Refined assessment and comparison of airtightness measurement of indoor chambers using the blower door and Pulse methods

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ABSTRACT

Previous studies have compared the airtightness measurement of test enclosures utilising both the novel Pulse technique and the conventional blower door method. Discrepancies between results of the two test methods were observed and it was concluded that differences either caused by wind or blower door installation integrity would have had an impact upon the results. This study, as a continued investigation as well as validation process for product development, reports on an experimental investigation that assesses the airtightness of an indoor chamber using both the blower door and Pulse methods with the envelope difference and wind impact being minimized. This was achieved by utilising two door-sized rigid panels to replace the existing door of an indoor chamber in the setup of the blower door and Pulse units. The blower door fan was located within one of these solid panels, which then negated any impact of leakage that would have otherwise been incurred around the frame of the blower door. A wooden plate with multiple openings was utilised and mounted in the chamber envelope to provide various leakage levels and characteristics for testing by taping up different number of openings, in which airtightness tests were performed using both methods in an overlapped pressure range. This allowed both methods to be compared directly with minimum difference in testing conditions. Tests were also carried out in a house-sized indoor chamber to assess the repeatability of the Pulse unit and its agreement with the blower door test. The initial results showed that in most of the testing scenarios a good agreement (up to 7.4%) was observed between the leakage results given by both methods; however a larger discrepancy was seen in the case where the largest opening was present. Strong repeatability was observed in the Pulse testing with an overall measurement uncertainty of ±5%; with a similar spread also presented by the blower door test method as part of the chamber testing.

KEYWORDS

Building airtightness, Blower door, Pulse, Sheltered environment

1 INTRODUCTION

A fundamental challenge for the Pulse technique is that its primary function, the ability to measure air leakage reliably at low pressures and report air permeability at a pressure rise of 4Pa, is difficult to directly validate. Citing air leakage at 4Pa is also at odds with established industry practices and building regulations which conform only to the established blower door method of testing at high pressure (typically reporting leakage at a 50Pa pressure difference).
Pulse has been specifically developed to measure leakage at 4Pa because this value is citied within a range of ASHRAE (Sherman 2004, Sherman 2009) and CIBSE standards (CIBSE TM23) as being a representative ambient background pressure level within occupied buildings i.e. the pressure level at which background exfiltration/infiltration occurs. Under normal real world test conditions, the blower door cannot directly measure at this low-pressure level and its results must therefore be extrapolated down which in itself causes large uncertainty errors,

whilst similarly, the Pulse 4Pa results cannot be reliably extrapolated up to 50Pa. One of the primary objectives of the lab-based chamber testing therefore has been to evaluate 4Pa Pulse vs 50Pa Blower Door further through a range of constructed lab based tests where blower door test pressures and Pulse test pressures are made to overlap.

Studies on the comparison of the blower door and Pulse methods in natural (Zheng 2018) and sheltered conditions (Zheng 2017) were previously reported. It was found that under sheltered conditions where the external weather condition has reduced impact on the testing, both methods showed a close agreement (0-5.3%) with each other on the measurement of air permeability at 4 Pa under most testing scenarios. Larger discrepancies, shown in the highly airtight scenarios, were attributed to the fact that insufficient time was captured in the 'quasi-steady period' of the Pulse test due to the combination of the fixed pulse test timing and delayed pressure pulse. In the natural conditions, the comparison study gave discrepancies ranging from 7.9% to 16.2%, it was suggested that this greater discrepancy compared to that in the sheltered environment might be caused by various factors such as environmental conditions, extrapolation and blower door installation.

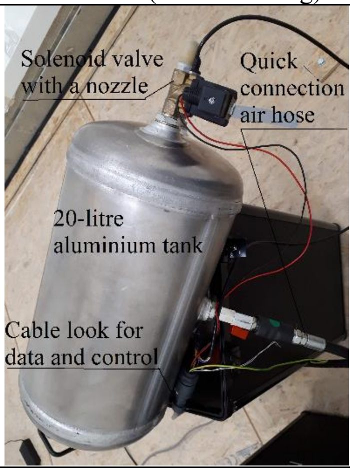
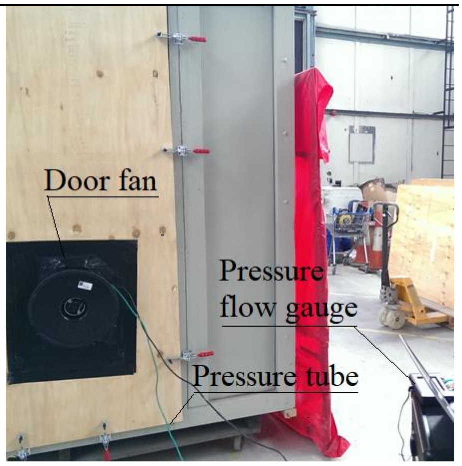
This paper reports a refined comparison study of the two methods in a sheltered condition accounting for some of the factors that were not considered in the previous investigations. The testing arrangement achieved herein provided better testing conditions by minimizing the impact of equipment setup on the enclosure airtightness and eliminating the site interference. A door-sized wooden panel was cut out to install the blower door fan into and airtight tapes were applied to the edges around the perimeter of the fan to aim for a near-identical condition in the envelope of a small chamber (13-feet sized cargo container). Tests were also carried out in a house-sized chamber to assess the repeatability of the Pulse unit and see how it compares with the blower door test method. Known openings were also used in the small chamber to compare how accurately each method measured these, further building on previous similar tests (Zheng 2017, Zheng 2019: Building and Environment). Both chambers were sheltered in a large detached building, which was solely used for testing, and therefore this eliminates any possible interferences of other building users during testing, such as operation of windows and doors.

2 METHODOLOGY

2.1 Equipment

The equipment used for blower door and Pulse testing includes a Minneapolis blower door Duct Blaster series B and a Pulse unit with a 60 litre, a 40-litre and a 20-litre aluminium tank. Table 1 lists the photos of the test equipment. PULSE-60 was used for testing in the large chamber while prototype PULSE-20 and PULSE-40 devices were mainly used for testing in the small chamber where smaller flow was required.

Table 1 Equipment and setup for the three testing methods

PULSE-60/40 (cased)	PULSE-20 (without casing)	Duct Blaster B
		
The Pulse units		Minneapolis blower door

2.2 Chambers

Two test chambers sheltered in a large detached building were utilised to provide testing spaces with two very different volumes. This allowed for an easy setup of multiple testing scenarios in the small chamber, and in the larger chamber a test space of sufficient size to represent a typical dwelling. The small test chamber (Figure 1) has dimensions of 4.0m (length) ×2.0m (width) ×2.0m (height), giving a volume of 16 m^3 and an envelope area of 40 m^2. This chamber shares a similar size with the one reported by Zheng (Zheng 2017, Zheng 2019: Building and Environment), which was improvised from half a standard 20-feet long cargo container with dimensions of 2.84m×2.23m×2.03m. There are two major differences between the chamber used in the investigation of the previous paper and the small chamber in this study. Firstly, the chamber used here is in a sheltered environment while the other one was exposed to an outdoor condition and secondly, the chamber here is detached, whilst the other one was semi-detached. The larger test chamber in this study (Figure 2) has an L-shaped structure, with dimensions similar to that of a typical dwelling. The volume and envelope area of the large chamber are 310 m^2 and 269 m^3, sharing a similar but slightly larger size than the one reported in a previous sheltered condition investigation by Zheng (Zheng 2018). The small chamber was used to carry out testing with different known openings, which provided various leakage levels while the large chamber on the other hand was used in its standard form i.e. without modification for leakage levels and would therefore have typical penetrations as found in a dwelling i.e. Door frame, service penetrations etc. This large chamber was primarily used for the Pulse repeatability test, with a simple comparison between the two testing methods being made to see how the two test methods compare in a large sheltered test space. The impact of the Pulse location was also experimentally investigated in various chamber conditions in the large chamber; the findings are not reported here but will be presented in later publications.

Figure 1 Small test chamber

Figure 2 Large test chamber

Two test plates were used for testing in the small chamber, herein named as test plate A and test plate B, which are shown in Figure 3 and Figure 4, respectively. The test plate A has four square (150mm×150mm) openings and four circular (diameter: 50mm) openings in the middle of the plate, all the openings are short sharp-edged, similar to holes that might be found in construction material layers or in window frames. Test plate B has three circular openings with tubular pipes connected to the top two openings. Panel B seeks to represent those openings found in service penetrations such as ventilation ducts or cable casing running through the wall. More details about the various testing scenarios are given in section 2.3. During testing, these plates were installed on the opposite side of the fenestration where the blower door was mounted. Wing screws were utilised to fix the plate onto the external surface of the chamber wall, as shown in Figure 5.

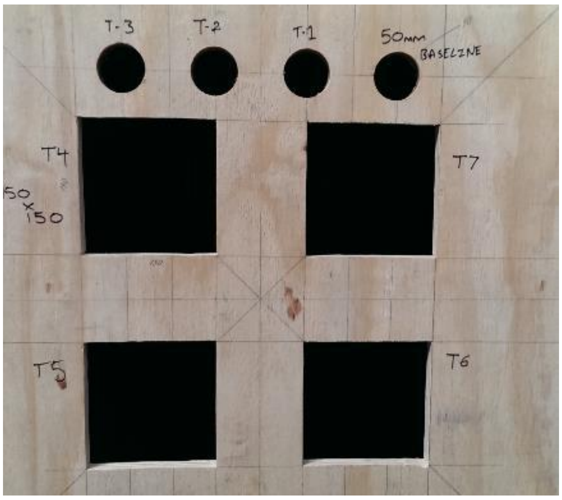


Figure 3 Testing plate A with a number of well-defined openings

Figure 4 Testing plate B with three circular holes (two extended by pipes)

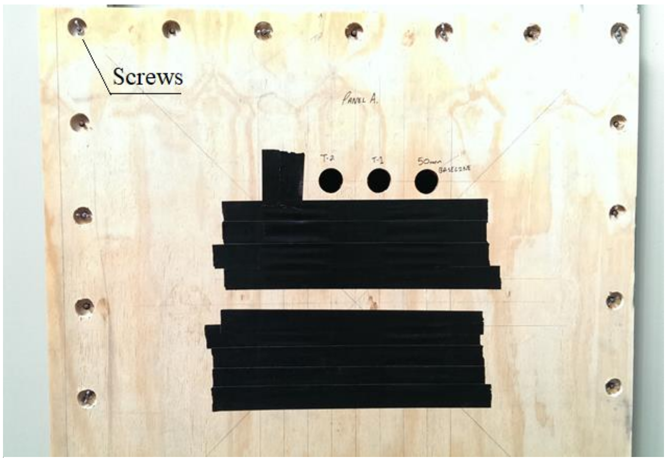


Figure 5 The mounted test plate on the chamber wall

2.3 Setup

To prepare the small chamber with minimized leakage difference between the blower door testing and the Pulse testing, two identical rigid wooden panels were prepared, one with an opening for the installation of the door fan during the blower door testing and the other one without any opening for the Pulse testing, as shown in Figure 6. Both panels were installed in an existing doorway using a number of lateral press type clamps, which were distributed around the perimeter of the door frame in both testing, as shown in Figure 7. Figure 7 also shows the installation of the blower door fan with the edges being sealed up by tapes to avoid air leaks around the boundary between the fan case and the opening in the panel during the testing.

Figure 6 Doorplates used for setting up both tests

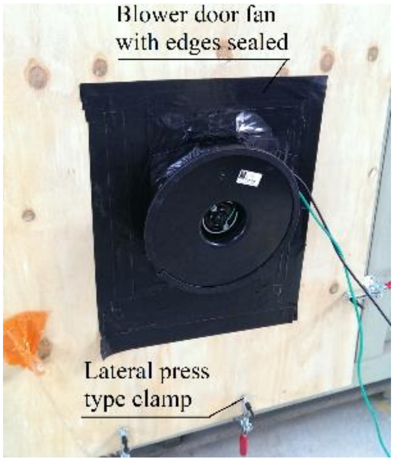


Figure 7 Installation of blower door fan

Figure 8 shows the setup of the PULSE-60 in the large chamber, where it was placed in the centre of the internal space. The blower door was installed in the existing doorway and the installation is shown in Figure 2.

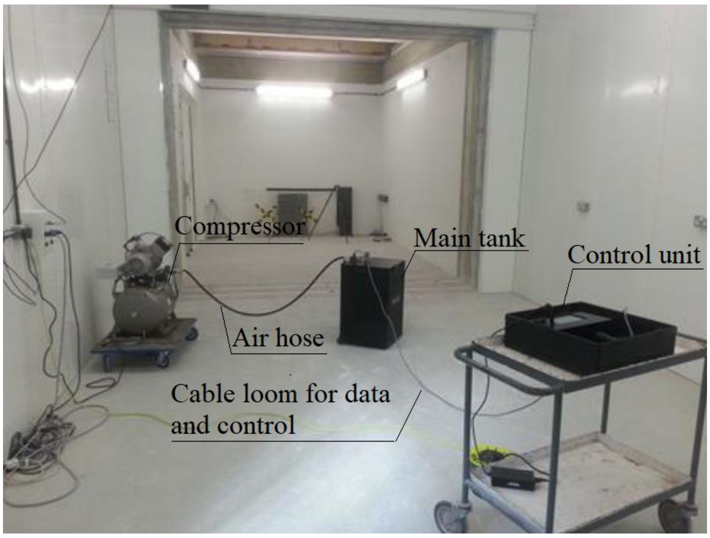
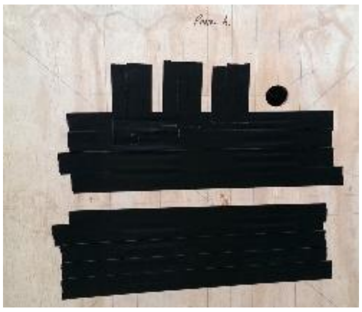


Figure 8 Setup of the Pulse unit in the large chamber

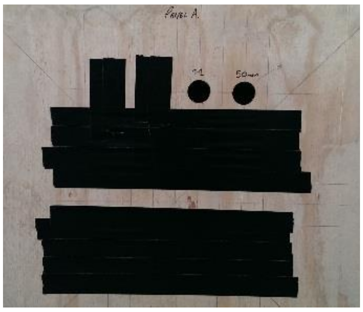
3 TESTING ARRANGEMENT

Compared to the Pulse unit used in the previous study (Zheng 2017, Zheng 2019: Building and Environment), the Pulse unit used in this study has gone through a product development phase. Modifications were made to the unit on a few aspects (Zheng 2019: Future Cities and Environment) to address issues related to the safe handling weight, exposed pressure reference tube and being vulnerable to rough site condition. Changes were also made to the system construction and design such as the operating system and differential pressure transducer to improve the user friendliness and cost effectiveness. One of the main objectives of this experimental study was to assess the precision and accuracy of the Pulse unit after it went through product developments.

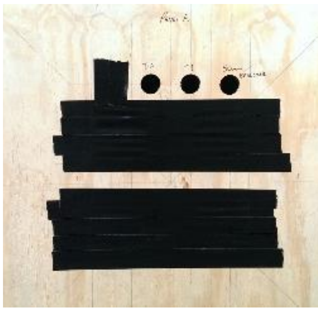
In the small chamber, eight different testing scenarios were achieved by sealing up various combinations of openings using the two testing plates (A+B). Figure 9 shows the details of how the eight testing scenarios were prepared using sealing tapes. Each testing scenario was named according to the testing order, i.e. starting from scenario T0 and ending with scenario T7. For instance, the blower door tests were carried out first in scenario T0. After the scenario T0 was completed, a piece of sealing tape was removed to introduce one more opening to the scenario T1, and this testing procedure was repeated until the scenario T7 was completed. The same testing process was repeated for the Pulse unit after the blower door testing was done. One pressurisation test was run in each scenario while the Pulse test was repeated three or four times in each scenario, along with scenarios T6 and T7, which could only be performed twice due to the time constraint at the end of testing. This testing arrangement allowed both testing methods to be subjected to various leakage characteristics and levels.



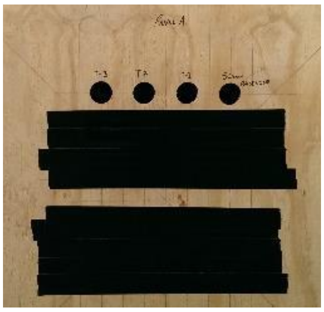
T0: Panel A – 1×circular opening



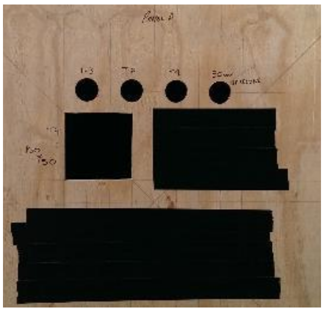
T1: Panel A – 2 circular openings



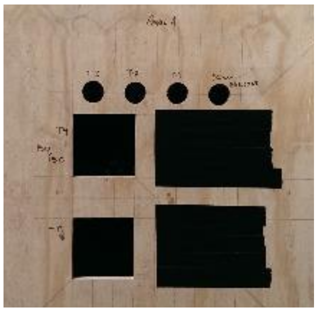
T2: Panel A – 3 circular openings



T3: Panel A – 4 circular openings



T4: Panel A – 4 circular openings plus 1 square opening



T5: Panel A – 4 circular openings plus 2 square openings

T6: Panel B (White blocked grey open)

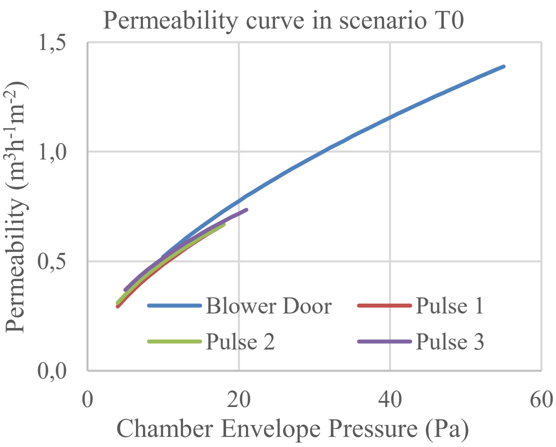
T7: Panel B (both pipes open)

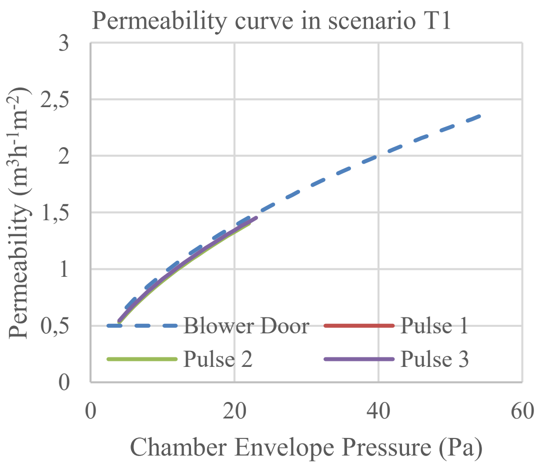
Figure 9 Testing scenarios in the small chamber

In the second test using the large chamber, the objective of the investigation was to assess the repeatability of the Pulse test in a ‘house’ sized sheltered condition and to compare with the blower door test. Ten repeated Pulse tests were carried out alongside the blower door.

4 RESULTS AND ANALYSIS

Figure 10 shows the test results of both blower door and Pulse tests taken in the small chamber in eight scenarios. Crossover in data in most of the scenarios were achieved to make direct comparison. For instance, in scenario T0, the lowest point in the overlapped pressure range was at 10Pa where the difference in test result between the blower door and the Pulse test was 8.8% and the highest was at 18Pa with 4.8% difference. The percentage difference of the test results in all testing scenarios given by blower door and Pulse is summarised in Table 2.





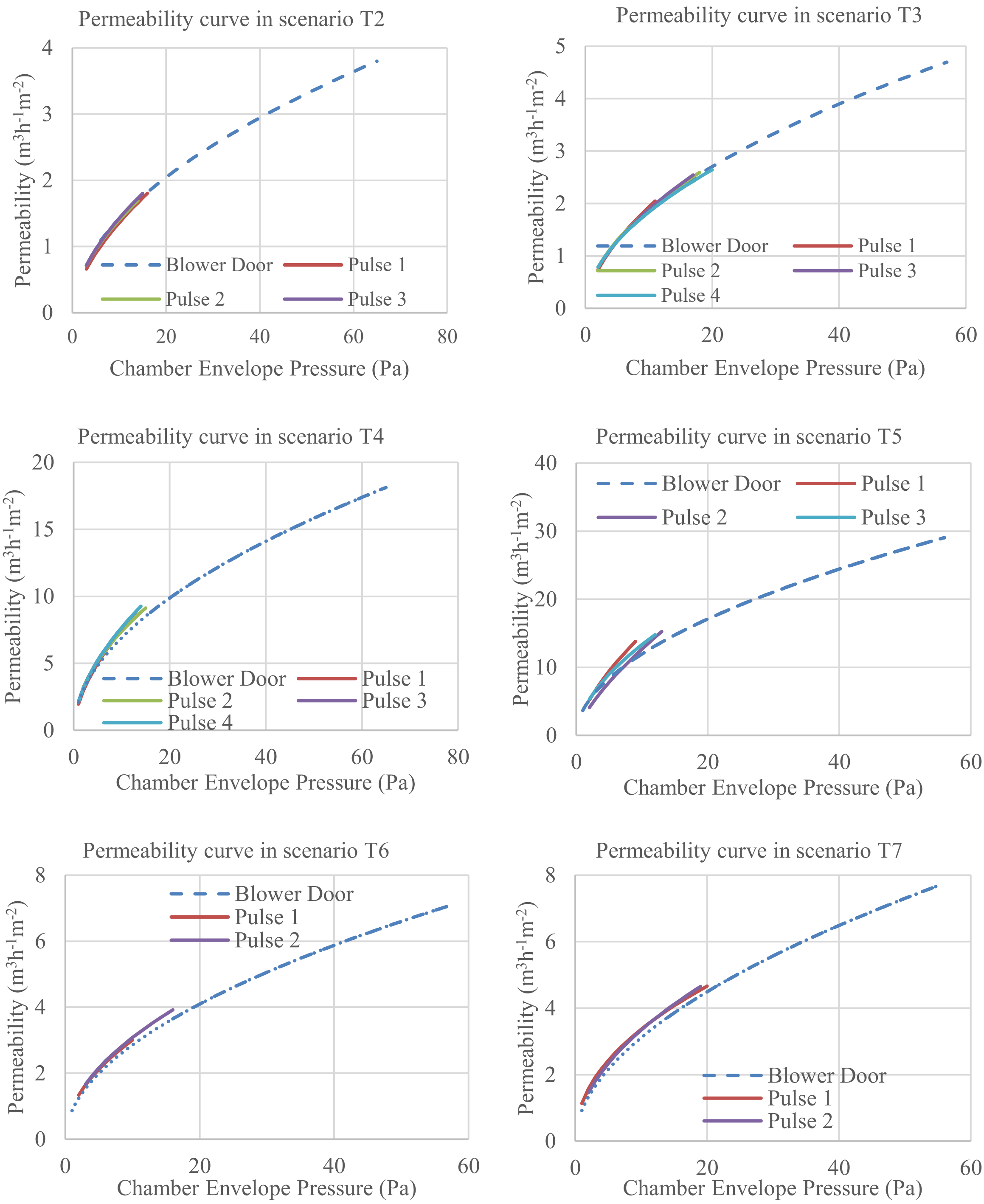


Figure 10 Testing results of all the scenarios in the small chamber

Table 2 Summary of test results given by the blower door and Pulse tests in all scenarios (the small chamber)

Scenario	Range of crossover (Pa)	Minimum (%)	Maximum (%)	Average (%)
T0	10-18	4.1%	7.8%	6.4%
T1	5-23	2.5%	7.8%	4.9%
T2	6-16	0.8%	4.1%	1.6%
T3	7-20	0%	2.2%	0.6%
T4	N/A	N/A	N/A	N/A
T5	9-13	6.0%	12.8%	9.6%
T6	16	7.4%	7.4%	7.4%
T7	14-20	3.8%	6.4%	5.5%

Note: N/A means no pressure overlap was achieved.

The results show the difference between the two testing methods varies from scenario to scenario with the average difference ranging from 0.6% to 9.6%. Scenario T3 gave the best agreement followed by the scenario T2, both of which showed an average percentage difference less than 2%. The largest difference was seen in the scenario T5 where four circular openings and two square openings were present in the test plate. The openings were lying closely in the centre of the test plate and hence large net fluid flow was generated through the test plate likely creating a 'pressure sink' near openings, i.e. non-uniform pressure distribution. This might consequently lead to errors in the pressure measurement, especially so in a small test space and therefore produce larger percentage difference between the two. The average difference in overlap between the blower door and Pulse data is 6.0%. Although this testing does not yield a consistent offset that may easily be accounted for, all testing comes with an inherent level of measurement uncertainty with ISO 9972:2015 (BS ISO 9972) citing an overall uncertainty of lower than ±10% in calm conditions for the blower door fan and the manufacturer citing ±5% uncertainty for Pulse measurements. In this context, the level of agreement is generally encouraging, especially for test scenario T2, T3 and T7.

In the large chamber without introducing external openings, repeated tests were carried out to assess the repeatability of the Pulse test and its agreement with the blower door test. The Pulse test was repeated 10 times and one blower door test was performed in both pressurisation and depressurisation modes. The permeability curves obtained in the Pulse tests as shown in Figure 11, are lying closely with each other, which is an indicator of a good repeatability. Figure 12 illustrates the repeatability of the Pulse test in the achieved pressure range (1-10 Pa) in the form of measurement uncertainty. The uncertainty of measuring the permeability at a pressure level lower than 4 Pa is greater than 5% and the uncertainty increases when the measured pressure decreases. However, it lies within ±5% when the measured level is no smaller than 4 Pa. In relation to the comparison of the blower door and Pulse measurements, the achieved pressure overlap includes 9 Pa and 10 Pa, where a 6.7% and 7.5% difference were observed respectively. Figure 11 shows the permeability curves obtained in the Pulse and blower door tests, which follow the same trend. It is worth to mention that it was observed that the sealing tape around the blower door fan had loosened slightly after the scenario T0 was completed. Therefore, sealing tapes were checked and reinforced prior to the testing in other scenarios. This might explain why the blower door test gave slightly leakier measurement than the Pulse test in the scenario T0.

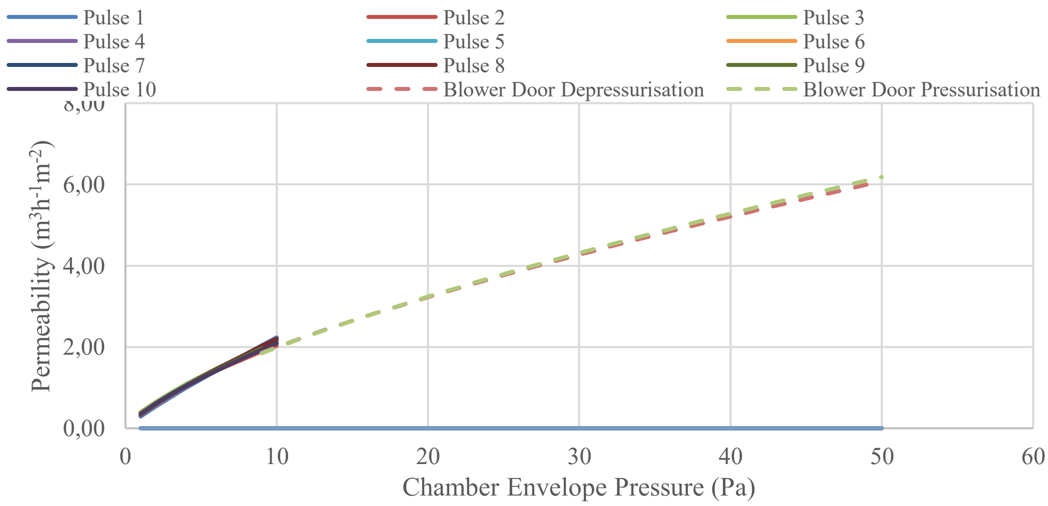


Figure 11 Permeability curves obtained in 10 repeated Pulse tests and one set of blower door tests

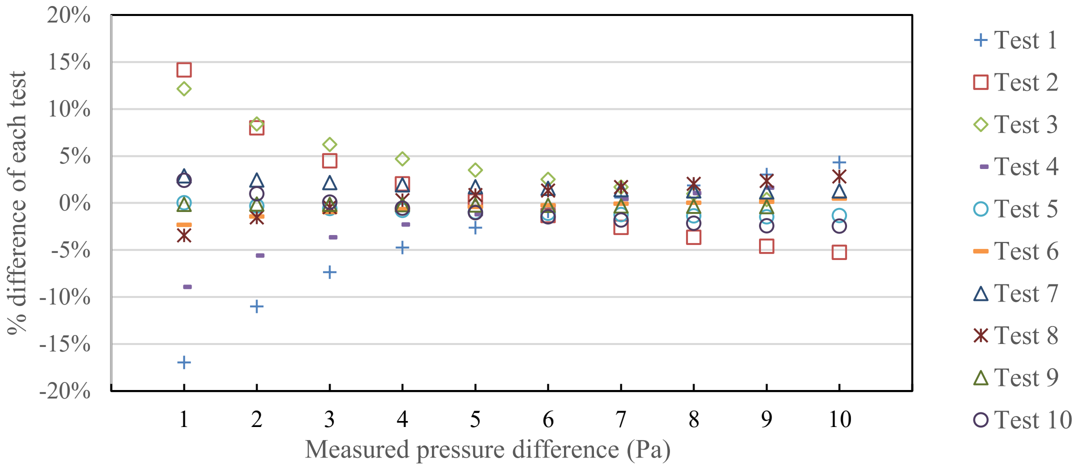


Figure 12 Measurement uncertainty (1-10Pa) of 10 repeated tests

5 CONCLUSIONS

Following on from previous studies concerning the repeatability of the Pulse test in determining air permeability and comparison to blower door results in a sheltered condition, this study has sought to perform similar tests but with improvements to the test arrangement. In the test setup, greater attention has been given to the preparation of the both testing methods in order to gain a 'clean' comparison by minimizing the difference in the testing and envelope conditions that both testing methods were subjected to. Such improvements have included the use of a bespoke solid panel installed in the external doorway for mounting the blower door in order to negate any potential movement of air through the blower door/ doorframe interface. Another improvement was to use a test building inside an outer building, which contained no other potential influences i.e. other windows and people movement etc. Since previous tests developments have also been made to the Pulse unit itself, in terms of its overall system design, instruments and control. In this experimental study, testing was performed in two chambers with very different sizes to verify the accuracy and repeatability of the Pulse unit in a sheltered environment alongside a calibrated blower door unit.

In most of the testing scenarios in the small chamber, where various leakage characteristic and levels were achieved, the Pulse tests provided a good agreement with the blower door tests in reporting the permeability in an overlapped pressure range measured by both testing methods, with a maximum difference of 7.4%. A similar difference was observed in the large chamber. Although this difference is slightly greater than that reported by Zheng (Zheng 2017, Zheng 2019: Building and Environment), an agreement was achieved to a similar extent. A slightly larger discrepancy was shown in the test scenario where the openings with the largest opening area were present when the small chamber was tested. The authors think this might be attributable to uneven pressure distribution around the large openings in the test plate and this could introduce errors in measuring the chamber pressure especially when the test space has a small volume. A good repeatability was demonstrated in the repeated tests carried out in the large chamber and the results showed the measurement uncertainty was within ±5% when the measured pressure level is no smaller than 4 Pa. Below 4 Pa, the measurement uncertainty increased up to ±17% when the measurement pressure level decreased to 1 Pa. This suggests measuring building airtightness at a pressure level below 4 Pa is subjected to a greater background noise.

ACKNOWLEDGEMENTS

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REFERENCE

BS EN ISO 9972. Thermal performance of buildings-Determination of air permeability of buildings-Fan pressurisation method. BSI Standards Publication (2015)

CIBSE standard TM23: Testing Buildings for Air Leakage. CIBSE (2000), ISBN 9781903287101

M.H. Sherman, R. Chan. Building Airtightness: Research and Practice. Lawrence Berkeley National Laboratory Report (2004), Report No. LBNL-53356

M.H. Sherman. Infiltration in ASHRAE's residential ventilation standards. Lawrence Berkeley National Laboratory, LBNL-1220E (2009)

Zheng X.F., Mazzon J., Wallis I., Wood, C.J. Experimental study of of enclosure airtightness of an outdoor chamber using the pulse technique and blower door method under various leakage and wind conditions In: 39th AIVC - 7th TightVent & 5th venticool Conference, 18-19 September 2018, Antibes Juan-Les-Pins. 352-362.

Zheng X.F., Cooper E.W., Mazzon J., Wallis I., Wood, C.J. A comparison study of the blower door and novel pulse technique on measuring enclosure airtightness in a controlled environment In: 38th AIVC conference, Nottingham, United Kingdom, 13-14 September 2017.

Zheng X.F., Cooper E.W., Mazzon J., Wallis I., Wood, C.J. Experimental insights into the airtightness measurement of a house-sized chamber in a sheltered environment using blower door and pulse methods. Building and Environment. https://doi.org/10.1016/j.buildenv.2019.106269.

Zheng, X. F., Cooper, E., Zu, Y. Q., Gillott, M., Tetlow D., Riffat S., WOOD C. J., 2019. Experimental Studies of a Pulse Pressurisation Technique for Measuring Building Airtightness. Future Cities and Environment, 5(1), 10.