Analysis of the Contribution of the Building Elements for Improving the Airtightness in Residential Buildings

Goopyo Hong  
Yonsei University  
goopyoh@gmail.com

Daeung Danny Kim, PhD  
King Fahd University of Petroleum & Minerals

Byungseon Sean Kim, PhD  
Yonsei University

ABSTRACT

The purpose of this study is to investigate the air leakage parts and analyze the airtightness in newly constructed apartments. For the study, the blower door and tracer gas tests were used to measure air leakage rate. Four parts in the building were applied and the measurements were conducted to obtain the air leakage rate of those parts. As a result, the air leakage rate was 0.7–1.0(ACH50) when all parts were sealed. On the other hand, the value was 1.6–2.7(ACH50) under unsealed condition. Considering these results, it can be assumed that the airtightness of newly constructed apartments was quite tight. In addition, the results showed that the parts of the air leakage were mainly affected in order by, the entrance door, windows, mechanic 2 (air system), mechanic 1 (water system), and electric. By improving these parts, it will be expected to improve the airtightness for residential buildings. Furthermore, building energy can be saved and provide more comfortable environments.

INTRODUCTION

In most residential buildings, indoor-outdoor air exchange is primarily attributable to air leakage through cracks and construction joints and can be induced by pressure differences due to temperature differences, wind, operation of auxiliary fans, for example, kitchen and bathroom exhausts, and the operation of combustion equipment in the building. Air leakage of buildings can cause many problems, including reduced thermal comfort, degraded indoor air quality, moisture damage of building envelope components, and increased energy consumption. For example, air leakage have caused an increased of energy costs of up to 30–40% during heating period and 10–15% for cooling. In addition, air leakage can have detrimental effects on how a building functions and reduces the life span of a building. The objective of this study is to investigate the air leakage parts and analyze the airtightness in newly constructed apartments. The blower door and tracer gas tests were used to measure air leakage rate. Four parts : electrical parts, mechanical parts-1(the water system), mechanical parts-2(the air system), and architectural parts (window systems) in the building were applied to predict the air leakage area. These elements were sealed to measure the air leakage rate and it was analyzed the airtightness by unsealing each part.
2. BUILDING ENVELOPE AIR LEAKAGE MEASUREMENT

Building envelope air leakage can be measured with pressurization testing, commonly called the blower-door test and tracer gas method. For this research, a blower door test was conducted and the results were compared with the tracer gas decay method.

2.1 Blower Door Test

A fan pressurization airtightness test is relatively quick and inexpensive, and it characterizes building envelope airtightness independent of weather conditions. For this test, a large fan or blower is mounted in a door or window and induces a large and roughly uniform pressure difference across the building shell [ASTM Standards E779 and E1827, Canadian general Standards Board (CGSB) Standard 149.10, ISO Standard 9972]. The airflow required to maintain this pressure difference is then measured. The building that has higher leakage, the airflow necessary to induce specific indoor/outdoor pressure difference is higher. The airflow rate is generally measured at a series of pressure differences ranging from about 10 to 75 Pa.

The pressure difference and flow data are generally fit to a curve using the power law equation. Once the values of $C$ and $n$ are obtained from the test data, the Equation (1) could be used to predict the airflow rate though the building envelope at any given pressure difference.

$$Q = c(AF)^n \quad (1)$$

Where,

- $Q = \text{airflow through openings [m}^3\text{/s]$, $c = \text{flow coefficient [m}^3\text{/s.Pa}^n\text{],}$
- $n = \text{pressure exponent [dimensionless]}$

2.2 Tracer Gas Measurements

The tracer gas is released into the building in a specified manner. The concentration of the gas in the building is monitored related to the building air exchange rate. Various tracer gases and associated concentration detection devices can be used. All tracer gas measurement techniques are based on a mass balance of the tracer gas in the building.

Three different tracer gas procedures are generally used to measure air exchange rate,

1. Decay or Growth
2. Constant Concentration
3. Constant Injection

<table>
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<th>Table 1. Measurements of airtightness and Features</th>
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<td>Tracer Gas Method</td>
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For the present study, the decay method was used to measure the tracer gas. A small amount of a tracer gas was injected into the space and was allowed to mix with the interior air. To mix tracer gas well, a fan in each room was installed.

Assuming that the outdoor concentration was zero and the indoor air was well mixed with the tracer gas, the total balance form was used for Equation(2). After the injection, \( F=0 \) and the solution Equation(2) became Equation(3). It is generally used to solve for \( I \) (air exchange rate) by measuring the tracer gas concentration periodically during the decay.

\[
V \frac{dC}{d\theta} = F(\theta) - Q(\theta)C(\theta) 
\]

(2)

\[
I = \frac{\ln C(\theta) - \ln C_0}{\theta}
\]

(3)

Where,

\( V = \) volume of space being tested \([m^3]\), \( \frac{dC}{d\theta} = \) time rate of change of concentration \([s^{-1}]\),

\( F(\theta) = \) tracer gas injection rate at time \([m^3/s]\), \( Q(\theta) = \) airflow rate at time \([m^3/s]\)

\( I = \) air exchange rate \([s^{-1}]\), \( C(\theta) = \) tracer gas concentration at time \( \theta \), \( \theta = \) time \([s]\)

3. MEASUREMENT

Descriptions of the test units. To measure the airtightness of the building envelope, three different types of apartments at three places in South Korea were chosen (Table 2). The selected units of apartments were popular residential buildings and they were newly constructed in 2012 and 2013. The airtightness test of the buildings was conducted in July through October of 2013.

Table 2. Descriptions of the test unit

<table>
<thead>
<tr>
<th>Measurement Unit</th>
<th>A</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location</td>
<td>Incheon</td>
<td>Gyeonggi-Do</td>
<td>Daegu</td>
</tr>
<tr>
<td>Unit Size</td>
<td>101 m(^2)</td>
<td>116 m(^2)</td>
<td>84 m(^2)</td>
</tr>
<tr>
<td>Completion date</td>
<td>September, 2012</td>
<td>June, 2012</td>
<td>September, 2013</td>
</tr>
<tr>
<td>Plan</td>
<td>![Plan A]</td>
<td>![Plan B]</td>
<td>![Plan C]</td>
</tr>
</tbody>
</table>

Method. The airtightness of building envelopes was measured using the fan pressurization test in which a fan was used to create a series of pressure differences between the building interior and the outdoor. A blower door was installed at the entrance door (Fig.1). All the interior doors were opened to equalize the indoor air pressures in the unit. The airflow rates through the fan were also measured. Elevated pressure differences of up to 75 Pa were used to override weather conditions and provide measurements of the physical airtightness of the exterior envelope of the building.
A data logger with pressure difference sensors was employed to continuously collect and display the pressure differences. The pressure sensors were attached to the blower door flow nozzles to allow for the calculation of airflow through the fan.

Figure 1 Measurement equipment and the results on monitor

Four leakage parts were divided to predict the contribution of the airtightness.

1. Electrical parts in the unit – speakers, monitors of meter, sensors for fire, distribution panelboards and communications connectors
2. Mechanical parts 1(realted to the water system) in the unit – water supply and drainage line for the kitchen, bathroom, and laundry room
3. Mechanical parts 2(realted to the air system) in the unit – ventilation system, exhaust duct line for the restroom, and the kitchen hood
4. Architectural part in the unit – window system

Plastic films and duct tapes were used to seal each part. After sealing all parts, the airtightness was measured using the tracer gas and the blower door. In addition, the airtightness measurements with unsealed electrical parts were performed using the blower door. Other airtightness measurements were conducted as shown in Table 3.
### Table 3. Measurements

<table>
<thead>
<tr>
<th>Method</th>
<th>Measurement</th>
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</table>
| Blower Door | ❶ all parts were sealed  
              ❷ only electrical parts were unsealed & others were sealed  
              ❸ electrical and mechanical-1 parts were unsealed & others were sealed  
              ❹ electrical, mechanical-1, and mechanical-2 parts were unsealed & windows were sealed  
              ❺ all parts were unsealed |
| Tracer Gas  | ❶ all parts were sealed  
              ❷ all parts were unsealed  
              (a) electrical parts were sealed  
              (b) mechanical parts 1(water system) were sealed  
              (c) mechanical parts 2(air system) were sealed  
              (d) architectural parts(window system) were sealed |

![Image of sealed parts](image-url)

Figure 2  The pictures of each sealed part
4. RESULT

4.1 Air leakage rate

ACH (Air Change per Hour)50 is defined as airflow rate by the gross internal volume of the unit when a 50 Pa pressure difference is applied between indoor and outdoor environments. Fig. 3 shows the value by using the blower door. When all parts in the units were sealed, the ACH50 value for units A, B, and C were 0.69, 0.69, and 1.0 respectively. When all parts were unsealed, the results of the ACH50 were 1.63, 2.28, and 2.73. The difference of the ACH50 in each unit between sealed and unsealed was about 1.0 ~ 1.7. When A and B units were sealed, the values were the same. However, the result was different when they were unsealed.

The tracer gas method (Decay) to unit A and B were also conducted. It measured natural conditions such as infiltration without artificial pressure differences. As shown in Fig. 4, the ACH values were very small and the units were very tight because of two reasons. One is that newly constructed apartments were made tighter and the other is that the temperature difference between interior and exterior was small about 2~5 °C. It is necessary to study the effect of climatic conditions on these infiltration measurements.

4.2 Airtightness according to each part

Fig. 5 shows the results of the tests in Table 3. In unit A, there were little different ACH50 values (0.69, 0.71, 0.71, and 0.78) before unsealing the architectural parts. However, ACH50 increased by 1.63 after unsealing the windows in unit A. The airtightness was influenced largely by the gap between window frames and a difference of construction for the installation of the windows in the walls. In unit B, the ACH50 increased by 1.82 after unsealing mechanical parts-2. In the case of unit B, the mechanical parts-2 caused the largest difference in airtightness. In unit C, the ACH50 value was largely influenced by the mechanical parts-2 and windows.
Therefore, the air leakage area was influenced by the mechanical-2 parts and the window parts. If the technology to improve the airtightness of these parts is developed, the air leakage rate will be decreased.

4.3 The airtightness of the door

To confirm the entrance door’s airtightness, a fan was installed on the other door under the same conditions. The ACH50 was 4.56 and increased about 1.8(ACH50) higher than the fan mounted on the main door when all parts were sealed. Under sealed condition, the original value of ACH50 was 0.69. After changing the fan’s location, the ACH50 was 1.28. The air leakage rate of the main door was much higher than that of other parts.

4.4 Cost savings by reducing air leakage

Fig.6 (a) shows monthly energy costs for a typical residential house in Korea. And it is also shown high, average, and low monthly temperatures. In winter, heating cost using a boiler is 130~200$/month. In summer, cooling cost using an electric air conditioner is 60~80$/month. By reducing air leakage, energy cost would be saved, especially heating cost. We don’t know the saving cost through this study, but it could save 30~40% cost during heating period and 10~15% cost for cooling by referencing other study. Future studies will be required the quantitative data between energy consumption and air leakage from newly constructed residential buildings.

![Fig.6 (a)](image1)

(a) Monthly electric and gas costs & high, average, and low temperature

![Fig.6 (b)](image2)

(b) Monthly electric consumption

![Fig.6 (c)](image3)

(c) Monthly gas consumption

**Figure 6** Monthly electric and gas consumption & costs
5. CONCLUSION

The air leakage rate for newly constructed apartments in South Korea were measured and analyzed to improve the airtightness on building envelopes. The airtightness measurements were conducted using the blower door test in accordance with ASTM E-779 and tracer gas method in accordance with ASTM E-741. To confirm the air leakage area, four parts, electric, mechanic-1, mechanic-2, and windows, were divided in the test unit.

The key findings are summarized as follows,

(1) The air leakage rate using a blower door was 0.7~1.0(ACH50) when all parts were sealed. On the other hand, the value was 1.6~2.7(ACH50) under unsealed condition and it can be considered that the unit is generally quite tight. The difference of the ACH50 in each unit between sealed and unsealed was about 1.0~1.7.

(2) To compare the results obtained by the blower door test and the tracer gas method was conducted. When all parts were unsealed, the infiltration rate was less than 0.1(ACH). Because air infiltration depends on the building envelope’s airtightness and the pressure differential across the envelope, these differentials were caused by wind, stack effect, and operation of the building’s mechanical equipment. It is necessary to study the effect of climatic conditions on these infiltration measurements.

(3) To find the most effective parts related to air leakage, the fan pressurization tests were also carried out. Gaps in the window frames and a mechanical parts 2 (air system – ventilation for rooms, hood for kitchen, and exhaust duct line for the restroom) mainly affected the airtightness of the units. The entrance door was also largely influenced the air leakage rate.

(4) Generally, the airtightness of newly constructed apartments was quite tight. The air leakage rate was mainly affected in order by, the entrance door, windows, mechanic 2 (air system), mechanic 1 (water system), and electric. By improving these parts, building energy can be saved and produce more comfortable environments.

In order to understand the influence of the airtightness in buildings, a scrutinization of the building elements and a large number of experiments are generally required. For the present study, the air leakage parts in residential buildings were analyzed and quantitative values related to the airtightness were obtained through the measurements. The data through the study can be used to develop the technology for materials and construction methods for improving the airtightness in buildings.

REFERENCES