BSL-4 Pressure Decay Equivalency Test

By;

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The following Pressure Decay Equivalency Test for BSL-4 facilities was created by Farhad Memarzadeh of the National Institutes of Health in 2006. This was developed to provide flexibility for commissioning agents in performing the standard 2”H_2O/20min/50% test in a BSL-4 laboratory.

Description of the physical phenomenon

When a room is negatively or positively pressurized, air can leak through small cracks. Over time, unless the pressure difference is actively maintained, the leak will reduce the pressure difference and eventually equalize the pressure between the room and the ambient.

Standard Test Condition

The standard test condition requires a room to hold a 2" H_2O pressure initially, then over a period of 20 minutes, the pressure should decay no less than 50%, (i.e. 1" H_2O), of its original pressure. If a room meets the above condition, then it passes the test.

Theory of the Equivalency

The standard test condition is in fact a method to specify the crack size.

1). The larger the crack, the lower the residual pressure will be.
2) For a given crack, the rate of pressure decay is different but *predictable* under different initial pressure. Therefore, an alternative and equivalent test, which has different initial pressure, can be performed to determine whether the room can pass the standard test. Since the standard test condition is difficult to meet experimentally, the alternative test condition provides a convenient yet accurate way to conduct the test.

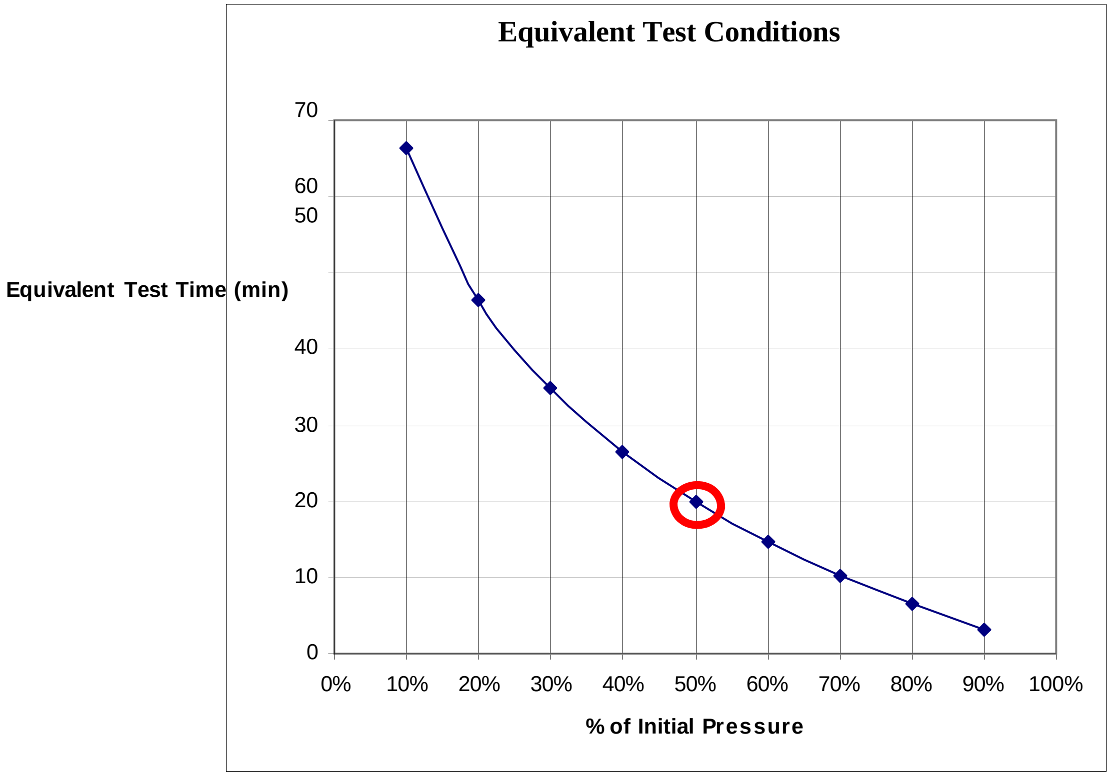

Figure 1. Equivalent test conditions based on pressure measurement.

Figure 1 gives equivalent test conditions under various residual pressures. The equivalency theory states that **"The time it takes to drop the pressure to a given percentage of its initial pressure should be the same".** In other words, the time it takes to drop the pressure from 0.5" H_2O to 0.25" H_2O, is the same as from 2"H_2O to 1"H_2O. Therefore, the equivalent test, i.e, test at lower pressure, can be conducted in the same fashion as the standard test. The point (50%, 20min) is highlighted to indicate the condition commonly used in measurement.

Furthermore, it is worthwhile to note all points on the curve are equivalent test conditions. For example, a (50%, 20min) test is equivalent to (70%, 10.3min) test.

The appendix gives the data points used to draw the above figure.

Note: The above plots are applicable for all room sizes as the allowed crack size area changes with room size proportionally.

Theory behind Equivalent Test Conditions

The following equations illustrate the theory behind the equivalency.

Pressure Decay and Equivalency Equations

$$\frac{dp}{dt} = \frac{dP}{dt} = \frac{d\rho}{dt} R_{air} T_{rm} = \frac{dM_{room}}{dt} \frac{R_{air} T_{rm}}{V_{rm}} = -\rho Q \frac{R_{air} T_{rm}}{V_{rm}} \qquad (1)$$

$$Q = cp^{n} \qquad (2)$$

Here, c is a flow coefficient, n is the pressure exponent. [1]When the flow through the crack is laminar, n is 1, when flow turns turbulent, n=0.5. A real building envelope will lie somewhere in between. [2]

Assume ρ , T = const

$$\frac{dp}{dt} = -p^{n} c \frac{R_{air} T_{rm}}{V_{rm}} = -Cp^{n} \qquad (3)$$

integrate (3)

when n =1, that is, laminar case (4)

$$p = p_0 \exp(-Ct) \qquad \text{or} \qquad t = 1/C \ln(\frac{p_0}{p}) \qquad (5)$$

otherwise,

$$p^{1-n} = p_0^{1-n} - Ct \qquad \text{or} \qquad t = \frac{1}{C} p_0^{1-n} (1 - \frac{p^{1-n}}{p_0^{1-n}}) \qquad (6)$$

General Equivalent Test Steps

1). Measure pressure change with time at any pressure range
2). Curve fitting and find n, using equation 5, or 6, whichever one gives the better correlation.
3). If step 2 finds n=1 (laminar condition), then

$$\frac{t_1}{t_2} = \ln(\frac{p_{01}}{p_1}) / \ln((\frac{p_{02}}{p_2}) \text{, if } \frac{p_{01}}{p_1} = \frac{p_{02}}{p_2} \text{, then } t_1 = t_2$$

If step 2 finds n is between 0.5 and 1, then

$$\frac{t_1}{t_2} = \frac{p_{01}^{1-n} - p_1^{1-n}}{p_{02}^{1-n} - p_2^{1-n}} \text{, if } \frac{p_{01}}{p_1} = \frac{p_{02}}{p_2} \text{, then } \frac{t_1}{t_2} = \frac{p_{01}^{1-n}}{p_{02}^{1-n}}$$

for example, if n=1, then a 2”H_2O 20 min test will be equivalent to a 0.5”H_2O 20min test,
if n is other than 1, then a 2”H_2O 20 min test will be equivalent to a 0.5”H_2O $20/4^{1-n}$ min test.

BSL-4 Equivalent Test Steps

Field test data suggested that flow in BSL-4 rooms is rather laminar. And common practice is to test the pressure to half of its original value, ie., $\frac{p_{01}}{p_1} = \frac{p_{02}}{p_2} = 2$. Therefore, the general equivalent test steps can be reduced to

1). Measure pressure change with time at lower initial pressure, for example, 0.5"H_2O
2). Measure the pressure change for 20 min
3). If the residual pressure is greater than 50% of its original pressure, in above example, 0.25"H_2O, the room passes the test.

Implication of the Equivalency Theory

Equations 1 through 6 illustrate the physical process of a room test. In addition, above theory can be applied to other, non-laminar flow rooms. This theory applies to any room size and room temperature.

Nomenclature

A	Crack Area
c	Flow coefficient
C	Combined coefficient $C = c\frac{R_{air}T_{rm}}{V_{rm}}$
M_{room}	Mass of the room air
P	Pressure of the room
R	Ideal gas constant of air
n	Pressure exponent, dimensionless
t	Time
T_{rm}	Temperature of the room
Q	Flow rate through the crack
V_{rm}	Volume of the room

Greek symbols

ρ	Room air density

Subscripts

air	Air property
rm, room	Room
int, 0	Initial condition

Reference:

[1] *ASHRAE Handbook Fundamentals 2001*, F26.12
[2] I.S. Walker, D. Wilson and M.H. Sherman, A comparison of the power law to quadratic formulations for air infiltration calculations, *Energy and Buildings*, Vol. 27, No.3, June 1997.

Appendix

Equivalent test condition data points used in figure 1.

p/p_0	Time (min)
10%	66.4
20%	46.4
30%	34.7
40%	26.4
50%*	20
60%	14.7
70%	10.3
80%	6.4
90%	3.0

* Commonly used