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Building air leakage analysis for individual apartments in North China

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ABSTRACT

There is little known on the airtightness performance of apartment building in China. The present study intends to investigate the airtightness performance of twelve individual apartments from four buildings in China's cold area using the blower door method. The air leakage of two building components of each of the three individual apartments from the 4# building was further investigated by a series of blower door tests. The normality test was performed to the test results, and the correlation coefficients between the air leakage and possible influence factors were analyzed.

Test results show that the air change rate of the tested individual apartments at 50Pa changes from 1.14 h^{-1} to 2.44 h^{-1} with an average of 1.77 h^{-1}. The check valves at the inlets of the discharge flue and exhaust airway were tested to be leakier than the outer windows and doors in the three measured apartments from the 4# building. Results of statistical analysis show that the data was significantly drawn from a normally distributed population at the 0.05 significance level, and the envelope area and the joint length of the opening part of the windows and doors were identified as the main factors that influence the air leakage of the tested apartments at the 0.05 significance level.

1. Introduction

The building airtightness can be defined as the resistance to the airflow through the building envelope and it is the determining factor to the air infiltration/exfiltration through the building facade. Air infiltration refers to uncontrolled airflow through the building envelope which depends on the characteristics of air leakage paths (ALPs) in the building façade and the magnitude of the pressure difference acting across the corresponding ALPs. The infiltration characteristics of a building are ultimately a function of its airtightness which is the sum of the leakage characteristics of all the cracks and gaps formed during the construction of the building envelope.

Studies showed that the air infiltration through building facade is critical to a lot of building related problems, such as the hygrothermal performance of construction material, indoor air quality (IAQ), building energy consumption, performance of the ventilation systems, thermal comfort, noise, and fire resistance [1–3]. The air infiltration significantly influences the energy performance of buildings as high infiltration rates can result in excessive energy demand because of the need of conditioning the infiltrating air for maintaining thermal comfort. Stabile et al. [4,5] evaluated the effect of the manual airing strategy on indoor air quality in Italian classrooms by experimental analysis, and the results showed that longer airing periods may result in reduced indoor CO_2 concentrations and other gaseous indoor-generated pollutants, but, simultaneously, in higher ultrafine particle levels in indoors due to infiltration from outdoors.

Considering the importance of building airtightness, many countries take into account airtightness in their energy performance calculation procedures [6]. Lots of studies on the techniques to measure the airtightness of the building envelope, air infiltration prediction models, and interaction with the other transfer phenomena have been performed [7–9]. International standards intended for the measurement of the air leakage of building envelope were developed which provide a standard procedure for the quantification of envelope airtightness. As far as we can know, the most widely applied two standards are the ISO 9972:2015 [10] and ASTM E779:2010 [11] in which a fan (de)pressurization method was described for the measurement of the air permeability of buildings or parts of buildings in the field.

According to the above standards, tens of thousands of fan (de) pressurization measurements have been carried out all over the word, especially in northern and central Europe [12–14] and U.S [15,16]. Graham Finch and Lorne Ricketts [17] compared the theoretical interaction of building airtightness and the driving forces of

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airflow with the measured results at a high-rise multi-unit residential building. Based on the analysis, they concluded that the measured results corresponded well with the theory of airflow, and suggested a holistic approach to building airflows when designing mechanical ventilation systems. Orme et al. [18] presented a summary of leakage characteristics of gaps and cracks to be found in buildings and an analysis of whole building air leakage based on thousands of measurements published in technical publications and on measurements provided directly by many research organisations and groups. Pinto et al. [19] tested the air permeability of five apartments with identical construction characteristics in the same building in Portugal, and the air permeability of buildings and components was characterized. Based on the analysis results, they suggested that the overall apartment air permeability should be reduced by improving the quality of roller shutter boxes and manufacturing and installation of external doors. d'Ambrosio Alfano, F.R. et al. [20] performed an experimental analysis about the air permeability values of a set of passive ventilation grilles available. Based on the analysis results they suggested manufacturers to certify their own products according to the existing standards. d'Ambrosio Alfano, F.R. et al. [21] also assessed the effectiveness of window retrofits in terms of air-tightness in three residential buildings using the fan (de)pressurization method. The test results demonstrated a high variability of the building air tightness after window retrofits, and the substitution of windows could result in an increase of air leakages, while airtight windows can lead to a strong reduction of the natural ventilation. The percentage distribution of infiltration air leakage by building components (e.g. windows, doors, walls, floors and ceilings) was estimated by ASHRAE [22] with reference to the studies of Dickerhoff et al. [23] and Harrje and Born [24]. Giacomo et al. [25] firstly measured the air tightness of a recently renovated Italian building (a three-storey, six-unit, multi-family building) by means of a series of fan (de) pressurization tests. Then a simulation model was developed based on the test results and simulations were performed to analyse in detail the winter magnitude of air infiltration. It was concluded that infiltration cannot be relied upon to provide adequate ventilation air and, if not assisted by other means of ventilation, IAQ deterioration is likely to occur. Based on the analysis results of the air leakage characteristics of nearly 70,000 US houses, Chan et al. [26] demonstrated a regression model to estimate the leakage area distribution of the single-family detached housing stock in the US. B. Zhao et al. [27] firstly determined the leakage area of buildings adopting the above regression model, then simulated the annual and seasonal average infiltration rates of 180 representative residences in Beijing using the multi-zone network airflow model (CONTAM). Via the simulation results, empirical and two-parametric lognormal distributions of the infiltration rate for residences in Beijing were obtained.

The above analysis shows that field tests of building envelope airtightness are meaningful and useful. The test results could be used to identify the construction techniques and materials that contribute to airtightness performance and to provide guidance on typical leakage values for use in design and simulation. The corresponding assessment results can provide essential data to policy makers and designers in making informed decisions and better detecting energy and environmental impact in the building audits. However, there is little research on the airtightness performance of apartment buildings in severe cold and cold zones of China. As far as we can know, only one airtightness performance measurement was found by 2016 in which the airtightness performance of six apartments from two old multi-unit residential buildings in North China was measured by blower door test (BDT) method [28].

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 apartment buildings in China. There are many influence factors to the airtightness of building envelope, such as the construction technology, architectural construction, architectural design choices, building envelope characteristics and so on. The size and flow characteristics of ALPs depend on the type of joint, material used and the quality of manufacture and fitting. The leakage characteristics of similar components may be widely varying, i.e. the in-situ performance of same components may be very different from each other. Also, the representative residential building type in China may be different from other countries. Mainly due to the rapid urbanization and population explosion, most of the residential buildings that have been constructed in the past two decades in China are mid/high-rise buildings (i.e. multi-family buildings). According to Beijing Statistical Year Book [29], the proportion of residents living in single family houses in Beijing is negligible. So, the airtightness performance of the residential buildings in China may be very different from those in other countries.

This study mainly presents the airtightness performance of twelve apartments and the air leakage of building components of three apartments in cold zone of China. The normality of the distributions of test results was tested, and the correlation coefficients between the air leakage and possible influence factors were analyzed.

2. Experiment process and method

2.1. Description of the measured apartments

Twelve apartments from four buildings located in Dalian of China were selected to conduct the airtightness performance investigation. The main information of the measured apartments is shown in Table 1. The internal volume, net floor area and envelope area of the selected apartments were calculated according to their definitions in ISO 9972:2015 [10]. The apartment number in Table 1 is composed of the building number (3#), the unit number (1) and the storey number (−01). The 1#, 2# and 3# buildings are located in the same residential district, and they were designed according to the current energy efficiency design standards for residential buildings in severe cold and cold zones in China. The 4# building lies in an energy efficiency demonstration district which was designed to be a low energy building (The designed heating demand is only 70% of the normal building). But no special measures were taken to increase the airtightness of this building. Three individual apartments from each building, located at the first, middle and top floor, were selected to perform the airtightness investigation.

All the tested apartments were in the for sale state when performing the airtightness test. (These apartments were unoccupied, but the outer doors and windows, check valves at the inlets of the discharge flue and exhaust airway, and other building subsystem for electric, network and communication were already fitted.) Since these apartments were unoccupied, the furniture, kitchenware, sanitary fittings were all uninstalled.

These apartments have reinforced concrete structure, cast on site concrete ground floor and ceilings. The outer wall is made of light concrete hollow brick with an external thermal insulation composite system based on polyurethane or polystyrene board. The insulation course is covered by ceramic brick. Party walls are made of thin hollow brick and several layers of plaster on both sides. The floor of kitchens and bathrooms and the roof have been coated with