A New Technique for Measuring Airtightness of the Building Envelope Using Pulse Pressurization

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Summary

A pulse pressurization technique to measure the airtightness of the building envelope is developed. The governing equations are introduced and the procedure for deriving air-tightness parameters from the pressure decay curve is shown. Pulse pressurization is supplied using a high-pressure air tank. The pressure decay after pulse pressurization is measured provides the air leakage equation for a test house.

Introduction

In rooms housing laboratory animals, sterilizing a previously occupied room by fumigation can injure animals in adjacent rooms. In order to prevent this harm, sufficient airtightness of the room envelope is necessary. The air leakage testing of animal rooms as built is inevitable. Conventional leakage test methods, such as the conventional DC pressurization method, are not well-suited to laboratory animal rooms because such methods require the envelope to be drilled and the pressure difference is supplied by a fan. In addition, the AC method, which is used to measure the pressure oscillation, must be performed using the same assembly. Laboratory animal rooms must be carefully constructed so as to have sufficient airtightness. Thus, it is not desirable to bore a hole in a wall or door of the animal room for the airtightness test after the completion of the construction. Unlike conventional leakage test methods, the pulse pressurizing (PP) method does no damage to the building envelope and is well-suited to the airtightness testing of the laboratory animal room.

Theory

The leakage can be determined by applying the continuity equation under the assumption that the pressure change is small compared to ambient pressure and therefore the air inside a room is incompressible. The amount of air M is injected into a room of volume V, and the leakage Q flows in and out through the envelope. The change of air density ρ in the room is then given as:

$$V\frac{d\rho}{dt} = M - \rho Q \qquad (1)$$

The air within the room is assumed to be an ideal gas, that is,

$$\rho = \frac{G}{V} = \frac{P}{RT} \qquad (2)$$

Then, substituting (2) into (1) yields

$$V\frac{dP}{dt} = RTM - PQ \qquad (3)$$

The pressure difference across the envelope is very small compared to atmospheric pressure, that is,

$$P = P_a + p \qquad P_a \ll p \quad \therefore P \cong P_a$$

This equation yields

$$V\frac{dp}{dt} = RTM - P_aQ \qquad (4)$$

The leakage may be described by a power law expression, that is,

$$Q = ap^n \qquad (5)$$

Substituting (5) into (4) yields

$$V\frac{dp}{dt} = RTM - P_aap^n \qquad (6)$$

if the pressure change is steady-state, i.e., the right side is zero and (6) expresses the conventional DC pressurization method. When the amount of air M is injected in a volume-oscillatory manner, (6) provides the interior pressure response synchronously to the volume oscillation and can be used together with the AC pressurization technique (1).

If $M=kp$, then (6) is Bernoulli's equation, which can be solved as follows: (2)

$$p = \left[\frac{A}{B'}\left(1 - e^{(1-n)B't}\right)\right]^{\frac{1}{1-n}} \qquad (7)$$

$$A = \frac{P_aa}{V} \qquad B' = \frac{RT\kappa}{V}$$

The value in the brackets on the right side of (7) is negative, which does not agree with the physical (natural) phenomena. When M is constant, (6) becomes nonlinear and can not be solved. When M is zero and the initial value of p is given, (6) becomes linear and can be solved. During a short time interval (from t=0 to t=t_0), the amount of air M_0 is injected into the room. After the room pressure reaches p_0, the air supply is suddenly stopped. The pressure will decrease according to the leakage rate. This pressure decay can be described as follows:

$$p = p_0\left[1 - \frac{\frac{P_aa}{V}(1-n)(t-t_0)}{p_0^{1-n}}\right]^{\frac{1}{1-n}} \qquad t \geq t_0 \qquad (8)$$

where p_0 is the initial pressure caused by pulsate injection of air.

Figure 1 shows the pulse pressurization and the pressure decay. As shown in figure 1, the pressure data is collected and fitted to (8). Thus, we can obtain values for leakage parameters n and a. In addition the leakage equation (5) can be determined.

Unfortunately (8) is not linear, so it is very difficult to obtain an approximate equation for (8) using the least-squares regression. Therefore, we derive the leakage (5) directly from the measurement of the pressure decay. From (4), the relationship between the pressure decay and the leakage is as follows:

$$Q = -\frac{Vdp}{P_adt} \qquad (9)$$

Using the sampling pressure $p(t)$, we can approximate (9) as follows:(3)

$$Q(t) = -\frac{V}{P_a}\frac{p(t+\Delta t)-p(t)}{\Delta t} \qquad (10)$$

A set of values $(p(t_1), Q(t_1))$, $(p(t_2), Q(t_2))$,..., $(p(t_n), Q(t_n))$, calculated from (10) will give the leakage equation (5) by using the least-squares regression.

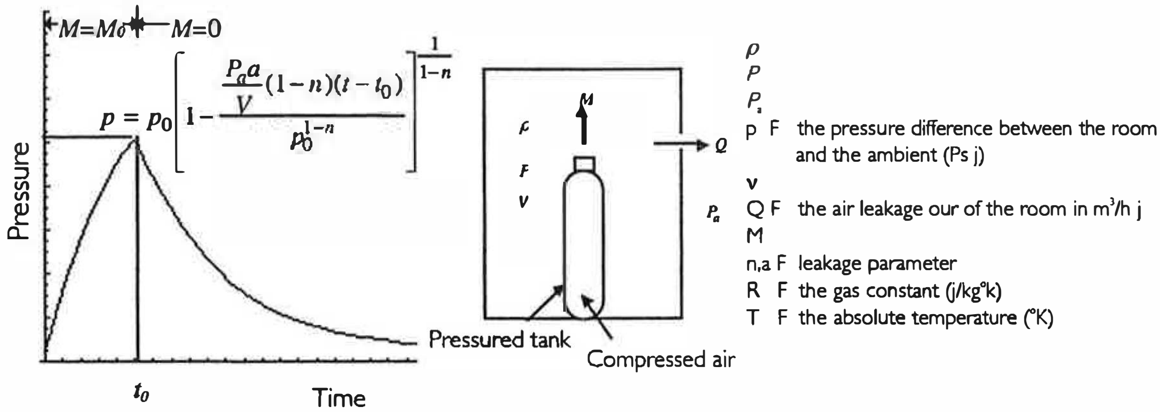

Figure 1. Pulse Pressure and Pressure Decay

Procedure and Experiment

Figure 2 shows the schematic view of the proposed technique. The necessary equipment consists of a pressure tank, a pressure sensor and a recorder. The pressure tank acts as the pressure source and releases the compressed air through a quick-opening valve into the room. The pressure sensor then detects the pressure change, i.e. the rise or fall after air has been released, and the recorder collects the pressure data. The valve of the pressure tank is opened to release a small amount of air into the room and is then closed shortly thereafter. The pressure in the room rises rapidly and then decays due to leakage. The pressure sensor measures either the difference in pressure between the room and the ambient, or the pressure change in the room. For laboratory animal rooms, the latter is preferable because this technique does not require holes to be bored in the wall.

Results

Figure 3 shows the experimental pressure decay results obtained using a test house for three airtightness conditions. Figure 4 show a comparison between the proposed pressurization method and the conventional DC pressurization method. This figure shows very good agreement between the results obtained using these two methods.

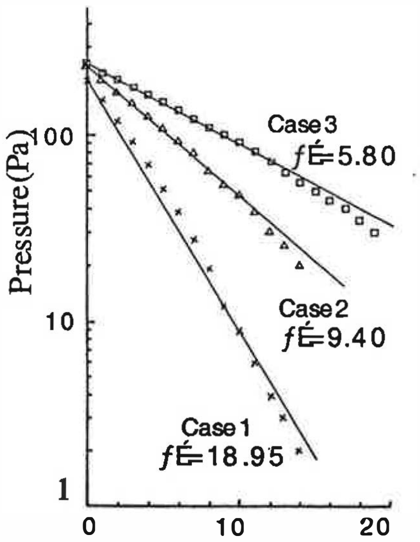

Figure 3. Pressure Decay

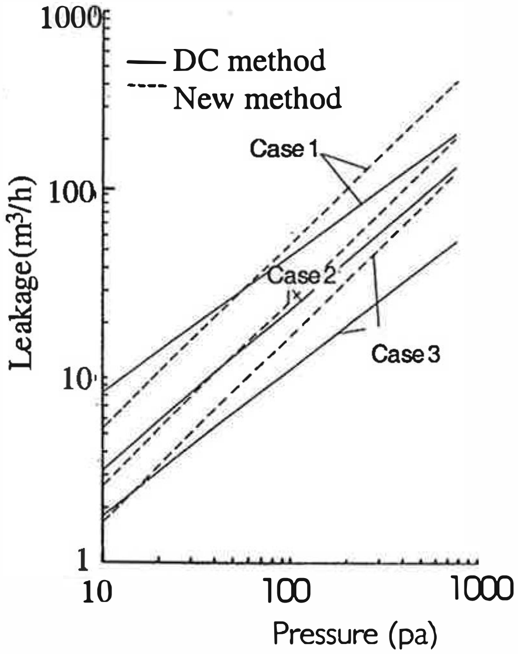

Figure 4. Leakage Equation

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