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An Analysis of ACHn for Improving the Performance of Green Remodeling through the Airtightness Measurements

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ABSTRACT

Purpose: The study analyzed the airtightness of several buildings which were constructed more than 30, 20, 10 years ago and recently constructed by using various air leakage metrics. In addition, the various ACHn values were estimated in which it is not possible to maintain the reference pressure difference of 50 Pa due to some building conditions such as aged or large volume. Moreover, the relationship between the values of ACH 50 and ACHn was analyzed. **Method:** Two rooms in four different buildings were chosen and the air leakage rates were measured by using the fan-pressurization method based on ISO Standard 9972. For the measurement, both pressurization and depressurization test modes were applied twice. Various airtightness metrics were analyzed for the air leakages in each room. **Result:** The biggest air leakages were observed in the oldest building in which the ACH50 value was 24.35 h^{-1}. Similar air permeability values were observed between the rooms in the buildings. Therefore, this metric can be used as a representative air leakage rate for the whole building. Moreover, the conversion coefficient for the ACHn values at different pressures from 4 Pa to 75 Pa based on the ACH50 value was estimated.

KEYWORD

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1. Introduction

1.1. Background and Purpose

Recently, the impacts of global warming have become a significant concern worldwide and lots of effort has been made to decrease carbon dioxide emissions targeting net-zero emissions finally by 2050[1]. While buildings in EU account for about 40% of the total energy consumption, one-fifth of the total energy has been consumed by buildings in South Korea[2]. Therefore, it requires to have energy-efficient or net-zero energy buildings for the goal of 2050 Carbon neutral.

To reduce energy consumed by buildings, it is important to figure out how much energy is consumed quantitatively as well as minimize energy consumption caused by unwanted heat gain or loss. According to this issue, the Korean government has recommended increasing the thickness of building insulation materials for reducing heat loss through them to outside. Among parameters of building envelope systems, heat loss by air infiltration accounts for about 15% to 60% of the total heat loss through building envelopes. Moreover, the amount of heat loss by air infiltration can be increased with the increase in the thickness of building insulation materials[3]. A previous study for the air infiltration investigation in a building highlighted that air leakage caused by walls and roofs, and windows and doors accounted for 18%~50% and 6%~22%, respectively[4].

While the improvement of airtightness in buildings can reduce building energy consumptions, it also requires specific air leakages in aged buildings. An energy simulation tool in South Korea used for the analysis of building energy consumption, building energy rating, and net-zero energy certified building design is ECO2. However, this tool requires values of air infiltration for an energy consumption analysis of existing buildings regarding Green remodeling, which is one of the key projects of South Korea's Green New Deal. Since it is difficult to quantify air infiltration rates for all buildings, the ACH50 (Air leakage rates) of 6 h^{-1} is generally recommended for residential buildings[5].

As basic research for specifying air infiltration rates for functions and ages of buildings, the present study measured the airtightness for several educational buildings by using the fan pressurization method. The air leakage rates for different aged buildings considering the areas of openings such as windows and doors were compared with the metric of air leakage rates. In addition, air leakage rates were estimated under the pressure difference of 50 Pa as well as other pressure differences. This can suggest a proper way

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of measuring the airtightness of buildings, where it is difficult to maintain a reference pressure difference (50 Pa) during the measurements due to a large building volume or much air leakages.

1.2. Methodology and Scope

For the present study, four educational buildings were chosen, which were constructed more than 30, 20, 10 years ago and recently constructed. In these buildings, air leakage rates were measured by using the fan-pressurization method based on ISO Standard 9972 from July 31st, 2021 to August 31st, 2021. For the blower door test, "Blower door model 3" from Minneapolis was used and both pressurization and depressurization test modes were applied more than twice. In addition, the indoor dry bulb temperature and the relative humidity were measured using Testo 400 and CEM DT-802d, respectively. During the measurements, all the openings such as doors and windows were closed and other building components were remained unsealed.

2. Method

2.1 The Blower-door Test

Air leakages can be generally measured by the fan pressurization method and the tracer gas technique. Between the two, the fan pressurization method using a blower door system has been preferred because it can require less cost and is simpler than the tracer gas method[4]. Moreover, an artificially induced condition by fans can measure the air change rates under any climate conditions. (Eq. 1) is used to estimate the airflow rates through building envelopes.

$$q_{pr} = C_L(\triangle p)^n \quad \text{(Eq. 1)}$$

where,

q_{pr} = air leakage rate at the reference pressure difference, (m^3/s)

C_L = air leakage coefficient, $m^3/(h \cdot Pa^n)$

$\triangle p$ = induced pressure difference, (Pa)

n = airflow exponent, dimensionless

In accordance with ASTM Standards E779, the measured airflow exponent can be considered as correct, if the values of the airflow exponent are ranged from 0.5~1.0. When the airflow through the opening is increased, air leakages are also increased. In addition, air leakages can be varied similarly with the variation of air leakage coefficient. While the airflow exponent is increased, air leakages are decreased and the sensitivity of the airflow exponent is about one-fifth of the air leakage coefficient[6].

2.2. Metrics for Analysis of Air Leakage

The air leakage rates through the blower-door test can be presented in several ways. The present study compared building air leakage rates by using several air leakage metrics below.

① CMH 50 (air leakage rate at 50 Pa) is the building air leakage rate under the pressure difference of 50 Pa between inside and outside.

② ACH 50 (air changes per Hour at 50 Pa) is the CHM 50 divided by the volume of the targeted room. It can be calculated by using (Eq. 2).

$$ACH_{50} = \frac{q_{50}}{V} \quad \text{(Eq. 2)}$$

where,

q_{50} = air leakage rate at 50Pa, m^3/h

V = internal volume, m^3

③ The leakage considering area of window and door

It can be calculated by (Eq. 3). The present study has used this air leakage rate which considered the area of openings. For example, there are two doors in a room, where the blower door is equipped at a door. It is considered that the air leakage has occurred through the other door, which is calculated by the area of doors and windows.

$$q_{W50} = \frac{q_{50}}{A_w} \quad \text{(Eq. 3)}$$

where,

A_w = window and door area, m^2

④ The leakage considering length of window and door

It can be CMH 50 divided by the length of gaps around window and door frames as (Eq. 4).

$$q_{WL} = \frac{q_{50}}{A_{wl}} \quad \text{(Eq. 4)}$$

where,

A_{wl} = window and door length, m

⑤ Air permeability

This presents the net air leakage rate per the pressure difference through the whole building envelopes[7]. It can be calculated by (Eq. 5). For the calculation, the area of the building envelopes exposed to the outsider is only considered.

$$q_{E50} = \frac{q_{50}}{A_E} \quad \text{(Eq. 5)}$$

where,

A_E = envelope area, m^2

Table 1. Overview of the measurement buildings

Building	A		B		C		D	
Picture								
Completion Date	1984		1995		2008		2019	
Room	A-1	A-2	B-1	B-2	C-1	C-2	D-1	D-2
Floor Area(m^2)	33.6	100.8	22.7	58.3	49.7	74.2	25.4	75.8
Envelope Area(m^2)	22.7	89.6	19.4	43.7	57.5	76.7	20.8	79.7
Volume (m^3)	90.7	272.2	51.0	157.5	134.1	200.3	76.6	209.3

Fig. 1. Blower-door setting

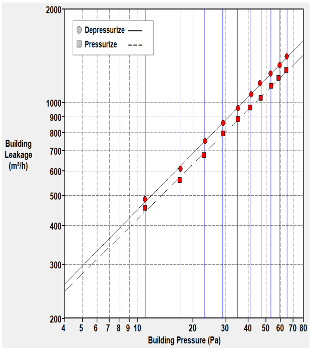

Fig. 2. Blower-door test graph

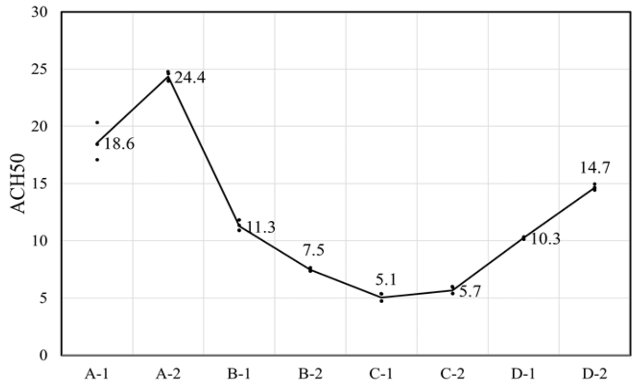

Fig. 3. Air leakage rates at 50Pa by building, ACH50

2.3. Building Description

Table 1. presents the description of four selected buildings for the air leakage measurements. In these buildings, two different sizes of rooms in each building were chosen. Building A was constructed in 1984 and has been used for about 37 years. In this building, a research office and a lecture hall were selected.

The size of the research office (A-1) and the lecture hall (A-2) were 33.6 m^2 and 100.8 m^2, respectively. Building B and C have been used for more than 25 years and 10 years, respectively. In the case of Building D, it was recently constructed a year ago. In the same manner, a small-sized research office and a large-sized lecture hall in the building B, C, and D were chosen.

Fig. 1. shows the blower door installed at a door. In addition, both pressurization and depressurization tests were performed more than twice for the blower door test to find the deviation of the pressurization and depressurization (Fig. 2.).

3. Measurement Result

3.1. ACH50

Fig. 3. shows the ACH50 values by using the blower door. The pressure difference was set to be changed from 10 Pa to 60 Pa and the air leakage rate was measured every 5~10 Pa by applying pressurization and depressurization test modes every twice. As a result, the biggest air leakages were observed in building A. The ACH50 values at rooms A-1 and A-2 in building A were 18.57 h^{-1} and 24.35 h^{-1}, respectively. In the case of building C in which the construction was completed in 2008, the smallest air leakages were measured. Specifically, the ACH50 values at the room C-1 and C-2 in the building C were 5.05 h^{-1} and 5.67 h^{-1}, respectively.

However, the measured air leakages in the building D, which is the newest building were relatively higher that these measured in the building B and C. This can be seen that the window systems installed on the exterior wall on the first and second floors in building D can cause high air leakages. The previous study also highlighted that relatively higher air leakage was observed in the recently constructed building than those measured in the buildings, which were constructed more than 45, 23, and 20 years ago[7]. Based on the outcome of the measurements, it requires to strengthen the energy-efficient design for educational buildings as well as investigate the impact of airtightness continuously.

3.2. The Analysis of ACH50 Considering Building Envelopes

The measured ACH50 values were presented by using various

Table 2. Measure results

	A-1	A-2	B-1	B-2	C-1	C-2	D-1	D-2
ACH50	18.6	24.4	11.3	7.5	5.1	5.7	10.3	14.7
q_{W50}	191.0	380.2	113.0	84.8	74.6	72.8	94.0	156.7
q_{WL}	66.9	79.6	43.3	25.7	20.1	21.2	30.6	46.7
q_{E50}	74.3	73.9	29.6	26.9	11.0	14.1	34.2	37.5

*q_{W50}=The leakage considering area of window and door $(m^3/h \cdot m)$
q_{WL}=The leakage considering length of window and door $(m^3/h \cdot m)$
q_{E50}=Air permeability $(m^3/h \cdot m)$

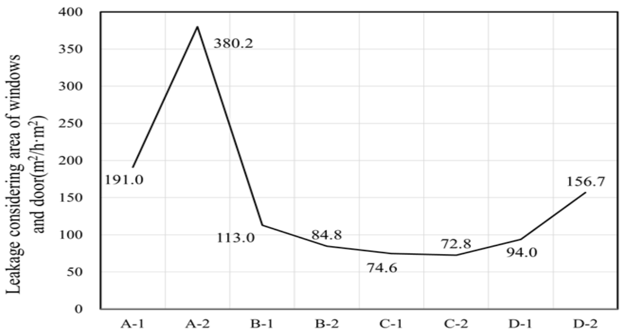

Fig. 4. Leakage considering area of windows and door

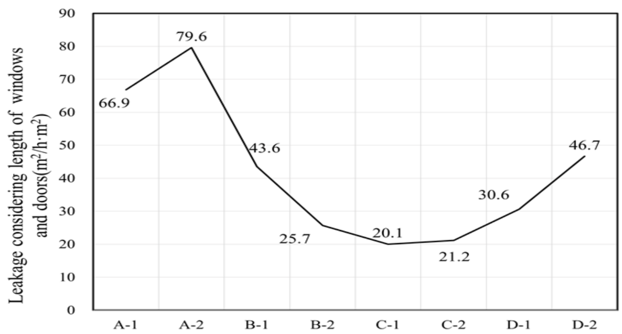

Fig. 5. Leakage considering length of windows and door

metrics. Fig. 4. and 5. show the air leakage rate considering the area and the crack length of windows and doors, respectively. When estimating the area of windows and doors, the area of the door with the blower door was excluded. For the crack length, all the length of windows and doors were included.

As can be shown in the graphs below, a similar trend was observed in the ACH50 values considering the area and the length of the gaps of windows and doors. This can be seen that the increased size of the openings by the increase in the floor areas can increase the air leakages. Moreover, it is important to find out the airtightness through the openings quantitatively. By this point, the ACH50 values were analyzed regarding the crack method[7].

As shown in Fig. 3.~5., the ACH50 values were different by the volume of the room, the area, and the length of the openings in the same building. For example, the ACH50 value in room A-1 was smaller about 6.0 h^{-1} than that measured at room A-2 in Fig. 3. However, slight different ACH50 values were observed between

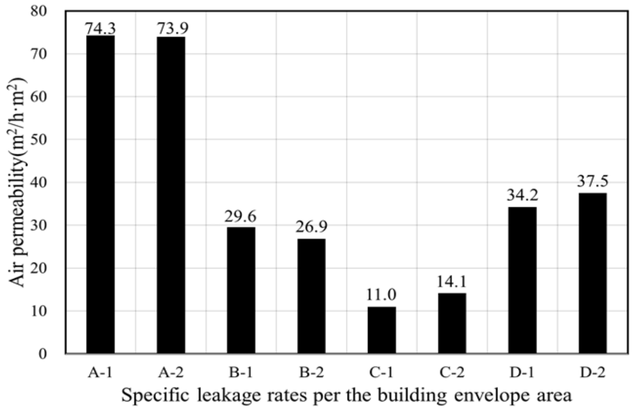

Fig. 6. Specific leakage rates per the building envelope area

the room A-1 and A-2, when the air leakages considering the net area of building envelopes were compared in Fig. 6. Likewise, the ACH50 values in the building B, C, and D in Fig. 6. showed a little difference between two rooms. This indicates that the measured air leakages in a few rooms in a building can be representative of the air permeability in the whole building. Since it is difficult to measure the air leakages in all rooms in a building.

3.3. Comprehensive Results of Measurement

According to the measurement results, the biggest air leakage rate was observed in the oldest building. Although the building D was the most recently constructed, the air leakage rate in the building were higher than those in the buildings B and C. The building was installed curtain wall, and the windows were connected vertically. Therefore, it requires a study to investigate the airtightness of new buildings and their envelopes.

4. The Analysis of ACHn

4.1 The Methods for ACHn

Generally, the ACH50 values can be used for the building airtightness investigation. This is generated in the condition with the artificially produced pressure difference of 50 Pa (Eq. 2). However, it is difficult to measure air leakages in aged buildings or a large volume because it is not possible to maintain the artificial pressure difference of 50 Pa in these buildings. Thus, the present study found the trend line from the airflow rate data at an artificially induced condition through the blower-door test based on the various pressure differences. At the pressure difference from 4 Pa~75 Pa, the value of ACHn is estimated and compared with the ACH50 values. Fig. 7. presents the airflow generated from the pressure difference between the inside and outside the building.

As mentioned above, ACHn was estimated from the measured fan flow rate at the pressure difference between the inside and outside the building (Fig. 7.). The estimated pressure difference was measured every 5 Pa from 4 Pa to 75 Pa. In the present study, the trend line was generated based on the baseline adjusted building pressure and the adjusted airflow. The estimated coefficient of determination (R2) was in the range of 0.987~0.999. In addition, the errors between the ACH50 values calculated from the data of the Fig. 7. and the blower-door test were in the range of 1.001~1.006. Thus, the estimated ACHn values can be accepted.

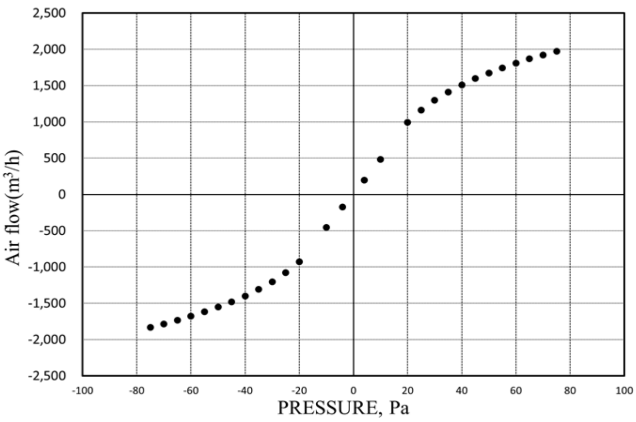

Fig 7. Airflow rate by different pressure

4.2 The ACHn Values at Different Pressures

The present study presents the conversion coefficient for the ACHn values at different pressures based on the ACH50 values. Fig. 8. shows the average ACHn values estimated from the data collected in room A-1 by applying twice pressurization and depressurization modes. Likewise, the ACHn values were estimated at all the rooms in other buildings, and the conversion coefficient was estimated based on the ACH50 values.

Table 3. shows the averaged conversion coefficient at different pressure conditions in all the buildings. By using the conversion coefficient, the ACH50 values were estimated (Eq. 6).

$$ACH_{50} = \frac{ACH_n}{N_{pr}} \qquad \text{(Eq. 6)}$$

where,

n = induced pressure difference

N_{pr} = Conversion coefficient, ($_{pr=}$ 10, 20, 30 ⋯)

As can be shown, the ACHn values at different pressures can be used to estimate the ACH50 values for the airtightness investigation.

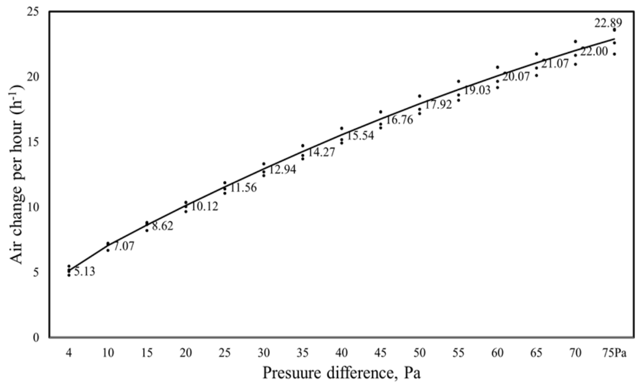

Fig 8. Air change rate at the reference pressure difference

Table 3. Conversion coefficient distribution

	4Pa	10Pa	15Pa	20Pa	25Pa	30Pa	35PA	40Pa	45Pa	50Pa	55Pa	60Pa	65Pa	70Pa
A-1	0.29	0.39	0.48	0.56	0.65	0.72	0.80	0.87	0.94	1.00	1.06	1.12	1.18	1.23
A-2	0.36	0.46	0.54	0.62	0.69	0.76	0.83	0.89	0.95	1.00	1.05	1.10	1.14	1.18
B-1	0.04	0.21	0.34	0.46	0.58	0.68	0.77	0.86	0.93	1.00	1.06	1.10	1.14	1.17
B-2	0.28	0.38	0.46	0.54	0.62	0.70	0.77	0.85	0.93	1.00	1.07	1.14	1.22	1.29
C-1	0.28	0.39	0.48	0.57	0.65	0.73	0.80	0.87	0.94	1.00	1.06	1.11	1.16	1.21
C-2	0.28	0.40	0.48	0.57	0.65	0.73	0.80	0.87	0.94	1.00	1.06	1.11	1.16	1.21
D-1	0.29	0.41	0.50	0.58	0.66	0.74	0.81	0.88	0.94	1.00	1.05	1.10	1.15	1.18
D-2	0.32	0.43	0.51	0.60	0.67	0.75	0.82	0.88	0.94	1.00	1.05	1.10	1.14	1.18
Average	0.27	0.38	0.48	0.56	0.65	0.73	0.80	0.87	0.94	1.00	1.06	1.11	1.16	1.21

For example, the ACH values can be estimated by using (Eq. 6) with the measured airflow under lower-pressure conditions than 50 Pa, where the pressure of 50 Pa can't be maintained due to the building conditions such as aged or large volume.

5. Conclusion

The present study investigated the airtightness of four buildings in which the construction was completed 1~37 years ago. In addition, the ACH50 values were presented considering various parameters. Moreover, the conversion coefficient was estimated from the trend line generated by the measured data for the ACHn values at different pressures. The outcomes from the study were presented below.

1) The biggest air leakages were observed in the oldest building (Constructed in 1984). The ACH50 values at two rooms were 18.6 h^{-1} and 24.4 h^{-1}. The smallest air leakages were measured in the building, which was constructed in 2008 and the ACH50 values in this building were 5.1 h^{-1} and 5.7 h^{-1}.

2) In the analysis of the airtightness considering various parameters, a similar trend of the ACH50 values was observed between the initial blower-door test and the test considering the area and the crack length of windows and doors. When comparing the air permeability values considering the net area of building envelopes, similar air leakages were measured at two rooms in the same building. By this point, the air permeability values measured in a few rooms can be used as a representative air leakage performance in a whole building.

3) The ACHn values at different pressures were estimated based on the trend line generated by the measured data. Based on the reference ACH50 value at the condition of the artificially induced pressure of 50 Pa, the conversion coefficient was estimated by using Eq. 6. Using this, the ACH50 value can be predicted in which the pressure of 50 Pa can't be maintained due to some building conditions.

The present study figured out the airtightness of educational buildings and estimated the ACH50 values by using the conversion coefficient generated by the ACHn values at different pressures. For further study, the calibration constant can be estimated through the analysis of the relationship between the tracer gas technique and the fan pressurization method.

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