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Trends in building and ductwork airtightness in the Republic of Korea

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1 General introduction

Standards for building airtightness performance are designed to provide specific values for assessing and guiding building and construction elements for the purpose of minimizing air infiltration, which directly affects the energy efficiency and indoor environmental quality of buildings. These standards can promote an improvement in construction quality of the building envelope, thereby improving the overall performance of a building. The framework of airtightness regulations varies according to the building energy policies and implementation schemes adopted by different countries or regions, and the specific details constantly change over time. In the Republic of Korea, the law code currently (as of August 2023) does not provide any standards relating to building airtightness performance or to the evaluation of the actual airtightness levels of completed buildings and installed air-conditioning or ventilation ductwork system. Although the Construction Standard for Energy-Saving Eco-Friendly Residential Buildings lists the airtightness performance of certain front doors and windows and the building certification system also provides some data on building envelope airtightness for preliminary evaluation, these do not accurately reflect actual airtightness performance. Furthermore, even though a non-residential building may also require high building airtightness, there are currently no relevant institutional standards or implementation regulations, so that the building designer and the construction company are not obligated to design and construction the building to have high airtightness. Also, since there are no established processes for diagnosing and increasing the airtightness performance at vulnerable positions, the airtightness performance of a completed building is generally not evaluated. The situation for ductwork airtightness is similar to building envelopes and components. There are currently no established national standards or regulations about performing or evaluating the detailed airtightness levels for ductwork. It is also not mandatory within official policies, even though it is needed to follow required testing regulations when performing the related airtightness tests. Some industrial companies and organizations have realized the significance of airtight ductwork systems, and related data and results are also available for internal use themselves. However, it should be noted that there have been ongoing research and discussions regarding the development of an institutional framework for assessing airtightness performance, and it is expected that relevant standards and procedures will be prepared in the near future. This paper presents the regulatory context, the control procedures, and the analysis results for building and ductwork airtightness in the Republic of Korea.

2 Building airtightness

2.1 Introduction

There are mentions of building airtightness within various building certification and performance evaluation programs implemented in the Republic of Korea that deal with improvements in the energy efficiency of buildings. However, there are yet no relevant standards for the detailed airtightness requirements that should be met by a completed building. An in-depth discussion of building airtightness performance data began with the implementation of the Korea Energy Performance Building System (EPB). This system was first implemented for residential buildings in 2001 and was expanded to include non-residential buildings in 2010. However, most measurements are primarily conducted for residential buildings, with only a few measurements conducted for non-residential buildings. Therefore, this paper reviews the national implementation at the institutional level of various information such as reference values, testers, measurement standards, and databases related to building airtightness performance in the Republic of Korea, as well as implementation measures performed by academic institutes and private associations.

2.2 Airtightness indicator

In Korea, the air change rate at 50 Pa (ACH50) is commonly used as the indicator for evaluating the overall airtightness performance of a building. The ACH50 indicator quantifies airtightness levels by converting the measured air leakage rate at 50 Pa (CMH50) to an hourly rate and then dividing it by the volume of the target building. In addition, air permeability ($m^3/h\cdot m^2$) at a particular pressure difference is frequently used to assess the airtightness of building components such as curtain walls, envelopes, windows, and doors. The air permeability values under 150 Pa and 300 Pa are used for curtain walls, while values obtained under 100 Pa are used for windows and doors. The derived air permeability values at each related pressure difference value can be converted to values at the reference pressure difference specified in KS F 2297 [1].

2.3 Requirements and drivers

2.3.1 Building airtightness requirements in the regulation

In the Republic of Korea, there are no national standards specifying the airtightness requirements for buildings. However, the airtightness performance values of certain building components are specified in the Energy Conservation Design Criteria for Buildings [2] and the Construction Standard for Energy-Saving Eco-Friendly residential buildings, particularly for airtight windows and doors. Moreover, the criteria published by the Korean Institute of Architectural Sustainable Environment and Building Systems (KIAEBS C-1: 2013 Building Airtightness Criteria) include airtightness criteria for three types of buildings, namely general buildings, energy-saving buildings, and zero-energy buildings [4].

Energy Conservation Design Criteria for Buildings [2]

- Airtight windows and doors should be used in living rooms that directly or indirectly contact outside air.
- "Airtight windows" and "airtight doors" refer to windows and doors of which the airtightness ratings are on a scale of 1 (i.e., having air permeability of less than 1 $m^3/h\cdot m^2$ at 100 Pa) to 5 (i.e., having air permeability of less than 1 $m^3/h\cdot m^2$ at 100 Pa) based on the Korean Industrial Standard (KS) F 2292.

Construction Standard for Energy-Saving Eco-Friendly residential buildings [3]

- High-insulation and High-tightness Steel Doors: Fire doors in living rooms and entrance doors directly contacting outside air must use products that meet airtightness rating 1, and entrance doors indirectly contacting outside air must use products that meet airtightness rating 2 or higher.

- Airtightness Performance of Windows Directly contacting Outside Air: Products having a performance rating of 1 or higher must be used, where the rating must be obtained according to the airtightness measurement method of windows provided by KS F 2292, with the exception of windows installed on the inner sides of the balconies.

KIAEBS C-1: 2013 Building Airtightness Criteria [4]

- For general buildings, the ACH50 must be less than 5.0.
- For buildings subject to an EPB (energy performance of building) evaluation, the ACH50 must be less than 3.0.
- From among the buildings above, an ACH50 of less than 1.5 is necessary for a building to be certified as a zero-energy building.

2.3.2 Incentive for Building airtightness

At present, it is not yet mandatory to comply with the detailed building airtightness criteria in the Republic of Korea, and as such, there were no incentives for complying with building airtightness guidelines. For new buildings, however, specific incentives are currently being implemented that allow increased floor area ratios based on EPB ratings.

2.3.3 Building airtightness justifications

Even though there are no mandatory requirements of a minimum airtightness level for general buildings in the national law, the airtightness criterion for buildings ready to apply for EPB certification is required. The ACH 50 of 6 should be followed at the stage of pre-certification, and this required value must also be met at least before the completion of the evaluated building when performing the final certification, as shown in Table 1. It is important to note that a sample testing for building airtightness is required for residential buildings, and it is not necessary to carry out field airtightness measurements for non-residential buildings due to measurement difficulties. The percentage of new residential buildings performing airtightness measurements is estimated to be less than 10%, taking into account the mandatory targets and buildings to be certified.

2.3.4 Sanctions

There are no sanctions as regards building airtightness in the Republic of Korea.

2.4 Building airtightness in the energy performance calculation

2.4.1 Calculation

In the Republic of Korea, new buildings exceeding a certain size must obtain an EPB certification, which is based on ISO 52016 and DIN V 18599. The residential complexes with more than 30 units, public dormitories with a gross area of more than 3,000m^2, and public buildings with a gross area of more than 500m^2 are in the range of certified building types based on the requirements of the Green Building Support Act in the Republic of Korea. The certification process mainly focuses on the yearly primary energy consumption per unit area and is calculated by the ECO2 program, which comprehensively assesses energy consumption in regard to heating, cooling, water heating, lighting, and ventilation. Moreover, heat loss resulting from ventilation is calculated by considering factors such as room volume, effective air change rates, heat capacity, and heating period, and default values for airtightness are used as inputs in the calculation process [6].

2.4.2 Default values

The EPB certification provides specific criteria for airtightness performance in both non-residential and residentials sectors, as shown in Table 1. It should be noted that the calculation process for the infiltration rate in the EPB certification process is simply conducted using the calculation method presented in ISO 13789 and DIN V 18599-2. That is, the infiltration under natural conditions is calculated by considering the ACH50 value shown in Table 1, shielding coefficient, and factor due to mechanical ventilation. As a result, it is calculated as a constant value. Research on what level to set the external natural pressure difference is also an issue in Korea. Also, there has been ongoing discussion and research on achieving measurement-based airtightness performance, and it is expected that the related revisions will be made in the future.

Table 1. Criteria for EPB certification

Classification		Criteria for airtightness performance
Non-residential sector	Buildings with exterior windows	1.5 ACH50
	Buildings without exterior windows	0.0 ACH50
Residential sector	Pre-certification	6.0 ACH50
	Final-certification	Based on field measurement results

2.5 Building airtightness test protocol

2.5.1 Qualification of Airtightness testers

In the Republic of Korea, there is currently no national or official qualification system related to measuring building airtightness. However, organizations such as academic institutes and industry associations offer programs aimed at training certified air leakage testers. The academic institute of KIAEBS has carried out the most training programs. Each year, around 50 individuals receive theoretical education perform exercises, and obtain expert certification upon passing a certification exam.

Theoretical training, 2 days

- Basic theory
- Airtightness within buildings
- Airtightness and ventilation performance
- Building airtightness measurement methods (KS, ISO, ASTM, EN standard)

Airtightness measurement exercise, 1 day

- Air leakage report writing
- Field exercise of fan pressurization method

Certified air leakage tester exam (Blower door test), 1 day

- Paper exam (over 70%)
- Blower door test (Pass/Fail) based on ISO 9972

In addition, it is mandatory for certified air leakage testers to conduct at least one field measurement or receive airtightness-related education annually to uphold their expert status. Since 2013, approximately 200 people have obtained certification as air leakage testers through the training programs. However, it is important to note that airtightness measurement certification is not a compulsory requirement for testers in the field, and many airtightness measurements are conducted by non-certified testers. As such, there are plans for an overall revision to the training programs and certification systems in the Republic of Korea.

2.5.2 National guidelines

In the Republic of Korea, the building airtightness measurements are conducted according to KS L ISO 9972 [8], but other relevant standards such as EN and ASTM may also be used alternatively. For buildings applying for EPB certification, the actual airtightness performance must be checked at the final certification stage. A certification organization designated by the government will measure the airtightness of the completed buildings based on the building airtightness measurements manual which is the fieldwork guidelines for the final-certification stage distributed by the Korea Energy Agency. This manual is based on KS L ISO 9972 but is not included in the standard. It describes details that were not covered in the standard. Recently, to ensure the reliability of airtightness measurements, the manual is being revised and will include information on measurement experts, proficiency testing, and equipment calibration. Generally, 5 to 10 units are selected as samples for a building having 500 to 1000 units. The field measurements are carried out on samples determined based on the characteristics of the building as follows [9].

- The unit types in the building overview plan
- Unit types with and without balconies
- Unit types having specific environmental & construction conditions

2.5.3 Requirements on measuring devices

In the Republic of Korea, the fan pressurization method is applied in performing the airtightness measurements based on the KS L ISO 992 standard. It is also recommended to calibrate the apparatus according to the guidelines provided in Annex A of the standard. However, there are no specific requirements for confirming whether or not a calibration process was performed in the field. This aspect is also currently under discussion as a point of possible improvement in the policy, and detailed review procedures are expected to be implemented in the future.

2.6 Building airtightness tests performed

2.6.1 Tested buildings

In the Republic of Korea, although there are no national standards regarding building airtightness performance, airtightness measurements are often conducted for the purpose of research or enhancing building performance in the construction industry. In addition, the implementation of the EPB certification has led to building airtightness measurements being carried out for quality control during the certification process. The EPB certification has been implemented for residential buildings since 2001 and was expanded to non-residential buildings in 2010. However, the majority of airtightness measurements up to the present have been conducted for residential buildings, and there have been almost no measurements conducted for non-residential buildings. When a certification that specifically requires airtightness measurements was adopted (ex. LEED) for urban development projects having special purposes, a one-time large-scale airtightness measurement was conducted, as one out of seven units were selected as samples.

2.6.2 Database

Currently, there is no national building airtightness database in operation. Instead, the Building Airtightness Information Platform (BAIP) compiles building airtightness performance data from publicly available sources, including field measurements, private industry reports, and journals published in the Republic of Korea since 1980, as shown in Figure 1. The BAIP database is classified into four categories and contains a total of 29 types of information [10-14].

- Building information: building name, building type, location, year of construction, total floor area, number of floors, building height, and picture
- Measured space: measurement supervisor, measurement purpose, measurement standard, measurement time, measurement date, floor area, height, volume, and envelope area
- Measurement results: temperature, barometric pressure, wind speed, relative humidity, airflow exponent (n), air Leakage coefficient (C), correlation (r2), and CMH500
- Measurement equipment: manufacturing company, model name, serial number, and calibration expiration date

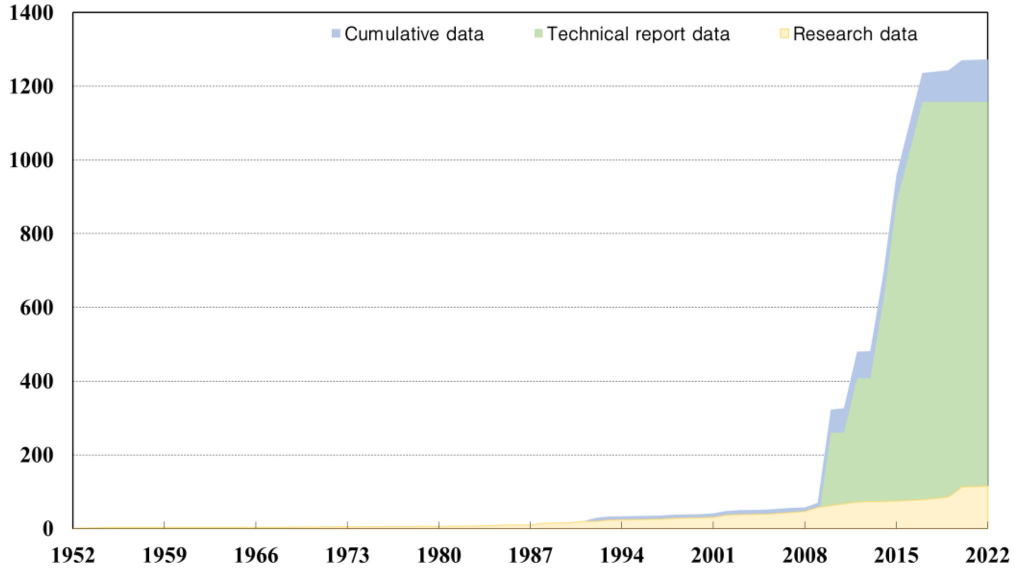

Figure 1 : Number of building airtightness data sets in the ROK

2.6.3 Evolution of the airtightness level

The total number of accumulated data in the BAIP database is 1,280 sets, with 96.5% of the data coming from multi-unit residential buildings and 2.0% from single-unit residential buildings. Most of the single-unit houses are old buildings, and there is very little data on educational buildings and office buildings. The average ACH50 for multi-unit residential buildings is 2.7 (interquartile range: 1.8-2.9). For single-unit residential buildings, the average ACH50 is 15.0 (interquartile range: 6.9-20.6). Educational buildings have an average ACH50 of 17.0 (interquartile range: 14.0-22.7). Office buildings have an average ACH50 of 3.5 (interquartile range: 2.9-4.0).

Since most of the data in the database is from multi-unit residential buildings, these data sets were used to analyze airtightness performance. The airtightness data further categorized by year of construction, show that 2% were built before 2000, 23% were built between 2000 and 2010, and 75% were built after 2010. As shown in Figure 2, the average ACH50 for buildings built before 2000 is 13.3 (interquartile range: 10.5-13.3), the average ACH50 is 3.5 (interquartile range: 2.3-3.4) for buildings built between 2000 and 2010, and for buildings built after 2010, the average ACH50 is 2.5 (interquartile range: 1.8-2.6).

Figure 3 further presents the ACH50 distributions for multi-unit residential buildings, categorized by floor area. The average ACH50 for all analyzed buildings with various floor areas is 5.59. It is worth noting that there is a significant difference based on the floor area of the analyzed buildings. Among these buildings, 2.9% have areas less than 50 m^2, 2.9% have areas of 50 m^2 to 100 m^2, 63.5% have areas of 100 m^2 to 150 m^2, 25.1% have areas of 150 m^2 to 200 m^2, and 5.6% have areas of more than 200 m^2. As shown in Figure 3, there is a large variation in ACH50 for buildings with floor areas of 50 m^2 or less, and the average ACH50 for buildings with floor areas of more than 100 m^2 (30 flats) is 2.3 (interquartile range: 1.8-2.7). It can be concluded that multi-unit residential buildings with larger floor areas consistently exhibit higher airtightness levels than buildings with smaller floor areas.

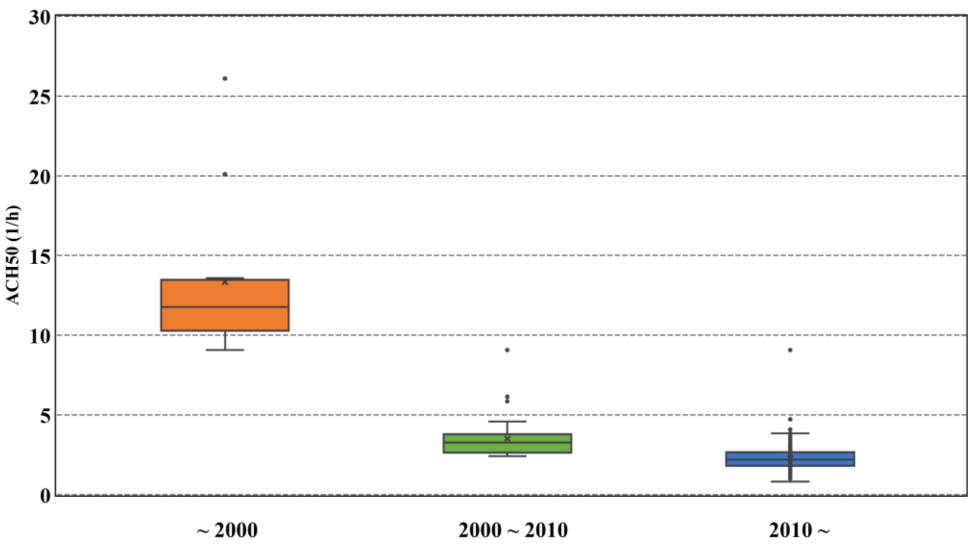

Figure 2 : Airtightness (ACH50) of multi-unit residential buildings by year

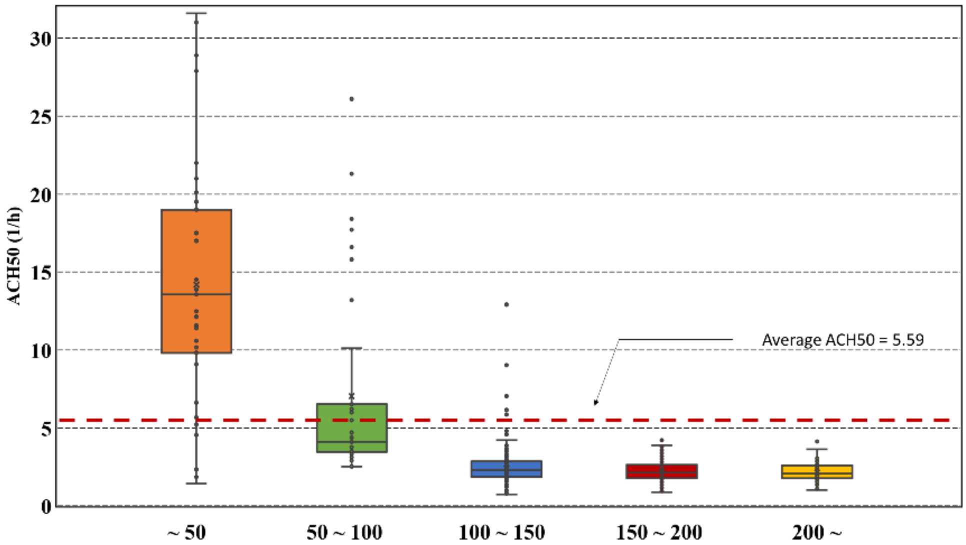

Figure 3 : Airtightness (ACH50) of multi-unit residential buildings by floor area

2.7 Guidelines to build airtight

A national R&D study was undertaken in collaboration with research institutes, construction and engineering companies, encompassing various aspects including building airtightness standards, building airtightness measurement methods, airtightness checklist, leakage site diagnosis, and processes applicable to specific construction methods and building elements for airtight buildings [15]. In addition, the Korea Land & Housing Corporation (LH) has been accumulating various practical guidelines regarding methods of increasing airtightness by using existing construction methods and airtight materials for various selected areas of possible air leakage [16].

2.8 Conclusion

In the Republic of Korea, there are currently no established national regulations or standards for building airtightness. However, guidelines are being developed as a part of efforts to promote building energy efficiency and carbon reduction policies. The current guidelines merely recommend the application of airtight techniques. There is an increasing demand for comprehensive guidelines that cover all aspects of building airtightness, including design criteria, airtightness measurements for obtaining certification, airtightness performance standards, airtightness techniques, and airtightness data. In collaboration with academic institutes and industrial organizations, the following fields related to airtightness standards, measurement procedures, and data management are being studied:

- Establishment of performance standards to provide adequate building airtightness performance
- Management of building airtightness performance and management of airtightness data for ensuring adequate airtightness performance
- Establishment of airtightness measurement guidelines for ensuring building airtightness reliability
- Development of certified air leakage testers through the training programs

In addition, with the expansion of the regulatory scope, the targets of airtightness measurements are being extended beyond public and residential buildings to non-residential buildings. As such, there remains a need to develop measurement guidelines and airtightness standards specific to large-scale buildings (i.e., buildings having large spaces and great heights).

3 Ductwork airtightness

3.1 Introduction

In the Republic of Korea, there is limited research on indoor air quality and energy consumption related to the airtightness of ductwork. Existing studies have focused on test standards, protocols, and devices for measuring the airtightness of air ducts in multi-unit residential buildings [17]. Although there is currently no national standard for ductwork airtightness, the technical standard for mechanical design (Notice No. 2021-851, Ministry of land, Infrastructure and Transport) includes a section on the design and construction of air-conditioning equipment that emphasizes the importance of achieving high airtightness performance at duct connections during the assembly process [18]. In particular, there are no related studies specifically aimed at the airtightness performance of ductwork within residential buildings. This is mainly because floor radiation heating systems are commonly used for heating in multi-unit residential buildings in the Republic of Korea. As shown in Figure 4, the air ducts in these kinds of buildings are mainly for the ventilation system of the utility room, as well as for the exhaust systems of the kitchens and bathrooms.

While there are association group standards set for methods of testing air leakage in the ductwork of HVAC systems in non-residential buildings, only certain private construction companies perform these tests through third-party companies at the time of TAB (Testing, Adjusting and Balancing) after building construction is completed.

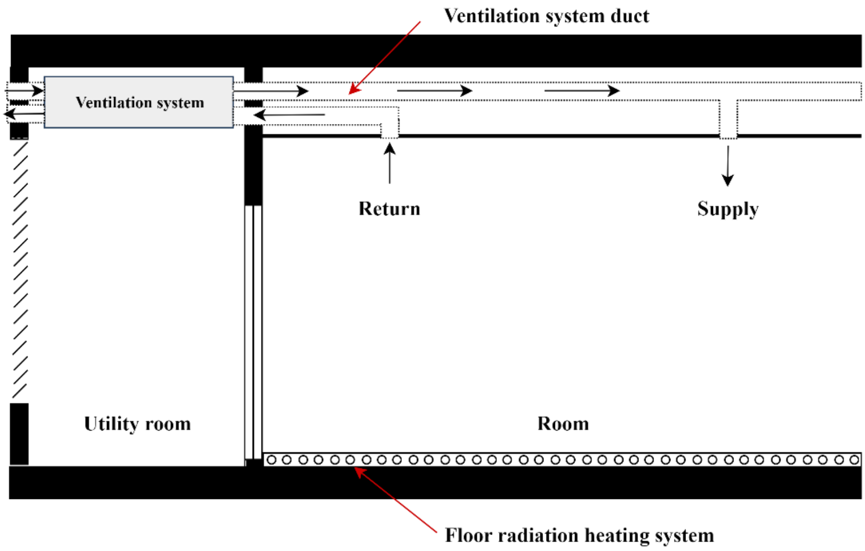

Figure 4 : Diagram of a typical unit in a multi-unit residential building

3.2 Airtightness indicator

At present, there are no established national standards for the airtightness performance of ductwork in the Republic of Korea. However, it is recommended to conduct TAB and other building performance evaluations, which include measurements of ductwork airtightness, after the installation of the ductwork has been completed. In addition, it should be noted that the air duct leakage standard for HVAC systems presented by the KARSE [14] (Korean Association of Air Conditioning Refrigerating and Sanitary Engineers) closely aligns with the standard of DW-143 Duct Work Leakage Testing established by the HVCA (Heating and Ventilating Contractors Association), which is applied as a standard for conducting air leakage tests of ductwork in the UK.

In the KARSE standard, allowable air leakage rates are presented for various classes that have been categorized based on the intended purpose. The allowable air leakage rate of the tested section of a duct is then calculated by multiplying the allowable leakage rate per duct surface area by the surface area of the tested section. The categorized classes include Classes A, B, C, and D, where Class A is designated for general air conditioning ducts, Class B is for the air ducts of CAV (Constant Air Volume) or VAV (Variable Air Volume) systems, and Classes C and D are for high-velocity air duct systems.

3.3 Requirements and drivers

3.3.1 Ductwork airtightness requirements in the regulation

The ductwork airtightness requirements proposed by industrial organizations can mainly be classified into criteria based on system leakage rates and criteria based on air leakage classes. Table 2 presents the first kinds of criteria for four recommended application situations based on the system leakage rates [19]. The second kinds of criteria based on the air leakage classes is to provide the allowable leakage rate for each of the classes based on the intended purpose. The allowable air leakage volume for a test duct section is then calculated by multiplying the allowable rate with the surface area of the test duct. Table 3 presents the specific allowable air leakage rates for each class [17].

Table 2: System leakage rates [19]

Index for system leakage rates	Recommended applications
> 5% and < 10%	Ventilation for unconditioned zones
≤5%	Smoke extraction ducts, CAV systems used on each floor
≤3%	VAV systems, kitchen exhausts, septic tank exhausts, toilet exhausts
≤1%	Special places (operating rooms, cleanrooms, etc.)

Table 3 : Allowable air leakage rates by air leakage classes [17]

Measurement pressure differential (Pa)	Maximum allowable air leakage rate per duct surface area (L/s·m^2)			
	Class A	Class B	Class C	≤ Class D
100	0.40	0.20	–	–
200	0.63	0.31	–	–
300	0.82	0.41	–	–
400	0.98	0.49	–	–
500	1.14	0.57	–	–
600	–	0.64	0.32	–
700	–	0.71	0.35	–
800	–	0.77	0.39	–
900	–	0.83	0.42	–
1000	–	0.89	0.45	–
1300	–	–	0.53	0.26
1800	–	–	0.65	0.33
2300	–	–	–	0.38
Recommended application pressure (atmospheric pressure)	≤ 500 Pa	≤ 750 Pa	≤ 1500 Pa	≥1501 Pa

Reference: Test code for leakage of HAVC (Heating, ventilation and air conditioning) air ducts

3.3.2 Incentive for Ductwork airtightness

At present, there are no specific national regulations in the Republic of Korea regarding the airtightness of ductwork. Additionally, there are no incentives or penalties related to measuring the airtightness of ductwork.

3.3.3 Ductwork airtightness justifications

The measurement of the airtightness of the ductwork is merely recommended as a part of the engineering inspection (ex. TAB) performed at the time of completion of a building. The measurement of ductwork airtightness is not itself a mandatory test, although it may be performed in compliance with building performance regulations, testing regulations, and the requirements of the contractor.

3.4 Ductwork airtightness in the energy performance calculation

In the Republic of Korea, the airtightness of the ductwork is not included in the EPB (energy performance building) program applied in related regulations.

3.5 Ductwork airtightness test protocol

Ductwork airtightness tests are performed primarily by mechanical equipment installation companies, subcontractor companies, and consulting companies. However, there are currently no standardized training or qualification systems for these testers. The national guidelines for ductwork airtightness tests and the required measuring devices are implemented according to the procedures outlined in the standards proposed by relevant associations or institutions.

3.6 Ductwork airtightness tests performed

Because there are no standards for ductwork airtightness, there are typically no evaluations performed of the airtightness of ducts in residential buildings. For non-residential buildings, the assessment for the ductwork airtightness is mainly conducted by the mechanical equipment installation companies and subcontractor companies. The test results are not publicly accessible, as these data are restricted to internal use within these companies. Therefore, there are no existing databases for collecting information regarding ductwork airtightness in the Republic of Korea.

3.7 Guidelines to build airtight ductwork

Concerning a guideline for providing airtight ductwork, the national standard of Notice No. 2021-851 (Technical Standards for Mechanical Equipment published by the Ministry of land, Infrastructure and Transport in the Republic of Korea) for the design and construction of air conditioning equipment highlights the significance of maintaining high airtightness and insulation performance at the connections during the assembly and installation process of air conditioning equipment, emphasizing the importance of constructing airtight ductwork.

In addition, the SPS-KARSE B 0016-0178:1999 standard describes the assembly method for the main sectors of the ductwork and emphasizes the importance of ensuring a tight seal between ducts. [19]. However, this standard does not provide specific instructions on how to build airtight ductwork during the construction process. The guidelines and procedures for airtight construction of ducts are mainly developed privately by research institutions and construction companies.

3.8 Conclusion

In the Republic of Korea, there are no related national standards or regulations relating to the airtightness of ductwork; neither are there many related studies. Some organizations and companies have recognized the importance of the airtightness of air ducts and have invested in some related research. However, the derived results and data are not open to the public, as the research is intended for internal use. In spite of this, it is well known that providing airtight ductwork can improve building energy performance and ventilation performance.

Therefore, it is necessary to establish the relevant standards for and regulations on the airtightness performance of ductwork in the Republic of Korea. Additionally, it is also expected that the implementation of training and qualification programs for conducting duct airtightness tests, as well as the development of manuals, will greatly enhance the overall quality in the installation of ductwork.

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