Air Leakage Characteristics and Leakage Distribution of Dwellings in High-rise Residential Buildings in Korea

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Abstract
Reliable airtightness data is needed to estimate the level of air infiltration and the thermal loads for improving building energy efficiency and indoor comfort. While useful information on air leakage in low-rise dwellings exists, there is little data available on dwellings in high-rise residential buildings (particularly those with a central core plan). In this study, airtightness measurements using the fan pressurization method were conducted on approximately 350 dwellings in 4 high-rise residential buildings in Korea. The results were compared with the airtightness requirements for high performance buildings or several airtightness ratings. The measured results showed that average ACH₅₀ (air change per hour at 50Pa) was 2.3. This is within the range of 2~5, which is the level of 'quite tight' based on the ASHRAE airtightness ratings. The results of the building component test showed that the parts of the dwelling that leaked the most were the internal walls between the residential units.

Keywords: airtightness; air leakage distributions; high-rise residential building; fan pressurization method

1. Introduction
A building envelope’s airtightness is important for energy-efficient building constructions, particularly in high-rise buildings, and is a fundamental building performance measure that affects the heating and cooling loads. Infiltration is the movement of air through leaks and cracks in a building envelope. Airtightness is also important because it impacts the transport of contaminants between indoor and outdoor air. Most residential buildings located in the United States, Canada, and Europe are low-rise dwellings. Many studies have examined the airtightness level of low-rise dwellings. Sherman and Chan (2004) reviewed a range of airtightness studies and practices. This report reviews the most important publications related to building airtightness. Many studies (Orme et al. 1994, Hamlin 1997, Stephen 1998, Sherman 2001, Chan et al. 2003, Yoshino 2008) presented data on the airtightness of single-family houses. The measurement methods of the airtightness of single-family houses (or detached houses) and the airtightness standard for each nation were also suggested. Over the last 10 years, the type of housing being constructed in Korea, China and other Southeast Asian countries has been in the form of high-rise buildings and multi-family housing, where many units are adjacent to each other. In Japan, however, more than half of the residential buildings are detached houses. Hiroshi Yoshino (1986) conducted an in-depth study of the airtightness performance of these buildings and similar studies were performed in Korea. Researches on airtightness performance have been carried out in most of Asia, excluding Japan in recent years. With regards to building airtightness, Japan (H. Yoshino 2008, H. Yoshino et al. 2009) has considered the impact of leaky envelopes on a building’s energy performance and indoor air quality. Studies on measuring the airtightness performance were conducted for early detached housing or experimental housing, as well as for current high-rise apartment housing in South Korea. Yun Jong-ho et al. (2008) and Kim Ju-su et al. (2010) examined detached housing. Park Seon-hyo et al. (2007) and Shin U-cheol et al. (2005) evaluated experimental housing. Jo Jae-hun et al. (2010), Kwon O-hyun et al. (2010), Koo Seong-han et al. (2004), and Kim Seung-cheol et al. (2011) assessed apartment housing. Most of these studies focused on presenting one or several airtightness data only. They presented neither the mean values nor established criteria for the energy performance or airtightness performance of a building. That is, most Asian countries except Japan lack airtightness standards and data. In addition, the measurement data or standards for low-rise dwellings in the United States, Canada,
and Europe are not applicable. Therefore, airtightness
data of high-rise residential buildings is needed to
provide airtightness standards.

This study presented the airtightness data and
air leakage distributions of dwellings in 4 high-
rise residential buildings in South Korea. The fan
pressurization method with a blower door was used
to measure the airtightness of approximately 350
dwellings, and the measurement results were compared
with the standards of other countries. The airtightness
of building components that form units of residential
buildings, such as the envelope, internal walls between
dwelling units and floors, were investigated.

2. Test Building Descriptions

The core was located at the center of all the buildings
tested, and hallways and each unit were on the
surrounding plane. In addition, the floor structure was a
flat slab, and the walls between the units and hallways
were dry walls. Therefore, compared to concrete walls,
it is difficult for airtight joints to be constructed in dry
walls, which degrades the airtightness. The exterior
wall was a curtain wall type for buildings A and B,
and a punched window type for buildings C and D.

3. Airtightness Measurement Method

The test conditions presented by the ATSM standard
E779-03 were followed to measure the airtightness
of the unit and building components, such as the
envelope, internal walls between dwelling units, floors
and ventilating equipment. To measure the airtightness
of a dwelling unit, a blower door was installed in the
entrance door at each dwelling unit, and the pressure
difference was controlled to 5–10Pa intervals for the
measurements. To prevent the effect of the airtightness
of the adjacent units on the tested unit, large openings
(windows and doors) of units located above and below
were left open so that the situation could be set based
on the ambient conditions. The building components
were distinguished as envelopes, internal walls between
dwelling units, floors, and ventilating equipment
for their air leakage distributions. To measure the
airtightness of the envelope, its airtightness data was
measured twice (built condition and no air leakage
condition).

When the difference in the amount of air leakage
was calculated before and after airtight processing,
the airtightness of the envelope could be identified.
The airtightness of the ventilation equipment was
measured using the same methodology. To measure
the internal walls between the dwelling units and
floors, two blower door sets were placed on either
side of the measurement target. Pressurization and de-
pressurization methods were used on the measured unit
and adjacent units. Air leakage did not occur from the
measurement target if the pressure difference between
the two dwelling units was ±1–2 Pa.

The amount of air leakage without leakage
through the internal walls was measured. Finally, the
airtightness data of the internal walls was obtained
from the differences between the whole airtightness
value of the dwelling unit and the measured value

Fig.1. Typical Plans of the Test Buildings
without air leakage through the internal walls.

4. Measurement Result
4.1 Analysis of the airtightness of a unit dwelling of each building

Fig.2. shows the measured ACH50 results for 350 dwellings in high-rise residential buildings, and the mean values for each building are marked. The mean ACH50 for buildings A, B, C and D was approximately 3.1 (1.9–3.8), 3.9 (2.6–5.2), 2.5 (1.4–3.8) and 2.3 (1.4–3.7), respectively. Building D was the most airtight followed in order by buildings C, A and B. Because the ground structure, internal walls between dwelling units and ventilation types of the buildings were similar, the exterior wall was considered to be the factor with the largest influence.

Fig.3. shows the airtightness measurement results compared to the normalized ASHRAE data (2009). The airtight housing units showed similar results, whereas buildings with low airtightness showed larger differences because these buildings are believed to have more leakage areas. Therefore, buildings with low airtightness need to be designed carefully to complement airtightness.

When the four test buildings were evaluated according to the ASHRAE ventilation standard for residential buildings, they revealed an "airtight" or "quite airtight" level, which is sufficiently airtight according to the standards of European nations, such as Norway, the Netherlands and Switzerland. On the other hand, the airtightness results were evaluated as insufficiently airtight based on the standards for
energy-conservation buildings, such as the passive house of Germany and R-2000 of Canada. Fig.4. compares the airtightness standards of each nation and the test buildings in this measurement study.

4.2 Leakage distributions of building components

To examine the air leakage distribution, the airtightness distribution of the individual building components was measured for building A using a similar method used in a previous study. ASHRAE (2009) presented the percentage distribution of the entire building leakage by the components estimated based on these guidelines: 35%, 18%, 18% and 15% for walls, ceilings details (floors), mechanical systems and windows (doors), respectively. In this study, nine dwelling units were selected for the measurements in building A.

Table 2. Test Dwelling Information

| Type  | Floor area (m²) | Floor height (m) | Envelope area (m²) | Volume (m³) |
|-------|----------------|------------------|--------------------|-------------|
| Type 1 | 103.85         | 3.1              | 342.71             | 321.94      |
| Type 2 | 132.53         | 3.1              | 418.17             | 410.84      |

Two dwelling types with typical plans and one side facing the ambient conditions were selected. Table 2. provides detailed information on the measured dwellings. The airtightness results were calculated as the air leakage distribution ratio for each building component, and are summarized in Figs.5. and 6. The interior walls between units showed the highest percentage with 30%–58% of the overall amount of air leakage. Because of the trend concerning lighting structures in high-rise residential buildings, they are constructed mainly with dry walls. Therefore, a large amount of air leakage occurred between the wall joints or joints where the columns and slabs came in contact with the walls. The envelope took up 5%–30% of the overall air leakage of residential units. In addition, 3%–32% air leakage occurred across the floors. Smoke inspection results revealed air leakage occurring from continuing curtain wall frames to the adjacent dwellings. As a heat exchanger ventilation system was installed in the dwellings, the amount of air leakage through the ventilation equipments was 3%–19% of the overall air leakage of the dwellings.
The remaining 7%–30% of air leakage was considered to originate from the entrance door of each dwelling unit, equipment penetration and electrical pipes. Further studies will be needed to identify the specific air leakage areas and the air leakage distribution ratio.

From the test buildings, the internal walls appear to be the most significant air leakage path, and the airtightness must be considered carefully in the design of buildings because the internal dry walls between housing units tend to have considerable leakage. Fig.7. presents a design ensuring airtightness methods (installation of expanding tapes at both ends of the internal walls expressed in c) of Fig.7.). As illustrated in the figure, this method complements the airtightness by inserting compressed airtight bands in the areas, where the wall and upper slab meet. This airtight construction method was examined in 3 dwellings, which improve the airtightness level by approximately 30% of the whole air leakage. Therefore, the air leakage of internal walls can be reduced further by 60% to 80%, when additional expanding tape at both ends of the wall is added.

5. Conclusion

The airtightness data of 350 dwellings in 4 high-rise buildings in Korea was approximately 1.4–5.2 ACH50. Buildings A, B, C and D had an average ACH50 of 3.1, 3.9, 2.5 and 2.3, respectively. The airtightness of the four test buildings was at the level of "quite airtight", which satisfied the standards of European nations, such as Norway, the Netherlands and Switzerland. By measuring the airtightness of the building components of each dwelling and by calculating the air leakage distribution ratio to identify the leaking parts where airtight-constructions are required, the air leakage distribution ratio was determined to be the highest (31%–58%) for the internal walls between dwelling units. This is believed to be a property of high-rise residential buildings constructed with dry walls, and airtight construction is needed at the internal walls between dwelling units. The air leakage of the internal walls can be reduced by 60% to 80% when ensuring that airtightness methods are added.

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