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Case Study 2: Air Pressurisation Tests

ROBUST Project: WP 2.4

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This report documents the outcome of air pressurisation and smoke propagation tests of two industrial sheds carried out on the 12 November 2008 in Milton Keynes, UK. Both buildings are typical 1960s and 70s steel framed industrial sheds with block wall partitions. The buildings are cladded with asbestos sheets and cavity brick forming the dwarf wall. The first building (Unit 2 – 4) was tested "Before renovation" while the second (Unit 16) was tested "After renovation". The renovated building was overcladded with mineral wool insulation and steel sheet to achieve the UK current thermal requirement (roof 0.25 and wall 0.35 W/m^{2}K).

Even though it is a general perception that the overcladding of existing building provides airtightness improvement, there is no research in the public domain to support this perception. Therefore, the purpose of the test was not to establish any form of regulatory compliance, but to contribute towards a greater understanding of the energy efficiency improvements that can be made by refurbishing this kind of legacy structure. The test procedure complied with regulatory requirements (ATTMA TS1:2006). The results from the airtightness are:

- Unit 2 – 4 "Before Renovation" 27.58m^3/h.m^2 @50 Pa
- Unit 16 "After Renovation" 26.36m^3/h.m^2 @50 Pa

These are considerably higher than the UK maximum standard for factories/warehouses[1] of 10m3/h.m2 @50 Pa. As can be seen from the results, both buildings are extremely leaky and current design detailing of over cladding provides little improvement to the envelope. For overcladding of existing building, it is strongly recommended that a separate airtightness membrane with vapour control must be introduced directly on the external surface of the existing cladding before insulation and new over cladding are installed. This is essential to allow moisture movement through the building envelope and prevent air leakage.

Customer: RFCS
Programme manager: Simon Vaughan

Approved by: Samir Boudjabeur

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Case Study 2: Air Pressurisation Tests

1. Introduction

The report presents the outcome of airtightness and smoke propagation tests carried out on two industrial sheds (units 2- 4 and 16) in Milton Keynes, UK. Unit 2 – 4 is yet to be refurbished while Unit 16 is newly over-cladded with built-up system. The tests were undertaken by Building Sciences Ltd and assisted by Corus RD&T personnel on site. These tests were subcontracted because Corus RD&T does not have the massive fans needed to pressurise these buildings.

It is a general perception that the overcladding of existing building provides airtightness improvement and thereby reduces heat loss and CO_2 emission. However, there is no research in the public domain to support this perception. Therefore, the purpose of the tests was not to establish any form of regulatory compliance, but to contribute towards a greater understanding of the envelope airtightness improvement that can be made by over-cladding of this kind of existing structure.

The contents of this report includes case studies description, site preparation and observation, test technique and equipment, test procedure, results, discussion, conclusion, recommendation and acknowledgement.

2. Building Description

2.1 General Description of the case study building

The buildings tested are typical 1960's and 1970s large steel portal frame industrial shed, which are partition with block walls into small units (double and single units). Unit 2 – 4 is a double unit and was tested “Before Renovation, while Unit 16 is a single unit and was tested “After Renovation”.

The buildings are constructed around a steel frame which is cladded with dwarf wall and asbestos cement sheet. The dwarf wall is an uninsulated cavity brick wall. On top of the dwarf wall is a single skin asbestos cement sheet. The roof consists of a single asbestos cement sheet and a single glazed roof light, which runs along the centre of the roof and down on the north elevation. On the west side of the building are a series of a single glazed windows. The floor is made of a ground bearing concrete slab.

Case 1- Units 2- 4: “Before Renovation”
This is a double unit with total floor area of about 1260m^2. The unit is a two storey rectangular shaped industrial unit with offices on the first floor and toilets and a large open plan warehouse facility on the ground floor (see Figure 1).

Roof light

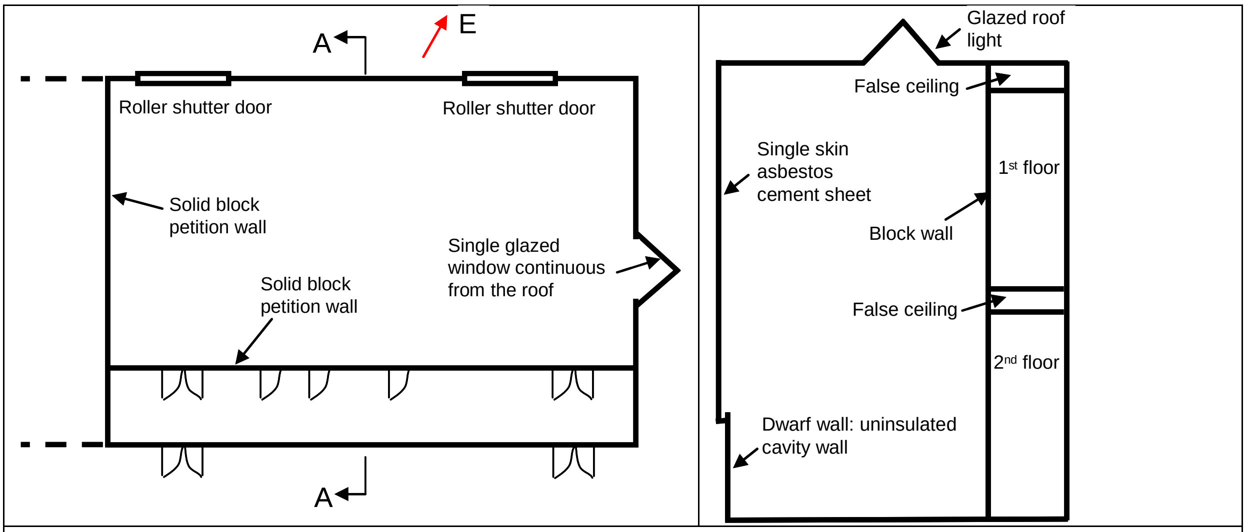


Figure 1: Sketch of Plan and Section

Picture showing front view

Picture showing back view

Picture showing side view

Picture showing internal view

Figure 2: Pictures showing Units 2 - 4

Case 2: Unit 16 – “After Renovation”
This is a single unit with a total floor area of about 630 m^2. The is effectively the same construction as unit 2-4 except that it is half the size and the existing asbestos sheet cladding has been over-cladded with mineral wool insulation and steel external liner attached to the existing envelope via steel brackets as shown in the picture below. Insulation thickness of 180mm and 120 mm for roof and walls were used to comply with the current minimum UK regulatory thermal requirement (for roof 0.25 and wall 0.35 $W/m^2.K$). The dwarf cavity walls remain uninsulated. All doors, windows, floor and internal walls were repainted.

This represents a typical practice for refurbishment of this type of building in the UK.

	
Picture showing steel rail, insulation and steel cladding	*Picture during construction*
	
Picture showing front view	*Picture showing back view*
	
Picture showing side view	*Picture showing internal view*

Figure 3: Pictures showing unit 16

3. Site Preparation

3.1 Site Preparation

The site preparation complied with BS EN 13829:2001 Method B – Test of the Building Envelope. All drainage traps were filled with water. All external doors, windows, trickle vents, smoke vents and all passive ventilation systems were closed. All mechanical ventilations were temporary sealed to prevent air leakage through the system during the tests.

	
Picture showing internal extractor sealed	*Picture showing toilet sink sealed*
	
Picture showing internal extractor sealed	***Picture showing external extractor sealed***

Figure 4: Picture showing temporary sealing for the test

4. Test Technique and Equipment

4.1 Test technique

Fan pressurisation techniques are used to quantify the air leakage of the envelope of non-domestic buildings, e.g. offices, superstores, schools and industrial buildings. The leakiness of the envelope is quantified by mounting a single large fan or a series of fans into an external doorway and pressurising the building whilst measuring the airflow rate required maintaining a pressure difference across the building envelope. The leakier the building, the more air is needed to maintain the required pressure differential.

Tests are normally carried out when the outside wind speed is low (< 6m/s) to minimise any wind induced pressure variations. Air volume flow rate Q (m^3/s) through the fans is measured by calibrated flow grids over a suitable range of building pressure differentials ΔP (Pa). These are then corrected for internal/external temperature difference, in accordance with TM23. A best-fit power-law profile of the form $Q = C_{env} (\Delta P)^n$ is fitted to the data where both the coefficient C_{env} and exponent n are constants. C_{env} is then corrected for the measured barometric pressure to a specified test pressure of 50Pa, providing C_L.

The theoretical leakage rate at 50Pa is then calculated from the formula:

$$Q_{50}=C_L(\Delta P)^n$$

To compare the envelope leakage characteristics between buildings of different shapes and sizes, air permeability Q_{50}/S_T is used. Q_{50} is the air volume flow rate (m^3/h) through the building envelope at a pressure differential of 50Pa, where S_T is the total external surface area (m^2). The result is expressed in terms of m^3 leakage per hour per m^2 of envelope area.

4.2 Establishing fan size

The fan system used on this test was a high capacity petrol-driven trailer fans sealed into the main entrance doors on the front elevation as shown in the pictures below. This fan is calibrated to BS848 with a volume flow rate between 2.5 – 33.0 m^3/s.

The size of the fan was established in accordance with ATTMA TS1 requirement, which states that the fan must be capable of achieving at least 80% of the required air volume flow rate, at 50 Pascal pressure difference (Q_{50}). $Q_{50} = A * 10 * 0.8 / 3600$ (m^3/s) where 10 is the Air Permeability target, and A = area of walls, roof and ground floor.

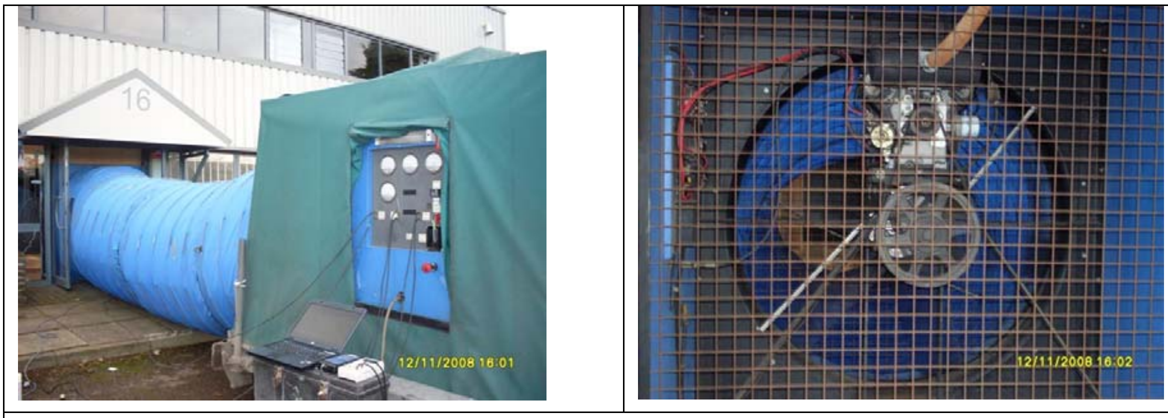


Figure 5: Pictures showing fans installation for the test

5. Test Procedure

The test was carried out in accordance with Building Sciences Ltd Standard Method Statement and test procedures. This is fully compliant with ATTMA TS1, and older reference CIBSE TM 23.

The test procedure is also generally in accordance with **BS EN 13829:2001 -** *Thermal performance of buildings – Determination of air permeability of buildings – Fan pressurization method* (Method B – test of the building envelope).

The mean internal and external temperatures were measured and recorded during the tests. The temperature values recorded were used to standardise the airflow rate though the fan systems to commonly agreed conditions.

Corrections were also made for 'static pressure'**-** this is the natural pressure difference that may exist between inside and out due to environmental conditions. Measured with all external doors and windows closed both before and after the test, had this been in excess of +/- 5Pa then the test would not have been undertaken.

Problems may also arise if internal/external temperature differences are excessive, particularly in high-rise buildings where 'stack effects' can induce sizeable pressure differences within the building. For a satisfactory test, it is recommended that the product of the inside/outside temperature difference (K) and the height of the building (m) should not exceed 500mK. This was not the case in this instance.

A further parameter measured was wind speed. The wind speed prior to the test was measured as 1.4m/s and afterwards 1.4m/s. These were both below the recommended level at which the pressure test should be carried out (6m/s), and therefore acceptable.

The test procedure consisted of pressurising the building to approximately 50Pa then taking a set of measurements of the building pressure differential and flow rate though the fans. The fan speeds were then reduced in several steps and the readings repeated at each of the speed settings.

The ventilation systems were closed by bagging off the industrial heater flews and extractors at each individual vent.

6. Test Results

Each set of measurements of pressure difference and air volume flow rate was averaged and a best-fit power-law profile of the form. $Q= C_{env} (\Delta P)^n$ was fitted to the data. Tests results are included in the Appendix.

6.1 Whole Building Test Result: Unit 2 + 4

A power law curve provided the following values:
n, exponent = 0.502
C_{env} = 3.663
C_L = 3.726 n(following barometric pressure correction at specified test pressure)
r^2 correlation value (an indication of the parametric fit) of 0.987

Air Permeability
Using the power law profile $Q_{50}=C_L(\Delta P)_n$, the air permeability of the building Q_{50}/S_T was calculated to be **27.58m$_3$/(h.m^2) @ 50Pa** differential pressure

Equivalent Envelop Leakage Area (ELA)
The estimated ELA was calculated to be **4.86m^2**

6.2 Whole Building Test Result: Unit 16

A power law curve provided the following values:
n, exponent = 0.632
C_{env} = 1.206
C_L = 3.220 n(following barometric pressure correction at specified test pressure)
r^2 correlation value (an indication of the parametric fit) of 0.990

Air Permeability
Using the power law profile $Q_{50}=C_L(\Delta P)_n$, the air permeability of the building Q_{50}/S_T was calculated to be **26.36m^3/(h.m^2) @ 50Pa** differential pressure.

Equivalent Envelop Leakage Area (ELA)
The estimated ELA was calculated to be **2.63m^2**

7. Smoke Propagation Test

The purpose of this test was to identify leakage paths from the building envelopes. This was carried out using hand held smoke generators employed around the tested enclosure.

7.1 Unit 2 + 4: Observation

The test revealed air leakage through the building envelope from all possible interfaces as listed below:

- Eaves
- Ridge roof light
- Corner
- Cladding to cladding
- Window glass louver
- Window/door head
- Window/door jam
- Window sill
- Under roller shutter
- Asbestos cladding to brick
- Service penetration
- Roof lights to cladding

	
Figure 6: Picture showing leakage from window sill	**Figure 7: Picture showing leakage from asbestos cladding and dwarf wall interface**
	
Figure 8: Picture showing leakage from the eaves interface	**Figure 9: Picture showing leakage from window jamb**

7.2 Unit 16: Observation

No leakage was observed from the eaves, corner, service penetration, steel laps and end joint interfaces. This indicates that adequate measures were taken from the building contractor to ensure that the joints a properly sealed in accordance with the cladding manufacturer's design details. However, a phenomenon was observed during this test. It was noted that the smoke from the internal enclosure leaked through the internal envelope and travels behind the new steel cladding. This then find it way out through the joints between windows to cladding, doors to cladding and steel cladding to brick wall interfaces. This finding departs from the current pervasive assumption that over cladding of existing buildings reduces the air leakage path.

The following leakage paths were identified through the building envelope:

- Ridge roof light
- Window glass louver
- Window/door head
- Window/door jamb
- Window sill
- Under roller shutter
- Steel cladding to brick
- Roof lights to cladding

	
Figure 10: Picture showing leakage from window interface	**Figure 11 Picture showing leakage from window jamb**

8. Discussion

Table 1 collates the airtightness results from the test and the regulatory requirement in the UK. The result obtained from Unit 2 -4: Before renovation is consistent with the aggregated results from the Building Sciences Ltd's Database of past tests for such buildings, which revealed that air permeability values of existing industrial shed built between 1960 and 1970 ranges from 25 - 30 $m^3/h.m^2$ @50 Pa. However, the result from Unit 16: After renovation shows very little improvement when compared to Unit 2 – 4: Before renovation and considerably higher than the regulatory required value. Thus represents a massive heat loss and major source of CO_2 emission.

Table 1: Air Permeability Test Results vs. Regulatory Requirement

Unit 2-4: Before renovation *($m^3/h.m^2$ @50 Pa)*	Unit 16: After renovation *($m^3/h.m^2$ @50 Pa)*	UK Regulatory requirement *($m^3/h.m^2$ @50 Pa)*
27.58	26.36	10

The airtightness results together with the observations from the smoke propagation tests of both buildings clearly indicate that the current practice and assumption that over-cladding of existing buildings bring about reduction in air leakage and CO_2 emission associated with heat loss appears to be flawed.

Under normal circumstance, the airtightness membrane is best place on the internal face of the building envelope. Previous laboratory tests and physical tests on new buildings have shown that steel cladded buildings are capable of achieving airtightness value of less than $3m^3/h.m^2$ @50 Pa when the internal steel liner joints are well sealed to serve as airtightness membrane. However, the use of external cladding as airtightness barrier for refurbishment of existing buildings is not effective. Therefore, there is an urgent need to re-think the design detailing of over-cladding of existing building.

9. Recommendation

Based on the finding, it is therefore, strongly recommended that a separate airtightness membrane be introduced directly on the external surface of the existing cladding before insulation and new over cladding are installed. This airtightness membrane needs to be breathable membrane (vapour permeable layer) to allow moisture movement through the envelope and avoid condensation risk, and at the same time prevent air leakage in line with current building regulation.

This research is largely based on two case study buildings, though limited in numbers; it does provide a strong base for further work in this area. Hence, there is a need for more case study buildings for further physical tests to confirm this finding and provide sustainable solution to this problem. In view of this, further tests are planned for Unit 2 -4 “After renovation”.

10. Conclusion

This report documents the outcome of airtightness and smoke propagation tests of two industrial sheds (Unit 2 – 4 and Unit 16). Unit 2 – 4 was tested before renovation while Unit 16 was tested after renovation. These buildings are a typical 1960s – 70s steel portal frame industrial shed clad with asbestos sheets and cavity brick dwarf walls.

The test procedure complied with regulatory requirements (ATTMA TS1:2006). The results from the airtightness are:

- Unit 2 – 4 “Before Renovation”: **27.58$m^3/h.m^2$ @50 Pa**
- Unit 16 “After Renovation”: **26.36$m^3/h.m^2$ @50 Pa**

These are considerably higher than the UK maximum standard for factories/warehouses of **10m3/h.m2 @50 Pa**. The airtightness and smoke propagation tests revealed that the buildings are very leaky and current design detailing of over cladding provides little improvement to the envelope. This finding departs from the current pervasive assumption that over cladding of existing buildings reduces the air leakage path. Therefore, there is an urgent need to re-think the design detailing of over-cladding of existing building.

The research outcome challenged the current detailing practice and airtightness performance of overcladding of existing buildings. The study advanced the body of knowledge and better understanding of airtightness performance of overcladding of existing buildings.

For overcladding of existing building, it is strongly recommended that a separate airtightness membrane with vapour control needs to be introduced directly on the external surface of the existing cladding before insulation and new over cladding are installed. This is essential to allow moisture movement through the building envelope and prevent air leakage in line with current building regulations.

ACKNOWLEDGEMENTS

The author acknowledges the input of Building Sciences Ltd in the completion of this test.

REFERENCES

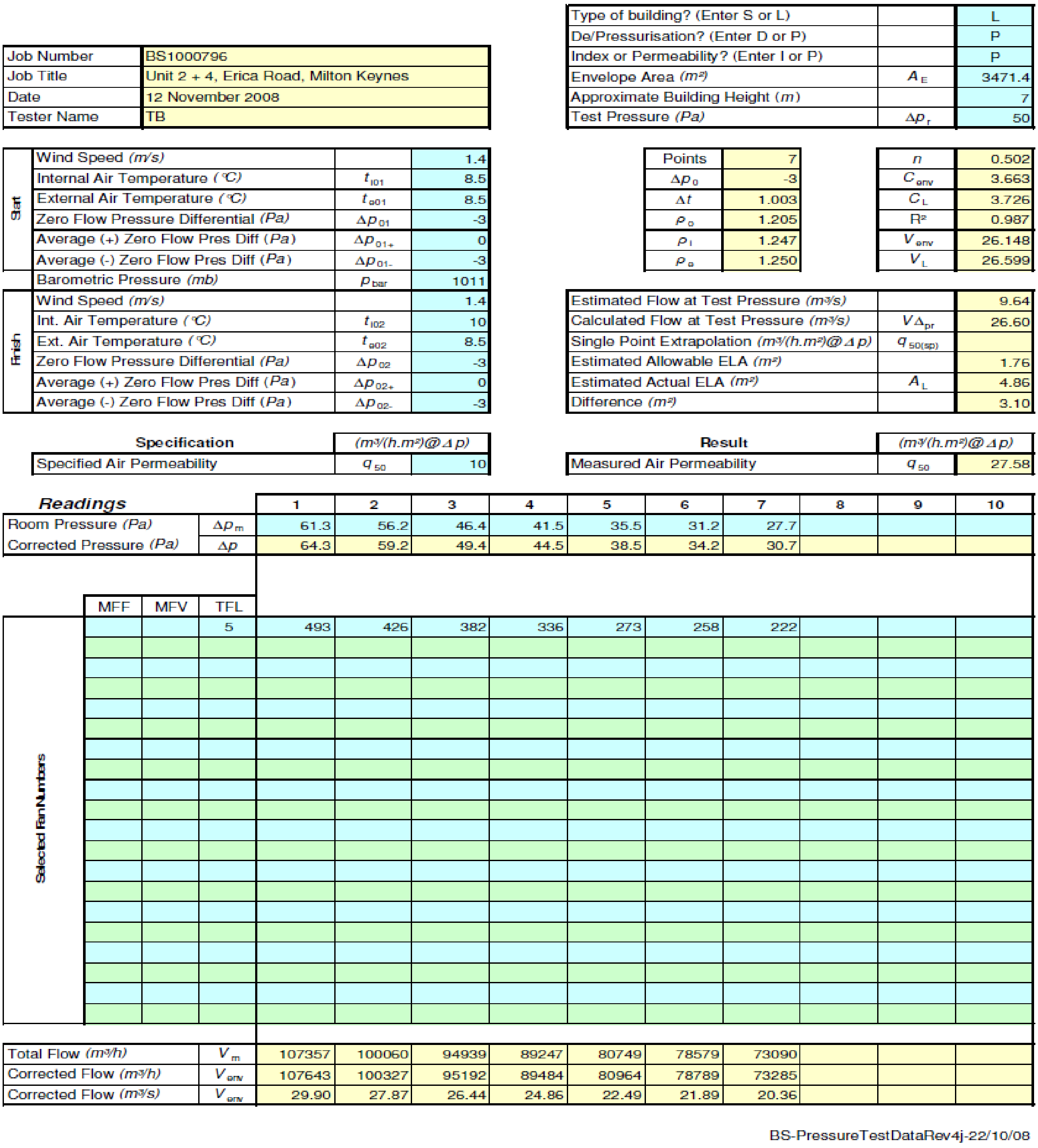
1. ATTMA TS1: 2006, The Air-tightness Testing and Measurement Association, Measuring air permeability of building envelopes

2. CIBSE Technical Memorandum TM23: 2000, *Testing Buildings for Air Leakage*

3. BS EN 13829:2001, *Thermal performance of buildings – Determination of air permeability of buildings – Fan pressurization method*

APPENDIX: Air Pressurisation Test Results

UNIT 2 – 4



Type of building? (Enter S or L)		L
De/Pressurisation? (Enter D or P)		P
Index or Permeability? (Enter I or P)		P
Envelope Area *(m^2)*	A_E	3471.4
Approximate Building Height *(m)*		7
Test Pressure *(Pa)*	Δp_r	50

Job Number	BS1000796
Job Title	Unit 2 + 4, Erica Road, Milton Keynes
Date	12 November 2008
Tester Name	TB

Start	Wind Speed *(m/s)*		1.4
	Internal Air Temperature *(°C)*	t_{i01}	8.5
	External Air Temperature *(°C)*	t_{e01}	8.5
	Zero Flow Pressure Differential *(Pa)*	Δp_{01}	-3
	Average (+) Zero Flow Pres Diff (*Pa*)	Δp_{01+}	0
	Average (-) Zero Flow Pres Diff (*Pa*)	Δp_{01-}	-3
	Barometric Pressure *(mb)*	p_{bar}	1011
Finish	Wind Speed *(m/s)*		1.4
	Int. Air Temperature *(°C)*	t_{i02}	10
	Ext. Air Temperature *(°C)*	t_{e02}	8.5
	Zero Flow Pressure Differential *(Pa)*	Δp_{02}	-3
	Average (+) Zero Flow Pres Diff (*Pa*)	Δp_{02+}	0
	Average (-) Zero Flow Pres Diff (*Pa*)	Δp_{02-}	-3

Points	7
Δp_0	-3
Δt	1.003
ρ_o	1.205
ρ_i	1.247
ρ_e	1.250

n	0.502
C_{env}	3.663
C_L	3.726
R^2	0.987
V_{env}	26.148
V_L	26.599

Estimated Flow at Test Pressure *(m^3/s)*		9.64
Calculated Flow at Test Pressure *(m^3/s)*	$V\Delta_{pr}$	26.60
Single Point Extrapolation *($m^3/(h.m^2)@\Delta p$)*	$q_{50(sp)}$	
Estimated Allowable ELA *(m^2)*		1.76
Estimated Actual ELA *(m^2)*	A_L	4.86
Difference *(m^2)*		3.10

Specification	*($m^3/(h.m^2)@\Delta p$)*	
Specified Air Permeability	q_{50}	10

Result	*($m^3/(h.m^2)@\Delta p$)*	
Measured Air Permeability	q_{50}	27.58

Readings		1	2	3	4	5	6	7	8	9	10
Room Pressure *(Pa)*	Δp_m	61.3	56.2	46.4	41.5	35.5	31.2	27.7			
Corrected Pressure *(Pa)*	Δp	64.3	59.2	49.4	44.5	38.5	34.2	30.7			

	MFF	MFV	TFL	1	2	3	4	5	6	7	8	9	10
Selected Fan Numbers			5	493	426	382	336	273	258	222			

		1	2	3	4	5	6	7	8	9	10
Total Flow *(m^3/h)*	V_m	107357	100060	94939	89247	80749	78579	73090			
Corrected Flow *(m^3/h)*	V_{env}	107643	100327	95192	89484	80964	78789	73285			
Corrected Flow *(m^3/s)*	V_{env}	29.90	27.87	26.44	24.86	22.49	21.89	20.36			

BS-PressureTestDataRev4j-22/10/08

UNIT 16

Type of building? (Enter S or L)		L
De/Pressurisation? (Enter D or P)		P
Index or Permeability? (Enter I or P)		P
Envelope Area (m^2)	A_E	1970.2
Approximate Building Height (m)		7
Test Pressure *(Pa)*	Δp_r	50

Job Number	BS1000796
Job Title	Unit 16, Erica Road, Milton Keynes
Date	12 November 2008
Tester Name	TB

Start	Wind Speed *(m/s)*		1.4
	Internal Air Temperature (°C)	t_{i01}	10
	External Air Temperature (°C)	t_{e01}	9.5
	Zero Flow Pressure Differential *(Pa)*	Δp_{01}	-0.4
	Average (+) Zero Flow Pres Diff *(Pa)*	Δp_{01+}	0
	Average (-) Zero Flow Pres Diff *(Pa)*	Δp_{01-}	-0.4
	Barometric Pressure *(mb)*	p_{bar}	1011
Finish	Wind Speed *(m/s)*		1.4
	Int. Air Temperature (°C)	t_{i02}	10.5
	Ext. Air Temperature (°C)	t_{e02}	9
	Zero Flow Pressure Differential *(Pa)*	Δp_{02}	-1.3
	Average (+) Zero Flow Pres Diff *(Pa)*	Δp_{02+}	0
	Average (-) Zero Flow Pres Diff *(Pa)*	Δp_{02-}	-1.3

Points	7
Δp_0	-0.85
Δt	1.004
ρ_o	1.205
ρ_i	1.243
ρ_e	1.247

n	0.632
C_{env}	1.206
C_L	1.220
R^2	0.990
V_{env}	14.266
V_L	14.429

Estimated Flow at Test Pressure (m^3/s)		5.47
Calculated Flow at Test Pressure (m^3/s)	$V\Delta_{pr}$	14.43
Single Point Extrapolation $(m^3/(h.m^2)@\Delta p)$	$q_{50(sp)}$	
Estimated Allowable ELA (m^2)		1.00
Estimated Actual ELA (m^2)	A_L	2.63
Difference (m^2)		1.63

Specification	$(m^3/(h.m^2)@\Delta p)$	
Specified Air Permeability	q_{50}	10

Result	$(m^3/(h.m^2)@\Delta p)$	
Measured Air Permeability	q_{50}	26.36

Readings		1	2	3	4	5	6	7	8	9	10
Room Pressure *(Pa)*	Δp_m	66.2	62.4	59.2	56	53	49.6	46.4			
Corrected Pressure *(Pa)*	Δp	67.05	63.25	60.05	56.85	53.85	50.45	47.25			

	MFF	MFV	TFL	1	2	3	4	5	6	7	8	9	10
Selected Fan Numbers			5	159	144.5	133	123	115	108	100			

		1	2	3	4	5	6	7	8	9	10
Total Flow (m^3/h)	V_m	62230	59428	57100	54989	53235	51648	49768			
Corrected Flow (m^3/h)	V_{env}	62451	59638	57302	55184	53424	51831	49944			
Corrected Flow (m^3/s)	V_{env}	17.35	16.57	15.92	15.33	14.84	14.40	13.87			