Field trialling of a new airtightness tester in a range of UK homes

Edward Cooper*[1], Xiaofeng Zheng[1], Christopher Wood[1], Mark Gillot[1], David Tetlow[1], Saffa Riffat[1] and Lia De Simon[1]

[1] *Architecture, Climate and Environment Research Group, Faculty of Engineering, University of Nottingham, University Park, Nottingham NG7 2RD, UK*
**Corresponding author: edward.cooper@nottingham.ac.uk*

ABSTRACT

A new low pressure 'quasi-steady' pulse technique for determining the airtightness of buildings has been developed further and compared with the standard blower-door technique for field-testing a range of typical UK homes. The reported low pressure air pulse unit (APU) has gone through several development stages related to optimizing the algorithm, pressure reference and system construction. The technique, which is compact, portable and easy to use, has been tested alongside the standard blower-door technique to measure the airtightness of a range of typical UK home types. Representative of the UK housing stock, the homes mostly have low levels of airtightness, resulting in poor energy performance, poor indoor air quality and poor thermal comfort. Some of these homes have been targeted for retrofitting and a quick, low cost and simple method for accurately determining their airtightness has clear advantages for correctly predicting the benefits of any improvements. A comparison between the results given by the two techniques is presented and the field trials indicate that the latest version of the pulse technique is reliable for determining building leakage at low pressure. Repeatability of multiple APU tests in the same house is found to be within +/-5% of the mean. A test where the leakage is increased by a known amount shows the APU is able to measure the change more accurately than the blower-door test. The APU also gives convenience in practical applications, due to being more compact and portable, plus it doesn't need to penetrate the building envelope. The field trials demonstrate the pulse test has the potential to be a feasible alternative to the standard blower-door test.

KEYWORDS

Airtightness, Building leakage, Blower door, Pulse test, Steady pressurisation;

1. INTRODUCTION

The impact of infiltration as a consequence of poor airtightness can be considerable; research by Jones (Jones, 2015) predicts that unintended infiltration across the UK housing stock may be responsible for as much as 5% of total UK energy demand. However, the standard blower-door method used to measure airtightness is something of a compromise and concerns about this technique have led to numerous attempts to find alternative, more preferable, ways of determining building airtightness. A partial selection of these attempts include AC techniques by Sharples (Sharples, 1996), Siren (Siren, 1997), Sherman (Sherman, 1986), Watanabe (Watanabe, 1999), Nishioka (Nishioka, 2003) and Modera (Modera, 1989), gradual decay techniques by Granne (Granne, 2001) and Mattsson (Mattsson, 2007), acoustic techniques by Varshney (Varshney, 2013) and Card (Card, 1978), and pulse techniques by Carey (Carey, 2001), and Cooper (Cooper, 2004, 2007, 2007). However, to date, none of these attempts have led successfully to widespread use by the airtightness testing industry.

The focus of this paper is the further development and field trialling of a low pressure pulse technique, described in a previous paper by Cooper (Cooper, 2014), referred to herein as the Air Pulse Unit (APU). Its historical development comprises of three versions, namely a gravity driven piston, a compressed air driven piston and most recently a nozzle unit. The latest nozzle test unit has recently been through several developmental stages related to optimizing the algorithm, pressure reference and system construction. It has been simplified from a bulky and heavy unit into a more compact, portable and quick-to-use version.

For validation purposes, the APU has been used to measure the airtightness of a range of UK houses, as shown in Figure 1. They are listed in the format of House Number-House type. The key parameters of the test houses are listed in Table 1.

Figure 1 Test houses (D: detached; SD: semi-detached; ET: end-terraced; MT: Mid-terrace)

Table 1: Key parameters of the test houses

House Number	Volume (m^3)	Age (years)	Position	Construction type
1	157	>100	End-terrace	Solid wall
2	196	>100	Mid-terrace	Solid wall
3	196	10-100	Semi-detached	Cavity wall
4	213	10-100	Semi-detached	Cavity wall
5	203	10-100	Semi-detached	Cavity wall
6	230	10-100	Detached	Cavity wall
7	447	10-100	Detached	Cavity wall
8	343	<10	Detached	Modern SIP
9	157	10-100	Semi-detached	Solid wall
10	371	>100	Semi-detached	Solid wall

The homes are representative of those commonly found in the UK housing stock; most have low levels of airtightness, resulting in poor energy performance, poor indoor air quality and poor thermal comfort. Five of the test homes (No 1-5) have been identified for retrofitting as part of the EU FP7 Holistic Energy Retrofit of Buildings (HERB) project and will be tested both pre and post-retrofit, with only the pre-retrofit tests reported here. A quick, low cost and simple method for accurately determining their airtightness has clear advantages for correctly predicting the benefits of any improvements.

2. METHODOLOGY

For purposes of comparison, all the houses were tested with both the APU device and the standard blower-door technique under the same conditions, with additional thermography carried in houses 1 to 5 for identifying the nature of leakage pathways.

Prior to the testing of both techniques, all the houses were prepared according to the UK's Air Tightness Testing and Measurement Association's Technical Standard L1 (ATTMA TSL1) for measuring air permeability of building envelopes in dwellings (ATTMA, 2010).

The blower-door tests followed the guidelines set out in the above mentioned ATTMA TSL1 and the BS EN:13829 (BSI, 2001). As such, the results should be comparable with those carried out for demonstrating compliance with the UK Building Regulations. The tests were conducted with the fan mounted in a suitable doorway, as shown in Figure 2, and under both pressurisation and depressurisation.

The latest APU device used for the tests is shown in Figure 3. It works by releasing a known volume of air from a pressurised tank for a short period of time. This creates a pulse in the internal air pressure and generates an airflow rate through adventitious openings. A period of quasi-steady flow is established that gives a leakage characteristic at low pressure, which with minor adjustments can be used to determine the airtightness in the same way as the high pressure technique. Further details of the equipment, test procedure and proof of the pulse concept used for the APU can be found in previous papers (Cooper, 2007, 2014).

Figure 2: The blower-door

Figure 3: The latest Air Pulse Unit (APU)

3. RESULTS

3.1. Repeatability

For the APU device to be a valid alternative to the standard blower-door test it needs to demonstrate a good degree of repeatability within a given test space. Table 2 shows the results of 18 such tests conducted in house No. 8. The relationship between pressure difference and leakage rate is represented in the table by a standardised leakage rate at 4 Pa, or V_4. The value is obtained by a curve fit to data obtained directly at the low pressures typically experienced under natural conditions. The repeatability is good, with a most of the tests falling comfortably within +/-5% of the mean V_4. If required, the repeatability could be improved further, simply by using a larger tank.

Table 2: V_4 (m^3/s) of 18 repeated test runs in house No. 8

Test ID	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**AVE**
V_4	0.1166	0.1189	0.1219	0.1199	0.1182	0.1182	0.1241	0.1241	0.1148	
RPD	-2.94%	-1.01%	1.47%	-0.16%	-1.55%	-1.60%	3.37%	3.34%	-4.39%	
Test ID	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	0.1201
V_4	0.1232	0.1207	0.1231	0.1194	0.1160	0.1157	0.1252	0.1194	0.1227	
RPD	2.59%	0.48%	2.47%	-0.62%	-3.44%	-3.68%	4.21%	-0.62%	2.18%	

NOTE: AVE and RPD stand for 'mean average' and 'relative percentage difference from mean' respectively.

The graph in Figure 4 shows the internal pressure pulses generated for each of the 18 repeated test runs in house No. 8, after adjustment to still-air conditions. The method used for the adjustment, by accounting for changes in background pressure, is described in a previous paper (Cooper, 2007). The labels identify the quasi-steady period used for analysis and the closing point of the pressurised tank valve. Interestingly, it can be seen there is considerable variation in the valve closing time for these tests, however, this part of the pulse is not used for analysis and, importantly, has no impact on the quasi-steady period, which shows good repeatability. On investigation, the variation in these tests was identified as a faulty power supply, which was replaced and subsequent tests show good repeatability for the closing point.

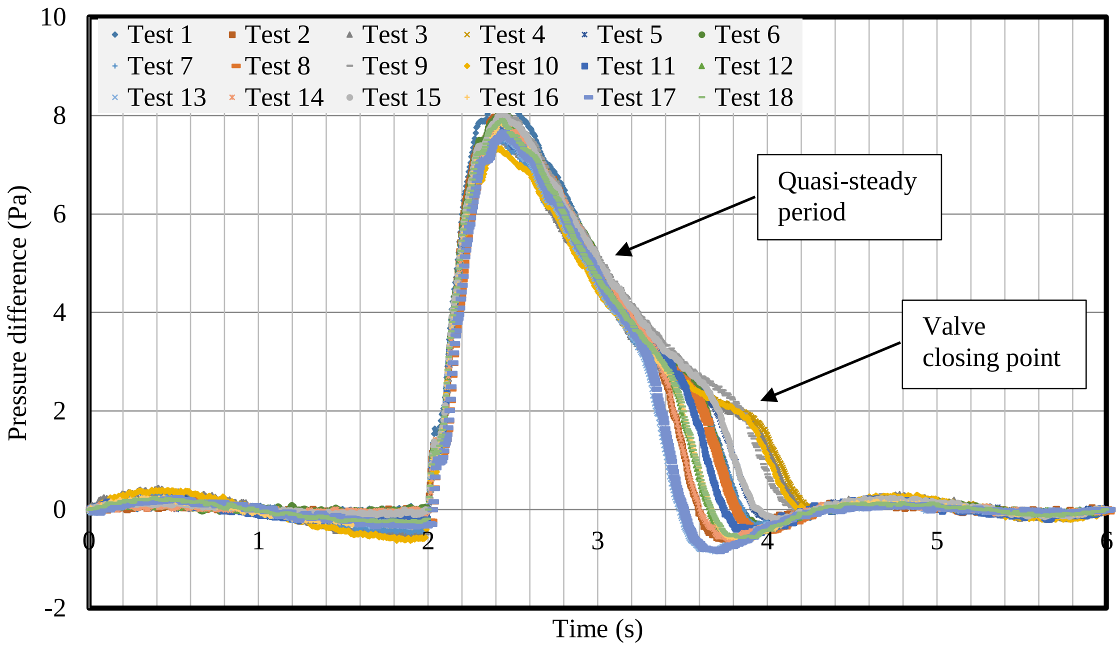

Figure 4: Adjusted internal pressure pulses from 18 repeated test runs in house No.8

3.2. Comparison between the blower-door and APU for measuring permeability

The blower door measures the leakage characteristic in a high pressure range (e.g. 10-60 Pa) and the leakage is typically presented at 50 Pa, whilst the APU measures it in a low pressure range (e.g. 1-20 Pa) and presents the leakage rate at 4 Pa. In order to make a direct comparison at the same pressure level, either at high or low level, either one or the other has to be extrapolated and uncertainties are introduced to the results as a consequence. In this report, considering that 4 Pa is typical of the pressure difference experienced by buildings under natural conditions, the test results are compared as an air permeability at 4 Pa, known as Q_4.

The power law equation is widely used for the blower door test to mathematically represent the relationship between pressure difference and leakage rate.

$$V = C\Delta P^{n} \tag{1}$$

Where, V is the leakage rate (m^3/s), C is an air leakage coefficient, ΔP is the pressure difference (Pa) and n is a pressure exponent. In order to predict the air leakage rate at 4 Pa from the blower-door test, Eq.(1) can be used to extrapolate down from higher pressures. In practice, the two techniques should not be expected to agree perfectly, due to the uncertainties in extrapolation, but they should be expected follow the same trends from house to house.

In Figure 5, the permeability at 4 Pa predicted by the blower-door, $Q_4(BD)$, is compared with the permeability measured directly at 4 Pa by the APU, $Q_4(Pulse)$. The comparison shows they follow a similar pattern and interestingly the APU gives lower Q_4 values than the blower-door in 9 out of 10 houses. The exception is house No.2, where the APU gives a higher Q_4 than the blower-door. However, during the blower-door tests in this house, it was noticed that the upper part of a loosely installed plasterboard panel, shown in Figure 6, opened when the blower-door depressurised the building, but not when it was pressurised (the mode also used by the APU). The thermographic image on the right side of Figure 6 shows the gap during depressurisation; the cool air being drawn into the building through the gap can be seen clearly by the plume surrounding the opening. The higher the pressure difference, the bigger the opening becomes and consequently the higher the leakage rate. Perhaps counterintuitively, this actually leads to a lower $Q_4(BD)$ for the depressurisation than pressurisation, due to the lower gradient of the relationship between leakage and pressure, as illustrated in Figure 7. In this graph, the annotated line represents the power law curve fit between the building leakage rate and pressure difference across the envelope if the position of the plasterboard were not affected by the induced depressurisation. It can be seen to make a significant difference at low pressure. In practice, the effect is reduced by using an average of the pressurisation and depressurisation results, but the impact would still be enough to explain the difference in the trend between house No.2 and the other houses.

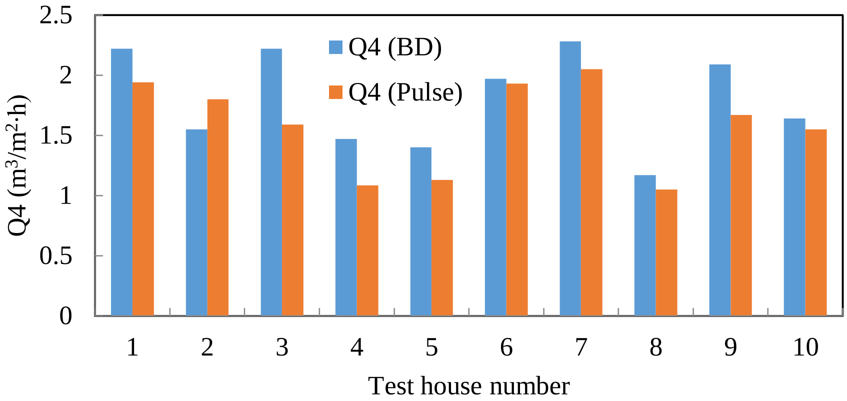

Figure 5: The permeability @4Pa, Q_4, predicted by the blower-door (BD) and measured by the APU (Pulse).

Figure 6: Photograph and thermographic image of a loosely installed plasterboard panel in house No. 2.

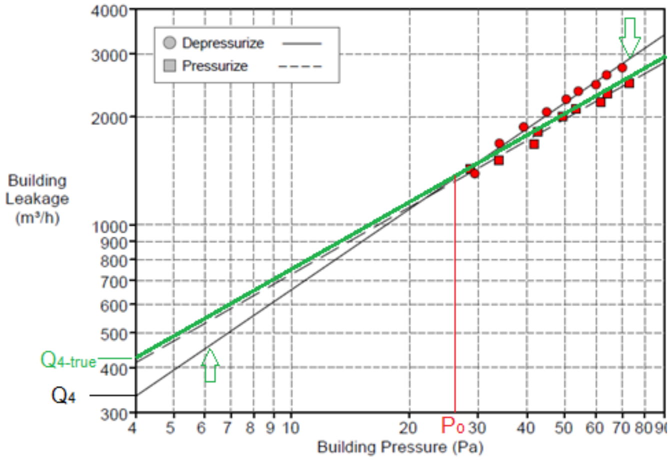

Figure 7: Logarithmic plot of blower-door test result for house No.2

3.3. Known opening test for accuracy

A full explanation for why the APU consistently gives a lower permeability than the blower-door is beyond the scope of this paper, however a simple check to see which technique is more accurate at measuring an added known opening can be made.

A short sharp-edged circular orifice with a diameter of 100mm was added into a window in house No.8, as shown in Figure 8. Assuming an appropriate discharge coefficient of 0.61 therefore gives an effective leakage area of 4.7909×10^{-3} m^2. Tests were conducted for both techniques with and without the added opening. The increase in leakage rate measured for both techniques was then converted to an effective leakage area and compared to the known opening, as shown in Table 3. It can be seen that the measurement made by the APU is much closer to the known effective area than the blower door measurement in this case. Other similar tests have been conducted with the same conclusion being drawn each time.

Figure 8: Setup of the known opening in house No. 8

Table 3: Results of known opening tests using the blower door and APU

Method	Measured area of the opening, m^2	Percentage difference from the actual known opening of 4.791×10^{-3} m^2
Blower door (@ 50 Pa)	5.9264×10^{-3}	23.7%
Blower door (@ 4 Pa)	6.0913×10^{-3}	27.1%
APU (@ 4 Pa)	5.0349×10^{-3}	5.1%

4. CONCLUSIONS

The low pressure air pulse unit (APU) has been through several development stages related to optimizing the algorithm, pressure reference and system construction. The technique was tested alongside the standard blower-door technique to measure the airtightness of a range of typical UK home types. A comparison between the results given by the two techniques was conducted and the field trials indicated that the latest version of the pulse technique is reliable for determining building leakage at low pressure. Repeatability of multiple APU tests in the same house was found to be within +/-5% of the mean. A test where the leakage was increased by a known amount showed the APU was able to measure the change more accurately than the blower-door test. The APU also gives convenience in practical applications, due to being more compact and portable, plus it doesn't need to penetrate the building envelope. The field trials demonstrated the pulse test has the potential to be a feasible alternative to the standard blower-door test.

ACKNOWLEDGEMENTS

The work reported in the paper relates to the InnovateUK 'Scaling up retrofit - Development of a novel low pressure technique for measuring the air tightness of buildings', EU FP7 'HERB' and EU Horizon2020 'Built2Spec' funded projects; the authors wish to thank all involved parties.

REFERENCES

ATTMA (2010). *Technical Standard L1. Measuring Air Permeability of Building Envelopes (Dwellings)*. Air Tightness Testing and Measurement Association. October 2010 Issue.

BSI, (2001). *Thermal performance of buildings - determination of air permeability of buildings - fan pressurization method*, British Standards Institution, London, UK, 2001.

Card W.H., Sallman A., Graham R.W., and Drucker E.E. (1978). Air leakage measurement of buildings by an infrasonic method, *Department of Electrical Engineering, Syracuse University, Tech. Rep. TR-78-1*.

Carey PS, Etheridge DW (2001). Leakage measurements using unsteady techniques with particular reference to large buildings. *Building Serv. Eng. Res. Technol. 2001; 22:* 69-82.

Cooper EW, Etheridge DW (2004). Measurement of building leakage by unsteady pressurisation. *25th AIVC Conference*, Prague, 2004.

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. 2007; 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, Poznan, September 2014*.

Granne, F. (2001). Air and Water Tightness in Building Envelopes – Evaluation of Methods for Quality Assurance, *Report R-01/187-SE, Stockholm, KTH*.

Jones B. et al (2015). Assessing uncertainty in housing stock infiltration rates and associated heat loss: English and UK case studies. *Building and Environment 92 (2015)* pp. 644-656.

Mattsson, B. (2007). A transient pressurisation method for measurements of airtightness. *Journal of Building Physics, Vol. 31, No.1*.

Modera M.P. and Sherman M.H. (1983). A detailed examination of the LBL infiltration model using the Mobile Infiltration Test Unit, *ASHRAE Trans. 89 (2B),* 157-179 (1983).

Nishioka T., Chen Q., Arai N., Fujiwara K., Umemiya N. and Okura R. (2003). Unsteady pressurization method to measure the airtightness of the building envelope. *Research in building physics international conference; 2nd, Building physics; Research in building physics; September 14-18, 2003.* pp 771-776.

Sharples S. and Thompson D. (1996). Experimental Study of Crack Flow with Varying Pressure Differentials. In Proceedings: *Optimum Ventilation and Air Flow Control in Buildings, 17th Air Infiltration and Ventilation Centre Conference, Gothenburg, Sweden, September 17-20, 1996*, pp. 243-253.

Sherman M.(1987). Estimation of infiltration from leakage and climate indicators. *Energy and Buildings, 10 (1987)* pp.81-86.

Sherman M.H. and Modera M.P. (1986). Low Frequency Measurement of the Leakage in Enclosures, *Review of Scientific Instruments*, *Vol. 57 (7), 1986*, pp. 1427-1430.

Siren K. (1997). A Modification of the Power Law Equation to Account for Large-Scale Wind Turbulence. In Proceedings: *Ventilation and Cooling*, *18th Air Infiltration and Ventilation Centre Conference, Athens, Greece, September 23-26, 1997*, pp. 557-561.

Varshney K., Rosa J.E., Shapiro I. (2013). Scott D . Air-infiltration Measurements in Buildings using Sound Transmission Loss through Small Apertures. *International Journal of Green Energy*, *10:5,* pp.482-493.

Watanabe Y., Kobayashi H., Utsumi Y (1999). Development of validation of AC-pressurization measuring of leakage area of houses. In proceedings: *Building Simulation '99, Sixth International IBPSA Conference, Kyoto, Japan. September 13-15, 1999*. pp. 807-814.