Development of an Air Duct Damper to Prevent Backflow Odor from the Ventilation Shaft in Buildings

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Abstract

Nowadays, backflow odor, along with floor noise, has been recognized as an environmental right dispute element between the units within a multi-unit dwelling in Korea because it causes not only foul odors flowing back into the unit vent pipe to flow indoors and cause a problem of degraded air quality but also annoyance by foul odors and steam in balconies and bathrooms. Therefore, this study relates to the performance improvement of bathroom air duct facilities in multi-unit dwellings. This study aims to develop an automatic backflow preventive damper capable of reducing the air leakage rate in comparison to conventional air duct dampers and verify the backflow blocking performance of the automatic backflow preventive damper.

As a result, unlike the existing damper, where air in the space assumed a bathroom was foggy because of the large amount of air leakage, the dry ice gas did not flow backwards to the bathroom in the space, where the automatic backflow preventive damper was applied. In addition, it was verified that the automatic backflow preventive damper had an excellent air leakage blocking performance of 98.6% compared to the air leakage blocking performance (80%) of the existing damper.

Keywords: backflow odor; air duct damper; vent pipe; ventilation shaft; air leakage

1. Introduction

Korea has a relatively small territory in comparison to its population. Accordingly, housing forms of multi-unit dwellings (apartments) were developed according to the country's topographic characteristics. A multi-unit dwelling refers to a housing structure, where each unit shares all or a portion of the walls, corridors, stairs, or other facilities of a building and has independent residential spaces within the building\(^1\). Recently constructed multi-unit dwellings are high-rise buildings with 40 stories or higher, which are designed as towers to increase the number of units in limited spaces. Consequently, the differences in the pressure distributions between the upper and lower floors are naturally formed. Furthermore, air frequently flows within the buildings as in the case of a stack effect\(^2\)-\(^5\).

The ventilation method used in the bathrooms of most multi-unit dwellings is moving and collecting foul odors discharged through the vent pipe of each unit in a ventilation shaft to discharge them to the atmosphere through a ventilator located on the uppermost portion of the ventilation shaft. However, sufficient ventilation cannot be obtained if this method is applied to a high-story building because of the low applied pressure of conventional ordinary bathroom ventilation fans. Moreover, the foul odors collected in the ventilation shaft flow backwards to the vent pipe of each unit if the pressure or temperature within the ventilation shaft of a multi-unit dwelling becomes higher than the pressure or temperature within the vent pipe of each unit, while the intake output of the ventilator of the ventilation shaft weakens or the bathroom ventilators are stopped\(^6\)-\(^8\). These cause the foul odors to flow back into the unit vent pipe to flow indoors and cause a problem of degraded air quality. Foul odors and steam constantly linger in the balcony, bathroom and kitchen,
thereby making the residents feel unpleasant. This phenomenon is referred to as the backflow odor (Fig. 1.).

In Korea, the backflow odor, along with floor noise, has recently been recognized as an environmental right dispute element between the units within a multi-unit dwelling. The causes and transfer paths of floor noise are easily obtained to clearly determine faults using the environmental dispute mediation law\(^{9(10)}\). However, the backflow odor sources are hard to find in most cases because the backflow odor is moved by the airflow through the bathroom and kitchen vents, balcony windows, and openings. Numerous environmental dispute cases have been raised lately because cigarette smoke within the units among the types of backflow odors has a property of rapid dispersion via the abovementioned path. Consequently, the residents of the multi-unit dwelling react sensitively to the harmfulness of second-hand smoking.

The research results of the National Institute of Environmental Research of the Ministry of Environment indicated that if one smokes a cigarette in the bathroom of a multi-unit dwelling while turning on the ventilator, the smoke flows into each unit within 5 min. Furthermore, the fine dust (PM10) concentration measured in the affected units increases by 15–20 μg/m\(^2\) when two cigarettes are smoked, with the influence of the cigarettes lingering over an hour\(^{11}\). Accordingly, the Ministry of Land, Infrastructure and Transport promulgated an amendment to ‘the rules related to the housing construction standards and the likes’, including the ventilation facility standards on March 17, 2015, to resolve the discomfort caused by odors and smoke produced in kitchens and bathrooms, among other spaces, of adjacent units in a multi-unit dwelling\(^{9)}\).

The main content of the amendment is applicable to newly constructed multi-unit dwellings. It mandates that automatic backflow preventive dampers or ventilation facility apparatuses of equivalent capabilities be installed in the vent pipes within the units. In addition, the vent pipes of the units should not be connected to each other and be installed to be directly opened to the open air. Constructing individual systems increases the construction costs for multi-unit dwellings.

Hence, most of the construction companies are reluctant to adopt the law. Automatic backflow preventive dampers are being used as the best alternative. However, as mentioned in Chapter 2, conventional air duct dampers do not structurally provide a backflow preventive performance. Therefore, the current law is not very effective even if legal standards were suggested.

Therefore, this study relates to the performance improvement of bathroom air duct facilities in multi-unit dwellings. This study aims to develop an automatic backflow preventive damper capable of reducing the air leakage rate in comparison to conventional air duct dampers and verify the backflow blocking performance of the automatic backflow preventive damper. In addition, an automatic backflow preventive damper system was developed to resolve the backflow odor problem caused by the backflow phenomenon inside pipes, which is attributed to the ventilation shaft piping structure of a multi-unit dwelling. The developed damper system aims to improve the indoor air quality of the multi-unit dwelling and resolve conflicts and disputes between the units in the multi-unit dwelling.

2. Background

2.1 Status of Backflow Odors in Korea

The backflow odors in the multi-unit dwelling were produced in the living environments of the occupants, such as food odors, cigarette smoke, and foul odors inside the pipes. Among the causes of the backflow odors, second-hand smoking by cigarette smoke had the biggest influence on civil complaints between the units.

The analysis results of the Anti-Corruption and Civil Rights Commission regarding backflow odors revealed that 1,025 civil complaints related to the harmfulness of second-hand smoking in multi-unit dwellings have been filed with the e-People Officer in the last four years (January of 2011 to October of 2014). The civil complaint distribution by types of multi-unit dwellings turns out to be 96.7% of apartments and 3.3% of row houses and multiplex houses (Fig.2.). The 2012 records indicated that the number of multi-unit dwelling households in Korea was 10.104 million (57% of the entire households). The ratios of apartments and row houses/multiplex houses are 82.2% (8,308 thousand) and 17.8% (1,796 thousand), respectively\(^{11}\).

The locations affected by second-hand smoking from cigarette smoke, which is the biggest cause of the backflow odors, were inside houses (53.7%) (i.e., balconies and bathrooms, common areas of buildings (31.9%) (e.g., corridors and stairs), areas around lower floors (12.6%) (e.g., playgrounds within a complex outside the buildings), and basement garages (1.8%), in the order listed) (Fig.3.). A multi-unit dwelling...
inherently has a structure ventilated by a ventilation shaft. Therefore, foul odors are inevitably transferred between the units inside the multi-unit dwelling.

The Ministry of Land, Infrastructure and Transport promulgated an amendment to ‘the rules related to the housing construction standards and the likes’, including the ventilation facility standards on March 17, 2015, to resolve the discomfort caused by odors and smoke produced in kitchens and bathrooms, among other places, of adjacent units in a multi-unit dwelling. The amended provision related to the backflow odors newly added the following content as the sixth clause to the existing Article 11 of the rules related to the housing construction standards and the likes: automatic backflow preventive dampers (facilities of a structure automatically opened and closed by electric or mechanical force if ventilation ports in units are opened or electric ventilation facilities operate) or ventilation facility apparatuses of equivalent capabilities shall be installed in the vent pipes inside the units. In addition, the vent pipes of the units shall not be connected to each other and be installed to be directly opened to the open air (Fig.4.).

2.2 Structural Vulnerability of Backflow Preventive Damper

These rules related to the housing construction standards and the like mandated the installation as resolution measures for backflow odors. However, applying individual ventilation duct structures to multi-unit dwellings are practically impossible. Therefore, employing automatic backflow preventive dampers are necessary in preventing the backflow between the units through the ventilation shaft of multi-unit dwellings.

The automatic backflow preventive damper is a ventilation facility apparatus installed inside a ventilation pipe or on the upper end of a ventilator to block air leakage inside the pipe caused by the backflow. The damper has a structure, where the opening and closing plates of a vane shape are mounted on a shaft in the middle of a circular body (Fig.5.). The opening and closing plates are opened by wind pressure applied to the lower portions of the opening and closing plates when the ventilator located below the plates is operated. The opening and closing portions are also closed by gravity when the ventilator stops operating, and the wind pressure applied to the lower portions of the plates dissipates. However, the conventional damper can easily form gaps around the shaft because of its structural features for opening and closing (Fig.5.). Such gaps are the direct cause of the loss of the function of the damper constructed to prevent backflow, block foul odors, and allow them to flow backwards from the ventilation shaft to flow indoors, instead of blocking them from degrading the indoor air quality.

Therefore, an automatic backflow preventive damper with a structure differentiated from the conventional air duct damper and improved airtightness, as in the background of the study, needs to be developed.

3. Research Methods

3.1 Development of an Automatic Backflow Preventive Damper

As mentioned in Chapter 2, the conventional air duct damper has opening and closing plates, such as valves with a fixed pin between the plates in the middle. The structural air leakage occurs through the gaps. The
automatic backflow preventive damper to be developed in this study breaks from the conventional method. Moreover, a system was designed with the following development standards:

- An opening/closing plate should not be divided in the damper.
- The damper should be completely sealed when a ventilation fan is not operated.
- The opening/closing plate should move when the ventilation fan is operated to efficiently perform a damper function.
- The damper should be designed to have the same size with the conventional damper to secure replaceability and durability.

The design plans were modified to meet the abovementioned conditions and develop the automatic backflow preventive damper, as in Fig.6.

![Fig.6. Structure of the Automatic Backflow Preventive Damper and a Prototype for Tests](image)

The automatic backflow preventive damper developed by this study has a structure, where a chip-shaped damper embedded in a cylindrical damper body is lifted and lowered to open and close the damper. The damper lifts the chip embedded in the damper by wind pressure produced when a ventilator located below the damper operates to open the damper and ventilate by itself. The damper then lowers the chip by gravity when the ventilator stops operating to dissipate the wind pressure applied to the lower portion of the damper to close the vent pipe. These structural features prevent an inflow of foul odors flowing backwards in the ventilation shaft even when the ventilation fan is not driven.

The damper body is formed into a mesh shape and operates as a passage for air to escape for ventilation by the ascent and descent of an inner damper membrane. The damper was constructed with a diameter of 100 mm and a height of 40 mm. These values are the dimensions of a ready-made damper to replace an existing bathroom air duct damper in a building. They were used throughout the study.

3.2 Outline of the Ventilation Performance Tests of the Automatic Backflow Preventive Damper

A test structure was constructed (Fig.8.) and used in the evaluation to assess the ventilation performance of the automatic backflow preventive damper developed in the structure explained in Section 3.1. The test body for the performance evaluation was made of a transparent acrylic material to measure the smoke dispersion and concentrations inside the pipes. The size of each pipe was assumed to be equal to the size of a real ventilation pipe. The pipes were made accordingly. Assuming a bathroom, a ventilation fan was installed on a seal measuring 500 mm x 500 mm on the lower end. The damper was fixed on the upper end of the ventilation fan. A holder for placing dry ice, which produces CO$_2$, was then constructed on the upper portion and used. Buttons were connected to the ventilation fan to efficiently operate the ventilation fan according to the test conditions. Moreover, a CO$_2$ meter was installed in the bathroom space on the lower end to measure the CO$_2$ concentrations flowing backwards.

![Fig.7. Measurement of CO$_2$ Concentration](image)

Table 1. shows the test conditions for the ventilation performance evaluation of the automatic backflow preventive damper. The CO$_2$ measurement range was 0–3,000 ppm. The measurement values were acquired for 0–3,600 s at 10 s intervals. The measured data were examined for changes in the amounts of air leakage based on an average of 525 ppm, which was the CO$_2$ concentration prior to the measurements. In addition, the amounts of the damper air leakage were converted into percentages, and then reconverted into blocking ratios to analyze the ventilation performance of the automatic backflow preventive damper. The temperature inside the test apparatus was kept at an average of 24.4°C. The amount of dry ice supplied was 1 cm$^3$. Three tests were conducted per day for 30 days. The result analysis was performed with the average values of 90 measurements.
4. Results

Fig.8. shows a visual verification of how much of the foul odors of the ventilation shaft flowing indoors the existing damper and the developed damper are blocked by mounting the dampers on the test apparatus modeling a bathroom, placing water and dry ice on the dampers, and generating dry ice gas. Unlike the existing damper, where air in the space assumed a bathroom was foggy because of the large amount of air leakage, the dry ice gas did not flow backwards to the bathroom in the space, where the automatic backflow preventive damper was applied. The same results were verified in all the 90 measurements taken three-times a day for 30 days.

Fig.9. shows the ventilation performance test results of the automatic backflow preventive damper. The CO$_2$ concentration of the test apparatus, on which the existing damper was mounted, exceeded 3,000 ppm. This value was the maximum measurable value at a time point of 24 min and 10 s. Further measurements could not be taken. The existing damper recorded 720 ppm at a measurement time of 10 min and 2,280 ppm at 20 min. These results showed that the air leakage rapidly increased. Moreover, this finding indicated that the air leakage blocking performance of the existing damper was inadequate and allowed one to estimate that a substantial amount of the backflow odors flows indoors when extended to the ventilation shaft of a multi-unit dwelling for interpretation.

On the contrary, the CO$_2$ concentration in the case of the damper developed herein was approximately 1,125 ppm, and did not greatly increase even after 1 h elapsed. The air leakage rate of the automatic backflow preventive damper increased by 14.7% on average every 10 min after recording 567 ppm at an early measurement point of 10 min. The measurement value at a time point of 10 min after the test was started showed that no values greatly differed from 525 ppm, which was the average value of the initial CO$_2$ concentration prior to the measurements. The fact that the CO$_2$ concentration gradually increased up to 60 min indicated that the measurement interval for one measurement after 10 min elapsed was a result of the phenomenon, where a portion of the dry ice gas was leaked out of the vent pipe cap connected upwards to flow back into the bathroom as the gas amount of the dry ice placed on the vent pipe of the test body increased.

Table 1. Ventilation Performance Test Conditions

| Test Subject | Experimental group: development damper | Control group: existing damper |
|--------------|----------------------------------------|---------------------------------|
| Measurement Target | Carbon dioxide | Carbon dioxide |
| Measurement Instrument | Carbon dioxide meter | Carbon dioxide meter |
| Measurement Range | ppm/10-sec intervals | ppm/10-sec intervals |
| Number of Measurement | 0~3,000ppm/0sec~3,600sec | 0~3,000ppm/0sec~3,600sec |
| Temperature inside Test Apparatus | 24.4°C on average | 24.4°C on average |
| Initial CO$_2$ Concentration | 525ppm on average | 525ppm on average |
| Amount of Dry Ice Supplied | 1cm$^3$ | 1cm$^3$ |

The measurement test results of the CO$_2$ concentration verified that the automatic backflow preventive damper developed in this study had an excellent air leakage blocking performance compared to the existing damper. The blocking performance calculation results in percentages were calculated based on 24 min and 10 s when the CO$_2$ concentration exceeded 3000 ppm, which was the maximum measurable value. The air leakage amount of the existing damper was 3,000 ppm and that of the development damper 697 ppm. These values verified that the automatic backflow preventive damper developed in this study had an excellent air leakage...
blocking performance of 98.6% compared to the air leakage blocking performance (80%) of the existing damper. The air leakage blocking performance of the existing damper was set based on the product specifications suggested by the manufacturer.

5. Conclusions

This study developed an automatic backflow preventive damper system to resolve the backflow odor problems caused by a backflow phenomenon inside pipes attributed to the ventilation shaft pipe structure of a multi-unit dwelling; improve the indoor air quality of the multi-unit dwelling; and resolve conflicts and disputes between the units of the multi-unit dwelling. The following results are drawn:

1) The backflow odors by the backflow of the ventilation shaft of the multi-unit dwelling cause serious civil complaints. Furthermore, second-hand smoking by cigarette smoking has the biggest influence among the causes of the backflow odors in the multi-unit dwelling.

2) The Ministry of Land, Infrastructure and Transport suggested the standards for the installation of individual ventilation ducts and automatic backflow preventive dampers in multi-unit dwellings to prevent the dispersion of the backflow odors. However, applying individual ventilation duct structures to multi-unit dwellings are practically impossible. Hence, introducing the automatic backflow preventive damper is necessary in preventing the backflow phenomenon between units through the ventilation of the multi-unit dwelling.

3) The existing damper does not satisfy the backflow-preventive and foul odor-blocking function because of the gaps around the shaft by its structural features for opening and closing. Therefore, this study developed an automatic backflow preventive damper with a structure differentiated from the conventional air duct damper and an improved airtightness.

4) The results of the ventilation performance evaluation of the automatic backflow preventive damper developed by this study verified that the forcible ventilation by the ventilation fan realizes the same performance as the existing damper. Moreover, the measured CO\textsubscript{2} concentration at an early measurement point of 10 min in the case of the automatic backflow preventive damper developed in this study was 567 ppm. This value was not significantly different from 525 ppm, which was the average value of the initial CO\textsubscript{2} concentration prior to the measurements. The air leakage rate increased by 14.7% on average after the first 10 min because of the phenomenon, where a portion of the dry ice gas leaked out of the vent pipe cap connected upwards to flow back into the bathroom, as the gas amount of the dry ice placed on the vent pipe of the test body increases.

The abovementioned results showed that the automatic backflow preventive damper developed herein is expected to greatly aid in resolving backflow odors when applied to the bathroom ventilation of the multi-unit dwelling. Future plans for this study include remedies for the phenomenon of reentering CO\textsubscript{2} caused by the test body structure. Additional tests will also be performed using materials for damper commercialization.

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