Proposal of a method for predicting the airtightness performance in a high-rise residential building using pressure difference

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Abstract. Recently, it is real to recognize the importance of airtightness performance and it has become mandatory to measure airtightness performance measurement through various standards in Korea. In Korea, air tightness performance is measured using blower door test based on pressurization / depressurization method. However, the conventional blower door test has various inconveniences and problems in the measurement. This study propose a method of predicting the airtightness performance by using the pressure difference, which can replace the conventional blower door test method that can measure the airtightness performance. In order to verify the method proposed in this study, the predicted results were compared to the measured results using blower door test. The proposed method is similar to the blower door test when compared to the blower door test, but there are some differences. The blower door test is measured by measuring the air flow at several pressure difference conditions (10 ~ 70 Pa) and finding C, n. C and n values can be calculated and the airtightness performance can be obtained by knowing the amount of air passing through the building envelope. However, the only way to measure the airflow through the actual building envelope is the blower door test, which is difficult to measure with other methods. This study measured the pressure difference between the front door and the building envelope, which can be easily measured, and calculated the airflow that pass to the building envelope based on the airflow at various pressure difference conditions shown in the airtightness report of the front door. This is possible because the amount of air flowing in and out under steady state conditions is always the same. Based on this, the airflow was calculated at several pressure difference conditions of the building envelope, and C and n were defined. With this, it is possible to calculate the airtightness performance, the leakage area under various pressure difference conditions. In order to verify the proposed method, this study measures the pressure difference and the airtightness performance of the building using the existing method. The results are as follows; the value of C, n was calculated using the proposed method, and C was about 19.4 and n was about 0.895. The airtightness performance was predicted based on the calculated C and n, and the airtightness performance was calculated to be 3.25 (1/h@50 Pa). When the error rate is calculated as NMSE (Normalized Mean Square Error) for the airtightness performance measured by the blower door test and predicted in this study, NMSE is calculated as 0.01, and the method proposed in this study is reliable because it is included in the reliable range of NMSE 0.25. Proposed method is possible to calculate all the values obtained from the existing blower door test. Therefore, the method can replace the blower door test because both C and n values, airtightness performance, and leakage area under various pressure difference conditions can be calculated.

Keywords. Airtightness performance prediction, Pressure difference, Blower door test, Validation, High-rise residential building
1. Introduction

Today, energy challenges concern the entire building sector, from field workers to researchers. Airtightness and Air infiltration can be responsible for up to 30% of the heating demand in winter [1] and it impacts insulation thermal performances, hygrothermal performances, occupant comfort, ventilation system efficiency and acoustic insulation [2]. At present, there are three types of airtightness performance of curtain wall, component and envelope, and the level of airtightness performance of each item is set by various standards. In addition, Korea is obliged to measure airtightness performance through standard specification of building construction and energy saving design standards of buildings. There are two methods to measure such important airtightness performance, namely, gas tracking method and pressurization / depressurization method. First, the gas tracking method has the advantage of measuring the ventilation rate in the natural state, but it is difficult to find the accurate value because it reacts sensitively to the wind and the temperature. Secondly, the pressurization / depressurization method is a method of obtaining the airtightness performance by measuring the amount of airflow flowing at a given internal / external static pressure difference after pressurization or depressurization using an air conditioning system or a fan. The most representative method is the blower door test. The measurement data obtained from the pressurization / depressurization using the fan determine the values of C and n by the power law, and the airtightness performance is obtained [3]. The problems and limitations of the blower door test can be divided into two types. The first is the problem with preparation and cost. The measuring equipment is very expensive, and it takes about 3 hours to measure one room. In addition, it is impossible to experiment alone. In fact, it is impossible to measure because of loud noises after moving in. In addition, there are many limitations in the measurement. The table shown is the measurement cost of an actual airtightness performance agent, which costs about $2,000 to $25,000 [4]. Next, it is a problem when the measurement is proceeded. First is the problem with difficulty of baseline foundation. Baseline is known Zero-flow pressure difference. Zero-flow pressure difference means the difference between the indoor and outdoor pressure in the state that there is no airflow of the fan (stationary state), and it is described as the zero-flow pressure difference. Baseline must be measured before and after the measurement. In addition, measurement is possible only when the pressure is not over five Pascal. Second, during the measurement courses, the measurement must be measured within the range of 10 to 60 Pa, and one pa is determined by taking 100 points for each pressure range and about 5 to 10 times are recommended. In addition, as the size of the building increases, it is difficult to derive sufficient pressure difference and airflow. As described above, the conventional blower door test for measuring airtightness performance has various problems and many constraints. Since there are many limitations, studies have been conducted to estimate and predict airtightness performance. Based on a database that measures the actual airtightness of various existing buildings, it is possible to calculate the coefficient value according to the characteristics of the building through statistical analysis and apply the coefficient value considering the characteristics of the building or the climatic environment [2, 3, 5-10]. However, if there is no database, it is hard to apply.

Thus, this study propose a new method for predicting the airtightness performance by using the pressure difference instead of using the existing blower door test to measure the airtightness performance. This method is possible because the differential pressure of each part of the building may vary depending on the airtightness performance of the building. In order to verify the validity and reliability of the proposed method, the predicted values and the measured values obtained by the blower door test were compared and verified.

2. Methods

2.1. Outline of the airtightness prediction methods

The blower door test is to find C, n by measuring the airflow at several pressure difference conditions. Then, the airtightness performance was that the airflow at 50 Pa was divided by the volume of the room. In other words, the airtightness performance is obtained by calculating the pressure difference and the air volume measured by the equipment. In fact, the method of measuring the amount of airflow passing through the building envelope is not the only method other than the blower door test. Therefore, this study propose a new method. It measures the front door and the building envelope of the pressure
difference, which can be measured easily, and measures the airtightness performance by calculating the amount of air passing through the building envelope using the airflow of the front door. This is possible because there is an assumption that the volume of air flowing into the front door and the amount of air flowing out of the building envelope are the same in the steady state. The concept of the proposed method is shown in Figure 1.

\[ Q = C(\Delta P)^n \]

- \( Q \): Air flow rate (m³/h)
- \( C \): Air Flow Coefficient (m³/h·Pa)
- \( \Delta P \): Pressure difference (Pa)
- \( n \): Air flow exponent (-)

**Figure 1.** Concept of the airtightness performance prediction using pressure difference

### 2.2. Relationship between pressure difference and airtightness performance

This study proposes a method for predicting airtight performance with differential pressure through the power law equation used in the blower door test. This study aims to replace the blower door test and it is proved that the method proposed in this study is theoretically possible by using the power law equation because the method of deriving \( n \) and \( C \) is similar to existing methods using blower door test. Equation (1) means that the inlet air volume of the front door and the outlet air volume of the building envelope are the same in steady state conditions. Equation (2) is the Power law equation. Equation (2) requires two equations because there are two unknowns, \( n \) and \( C \). Since the same differential pressure is always generated in the same space, the equation is developed with two different situations in which the outdoor temperature is different which may affect the pressure difference. Equations (3) and (4) are two power law equations with different outdoor temperature conditions. Equation (3) gives Equation (5) as the value of \( C \). Equation (6) is obtained by substituting the \( C \) value of Equation (5) into Equation (4). Equation (6) summarizes Equation (7). In Equation (7), the natural logarithm is taken on both sides to obtain the \( n \) value, which is equal to Equation (8). The value of \( n \) in Equation (10) can be defined. Equation (11) is obtained by substituting the \( n \) value of Equation (10) into Equation (5). Since \( n \) and \( C \) can be obtained as in the above equation, airtightness performance can be predicted, and the method proposed in this study is theoretically valid since \( n \) and \( C \) can be defined as pressure difference and airflow. However, it is necessary to measure the differential pressure under at least two different outdoor temperature conditions. In this study, the theoretical basis for predicting the airtightness performance using the pressure difference is presented using the equations (1) - (12).

\[ Q_r = Q_t \quad \text{(1)} \]
\[ Q = C(\Delta P)^n \quad \text{(2)} \]
\[ Q_{i,t} = C(\Delta P_{i,t})^n \quad \text{(3)} \]
\[ Q_{j,t} = C(\Delta P_{j,t})^n \quad \text{(4)} \]
\[ C = \frac{Q_{i,t}}{(\Delta P_{i,t})^n} \quad \text{(5)} \]
\[ Q_j^t \times \frac{Q_i^t}{\Delta P_i^t} = Q_i^t \times \frac{Q_j^t}{\Delta P_j^t} \quad (6) \]

\[ \ln \left( \frac{Q_j^t}{Q_i^t} \right) = \ln \left( \frac{\Delta P_i^t}{\Delta P_j^t} \right) \quad (7) \]

\[ \ln Q_j^t - \ln Q_i^t = n(\ln \Delta P_i^t - \ln \Delta P_i^t) \quad (8) \]

\[ \therefore n = \frac{\ln Q_j^t - \ln Q_i^t}{\ln \Delta P_i^t - \ln \Delta P_i^t} \quad (9) \]

\[ \therefore C = \frac{\frac{Q_i^t}{\ln Q_j^t - \ln Q_i^t}}{\Delta P_i^t - \ln \Delta P_i^t} \quad (10) \]

\[ \therefore Q = \frac{Q_i^t}{\ln Q_j^t - \ln Q_i^t} \times (\Delta P)^{\ln Q_j^t - \ln Q_i^t} \quad (11) \]

\[ \therefore C = \frac{Q_i^t}{\Delta P_i^t - \ln \Delta P_i^t} \quad (12) \]

3. Application (Case study)

3.1. Field measurement

The purpose of measurement in this study is to verify the reliability of the proposed method. First, the experiment was conducted on three layers of 4F, 16F, and 42F using the blower door test, which measures the existing airtightness. In addition, the pressure difference required to apply the proposed method in this study was measured. Also, the internal temperature, humidity and outdoor weather environment was measured for the blower door test. The pressure difference was measured in the same number of layers in which airtightness performance was measured, and the pressure difference between the front door and the building envelope was measured. Since the proposed method requires pressure difference data for different outside temperature conditions, it has been carried out twice from October 31 to November 1, 2017 and January 26 to January 27, 2018. The survey was conducted on 3 floors underground and 42 floors above ground in Hyozja-dong, Jeonju and Figure 2 is measurement photo.

Figure 2. Measurement photo in the analyzed building

3.2. Process of airtightness prediction using pressure difference

Figure 3 is a process for predicting airtightness performance using the pressure difference proposed in this study. First, the amount of air that flows out to the building envelope was estimated using the airflow data flowing into the front door, the differential pressure of the front door and the differential pressure of the building envelope. This is possible because it is a steady-state condition. Next, c and n are predicted by using the formula proposed in this study using the differential pressure of the building envelope and the airflow. It is possible to predict the airtightness performance and the leakage area under various differential pressure conditions using predicted c and n.
4. Result and Discussion

4.1. Result of pressure difference and airtightness using blower door test

The pressure difference was -48 Pa on October 31st at the front door of the top floor, on January 26, a very large pressure difference of -102 Pa occurred on the top floor front door because the outdoor temperature was very low. In the case of airtightness performance, the measurement was conducted for 4F, 16F and 42F, and the average value was 3.09 1/h at 50 Pa. The airtightness measurement results are shown in Figure 4. The predicted value of airtightness using differential pressure was compared with the result of 42 layers.

4.2. Result of airtightness prediction using pressure difference

The airtightness performance was predicted using the differential pressure measured above. The amount of air flowing out to the building envelope was calculated by using the inlet airflow of the front door and the differential pressure of the front door and the pressure difference of the building envelope. In addition, the c and n values of the building envelope were calculated by using the differential pressure of the building envelope measured and the airflow passing through the building envelope. That is, the pressure difference is measured at the building envelope, and the airflow corresponding to the pressure difference at the actual front door at the same time is applied. The pressure differentials of the front door are -102 and -48 Pa, respectively, and the pressure differences of the building envelope are -5.5 and -9 Pa, respectively. Moreover, the airflow of the building envelope is calculated by applying the airflow of the front door of -102 Pa and -48 Pa, respectively. Using the c and n equations as defined above, c and n values were calculated to be about 19.4 and about 0.895, respectively. The final predicted c and n values are shown in Equation (13).

\[ Q = 19.4(\Delta P)^{0.895} \]  

(13)

4.3. Verification and comparison between prediction and measurement

Table 1 compares the c, n, and airtightness performance values measured by the blower door test, the c, n, and airtightness performance values predicted using the differential pressure. In addition, the error rate between the measured value and the predicted value was calculated using NMSE (Normalized Mean Square Error). The method proposed in this study is reliable because all predicted values are included in the reliable range of NMSE <0.25. It is possible to calculate all the values obtained from the existing blower door test. Therefore, the proposed method can replace the blower door test because both C and n values and airtightness performance can be calculated.
Table 1. Comparison of measured airtightness and predicted airtightness

| Verification | Air Flow Coefficient (C) | Flow Exponent (n) | Airflow (CMH/m²) | Air Change Rate (1/h) |
|--------------|--------------------------|-------------------|------------------|----------------------|
| Measurement  | 19.7                     | 0.707             | 7.39             | 3.14                 |
| Prediction   | 19.4                     | 0.895             | 7.64             | 3.25                 |
| Error (NMSE) | -0.376                   | 0.188             | 0.25             | 0.11                 |
|              | (0.14)                   | (0.02)            | (0.06)           | (0.01)               |

5. Conclusion
In this study, a method of predicting the airtightness performance in a high-rise residential building using differential pressure was proposed, and all values calculated from the existing Blower Door Test were calculated. In addition, when the error rate between the predicted airtightness performance and the measured airtightness performance result is calculated by NMSE, it is included in the reliable range of NMSE <0.25. Therefore, the airtightness performance prediction method proposed in this study is reliable.

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