Long Term Experience Of The Passivhaus Standard in North East England: Does Airtightness Decay?

Mark Siddall, LEAP
3 Toll House Road, Durham, United Kingdom +44(0)191 375 7702, mark@leap4.it

Professor David Johnston, CeBE Group, Leeds Sustainability Institute,
Leeds Beckett University, Leeds, UK

Jack Harvie-Clark and Andrew Wyke, Apex Acoustics, Design Works, William St,
Gateshead, United Kingdom +44(0)191 423 6272, jhc@apexacoustics.co.uk

1 Introduction

It is not unusual for air infiltration to increase in new buildings as the building fabric shrinks and settles, wear-and-tear occurs to window and door seals and changes to the building fabric made by the occupants.

In this context, within the UK, many construction industry professionals are sceptical about whether or not the Passivhaus Standard provides a robust long term solution. A primary concern is that performance, notably airtightness, degrades over time.

Furthermore, to help prevent moisture damage in roof spaces Protokolband 29 [Feist, 2005] recommends an air permeability of 2 m^3-h/m^2 where the fabric is diffusion open and where it is diffusion closed construction requires an air permeability of 0.5 m^3-h/m^2. In addition to considering longevity of air barriers this paper examines whether, after 5 years occupation, the dwellings in this study are protecting the building fabric from moisture damage.

In the North East of England the first homes achieving the Passivhaus Standard were completed in 2011 (25 houses at the Racecourse Estate) and a further house meeting the Passivhaus Standard was completed in 2013 (Steel Farm). There are no other Passivhaus Certified buildings in the North East of England. To understand and address the concerns that are being raised, the longevity of airtightness requires further examination.

2 An Investigation into the Longevity of Airtightness

The Racecourse Passivhaus Estate is one of the largest projects of its kind in the UK. It is now almost 5 years since the dwellings became occupied. Building performance evaluation has been undertaken over this period [Fletcher & Johnston, 2014; Johnston & Fletcher, 2013]. There have been two significant findings.

Firstly, the measured *in-situ* heat losses from two of the dwellings were very similar to those predicted in PHPP [Johnston et al, 2014b]. In fact, it falls within the margin of error of the coheating test. This is significant because Leeds Beckett University have demonstrated that in the UK there is a building fabric thermal performance gap [Johnston et al, 2014b, 2015]. The work undertaken by Leeds Beckett University has proven that the measured *in-situ* heat loss tends to be far greater than that predicted, and in some extreme cases, has been over 100% more than intended. The dwellings at Racecourse are the first to demonstrate that the fabric performance gap can be closed [Siddall et al, 2013].

Secondly, the people living in these homes report high levels of comfort and satisfaction [Siddall et al, 2014].

2.1 Pressure Test Results (2011)

The dwellings at the Racecourse Estate are timber-frame and utilise diffusion-closed (i.e. highly moisture-resistant) construction. The air barrier was formed using a membrane with taped joints and an *in-situ* cast concrete floor. Services penetrations were sealed using proprietary EPDM grommets.

The original pressure tests were undertaken using the Passivhaus Standard, based upon BS EN 13829 and ATTMA Technical Standard L1 [Outhwaite, 2011]. As the dwellings are terraced, air leakage was determined using co-pressurisation (also known as pressure equalisation) whereby the dwellings either side of the house being tested were also pressurised. This means air leakage from the test dwelling to neighbouring dwellings can be avoided during testing, and a more accurate understanding of the air leakage of the external envelope can be determined. This method is not normally used for ATTMA TS-L1 compliant Building Regulations assessments, which involves testing a single dwelling at a time without co-pressurisation.

<u>Pressure Equalisation Tests</u>

The two bungalows described here form part of a terrace of seven properties. The air barrier is continuous around the entire terrace, of seven properties rather than around each individual bungalow within the terrace. Whilst this results in a greater risk of air leakage between properties, at the design stage the impact of this risk was considered to be lower than the risk of undetected thermal bypass occurring at the party wall.

Dwellings 1 and 2 were independently tested by Leeds Beckett University a few weeks after practical completion, but immediately prior to the commencement of an electric coheating test. The total fabric heat loss area of the dwelling as used in the electric coheating test was 245.6 m^2 for dwelling 1 and 244.5 m^2 for dwelling 2.

Figure 1 shows ATTMA-derived air leakage results and Figure 2 shows the results obtained from pressure equalisation tests.

Dwelling	Date	Depressurisation only	Pressurisation only	Mean Air Permeability	Pre / post coheating test
		$m^3.h^{-1}.m^{-2}$ @ 50Pa	$m^3.h^{-1}.m^{-2}$ @ 50Pa	$m^3.h^{-1}.m^{-2}$ @ 50Pa	
Dwelling 1	08/11/11	0.83	0.94	0.89	Pre
	21/12/11	0.86	0.91	0.89	Post
Dwelling 2	09/11/11	1.30	1.33	1.31	Pre
	22/12/11	1.30	1.33	1.31	Post

Figure 1: Tested to ATTMA Technical Standard L1 (ATTMA, 2010) [Johnston et al, 2012]

Dwelling	Date	Depressurisation only	Pressurisation only	Mean Air Permeability	Pre / post coheating test
		$m^3.h^{-1}.m^{-2}$ @ 50Pa	$m^3.h^{-1}.m^{-2}$ @ 50Pa	$m^3.h^{-1}.m^{-2}$ @ 50Pa	
Dwelling 1	08/11/11	0.43	0.46	0.44	Pre
	21/12/11	0.62	0.54	0.58	Post
Dwelling 2	09/11/11	0.66	0.62	0.64	Pre
	22/12/11	0.59	0.67	0.63	Post

Figure 2: Pressure Equalisation Tests to Passivhaus Standard [Johnston et al, 2012]

Dwelling 1 is an end-terrace plot, and dwelling 2 is mid-terrace. This means that dwelling 1 has one party wall, and dwelling 2 has two party walls. It may be considered that the only difference in air leakage between the ATTMA tests and pressure equalisation tests is through the party wall. Using the reference envelope areas to calculate the difference in flows between these two tests enables calculation of the assumed flow through the party wall area. Each party wall has an area of 29.3 m^2; it can be determined from these two test regimes that the air permeability of the party walls themselves is between 2.6 and 3.8 $m^3.h^{-1}.m^{-2}$ for these four tests. Thus although the party wall is only a small proportion of the envelope area, its permeability is calculated to be far higher than the external envelope.

Whilst it was not possible to access dwellings 1 and 2 for the latest series of pressure tests, it is anticipated that the nature of the air leakage and the variations between test conditions has remained similar. However, the air leakage through the party wall is known to be significantly influenced by the conditions within the adjacent property. If any doors or windows are open this will facilitate flow through the party wall, whereas if the adjacent dwelling is sealed there will be less flow through the party wall. Therefore the potential performance of a party wall cannot be properly considered without also controlling the conditions within the adjacent dwelling, which is not possible if the residents do not agree to cooperate with the tests.

<u>External Contractor Tests</u>

For compliance testing, an external contractor was used. Dwelling 1 used an internal volume of 232.7 m^3 and dwelling 2 used an internal volume of 227.2 m^3. Dwelling 1 and dwelling 2 used an internal volume of 260.7 m², some 15 m² larger than that used by Leeds Beckett. Figure 3 shows the results reported by the external contractor.

Dwelling	Date	Depressurisation only	Pressurisation only	Mean Air Permeability	Comment
		h^{-1} @ 50Pa	h^{-1} @ 50Pa	h^{-1} @ 50Pa	
Dwelling 1	27/10/11	0.40	0.58	0.49	Practical completion
Dwelling 2	27/10/11	0.43	0.56	0.50	Practical completion

Figure 3: External Contractor test to the Passivhaus Standard [Johnston et al, 2012]

The external contractors report states that the test results in Figure 4 were conducted to ATTMA Technical Standard L1 (ATTMA, 2010).

It is worth taking a moment to consider these results further. The low level of air leakage suggested by the external contractor's pressure tests (Figure 4) strongly agrees with the pressure equalisation tests undertaken by Leeds Beckett (Figure 2), when in fact they could be expected to agree with Table 1 (ATTMA Technical Standard L1). There are two conceivable reasons for the contrast between the external contractor's pressure test result and those of Leeds Beckett.

The first, least probable reason, is that the airtightness of the party walls degraded significantly between 27/10/11 and 08/11/11 (in just 12 days air leakage doubled). The second option is that the external contractor did not state the test conditions used to derive the results shown in Figure 4 i.e. it is suggested that these results may have been derived using the pressure equalisation test method.

Dwelling	Date	Depressurisation only	Pressurisation only	Mean Air Permeability	Comment
		$m^3.h^{-1}.m^{-2}$ @ 50Pa	$m^3.h^{-1}.m^{-2}$ @ 50Pa	$m^3.h^{-1}.m^{-2}$ @ 50Pa	
Dwelling 1	27/10/11	0.43	0.55	0.49	Practical completion
Dwelling 2	27/10/11	0.39	0.55	0.49	Practical completion

Figure 4: Suspected pressure equalisation test results by external contractor [Johnston et al, 2012]

2.2 Pressure Test Results Two and Three Years On (2013 / 2014)

Leeds Beckett undertook extensive monitoring in one of the Racecourse dwellings located at the end of a terrace as part of an in-use monitoring project funded by the Technology Strategy Board, now Innovate UK [Fletcher & Johnston, 2014]. As part of this project, a series of pressure tests were taken, see Figure 5. They did not use the pressure equalisation method. Broadly speaking there is good correlation between Figure 1 and Figure 5. The results in

Figure 3 could suggest that air leakage increased over time, however, it is possible that during the test on 22/07/14, given that this was during the summer, windows are more likely to have been open in the adjacent property. This could have affected the result.

Dwelling	Date	Depressurisation only	Pressurisation only	Mean Air Permeability	Pre / during / post in-use monitoring
		$m^3.h^{-1}.m^{-2}$ @ 50Pa	$m^3.h^{-1}.m^{-2}$ @ 50Pa	$m^3.h^{-1}.m^{-2}$ @ 50Pa	
Dwelling 7	22/07/14	1.45	1.28	1.36	Post
Dwelling 7	10/02/14	1.01	1.15	1.08	During
Dwelling 7	09/04/13	0.99	1.02	1.01	Pre

Figure 5: Tested to ATTMA Technical Standard L1 (ATTMA, 2010) [Johnston et al, 2014a]

2.3 Pressure Tests Five Years On (2016)

We found that neighbouring residents did not wish to take part in the new air leakage tests. For this reason, the air leakage was determined solely by testing single dwellings to ATTMA Technical Standard L1. As a consequence, the air leakage through the party wall into the neighbouring property is included in the measurements. Fortunately, because reference can be made to the results from the Leeds Beckett tests, generalised comparative analysis remains possible.

2.4 Terraced Dwellings Air Leakage Detection Five Years On (2016)

Temporary air sealing was undertaken around door and window openings in order to determine the extent of the air leakage associated with these components. For dwelling 7 thermographic imaging and a thermometer anemometer were used to assist with leakage detection. In practice it proved difficult to identify specific leaks, due to the very low leakage.

The results from the pressure tests without additional sealing are shown below in Figure 6.

Dwelling	Date	Depressurisation	Pressurisation	Mean Air Permeability
		$m^3.h^{-1}.m^{-2}$ @ 50Pa	$m^3.h^{-1}.m^{-2}$ @ 50Pa	$m^3.h^{-1}.m^{-2}$ @ 50Pa
Dwelling 7 (terraced)	05/01/16	0.84	0.82	0.83
Dwelling 7 (terraced)	11/12/15	0.79	0.91	0.85
Dwelling 9 (terraced)	10/12/15	1.13	1.23	1.18
Dwelling 3 (terraced)	06/01/16	1.24	1.34	1.29

Figure 6: Results of air leakage tests by Apex Acoustics

Using the data determined by calculating the effective party wall air leakage, as discussed in section 2.1, the authors have developed corrected air leakage calculations in order to estimate a likely range of air leakage through the fabric of the external envelope excluding the party wall leakage. The range of potential permeabilities illustrated for the party wall area is between the extremes measured, i.e. between 2.6 and 3.8 $m^3.h^{-1}.m^{-2}$. The results are shown in Figure 7, noting that dwelling 7 has one party wall, whereas dwellings 3 and 9 each share two party walls.

Dwelling / mean result from +ve and -ve pressure tests	Date	Low Party Wall Air Leakage	High Party Wall Air Leakage	Co-pressurised tests, 2011
		$m^3.h^{-1}.m^{-2}$ @ 50Pa	$m^3.h^{-1}.m^{-2}$ @ 50Pa	$m^3.h^{-1}.m^{-2}$ @ 50Pa
Dwelling 7 (terraced)	05/01/16	0.52	0.38	0.41
Dwelling 7 (terraced)	11/12/15	0.54	0.40	
Dwelling 9 (terraced)	10/12/15	0.56	0.28	0.51
Dwelling 3 (terraced)	06/01/16	0.67	0.39	0.44

Figure 7: Theoretical external envelope only air leakage compared with original tests [Outhwaite, 2011]

2.4 Detached Dwelling Air Leakage Detection Five Years On (2016)

There are three detached bungalows on the Racecourse Estate. The dwellings were the first constructed on the site. In essence they provided the test ground for the terraces that were built later.

Though these dwellings were constructed using the same fabric standards (including airtightness), construction technologies and building services they do not suffer from the added complexity of a party wall. In terms of energy performance, the only major difference is that fact they have a worse surface area to floor area ratio, consequently they do not satisfy the Space Heating Demand requirements of the Passivhaus Standard.

Access was granted to one of these dwellings. The history of pressure test results are shown below in Figure 8 and 9. It should be noted that the 14/04/11 test was undertaken when the air barrier was accessible and before any building services were installed.

Dwelling	Date	Depressurisation only	Pressurisation only	Mean Air Permeability	Comments
		$m^3.h^{-1}.m^{-2}$ @ 50Pa	$m^3.h^{-1}.m^{-2}$ @ 50Pa	$m^3.h^{-1}.m^{-2}$ @ 50Pa	
Dwelling 19	10/02/16	0.48	0.46	0.47	Occupied
Dwelling 19	12/08/11	0.31	0.47	0.39	Completion
Dwelling 19	14/04/11	0.35	0.28	0.32	Pre-services

Figure 8: Results of air leakage tests by Apex Acoustics compared with original tests [Outhwaite, 2011]

Dwelling	Date	Depressurisation only	Pressurisation only	Mean Air Permeability	Comments
		h^{-1} @ 50Pa	h^{-1} @ 50Pa	h^{-1} @ 50Pa	
Dwelling 19	10/02/16	0.50	0.48	0.49	Occupied
Dwelling 19	12/08/11	0.27	0.41	0.34	Completion
Dwelling 19	14/04/11	0.35	0.27	0.31	Pre-services

Figure 9: Results of air leakage tests by Apex Acoustics compared with original tests [Outhwaite, 2011]

3 Observations

Terraced Dwellings

Due to the limitations of the test regime, reliable comparison cannot be made with the air leakage requirements of the Passivhaus Standard. However, accounting for the potential range of air leakage through the party wall shows that current performance may not have changed since the original tests were undertaken in 2011.

Estimation of party wall air leakage is only possible with the results of tests using both the Passivhaus and normal ATTMA method on the same dwellings; this type of information is not usually available. In this case it illustrates how the party wall is far leakier on average than the external envelope.

Undertaking pressure tests years after project completion using co-pressurisation is always likely to be very difficult, as it requires a very high level of cooperation from the residents. For this reason it would be preferable to undertake this type of investigation on detached buildings.

Detached Dwelling

During the last five years one pane of triple glazing was removed and replaced due to a manufacturing error. The pressure tests identified that the glazing beads were poorly installed resulting in avoidable air leakage. It is considered that the majority of the increase in air leakage is associated with this window as no other significant air leaks could be readily identified throughout the house. A number of minor leaks appeared to exist at the corner of other windows.

In the detached dwelling air leakage has increased in real terms by 0.08 $m^3.h^{-1}.m^{-2}$ @ 50Pa (0.15 h^{-1} @ 50Pa). That infiltration is not significantly worse is considered to demonstrate that air tight design and construction, when undertaken properly, can perform over time. In this case it also means that air infiltration remains below the threshold required by the Passivhaus Standard.

4 Conclusion

The air leakage tests conducted for this study took place roughly five years after occupation. They suggest that:

- The air permeability criterion of 0.5 m^3-h/m^2, for protecting the building fabric from moisture damage, is still likely to be satisfied.
- High standards of air tightness can be maintained over significant period of time without significant degradation. As no further shrinkage and settlement can be expected the only risk to airtightness is wear-and-tear to window and door seals and changes to the building fabric made by the occupants.

In conclusion, with suitable maintenance it is considered that the airtightness of these properties should not significantly degrade.

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Short summary of your contribution:

Within the UK construction industry there is skepticism about whether or not the Passivhaus Standard provides a robust long term solution. A primary concern is that airtightness may degrade over time. This paper examines the performance of Certified Passivhaus homes located in the North East of England to compare as-built and current air tightness, 5 years on.