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BRE Test Report

Pulse vs Blower Door comparison airtightness chamber testing - Build Test Solutions Ltd

Prepared for: Build Test Solutions Ltd

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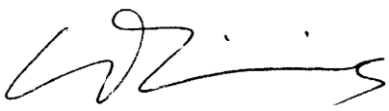

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1 Introduction

At the request of Luke Smith, Build Test Solutions Ltd, 16 St Johns Business Park, Lutterworth LE17 4HB, BRE issued proposal number P112784 on 6th July 2018. The proposal was accepted on 23rd July 2018.

The purpose of this project was to compare the test outcomes using a new measurement system (PULSE Air Test) against the industry standard method for measuring building airtightness in residential buildings (ATTMA TSL1).

Testing was proposed to be undertaken in BRE's laboratory on two chambers of differing air leakage to provide controlled-conditions to assess the repeatability of the PULSE Air Test system (PULSE) and to compare the results with testing carried out in accordance with ATTMA TSL1.

The tests on the chambers using the PULSE were carried out by Luke Smith, Adam Moring and Stephen Jackson of Build Test Solutions (BTS). The PULSE testing was witnessed by Simon Feeley (ATTMA registered Level 2 Airtightness Engineer), the comparative testing using the blower door was carried out by Adam Moring in accordance with ATTMA TSL1.

The work detailed in this report was conducted under the Building Research Establishments Standard Terms and Conditions of Business with reference to BRE project number P112784-1001 as an extension to the work.

2 Test Programme

The following test programme was provided by the client, for the purpose of the project.

BRE Chamber Testing

31st July 2018 and 26th October 2018

Testing Objectives (31st July 2018)

Testing in BRE's laboratory will provide controlled-conditions testing to verify the repeatability and reliability of the Pulse test. This will be achieved by the following:

1. Direct comparison with the verified blower-door test, testing at similar pressures should give the same results in control conditions
2. Extensive repeatability testing by comparison of repeat tests in the same condition, and with different varieties of the Pulse technology, with differing tank sizes and starting tank pressures.
3. Further testing of the Pulse technology positioned in varying locations within the same test environment, with the pressure sensor in different locations as well as the whole unit in different locations with varying degrees of air flow obstruction.

The following method statement outlines the 3 primary areas of testing to be carried out.

A - High Pressure Range Pulse vs Low Pressure Range Blower Door

Objective/Description

Further verify Pulse leakage measurements against the Blower Door, by testing in the upper range of Pulse and the lower range of the Blower Door to allow for a cross-over of results ranges.

Methodology

It is possible to Pulse test at higher pressures, when in a small test chamber. Controlled conditions allow for the blower door to test at the bottom of its range, even as low as 4Pa. The Pulse and Blower Door will be used to test the smallest BRE chamber at various pressures and various leakages, by use of known-opening plates.

For each known-opening panel:

1. Test twice with the Pulse, 3-step test, with starting pressures of 6 and 10 bar, i.e. 4 tests per panel (2 tests at each starting tank pressure. The results can be processed to produce results for 1-15Pa where possible. This will initially be carried out with a Pulse-40, however a Pulse-60 or Pulse-20 can be used if it is found to be over- or under-pressurising.
2. Test with the Blower door to produce results from 4-50Pa for each panel. The blower door installation will need to be checked each time to ensure no additional leakage is caused by the installation of the panel. Any leakage points detected resulting from the panel will be sealed accordingly.

Test plan:

1. Set up test chamber with no opening in place, while setting up blower door [30mins]
2. Blower door test 4-50Pa [15mins], charging Pulse.
3. Pulse, 10bar, 3-step [3mins]
4. Pulse, 6 bar, 3-step, [5mins]

5. Change orifice while setting up blower door [5mins]
6. Repeat steps 2-5 for 8 openings [(15+3+5+5)x8=224mins]

Approximately 5 hours of testing with 20mins slack, depending on the size of Pulse tank used (24L much faster than 60L)

Personnel

AM to lead blower door testing, SMJ to lead Pulse testing. Ken UoN oversight e.g. known opening discussions.

Results output

1. Comparison of the leakage curves between the tests for each opening.
2. Comparison of results (Permeability, ELA) produced at various pressures for each opening and test.
3. Comparison of Pulse known-opening results with actual known-opening values.
4. Analysis of any correlation between 4Pa and 50Pa results when all openings are considered.

B - Pulse Repeatability Testing (26th October 2018)

Objective/Description

Inspect the Pulse's repeatability in "perfect" conditions. The large chamber can be used for repeat testing to verify the test's repeatability in stable conditions. This will include testing with various Pulse tank sizes, 24L, 40L and 60L. Further tests will also be carried out to assess the effects that moving the unit and its differential pressure sensor to different locations has on results.

Methodology

Pulse test the large chamber in a single configuration throughout. Carry out 5x 3-step tests with each tank size. If 3 tank sizes, 24L, 40L and 60L are used, 15 tests.

The chamber can also be tested with the blower door to low pressures for further comparison and as an additional data point in the "High Pressure Pulse vs Low Pressure Blower Door" testing.

If more data is advised, this testing could be repeated with a different configuration of the test chamber (e.g. with a one-third section sealed off).

Approximately 3hrs of testing, 6 hours if a separate configuration is used.Tests will also be run with the sensor in different locations within the testing volume. Pulse protocol is to always place the sensor lid as far away from the main tank as possible. With this in mind, 3 orientations will be used to test;

1. At ground level as far from the unit as possible (around 2.5 metres)
2. At ground level around 1 metre from the unit
3. As far from the unit as possible and elevated

Each of these arrangements is to be properly catalogued and photographic evidence taken, specifically;

1. The exact location of the main tank in reference to the room
2. The horizontal distance between the main tank and the lid plate
3. The vertical elevation of the lid plate from the floor

Approximately 1 hour 50 mins of testing with 10mins slack.

In order to assess the effect of unit positioning, further testing of the device in three different positions will be carried out. The lid plate will remain in the same position for consistency. As in our first objective,

recording the exact position of the instrumentation is key. There will be three tests from each location. The three locations used will be each a third of the way along the longest side of the rectangular floor.

Test plan:

1. Set up arrangement 1, recording the necessary location data [10mins]
2. Charging the tank and firing three tests in this configuration [30mins]
3. Setting up arrangement 2 while charging PULSE and firing three tests [30mins]
4. Setting up arrangement 3 while charging PULSE and firing three tests [30mins]

Approximately 1 hour 50 mins of testing with 10mins slack.

Lastly, in order to examine the effect of testing at different starting pressure on the PULSE result, repeat testing at 4 different starting pressures (roughly 10,8,6,4 BAR) will be carried out. These tests will be in the optimal central location.

Test plan:

1. Three tests at 10 BAR [30mins]
2. Three tests at 8 BAR [25mins]
3. Three tests at 6 BAR [20mins]
4. Three tests at 4 BAR [15mins]

Approximately 1 hour 40 mins of testing with 10mins slack.

Results Output

1. Circa 50 x test results in a steady chamber, allowing for analysis of repeatability and comparison between tank sizes, different start pressures and different unit locations.
2. Additional Pulse vs Blower Door Data

3 Test Equipment

All test equipment on the day was provided by Build Test Solutions and inspected by BRE. UKAS calibration certificates for all the blower door fan equipment, Pulse equipment sensors and supporting environmental condition sampling devices have also all been supplied and reviewed under the BRE's ISO 14034:2016 accredited Environmental Technology Verification (ETV) project.

Pulse 585 (60L) unit, ¾" air release valve

Pulse 398 (40L) unit, ½" air release valve (foreground)

Pulse 201 (20L) unit, ¼" air release valve. Aluminium tank not encased.

Energy Conservatory Duct Blaster and DG1000 gauge used for all chamber testing

Other equipment used included:

- Leica D110 laser distance measurer
- Testo 511 Absolute pressure meter
- Testo 110 Thermometer with thermistor type probe
- JDC Skywarch Eole 1 Anemometer

4 Test Chambers

Lab chamber testing was carried out across two separate days *(31.7.18 and 26.10.18)* and four different chamber configurations.

Test Chamber A' *(see figure 1, 2 and 3)* has an Envelope area of 39.98 m^2 and Volume 15.98 m^3 this was used to carry out the known opening testing on 31.7.18

Test Chamber B' *(see figure 4 and 5)* has an Envelope area of 310 m^2 and Volume 269 m^3 this was used to carry out 31.7.18 Pulse repeatability testing.

Test Chamber C' (see figure 6) is the ground floor divided proportion of chamber B, providing an Envelope are of 242 m^2 and Volume of 200 m^3. This was used to carry out further repeatability testing on 26.10.18.

Test Chamber D' (see figure 7) is the upper floor section of chamber B, providing an Envelope area of 135 m^2 and Volume of 106 m^3. This was also used to carry out further repeatability testing on 26.10.18 specifically the 20, 40 and 60L comparative Pulse unit testing.

Figure 1 Chamber A, 15.98 m3 volume. Timber panel construction, externally insulated

Figure 2 Chamber A – Blower Door set-up. To eradicate leakage around the door canvas and ensure like for like comparison, a ply board was used for mounting the fan in this chamber.

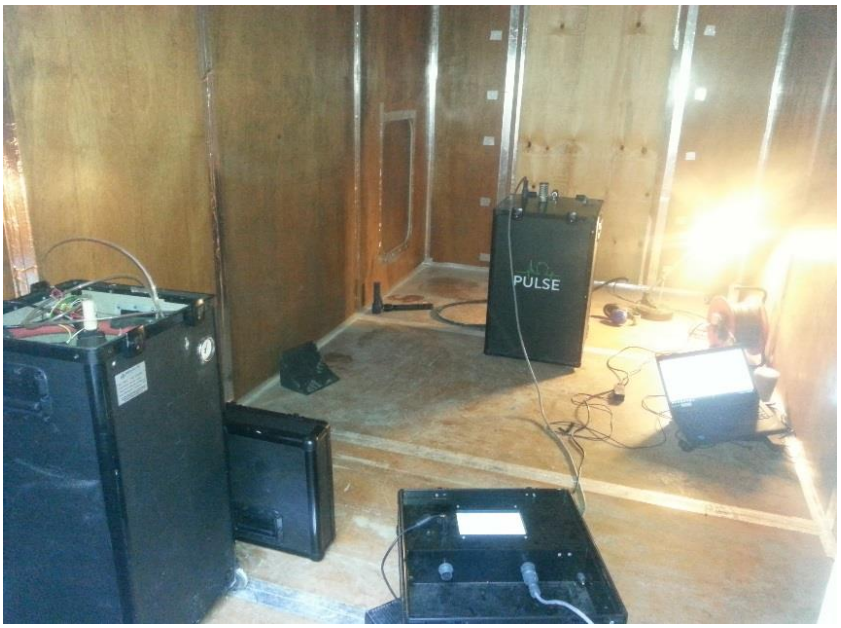


Figure 3 Chamber A – Pulse set-up inside chamber A (60L and 40L unit)

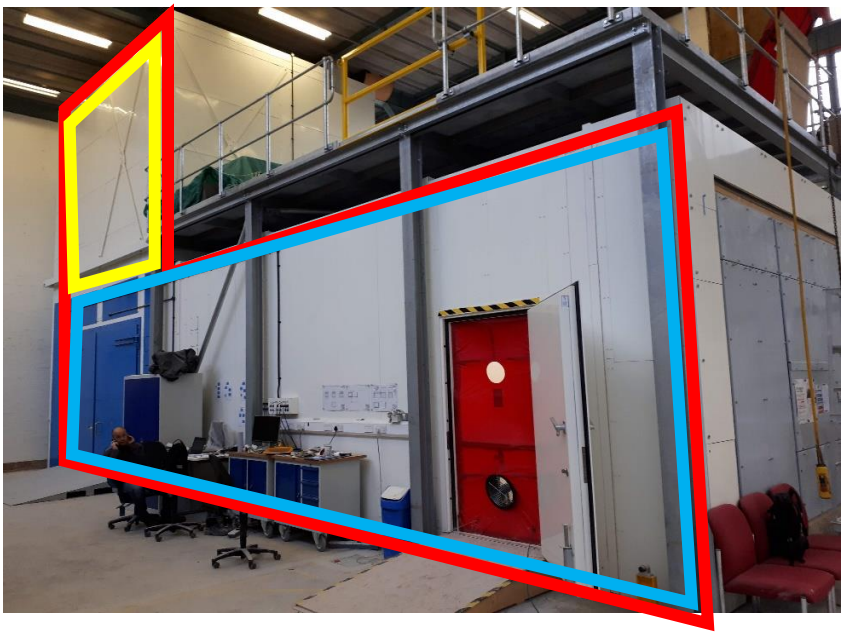


Figure 4 – External of B, C and D chamber. Red outline chamber B, blue outline chamber C and yellow outline chamber D. Solid cast concrete construction, removable timber floor cassette dividing chamber C and D.

Figure 5 Chamber B - 269 m³Volume. Pulse set-up

Figure 6 Chamber C –200 m³ Volume. Pulse set-up

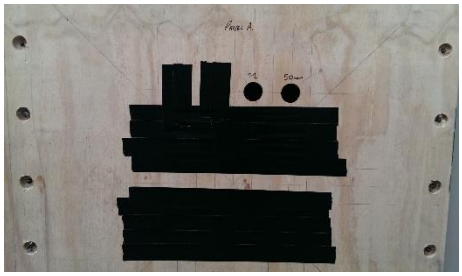
Figure 7 Chamber D – 106 m³ Volume. Pulse set-up

The envelope areas were calculated from supplied drawings and on-site measurements.

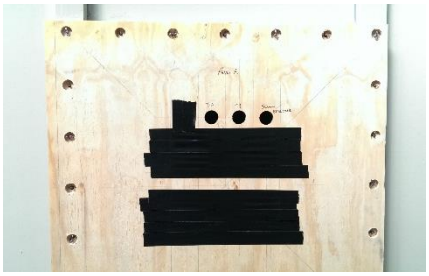
5 Test Known Opening Panels

The following known opening panels were cut by BRE from 12mm ply board and used on chamber A inorder to test the ability of the Pulse system to accurately measure effective leakage area.

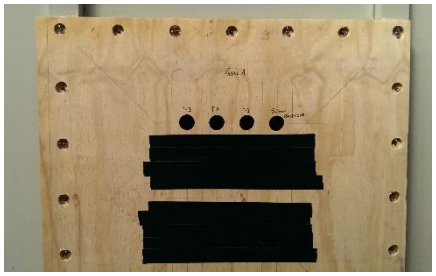
Panel A - Baseline



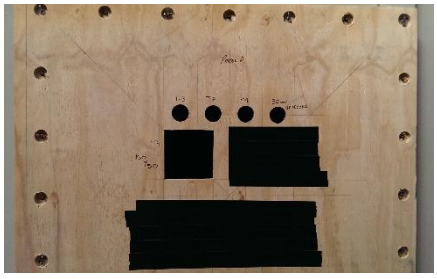
Panel A T1 – 2 x 50mm holes



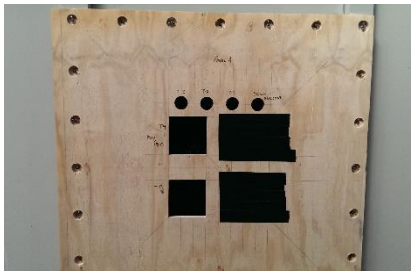
Panel A T2 – 3 x 50mm holes



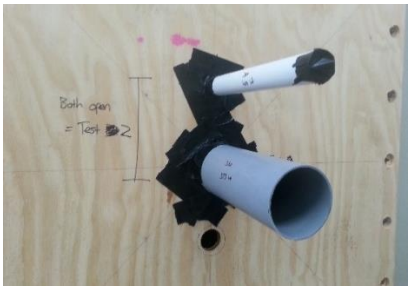
Panel A T3 – 4 x 50mm holes



Panel A T4 – 4 x 50mm holes plus 150mm square



Panel A T5 – 4 x 50mm holes plus 2 x 150mm square



Panel B T6 (White blocked grey open) and T7 (both open) – 1 x 50mm, 1 x 110mm pipes

Panel B T6 (White blocked grey open) and T7 (both open) – 1 x 50mm, 1 x 110mm pipes

Panel A opening are all short sharp-edge openings, similar to holes that might be found in construction material layers or in window frames.

Panel B seeks to represent square tubular pipe openings, similar to those found in service penetrations such as through the wall ventilation ducts or cable runs.

6 Summary of Test Results and Observations

All data processing and analysis was undertaken by BTS and supplied to BRE for further analysis and review.

Pulse has been developed to measure leakage at 4Pa because this value is citied within a range of ASHRAE and CIBSE standards as being a representative ambient background pressure level within occupied buildings i.e. the pressure level at which background exfiltration/infiltration occurs.

One of the primary objectives of the lab-based chamber testing therefore has been to evaluate 4Pa Pulse vs 50Pa Blower Door Fan the established industry practice and building regulations testing, over a range of tests where blower door test pressures and Pulse test pressures are made to overlap.

Pulse and blower door pressure reading crossover

Figure 1 below shows a set of test results taken in chamber 'A' highlighting the crossover in data collected from the pulse tests and blower door test (represented by the orange and blue lines respectively). The lowest crossover in data was compared at 10Pa where the difference in test result between the blower door and the pulse test is 8.8% and at the highest useable data crossover point at 18Pa the difference was 4.8%.

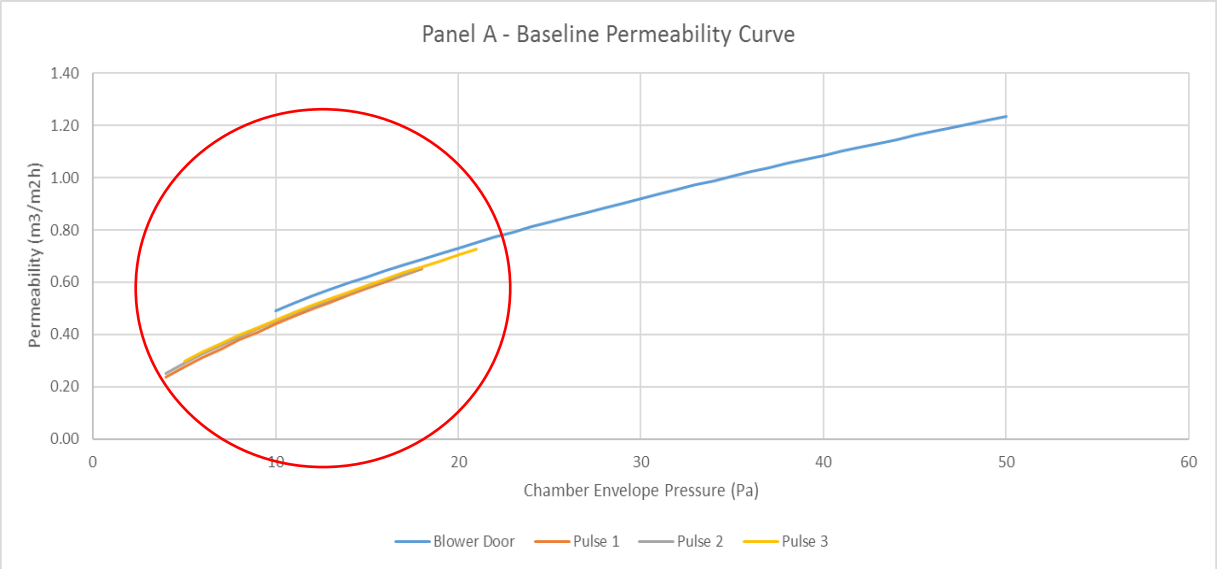


Figure 1 Chamber 'A' Panel A Baseline

A graph of the parameters; air volume flow rate through the chamber surface area (m^2) and differential pressure were plotted for all of the tests, all of which are presented within Annex A of this report.

Table 1 presents a comparison between the data supplied by BTS from Pulse and the Blower Door test carried out on the different plate configurations and presents the percentage difference in test outcome between the two methods at the highest and lowest cross-over points.

Panel Tested	Blower Door (m3/m2h @50Pa) Single pressure test	PULSE (m3/m2h @4Pa) Average of 3 tests	Correction Factor PULSE to 50Pa	Lowest data point crossover Pa	Highest data point crossover Pa	Difference between data in the overlap (%) Minimum	Maximum	Average
PA-BL	1.22	0.25	4.88	10	21	9.0%	15.5%	11.5%
PA-T1	2.24	0.53	4.23	5	23	2.5%	8.7%	5.0%
PA-T2	3.3	0.82	4.02	6	16	0.1%	7.7%	2.2%
PA-T3	4.39	1.13	3.89	7	20	0.0%	3.7%	1.2%
PA-T4	15.81	4.55	3.55	No crossover	No crossover	n/a	n/a	n/a
PA-T5	27.36	7.57	3.61	9	13	3.9%	12.6%	9.5%
PB-T6	6.6	1.91	3.46	16	16	7.4%	7.4%	7.4%
PB-T7	7.3	2.13	3.43	14	20	0.0%	6.9%	5.5%
					Minimum	0.0%	3.7%	1.2%
					Maximum	9.0%	15.5%	11.5%
					Average	3.3%	8.9%	6.0%

Table 1 Chamber 'A' pressure cross over measurements

Here, a test scenario has been created which takes both the blower door and Pulse test methods outside of their optimal operating windows but allows for results at equal test pressures to be directly compared.

The data presented in Table 1 demonstrates a maximum deviation between blower door and Pulse results of 15.5%. The average difference in overlap between the blower door and Pulse data is 6.0%.

The greatest difference seen between the two tests was with panel A baseline, which had the smallest geometric opening at 1,963mm^2 and panel A test 5 which had the largest introduced opening with an area of 52,854mm^2.

Based on the test data presented in Table 1 for both test methods, there does not appear to be a straightforward way to correct from the 4 Pa result to the standard air leakage rate at 50 Pa as currently required by Approved Document L1A to The Building Regulations. These results are however based upon testing of a small enclosure (15.98m^3) and it is recommended that a correction factor/method is sought from comparative testing across a large sample of property types in order for the Pulse system to be used to determine compliance with the requirements of Approved Document L1A.

Known-opening measurement

Known-opening panels into chamber 'A' were used to assess the accuracy of the Pulse test in directly measuring leakage areas. Here the geometric measured areas offered by the openings are corrected for a flow discharge coefficient and then compared against the effective leakage area (ELA) as measured by both the Pulse and blower door device.

Panel	Description	Geometric Area	Percentage of Envelope	Discharge coefficent
		mm^2	%	
PA - BL	Baseline - 1x 50mm hole	1,963	0.005%	0.61
PA - T1	2x 50mm holes	3,927	0.010%	0.61
PA - T2	3x 50mm holes	5,890	0.015%	0.61
PA - T3	4x 50mm holes	7,854	0.020%	0.61
PA - T4	4x 50mm holes plus 1x 150mm square	30,354	0.076%	0.61
PA - T5	4x 50mm holes plus 2x 150mm square	52,854	0.132%	0.61
PB - T6	1x 110mm pipe open	17,671	0.044%	0.5
PB - T7	1x 50mm pipe open	1,963	0.005%	0.5

Table 2 Chamber 'A' known openings

The Pulse device calculates and presents an ELA figure as part of its standard set of results whilst the calculation cited in Appendix C of ATTMA TS1 was used to calculate a blower door fan ELA for each test. All results are based on the use of the same aerodynamic discharge coefficients.

Panel Tested	Geometric Area (mm2)	Geometric Area (m2)	Discharge coefficient	Measured ELA (m2)		% Difference between actual and measured area		Difference between the accuracy of the PULSE and BDT
				PULSE @4Pa	BDT @50Pa	PULSE @4Pa	BDT @50Pa	
				Average of 3 tests	Single pressure test	Average of 3 tests	Single pressure test	
PA-BL	1,963	0.0020	0.61	0.0018	0.0020	10.5%	1.9%	-8.6%
PA-T1	3,927	0.0039	0.61	0.0038	0.0040	4.0%	1.9%	-2.1%
PA-T2	5,890	0.0059	0.61	0.0058	0.0070	1.7%	18.8%	17.2%
PA-T3	7,854	0.0079	0.61	0.0079	0.0090	0.7%	14.6%	13.9%
PA-T4	30,354	0.0304	0.61	0.0318	0.0320	4.9%	5.4%	0.5%
PA-T5	52,854	0.0529	0.61	0.0527	0.0550	0.2%	4.1%	3.8%
PB-T6	70,686	0.0707	0.50	0.0163	0.0159	76.9%	77.6%	0.6%
PB-T7	1,963	0.0020	0.50	0.0177	0.0183	801.5%	832.0%	30.6%
							Average	7.0%

Table 3 accuracy in measuring effective leakage area

Based on the test data presented in table 3, overall there is a 7% average difference between the two methods.

Neither method accurately measured the true geometric area of the two square edge tubular outlets, one with just a single 50mm outlet (PB-T7) and the other at 110mm (PB-T6). These specific observations are perhaps reflective of the discharge coefficients used for these specific penetrations or is more likely as a result of the surface resistance presented by the air within the tubes themselves. For such leakage paths, the measured effective leakage area would not be expected to be the same as the physical geometric area presented and the fact that both methods generally agree in their measurement of this is positive.

During the test programme in chamber 'A it was noted by BTS that when testing in a very airtight chamber the Pulse test over pressurised the chamber on numerous occasions and due to the sensitivity of the sensors this was giving a reverberation error in the results. The explanation provided by BTS was that they thought the sudden release of the Pulse was causing the walls of the chamber to vibrate which caused a reverberation such that a result could not be obtained.

One concern is that in practice, if the above situation was to arise during site testing there is not currently a robust solution to correct this.

Repeatability testing

Air Permeability Results					**Building Volume**	269	**Building Envelope:**	310	
Test Ref	**Test Time**	**Pulse Model**	**Pulse Valve**	**Pulse Start Pressure (Bar)**	**Pulse Result (4Pa)**	**Blower Door Result (50Pa Pressure)**	**Flow Coefficient C**	**Pressure Exponent n**	**Max Pressure Tested**	**Min Pressure Tested**
1	10:04	585	3/4"	9.65	0.99		89.1276	0.8909	10.18	0.96
2	10:10	585	3/4"	9.89	1.06		122.5094	0.7110	10.24	0.52
3	10:19	585	3/4"	9.75	1.09		120.3545	0.7422	9.97	0.51
4	10:25	585	3/4"	9.89	1.01		97.7592	0.8426	10.17	0.77
5	10:31	585	3/4"	9.96	1.03		107.3718	0.7859	10.37	0.67
6	10:37	585	3/4"	9.77	1.03		104.8338	0.8041	10.03	0.67
7	10:44	585	3/4"	9.93	1.06		110.4143	0.7852	10.14	0.63
8	10:49	585	3/4"	9.93	1.04		103.6398	0.8192	10.16	0.68
9	10:54	585	3/4"	9.81	1.04		107.1653	0.7917	9.81	0.63
10	11:00	585	3/4"	9.90	1.03		109.9087	0.7708	10.37	0.58
14	n/a					**6.08**	126.4008	0.6906	65.50	8.40
15	n/a					**6.18**	121.5468	0.7050	56.20	8.70

Table 4 Chamber 'B' Pulse 585 repeatability testing

Table 4 above presents the test results from chamber 'B' used to evaluate the Pulse's repeatability in a controlled environment e.g. without influence from environmental conditions such as wind. The data shows generally consistent test results with a mean result of 1.038 and a standard deviation of 0.0264 at 4 Pa, the maximum Relative Percentage Difference (RPD) was 4.7%.

Repeatability across different Pulse units and different tank starting pressures was then carried out on the second day of chamber testing in the smaller chamber 'D' that needed to be a size and leakiness to allow the full range of tank sizes and flow rates to be reliably tested and directly compared.

Air Permeability Results					Building Volume:			Building Envelope:		135					
Tank Size	Test Ref	Test Time	PULSE Model	PULSE Valve	PULSE Start Pressure (BAR)	Pulse Result (4Pa)	Blower Door Result (50Pa)	Flow Coefficient C	Pressure Exponent n	Max Pressure Tested	Min Pressure Tested	Average Permeability (4Pa)	RPD	Max RPD per location	RPD overall (4Pa)
60	1	13:51	585	3/4"	9.72	1.25		0.0161	0.773	6.4	1.4	1.22	2.3%	2.6%	1.4%
	2	14:02	585	3/4"	9.79	1.19		0.0145	0.813	22.5	1.7		2.6%		6.1%
	3	14:13	585	3/4"	9.84	1.23		0.0157	0.777	6.6	1.6		0.3%		3.4%
40	1	12:19	398	1/2"	9.83	1.28		0.0155	0.815	10.2	2.9	1.31	2.2%	4.7%	0.5%
	2	12:27	398	1/2"	9.81	1.37		0.0178	0.765	9.9	2.6		4.7%		7.6%
	3	12:49	398	1/2"	9.73	1.27		0.0143	0.872	10.0	1.5		2.5%		0.2%
20	1	13:20	201	1/4"	9.98	1.26		0.0189	0.659	2.7	2.3	1.28	1.9%	8.5%	1.0%
	2	13:28	201	1/4"	10.00	1.20		0.0179	0.664	1.2	0.4		6.6%		5.8%
	3	13:31	201	1/4"	9.97	1.39		0.0179	0.770	2.6	1.0		8.5%		9.4%
n/a	n/a						**8.21**								
n/a	n/a						**9.14**								
					Average	1.27								Max RPD	9.4%
					STDev	0.0648									

Table 5 Chamber 'D' Pulse 585, 398 and 201 repeatability testing

The above table 5 presents the air leakage results derived from three successive tests from three different Pulse units, each with a different size vessel (58.5L, 39.8L and 20.1L) and each with a different valve providing a different orifice and delivered flow rate.

The 20.1L unit is a prototype unit under development for testing in small airtight envelopes the unit was unable to raise the chamber pressure above 2.7Pa and therefore none of these tests were valid.

The average from the 9 tests is within 10% across the different tank sizes, valves and delivered flow and pressure.

To evaluate the effect of the air receiver starting pressure on results, a series of further repeat tests were carried out with the 585 unit in chamber D.

Air Permeability Results					Building Volume:	106		Building Envelope:		135					
Location	Test Ref	Test Time	PULSE Model	PULSE Valve	PULSE Start Pressure (BAR)	Pulse Result (4Pa)	Blower Door Result (50Pa)	Flow Coefficient C	Pressure Exponent n	Max Pressure Tested	Min Pressure Tested	Average Permeability (4Pa)	RPD	Max RPD per location	RPD overall
10 BAR	1	09:08	585	3/4"	9.69	1.24		0.0152	0.807	22.1	1.7	1.26	1.3%	1.8%	4.7%
	2	09:18	585	3/4"	9.79	1.24		0.0151	0.812	21.5	1.5		1.5%		4.8%
	3	09:31	585	3/4"	9.82	1.25		0.0191	0.770	5.2	0.9		0.7%		4.0%
	4	09:42	585	3/4"	9.78	1.28		0.0163	0.778	21.8	1.4		1.8%		1.7%
	5	11:49	585	3/4"	9.83	1.28		0.0162	0.784	22.0	4.1		1.7%		1.7%
8 BAR	1	09:51	585	3/4"	7.79	1.26		0.0261	0.609	4.9	0.8	1.28	1.2%	1.2%	3.1%
	2	10:00	585	3/4"	7.84	1.29		0.0256	0.624	4.7	3.1		0.7%		1.1%
	3	10:09	585	3/4"	7.81	1.28		0.0160	0.795	16.1	3.2		0.5%		1.4%
	4	10:18	585	3/4"	7.70	1.28		0.0187	0.680	4.5	3.1		0.0%		1.8%
6 BAR	1	10:27	585	3/4"	5.74	1.32		0.0160	0.812	10.9	2.1	1.31	1.0%	2.4%	1.3%
	2	10:36	585	3/4"	5.77	1.33		0.0158	0.829	10.6	2.1		1.5%		1.8%
	3	10:45	585	3/4"	5.82	1.31		0.0163	0.791	11.0	2.2		0.0%		0.3%
	4	10:54	585	3/4"	5.76	1.27		0.0145	0.861	10.7	2.3		2.4%		2.0%
4 BAR	1	11:03	585	3/4"	3.86	1.33		0.0143	0.904	6.5	1.4	1.36	2.2%	2.2%	2.3%
	2	11:11	585	3/4"	3.85	1.35		0.0161	0.826	6.5	1.3		0.7%		3.9%
	3	11:20	585	3/4"	3.86	1.37		0.0179	0.761	7.2	1.1		0.6%		5.2%
	4	11:28	585	3/4"	5.06	1.37		0.0168	0.806	9.0	1.7		0.8%		5.4%
	5	11:37	585	3/4"	3.79	1.38		0.0177	0.774	6.5	1.1		1.5%		6.1%
n/a	n/a						**8.21**								
n/a	n/a						**9.14**								
					Average	1.30								Max RPD	6.1%
					STDev	0.044071									

Table 6 Chamber 'D' Pulse 585 10 vs 8 vs 6 vs 4 Bar starting pressure data

Over the full range of starting pressures, the maximum RPD of 6.1% and standard deviation of 0.0440 is generally in line with the performance of the Pulse test as seen elsewhere.

Each set of results for a given pressure have an average RPD of 1.9%.

Testing highlighted an increase in measured leakage as the starting tank pressure reduces, with the average air permeability measured from 10bar 8.2% lower than the average result from the 4 bar tests. BTS explanation of this is due to the number of tests being carried out in succession (with lower levels of charge) causes the Pulse air pressure system to heat up to the extent that the system believes it measures more air that there really is, causing the system to give inaccurate result.

Unit and sensor location testing

The unit and sensor location testing were carried out to compare the results with the control module positioned in four different locations within chamber 'C' as per the below illustration

The Pulse control module and the differential pressure sensor housed within it can be positioned up to 4 meters away from the Pulse air release nozzle.

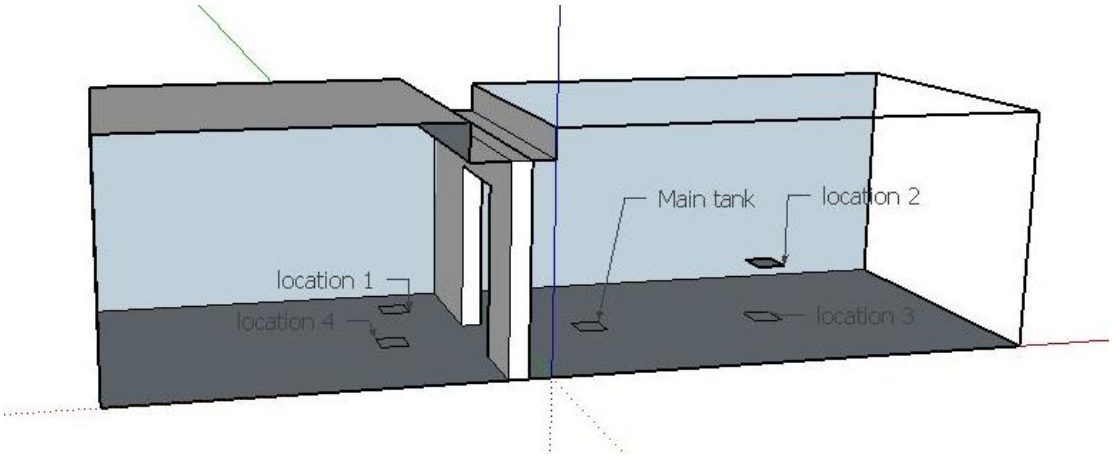


Figure 2 Chamber 'C' varying the differential pressure sensor location

Location 1: Around the corner from the main tank to assess the effect of obstruction (593 / 4,352 / 0)*

Location 2: Elevated from the floor to a height level with the nozzle (2,079 / 9,869 / 856)*

Location 3: Location for comparison with elevated results (2,079 / 9,869 / 0)*

Location 4: Through a doorway but unobstructed (2,266 / 4,086 / 0)*

* Distances are quoted to the top wall (mm) / to the left wall (mm) / from the floor (mm)

Air Permeability Results					Building Volume:	200			Building Envelope:	242					
Location	Test Ref	Test Time	PULSE Model	PULSE Valve	PULSE Start Pressure (BAR)	Pulse Result (4Pa)	Blower Door Result (50Pa)	Flow Coefficient C	Pressure Exponent n	Max Pressure Tested	Min Pressure Tested	Average Permeability	RPD	Max RPD per location	RPD overall
1	1	09:24	585	3/4"	9.94	1.14		0.0241	0.835	12.6	1.0	1.12	1.7%	2.5%	3.9%
	2	09:35	585	3/4"	9.93	1.13		0.0239	0.835	12.7	1.0		0.8%		2.9%
	3	09:44	585	3/4"	9.97	1.09		0.0243	0.800	12.7	0.7		2.5%		0.4%
2	1	09:54	585	3/4"	9.91	1.05		0.0228	0.816	12.0	1.0	1.12	6.4%	6.4%	4.4%
	2	10:03	585	3/4"	9.92	1.17		0.0299	0.694	12.0	0.7		3.9%		6.1%
	3	10:12	585	3/4"	9.92	1.15		0.0286	0.717	12.9	0.6		2.6%		4.8%
3	1	10:21	585	3/4"	10.00	1.12		0.0269	0.741	12.7	0.8	1.08	3.1%	3.1%	1.7%
	2	10:29	585	3/4"	10.00	1.07		0.0252	0.758	12.8	0.8		1.3%		2.6%
	3	10:38	585	3/4"	9.99	1.06		0.0209	0.887	12.4	1.0		1.8%		3.2%
4	1	10:47	585	3/4"	10.00	1.04		0.0226	0.816	12.6	0.9	1.07	2.1%	2.1%	5.0%
	2	10:56	585	3/4"	10.00	1.08		0.0255	0.755	12.6	0.8		1.2%		1.8%
	3	11:05	585	3/4"	9.98	1.08		0.0255	0.751	12.6	0.8		0.9%		2.0%
n/a	n/a						**7.35**								
n/a	n/a						**7.28**								
					Average	1.10	7.32							**Max RPD**	6.1%
					STDev	0.03965									

Table 7 Chamber 'C' varying the differential pressure sensor location

Table 7 shows the results using four different pressure sensor locations, the RPD of the tests is higher with the lid in the elevated position (location 2) with a standard deviation of 0.0395 at 4Pa across the set of results of and a max overall RPD of 6.1%.

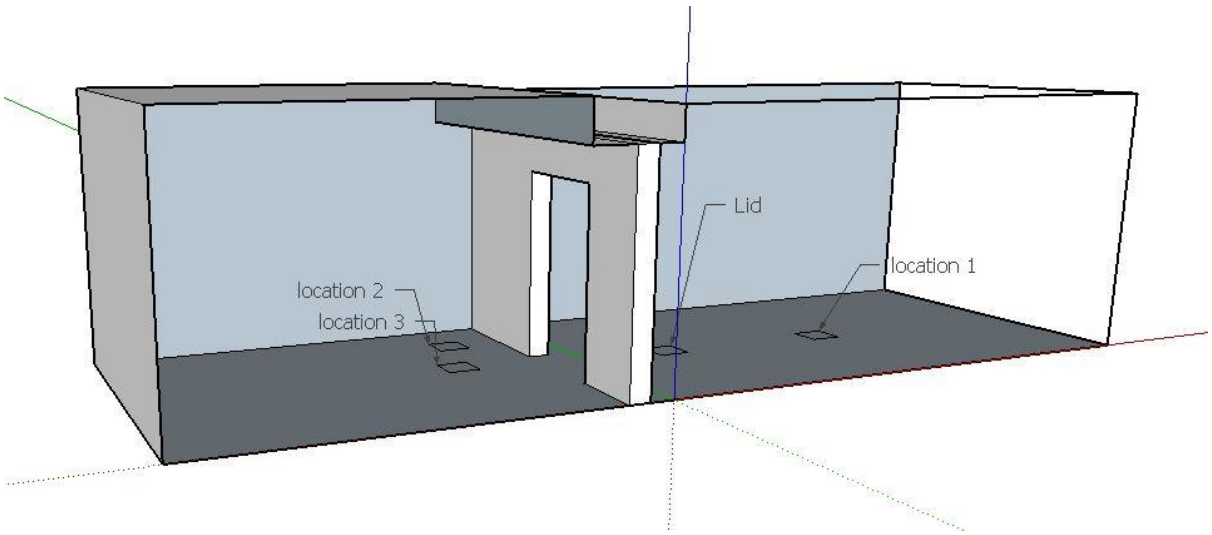


Figure 3 Chamber 'C' varying the air receiver position

The locations for air receiver position testing were the inverse of those used to examine the effect of lid positioning with the control module containing the pressure sensor located in the same position on the ground throughout.

Air Permeability Results					Building Volume:		200		Building Envelope:		242				
Location	Test Ref	Test Time	PULSE Model	PULSE Valve	PULSE Start Pressure (BAR)	Pulse Result (4Pa)	Blower Door Result (50Pa)	Flow Coefficient C	Pressure Exponent n	Max Pressure Tested	Min Pressure Tested	Average Permeability	RPD	Max RPD per location	RPD overall
1	1	11:13	585	3/4"	9.95	1.01		0.0232	0.775	13.1	1.0	1.04	2.8%	4.7%	7.2%
	2	11:22	585	3/4"	9.98	1.02		0.0209	0.857	12.6	1.1		1.9%		6.4%
	3	11:30	585	3/4"	9.99	1.09		0.0256	0.759	13.1	2.5		4.7%		0.1%
2	1	11:42	585	3/4"	9.84	1.01		0.0223	0.801	12.7	0.9	1.07	5.9%	5.9%	7.7%
	2	11:53	585	3/4"	9.88	1.07		0.0247	0.774	12.6	2.7		0.3%		1.7%
	3	12:03	585	3/4"	9.86	1.13		0.0275	0.732	12.2	2.4		5.6%		3.5%
3	1	12:12	585	3/4"	10.00	1.24		0.0344	0.636	12.3	1.8	1.16	6.3%	6.3%	13.3%
	2	12:21	585	3/4"	9.98	1.09		0.0249	0.781	12.3	2.6		5.9%		0.3%
	3	12:30	585	3/4"	9.98	1.16		0.0298	0.692	12.6	2.2		0.5%		6.0%
n/a	n/a						**7.35**								
n/a	n/a						**7.28**								
					Average	1.09								**Max RPD**	13.3%
					STDev	0.070924									

Table 8 Chamber 'C' varying the air receiver position

Location 2 - around the corner from the air receiver and in a corner, near two walls. This presents an RPD of 5.9% at 4Pa. The other two air receiver locations are in free space and within direct line of sight of the control module and pressure sensor. For each of these locations, the RPD is 4.7% and 6.3% at 4Pa respectively.

Location 3 test 1 show an anomaly, it is unclear what caused this issue, but this tests RPD is 13.3%, BTS note that the equipment user manual states that the air release nozzle should have at least 1 metre clearance around it in all directions to allow for unhindered air dispersal.

7 Conclusion

A - High Pressure Range Pulse vs Low Pressure Range Blower Door

When the testing programme was carried out in a controlled environment using chamber 'A, to make a direct comparison with the verified blower-door tests and the Pulse test using known-opening results it was found that:

- The comparison of the leakage curves between the tests for each opening demonstrates a maximum deviation in results of 15.5% with an average difference of 6.0%.
- Further testing across a wider sample of real property tests may be necessary, to give greater confidence in the Pulse system.

During the test programme on chamber 'A it was noted by BTS that when testing in a very airtight 15.98m^3 chamber the Pulse test over pressurised the chamber on numerous occasions and due to the sensitivity of the sensors this was giving a reverberation error in the results, the concern is that in practice, if this situation was to arise during site testing there is not currently a robust solution / procedure to correct this.

B - Pulse Repeatability Testing

The Pulse's repeatability testing in a range of controlled environment chamber's yielded consistent results across a range of unit configurations, including:

- One 585 unit testing repeatedly 10 times
- Different tank sizes and orifices
- Different tank starting pressures
- Different pressure sensor locations
- Different air receiver/nozzle locations

This programme has proven a good test of the underlying physics of the Pulse test approach and demonstrates individual Pulse units under the same conditions are able to reliably produce very repeatable results. It is noted that in one instance where there were 18 repeat measurements, the testing showed a gradual increase in measured leakage likely caused by warming of the equipment that the system tested was unable to account for.

8 References

ATTMA TSL1 September 2016 Edition – Air testing standard for residential dwellings

Approved Document L1A 2013 edition, incorporating 2016 amendments, to The Building Regulations 2010.

Annex A Air tightness test results

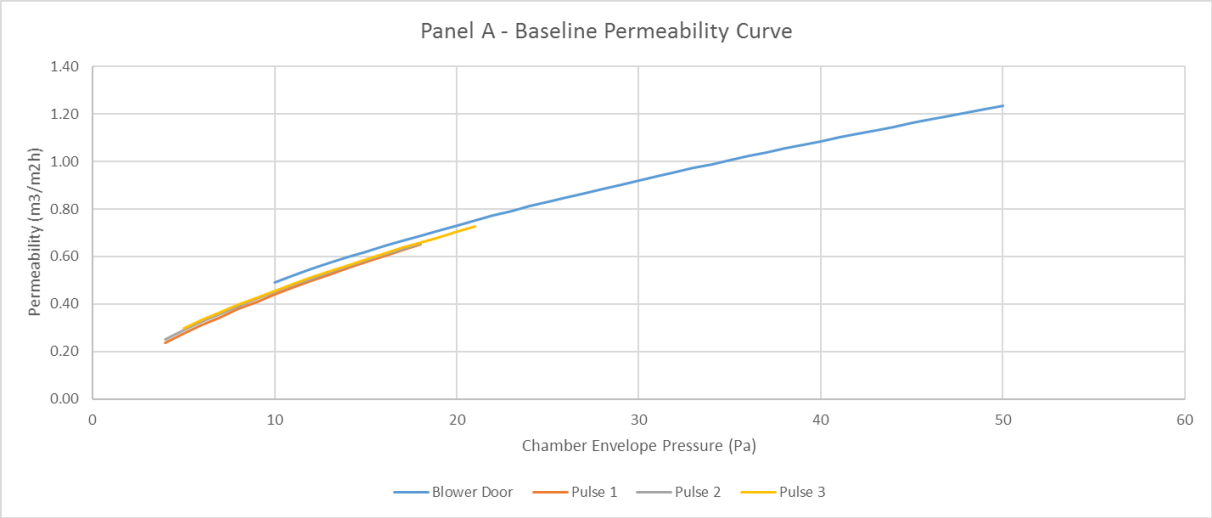


Figure A1 Chamber A Panel A Baseline

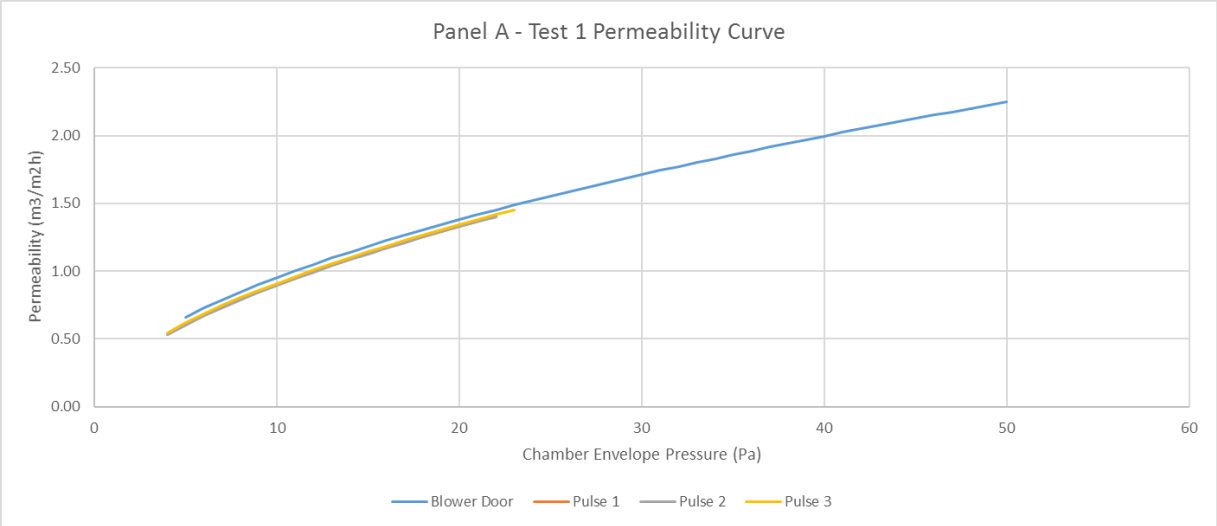


Figure A2 Chamber A Panel A Test 1

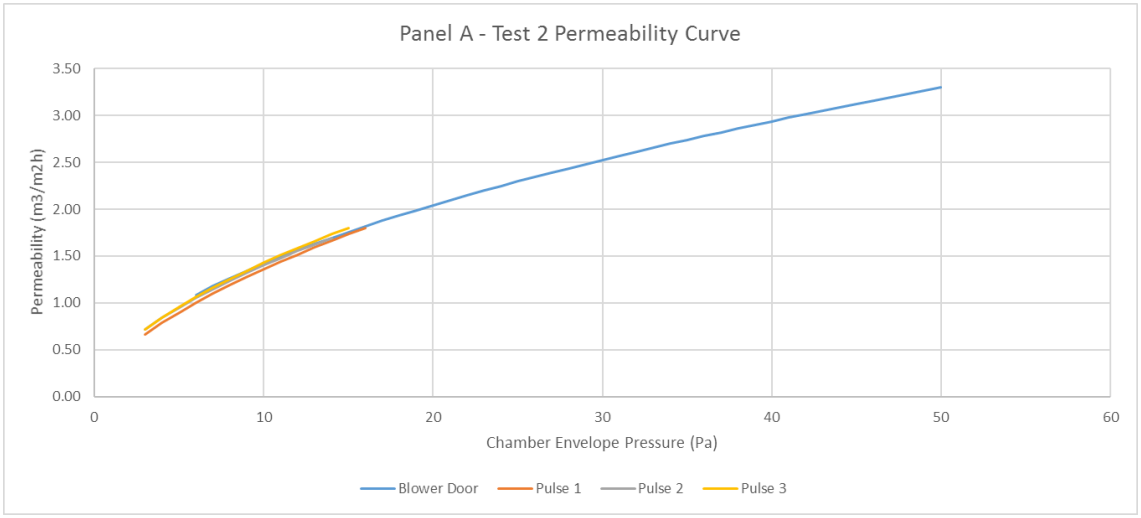


Figure A3 Chamber A Panel A Test 2

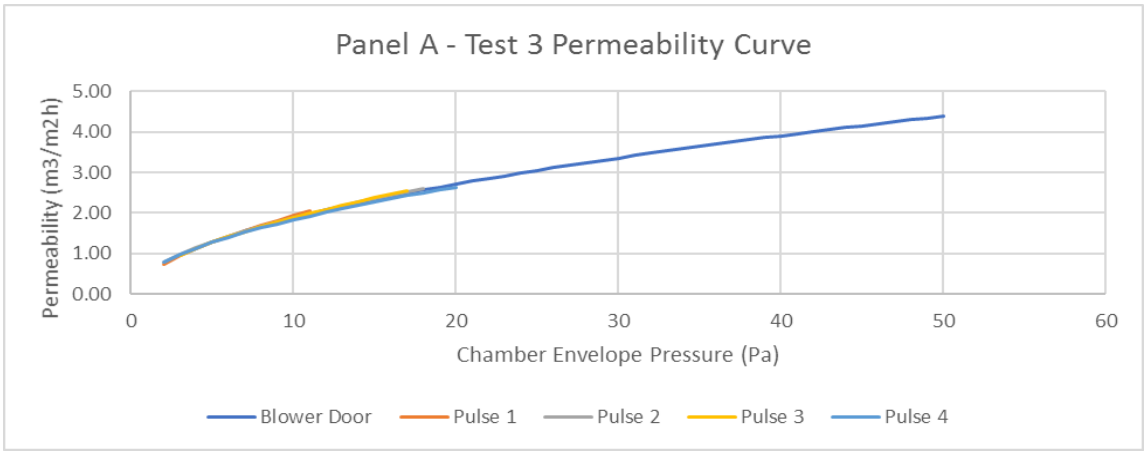


Figure A4 Chamber A Panel A Test 3

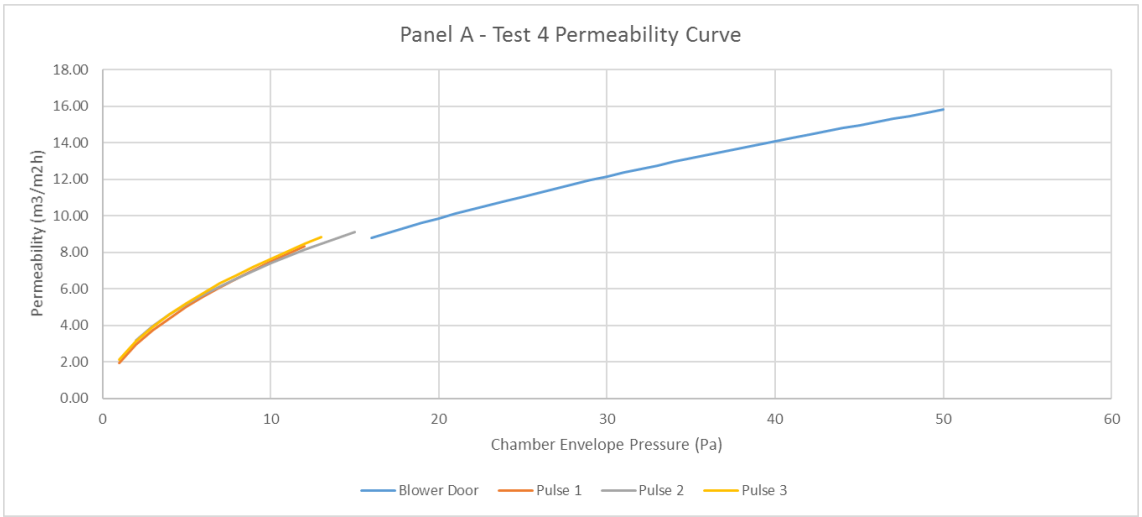


Figure A5 Chamber A Panel A Test 4

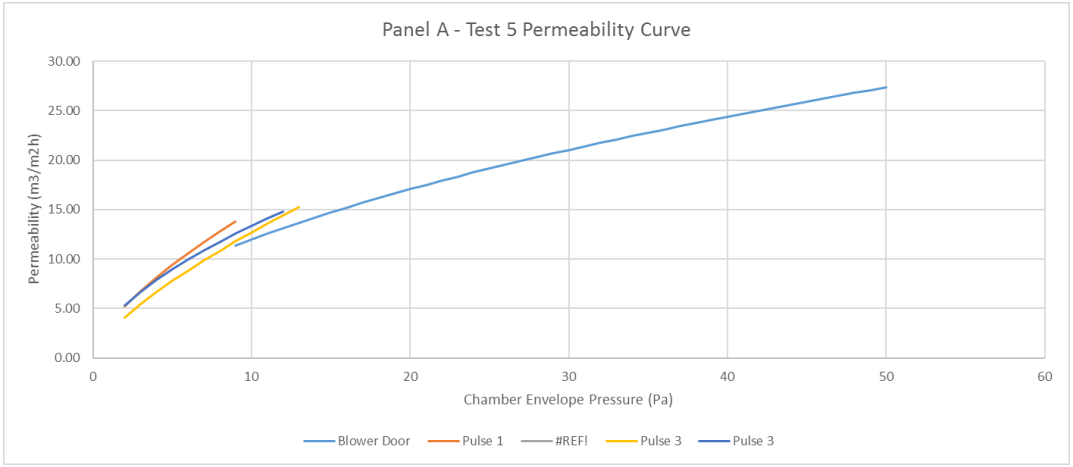


Figure A6 Chamber A Panel A Test 5

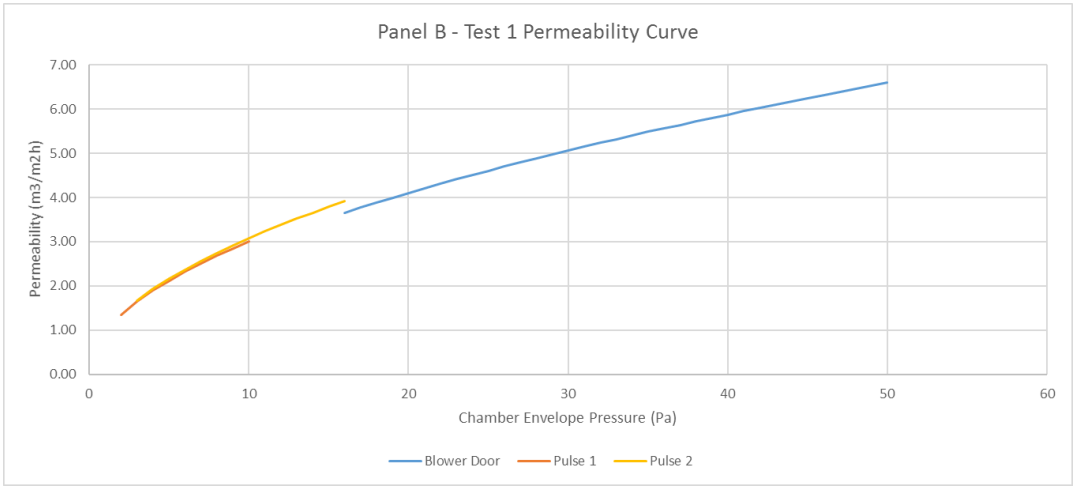


Figure A7 Chamber A Panel B Test 1

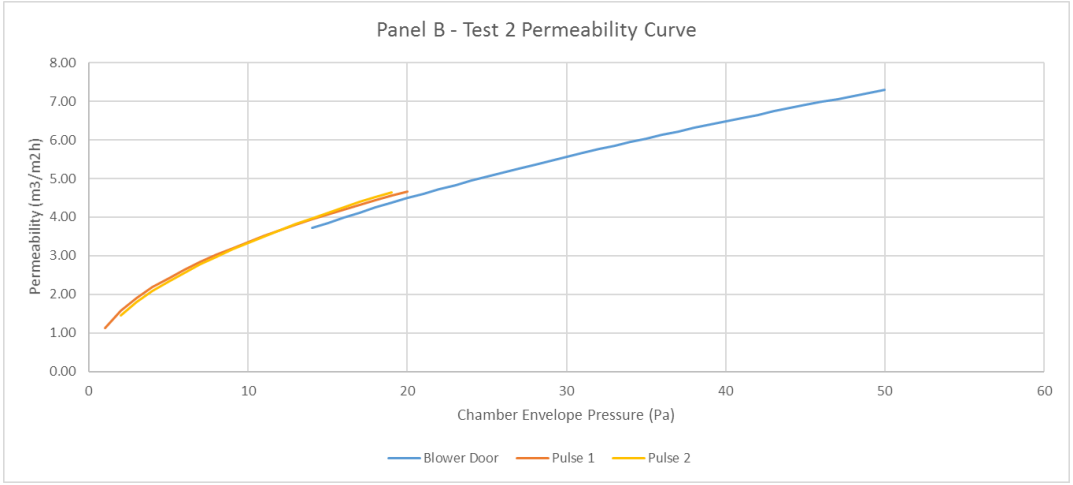


Figure A7 Chamber A Panel B Test 2

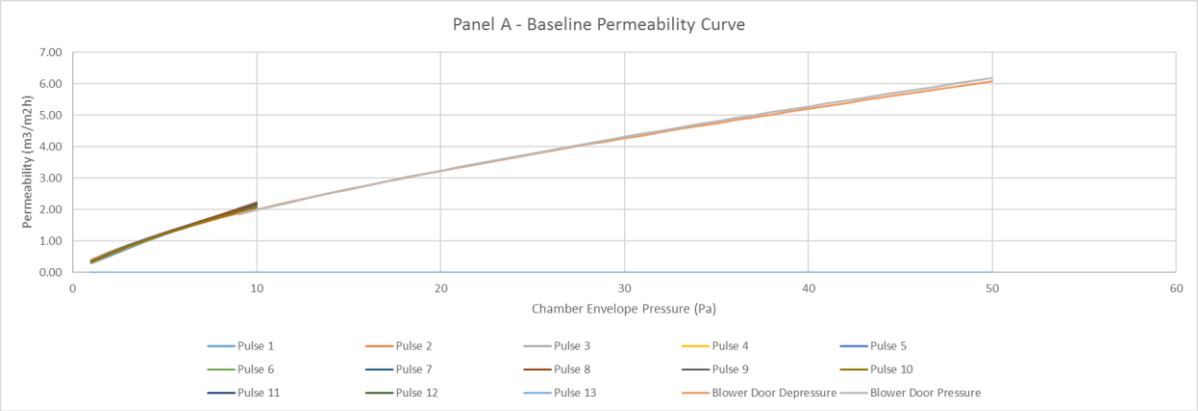


Figure A8 Chamber B Test 1-13