A comparison study ofthe blower door and novel pulsetechnique on measuring enclosure airtightness in a controlled environment

Xiaofeng Zheng*[1],Edward Cooper[1], Joe Mazzon[2], Ian Wallis[2], Christopher J Wood[1]

1 Architecture, Energy and Environment Research Group, Faculty of Engineering, University of Nottingham
University Park, Nottingham NG7 2RD, UK

2 BSRIA Limited
Old Bracknell Lane West
*Bracknell, Berkshire, RG12 7AH, UK*Corresponding author: xiaofeng.zheng@nottingham.ac.uk*

ABSTRACT

This paper introduces a comparison study of measuring the airtightness of a house sizedtest chamber using the novel pulse technique and the standard blower door method in a controlled environment. Eight different testing plates have been applied to the improvised envelope of the chamber to establish different leakage characteristics. Each testing plate has a unique opening in the centre of the plate, achieved by obtaining a different combination of shape and thickness of the opening. By using the controlled environment, the vagaries of the natural condition when testing within buildings have been reduced providing a more robust testing environment. This investigation focuses on how the air leakage rate calculated from the measurements made by both techniques compare with each other. Comparable results (±3%) under most scenarios have been obtained. Additionally, other aspects such as usability of the equipment used for the pulse testing have also been appraised.

KEYWORDS

Building airtightness, Blower door,PULSE unit, Controlled environment

1. INTRODUCTION

1.1. Context

One of the main challenges in the measurement of building airtightness lies in accurately measuring low pressures that a building experiences under natural conditions. This pressure is typically in a range of 1-4 Pa and difficultiesin measurement exist at this level due to the uncertain nature of external wind and buoyancy effects.Pressure changes due to external influences need to be accounted for in the measured pressure difference across the building envelope in order to obtain the actual pressure difference that the building is subjected to. One of the approaches to overcome this issue is to perform the test at high pressures in order to negatethe wind and buoyancy effects; as with the steady state, *alias* blower door test at 50Pa. However, this approach has its own shortcomings, which have been discussed in scientific studies and practical uses (Cooper 2007, Cooper 2014, Cooper 2016, Zero Carbon Hub 2014, Sherman 1994, Sherman 2002, Sherman 2009).It can be understood by performing the blower door test at 50Pa it will reduce the impact of the natural vagaries of wind and buoyancy; however this does not preclude the use of such a test at 4Pa. Nevertheless, one must consider the increasing impact of such influences upon the accuracy of the final result at 4Pa. In fact in a number of countries, including the UK the test measurement must be recorded at 50Pa for regulatory requirements. In this study, the difference in error between the 4Pa and 50Pa blowerdoor test is not investigated explicitly in terms of causation, butboth measures are used to compare against the novel airtightness testing process known as the pulse technique. The pulse technique is a low pressure process (typically around 4Pa) whereby the airtightness of a building is determined through the release of a 1.5second pulse of air from a pressurised vessel. The rapid measurement of the consequential change in internal pressure of the building can be used to calculate a flow rate through the building envelope at 4Pa. The underlying principle is that of a quasi-steady flow, which can be shown to exist via the temporal inertial model and further detail is given by Cooper (Cooper 2007 and Cooper 2014).

A recent study by Remi (Remi 2016)using the blower door method shows an uncertainty of 6%-12% can be caused by steady wind in a range of 6-10 m/s combined with other sources of error in a steady state test at 50 Pa. Given the low operating pressure (around 4 Pa) of the pulse techniquethe wind could be considered the foremost important environmental factor due to its direct impact on the building pressure.In this study, the pulse and blower door units are used to measure the air leakage rates of an environmental chamber installed with 8 different testing plates, which provide 11 testing scenarios. The test chamber is housed inside another large building and therefore the ambient external condition is more stable than that of real houses. This test arrangement allows both the blower door and the pulsetechnique to measure leakage at low pressures. The objective of this comparative testing is to find out how these two techniques performunder different building leakage scenarios in a controlled environment.

1.2. Equipment

The blower door unit that is used in this study is aDuct Blaster B (DBB), manufactured by ‘The Energy Conservatory’ in the United States. It consists of an adjustable door frame, flexible canvas panel, a variable-speed fan, and a DG700 pressure and flow gauge, as shown in Figure 1. The DBB is calibrated to take reliable readings at lower pressures than the larger blower door unitsandis therefore used to carry out the comparative tests alongside the PULSE-80 unit in this investigation.

The PULSE-80 unitincorporatesan80 litre light weight composite tankand oil free double piston compressor as shown in Figure 2. The outlet utilises a ¾ inch(BSP) solenoid valveto release compressed air from the air tank intothe test space, which delivers the 1.5second pressure rise. The data is recorded and analysed by the control box and results are displayed on the LCD screen of the control box.

Figure 1 Energy Conservatory Duct blaster B (DBB)

Figure 2PULSE-80 and associated control box

2. METHODOLOGY

2.1. Chamber

The tests were carried out in environmental chamber (No.4) at the testing laboratories of BSRIA Ltd, UK.The chamber, built inside a building, is made of insulated cold–store panels. The dimensions of the chamber are 6.01 m×4.64 m×7.20 m (L×W×H) with a 50 mm wall thickness, which give an envelope area and internal volumeof 209m^2 and 200 m^3 respectively. The spaces surrounding the chamber were left open duringthe tests. The chamber's air supply, extract and instrumentation holeswere all sealed duringthe course of testing.

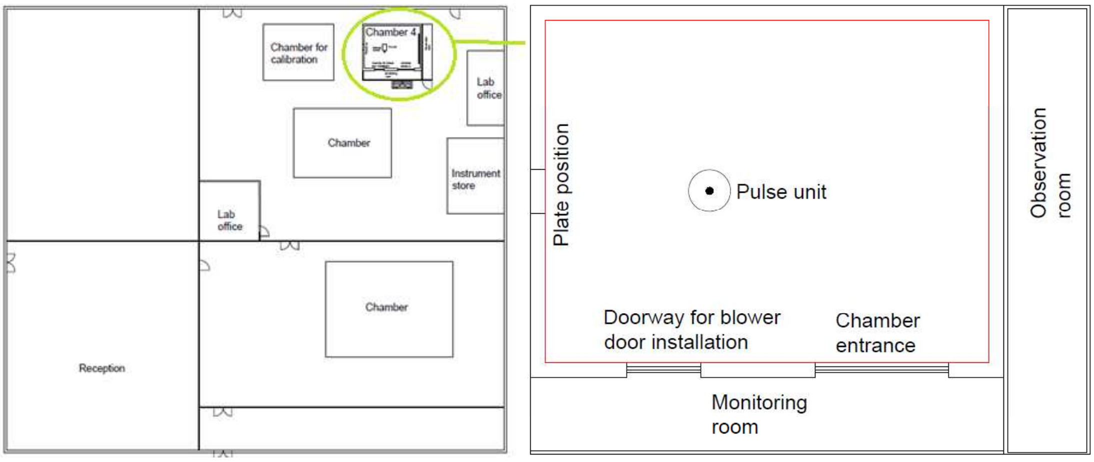


Figure 3 Environmental chamber for testing inside outer building (left) and test enclosure inside the chamber (right)

As shown in Figure 3, the chamber has a main entrance door and two smaller doors. One of them was used to install the DBB and the other was replaced by a compressed-fibreboard (MDF) sheet where plates with different openings were installed. The setup of the pulse unit in the environmental chamber is shown in Figure 3, in which the red rectangle represents the test space.Table 1 shows the details for thethree tests conducted, with the aim to investigate the following:

- The difference between the Q_4(air permeability at 4 Pa, m^3/hm^2) measured by DBB using standard and Non-standard approach (see Table 1).
- The measurement of Q_4 using DBB and PULSE-80 under various testing scenarios.

Table 1Three testing approach

Equipment	DBB		PULSE
Test approach	Standard	Non-standard	PULSE-80

Standard test: carried out in accordance to ATTMA technical standard L1, typically in 10-60 Pa;
Non-standard test: carried out mainly in accordance to ATTMA technical standard L1, but in 4-60 Pa.

2.2. Plates

8 fibre-board plates of two thicknesses were cut to providevarious openings of known geometric area as shown together with their associated photograph in Table 2. Plates 2 and 6 were also modified to make three more testing plates, the details are listed in Table 3, therefore giving 11 plate test scenarios overall.

Table 2 Details of the testing plates

Test	Plate No.	Thickness	Description	Measured Area
1	1	18mm	Blank plate	0 cm^2
2	2	18mm	Circle	318.10 cm^2
3	3	18mm	Four squares	314.76 cm^2
4	4	18mm	Slots	230.04 cm^2
5	5	50mm	Circle	307.91 cm^2
6	6	50mm	Four squares	306.56 cm^2
7	7	50mm	Slots	328.73 cm^2
8	8	50mm	Angled circle	381.44 cm^2

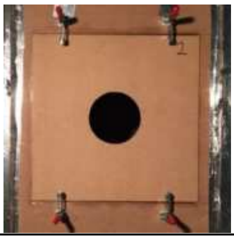
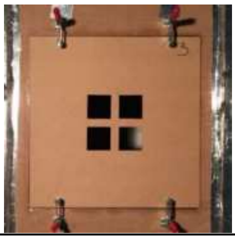
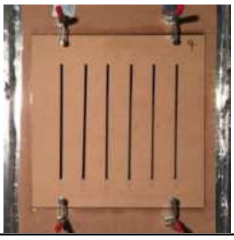
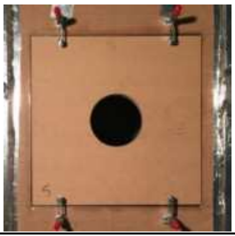
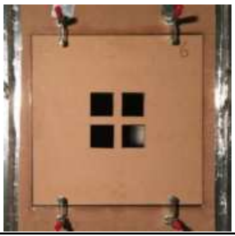
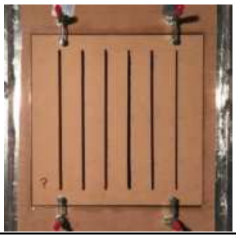
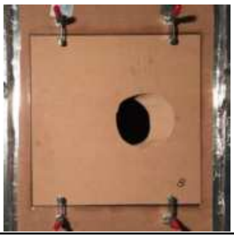
Plate 1	Plate 2	Plate 3	Plate 4
			
Plate 5	Plate 6	Plate 7	Plate 8
			

Table 3Additional testing arrangements with modifications made to plates 2 and 6

Plate No.	9	10	11
Test	9	10	11
	A 410 mm circular duct is added	Three squares were sealed	Straws in one square with others sealed
Modification			

2.3. Basic testing process

The comparison tests were carried out under the assumption that any difference in environmental conditions over the course of testing is insignificant. TheDBB tests were conducted by a qualified BSRIA compliance engineerand the testing procedure followed the ATTMA (the Air Tightness Testing & Measurement Association)technical standard L1.The tests were performed in the pressurisation state. The pulse tests were conducted under the same experimental conditionsas the DBB tests. In this paper the air permeability measured by both the DBB and PULSE-80is compared at 4Pa, but a discussion to the comparison at50 Pa is also made. In order to predict Q_4 and Q_{50}(air permeability at 4Pa and 50Pa, m^3/hm^2), the power law equation $V = C\Delta P^n$ is used, where V is the air leakage rate (m^3/s), C is the flow coefficient (m^3/s·Pa^n), ΔP is the building pressure (Pa) and n is the pressure exponent.

3. RESULTS AND ANALYSIS

3. 1. Tested plates

Q_4 of the 11testing plates are shown in Table 4 with achieved pressure range (ΔP). All the plates were tested by each approach consecutively. For the pulse tests, ideally the ΔP needs to cover 4 Pa so as to avoid any extrapolation, however, in some of the pulse tests, the ΔP doesn't cover 4 Pa but is in close proximity. Considering the hydraulic similarity at low pressures, minor extrapolations are madeto the results close to 4Pa in order to calculate Q_4, all the pulse tests that cover or are in close proximity of 4 Pa are used for comparison.

Table 4 Air permeability at 4 Pa of pulse and DBB tests (m^3/h·m^2)

Test	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Standard (DBB)	0.50	1.24	1.27	1.10	1.28	1.33	1.48	1.01	1.51	0.79	0.57
ΔP range (Pa)	25-60	25-61	25-57	26-59	27-57	27-57	25-56	29-63	27-55	23-60	26-50
Non-standard (DBB)	0.48	1.31	1.34	1.23	1.34	1.36	1.51	1.08	1.59	0.73	0.55
ΔP range (Pa)	4.5-60	4.0-61	4.2-57	4.2-59	4.0-57	4.0-57	4.0-56	4.0-63	4-55	4.4-60	4.4-54
PULSE-80	0.51	**N/A**	1.37	1.24	1.37	1.40	1.51	1.06	1.38	0.71	0.72
ΔP range (Pa)	4.6-6.7	**N/A**	3.3-4.9	2.8-4.5	3.2-4.1	3.1-4.1	2.6-4.3	4.9-8.5	3.0-4.6	5.7-9.3	5.9-6.9

ΔP range stands for the achieved pressure range in which the leakage is measured.
N/A stands for the fact that the test was not carried out due to the time constraint.

The air leakage vs building pressureof all tests measured by DBB and PULSE-80 is plotted in log-log scale graph, as shown inFigure 5. The pulse and DBB tests of the same plate are plotted in the same colour with a trend line added to each DBB test.It can be seen that the pulse measurement of tests 1 to 8 lie closely to the trend line of each corresponding DBB measurement, however this is not the case for tests 9, 10 and 11.

3.1.1. Comparison between DBB Standard and Non-standard

Two testing approaches, including the Standard and Non-standard DDB tests, are compared to see the impact of extrapolation to the prediction of Q_4. Assuming the influence of wind and buoyancy is insignificant due to the experimental arrangement then, theoretically, Q_4 given by the Non-standard approach should be more reliable than the Standard approach considering it doesn’t involve any extrapolation. In the analysis, the Q_4 given by the Non-standard approach is used as the baseline to present the percentage difference of Q_4 given by both approaches, as shown inFigure 4. Hence, it is seen that by measuring the building leakage according to the standard procedure in a controlled environment, the DBB test produces a deviation of between 2.2% and 10.6% when predicting Q_4.

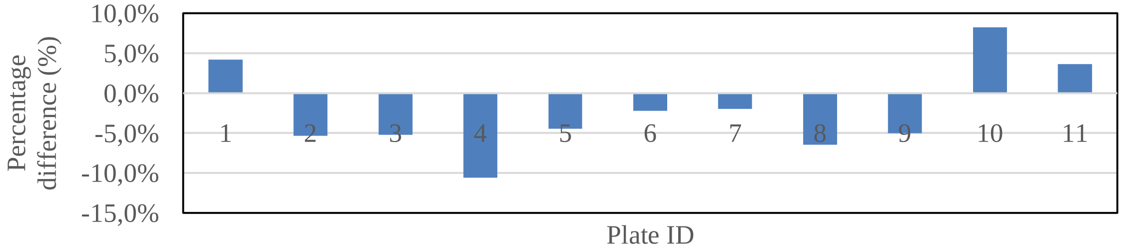


Figure 4Percentage difference of Q_4 measured by DBB in Standard and Non-standard approach

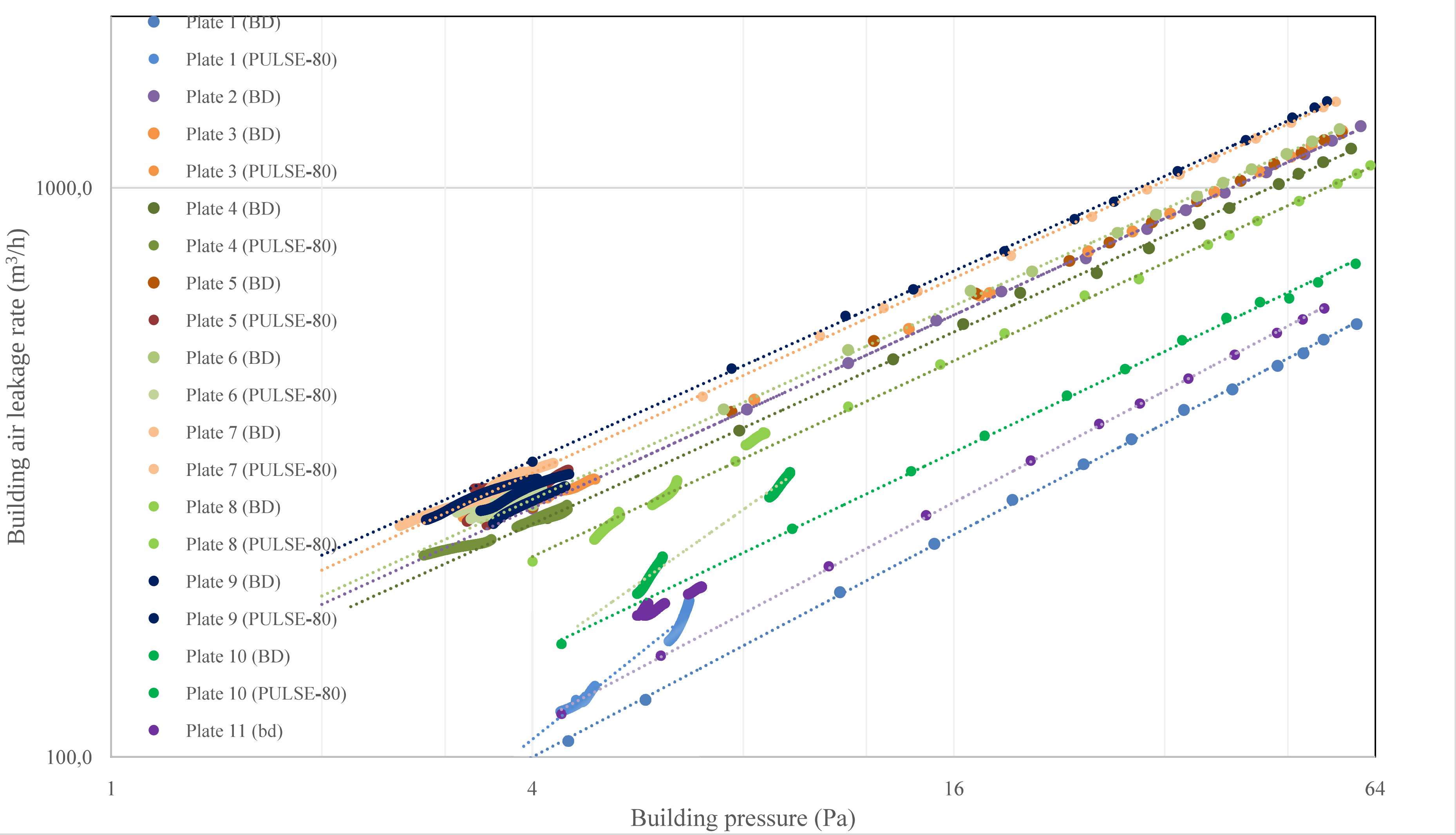


Figure 5Log-log scale graph of leakage-pressure measured by DBBand PULSE-80

3.1.2. Comparison between the DBB and PULSE-80

Tests using PULSE-80 are compared with those done inStandard and Non-standard approach using DBB. The percentage difference of Q_4measured by PULSE-80against that given by the Standard DBB test lies in 2.0%-26.3%, and 0%-30.9% for the Non-standard DBB test, as shown in Figure 6.

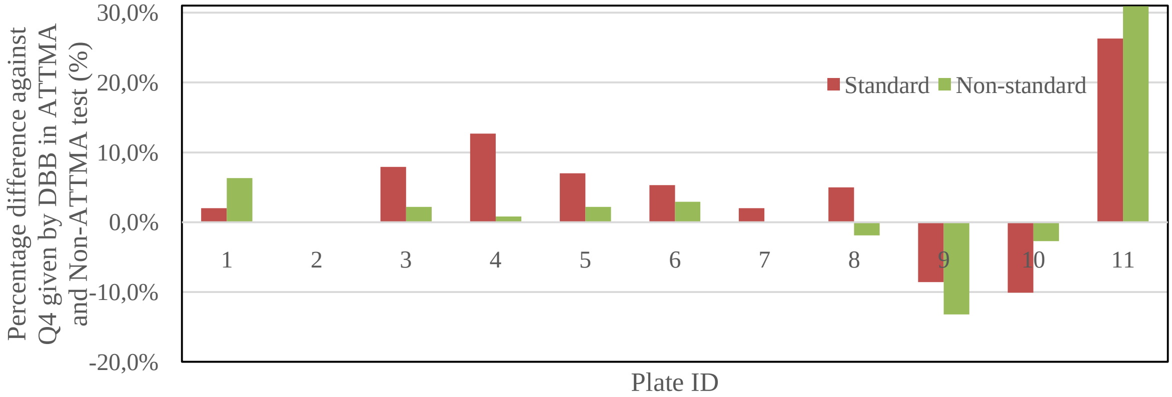


Figure 6Percentage difference of Q_4 measured by pulse units against that measured by DBB in two approaches

The percentage difference ofQ_4measured by PULSE-80 against that given by DBBfalls into awiderange, from 0% to 31%. But when tests 9 and11areexcluded, the percentage difference of Q_4 given by PULSE-80 and DBB (Standard) comes down to 2.0%-12.7% and 0%-6.3% for DBB (Non-standard).Tests 9 and 11 are excluded on the basis that the openings in the modified plates are of long duct (s) and are therefore significantlyunrepresentative of the flow conditions of the other plate openings. Therefore, in most of the testing scenarios, a good agreement has been achieved in the measurement of Q_4 using PULSE-80 and DBB. It is also seen that PULSE-80 has closer agreement with the non-standard DBB than the standard approach. This may suggest that the extrapolation error with the Q_4 obtained from the standard DBB could be responsible for this greater difference when compared to the PULSE-80 and non-standard DBB results.

Using the results of the tests described above and assuming all openings being sharp edged with a discharge coefficientof 0.61, the geometric area of each test plate was calculated by using eq.(1).

$$GA = V\sqrt{\rho / 2P} / 0.61 \tag{1}$$

Where GA stands for the geometric area of the opening (m^2), V is the air leakage rate (m^3/s), ρ is the air density (kg/m^3), and P is the building pressure (Pa).Table 5 shows the geometric areas of the openings from plate 2 to plate 8 measured by PULSE-80 and DBB with the relative percentage difference of them to the actual measured areas givenin Table 2. The GA of the opening in plate 3, 5 and 6 measured by both methods differs from the manuallymeasured one by from 0.38% to 7.63%.For the plate 4, 7 and 8, the percentage difference is much larger. This could be caused by the fact that plate 8 has an angled opening and that plate 4 and 7 have six long slots fabricated with uneven edges and finishes, both of which are difficult to quantify accurately.This could contribute to the difference between the manually measured GA and the actual one. However, both methods have shown similar percentage difference from the manually measured GA. The assumed discharge coefficient

0.61 is for sharp edged orifice and hence not applicable for some of the openings, especially plate 8.This calculation of GA should only be treated asan approximation.

Table 5 Comparison of Q_{50} predicted by the pulse test using various methods

Plate ID	1	2	3	4	5	6	7	8
Measured GA (m^2)	0	0.0318	0.0315	0.0230	0.0308	0.0307	0.0329	0.0381
GA by PULSE-80 (m^2)	N/A	N/A	0.0314	0.0265	0.0316	0.0325	0.0365	0.0201
RPD (%)	N/A	N/A	-0.38%	15.09%	2.65%	6.04%	10.99%	-47.30%
GA by DBB (Standard) (m^2)	N/A	0.031	0.032	0.027	0.032	0.033	0.040	0.022
RPD (%)	N/A	-2.55%	1.65%	17.39%	3.93%	7.63%	21.69%	-42.32%

GA: geometric area of the openings in test plates, as listed in Table 2.**RPD**: the relative percentage difference of GA measured by PULSE-80 or DBB to the manually measured GA.**N/A** means either the test is not carried out due to time constraint or not applicable.

Although the pulse test is designed to resolve the issues existing in the measurement of building air leakage at low pressures, it is frequently asked howit is compared with the blower door test at 50Pa. The flow regimes at low pressure and high pressure levels are hydraulically dissimilar and therefore significant errors will occurin the prediction of air leakage rate from one level to theother. One of the issues with extrapolating a low pressure reading to a high pressure level is the absence of a higher data point, whereas an extrapolation downwards (as with the DBB tests) at least has the presence of the origin at the lowest point.Nevertheless, Q_{50} is predicted by using the pulse test datain various ways and compared with the DBB test,aslisted in Table 6.

Table 6 Comparison of Q_{50}predicted by the pulse test using various methods against Q_{50} (standard method by DBB)

Plate	1	2	3	4	5	6	7	8	9	10	11
n	0.627	0.588	0.583	0.606	0.582	0.576	0.578	0.595	0.576	0.548	0.631
(DBB)Q_{50}	2.45	5.45	5.56	5.08	5.54	5.7	6.37	4.56	6.45	3.17	2.80
(Pulse) Q_{50} (n)	2.49	N/A	5.97	5.73	5.96	6.00	6.50	4.76	5.91	2.83	3.54
RPD (%)	1.6%	N/A	7.4%	12.8%	7.6%	5.3%	2.0%	4.4%	-8.4%	-11%	26%
(Pulse) Q_{50} (0.66)	2.70	N/A	7.26	6.57	7.26	7.42	8.00	5.62	7.31	3.76	3.82
RPD (%)	10.2%	N/A	30.6%	29.3%	31.0%	30.2%	25.6%	23.2%	13.3%	18.6%	36.4%
(Pulse) Q_{50} (Qua)	7.88	N/A	3.85	4.13	8.39	5.67	6.08	5.56	6.50	5.27	2.70
RPD (%)	222%	N/A	-31%	-19%	51%	-0.5%	-4.6%	21.9%	0.8%	66.2%	-3.6%
(Pulse) Q_{50} (Pow)	6.18	N/A	3.10	3.75	5.05	4.25	5.75	7.35	2.89	6.37	2.56
RPD (%)	152%	N/A	-44%	-26%	-8.8%	-25%	-9.7%	61%	-55%	101%	-8.6%

RPD (%): relative percentage difference of Q_{50} predicted by using various methods using the Q_4 measured by PULSE-80 against the **(DBB)Q_{50}**measurement. **(Pulse)Q_{50}(n)** stands for the air permeability at 50 Pa predicted by the pulse test using the pressure exponent n given by DBB test. **(Pulse)Q_{50}(0.66)** stands for the air permeability at 50 Pa predicted by the pulse test using the empirical n value(Orme 1994).**(Pulse)Q_{50}(Qua)** stands for the predicted air permeability at 50 Pa using quadratic equation based on the pulse test. **(Pulse)Q_{50}(Pow)** stands for the predicted air permeability at 50 Pa using power law equation based on the pulse test.

Compared with the Q_{50} measured by the DBB in the Standard tests, the percentage difference of Q_{50} predicted by PULSE-80 lies in 1.6%-26%, 10.2%-36.4%, 0.5%-222% and 8.6%-152% when ‘n’ value measured by DBB,the empirical n value 0.66, quadratic equation based on the pulse test and power law equation based on the pulse test is used, respectively.The best prediction is the one using the n value measured by DBB, which gives predictions of Q_{50} within 13% difference excluding plate 11. However, this wouldn’t fit the practical purpose becausea DBB test wouldn’t be available when a pulse test is carried out as an alternative. For the predictions using the empirical n value obtained by Orme (Orme 1994), the percentage difference generally lies in the range of 20%-40%. It indicates the empirical n value is not representative of that of most testing scenarios. This could also be explained roughly by the fact the test environmental chamber is a single cell enclosure without the adventitious openings that are present in typical dwellings.For the predictions using either quadratic or power law equation based on the pulse test, there is lack of accuracy in most predictions although for a few reasonable accuracy is seen. Therefore, similar with the findings reported by Cooper and Zheng (Cooper 2016) the low pressure pulse test doesn't always provide accurate indication of Q_{50}. The measurement needs to be made over a wider pressure range in order to reduce the error in extrapolation if Q_{50} is calculated using the pulse test.

3. 2. Observations and discussions

In addition to the above comparison testing, there are a number of notable observations from the testing, which are worthy of discussion. Firstly it is interesting to observe that Q_4 of tests 9 and 11 measured by PULSE-80 and DBB don't agree with each other well. The similarity of the arrangement of both tests is the use of an extended opening; test 9 the addition of a single duct and test 11a collection of tightly packed of straws.

For a well-developed flow in a steady test, the discharge coefficient of the openings changes when they are extended. In a pulse test, the air flow through the extended openings occurs in a short time and might behave in a different way to that of a steady state test. This may explain why the measurements by the two methods are different in this case.It is therefore considered that further investigative work needs to be performed to not only understand the difference between the airflow through an extended opening produced by a DBB and a pulse test but also how these flows relate to that of natural building infiltration. Future work, will also report on other findings, such as the impact ofthe location of pulse unit in relation to internal barriers, artificial cross wind outside the opening and vibration effects upon the pulse test readings.

Observations were also made in regards to the practical aspects of both the PULSE-80 and the DBB. Due tothe fact the weight ofPULSE-80 used in this study is 40.4kg, setup of the pulse unit in the chamber relied on two people lifting between different levels, while the DBBshowed a big advantage in the portability due to smaller weight, 19.2 kg. This advantage would be weakened when a model of blower door with larger capacity is needed, such as Minneapolis blower door model 4 with a 25 kg door fan. It must also be noted however that the PULSE-80 unit is a prototype system and in fact in terms of capacity is much larger than that which would be required for testing an enclosure of this size and airtightness. Hence it could be considered that in future testing, smaller units of reduced size and weight would be available.

The PULSE-80 did not require any complex assembly on site apart from the connection of control plugs and therefore it isseen to be quick and efficient in terms of setup, implementation and disassembly. However, as discussed above the PULSE-80 in terms of stored air capacity was much larger than required for the testing and therefore extra time was required to adjust tank pressure prior to testing. This adjustment required computer based data analysis to ensure a suitable ΔP was being achieved. This finding of 'required adjustment' has subsequently been used to direct the development of PULSE, whereby the LCD screen now incorporates achieved pressure difference and the unit is able to perform a step process of 3 separate tests using different starting tank pressures. Hence this ensures that the correct range ofΔP can be captured without the need for post-test analysis.

4. CONCLUSION

The experimental study, usingPULSE-80 and DBBto measure the airtightness of a house size chamber in a controlled condition, has allowed us to compare two methods from a different perspective.For 9 out of 11 plates, the pulse tests using PULSE-80 and the Non-standard DBB tests have given Q_4 that are in close agreement, with a percentage difference ranging in 0%-6.2%, whereas the Standard DBB tests have given a percentage difference up to 12.7%. This maysuggest that extrapolationerrorin Standard DBB test may be contributing to the greater deviation.The tests of plates with extended openings did not provide good agreement and further investigation on the flow dynamics of the air flow through extended opening under two testing methods is required. This study has also led to a question on howthese two particular test units compare in a real life scenario, i.e. uncontrolled environment.It was previously reported by Cooper and Zheng (Cooper 2016) that it is unreliable for both methods to make extrapolationsbetween low pressure and high pressure, which was based on the tests done in a number of dwellings usingMinneapolis blower door model 4. Following this comparison study in a controlled environment, continued comparison study in an external chamber using the same units has been carried out and will be reported in future.

5. REFERENCES

Cooper EW, Etheridge DW (2007). Determining the adventitious leakage of buildings at low pressure. Part 1: uncertainties. Building Serv. Eng. Res. Technol. 2007; 28: 71-80.

Cooper EW, Etheridge DW. (2007). Determining the adventitious leakage of buildings at low pressure. Part 2: pulse technique. Building Serv. Eng. Res. Technol; 28: 81-96.

Cooper E., Zheng X.F., Gillot M., Riffat S., Zu Y.Q.(2014). A nozzle pulse pressurisation technique for measurement of building leakage at low pressure. *35th AIVC Conference* “*Ventilation and airtightness in transforming the building stock to high performance*”, Poznan, Poland, 24-25 September 2014.

Cooper E., Zheng X.F., Wood C., Gillott M., Tetlow D., Riffat. S, Simon L. (2016) . Field trialling of a new airtightness tester in a range of UK homes. *International Journal of Ventilation*.http://dx.doi.org/10.1080/14733315.2016.1252155

Zero Carbon Hub (2014). Closing the gap between design and as-built performance: End of term report, July 2014. Available from:http://www.zerocarbonhub.org/sites/default/files/resources/reports/Design_vs_As_Built_Performance_Gap_End_of_Term_Report_0.pdf

Sherman M.H. and Matson N.E., 2002. “Air Tightness of New U.S. Houses: A Preliminary Report”, Lawrence Berkeley National Laboratory, LBNL 48671. LawrenceBerkeley National Laboratory, Berkeley, CA.

Sherman M.H. and Dickerhoff D.,1994 “Air-Tightness of U.S. Dwellings” In Proceedings, 15th AIVC Conference: The Role of Ventilation, Vol. 1, Coventry, Great Britain: *Air Infiltration and Ventilation Centre*, pp. 225-234. (LBNL-35700).

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

Remi C.F., Leprince V, 2016. Uncertainties in building pressurisation tests due to steady wind. Energy and Buildings. Vol.116, 15th March 2016, pp 656-665.

Orme M., Liddament M. and Wilson A., 1994 "An Analysis and Data Summary of the AIVC's Numerical Database”, Technical Note 44, Air Infiltration and Ventilation Centre, Coventry, 1994.