fig.7. A Single Unit of the Scale Model

For the model experiment, the external wind velocity was set to 2m/s, and for accurate comparison with the simulation value, the average exhaust wind velocity was measured at the upper part (where the blade is

installed) and the lower part.

The result of the comparison of the miniature and the simulation measurements is shown in Table 7.

Table 7. Simulation Results of the Wind Velocity Measurement of the Scale Model and Simulation (Unit: m/s)

	Scale model	CFD simulation
Top	1.00	0.88
Bottom	0.49	0.63

Considering that the air current was turbulent, while there was some error in the comparison of the miniature model experiment with the simulation measurements, the result was still quite similar, confirming the increasing effect of the exhaust wind when the external wind flows in at the exhauster.

### 5.2 Mock-up measurement experiment

To determine the exhaust effect and wind velocity amplification effect when the multi-diffuser was actually installed on the exhauster, the mock-up model shown in Fig.8. was produced and a wind velocity measurement experiment was conducted. The multi-diffuser that was produced was stainless steel, and  $\Phi 500 \times 320$  in size. In addition, according to the simulation result that the number of units should be between six and a maximum of eight, six units were produced.



Fig.8. Mock-Up Model of the Multi-Diffuser

In the experiments, the number of installations was set at 3, 4, 5, or 6, and the exhaust effect and wind velocity at the blade installation location were measured by the second according to the increased number of installations. The experimental device and wind velocity measurement location are shown in Table 8. and Fig.9., and the actual installation at the exhauster is shown in Fig.10.



The discharge wind velocity of the exhauster was found to be 0.23 m/s for eight days before the measurement.

### 5.3 Measurement result

The measurement result is shown in Table 9.

When the average wind velocity of the external air was measured to be 0.87m/s, the increase in the numbers of installations of multi-diffusers from three to six led to increase in the exhauster discharge

Table 8. Measurement Instruments of Wind Velocity

Type of instruments	Description
 Multi-channel anemometer	- From one Channel up to 64 Channels - Index of measurement: wind velocity, temperature, humidity, pressure
 Velocity probe 0964-1	- Sensor for measuring wind velocity - Measurement range: 0.1-50m/s

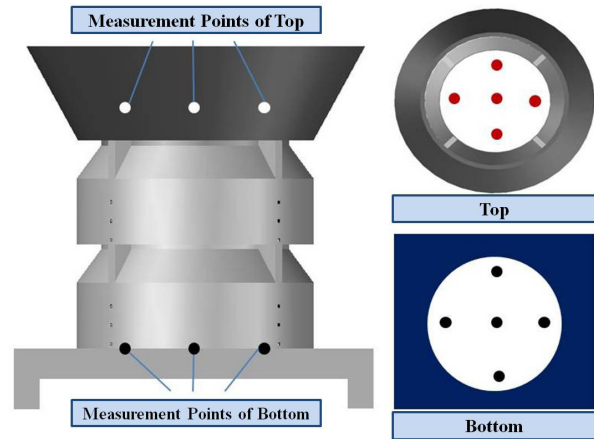


Fig.9. Measurement Points of Wind Velocity



Fig.10. Installation of Mock-Up Model on Exhaust

wind velocity up to 1.120m/s. Therefore, it could be confirmed that there was an exhaust effect due to the generation of an increase in the exhauster discharge wind velocity according to the external air inflow at the exhauster in apartment buildings. In particular, the

Table 9. Results of the Measurement of Wind Velocity According to the Mock-Up Model Installation on Exhaust (Unit: m/s)

	O.A	Top	Bottom
3 units	1.19	0.82	0.59
4 units	0.5	1.01	0.6
5 units	0.77	1.35	1
6 units	1.02	1.12	0.84

wind velocity increase rate was higher in the upper part than the lower part, leading to the prediction that it is possible to secure over 3 m/s in initial operation wind velocity for small-sized wind power.

## 6. Conclusion

An elementary study was carried out for the application of small-sized exhaust wind power generation to exhausters on the rooftops of high-rise apartment buildings. In the research, CFD simulation was conducted to determine the effect of multi-diffusers in exhaust wind velocity amplification and external wind attraction; furthermore, experiments were conducted using miniatures and actual mock-ups. The results of this study can be summarized as follows.

1) In the results of simulation of multi-diffusers for exhaust and ventilation, the wind velocity increased with the number of devices installed; it was possible to include up to eight, and about six was determined to be appropriate.

2) In the simulation of exhaust effect with an increase in external wind velocity, an increase in external wind velocity led to the augmentation of exhauster wind velocity; in particular, it was confirmed that even when there was no exhaust wind (0 m/s), there was an exhaust air rise effect due to inflow of external wind.

3) In the result of experiments with miniatures and mock-ups, it was found that the exhauster discharge wind velocity increased due to the external air inflow in the apartment building exhauster, confirming the existence of an exhaust effect. Specifically, the wind velocity increase rate was greater at the upper part than the lower part, leading to the prediction that it would be possible to secure over 3 m/s, which is the initial operation wind velocity of small wind power.

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