MEASUREMENT OF BUILDING LEAKAGE BY UNSTEADY PRESSURISATION

E. W. Cooper[1] and D. W. Etheridge[2]

School of the Built Environment, University of Nottingham,
Nottingham, NG7 2RD, UK
[1] *+44 (0) 115 951 3028 email:- laxewc@nottingham.ac.uk*
[2] *+44 (0) 115 951 3171 email:- david.etheridge@nottingham.ac.uk*
Fax +44 (0) 115 951 3159

ABSTRACT

The paper describes the development of unsteady pulse pressurisation techniques for measuring the leakage of buildings. The original version of the technique (the UP technique) has been investigated experimentally and theoretically in a single cell test space. The initial results are very promising, with a good degree of repeatability and similar sensitivity to changes in leakage levels as the conventional steady (DC) technique. An interesting outcome of these early tests was the observation that quasi-steady flow could be established in a short time. This has led to a second version of the technique (the QP technique) and evidence is provided which indicates that this version could offer greater accuracy than the UP and DC techniques.

KEYWORDS

Leakage, infiltration, buildings, unsteady, quasi-steady, pressurisation,

INTRODUCTION

The importance of adventitious leakage has long been known, but it has recently been highlighted in the UK by amendments to Part L2 of the Building Regulations, see DTLR (2002), which require that the air leakage of large buildings be measured on completion, and that it should comply with set levels. The legislation may eventually be applied to virtually all buildings, including dwellings. Currently adventitious leakage is measured by subjecting the building to a known steady flow and measuring the resulting pressure difference. This is the well-known steady leakage technique, often called the DC technique. Although well-established, the technique is not perfect, particularly for large buildings.

In an earlier paper by Carey and Etheridge (2001) it was concluded that a novel form of pulse pressurisation technique allied to a mathematical model of unsteady ventilation offers a way of determining the adventitious leakage of large buildings that would be difficult or impossible with the conventional DC technique. Since that time more precise equipment and instrumentation have been developed and tests have been carried out that demonstrate the promising nature of the technique. During these studies it became apparent that there is another way in which the pulse technique and the mathematical model could be used. This followed from the observation that quasi-steady flow is established quickly after the start of the pulse.

This paper is therefore concerned with two techniques and to distinguish them the first is called the unsteady pulse (UP) technique and the second is called the quasi-steady pulse (QP) technique. Both techniques use the same equipment and mathematical model; they differ only in the way in which the results are analysed.

EXPERIMENTAL EQUIPMENT AND PROCEDURE

The basic technique is to subject the building to a rapid and known change of volume and to record the pressure response with time. For small buildings a single pulse unit is used. For large buildings a number of identical units would be distributed around the building and fired simultaneously. In principle there is no limit to the size of building that can be tested. One simply increases the number of units. This is potentially a major advantage of the technique. Another major advantage is that testing time is reduced. With the pulse technique there is no need to penetrate the envelope and the test itself takes only a few seconds. The pulse unit is simple, relatively inexpensive and can easily be reproduced for multiple applications.

The basic pulse generation equipment consists of a piston that slides along a fixed shaft in a cylinder. The piston is displaced by injecting air into the cylinder from one or two compressors with solenoid valves operated by a time sequencer. A displacement transducer is used to measure the instantaneous position of the piston.

THEORETICAL MODEL AND ANALYSIS

It is the theoretical model that relates the measured pressure pulse to the leakage characteristics of the envelope. The model is described in Carey and Etheridge (2001) and only an outline is given here. This is followed by an explanation of how the model is used specifically for the two techniques.

The basic concept can be seen by considering Figure 1, which shows a single cell of volume, V, with a single opening and a piston. A displacement of the piston, δV, leads to a piston volume flow rate, q_p, and a flow rate through the opening, q. There will be a corresponding change in the internal pressure, P_i, relative to the external pressure, P_e.

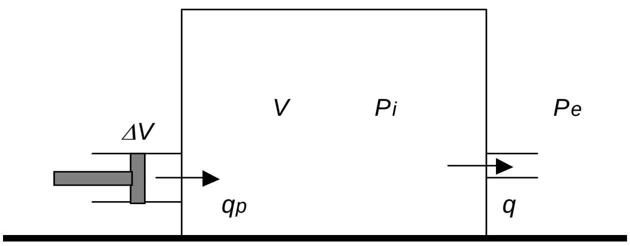

Figure 1: Cell with single opening acted on by a piston.

The theoretical approach is known as the quasi-steady temporal inertia model (QT model). It solves a set of simultaneous first order differential equations, namely the continuity equation for the enclosed space and integral momentum equations for the openings in the envelope.

The continuity equation includes the effect of compressibility of the air in the space and takes the form

$$\frac{1}{\rho_i} V \frac{d\rho_i}{dt} = q_p\{t\} + q\{t\} \quad (1)$$

Isentropic expansion of the air is assumed, to provide the relation between density and internal pressure.

The momentum equation takes the form

$$\Delta p\{t\} = \frac{\rho B}{2}\left(\frac{q}{A}\right)^2 + \frac{\mu CL}{2d^2}\left(\frac{q}{A}\right) + \rho \frac{dq/A}{dt}\left(L + 1.67d\right) \quad (2)$$

Where Δp denotes the pressure difference across the opening. The third term on the right-hand side accounts for the inertia of the air that flows through the opening i.e. the air at the inlet and outlet and the air contained within the opening itself.

The Unsteady Pulse (UP) Technique

For the UP procedure, the leakage characteristic of the complete envelope is represented by a single opening, with a leakage Q_{50} and a shape parameter a/b^2. The equation for the flow through the opening is taken to be the quadratic form.

The adventitious leakage of the building is obtained by determining the value of Q_{50} (with a specified value of a/b^2) that best matches the predicted pressure response to the measured pressure response. The value specified for a/b^2 will generally be the value that lies midway in the range of values encountered in buildings. For the investigations described below, the values of Q_{50} and a/b^2 were obtained from a DC test. For the basic data analysis the program in essence determines the difference between the pressure at the peak of the pulse and at reference points before and after the pulse. This value is referred to as ΔP_{max}.

The Quasi-Steady Pulse (QP) Technique

For quasi-steady flow to occur, the inertia term in Eqn. 2, i.e. the third term on the right-hand side, needs to be small compared to the other terms. When quasi-steady flow occurs, the relationship between the instantaneous values of $q\{t\}$ and $\Delta p\{t\}$ is the same as that for steady flow i.e. a plot of $q\{t\}$ against $\Delta p\{t\}$ will lie on the steady flow characteristic. To determine $q\{t\}$ from the measurements it is necessary to take account of the change of internal pressure by using the continuity equation (Eqn. 1).

When the steady flow leakage characteristic is known, from a DC test, it is relatively easy to check the existence of quasi-steady flow. However, in a real situation one would not have the DC curve and it would not be obvious whether quasi-steady conditions had been reached. This is where the theoretical model is used in the QP technique. It is simply used to determine at what time the inertia term in Eqn. 2 becomes negligible. In principle, the QP method is more accurate than the UP technique, because assumptions about a/b^2 and the depth L of the openings do not have a direct effect on the results.

EXPERIMENTAL RESULTS

All experimental investigations so far have been in a single cell test room of volume 406 m^3.

The first measurement to be done was a conventional DC test to ascertain Q_{50} for the room and thereby the air permeability. This was done using the British Gas leakage tester, which offers relatively high accuracy by virtue of the fact that is makes use of an averaging flow meter (Wilson flow grid) in a long duct (see Section 10.2 of Etheridge and Sandberg (1996)). Q_{50} was found to be 2294 m^3/h, which corresponds to a value for the air permeability that is slightly less than the requirements of the new Building Regulations of 10 $m^3/(h.m^2)$, so the room is a suitable test case.

The Unsteady Pulse (UP) Technique

The first investigation concerned the repeatability of the UP technique. Measurements were carried out on different days and with the piston in different locations and facing different directions. The deviation of ΔP_{max} remained less than +/- 5 %, with an average value of approximately 9 Pa. The results of some of these early tests, conducted at different times, are shown in Figure 2. The left-hand plot shows the actual recorded pressure responses, which start from different base levels. It is the change in pressure that is relevant, so the right-hand plot shows the collapse of the data when the base levels are shifted. The pulse start times are slightly offset for clarity.

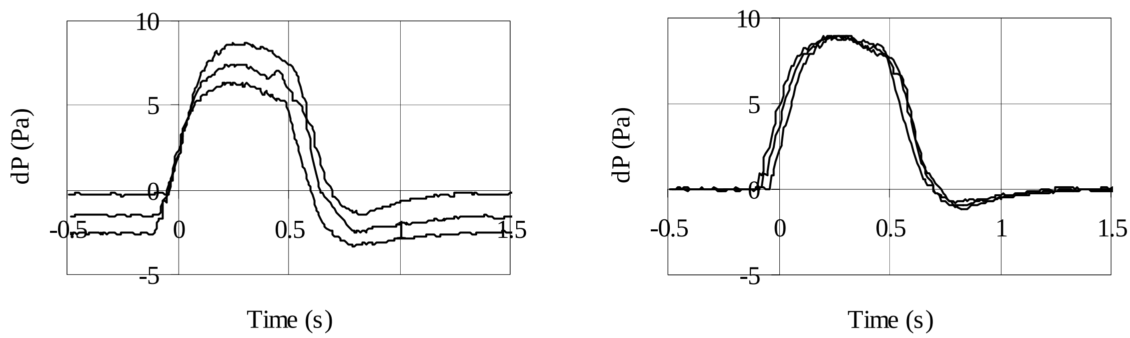

Figure 2: Early experimental results showing repeatability before and after shifting base levels.

An investigation into the sensitivity of the UP and DC techniques to changes in leakage levels was carried out by using both techniques before and after sealing an opening in the test room envelope.

TABLE 1
Sensitivity to changes in leakage levels.

	DC measurement Q_{50} (m^3/s)	Experimental UP ΔP_{max} (Pa)	Theoretical UP ΔP_{max} (Pa)
Before sealing opening	0.64	8.492	8.322
After sealing opening	0.58	9.3272	9.088
Percentage change	-9.38 %	9.84 %	9.21 %

The percentage changes can be seen in Table 1. The Q_{50} and experimental ΔP_{max} percentage changes were of similar magnitude, suggesting that the pulse test is at least as sensitive to changes in leakage as the steady test. Importantly the experimental UP and theoretically predicted ΔP_{max} were within less than 1% of each other. This suggests that the model is a good predictor of what can be expected in practice.

Figure 3 shows the experimental and theoretical pressure pulses for an unsteady pressurisation test after the opening was sealed. It can be seen that the model provides a reasonably close fit with the experimental pulse.

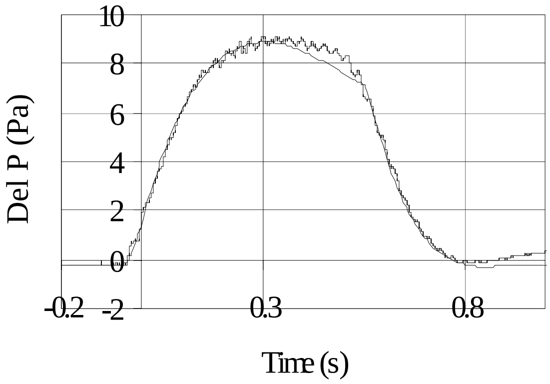

Figure 3: Comparison of experimental (jagged) and theoretical (smooth) pressure pulses.

The Quasi-Steady Pulse (QP) Technique

In Figure 3, it is seen that there is a region between the peak pressure and the start of the rapid fall in pressure where the pressure reduces relatively slowly with time. This is where the flow could be behaving in a quasi-steady manner. When the steady flow leakage characteristic is known, it is relatively easy to check the existence of quasi-steady flow. Figure 4 shows results plotted in this way (only data recorded in the region of interest is plotted), with the arrow showing the direction of increasing time. The DC curve is extrapolated from measured data and may itself be subject to error. Comparison with the DC curve indicates that the results are tending towards a quasi-steady condition, but it seems that condition is not quite reached. The total piston travel time is about 0.7 s for the QP test.

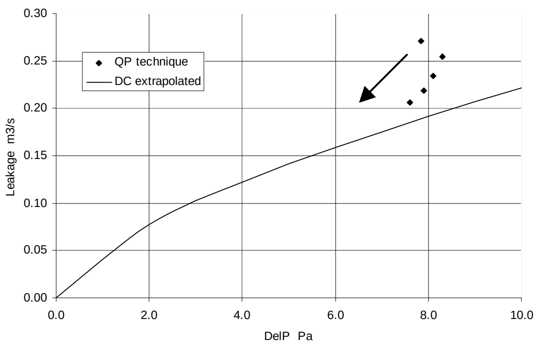

Figure 4: Checking for quasi-steady flow (with short pulse time).

In view of this, a further test was carried with a longer pulse time. The corresponding results are shown in Figure 5. Here it can be seen that quasi-steady conditions appear to have been reached, with good agreement with the DC curve.

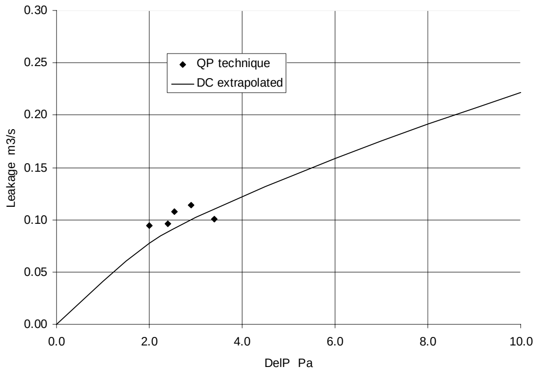

Figure 5: Checking for quasi-steady flow (with long pulse time).

CONCLUSIONS

Two techniques based on an unsteady pulse pressurisation method, for measuring the leakage of building envelopes, have been investigated. Both techniques have potential advantages over the conventional steady (DC) pressurisation technique. The key advantages are that there is no need to penetrate the building envelope, the testing is rapid, results are obtained at pressures normally encountered in ventilation and there is no limit to the size of building that can be tested.

The unsteady pulse (UP) technique has been shown to work well in a single cell test space. Experiments have shown that it is repeatable and is as sensitive to leakage changes as the steady (DC) technique.

The quasi-steady pulse (QP) technique has been shown experimentally to be viable and theoretical investigations indicate that it offers greater accuracy than both the UP and DC techniques.

Further work is concentrating on the use of multiple pulse units for large buildings and on a full theoretical investigation of uncertainties under real operating conditions.

ACKNOWLEDGEMENTS

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REFERENCES

1. DTLR, 2002. The Building Regulations 2000: Approved Document Part L2 Conservation of fuel and power in buildings other than dwellings, 2002 Edition. The Stationary Office.
2. Carey PS and Etheridge DW, 2001. Leakage measurements using unsteady techniques with particular reference to large buildings. *Building Serv. Eng. Res. Tech.* 22, 2 (2001) pp. 69-82
3. Etheridge, D. W. and Sandberg, M. (1996). *Building Ventilation: Theory and Measurement*, John Wiley & Sons, Chichester, UK, 720pp. ISBN 0 471 96087 X