An extended pressure range comparison of the blower door and novel pulse method for measuring the airtightness of two outdoor chambers with different levels of airtightness

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ABSTRACT

The steady pressurisation method measures the building leakage in a range of high pressures, typically 10-60 Pa. It is implemented by creating a steady pressure difference across the building envelope and measuring the corresponding airflow exchange rate between the indoor and outdoor simultaneously. This method has been widely used and accepted as the standard test for demonstrating building air-tightness compliance. Conversely, the novel pulse technique, has been developed to measure the building air leakage at low pressures typically in the range of 1-10 Pa. The method is implemented by rapidly releasing a known volume of air from a compressed air tank into the test building, thereby creating an instantaneous pressure rise that quickly reaches ‘quasi-steady’ conditions. The pressure variations in the building and tank are monitored and used for establishing a correlation between leakage and pressure.

Although both techniques are designed to make measurements at different pressure levels, direct comparison between the results has always been of interest. In typical dwelling tests, it is not possible to achieve a direct comparison in an overlapped pressure range due to the low-pressure nature of the pulse technique. In this study, two small chambers, each with a volume of about 22 m^3 and with different leakage levels, were utilised to allow both testing techniques to measure the enclosure leakage in a much wider overlapped pressure range (up to 50 Pa). Blower door tests were performed in both pressurisation and depressurisation modes. Initial tests showed that due to the very small testing environment gaps around the blower door frame could account for up to 60% of the air leakage in the more air tight pod. As the pulse test requires no penetration of the building envelope, sealing of the door frames was essential to ensure a fair comparison. In the sealed condition it was found that there was less than 13% deviation between the blower door and pulse results across the range up to 50 Pa. However for the highly airtight chamber there was less agreement with up to 42% deviation.

KEYWORDS

Enclosure airtightness, Blower door, PULSE unit, outdoor environment, chamber

1. INTRODUCTION

1.1. Context

As a well-known and widely accepted steady pressurisation method for measuring building air leakage, the blower door method makes measurements in a range of high pressures, typically 10-60 Pa. It is implemented by creating a steady pressure difference, either negative or positive, across the building envelope and measuring the corresponding airflow exchange rate between the indoor and outdoor simultaneously. The novel pulse technique, developed to measure the building air leakage at low pressures typically in the range of 1-10 Pa, is implemented by rapidly releasing a known volume of air from a compressed air tank into the test building, thereby creating an instantaneous pressure rise that quickly reaches 'quasi-steady' conditions. The underlying principle is that of a quasi-steady flow, which can be shown to exist via the temporal inertial model and further detail is given by Cooper (Cooper 2007 and Cooper 2014). The pressure variations in the building and tank are monitored and used for establishing a correlation between leakage and pressure. The building air leakage result is quoted at low pressure, i.e. 4 Pa which is regarded as a typical weather-induced pressure level.

Although the pulse test is designed to resolve the issues existing in the measurement of building air leakage at low pressures, it is frequently asked how it compares with the blower door test at 50 Pa. The flow regimes at low pressure and high pressure levels are hydraulically dissimilar and therefore significant errors will occur in the prediction of air leakage rate from one level to the other (Cooper 2016, Zheng 2017). One of the issues with extrapolating the result at low pressure level to that at high pressure level is the absence of a higher data point, whereas an extrapolation downwards (as with the blower door tests) at least has the presence of the origin at the lowest point. Nevertheless, a direct comparison on the measurement of building leakage in wide pressure range is not practical in a typical house, due to the high mass flow rate that would be required of a single pulse to achieve the greater elevated building pressure.

In order to achieve direct comparison between the two methods, the measurement range of the pulse tests, carried out alongside blower door, is extended up to 50 Pa in two small outdoor pods with different leakage levels. Originally, one was designed to be Passivhaus standard and hence highly airtight (Pod 2) ; while the other one was fabricated to satisfy 2010 UK building regulations making it less airtight (Pod 1) (See Figure 3).

1.2. Equipment

The blower door unit that is used in this study is a blower door model 4 unit (abbreviated as BD-4), manufactured by 'The Energy Conservatory' in the United States. It consists of an adjustable door frame, flexible canvas panel, a variable-speed fan, and a DG700 pressure and flow gauge, as shown in Figure 1. The BD-4 with ring D and E was used to carry out the comparison tests alongside the PULSE-20 unit in this investigation. The PULSE-20 unit incorporates a 20 litre stainless steel tank and oil free double piston compressor as shown in Figure 2. The outlet utilises a ¼ inch (BSP) solenoid valve to release compressed air from the air tank into the test space for 1.5 seconds. The data is recorded and analysed by the control box and results are displayed on the LCD screen of the control box.

Figure 1 Energy Conservatory blower door model 4 (BD-4)

Figure 2 PULSE-20 and associated control box

1.3. Pods and Setup

Figure 3 shows the two test pods used for the comparison tests, located in the department of Architecture and Built Environment, University Park, Nottingham. Due to the ageing process, both pods have become leakier over the years but still maintain very different leakage characteristics from each other. The parameters of the pods are listed in Table 1.

Figure 3 Test pods (left: a Passivhaus pod (pod 2), right: a standard pod (pod 1))

Table 1 Envelope area and volume of the test pods

Pod	1: Standard	2: Passivhaus
Volume (m^3)	21	22
Envelope area (m^2)	47	48
Approximate ACH @50Pa	6	1.65

The setup of both units is shown in Figure 4 and Figure 5.

Figure 4 Setup of blower door model 4 (BD-4)

Figure 5 Setup of PULSE unit (PULSE-20)

2. TESTING ARRANGEMENT

When BD-4 was installed in the doorway, gaps could be seen between the BD-4 frame and the door frame, as shown in Figure 6. Such gaps result in a difference in envelope conditions when tests are being performed with the pulse and the blower door methods.

Figure 6 Difference between blower door installation (left) and actual door(right)

In order to evaluate and mitigate this difference, both tests are implemented in two different scenarios. For the blower door tests, they were performed with the gaps, sealed and unsealed and for the pulse tests with the door – door frame interface sealed and unsealed. Figure 7 shows how the sealing was applied in both tests. This arrangement therefore allows for the direct comparison of both the sealed and unsealed scenarios over a wide pressure range.

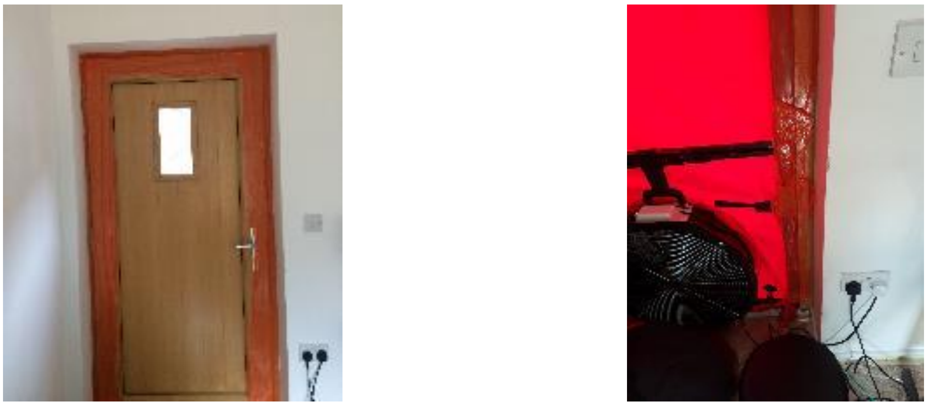

Figure 7 Sealing preparations (light red edging tape) in pulse (left) and blower door (right) test

3. RESULTS AND ANALYSIS

3. 1. Pod 1 (Standard Pod)

Figure 8 shows the pressure leakage correlations measured by both the pulse and blower door testing methods under two different scenarios. When sealed, the pressure-leakage curves produced by both pulse and blower door lie closely to each other throughout the entire testing range. Interestingly, the unsealed pressurisation test also provides a pressure-leakage curve that lies in proximity with the sealed tests which indicates the blower door might be pushed against the doorway to achieve a similar seal with that in the sealed condition when the pod is pressurised. Hence, the blower door test in the unsealed condition reported larger discrepancy between the pressurisation test and depressurisation test than that in the sealed condition. The pulse test shows a smaller difference between sealed and unsealed condition, which amounts to the leakage of the closed external door.

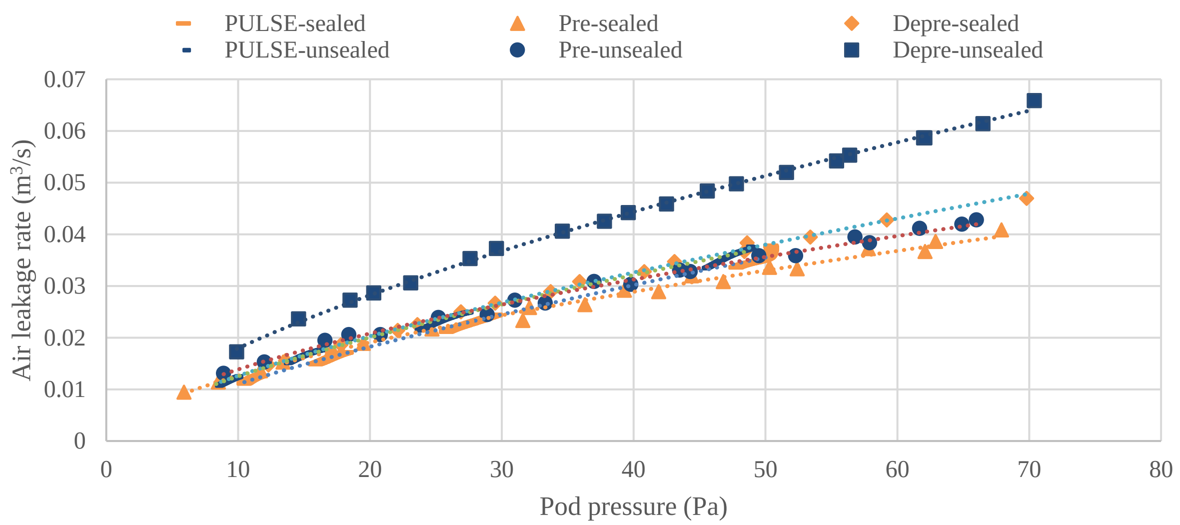

Figure 8 Pressure-leakage curves measured by both methods with and without sealing in pod 1

To have a quantitative insight, the power law was fitted to the pressure-leakage curves provided by both methods in sealed and unsealed conditions and the derived equations are listed in Table 2Table **2**. The equations mathematically represent the pressure-leakage correlations obtained in testing.

Table 2 Power law equation of blower door and pulse tests under sealed and unsealed conditions in pod 1

Test	Pressurisation	Depressurisation	PULSE-20
Sealed	$Q=0.0032\times P^{0.5976}$, $R^2=0.9957$	$Q=0.0026\times P^{0.6855}$, $R^2=0.9900$	$Q=0.0021\times P^{0.7267}$, $R^2=0.9978$
Unsealed	$Q=0.0036\times P^{0.5871}$, $R^2=0.9934$	$Q=0.0004\times P^{0.6525}$, $R^2=0.9983$	$Q=0.0026\times P^{0.681}$, $R^2=0.9984$
Note	Q (m^3/s) is the leakage rate at pressure difference P (Pa); R^2 represents the quality of curve-fit;(Coefficient of determination)		

In order to make direct comparison between the two testing methods, the range 10 Pa-50 Pa is chosen as the range of comparison as both contain actual measurements in this region. Figure 9 shows the relative percentage difference (RPD) of the blower door test results (pressurised and depressurised) from the corresponding pulse test result (i.e. sealed or unsealed.). When unsealed, the depressurisation test result deviated from the pulse result by 44.1% at 10 Pa, before steadily decreasing to 37.6% when the pressure increased up to 50 Pa; whilst the pressurisation test shows a deviation from 11.5% to -4.1%. It is therefore observed that pulse tends to agree well with the pressurisation test but deviates significantly from the depressurisation test for these unsealed door conditions. In the sealed condition, the blower door pressurisation test showed an RPD from the pulse test of 13.2% at 10 Pa before steadily reducing to -8.0% when the pressure increased to 50 Pa. The depressurisation test showed a deviation ranging from 12.6% to 5.4% when the pressure increased from 10 Pa to 50 Pa. Hence, the blower door test results, especially the depressurisation test, showed reasonably good agreement to the pulse test result and more so at the higher end of the pressure range for this sealed door scenario.

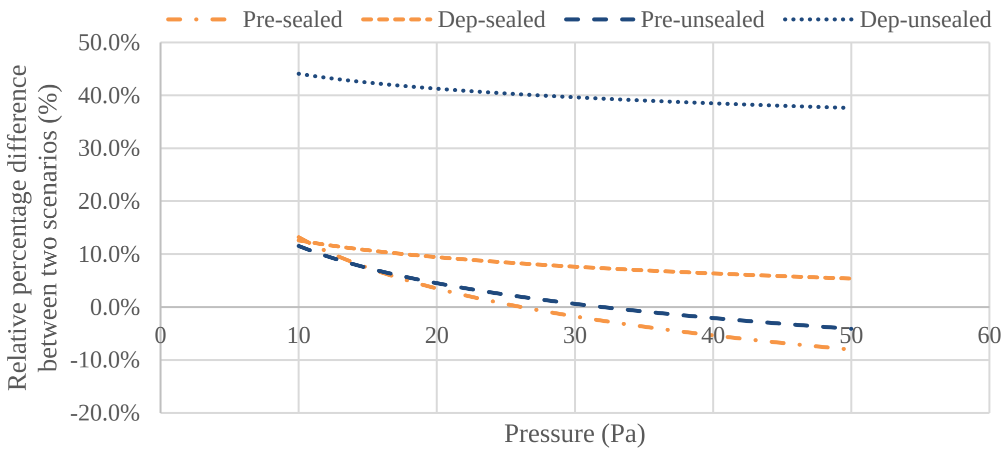

Figure 9 Relative percentage difference (RPD) of blower door test results against the pulse results in sealed and unsealed condition

It is clear from the analysis above that ensuring the test condition is comparable, by mitigating leaks around the door for both methods has provided results, which demonstrate a closer agreement. The impact of the leaks around the blower door and lack of sealing of the main door in the pulse test contribute to a deviation of the results provided by both methods. Further investigation illustrates the impact of this in Figure 10. By sealing the gaps, the pulse test measured leakage rate of the pod envelope is reduced by 10.3% at 10 Pa and down to 3.4% at 50 Pa. For the blower door test with the pressure increasing from 10 Pa to 50 Pa, the reduction in the measured leakage changed by 29.9% to 26% in the depressurisation test, and by 8.9% to 7.4% in the pressurisation test. Hence, when applying the sealing the measured leakage of the pod envelope shows the greatest impact on the blower door depressurisation test, followed by the pressurisation test and with the smallest impact on the pulse test. This would seem intuitive given that the blower door frame is a temporary fixture and liable to some movement when under a sustained pressure differential.

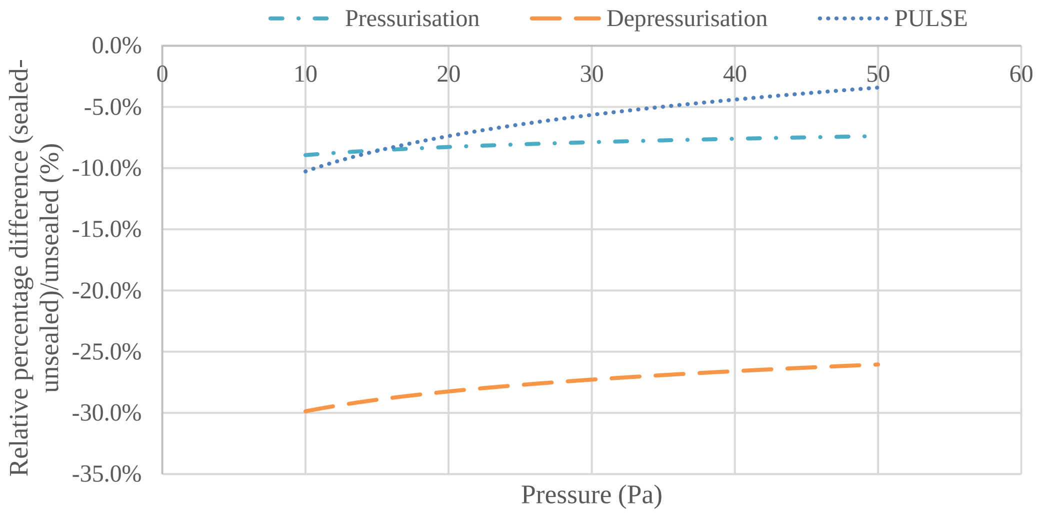

Figure 10 Impact of the sealed testing condition on the pulse and blower door test results

3. 2. Pod 2 (Passivhaus Pod)

Figure 11 shows the pressure-leakage correlations measured by both testing methods under the two different scenarios for the more airtight Pod 2. When the sealing was applied, the pressure-leakage curves produced by blower door tests gave a measurement that is more airtight than the pulse test. When unsealed, it is the opposite, i.e. the pulse test provided a measurement of airtightness that is better than the blower door test result. In both sealed and unsealed conditions, the pressurisation test gave more airtight measurement than the depressurisation test. A practical reasoning for this is possibly due to the blower door frame being pushed against the door frame consequently making the blower door installation slightly more airtight in pressurisation test than in the depressurisation test.

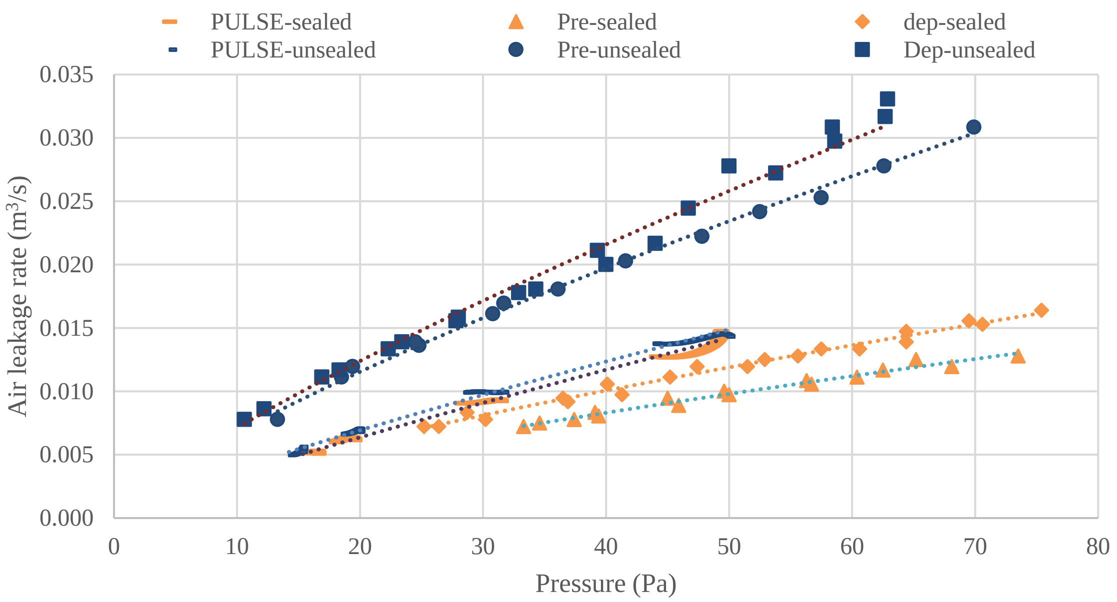

Figure 11 Pressure-leakage curves measured by both methods with and without sealing of Pod 2

The Power law was fitted to the pressure-leakage curves and the equations for all the tests are obtained for pod 2 and listed in Table 3. The range for comparison is chosen as 15 Pa-50 Pa to cover the available data points.

Table 3 Power law equations of blower door and pulse tests under sealed and unsealed conditions in pod 2

Test	Pressurisation	Depressurisation	PULSE-20
Sealed	$Q=0.0005\times P^{0.7365}$, $R^2=0.9828$	$Q=0.0006\times P^{0.7496}$, $R^2=0.985$	$Q=0.0005\times P^{0.8773}$, $R^2=0.9944$
Unsealed	$Q=0.0011\times P^{0.7727}$, $R^2=0.9932$	$Q=0.0011\times P^{0.8007}$, $R^2=0.9904$	$Q=0.0006\times P^{0.8344}$, $R^2=0.9961$
Note	Q (m^3/s) is the leakage rate at pressure difference P (Pa); R^2 represents the quality of curve-fit; (Coefficient of determination)		

Figure 12 provides details of the RPD of leakage tests results for blower door versus pulse for the sealed and unsealed conditions. The leakage rate measured at 15 Pa by the blower door in the sealed condition is 31.7% and 15.1% smaller in pressurisation and depressurisation tests respectively, when compared to the pulse test at 15 Pa. As the pressure difference across the pod envelope increased up to 50 Pa, the figures steadily drifted away from the pulse result by 42.4% and 27.2% respectively. This shows the depressurisation test provides relatively better agreement with the pulse test than the pressurisation test for the sealed condition. In the unsealed condition tests across the range of pressure 15 Pa to 50 Pa, the blower door gave leakier measurement than pulse by 55.1% to 44.0% in pressurisation, and by 67.3% to 60.7% in depressurisation. Hence in the unsealed condition the pressurisation result gave slightly closer agreement with pulse. It is seen that the sealed condition provides results which have slightly better agreement between the two methods, particularly at the lower end of the pressure range. However it is interesting to see that the sealed condition deviates further from pulse towards higher pressure, whereas the unsealed condition tends towards pulse.

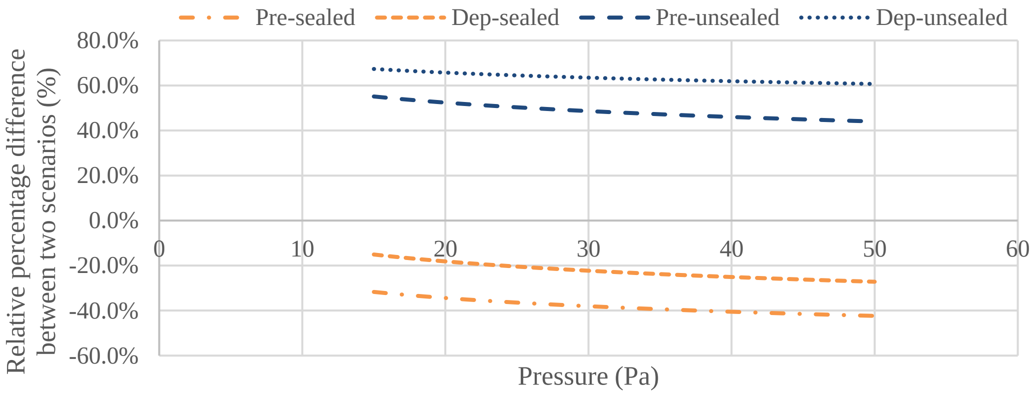

Figure 12 Relative percentage difference (RPD) of blower door test results against the pulse results in sealed and unsealed condition

The impact of the sealed condition on the measurements of the pod leakage level by both testing methods in the comparison range is plotted in Figure 13. For the pulse test, sealing of the doorway reduces the leakage rate by 6.4% to 1.4% across a pressure difference range of 15 to 50 Pa. This therefore, indicates that the leakage through the door frame could represent 1.4%-6.4% of overall leakage of the pod envelope, i.e. a slight leakiness of the pod door exists. For the blower door test, the sealed condition reduced the leakage rate by 58.8%-60.5% in pressurisation mode and 52.5%-55.3% in depressurisation mode. This shows the leakage through the blower door installation contributes significantly to the overall chamber leakage of the more airtight pod. Overall, the sealed condition provides a better airtightness for both the pulse and blower door methods but with a significantly larger impact on the blower door test in this situation.

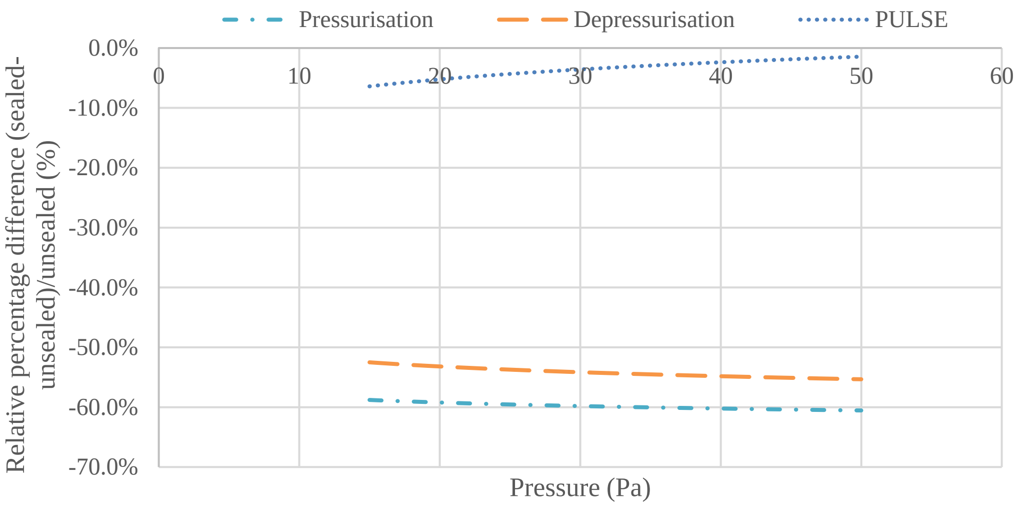

Figure 13 Impact of sealed condition on the pulse and blower door test results

4. DISCUSSION AND CONCLUSION

This experimental study has investigated measuring building airtightness by means of the pulse method at higher pressure differentials than previously observed. Pulse is a low pressure technique (reported at 4Pa), where pressure increase within the building envelope is typically no higher than 10 Pa, due to the combination of volume flow rate of air from the pulse unit and the overall airtightness of the dwelling. In this investigation two small test chambers, with different airtightness levels enabled a pressure rises up towards 50 Pa. This has enabled a direct comparison between the pulse and blower door methods throughout this pressure range.

It was observed for both Pod 1 and the more airtight Pod 2 that the gaps between the blower door and door frame were responsible for a significant proportion of the overall air leakage in the test arrangement when the door/ blower door interface was not over sealed; up to 30% for Pod 1 and up to 60% for Pod 2. This could be expected due to the very small environment being tested and therefore gaps around the test door become a significant component of the overall leakage. It is therefore imperative that comparative tests between pulse and blower door must ensure that these gaps are sealed to ensure that overall envelope conditions are as close as possible.

In the scenario where the door frames were sealed, Pod 1, which has an airtightness level typical of new build dwellings in the UK, has shown good agreement of results between the pulse and blower door methods, circa <13% deviation across the range. However, Pod 2 gave less agreement than in Pod 1; circa <42% maximum, though this maximum exists at the higher end of the pressure range with closer agreement at lower pressures. It must be noted that in such an airtight enclosure the test results will be highly sensitive to any differences in the envelope condition due to the blower door installation/ sealing of the door with pulse. To further investigate the potential for this will require repeated tests in scenarios of re-installation of door sealing etc. For the pulse test, each individual test provides a number of data points across a small range of pressure. Ordinarily, when the pulse test is used at low pressure the air leakage of a dwelling would be calculated using this gradient. The gradients of the individual pulse results are therefore an area of interest and results for Pod 1 show line gradients close to that of the curve produced by blower door, whilst Pod 2 show some interesting variations. It was found in testing that the pulse created in Pod 2 was unlike that seen in average dwellings, which was caused by the fact that in this highly airtight pod it took longer for the pressure pulse to peak and hence a range of data that is closer to the peak was captured for analysis i.e. the elevated pressure persisted for a prolonged period following the cessation of air from the pulse unit. Further testing in this field will look at the behaviour of pulse i.e. pulse shape in the highly air tight environments and how this may affect the results.

The BD-4 blower door used in this test is considered to be quite large for this testing; though still within flow calibrated limits. Further testing in this area will use a smaller capacity blower door arrangement.

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