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Airtightness field tests of residential buildings in Dalian, China

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A R T I C L E I N F O

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A B S T R A C T

There is little known on the airtightness performance of residential buildings in China. The present study intends to investigate the airtightness performance of ten detached houses in China's cold area using "blower door test". The thermal infrared imager and smoke pencil were used to find out the typical air leakage places in the building envelope.

Test results show that the air change rate at the pressure difference of 50 Pa of the tested houses varies from 1.89 h^{-1} to 0.84 h^{-1} with a mean value of 1.42 h^{-1}. The typical air leakage places happen at the reserved holes in the outer wall that were not well filled after construction, the frames of window and door that were not fitted correctly and the draught seal was deformed, and the check valves at the inlets of the discharge flue and exhaust airway in the house.

The tested detached houses were ranked by their airtightness performance. The total joint length of the opening part of the windows and doors was estimated for each detached house and a linear correlation between the n_{50} and the joint length of the opening part of the windows and doors was examined.

1. Introduction

The energy efficiency researches of the residential buildings in China began from 1980s and four energy efficiency design standards for residential buildings in severe cold and cold zones have been issued by Ministry of Construction so far. The current standard enacted in 2010 is usually called the 65% energy efficiency standard [1] which means that the heat and coal demand of the residential buildings built after 2010 is reduced by 65% compared with that of the residential buildings in 1980s. During the research and exploration of the next design standard for energy efficiency of residential buildings, i.e. the ultra-low energy building or nearly zero energy building, the importance of airtightness was gradually recognized by more and more researchers and designers in China.

The building airtightness, i.e. the resistance of the building envelope to the airflow, is the determining factor to avoid uncontrolled airflows through the building envelope. Studies showed that it has different influences on a lot of building related problems, such as the hygrothermal performance, occupants' health, building energy consumption, performance of the ventilation systems, thermal comfort, noise, and fire resistance [2–4]. For example, raising building airtightness helps reduce the air infiltration/exfiltration through the building envelope, then results in less energy demand for maintaining indoor thermal comfort. On the other hand, the indoor air quality deterioration may happen for the buildings that rely upon the air infiltration to provide adequate fresh air for occupants when raising building airtightness to a certain level.

Considering the importance of the airtightness of buidling envelope, many studies on the test methods, prediction models, quantification, and interaction with the other transfer phenomena have been performed [5], and many countries take into account airtightness in their energy performance calculation procedures [6]. International standards intended for the measurement of the air leakage of building envelope were developed. As far as we can know, the most widely applied two standards are the ISO 9972:2015 [7] (supersedes EN 13829:2000 [8]) and ASTM E779:2010 [9]. By using the fan pressurization method, a lot of airtightness field tests have been carried out. Alfano et al. [10] tested the airtightness of 20 residential buildings located in southern Italy and found that the average air change rate n_{50} value is fairly high, and the windows and chimney without sealing and natural ventilation systems have been found to be the most critical causes in building over-ventilation. Papaglastra et al. [11] presented a comparable analysis among a total of 1094 n_{50} values from field airtightness measurements from 7 European countries, and it was

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Acronyms and symbols

BDT	blower door test
ALP	air leakage path
q_{env}	air flow rate through the building envelope, m^3/h
ΔP	induced pressure difference, Pa
C_{env}	air flow coefficient, $m^3/(h\cdot Pa^n)$
C_L	air flow coefficient under standard conditions, $m^3/(h\cdot Pa^n)$
q_{pr}	air leakage rate at the reference pressure, m^3/h
ΔP_r	reference pressure, Pa
n_{pre}	air flow exponent under pressurization test mode
n_{dep}	air flow exponent under depressurization test mode
n_{50}	air change rate under the pressure difference of 50 Pa, h^{-1}
q_F	leakage rate per net floor area, $m^3/(h\cdot m^2)$
q_E	leakage rate per envelope area, $m^3/(h\cdot m^2)$
V_H	wind velocity at height H, m/s
V_0	wind velocity at the reference height, m/s
H_{met}	reference height, m
α	ground roughness coefficient

found that airtightness data for houses fits into a theoretical Weibull distribution while a considerable asymmetry in distribution was found for all countries except for Greece and Norway. Sfakianaki et al. [12] performed air tightness and infiltration measurements in 20 houses in Attica of Greece, and a statistical homogeneity test was performed and a correlation between the air tightness measurements and the total frame length was examined for each category of airtightness. They found that "medium/high air-tightness level" buildings are uneven, and it becomes necessary to either redefine the values' range of each category or to create a new category, and the total frame length affects the air leakage of each house. Kalamees [4] conducted a field measurement study of the air tightness and the air leakages of 32 detached houses in Estonia, and the typical air leakage places in the studied houses were found out using an infrared image camera and a smoke detector. It was reported that the mean air leakage rate and air change rate at the pressure difference of 50Pa in the entire database was $4.2m^3/(h\cdot m^2)$ and 4.9 h^{-1}, respectively. Alfano et al. [13] tested the airtightness of three residential buildings located in the Mediterranean region before and after a window retrofit (the application of rubber seals on window frames and the substitution of existing windows with new certified high performance windows), and a high variability of the building airtightness after window retrofits was found despite the fact that air tight–certified windows were used. Stabile et al. [14] performed the air permeability measurements and indoor pollutant concentration measurements in schools placed in the Central Italy, and the pressurization tests revealed that infiltration through leakages of the classroom solely is not adequate to guarantee minimum indoor air quality conditions in the classrooms (the estimated average air exchange rates was 0.12 h^{-1}). The analysis of the classrooms' air quality showed that during the fall and winter seasons the airing was ineffective, while it positively affected the indoor air quality during the spring season when strong reductions in CO_2 and radon concentrations were recorded. The percentage distribution of infiltration air leakage by building components was estimated by ASHRAE [15] with reference to the studies of Dickerhoff et al. [16] and Harrje and Born [17]. Based on the analysis results of the air leakage characteristics of nearly 70,000 US houses and multivariate regressions, Chan et al. [18] demonstrated a regression model to estimate the leakage area distribution of the single-family detached housing stock in the US. By applying this regression model to housing characteristics from the American Housing Survey, a leakage-area distribution for all single-family houses in the US could be derived.

From the above analysis, it can be seen that the results of field tests of building envelope airtightness have provided basic data for the prediction of building air leakage which could be further used for the performance assessment of the building. The corresponding assessment results can provide essential data to policy makers and designers in making informed decisions and better detecting energy and environmental criticalities in the building audits.

However, there is only a few researches on the airtightness performance of residential buildings in severe cold and cold zones of China. As far as we can know, only one airtightness performance measurement of residential building in North China was found by 2016. In this study, the airtightness performance of two old buildings (constructed in 1980s and 1990s) was measured by blower door test (BDT) method [19]. Though there are tens of thousands of airtightness test results available in the current studies, it is inappropriate to directly use them for the performance analysis of residential building in China. There are many influence factors to the airtightness of building envelope, such as the construction technology, architectural construction, building materials and so on. So, the airtightness performance of the residential buildings in China may be very different from those in other countries. For example, the fire place is very common in the detached houses in Northern Europe and the United States, but no fire place exists in most of the detached houses in China.

Given the lack of airtightness measurements in China, it is meaningful to do a series of tests to the residential buildings. In this study, the airtightness performance of ten detached houses in cold zone of China was measured using the BDT method.

2. Experiment process and method

2.1. Descriptions of the measured residential buildings

All the detached houses are located in the cold area of China. Their main information is shown in Table 1. When performing the airtightness test, the outer doors and windows, the electric, network and communication systems of all the tested houses were already fitted and the relevant project of acceptance has been completed. All the tested houses were without decoration and the furniture, kitchenware, sanitary fittings were all uninstalled. But, the check valves were already installed at the inlets of the discharge flue and exhaust airway in the houses. The designed heat and coal demand of all the tested houses is only 35% of that of the residential buildings built in 1980s, so conforming to the so-called 65% energy efficiency standard in force in China since 2010 [1].

The tested houses have reinforced concrete structure, cast on site concrete ground floors and floors. The outer wall is mainly made of light concrete hollow brick with an external thermal insulation composite system based on polyurethane or polystyrene board or polystyrene board. The insulation course is covered by ceramic brick or coating. The interior wall is mainly made of thin hollow brick or aerated concrete block or solid clay brick and several layers of plaster on both sides. The ground of kitchens and bathrooms and the roof have been coated with continuous polymer modified cementitious waterproofing coating and asphalt waterproof material, respectively. As an example, Table 2 shows the detailed materials of main components of tested buildings. The 1#, 2#, 3# and 9# detached houses have the aluminum plastic compound windows, and the 4#, 5#, 6#, 7# and 8# detached houses have the aluminum wood composite windows. Only the 10#