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12 December 2018

To whom it may concern,

The BRE Global published final draft Environmental Technology Verification (ETV) report provided to Build Test Solutions Ltd is compliant with BS EN ISO 14034:2018 and the EU ETV General Verification Protocol v1.3.

It is a requirement of the ETV protocol that the verification report is presented to a panel of European experts and is subsequently put through a formal publishing process which can take up to 6 weeks.

I am writing to confirm, however, that the report provided here is in my opinion complete and not likely to change materially.

To complete this report BRE Global witnessed a wide range of Low Pressure PULSE testing on a variety of test buildings on the BRE campus. We also extensively reviewed both the test system, company procedures and the results from a number of PULSE Low Pressure air tests. This work falls within the scope of BRE Global's schedule of accreditation (No. 4601) issued by the United Kingdom Accreditation Service.

Based on the findings of our verification report I will be recommending that a formal Statement of Verification covering the verified technology be issued to Build Test Solutions.

The final version of the Pulse ETV verification report and statement of verification are expected to be in the public domain from mid-January 2019.

Yours faithfully,

Dr John Holden
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Verification Report

Low Pressure PULSE Air Test Process

IN20170128UK03E

6 December 2018

Verification Report prepared by:

Name Dr John Holden/Nicolas Randall

Position Business Group Manager/ETV Assessor

Signature

Verification Report authorised by:

Name Laura Critien

Position Operations Manager, Verification

Date

Signature

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Opinions and interpretations expressed herein are outside the scope of UKAS Accreditation.

Table of Contents

1. Introduction

1.1. Name of technology and unique identifier of the technology being verified

Name: Low Pressure PULSE (LPP)

Model: BTS-PUL-001-585 (58.5 litre tank)

Unit reference: Pulse 585 FTU

Software: File Format version 4

Figure 1 – LPP main case

1.2. Name and contact of proposer

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1.3. Name of Verification Body and responsible of verification

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1.4. Organisation of verification including experts, and verification process

Verification Body:	BRE Global
Internal Experts:	Dr John Holden (ETV), Nicolas Randall (ETV), Simon Feeley (Airtightness Testing Team, BRE Ltd)
External Expert:	Dr Colin Cunningham (EU ETV appointed expert)
Test Body:	Build Test Solutions Ltd
Internal Experts:	Luke Smith, Stephen Jackson
Technician:	Adam Moring

Verification of the Low Pressure PULSE (LPP) Air Test process was carried out in accordance with GVP 1.3[1] on 1 August 2018 on the BRE Innovation Park in Watford, UK and witnessed by BRE Ltd's airtightness testing expert Simon Feeley, BRE Global's ETV expert John Holden, and BRE Global's ETV assessor Nicolas Randall.

The airtightness tests were performed by Build Test Solutions Ltd's trained operative Adam Moring, using the LPP test equipment detailed in section 1.1 above, and following the test procedure set out in the instruction manual[2].

Adam Moring also carried out airtightness tests using the industry recognised 'Blower Door' method as described in BS EN ISO 9972:2015[3]. Adam is a Level 1 tester approved by the Independent Airtightness Testing Scheme (iATS). The Blower Door fan used for this testing was manufactured by Energy Conservatory.

The technical guidance document 'ATTMA Technical Standard L1'[4] was observed.

6 'single zone' whole property tests were conducted consecutively on selected properties; 2 tests by 'Blower Door' (BD) and 4 by LPP. Testing was conducted in the following sequence:

- Test 1 – BD
- Test 2 – LPP
- Test 3 – LPP
- Test 4 – LPP
- Test 5 – LPP
- Test 6 – BD

1.5. Deviations from the specific verification protocol

On the day of testing, the test body performed tests on an additional 2 houses on the BRE Innovation Park making a total of 5 houses tested.

2. Description of the technology and application

2.1. Summary description of the technology

The LPP air test process is a compressed air-based technology which releases a measured amount of air from its tank into a building and monitors the subsequent internal pressure response. During each test, the LPP equipment measures and accounts for background pressure behaviours, releases 1-3 bursts of air at set intervals, and calculates the amount of air leakage induced by the air release.

The technique measures the air leakage at pressures typically between 1 and 8 Pa (positive pressure testing only) and determines air permeability and air change rates at 4 Pa. 4 Pa is generally considered to be the typical pressure difference across the envelope of occupied spaces[5], thus allowing the LPP test results to serve as an indicator of as-inhabited air change/ventilation rates.

2.2. Intended application (matrix, purpose, technologies, technical conditions)

Matrix: Thermal performance of buildings.

Purpose: Determination of air permeability of buildings.

Technologies: Measurement of the air permeability of buildings.

Technical conditions: Equipment operated in accordance with manufacturer's instructions and testing conducted in accordance with industry guidelines.

2.3. Verification parameters definition

Performance parameters:

- Accurate measurement/calculation of the following at 4 Pa;
  - Air leakage rate (ALR)
  - Effective leakage area (ELA)
  - Air Permeability (AP_4)
  - Air changes per hour (ACH)
- The following processes which form part of the full LPP test sequence described in the instruction manual[2] are completed in under 15 minutes;
  - LPP equipment set-up;
    - Equipment lid detached from base
    - Charge the 58.5 litre compressed air tank (LPP base) to 10 bar
    - Power-up the LPP control panel (LPP lid) and let the software boot-up
    - Input relevant test parameters in to software programme
  - Testing;
    - Pre-programmed series of 3 separate releases (pulses) of air, at different pressures, are made into the building
    - The time-based pressure response of the building is measured and recorded
    - Test results and test status information are generated by the LPP onboard computer and displayed on screen.
  - LPP equipment pack-down;
    - Empty compressed air tank
    - Shut-down control panel
    - Attach equipment lid to the base

For the avoidance of doubt, the time taken to transport the LPP test equipment to and from the appropriate test location within the test property is a variable that is not included in the 'under 15 minute' claim. The building preparation methods stated in BS EN ISO 9972:2015 section 5.2.1 require a varying amount of time to implement, depending on method selected and the specifics of the property, and are not included in the claim. The overall time may be impacted by the specification of compressor used to charge the 58.5 litre compressed air tank to 10 bar. The specification of the compressor used in these tests are detailed in section 4.3.2 below.

Operational parameters:

- The LPP (model BTS-PUL-001-585) operates within the following boundaries;
    - Test building volume of ≤ 420 m^3
    - Test building envelope air permeability of ≤ 10 $m^3/(h \cdot m^2)$ at 50 Pa
    - Meteorological wind speed ≤ 6 m/s
    - The LPP test equipment must be positioned in the test building to ensure a minimum of 1 metre clearance around the air exhaust nozzle to enable unhindered dispersal of the air pulses.
    - Sensor positioning according to manufactures instructions.

Environmental parameters:

Testing a building for airtightness will help determine if a building has unintentional air leakage paths. Such leakage paths can give rise to heat loss. If such leaks are identified, appropriate measures can be taken to seal the building envelope, preventing heat loss, and allowing the building's heating and ventilation system to operate correctly and efficiently. Correct operation of heating and ventilation reduces energy consumption, saves money and improves comfort so that heating and cooling of the space is done efficiently and in accordance with the design specification. The environmental parameters were not verified as part of this verification.

Additional parameters:

For correct and safe operation of the LPP equipment, the Build Test Solutions Ltd Instruction Manual[2] must be adhered to.

3. Existing test data

3.1. Accepted existing test data

Earlier test data were not accepted in support of this verification principally because the tests had been carried out using a different LPP model and software.

BRE Ltd were separately commissioned to carry out further testing and evaluation of the performance of the LPP in laboratory-controlled conditions.[6] Relevant findings from this testing have been taken into consideration in our wider evaluation of the LPP air test process.

4. Evaluation

4.1. Calculation of verification parameters including determination of uncertainty

Software (verified by the University of Nottingham[7]) was used to calculate the verification parameters using known data (e.g. Gas Constant) manually input data (e.g. tank volume(s), building volume) and data collected during LPP testing (e.g. atmospheric pressure, room temperature and the time-based pressure response of the test building following each air pulse).

4.2. Evaluation of test quality

The uncertainty associated with the LPP air test process has been calculated by the University of Nottingham[8] to be less than +/- 1%.

For each test the LPP software provides feedback on the quality and validity of the test data. This is based on analysis of a number of parameters including:

- Pressure increase during testing is below upper limit for pressure sensor (<24.8 Pa)
- Quality of curve fitting (R^2 value) for power-law equation > 0.96
- The maximum quasi steady-state pressure recorded is above 4 Pa and the minimum quasi steady-state pressure recorded is below 4 Pa, i.e. extrapolation not required
- n-value (between 0.5 and 1)
- Consistency of air flow from compressed air tank during pulses (Max curve fit vs reading errors)

4.2.1. Audits

A Test System Audit was conducted of the testing on the BRE Innovation Park in Watford.

4.3. Verification results (verified performance claim)

The LPP test equipment, specifically model BTS-PUL-001-585, was used to assess the air permeability of the following buildings:

Test building	Construction type	Storeys	Test building envelope area	Test building volume
Test Building 1	Aerated clay block	2	287 m^2	290 m^3
Test Building 2	Light gauge steel	2	279 m^2	292 m^3
Test Building 3	Timber frame	3	291 m^2	311 m^3
Test Building 4	SIPS	2	237 m^2	232 m^3
Test Building 5	Timber frame	2	236 m^2	243 m^3

Table 1

A single 58.5 litre Low Pressure PULSE (BTS-PUL-001-585) air tightness measurement instrument measured the air leakage characteristics of the above buildings, with volumes from 232 m^3 to 311 m^3 and envelope areas from 236 m^2 to 291 m^2, and generated results at 4 Pa for the following performance parameters in ≤ 15 minutes with a maximum relative percentage difference (RPD) of ±5% between tests.

- Air leakage rate (ALR)
- Effective leakage area (ELA)
- Air Permeability (AP_4)
- Air changes per hour (ACH)

4.3.1. Description of statistical methods used

Performance parameters were calculated from test data collected and derived using manufacturer's bespoke software 'File Format version 4'. This software has been verified by the University of Nottingham[7].

4.3.2. Verification parameters

Performance parameters

Calculation of tank volume:

Build Test Solutions Ltd provided a written explanation of how the compressed air tank volume was calculated. This is summarised below.

The tank was weighed when empty then filled with water and weighed again. The empty tank weight was then subtracted from the filled tank weight to determine the total volume.

The tank was weighed using Dymo S100 Portable Digital USB Shipping Scales with a calibrated accuracy of ± 0.1kg at 60.0kg. The calibration certificate was issued by Chamois Metrology Ltd who are accredited by UKAS to perform measurement of mass up to 26kg. We accept that this calibration is beyond their scope at the time of this report and consider this not to have a detrimental impact on the verification.

For the purposes of this measurement the mass of 1 litre of water was taken to be 1.0kg. The effect of temperature on the density of water used in the calculation of the tank volume (+/- 0.002%) was not considered significant for this measurement.

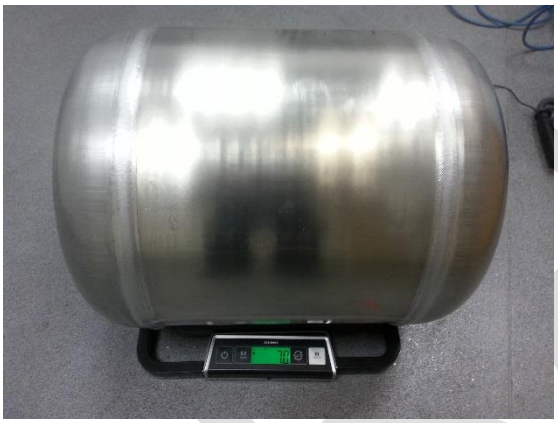

Figure 2 - empty tank weight of 7kg

Figure 3 - filled tank weight of 65.5kg

The confirmed volume of the compressed air tank used for testing on the Innovation Park was 58.5 litres.

Measurement of building envelope air leakage characteristics:

Test results[9] and data generated during testing on the BRE Innovation Park were submitted for review. These results included the data required for the calculation, at a pressure difference of 4Pa, of the following performance parameters: Air leakage rate (ALR); effective leakage area (ELA); air permeability (AP4); air changes per hour (ACH).

Test results were reviewed to confirm the quality of the data generated by the LPP test equipment, that the quality checks made by the software are justifiable and valid and that the performance parameters described above are calculated correctly.

It was noted that during one test, a timing problem was encountered when the LPP software failed to correctly identify the start of the release of an air pulse. This was identified by the test operator and resolved by manually analysing the data. Build Test Solutions Ltd have subsequently updated the LPP software to reduce the likelihood of this problem occurring in the future.

Test process completed in under 15 minutes:

The LPP test procedure was carried out in accordance with the guidance given in the manufacturer's instruction manual[2].

The time taken to complete the full LPP test sequence, which included all of the process elements listed in the performance parameters of section 2.3, was measured for tests on two different buildings. The following results were obtained:

Test Building 2: Test duration = 13 minutes and 19 seconds.

Test Building 4: Test duration = 12 minutes and 5 seconds.

Based on recorded times, and having observed the process multiple times throughout testing completed in 5 different buildings, it was verified that the full LPP test sequence can be completed in under 15 minutes.

The actual time taken will vary according to the speed of the operator in setting up and packing down the equipment and variables such as the building layout and proximity of a suitable power outlet.

The recorded test duration times did not include preparing the building according to 'Method 2' of BS EN ISO 9972:2015 section 5.2.1 (sealing of dedicated ventilation openings). It was noted that the required building preparations may be carried out while the LPP compressed air tank is being charged however, due to the nature of the test programme being followed, this was not assessed.

Figure 4 – method 2 sealing

Figure 5 – DÜRR TECHNIK compressor

For the tests conducted on the BRE Innovation Park buildings the compressor used to charge the compressed air tank was a DÜRR TECHNIK 230 V, 50Hz, 0.82 kW model. The use of a different compressor could affect the charging time for the Pulse compressed air tank. During many of the PULSE tests on the BRE Innovation Park, any air that remained in the tank (after the 3 pulses had been released for each test) was not always emptied from the tank before re-pressurising. This meant that charging to 10 bar (in readiness for the next test) could be achieved in a shorter time. However, for the purpose of verifying the 'under 15 minutes' claim, the tank was fully emptied (i.e. 0 bar) for the relevant tests before the charging commenced.

Maximum Relative Percentage Difference (RPD) of ±5% between tests:

To determine the maximum relative percentage difference (i.e. the consistency of test results) a 'Reference' (mean average) of the Air Permeability at 4 Pa for each tested building was calculated and the 'Difference' between the Reference and each test was determined and applied to the following equation:

$$\text{Relative Percentage Difference} = \frac{\text{Difference}}{\text{Reference}} \times 100$$

The following results were obtained:

RPD of LPP test results

Test building	LPP Test - Air Permeability at 4 Pa				Mean Average (Reference)	Relative Percentage Difference (RPD)
	Test 1	Test 2	Test 3	Test 4		
Test Building 1	0.7009	0.6909	0.7121	0.6995	0.7009	1.6%
(Difference)	0	0.0100	0.0112	0.0014		
Test Building 2	0.8437	0.8349	*rejected*[1]	0.8478	0.8421	0.9%
(Difference)	0.0016	0.0072	-	0.0057		
Test Building 3	0.1794	0.1669	0.1705	0.1705	0.1718	4.4%
(Difference)	0.0076	0.0049	0.0013	0.0013		
Test Building 4	0.5713	0.6015	0.5974	0.5727	0.5857	2.7%
(Difference)	0.0144	0.0158	0.0117	0.0130		
Test Building 5	0.9798	0.9962	1.0007	*no test*[2]	0.9922	1.2%
(Difference)	0.0124	0.0040	0.0085	-		
Average RPD						2.2%
Maximum RPD						**4.4%**

Table 2

[1] The result of Test 3 on Test Building 2 was rejected as the rear door of the property had been opened after Test 2 and not fully closed – BRE have confirmed that this occurred and accept the rejection of Test 3.

[2] Test 4 on Test Building 5 did not take place due to time constraints.

During initial testing in the three-story Test Building 3, the Pulse software reported an invalid sequence of tests. It was concluded by the test operator that this was due to the nature of the building and that a valid sequence of tests could be achieved by positioning the LPP equipment more centrally within the building, i.e. on the first floor instead of the ground floor.

For all of the testing conducted on the BRE Innovation Park, a maximum Relative Percentage Difference of 4.4% was calculated, which is within the claimed tolerance of ±5%.

Operational parameters

The operational parameters were assessed during the test system audit performed on the Innovation Park at BRE Watford.

Building volume:

Build Test Solutions Ltd have specified[2] that the BTS-PUL-001-585 equipment will operate correctly in buildings with a volume of ≤ 420 m^3. Practical testing on the BRE Innovation Park established that the BTS-PUL-001-585 equipment operated correctly in buildings with volumes from 232 m^3 to 311 m^3 when the equipment is correctly sited within the property and operated in accordance with the manufacturer's guidelines[2].

Building air permeability:

Build Test Solutions Ltd have specified[2] that the BTS-PUL-001-585 equipment will operate correctly in buildings with an air permeability of ≤ 10 $m^3/(h \cdot m^2)$ at 50 Pa which is the limit value stated in Approved Document L1A[10]. Practical testing on the BRE Innovation Park established that the BTS-PUL-001-585 equipment operated correctly in buildings with an air permeability of 1.57 $m^3/(h \cdot m^2)$ at 50 Pa to 5.75 $m^3/(h \cdot m^2)$ at 50 Pa. See below:

Blower Door test results at 50 Pa

Test building	Blower Door Test - Air Permeability at 50 Pa				Mean Average
	Before LPP tests		After LPP tests		
	Depressurisation Test 1	Pressurisation Test 2	Depressurisation Test 3	Pressurisation Test 4	
Test Building 1	4.04	4.17	4.09	4.24	4.14
Test Building 2	4.28	4.35	4.64	4.56	4.46
Test Building 3	1.74	1.54	1.52	1.47	1.57
Test Building 4	2.79	3.00	2.85	2.97	2.90
Test Building 5	5.82	5.76	5.61	5.81	5.75

Table 3

Meteorological wind speed:

Build Test Solutions Ltd have specified that the BTS-PUL-001-585 equipment will operate correctly for external (meteorological) wind speeds ≤ 6 m/s.

External wind speeds of 0.1-0.9 m/s were recorded during the audited testing on the on the BRE Innovation Park.

5. Quality assurance

This verification was conducted according to the documented procedures of BRE Global. These procedures fall within the scope of BRE Global's Schedule of Accreditation to ISO/IEC 17020:2012 issued by the United Kingdom Accreditation Service (UKAS) and which includes internal and external review.

6. References

[1] **EU ETV General Verification Protocol** Version 1.3 – 1 April 2018
[2] Build Test Solutions Ltd – PULSE Air Tightness Measurement Instrument – Model: BTS-PUL-001-585 – Main Case – **Instruction Manual and Safety Guidelines** - Version 5.0, 10/08/2018
[3] **BS EN ISO 9972:2015** - Thermal performance of buildings - Determination of air permeability of buildings - Fan pressurization method
[4] **ATTMA Technical Standard L1** – Measuring Air Permeability in The Envelopes of Dwellings – Issue 3: 9 September 2016
[5] **Testing Buildings for Air Leakage** - Technical Memoranda TM23 - The Chartered Institution of Building Services Engineers (CIBSE) – October 2000
[6] **Pulse vs Blower Door comparison airtightness chamber testing** - BRE Test Report Number P112874-1000 Issue 1, 25 September 2018
[7] **Low pressure Pulse air test software verification** – University of Nottingham - 21 September 2018
[8] **Initial results for the calculation of uncertainty in the Pulse method** - University of Nottingham - 22 November 2018
[9] **PULSE Air Test** – ETV Test Report – Ref. 'BRE Global/Build Test Solutions Ltd - Test Report' 2 August 2018
[10] **Approved Document L1A**: Conservation of fuel and power in new dwellings (2013 edition with 2016 amendments)