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Field Experiment of the Measures to Control the Stack Effect in Stairwell of Building

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Abstract **-** In a high-rise building, stack effect occurs through a vertical passage, such as stairwell or elevator shaft due to a difference in indoor-to-outdoor temperature in winter and summer. Since this stack effect leads to adverse effects in terms of residential environment, energy and disaster prevention, there is a need to come up with the measures to control the pressure difference caused by the stack effect. In a recent research, a circulation-type stack effect control device for performing air supply and exhaust using a blower and a vertical airduct has been proposed as a method for active and quantitative control of the stack effect. In this study, useful measures that can control the stack effect in the stairwell of a high-rise building were developed through field experiments in a situation where the stack effect occurs, and the feasibility of the proposed stack effect control technique was reviewed through a full-scale experiment in the actual building during the winter season.

Keywords**:** Stack effect; Pressure difference; High-rise building; Stairwell; Field experiment

1. Introduction

In a high-rise building, stack effect occurs in a vertical passage, such as stairwell or elevator shaft due to a difference between indoor and outdoor temperatures in winter and summer. Due to the stack effect, air outside the building enters the room on the lower floors of the high-rise building while indoor air is discharged to the outside on the upper floors. In addition, a pressure difference between indoor and outdoor and compartments inside occurs in each floor.

The pressure difference formed in the building due to the stack effect can be theoretically obtained by the following Equation (1).

$$\Delta P_{st} = g\Delta\rho(N-h) = g\rho_O(\Delta T/T_i)(N-h) \tag{1}$$

where ΔP_{st}represents the pressure difference caused by the stack effect(Pa), g the gravitational acceleration(m/s^2), h the height of measurement point(m), N the height of neutral zone(m), T_i the room temperature(K), and ρ_O the outdoor air density(kg/m^3), respectively.

Thus, if flow occurs and the pressure difference between compartments is caused due to the stack effect, adverse effects occur in terms of residential environment of the high-rise building, energy and disaster prevention. For instance, the heating energy loss caused by the stack effect is estimated at about 5-10 % in case of the high-rise building. In terms of residential environment, opening and closing the doors is difficult or a malfunction of the elevator may occur. In addition, high-frequency noise generated through the gap of evacuation door or elevator door may cause a serious problem. Therefore, the development of control technology on the stack effect are needed in order to improve the energy and environmental performance in high-rise building.

So far, the analysis of the stack effect in buildings and the study on improvement directions have been underway.

The change in pressure caused by the stack effect was measured in a high-rise office building and the pressure-generation characteristics were analyzed using a thermal draft coefficient [1]. Empirical experiments of the stack effect were performed in two high-rise residential buildings for analysis and the method to control the stack effect by using an air-lock door was proposed [2].

The pressure change due to the stack effect was measured and analyzed through the field experiments conducted in a

39-story office building and the problems caused by the stack effect and complementary measures were investigated [3]. In addition, the architectural factors to the stack effect in high-rise buildings were selected to perform the simulation of a network model and the quantitative evaluation of the factors was conducted [4]. In line with the increase in number of high-rise residential buildings, the influence caused by the stack effect in Korean buildings with the architectural and mechanical characteristics for residential purpose was identified through the measurement and simulation [5, 6].

In the field of fire safety, many studies focusing on safe evacuation were conducted through the suggestion of countermeasures and analysis on the stack effect in the vertical evacuation route. Kim and Lee [7] proposed the method to control the stack effect of elevator shaft by pressurizing elevator shaft while reducing the pressure difference between elevator shaft and living room, and Son and Kim [8] pointed the problems that might be caused by the creation of overpressure or the performance degradation in pressurization system of smoke control due to the stack effect in winter and proposed the air supply of lower stairwell, simultaneous pressurization of stairwell and lobby and installation of overpressure relief damper. Kim [9] analyzed the results of the field experiments on pressurization system of smoke control which were conducted in winter and summer and pointed the problems of overpressure formed between lobby and stairwell due to the rise in pressure at the upper level of the evacuation stairs when stack effect and pressurization effect are combined in winter.

On the basis of the previous studies, a review of the method to effectively control the stack effect should be performed in order to analyze the stack effect in the vertical passage of a high-rise building, and thus to provide pleasant and safe environment in the building. The current method applied to control the stack effect in the high-rise building is an architectural approach for minimizing the penetration of air in a way of increasing the air tightness of outer wall or installing a windproof room or for dispersing the indoor pressure difference by installing a double door. In addition to this method, it is necessary to review a method in terms of facility for active and quantitative control of the stack effect.

In this study, useful measures that can control the pressure difference caused by the stack effect in the stairwell of a high-rise building were developed through field experiments in a situation where the stack effect occurs, and the feasibility of the proposed stack effect control technique was reviewed through a full-scale experiment in the actual building during the winter season.

2. Field Experiment

2.1. Field experiment methods

In this study, a field experiment was conducted using the method to control the stack effect in stairwell of a high-rise building (I Building) located in Seoul during winter season when the stack effect becomes great. I Building has a 21 stories above the ground and 6 stories below the ground and has two stairs and seven elevators as a business and complex facility. Fig. 1 shows the foreground and internal structure of I Building. As shown in the figure, it is connected from the corridor of each floor to the stair through the lobby and the stair serves the vertical passage from B6 level to the rooftop.

(a) Whole view. (b) Corridor at 21st floor. (c) Stair and lobby.

Fig. 1: Photograph of building structure.

Fig. 2 shows the overview of the field experiment on stack effect control method. As shown in the figure, the stack effect control equipment and various measuring devices were installed on the stair of I Building. The stair was designed to be connected to the rooftop after going up one floor from the 21st floor and in the experiment, a blower was installed in space right in front of the entrance leading to the rooftop. The steel duct with a certain length was connected to the outlet of the blower and installed by extending a flexible airduct vertically to the first floor. Through the installation of air flow passage, a system was configured to exhaust air within the stair from the upper part of the stair through a blower and supply air in the lower floor.

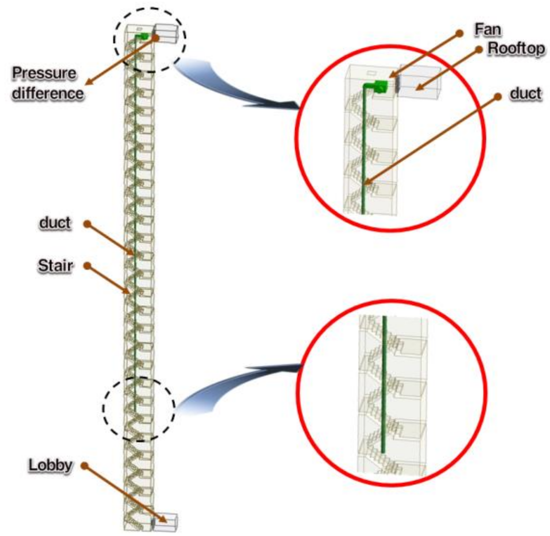

Fig. 2: Schematic diagram of field experiment condition.

For measuring the change in pressure caused by operation of the blower and indoor/outdoor temperature at the time of the experiment, indoor temperature on the corridor of the 21st floor(T_i), outdoor temperature on the rooftop (T_o), pressure difference of stairwell and outside on the rooftop of the 21st floor (ΔP_{TOP}), pressure difference of stairwell and corridor on the 21st floor ($\Delta P_{21F,COR}$), pressure difference of stairwell and lobby on the 21st floor ($\Delta P_{21F,LOB}$) and flowrate of the blower (Q_f) were measured, respectively.

Fig. 3 shows the experimental process of the method to reduce the stack effect. Fig. 9(a) shows a blower installed in the uppermost part of the stair and Fig. 9(b) shows a steel duct connected to the outlet of the blower. Fig. 9(c) is a flexible airduct installed vertically from the upper part of the stair to the first floor. Meanwhile, Fig. 9(d) shows a logging system to collect and record the measured data.

(a) Blower. (b) Steel duct. (c) Flexible duct. (d) Logging system.

Fig. 3: Photograph of experiment facilities.

In the field experiment on the stack effect control method, the measurement was performed under conditions where a blower was not operated and then the blower was operated to increase the air flowrate up to about 150 CMM by the unit of about 25 CMM.

2.2. Field experiment results

Fig. 4 shows the measurement values of the indoor temperature(T_i) and outdoor temperature(T_o) measured during the test. The average indoor temperature was about 14.4 ℃, and the outdoor temperature was about -6.9 ℃. The difference between the indoor and outdoor temperature was about 21.3℃ which was determined an average value.

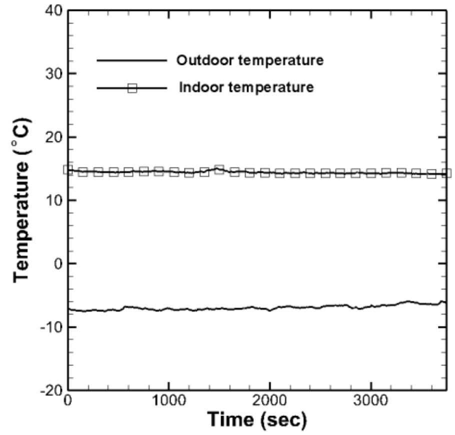

Fig. 4: Variations of indoor and outdoor temperature.

Fig. 5 shows the pressure difference (ΔP_{TOP}) of the stairwell and the outside of the rooftop on the 21st floor and air flowrate of a blower (Q_f) depending on the experimental time. As shown in the figure, the pressure difference caused by the natural stack effect was measured at the initial stage of the experiment and then the change in the pressure difference depending on the air flowrate was measured by increasing the air flowrate at about 300-second intervals from 400 seconds when a blower starts operating. The measurement results showed that as the air flowrate of a blower increases, the amount of air flowing into the vertical passage of the stairs increases as well and thus the pressure difference between the stairwell and the outside is gradually reduced.

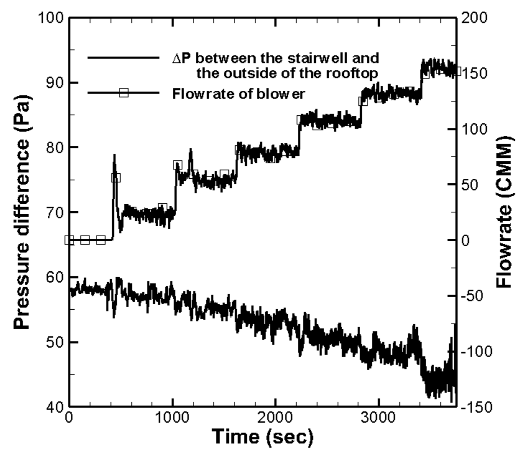

Fig. 4: Variations of pressure difference and flowrate on rooftop.

Fig. 5 shows the average value of the time obtained with respect to the experimental results of Fig. 4. That is, it's the result obtained by selecting the section with constant air flowrate from the experimental results of Fig. 4 and by calculating the average value on the pressure difference between the outside and the stairwell of the rooftop in each section. As shown in the figure, the pressure difference between the outside and the stairwell that occurred due to the stack effect becomes about 58.1 Pa under the conditions of indoor/outdoor temperature of the experiment and the building for the field experiment. Meanwhile, if the air flowrate becomes about 155.1 CMM after the operation of stack effect control device, the pressure difference between the outside and the stairwell becomes about 44.3 Pa, which is a reduction of about 13.8 Pa in comparison with the pressure difference caused by the natural stack effect. In addition, depending on the air flowrate of the stack effect control device, the pressure difference between the outside and the stairwell on the rooftop is reduced on quadratic characteristics. The experimental results of Fig. 5 confirmed that the stack effect control method proposed in this study could control the pressure difference caused by the stack effect that occurs in a high-rise building in winter.

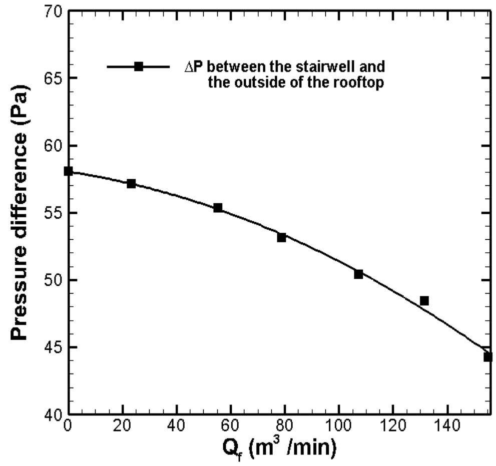

Fig. 5: Average of pressure difference on rooftop.

Fig. 6 shows the changes in the pressure difference between corridor and stairwell on the 21st floor(($\Delta P_{21F,COR}$)and the pressure difference between lobby and stairwell on the 21st floor(($\Delta P_{21F,LOB}$) in the same experiment above. As shown in the figure, each pressure difference also shows a tendency to decrease due to an increase in air flowrate of a blower, which is similar to the results of Fig. 4. Meanwhile, the scale of pressure difference on stairwell-corridor and stairwell-lobby is smaller than the pressure difference between the outside and the stairwell on the rooftop, which is attributable to the fact that total pressure difference formed between the stairwell and the outside is distributed to the pressure difference between the several compartments.

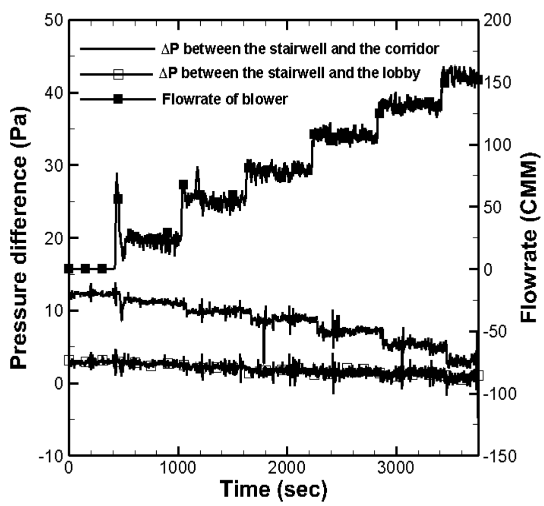

Fig. 6: Variations of pressure difference and flowrate on 21st floor.

Fig. 7 shows the average value of the time with respect to the experimental results of Fig. 6. As shown in the figure, the pressure difference between stairwell and corridor on the 21st floor is reduced to about 3.0 Pa when the pressure difference of about 12.3 Pa is formed due to the natural stack effect, and the air flowrate of the stack effect control device is about 155.1 CMM. Meanwhile, the pressure difference between stairwell and lobby on the 21st floor is reduced from 2.9 Pa to 0.7 Pa.

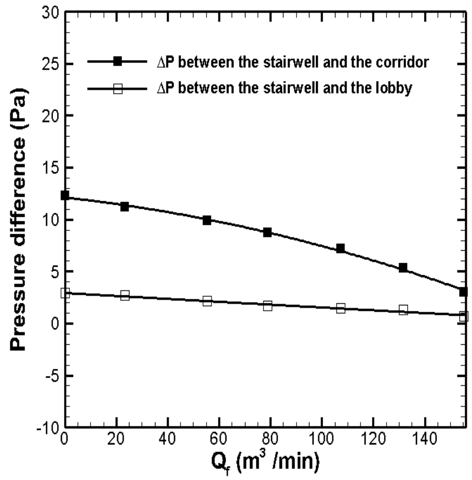

Fig. 7: Average of pressure difference on 21st floor.

3. Conclusion

This study proposed a circulation-type stack effect control method to control the pressure difference caused by the stack effect in stairwell of a building by using air supply and air exhaust. In addition, the performance of the proposed method was evaluated through the field experiments. The following conclusions were obtained as below.

In case the indoor temperature is 14.4 ℃ and outdoor temperature is –6.9 ℃ on the stairs of 124m height, a positive pressure of 58.1 Pa is formed on the stairs of the top floor due to the stack effect.

If the circulation-type stack effect control method that supplies air through air supply grille from the lower part of the stair and exhausts air through air discharge grille in the upper part of the floor is operated, the pressure difference caused by the stack effect in stairwell of the building decreases. If the circulation-type stack effect control method is applied and the air volume of 155.1 CMM is operated under conditions where the indoor temperature is 14.4 ℃ and the outdoor temperature is –6.9 ℃ on the stairs of a 124m height, the pressure difference caused by the stack effect on the stairs of the top floor decreases by about 13.8 Pa.

In case the circulation-type stack effect control method is applied, the pressure difference that occurs on the stairs of high floor due to the stack effect decreases on the relationship of quadratic characteristics with an increase in air flowrate.

Acknowledgements

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