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# The effect of an enclosure retrofit on air leakage rates for a multi-unit residential case-study building

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ABSTRACT

This paper presents a relatively new, simple and robust, method for air leakage testing. A thirteen-story multi-unit residential building was tested for air leakage before and after an enclosure retrofit. The building suites had a pre-retrofit $NLA_{50}$ average of 6.77 $cm^2/m^2$ and an average post-retrofit $NLA_{50}$ of 2.82 $cm^2/m^2$—a 58% betterment. The effect of the retrofit on air leakage rates was assessed and compared to other multi-unit residential buildings across Canada and USA. The case study building was significantly tighter than other multi-unit residential buildings included in published studies. Recommendations were made for field-testing procedures in order to maximize the potential for accurate measured flow characteristics. Field-testing for air-tightness needs to be standardized in order for useful comparative results to be generated in order to inform future research and operational considerations for the multi-unit residential building stock across North America.



## 1. Introduction

As the current stock of multi-unit and high-rise residential buildings (MURBs) ages, it will increasingly face problems associated with efficiency and durability. There are a variety of factors stimulating large scale retrofits of this building stock, including; leaking enclosures, outdated aesthetics, increased electrical rates, meeting greenhouse gas reduction targets and building code requirement changes [1,2]. These retrofits can take a variety of forms, but enclosure measures predominantly focus on decreasing thermal conductance in the assembly and improving the continuity of the air barrier system and moisture management strategies [3]. Post-retrofit studies tend to focus on the energy savings of retrofits, and ignore investigation on air leakage improvements. However, air leakage is a key determinant of a building enclosure's functionality, durability, future maintenance requirements and can account for 5% to 15% of a MURB's energy consumption [4,5].

There is currently no industry standard for air leakage testing of MURBs [5]. The complexity of multiple zones makes traditional, single-zone depressurization methods inadequate. Studies have proposed a variety of techniques for testing large, multi-unit buildings, some of which are discussed in this paper. Additionally, air leakage rates are measured in many different ways making direct comparisons between different buildings difficult [6].

It is important to understand how enclosure retrofits affect air leakage rates in MURBs and also to be able to directly compare values between buildings. This paper presents a relatively new, simple and robust, method for air leakage testing. A thirteen-story MURB was tested before and after an enclosure retrofit. The effect of the retrofit on air leakage rates was assessed and compared to other MURBs across Canada and USA.

## 2. Previous research

### 2.1. Fan (de)pressurization methods for MURBs

All buildings allow air to move through the enclosure to some degree. Uncontrolled air movement (infiltration/exfiltration/leakage) is predominantly pressure driven by wind, stack effect and differences in relative humidity [7,8]. Due to the variability of in-situ conditions, it can be difficult to measure the rate of air movement in the natural setting of a building [9]. It is often preferential to test enclosure leakage at an artificially high pressure difference between the test space and the ambient outdoor. The advantage to measuring leakage at an induced pressure difference is that it negates the 'noise' of stack effect, wind and humidity pressure [5] in addition to fully engaging leakage paths across the enclosure.

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One of the most common methods for inducing pressure differences to test enclosure leakage is through fan pressurization or depressurization [10]. The test is relatively simple for a small, single-zone building and becomes more difficult as building size increases [5]. The size and nature of MURBs requires fan sizes in excess of conventionally produced models in order to (de)pressurize the entire building uniformly and in an efficient manner. There are currently no universally accepted methods for air tightness testing MURBs [8,11] making standardization and comparison of leakage rates between buildings difficult.

The American Society for Testing and Materials has outlined a method for testing building enclosure tightness of single unit, low-rise buildings [12,13] and is commonly used throughout the industry. The method cannot account for stack effect or temperature gradients accurately and requires the test to be conducted under specific circumstances. The method is accurate for small, single-zone buildings, but due to fan power and limitations due to building geometry, is not directly applicable to larger, multi-unit buildings. As yet, ASTM has not set a standard for high-rise or multi-unit buildings [13].

The US Army Corps has developed a fan depressurization method by which to test its buildings and ensure its mandated air leakage rates [14]. The method is straight forward and similar to the ASTM 779 standard [12]. Units within the barracks that are self-contained (i.e., openings only to the exterior) must be tested individually and simultaneously using multiple fans. Units that have openings to a common space (e.g. a corridor) must be tested collectively using one fan. All units, except the test unit are brought to exterior pressure by opening doors and windows to the exterior. The test unit is then (de)pressurized to 75 Pa and air leakage rates recorded. In essence, this method aims to equalize all spaces surrounding the test space. There are two major problems with this method. First, large buildings with many self-contained units require many fans to run simultaneously. This can present significant logistical difficulties and be prohibitively expensive [15]. The second problem involves the scenario of testing a single unit. This method of testing cannot separate internal air leakage from enclosure leakage (i.e. that across the building envelope). As Genge [15] notes, the Army Corps method is a good starting point, but further development is required to ensure more reliable and complete results. This could involve neutralising pressure between adjacent suites and the test suite to ensure that the only leakage pathway is through the enclosure.

The German “Fachverband Luftdichtheit im Bauwesen e.V.” (Association for Air Tightness in the Building Industry) has proposed a similar method to the US Army Corps for testing a MURB building enclosure [16]. They advocate fan (de)pressurization testing of 20% of individual units in a MURB including at least one apartment on the top floor, one on the ground floor and one at the building’s mid-height. The air leakage values include air movement between floors as well as air leakage through the enclosure. The data extrapolation takes the internal leakage pathways into account by allowing an individual unit’s air leakage rate to exceed the maximum whole-building leakage rate by 30%. If any unit exceeds the 30% threshold the building does not pass the test. The significant disadvantage of this test method is that there is little allowance for considerable leakage in untested zones, such as elevators, corridors and ventilation systems [11].

Proskiw and Parekh [4] propose a method for separating leakage between internal partitions from leakage through the building enclosure by installing a single fan between the zones. The method relies on arithmetic subtraction of flow rates between two zones. In a two zone example, Zone 1 is of primary interest and Zone 2 is of secondary interest. The fan is used to pressurize Zone 2 and the air flow rate recorded. Zone 2 is then equalized with the ambient outdoor pressure by opening a window or door. The pressure difference across the fan is maintained at the pressure of the original measurement. The new air flow rate is recorded. The difference in air flow rates shows the amount of leakage between Zone 2 and Zone 1. The method is mathematically quite simple and yields robust data. However, it is a one-dimensional method and does not take into account leakage pathways from other units adjacent to (above, below and sides) the test unit.

In the late 1980s, researchers [17,18] developed the “guarded-zone” method (also known as “pressure-masking”) whereby the test unit is guarded from pressure differential between adjacent spaces, leaving the only pressure differential across the enclosure. The method requires up to six calibrated fans to equalize pressures throughout the building and create a pressure difference across the test unit enclosure. Once the enclosure leakage is recorded, the adjacent spaces can be pressure equalized with the ambient outdoor pressure and the increase in airflow shows the air leakage to those areas. The method determines the geometric coefficient of the enclosure directly. As Feustel [19] notes, the method relies on keeping the adjacent zones at exactly the same pressure as the guarded zone, which can be difficult under some conditions (e.g. high winds, complex building geometry, etc). The other limitation is the method provides only two values–air leakage through internal partitions and air leakage through the enclosure. It does not provide indication as to the location of air leakage within these areas.

To improve on the Guarded-zone Method, the Deduction Method was developed to more accurately measure leakage between individual internal partitions [19]. There are different incarnations of the deduction method, but the most recent and applicable comes from Finch et al. [5]. The method relies on (up to four) high-powered, calibrated fans. The premise of the method is similar to the Guarded-zone Method in that pressure is neutralized between adjacent spaces and the test unit. The test unit is first measured with adjacent spaces at ambient pressure. One by one the adjacent spaces are brought to the same pressure as the test unit, thereby eliminating leakage across the envelope between each unit and the test space. By eliminating leakage to each adjacent space one by one, the researcher can determine leakage values through internal partitions and the building enclosure. Technological improvements over the last decade allow for increased accuracy and efficiency when controlling fans and recording multiple, time averaged data points for a given pressure difference. Finch et al. [5] argue that by recording multiple data points, which are then put through linear regression, and pressurizing each unit at varying intervals, ambient “noise” (stack, wind, temperature) is further reduced.

For the purposes of this research, the Guarded-zone Method is most appropriate as air leakage rate through the enclosure is of chief concern. However, it is further developed by recording multiple data points at each pressure level and testing at a variety of pressure differences. This is expected to yield more robust and accurate data [5].

### 2.2. Quantifying air leakage rates for MURBs

There are many standards and targets for air leakage in MURBs. Table 1 shows examples of the more common target levels for various standards in Canada. The values are listed in normalized air leakage at 50 Pa ($NLA_{50}$) [5].

Existing studies repeatedly mention the scarcity of measured data relating to leakage rates of MURBs [5,20–23]. The vast majority of air leakage measurements have been conducted on houses (i.e. single family detached or semi-detached dwellings). A study of North American buildings [23] states “as for apartment data, we were (unpleasantly) surprised at the paucity of information in this