Performance Experiment of Small-Sized Wind Power Generation Using Outdoor Air and Exhaust

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Abstract

This study explains the experiment for evaluating the performance of small-sized wind power generators, in which outdoor air that increases with height of high-rise apartment buildings is induced into the exhaust openings of kitchens and bathrooms. This outdoor air generates an ascending air current and a certain amount of electric energy, which are needed for operating buildings. To apply small-sized wind power generators to exhaust openings of kitchens and bathrooms in existing apartment buildings, a constant driving wind velocity of 3 m/s is required. Performance experiments in laboratories and application experiments on building rooftops, in which outdoor air induction modules were applied to existing exhaust openings of kitchens and bathrooms, show that when outdoor air and exhaust wind velocity are lower than 2 m/s, a driving wind velocity of higher than 3 m/s, which is needed to generate wind power, can be obtained. Furthermore, the generated amount increases by 29%.

Keywords: high-rise apartment buildings; small-sizes wind power generation; exhaust openings of kitchens and bathrooms; outdoor air induction module; performance experiment

1. Introduction

Korea has established a new paradigm for national development through "green growth" to ameliorate global warming, address the energy crisis, and promote new, sustainable growth. For green growth in the building sector, the government has applied new renewable energy systems to buildings, including solar radiation, solar heat, geothermal heat, and wind energy, to increase the number of green buildings in accordance with various policies and systems, such as the National Strategy for Green Growth, the Five-Year Plan, the 100 green homes supply project, mandatory implementation of renewable energy in public institutions, and a building energy efficiency grade certification. A culmination of such efforts is the reduction of building energy consumption through wind power generation.

Wind power generation for building use is a clean, eco-friendly, renewable energy source that produces no pollution and is fueled by the abundant resource of wind.

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Wind flow decreases through frictional resistance with the ground and, conversely, wind speed increases with height. Therefore, a high-rise building can take advantage of this exceptional energy source through the installation of a wind power generator.

Furthermore, residential buildings in Korea often consist of high-rise apartments because of limited construction space due to high urban densification as well as economic, environmental, and symbolic reasons.

In an effort to address energy overconsumption by high-rise apartment buildings, this study, based on previous research, has evaluated the feasibility of constructing a small wind power generator that generates sufficient electricity for the operation of a building. The electricity is generated by inducing outdoor air that increases in speed proportionate to the height of the building into exhaust openings to generate ascending air flow. The study also included performance tests and actual site tests.

2. Consideration of Preceding Studies and Examination of Current Conditions of Facility Shafts

2.1 Consideration of Preceding Studies

Recently, there has been much research in Korea, and globally, into the application of wind power generation to buildings.

To effectively develop a wind power generator for buildings, the U.S. company, CCP Inc., has studied variations in wind power resources created by a building itself and its various surrounding structures, proposed building shapes that can enhance the efficiency of wind power generation, and studied methods by which a building designer can evaluate the characteristics of wind power and wind conditions at the location of a wind generator proposed in the design stage (Brad and Rick, 2008).

The British company BMT Fluid Mechanics Ltd. has studied the aerodynamic interaction between building shape and the wind power generator and proposed testing and simulation techniques to evaluate the aerodynamic performance of wind power generators applied to buildings (Buttgereit *et al.*, 2009).

The British company, Glasgow School of Art and Proven Energy Ltd., has proposed a mechanical design technique that considers building characteristics to enhance the efficiency of conventional tower-supported wind power generators, which degrades due to wind direction changes, turbulence, safety issues, and environmental problems (Sharpe and Proven, 2010).

In Korea, Jong-geun Kim (2010) evaluated the proposed design integrating wind power generation and buildings and evaluated energy efficiency by modeling an actual building in various dynamics tests.

Yong-yee Kim (2010) investigated and analyzed the construction needs of existing designs of foreign wind power generators for buildings that have already been built or are planned, and analyzed the construction requirements that could be restrictive in achieving higher efficiency in wind power generation.

Jin-cheol Park (2011) analyzed the local wind direction and wind power resources around a high-rise building for application of wind power generation; investigated various obstacles to the application of a wind power generator to the building; proposed building application techniques by studying apartment buildings; and performed an economic analysis. Although there have been many case studies and research into the application of small wind power generators for residences due to increasing interest in wind power generators for buildings (Park *et al.*, 2013a, Park *et al.*, 2013b), there have been no actual cases in which a small wind power generator has been applied to a high-rise building, and performance test research like this study is believed to be in its infancy.

2.2 Examination of Current Conditions of Facility Shafts

The current conditions of facility shafts of nine high-rise apartment buildings, located in four cities of Korea, were examined. As shown in Fig.1., six types of shafts were installed at 14 to 19 points in the respective buildings. Among these shafts, those through which air flew vertically from lower to higher floors were flues of boilers and generators as well as exhaust openings of kitchens and bathrooms. The flues of boilers were installed only in six of the nine buildings - D1, D2, S1, C1, B1, and B2 - and in the remaining three buildings - S2, C2, and B3 - district heating was applied for use during winter alone. However, the flues of generators were installed in all the nine buildings for use in case of emergencies, such as power outages. The exhaust openings of kitchens and bathrooms leading to building rooftops were installed in all but two buildings - D1 and C2 - where exhaust directly occurred from houses on each floor to the outside. Consequently, it is considered that exhaust openings of kitchens and bathrooms of existing apartment buildings are most suitable for the performance evaluation experiments of small-sized wind power generators proposed in this study.

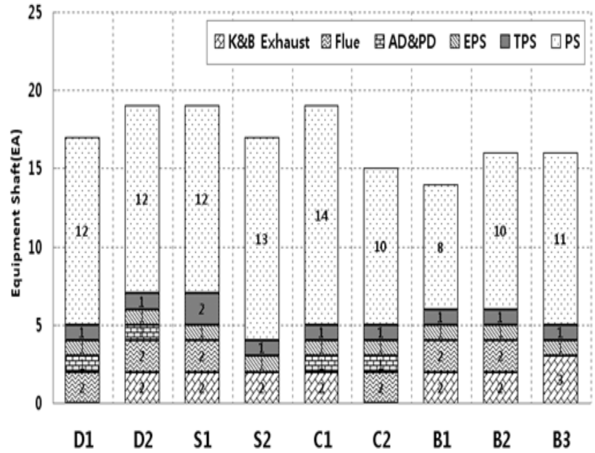


Fig.1. Current Conditions of Facility Shafts by Building

3. Manufacture of Basic Models and Evaluation of Performance Experiments

3.1 Existing Models and Conditions of Performance Experiments

Fig.2. (a) shows the basic model for small-sized wind power generators proposed in this study. The outdoor air induction module, consisting of an induction inlet (①) and an induction pipe (②), was manufactured for it to be capable of adjusting its length and being removable, considering the rooftop railing and structures around the exhaust openings. The induction unit (3) was manufactured with a lower diameter of Ø500 mm, and to be able to induce air current to increase velocity by Venturi effect. The upper diameter of the induction unit was set to Ø400 mm, considering the sizes of the exhaust openings of kitchens and bathrooms, and to maximize the wind collecting effect of outdoor air by adjusting the number of laminated layers (1–6 layers).

To evaluate the performance of the manufactured basic model, a ventilator (b) of 10,560 m^3/h and an exhaust fan (c) of 2,700 m^3/h were installed in the lower part of the outdoor air induction module (d). The performance evaluation experiment was conducted in a laboratory of size 20 m x 25 m x 9 m, by generating outdoor air and exhaust.

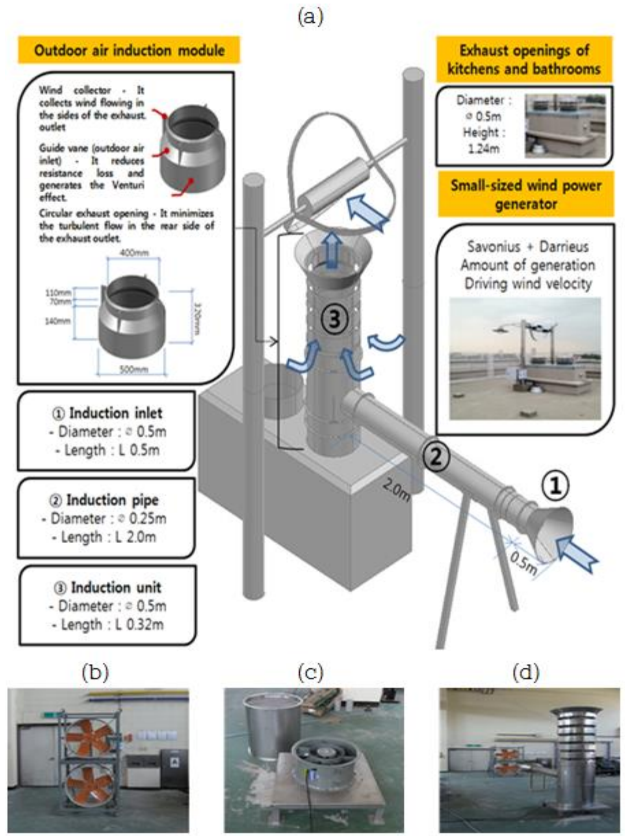


Fig.2. Manufacture of Basic Model and Evaluation of Performance Experiments

As shown in Table 1., in the performance experiment, velocity of the exhaust and outdoor air and the direction of outdoor air of kitchens and bathrooms were each measured six times for 60 min, at intervals of 10 sec, while being adjusted in stages, under test conditions 1 through 3. As shown in Fig.3., the wind velocities at outdoor air inlet point P1, lower point P2, middle point P3, and upper point P4 of the outdoor air induction module were measured. In particular, the average wind velocities, excluding the maximum and minimum values, were used for analysis at P1 through which the outdoor air flows in, P2, which is in contact with the end of the exhaust opening, and P4 at which the blades of the wind power generator are installed.

The wind speeds of the ventilator and exhaust fan were changed incrementally to 1~7 m/s by controlling their revolutions per minute (RPM) based on the wind speed at the kitchen and bathroom exhaust openings and the outdoor wind speed at the rooftop, which were previously measured during the monitoring of the facility shaft.

Table 1. Performance Experiment Parameters

Items	Parameter		
Test-1	[Ev]:1~7$^{m}/_{s}$	[Ov]:1$^{m}/_{s}$	[Od]: 0°
Test-2	[Ev]: 2$^{m}/_{s}$	[Ov]:1~7$^{m}/_{s}$	[Od]: 0°
Test-3	[Ev]: 2$^{m}/_{s}$	[Ov]: 2$^{m}/_{s}$	[Od]:0~180°

[Ev]: Exhaust wind velocity ($^{m}/_{s}$), [Ov]: Outdoor air wind velocity ($^{m}/_{s}$), [Od]: Outdoor air wind direction (°)

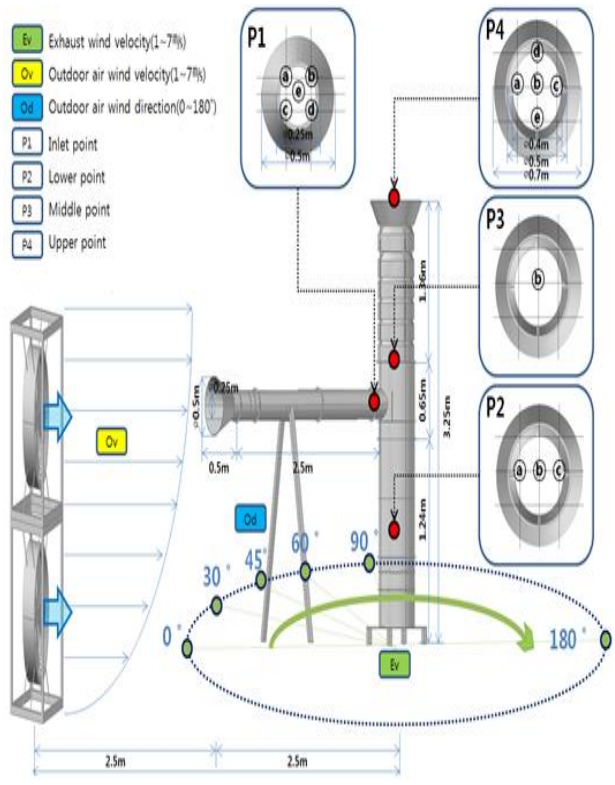


Fig.3. Location of Measuring Points on Basic Model

3.2 Analysis of Air Current Distribution in Performance Experiment

In Test-1, when the outdoor wind velocity is 1 m/s, the direction of the outdoor air induction module is equated to 0° with respect to the outdoor wind direction, and the air current distribution is analyzed by changing the exhaust wind velocity from 1 m/s to 7 m/s in stages as shown in Fig.4. At P1, the outdoor air with a velocity of 1 m/s flew in from the induction inlet through the induction pipe, and leads to the exhaust wind velocity loss ranging between 0.2 m/s to 0.5 m/s due to resultant pipe friction loss. At P2, the exhaust of 1 m/s to 7 m/s joins the outdoor air and leads to an increase in velocity by 0.4 m/s on an average. At P3, the velocity of the exhaust increased by 0.9 m/s on average due to the ascending air current. And at At P4, since the exhaust increased in velocity by 1.4 m/s on an average due to the cumulative effect of 6 induction units added, it seems that even with a weak outdoor air with a velocity of 1 m/s, if the exhaust with a velocity greater than 2 m/s is ensured, the driving velocity (3 m/s) needed for wind power generation can also be ensured.

In Test-2, on the basis of the results of Test-1, the air current distribution was analyzed as shown in Fig.5. by stepwise changing the outdoor air wind velocity from 1 m/s to 7 m/s, with the exhaust wind velocity of 2 m/s and the outdoor air wind direction at 0°. At P1, it is important to adjust the appropriate length of the induction inlet because of the loss in the wind velocity

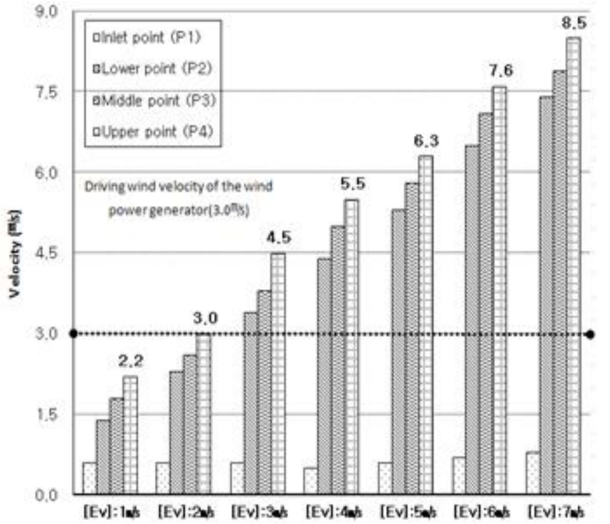


Fig.4. Air Current Distribution According to Changes in the Exhaust Wind Velocity (Ev: 1-7^{m}/s, Ov: 1^{m}/s, Od: 0˚)

loss by 50 – 63% due to pipe friction loss as seen in Test-1. Furthermore, as the outdoor wind velocity increases, the wind velocities at P2 to P4 also increase by 1.9 m/s to 3.1 m/s. Thus, if the outdoor wind velocity is increased by 2 m/s, it is possible to ensure the driving wind velocity of 3 m/s that is needed for wind power generation.

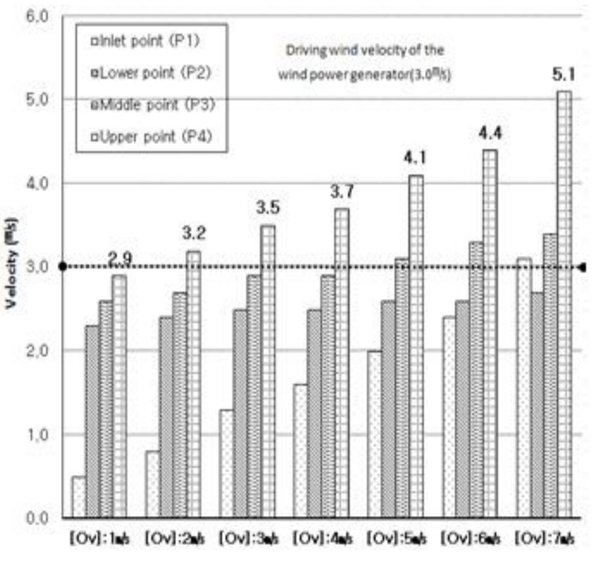


Fig.5. Air Current Distribution According to Changes in the Outdoor Air Wind Velocity (Ev: 2^{m}/s, Ov: 1-7^{m}/s, Od: 0˚)

In Test-3, on the basis of the results of Test-1 and Test-2, the air current was analyzed as shown in Fig.6. by changing the outdoor air wind direction to 0° for main wind, 30 to 90° for cross wind, and 180˚ for tail wind — with both the exhaust wind velocity and outdoor air wind velocity at 2 m/s. As the outdoor wind direction changes between the range of 0 and 180°, the wind velocity reduction at P1 is found to be the smallest at 0° with respect to the main wind direction. The wind velocity decreases remarkably at 30 to 90° of the cross wind direction and at 180° of the tail wind direction. Since the inlet angle becomes greater than 30° with respect to the cross wind direction, the wind velocities at P2 to P4 show lesser increase., The smaller the angle (°) between the outdoor air induction module and the main wind direction, the more advantageous it is to secure the driving wind velocity (3 m/s) that is needed for wind power generation.

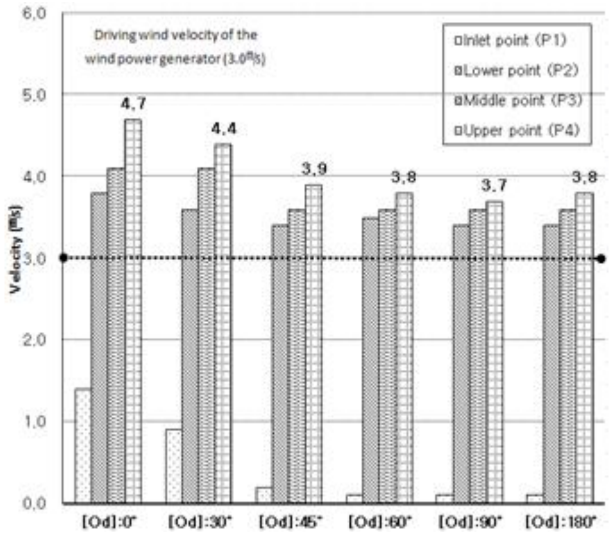


Fig.6. Air Current Distribution on the Basis of Changes in the Outdoor Air Wind Direction (Ev: 2^{m}/s, Ov: 2^{m}/s, Od: 0-180˚)

4. Performance Improvement and Evaluation of the Field Application Experiment

4.1 Performance Improvement and Conditions of the Field Application Experiment

Before installing the basic model of the proposed small-sized wind power generator at the end of the exhaust openings of kitchens and bathrooms on building rooftops for field application experiments, the problems arising from the laboratory performance experiments were resolved.

The performance of the wind power generator was improved so as to automatically rotate it in the direction of the main wind using wind direction rudder, which is installed in the rear side of the rotation body of a generator. When the outdoor air wind velocity is 3 m/s, by shortening the length of the induction inlet and the induction pipe of the outdoor air induction module, to minimize the inflow wind velocity loss by the pipe friction loss as shown in Fig.7., and by enabling the stationary generator support fixture to rotate at 360° in response to the seasonal outdoor air wind direction, the performance of the generator can be improved. Furthermore, after installing a weather measuring equipment and the improved power generator on the rooftop of the 18-story apartment building, wind velocity sensors were installed at the same measurement points (P1–P4) as in the laboratory performance experiment to measure the air current distribution and amount of power generation depending on usage factor [α] of 33–100% of the kitchen hoods and the bathroom exhaust fans as shown in Table 2.

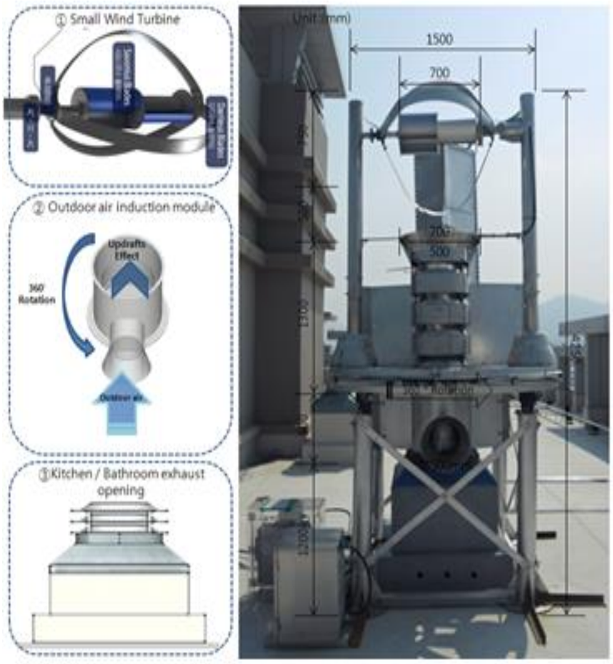


Fig.7. Application of the Improved Model to the Building Rooftop

Table 2. Parameters of the Field Application Experiment

Experimental parameters		Setting conditions		
Exhaust air volume variable	Kitchen	430^{CMH} $(3.7^{m}/s)$	Number of operations 02~18F	
	Bathroom	90^{CMH} $(1.2^{m}/s)$		
Usage factor variable	Zone [α]	[α]=33%	[α]=66%	[α]=100%
	13-18F	●	●	●
	07-12F	-	●	●
	02-06F	-	-	●
Generation compared		[α]=66%	Unapplied	
		[α]=33~ 100%	Application	

4.2 Analysis of the Air Current Distribution and Amount of Generation of Field Application Experiments

When the outdoor air wind velocity was in the range of 2.57 m/s to 3.21 m/s as shown in Fig.8., the exhaust wind velocity was found to be in the range of 1.26 m/s to 2.35 m/s depending on usage factor of the kitchen hoods and the bathroom exhaust fans. As the outdoor air with a velocity of 1.08 m/s to 1.96 m/s passed in the horizontal direction from P1 through P2 and P3 and combined with the exhaust air in the vertical direction to ascend, the measured wind velocities at the respective usage factors [α] 33%, 66%, and 100% were 3.64 m/s, 4.72 m/s, and 4.8 m/s respectively at P4 so that the driving wind velocity (higher than 3 m/s) needed for wind power generation can be smoothly ensured.

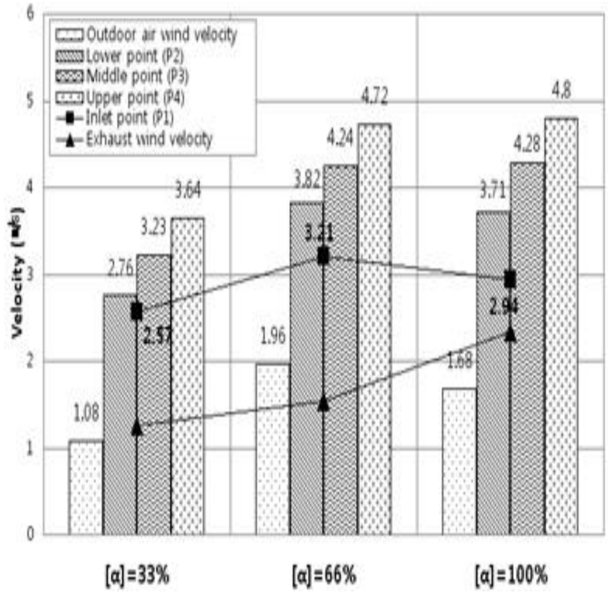
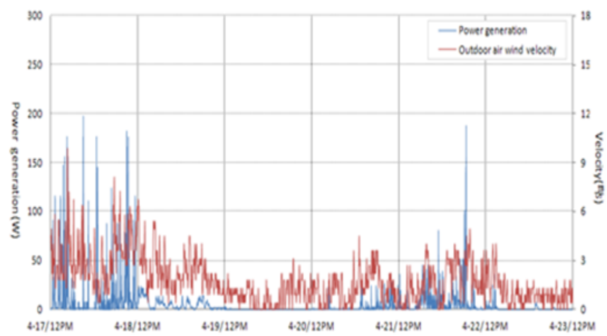


Fig.8. Air Current Distribution According to Usage Factors

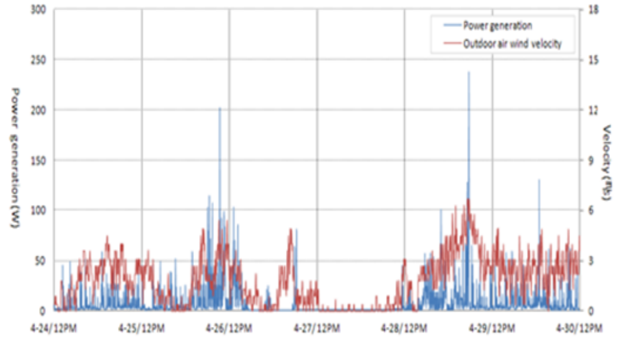
The total generation of the existing exhaust openings of kitchens and bathrooms was 44,551 Wh, which corresponds to on average of 309.4 Wh/h, at [α]=66% as shown in Fig.9., whereas when the outdoor air induction module is applied, the total generation of the existing exhaust openings of kitchens and bathrooms was 57,894.3 Wh, which corresponds to 402.1 Wh/h on an average, indicating that the increase in the wind velocity by the outdoor air induction also increased the amount of generation by 29% as shown in Fig.10.



Date(2013)	4/17~4/23
Cumulative Power(Wh)	44,551
Hourly Power(Wh)	309.4
The main wind direction	SW
Wind speed/Average($^{m}/s$)	0.13~9.42 / 1.85

Fig.9. Amount of Generation of the Existing Exhaust Openings of Kitchens and Bathrooms ([α]=66%)

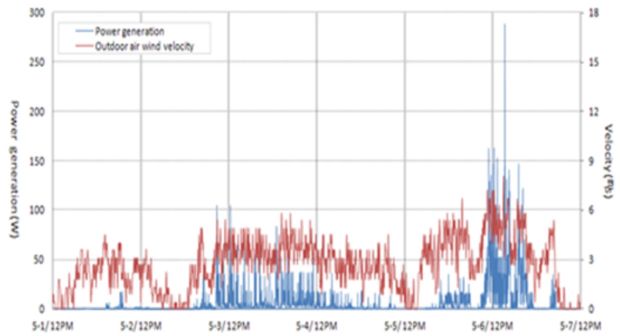
The cumulative generation at different usage factors [α] = 33%, 66%, and 100% was 4,231 Wh, 16,129 Wh, and 31,772 Wh respectively in the most frequent southwest wind and at the average outdoor air wind velocity of 1.88 m/s to 3.21 m/s as shown in Fig.11. Accordingly, the measured average amount of generation per hour at different usage factors [α]



Date(2013)	4/24~4/30
Cumulative Power(Wh)	57,894
Hourly Power(Wh)	402.1
The main wind direction	SW
Wind speed/Average ($^m/_s$)	0.25~6.4/1.84

Fig.10. Amount of Generation According to the Installed Outdoor Air Induction Module ([α]=66%)

= 33%, 66%, and 100% was 88.1 Wh, 336 Wh, and 661.9 Wh respectively. It is so because the lowest average outdoor wind velocity of 1.88 m/s at [α]=33% led to a decrease in the amount of generation, whereas the velocity of the average outdoor wind, which flowed into the outdoor air induction module, was found to be the highest at 3.21 m/s at [α]=100% and the average hourly amount of generation also increased by 325.9 Wh at [α]=100% in comparison to [α]=66%.



Date(2013)	5/1~5/2	5/3~5/4	5/5~5/7
	[α]=33%	[α]=66%	[α]=100%
Cumulative Power(Wh)	4,231	16,129	31,772
Hourly Power(Wh)	88.1	336	661.9
The main wind direction	SW	SW	SW
Average wind speed($^m/_s$)	1.88	3.02	3.21

Fig.11. Amount of Generation According to the Usage Factor when Installing the Outdoor Air Induction Module ([α]=33-66%)

5. Conclusion

This study focusses on the performance experiments of small-sized wind power generation using the outdoor air and exhaust, and the findings are summarized as follows.

Firstly, the survey results of current building conditions show that the wind power generator proposed in this study is most efficiently applied to exhaust openings of kitchens and bathrooms, where the air can vertically flow from lower to higher floors.

Secondly, the performance experiment results show that a specific driving wind velocity (3 m/s) should be ensured to apply wind power generators to exhaust openings of kitchens and bathrooms. Consequently, the driving wind velocity, which is needed for wind power generation, can be ensured by maintaining the angle between the outdoor air induction module and the main wind direction within ±30°, with the outdoor air and exhaust at a velocity greater than 2 m/s.

Lastly, the field application experiment results show that when the outdoor air induction module is applied, the occurring wind velocities at the respective usage factors [α] = 33%, 66%, and 100% were found to be 3.6 m/s, 4.8 m/s, and 4.7 m/s respectively so that the driving wind velocity required for wind power generation can be smoothly ensured. Furthermore, while installing the outdoor air induction module, the amount of generation increases by 29% in comparison to that from the existing exhaust openings of kitchens and bathrooms. Both the usage factor and the outdoor air wind velocity increases, and the amount of generation also tends to increase proportionately increase in the order[α]=100% > [α]=66% > [α]=33%.

The results mentioned above confirm that the wind power generation using the outdoor air and exhaust has a potent applicability, so as to raise the possibility of practical use. However, further studies for ensuring the structural stability against instantaneous gusts or typhoons on building rooftops and for miniaturizing and lightening structures, are required.

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