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Trends in building and ductwork airtightness in China

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1 General introduction

From 1978 to 2020 in China, urban housing stock increased from less than 1.4 to 31.3 billion square meters, and urban housing floor area per capita increased from 8.1 to 34.7 square meters; rural housing stock increased from 10.0 to 27.0 billion square meters, and rural housing floor area per capita increased from 10.7 to 48.9 square meters. According to the census data on the age structure of housing, about 97% of urban housing was built since 1978, about 87% was built since 1990, and about 60% was built since 2000. Due to the impact of the COVID-19 epidemic, real estate development in the past three years was not optimistic. However, based on Chinese infrastructure capacity and economic development, it is estimated that the urban housing stock in China can still reach 40.6~41.3 billion square meters by 2030 [1, 2]. Currently, the number of non-residential buildings constructed is much lower than residential buildings in China, as illustrated in Figure 1.

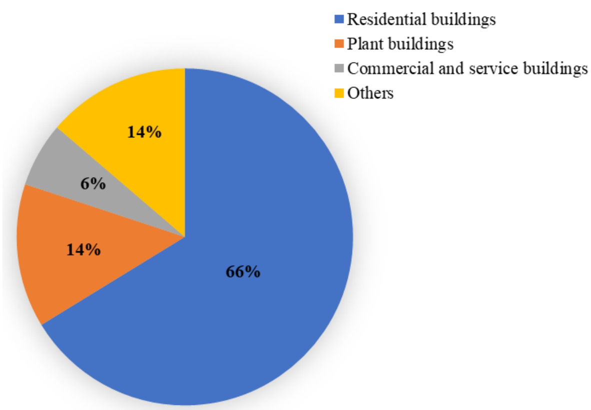

Figure 1: The composition of the completed building area in the Chinese construction industry in 2021.

2 Building airtightness

2.1 *Introduction*

The building's airtightness can be defined as the ability of a building to prevent air from flowing into or out of it in the closed state [3]. Past studies have shown that airtightness has various effects on many aspects of buildings, such as indoor air quality (IAQ), indoor acoustic environment, thermal comfort, thermal performance of building envelope, and building energy consumption [4-6].

Although airtightness has been widely investigated and discussed internationally since the 1970s, it was not in China until 20 years ago. It was stipulated that buildings built in parts of China must meet the energy standards with high airtightness requirements by 2020 [7], and China Passive Building Alliance (CPBA) pointed out that 30% of new buildings would meet the requirements of ultra-low energy consumption by 2030 in China. With the increased requirement on building energy efficiency, the airtightness of building envelope has become an important concern to improve the quality of buildings in China.

At present, most studies on airtightness in China focus on the northern regions. From the results of a recent survey, the heat loss due to air infiltration decreases from 71% to 18% when the air infiltration rate in large spaces decreases from 0.56 to 0.06 h^{-1} in northern China [8]. Hence, improving the airtightness of buildings is one of the important measures for effective energy saving.

2.2 Airtightness indicator

In China, the parameters of N_{50} [h^{-1}] and Q_{50} [$m^3/(m^2 \cdot h)$] are used as airtightness indicators, which correspond respectively to the air change rate and air leakage rate divided by the building envelope area at the reference pressure of 50 Pa.

2.3 Requirements and Drivers

2.3.1 Building airtightness requirements in the regulation

In China, the primary concern is the airtightness of building components, such as doors and windows, which is regulated according to the national standard GB/T 7106-2019 [9].

In recent years, the whole airtightness of the building envelope has been receiving more and more attention. The first national standard that provides guidelines on airtightness testing in a complete way is GB/T 34010-2017 [10], which is developed based on the standard ISO: 9972 [11], but it does not define limit values for building airtightness. At the end of 2020, China implemented the standard T/CECS 704-2020 [12], which is more in line with Chinese conditions. The whole airtightness is graded to judge the level of airtightness of a building. More details are shown in Table 1.

Table 1: The classification of the whole airtightness of buildings under natural pressure difference (outdoor wind speed not exceeding 3 m/s).

Level	1	2	3	4
Value/ h^{-1}	N>0.3	0.2<N ≤0.3	0.13<N ≤0.2	0.08<N ≤0.13
Level	5	6	7	8
Value/ h^{-1}	0.05<N ≤0.08	0.03<N ≤0.05	0.015<N ≤0.03	N≤0.015

It is worth noting that there are five different climate regions in China, and the airtightness requirements vary from one climate region to another, and the distribution of climate regions is shown in Figure 2. The design standards of building energy efficiency in each climate zone stipulate the corresponding limit for airtightness of general buildings, but only for the components of doors and windows.

Figure 2: Distribution of the five climatic regions for building design in China.

With the promotion of green and energy-efficient buildings in recent years, the design requirements for the whole airtightness of the building envelope have gradually increased. According to the standard GB/T 51350-2019 (recommended for buildings, i.e. used only in some buildings) [13], the related requirements are shown in Table 2. However, there is a lack of comprehensive regulations for office buildings.

Table 2: Airtightness requirements for ultra-low and nearly-zero energy buildings in different climate regions in China.

Climate region	N_{50}/ h^{-1}	
	Ultra-low energy buildings/ Nearly zero energy buildings	
	Residential buildings	Public buildings

Severe cold region	≤0.6	≤1.0
Cold region	≤0.6	≤1.0
Mild region	≤1.0	-
Hot summer and cold winter region	≤1.0	-
Hot summer and warm winter region	≤1.0	-

2.3.2 Incentive for building airtightness

The difficulty of airtightness statistics in China lies in the fact that a large number of domestic buildings are widely distributed in various climatic regions, and airtightness tests require huge human resources. In fact, airtightness-related research is coordinated and promoted mainly by agencies responsible for energy efficiency in the capital cities of each province.

2.3.3 Building airtightness justifications

At present, the standards T/CECS 704-2020 and GB/T 34010-2017 provide guidelines on testing airtightness of buildings in China, because they introduce the airtightness test and evaluation method in detail. On one hand, the fan pressurization method can be performed according to the above two standards. On the other hand, the standard T/CECS 704-2020 promotes the adoption of the tracer gas method for airtightness tests, where the infiltration air change rate is calculated by means of Equation (1):

$$N_n = \frac{\frac{1}{n}(\sum_{i=1}^{n} t_i)(\sum_{i=1}^{n} y_i) - \sum_{i=1}^{n} t_i \cdot y_i}{(\sum_{i=1}^{n} t_i^2) - \frac{1}{n}(\sum_{i=1}^{n} t_i)^2} \qquad (1)$$

where: N_n is the air change rate under natural pressure difference [h^{-1}]; t_i is the time of the i-th recording point from the start of the test [h]; and n is the number of test records. Among them, y_i is calculated by Equation (2):

$$y_i = ln\,[C(t_i) - C_{out}] \qquad (2)$$

where: $C(t_i)$ is the concentration of tracer gas at the i-th recording point [ppm]; and C_{out} is the concentration of outdoor tracer gas [ppm].

2.3.4 Sanctions

In the case of China, there is no mandatory requirement for airtightness tests of existing buildings so far. If a new-build building does not meet the airtightness requirements, the developer is responsible for improvement, for example, by filling the gaps of door and window frames, sealing redundant pipelines and holes, etc.

2.4 *Building airtightness in the energy performance calculation*

2.4.1 Calculation

The energy performance calculation is carried out mostly by inputting specific airtightness values of the whole building and windows. In China, the main energy performance calculation tool developed by a domestic institution is DeST. The input values of airtightness for most energy performance calculations related to China were obtained by the tests based on the standards GB/T 7106 and ISO: 9972.

2.4.2 Default values

If tests cannot be performed to obtain the infiltration air change rate or air permeability, the energy simulation can be performed using the recommended airtightness values specified in relevant standards, such as T/CECS 704-2020. If these values can be obtained by tests, the test results are inputted into the energy simulation tools for calculation.

2.5 *Building airtightness test protocol*

2.5.1 Qualification of airtightness testers

There is no qualification scheme for airtightness testers in China.

2.5.2 National guidelines

Most of the past airtightness tests were performed according to the international standard ISO: 9972 with a Blower Door. After the end of 2020, T/CECS 704-2020 gradually became the main reference standard.

2.5.3 Requirements on measuring devices

There are no requirements for the selection of measuring devices, but there are requirements for the accuracy of the measuring devices, as shown in Table 3[10, 12].

Table 3: Requirements for the accuracy of the measuring devices in Chinese standards.

Standard	Accuracy requirements		
	Pressure measuring devices	Temperature measuring devices	Airflow measuring devices
GB/T 34010-2017	±2 Pa	±1.0 K	Below ±7%
T/CECS 704-2020	±2 Pa	±0.2 K	-

2.6 Building airtightness tests performed

2.6.1 Tested buildings

Current regulations and standards in China do not impose mandatory requirements for airtightness tests after the construction of new-build buildings. The actual percentage of buildings tested in China is unknown so far, and it is also impossible to determine how many buildings will be tested soon. Besides, in recent years, the number of new-build buildings has continued to rise, which resulted in an increasing number of tested cases, but there is still no way to know the percentage of change in tested buildings.

It can be learned that most airtightness studies of existing buildings in China are up to about 2000, and most of the buildings before 2000 have serious air leakages. There are relatively few such studies after 2000. The average N_{50} value of residential buildings from the 1980s to 1990s is about 10.4 h^{-1}. Some data shows that the N_{50} is mostly 1.2~2.0 h^{-1} for ordinary energy-efficient buildings, with an average value of 1.7 h^{-1}. Most of these studies focus on the buildings in the northern part of China, where residential buildings account for a dominant proportion. Most of these buildings do not have a mechanical ventilation system and obtain outdoor air basically through natural ventilation.

2.6.2 Database

Since airtightness tests have not been fully promoted, there is not a comprehensive airtightness database in China so far. However, airtightness surveys have been organized at the government level, mainly in the northern region as well. For example, in the "Survey of Basic Data on Energy Efficiency Renovation of Existing Buildings in China" spanning from 2005 to 2010 [14], the airtightness of typical buildings in the northern region was documented, as shown in Table 4.

Table 4 : Some airtightness test results of typical buildings at the government level in Northern China ($\bar{N}_{50}$ is the mean value).

Region	Year	Number	N_{50}/ h^{-1}	$\bar{N}_{50}$/ h^{-1}
Hebi	1977-1997	5	8.3~20.7	13.5
Tangshan	1982-1995	8	5.6~19.3	12.6
Tianjin	1965-2002	6	5.5~10.8	7.2
Urumqi	1980-2003	7	4.4~6.8	5.4

Sporadic tests were performed usually at the level of local organizations or for research purposes. Some results are shown in Table 5. The airtightness test data for the mild region and the hot summer and warm winter region is basically absent, probably because the warm climate of these regions makes the attention on airtightness fairly low. The airtightness tests in southern China are mainly concentrated in hot summer and cold winter region, and airtightness of buildings in this area is getting more attention.

Table 5 : Some sporadic airtightness test results of buildings in China ($\bar{N}_{50}$ is the mean value).

Region	Year	Type	Number	$\bar{N}_{50}$/ h^{-1}
Beijing	1990-2010 [15]	Apartment	34	2.89
Beijing	1990-2007 [16]	Public building	3	4.47
Beijing	1980 [17]	Apartment	1	4.08
Tangshan	1990 [17]	Apartment	1	16.67
Dalian	2013 [18]	Detached dwelling	10	1.42
Dalian	2013-2015 [5]	Apartment	4	1.77
Dalian	2016 [19]	Public building	1	0.47
Qingdao	2016 [20]	Public building	1	0.30
Chengdu	2010-2020 [21]	Apartment	14	13.17

Some of these tests were funded by the government through research projects and the funding bodies include “the Fundamental Research Funds for the Central Universities”, “National Natural Science Foundation of

China", and "the National Key Research and Development Program of China".

2.6.3 Evolution of the airtightness level

The installation of air conditioning systems increases the air leakage paths (ALPs) and enhances the exchange of air between the interior and exterior. Therefore, the wide popularity of HVAC systems decreases the building airtightness level to some extent, regardless of whether the central heating and air conditioning systems are usually used in the northern region or the split HVAC systems commonly used in the southern region [16].

China has been vigorously developing prefabricated buildings since the year of 2012. Although the construction period of this building is quite short, there are specific experimental data showing that the airtightness level is relatively lower than that of traditionally constructed buildings [22]. However, in the past three years, China has launched several guidelines and documents related to intelligent construction, so the airtightness of prefabricated buildings is also being improved.

Although no absolute statistical relationship between the airtightness level and the year of construction has been found, the airtightness level of new buildings will generally be higher than that of existing buildings with the advancement of the constructing and manufacturing industries as well as the corresponding standard requirements [22]. This can be demonstrated to some extent by the data presented in Table 4 and Table 5.

The internal components of the building have a certain influence on the excellence of airtightness, but the construction process and technology are the key factors affecting the building's airtightness. In general, buildings in China are moving towards a higher level of airtightness and energy efficiency.

2.7 *Guidelines to build airtight*

In China, the guideline T/CECS 826, published in 2021, applies to the design, construction, and acceptance of airtight materials for building construction [23].

2.8 *Conclusion*

With the technological development and the promotion of low energy and near zero energy buildings, as well as the stimulation of the goal of carbon peaking and carbon neutrality, the importance of building airtightness is increasingly recognized in China. Airtightness tests for buildings are being promoted across the country, as evidenced by the fact that there are more tests in the southern regions of China, but the tests performed previously were aimed mostly at the northern regions. The relevant standards and technologies are gradually improved, and the construction process of workers is also better supervised. In the future, buildings with good airtightness will account for an increasingly large proportion.

3 Ductwork airtightness

3.1 *Introduction*

Ductwork airtightness affects the air flow rate, indoor air quality, and energy consumption, etc. Considering that ventilation and air conditioning systems are widely applied in China, the attention paid to ductwork airtightness should be relatively high. However, there are not many studies on airtightness tests of ductwork in China, and people are concerned more about the flow resistance, noise control, and air filtration of ductwork. In fact, the air loss in ductwork due to air leakage is huge. Statistics show that the air leakage ratio of ductwork of HVAC systems is generally around 18%, and that due to poor joints is often as high as 10% to 15% in China [24]. In old buildings where the ductwork is in disrepair, the problem of ductwork leakage is particularly serious. Hence, it is necessary to pay more attention to ductwork airtightness.

3.2 *Airtightness indicator*

In China, there is only the concept of air leakage rate level of ductwork, rather than airtightness level. The former is defined in terms of the maximum volume of air allowed to escape or infiltrate per unit of time in the ductwork under a certain pressure. The indicator is Q [$m^3/(m^2 \cdot h)$], but the tested pressure difference is not clearly defined [25].

3.3 *Requirements and Drivers*

3.3.1 Ductwork airtightness requirements in the regulation

According to the Chinese requirements for HVAC ductworks, the air leakage rate level ranges from level A to E (level A is the best level and level E is the worst level), and its maximum air leakage limits range from 0.1056 to 0.0010 $P^{0.65}$ m³/(m²·h), respectively. The classification and airtightness requirements of ductwork are shown in Table 6, according to the standard GB 50243-2016 (mandatory for all buildings) and related requirements [25, 26]. In addition, the air leakage rate of ducts with special requirements shall not exceed 0.0036 $P^{0.65}$ m³/(m²·h), and that used only in virology laboratories and other similar applications shall not exceed 0.0010 $P^{0.65}$ m³/(m²·h) (P is the value of design pressure, Pa).

Table 6: Air leakage constant and air leakage limit per unit surface area for different types of ductworks (A is the rectangular metal duct; B is the round metal duct).

Ductwork type	P value	Air leakage constant		Permitted air leakage rate/ m³/(m²·h)	
		A	B	A	B
Low pressure ductwork	$P \leq 500$	0.1056	0.053	$\leq 0.1056P^{0.65}$	$\leq 0.0528P^{0.65}$
Medium pressure ductwork	$500 \leq P \leq 1500$	0.0352	0.018	$\leq 0.0352P^{0.65}$	$\leq 0.0176P^{0.65}$
High pressure ductwork	$P \geq 1500$	0.0117	0.006	$\leq 0.0117P^{0.65}$	$\leq 0.017P^{0.65}$

3.3.2 Incentive for ductwork airtightness

No information is available at the time of writing this paper about incentive for good airtightness of ductwork.

3.3.3 Ductwork airtightness justifications

In practice, ductwork airtightness is tested usually when problems arise and the owners or managers permit it. If the measured air leakage rate does not meet the requirements, repair work will be performed. The air leakage rate of the tested ductwork can be calculated according to the following Equation (3):

$$Q = 3600 \cdot \varepsilon \cdot \alpha \cdot A_{n} \cdot \sqrt{\frac{2\Delta P}{\rho}} \qquad (3)$$

where: Q is the air leakage rate [m³/h]; ε is the expansion coefficient of air flow; α is the flow coefficient of orifice plate; A_n is the opening area of orifice plate [m²]; ΔP is the differential pressure of orifice plate [Pa]; and ρ is the air density [kg/m³].

3.3.4 Sanctions

It seems that the developer will not be severely penalized if the ductwork does not meet the requirements of airtightness.

3.4 *Ductwork airtightness in the energy performance calculation*

Ductwork airtightness is not an input value for energy performance calculations, and there is a lack of attention to this.

3.5 *Ductwork airtightness test protocol*

3.5.1 Qualification of ductwork airtightness testers

There is currently no qualification scheme for testers of ductwork airtightness in China.

3.5.2 National guidelines

There is no specialized standard for the ductwork airtightness test in China, GB 50243-2016 is the most commonly used standard to deal with ductwork inspection. In addition, the standard GB 50591-2010 [27] has mandatory requirements for on-site airtightness tests of ductwork, but only for the cleanroom air conditioning systems [28].

3.5.3 Requirements on measuring devices

There are no specific requirements for measuring devices, and it is recommended to use measuring devices and components manufactured in accordance with the current national standard GB/T 2624-2006 (for round duct) [29] and GB/Z 35140-2017 (for rectangular duct) [30].

3.6 *Ductwork airtightness tests performed*

3.6.1 Tested ductwork

Few large-scale tests of ductwork airtightness have been conducted in China, and thus such test data is difficult to obtain. According to the current national standard, the constant pressure test method is adopted to measure the air leakage rate by the air duct leakage meter [31]. The air leakage rate under different pressures can be calculated by the following Equation (4):

$$Q_0 = Q(P_0/P)^{0.65} \tag{4}$$

where: Q_0 is the air leakage rate at a specified pressure [$m^3/(m^2 \cdot h)$]; Q is the measured air leakage rate [$m^3/(m^2 \cdot h)$]; P_0 is the prescribed working pressure for ductwork tests [Pa]; and P is the tested pressure [Pa].

Several test cases are briefly described here. For example, study [32] reported that the air leakage rate of engineering ventilation ducts under the pressure of 50~1500 Pa varies between 0.275 and 1.414 m^3/h. Study [33] showed that the air leakage rate of rectangular metal ducts of different sizes under the pressure of 1500 Pa is 1.448~3.704 $m^3/(m^2 \cdot h)$. More ductwork airtightness tests are expected in the future.

3.7 *Guidelines to build airtight ductwork*

The most relevant guidelines should be the standard GB 50738-2011 [34] and JGJ 141-2017 [35], compiled by the Ministry of Housing and Urban-Rural Development of the People's Republic of China. In order to build qualified ductwork, material selection, production, installation and inspection, etc., are stipulated.

3.8 *Conclusion*

In China, ductwork airtightness is stipulated in standards, but it is not easy to perform airtightness tests after the installation of the ductwork is completed. As a result, it seems that ductwork airtightness has not received enough attention. To better understand ductwork airtightness, the relevant test standards need to be improved, and more studies should be conducted in the future. With a better understanding, the airtightness of the ventilation ductwork can be included in the energy performance evaluation.

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The Air Infiltration and Ventilation Centre provides technical support in air infiltration and ventilation research and application. The aim is to promote the understanding of the complex behaviour of the air flow in buildings and to advance the effective application of associated energy saving measures in the design of new buildings and the improvement of the existing building stock.