Evaluation of indoor pressure distributions in a detached house using the Pulse airtightness measurement technique

Yun-Sheng Hsu*[1], Xiaofeng Zheng[1], Edward Cooper[2], Mark Gillott[1], Shin-Ku Lee[3] and Christopher J Wood[1]

1 Buildings, Energy and Environment Research Group, Faculty of Engineering, University of Nottingham
University Park, Nottingham NG7 2RD, UK
** Yun-Sheng Hsu: yunsheng.hsu@nottingham.ac.uk*

2 Department of Architecture and Built Environment, Faculty of Science and Engineering, University of Nottingham
199 Taikang East Road,
Ningbo, 315100, China

3 Research Centre for Energy Technology and Strategy, National Cheng Kung University
No.1, University Road,
Tainan, 701, Taiwan

ABSTRACT

Building airtightness is a critical aspect for energy-efficient buildings as energy performance of a building can be reduced significantly by poor airtightness. The Pulse technique has been regarded as a promising technology, which measures the building airtightness at a low pressure of 4Pa by rapidly releasing a 1.5-second pulse of air from a pressurised vessel into the test building and thereby creating an instant pressure rise that quickly reaches a "quasi-steady" condition. However, questions have often been asked on the test viability due to the nature of the test. One of the frequently raised questions concerns uniformity of the pressure distribution across the internal space of the test building during the air pulse release. To provide insight into this, experimental work was conducted to measure the indoor pressure distribution during the pulse pressurisation process. The effect of the specific pulse release location on the building airtightness measurement has also been assessed by performing tests at various locations within the building. The test building, which is a five-bedroom house located in the University of Nottingham, was chosen for the testing. Five differential pressure transducers were used to obtain the pressure distribution within the dwelling. In addition, an ultrasonic anemometer was employed to measure the outdoor wind condition to eliminate the impact of wind on the indoor pressure. All the tests were conducted in December 2018 at wind speeds less than 0.5m/s (at a height of 2.2 metres above ground). The results show that a maximum relative percentage difference of 1.4% was obtained by comparing the pressure distribution between living room (Pulse test location) and the other rooms. This indicates that a pressure difference within the building during the Pulse test does exist but considering the accuracy of pressure transducers (0.15%), the deviation is not significant. Comparatively, smaller differences of the pressure level in the five rooms were observed in the fan pressurisation (Duct Blaster B, abbreviated as DBB) test at 10Pa and 15Pa, which are 0.5% and 0.2% respectively. In terms of building airtightness measurement, a subtle variation (i.e. 1.05%) is noted when the Pulse test was conducted at different locations on the ground floor, which may also be caused by variations in the environmental condition (e.g. temperature and wind condition).

KEYWORDS

Building airtightness, Pulse technique, Blower door, Pressure distribution, Anemometer

1 INTRODUCTION

In recent years, energy saving has attracted increased attention, especially in the domestic sector as this sector alone accounted for 28% of UK energy consumption in 2017 (Department for

Business, 2018). Research shows that domestic energy consumption is dominated by several factors, such as household characteristics, building energy performance and electrical appliances. Building energy performance plays an important role in energy conservation and can be significantly affected by ventilation, which is influenced by uncontrolled air leakage (i.e. air infiltration) across the building exterior (Wang et al., 2018). Researchers have confirmed that thermal losses from the building envelope are mainly attributed to heat transfer and ventilation, including infiltration (Lerma et al., 2018). Airtightness is regarded as the fundamental building property that impacts infiltration and exfiltration (Han et al., 2015). Due to the fact that building airtightness is a crucial factor for energy-efficient buildings, the influence of poor airtightness on the built environment has aroused wide concern since the 1970s, for example, the impacts on building energy consumption, building damage, indoor air quality and noise transmission (Carrié and Rosenthal, 2008).

The blower door method is a well-known and widely accepted steady pressurisation method, which can be implemented by fan pressurisation in a range of pressure differences, usually in steps of 10–60Pa (British Standards Institute, 2015) . For the blower door test, a range of steady pressure differences across the building envelope is created by a blower door fan, and the corresponding airflow rate through the fan is measured simultaneously to establish the pressure-leakage relationship of the test building. An alternative method for measuring airtightness, is the Pulse technique, which measures building airtightness at lower pressures compared to the blower door. Typically the test is performed at much less than 10Pa and reported at 4Pa, which has been regarded as a more precise indicator of the pressure level experienced by buildings under natural conditions than the conventional steady-state measurement at 50Pa (Sherman and Matson, 2002). It measures the building air leakage by rapidly releasing a known volume of air from a pressurised vessel into the test building and thereby creating an instantaneous pressure rise that quickly reaches "quasi-steady" condition (Zheng et al., 2019a, Zheng et al., 2019b). Theoretically, the underlying principle of Pulse technique is a quasi-steady flow, which can be shown to exist via the temporal inertial model as given in studies by Cooper and Etheridge (2007), Cooper et al. (2007), Cooper et al. (2014). The Pulse technique is capable of measuring the building airtightness dynamically within a short period, typically 11-15s. The quick measurements of the corresponding change in the indoor pressure and the pressure change in the air tank can be measured to obtain the air leakage through the building envelope at 4Pa. The Pulse technique has proven to be of great practical value (Zheng et al., 2017). However, questions have often been asked by professionals in the industry and researchers in academia on the test viability due to the nature of the test. One of the frequently raised questions considers the uniformity of the pressure distribution across the internal spaces of the test building during the air pulse release. In this study, experimental work was conducted in a five-bedroom detached house to verify whether a uniform indoor pressure distribution can be achieved during the pulse pressurisation process. This distribution is also compared with that of a steady pressurisation test. In addition, the effect of the pulse release location on the building airtightness measurement is also investigated. The tests in this study were routinely done as part of the ongoing development of Pulse technique and the investigation presents results of testing using the latest Pulse equipment as an answer to the aforementioned questions.

2 EQUIPMENT

Different devices were used for experimental work in this study, as listed in Table 1. A PULSE-60 unit (Figure 1), which consists of a 58.5-litre lightweight aluminium tank and oil-free compact air compressor, was used for the Pulse test. A ¾ inch (BSP) solenoid valve was installed at the outlet to release compressed air from the air tank into the test building. In addition, the Pulse test data, such as chamber and tank pressures were recorded and analysed by the on-board PULSE-60 control box, with results displayed on the LCD screen as seen in Figure 1. In this study, a complete three-step Pulse tests consists of three consecutive pulses, namely Pulse 1, Pulse 2 and Pulse 3.

For the blower door test, Duct blaster series B (DBB), which is manufactured by The Energy Conservatory (US), was employed. The photo of the DBB unit is presented in Figure 2. The unit is mainly composed of an adjustable doorframe, a flexible canvas panel, a variable-speed fan and a DG-1000 digital pressure and flow gauge. In order to obtain the weather condition during testing, an ultrasonic anemometer was used to measure the outdoor wind speed (Figure 3), and thermocouples were used to measure ambient temperature. A sensitive FCO44 differential pressure transducers (diaphragm-type), which are manufactured by Furness Controls Ltd, were adopted to measure the pressure level of the internal spaces (Figure 4). Experimental data acquisition was accomplished by Datataker DT85.

Table 1: List of test equipment

Airtightness	Others
	Ultrasonic anemometer,
PULSE-60	FCO44 Differential pressure transducers (Accuracy < 0.25%),
Duct blaster series B (DBB)	Temperature sensors,
	Datataker DT85

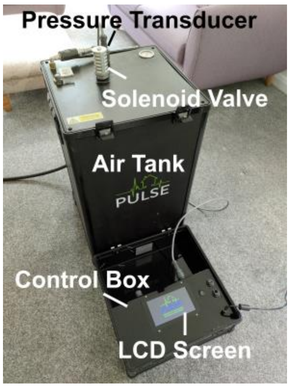

Figure 1: PULSE-60 unit with control box

Figure 2: Energy Conservatory duct blaster series B

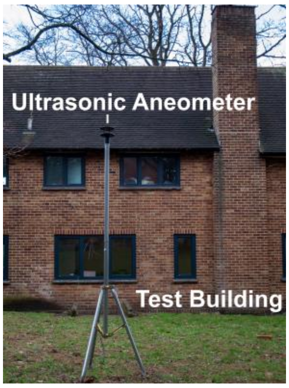

Figure 3: Ultrasonic anemometer

Figure 4: Differential pressure transducers and Datataker DT85

3 DWELLING, SETUP AND TEST ARRANGEMENT

A five-bedroom detached house located on the University Park campus in Nottingham University was chosen as the test building. Figure 5 and Figure 6 show the front and back views of the house and the floor plans are presented in Figure 7 and Figure 8, respectively. The house has one bedroom, one living room, one kitchen on the ground floor and four bedrooms on the first floor. The building parameters are listed in Table 2 and the measurement and calculation of envelope area and volume of the test dwelling complied with ISO 9972.

In this study, all experimental tests were conducted under wind speeds less than 0.5m/s, which was measured at height of 2.2 metre above ground in the backyard and a distance of 12-meter away from the perimeter of the test building, without any obstructions within a radius of 12 meters. The purpose of this arrangement is to minimise the wind impact on the indoor pressure distribution so insights on the pressure distribution produced solely by the Pulse test can be gained. Due to the fact that the sampling rate of data loggers reduces when more differential pressure transducers are connected to them, five differential pressure transducers were utilised to measure the indoor pressure distribution in order to make a balance between the sampling rate and the number of monitored rooms. The sampling rate was 4hz. The accuracy of the differential pressure transducer is 0.15% and all five differential pressure transducers were calibrated by connecting to the same tapping point.

Figure 5: Front view of test building

Figure 6: Back view of test building

Figure 7: Ground floor plan of test building

Figure 8: First floor plan of test building

Table 2: Envelope area and volume of the test dwelling

Dwelling	Wortley 5 - University of Nottingham, University Park, Nottingham
Volume (m^3)	447
Envelope area (m^2)	416
Approximate ACH @50Pa	3.71 (DBB tested on December 2018)
Approximate ACH @4Pa	0.73 (PULSE-60 tested on December 2018)

4 RESULTS AND ANALYSIS

4.1 Indoor Pressure Distribution During the Pulse Test

A series of Pulse tests have been conducted in the house to verify whether a uniform pressure distribution across the internal spaces of the test building can be achieved during the air pulse release, so that the viability of the Pulse test for accomplishing building airtightness measurement at 4Pa in a very short period (i.e. typically 11-15s) can also be evaluated. The Pulse unit was placed in the centre of the living room on the ground floor for testing, and the indoor pressure distributions for five rooms on both floor levels (i.e. living room, kitchen and three bedrooms) have been measured respectively during the pulse pressurisation process. This research is part of a wider study to investigate various aspects of the Pulse technology and therefore in total 682 Pulse tests were conducted. However, in this analysis concerning pressure distribution a typical test result is shown which represents the operation in a calm condition i.e. at the lowest external wind speed (<0.5m/s) to avoid any effects which may be caused by wind loading on the building. Figure 8 displays the pressure variation in each room during the complete three-step of the Pulse test (i.e. Pulse 1, Pulse 2 and Pulse 3). A three-step Pulse test consists of three consecutive pulses, and therefore the 1.5-second pressure rise in the third pulse is much lower than that of the first one due to the declining tank air pressure. It can be noted that the curves representing the pressure responses of five rooms are nearly identical, which indicates good uniformity of the pressure distribution across the five rooms during the pulse release. More discussions for each step of the Pulse tests are given in the following sections.

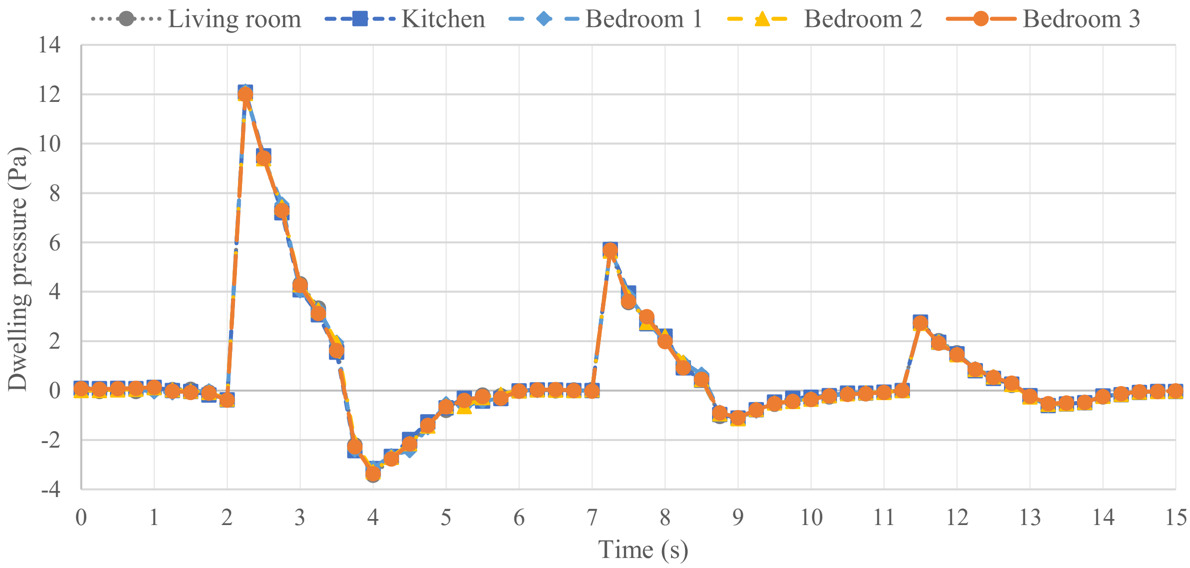

Figure 8: Pressure profiles of five rooms during the complete pulse test

Figure 9 shows the measured pressure distribution of each room during Pulse 1. Similar trends were observed in the five rooms and the indoor pressure of every room reached around 12Pa at 2.25s, i.e. 0.25 second after the valve opened to release compressed air from the tank into the internal spaces. Slight differences of the maximum pressure in each room were obtained. For evaluation, the relative percentage difference between the maximum pressure levels of five rooms is calculated. For Pulse 1, the maximum relative percentage difference between living room and the other rooms is approximately 0.8%, as the maximum pressure measured in the living room is 12.09Pa and 11.99Pa in Bedroom 3.

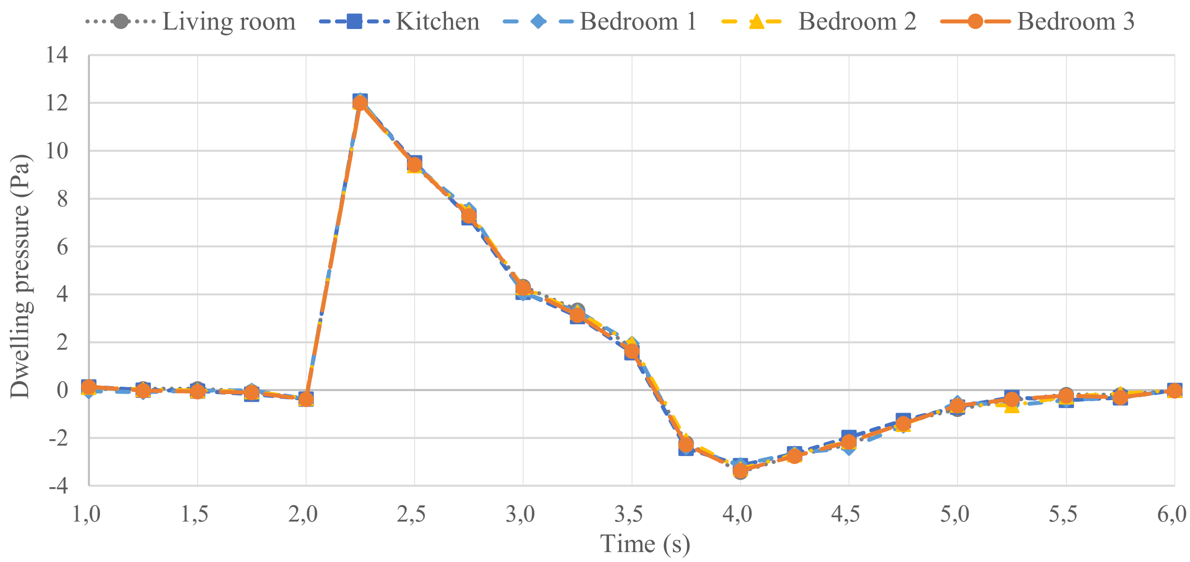

Figure 9: Pressure profiles of five rooms during Pulse 1 testing

The results of pressure distribution in the five rooms for Pulse 2 testing are presented in Figure 10. At 7.25s, 0.25 second after the pulse air was released into the internal rooms, the maximum pressure level was obtained for each room, which ranged from 5.65 to 5.73 Pa. Compared to the curves of the Pulse 1 test in Figure 9, some differences were seen among the five pressure curves of Pulse 2. As the Pulse test unit was located in the living room, the maximum pressure level of 5.73 Pa was achieved in the living room, while 5.65Pa was measured in Bedroom 2. The relative percentage difference is 1.4%, which is slightly higher than that of Pulse 1.

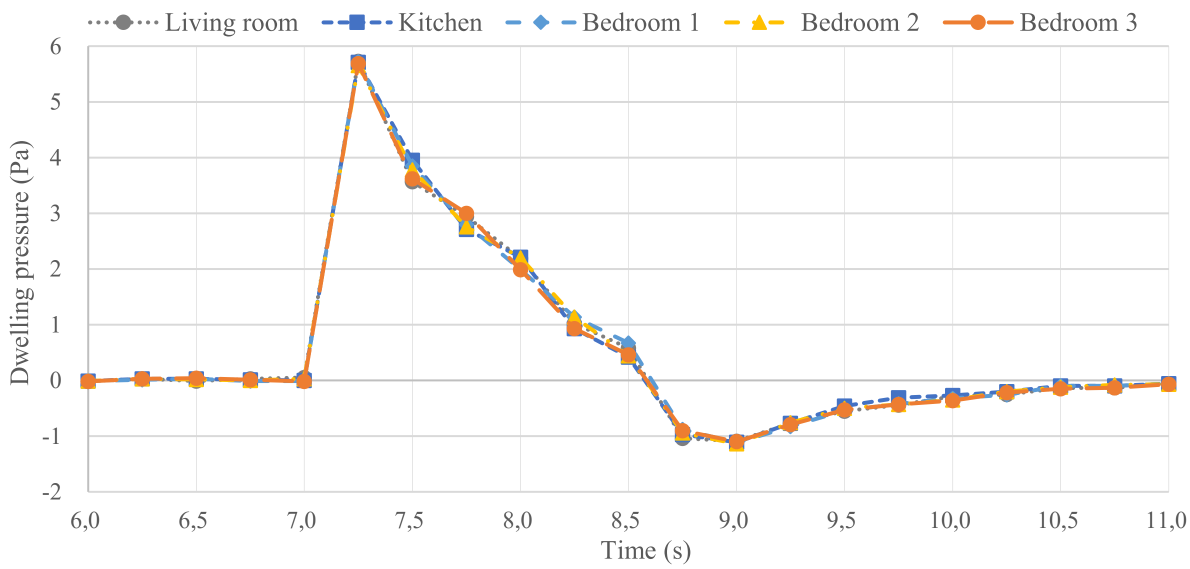

Figure 10: Pressure profiles of five rooms during Pulse 2 testing

Figure 11 demonstrates the pressure distributions of the five rooms during Pulse 3. Similar to Pulse 2 test, the pressure in each room peaked around 2.7 Pa at 11.25s, 0.25 second after the release of air pulse. The relative percentage differences between living room and Bedroom 1, between living room and Bedroom 2 are both 1.4%. Table 3 lists the measured maximum pressure level in each room for Pulse 1, Pulse 2 and Pulse 3 tests.

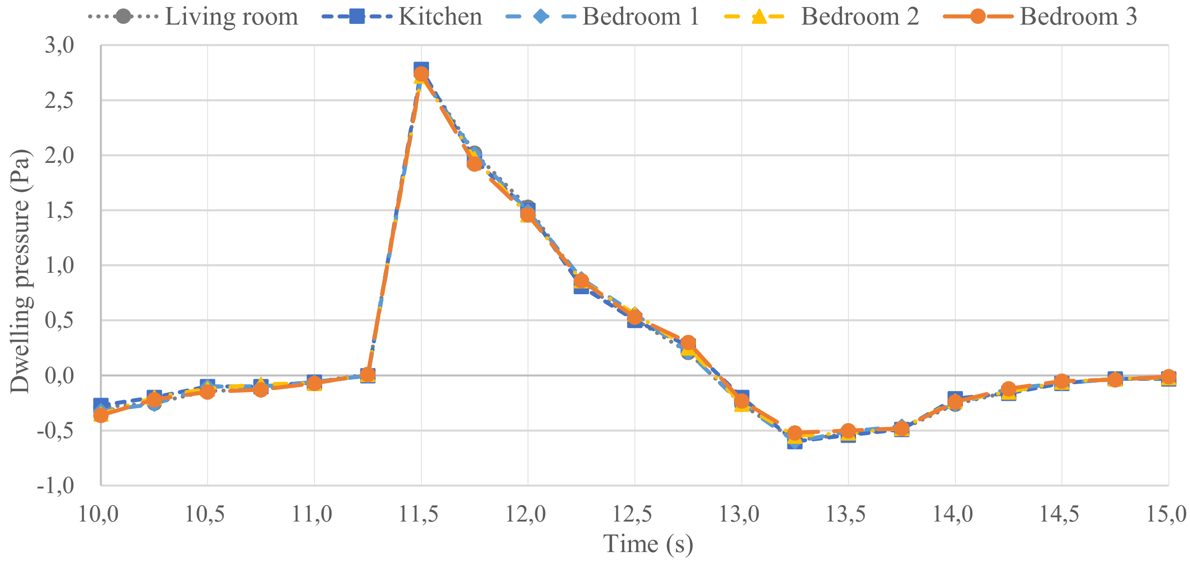

Figure 11: Pressure profiles of five rooms during Pulse 3

Table 3: Maximum pressure level in each room for Pulse 1, Pulse 2 and Pulse 3 tests

	Living room	Kitchen	Bedroom 1	Bedroom 2	Bedroom 3	%*
Pulse 1	12.09 Pa	12.09 Pa	12.13 Pa	12.04 Pa	11.99 Pa	0.8%
Pulse 2	5.73 Pa	5.71 Pa	5.72 Pa	5.65 Pa	5.69 Pa	1.4%
Pulse 3	2.76 Pa	2.78 Pa	2.72 Pa	2.72 Pa	2.74 Pa	1.4%

*The maximum relative percentage difference between living room and the other rooms

4.2 Indoor Pressure Distribution During the DBB Test

Experimental work was also undertaken to investigate the uniformity of pressure distribution within the house during the blower door test. The DBB was installed at the main entrance door of the dwelling and tests were carried out under similar weather conditions as the Pulse test. Due to the limited measurement range (±20 Pa) of the differential pressure transducers, the uniformity of pressure distribution was only investigated at 10Pa and 15Pa. The results are presented in Table 4, Figure 12 and Figure 13 respectively. The overall measurement lasted about 15 seconds after the building pressure became steady. As seen from both figures, the overall trends of the pressure variation in each room are similar. For a test at 10Pa, the maximum pressure difference is about 0.05Pa, with a relative percentage difference of 0.5% and only 0.03Pa of the maximum pressure difference is observed for a test at 15Pa, with a relative percentage difference of 0.2%. Considering the accuracy of pressure transducers (0.15%), uniform pressure distribution across the internal spaces has been demonstrated for the fan pressurisation test. In this study, tests were conducted under calm conditions (i.e. wind speed lower than 0.5m/s) with less notable wind impact on measurement. It is worth noting that for fan pressurisation test, wind speed is usually measured only when the testing starts and after completion, while the variation in wind speed during testing is ignored. Due to the dynamic characteristics of wind, wind condition may vary during testing period, which could affect measurement of building airtightness.

Table 4: Maximum pressure level in each room for DBB tests at 10 Pa and 15Pa

	Living room	Kitchen	Bedroom 1	Bedroom 2	Bedroom 3	%*
DDB 10 Pa	14.93 Pa	14.94 Pa	14.95 Pa	14.92 Pa	14.93 Pa	0.2 %
DDB 15 Pa	10.03 Pa	10.04 Pa	10.03 Pa	10.05 Pa	10.08 Pa	0.5 %

*Relative percentage difference between maximum and minimum

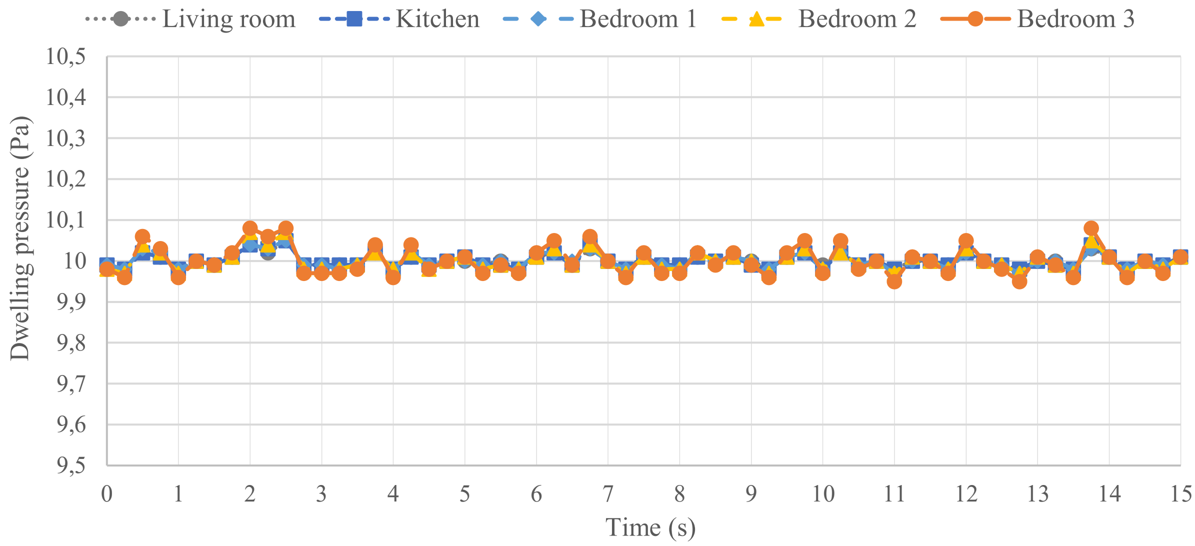

Figure 12: Pressure profiles of five rooms during the DBB test at 10Pa

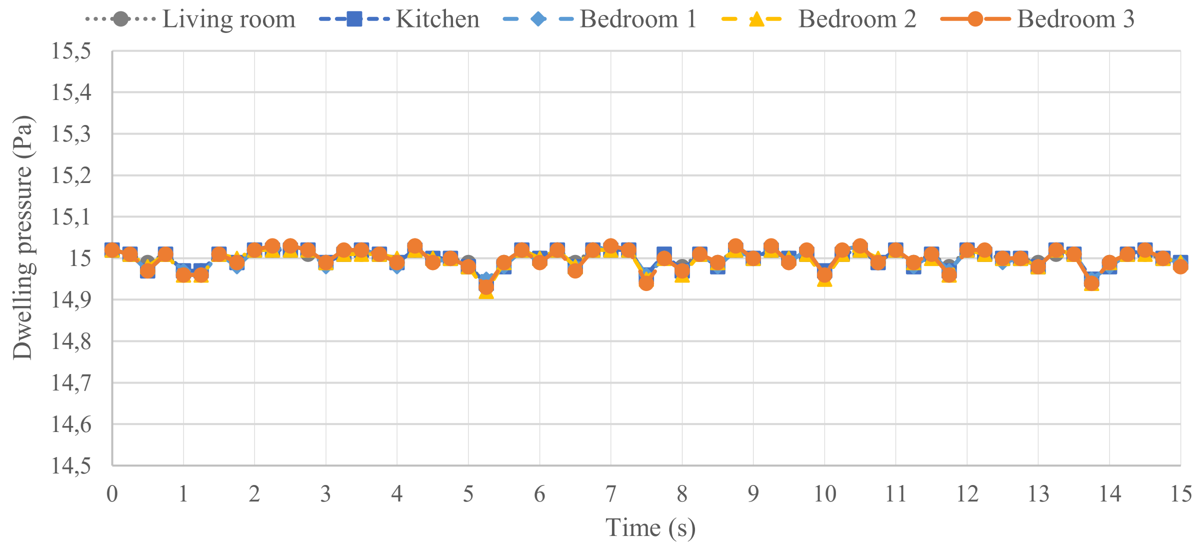

Figure 13: Pressure profiles of five rooms during the DBB test at 15Pa

4.3 Effect of Pulse Release Location

Investigations were made to the effect of the specific pulse release location on the building airtightness measurement by performing tests in various locations within the building. Figure 14 illustrates the floor plan of the dwelling with marked test points. In total, six locations on the ground floor were selected, including living room, living room corner, Bedroom 1, Bedroom 1 corner, kitchen and kitchen corner. At each test location, five repeated tests were implemented under calm weather conditions. Table 5 shows the building airtightness measurement results for the 30 tests at different pulse release locations. The average building permeability value is calculated based on the five tests for each location. As listed in Table 5, the average permeability for pulse release in living room, living room corner, Bedroom 1, Bedroom 1 corner, kitchen and kitchen corner are 0.725, 0.721, 0.721, 0.728, 0.731 and 0.716 m^3/m^2h respectively. A subtle difference in the average building permeability is noted with variability of 1.05%, which is possibly caused by other factors, for instance variation in the environmental condition (temperature and wind condition). Therefore, the results indicate that the Pulse test location in this study has little effect on building airtightness measurement.

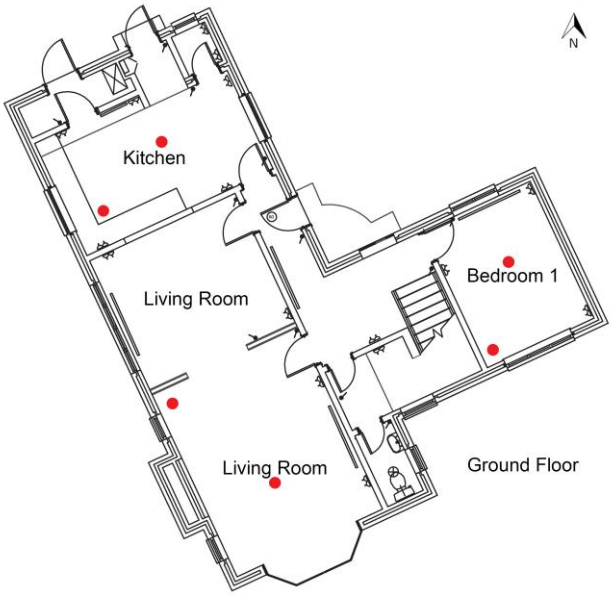

Figure 14: Pulse Test locations

Table 5: Measurement results of building permeability (m^3/m^2h) for the pulse tests at different locations

	Living room	Living room Corner	Bedroom 1	Bedroom 1 Corner	Kitchen	Kitchen Corner
Test 1	0.721	0.715	0.719	0.718	0.721	0.718
Test 2	0.730	0.719	0.726	0.723	0.726	0.722
Test 3	0.725	0.714	0.702	0.730	0.763	0.725
Test 4	0.732	0.722	0.733	0.764	0.732	0.709
Test 5	0.715	0.733	0.723	0.706	0.713	0.706
Average	0.725 (±1.38%) *	0.721 (±1.66%)	0.721 (±2.64%)	0.728 (±4.95%)	0.731 (±4.38%)	0.716 (±1.40%)
Overall Average	0.724					
%**	0.15%	0.40%	0.40%	0.65%	1.03%	1.05%

* Highest relative percentage difference between each test and average
** Relative percentage difference between location average and an overall average

5 CONCLUSIONS

In this study, experimental investigations were made in a five-bedroom detached house using the PULSE-60 unit and the fan pressurisation (Duct Blaster B, abbreviated as DBB) to measure building airtightness under calm weather conditions that wind speeds less than 0.5m/s. For assessment, pressure distributions among five different rooms within the building were monitored together with the building permeability. Based on the experimental results, it can be noted that the pressure distributions among the rooms were identical during the three-step Pulse test. A minor pressure difference within the building during Pulse test was observed, but the deviation is not significant, with the highest relative percentage difference of 1.4% in Pulse 2 and Pulse 3 test when comparing thee pressure in each room with living room pressure. In terms of the DBB tests, the relative percentage difference of the maximum pressure level in each room is 0.5% at 10Pa and 0.2% at 15Pa, which is lower than that of the Pulse tests. It is also worth noting that with longer testing period, a noticeable wind impact is more likely to occur on building indoor pressure variation. Furthermore, an insignificant impact of Pulse test location on building airtightness measurement was observed with a subtle variation (i.e. 1.05%) in building air permeability when Pulse tests were conducted at different locations inside the

building. There is a possibility that the subtle variation is caused by changes in the environmental condition, for example temperature or wind condition.
The adopted data acquisition device in this study has a limited measurement frequency, which led to limitations of the experimental work. Firstly, due to the fact that the rapid 1.5-second pulse of air is released from the pressurised vessel, and the "quasi-steady" condition is achieved only in 0.8s, limited pressure data were gathered by the acquisition device with the maximum measurement frequency of 4Hz, which may not be adequate to entirely describe the pressure variation throughout the Pulse test. In addition, to ensure data is collected at the maximum frequency, only five pressure transducers could be used for testing, which is not enough to measure the pressure distribution in every room of the test building. For future work, CFD-based numerical studies are recommended to identify in detail how the pressure wave propagates within the internal spaces of the test building and how the building pressure distributes across different zones within the building during the Pulse test.

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