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Airtightness of electrical, mechanical and architectural components in South Korean apartment buildings using the fan pressurization and tracer gas method

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ABSTRACT

The purpose of this study is to measure airtightness of building components in newly constructed apartment buildings in South Korea. For the measurements, electrical, architectural and two mechanical components regarding water and air systems were categorized and air leakage rates of these parts were measured by the blower door test. In addition to these building components, air leakage rates on the entrance door and three different building heights were analyzed. Moreover, the results obtained by the blower door test were compared with the tracer gas measurements. As a result, the air leakage rates (ACH_{50}) were between 0.7 and 1.0 h^{-1}, when all parts were sealed. When unsealing all parts, the ACH_{50} values ranged from 1.6 to 2.7 h^{-1}. In addition, the ACH_{50} values were highly influenced by the entrance door and window systems. By improving the windows and the entrance door, the air leakages can be significantly reduced in residential buildings. Furthermore, the comparison results obtained by the tracer gas and blower door showed that artificially produced pressure difference condition can cause the overestimated ACH value.

1. Introduction

As one of the common residential building type, the apartment building is the most preferred in South Korea [1,2]. With the remarkable economic growth and the increase in population, it has caused the largest expansion of apartment buildings that play a significant role in energy consumption [3–5]. Energy efficiency in apartment buildings is thus the major concern and a considerable effort has been made to reduce energy consumptions.

Generally, most of energy consumed in residential buildings has been used for heating and cooling for occupants [6]. Specifically, more than half of the total energy consumption has been wasted through building envelopes and it is significantly considered that improving building envelopes' efficiency is an essential key for the energy performance in buildings [7,8]. As the interface between the indoor and the outdoor environment, the building envelope plays a significant role in determining the amount of energy for thermal comfort and several parameters such as design, materials and construction, site parameters have been investigated in order to assess building envelope performance [6,9,10].

Based on the increasing awareness of the importance of the building envelopes' role in building energy consumption, many studies have been conducted to achieve optimal building envelope design considering parameters. Focusing on the thermal performance, the impact of building envelope components including windows, inner/outer walls and roofs have been investigated [11–13]. In addition, air leakage is a critical parameter, which influences thermal loads in building [14–18]. As a resistance to inward or outward air leakage, several studies for the airtightness performance for residential buildings have been performed. Alev et al. studied the energy saving potential in old residential buildings through the energy performance analysis focusing on airtightness [15]. As an important energy saving measure, Tuominen et al. utilized a novel calculation tool to investigate the effectiveness of airtightness in apartment buildings [18]. In addition, air-tightness performance of residential buildings was investigated by blower door method with an emphasis on the heating energy consumption [19]. Thus, energy demand can be highly influenced by building air-tightness and the importance of the building airtightness has been recognizably increased [20–23].

Air leakage through cracks and construction joints is primarily induced by pressure differences due to temperature differences and wind around a building. In residential buildings, operation of auxiliary fans such as kitchen and bathroom exhausts, and the combustion equipment are also key factors that can cause air leakages by the pressure

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difference due to exposure to outdoors. In South Korea, the Korea government has regulated the minimum rate of airflow of 0.5 ACH for the improvement of indoor air quality in residential buildings [24]. Thus, considerable attention has been paid to components and systems that can cause air leakages in residential buildings. However, most studies have focused on air leakage rates through the building envelope in the unit focusing on factors such as construction methods, housing type, fenestrations, floors and envelope area [19–21,25–28]. Moreover, those studies have been conducted in 1 to 3-story houses in US [22,29], Finland [21], China [20], Ireland [25] and Italy [30]. A few studies investigated the air leakage rates for 13-story building in Canada [27] and a 6-story residential building in China [19]. Thus, it is difficult to apply their achievements to improve airtightness of apartment buildings with more than 20 floors in South Korea. Moreover, few studies have been performed for the airtightness of individual building components.

Most researchers have preferred to employ the fan pressurization method using a blower door system which employs artificial conditions by adding some rate of airflow to induce a particular pressure difference between in/outside of a building for air leakage measurements [31]. In case of infiltration measurement using the tracer gas technique, more reliable results can be obtained [31–33]. While the tracer gas technique requires greater costs and more experienced professional support than the fan pressurization method, it can provide more accurate airtightness measurement results under natural airflow condition [24,31].

The objective of the study is to investigate the airtightness performance for various building components such as electrical, mechanical and architectural parts in recently constructed apartment buildings by employing the fan pressurization method. In addition, the airtightness performance of the selected apartment buildings on three different building heights and the entrance door is investigated. Moreover, the tracer gas technique is used to measure the airtightness for the same apartment buildings under the natural pressure difference conditions and the obtained data are compared with the results by the blower door method.

2. Field measurements

2.1. Descriptions of the selected apartment buildings

The selected apartments are located in urban areas. Commonly, all units have a reinforced-concrete wall structure and use PVC window systems with 22 mm (5 mm clear glass + 12 mm air + 5 mm low-e glass) + 22 mm. The public areas such as elevator halls, corridors, parking lot areas, etc. were excluded in each floor area. In addition, all units have heat recovery ventilation systems and the air supply inlet and exhaust outlet are located in each room. Moreover, kitchen hoods and exhaust fans in the bathroom are connected to the airshaft. Table 1 summarized the descriptions of each unit.

2.2. Influencing features in apartment buildings

There are physical features in apartment buildings that affect airtightness. As mentioned previously, most studies have investigated air leakages of building envelope components by sealing openings and joining points with silicone rubber or cellophane tape [21,34]. In residential buildings, exhaust fans and ventilators, dryers and air conditioners were also sealed or closed [19]. In addition to the air-tightness performance investigation by Ji and Duanmu [20], the drainage traps in toilets, sinks, showers, sanitary fittings and reserved holes for future installation were sealed or remained closed.

Given the continuing emphasis on features influencing the airtightness in apartment buildings, components in apartment buildings were categorized as four parts to measure the airtightness in the selected apartment buildings. Speakers, sensors such as smoke detection, carbon monoxide detection, etc., distribution boards and connectors, electric sockets were arranged into the electrical part. Mechanical system components such as water supply and drainage, ventilation and exhaust, etc., were separated into two parts as the water and air systems. In addition, window systems were arranged into the architectural part. These are presented in Table 2. Since there is a potential air leakage due to of the entrance door, the air leakage rate on the entrance door was measured [35]. Moreover, air leakage rates on the top, middle and bottom levels in the selected buildings were measured by the blower door tests.

2.3. Experimental methods

2.3.1. The blower door test

The blower door tests were performed in accordance with ASTM Standards E779-10 [36] and E1827-11 [37]. In addition, the fan pressurization approach described by Canadian general Standards Board (CGSB) Standard 149.10 [38] and ISO Standard 9972 [39] were applied. The airflow data are generally fit to a curve using the power law equation. Once the values of the airflow coefficient and the airflow exponent are obtained from the measurement data, Eq. (1) is used to predict the airflow rate though the building envelope at any given pressure difference.

$$Q= C(\Delta p)^n \tag{1}$$

where, Q is airflow rate through the building envelope [m^3/s] and C is the airflow coefficient [$m^3/(s.Pa^n)$]. Δp is the difference of pressure (Pa) and 50 Pa has been used as reference pressure difference [40,41]. In addition, n is airflow exponent which is 0.5 and 1.0 for turbulent flow and laminar flow, respectively [30,42]. With the reference pressure difference, air leakage rate, Q_{50}, is achieved and air change rate, ACH_{50}, is used as airtightness parameter and can be calculated in Equation (2).

$$ACH_{50} = \frac{Q_{50}}{V} \tag{2}$$

In order for the equalization of air pressures in the apartment unit, a blower door was installed in the entrance door while all the interior doors were opened. The fan induced pressure differences in a range of approximately 5–75 Pa. All data were collected by a data logger. In addition, the indoor and outdoor dry bulb temperatures were measured. For the wind direction and speed, the wind data at 10 m height from the ground were used by the Korea Meteorological Administration.

Before the air leakage measurement, all parts were sealed with plastic films and duct tapes in the unit. For the window, a plastic film was also used to cover the inside window and pasted on the frames by duct tapes. The window frames and the wall around the window were not sealed. For the balcony, the external window systems were sealed and the internal door that was connected to the indoors was unsealed. These are shown in Fig. 1.

For the measurements, the air leakage rates were measured unsealing the individual part in the order of the electrical part, the mechanical part – water systems, the mechanical part – air systems and the architectural part. In addition, two sets of the air leakage measurements were performed when all parts were sealed and unsealed. Moreover, the air leakage rates on three different building heights and the entrance door in the unit B and C were measured.

2.3.2. Tracer gas measurements

For the selected apartment buildings, another airtightness measurement was conducted using the tracer gas method. In case of blower door test, the air changes per hour (ACH_{50}) at a 50 Pa pressure difference is used as an airtightness indicator to estimate the air leakages through the building envelopes. However, there is a discrepancy between ACH_{50} and the natural airflow rate because ACH_{50} is an airflow rate at an artificially induced condition by fans [30,43]. In order to