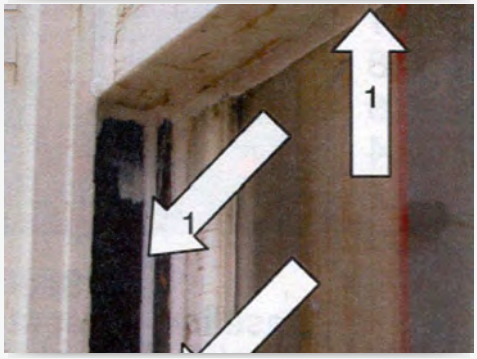
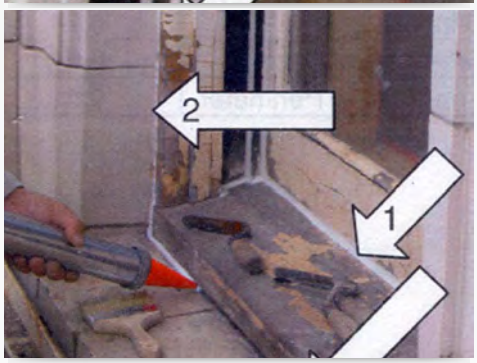




Meier & Frank

Hotel constructed to LEED Silver standards in the upper 10 floors of the Meier & Frank building. SERA architects and consultants performed tracer gas window infiltration tests on a mock up guest room to determine the actual impact of five different window conditions on energy performance during the planning of the hotel. The results are generally transferable to buildings with comparable conditions.

Project Highlights

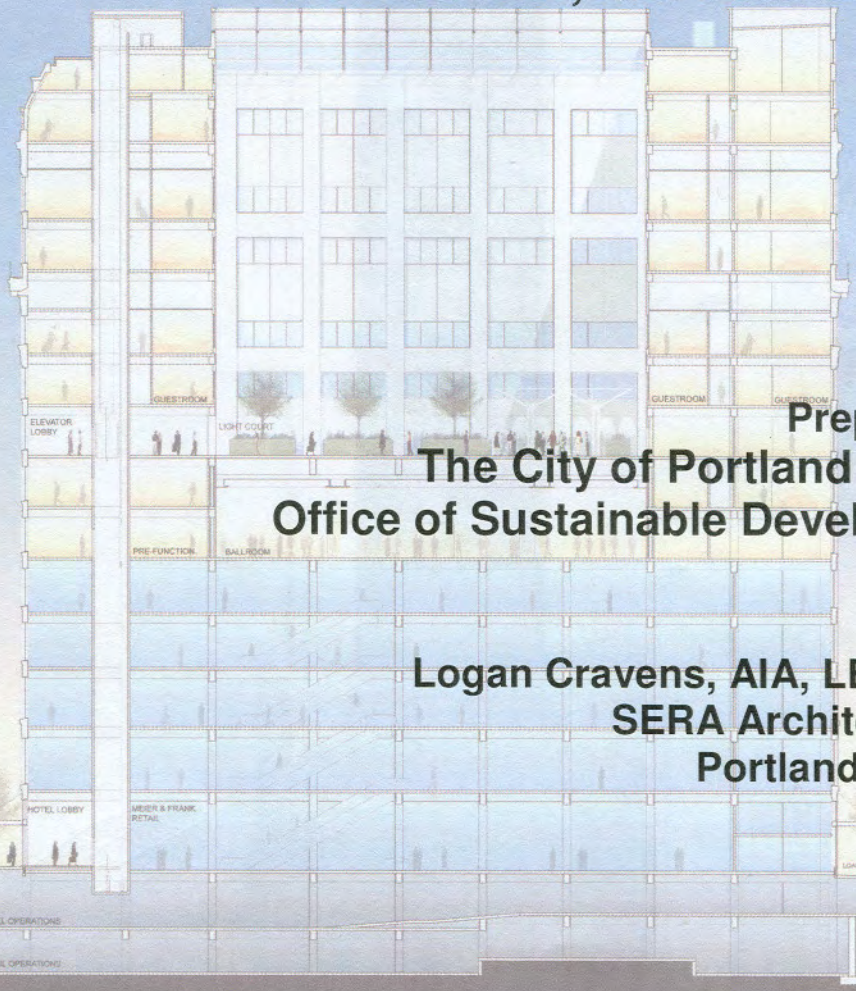
Applied air flow analysis

Portfolio Contents

Final Report

Final Report:

Air Infiltration Testing of Existing Double-Hung Windows in an Existing Urban Historic, Commercial, Mid-Rise Building



Prepared for
The City of Portland Oregon
Office of Sustainable Development

Logan Cravens, AIA, LEED® AP
SERA Architects, Inc.
Portland, Oregon

November 27, 2006

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Project Background

Funding was provided by the Portland Office of Sustainable Development (OSD) to investigate the benefits of reducing air infiltration in an existing, historic downtown commercial building. The building selected for this study is the old 15 story Meier and Frank Department Store which is now owned by two condominium tenants, the hotel portion by Portland Hotel Developers LLC (PHD) and the retail portion by Federated Department Stores Inc. Bounded by SW Morrison Street on the south, SW Alder to the north, and between the two bus mall streets, SW 5th and SW 6th the structure sits on the newly designated Meier and Frank Block. Macey's is now the store tenant on floors 1 through 6. Floors 7 through 15 are owned by the hotel group.

Figure 1 Test Window Site

PHD is seeking a Silver LEED rating for the hotel portion and the condition of the existing building envelope is a major factor in the energy performance of the upper floors. Early calculations showed energy savings worth 3 LEED energy points. LEED Energy Credit 1 requires the modeling of the building according to ASHRAE 90.1-2004. In the model information, the existing double hung windows will not be replaced yet are a major source of air infiltration. Unless there are actual measurements, air infiltration through the envelope is an *assumed constant* between the baseline energy model and the design building energy model. This study gave us the data to show a significant reduction in air infiltration by sealing the outside sashes, improving performance between 5%-7% and gaining 2 additional points for a total of 5 points under LEED credit EAc1- Optimizing Energy.

These results, proven by industry standard test methods, demonstrate the direct benefit of low cost strategies, such as sealing air leaks, in a construction type that is most prevalent in Portland's historic building stock. More importantly, it reveals the extent to which energy (and dollars) are lost in the Portland region due to lack of maintenance and the effects of aging building stock. This study provides a simple methodology suitable for other buildings with similar conditions.

Window selection

Two adjoining window bays, one small (36.3 sf) and one large (55 sf), were selected on the west side of the building at the 12th floor. Each window was independently sealed for testing using methods compliant with ASTM E 783-93, Standard Test Method for Field Measurement of Air Leakage Through Installed Exterior Windows and Doors. (Fig.

Test Equipment Setup

A Laminar Flow Element (Fig. 2), used to measure the air infiltration, was installed in-line of a 2" plastic pipe that is connected to the sealed chamber around the window (Fig. 3). This was in turn attached to an inclined manometer that measures air infiltration. Another inclined manometer and blower motor, attached to the end of the plastic pipe measures static pressure differentials.(Figures 4 & 5).

Figure 2 – Laminar Flow Element

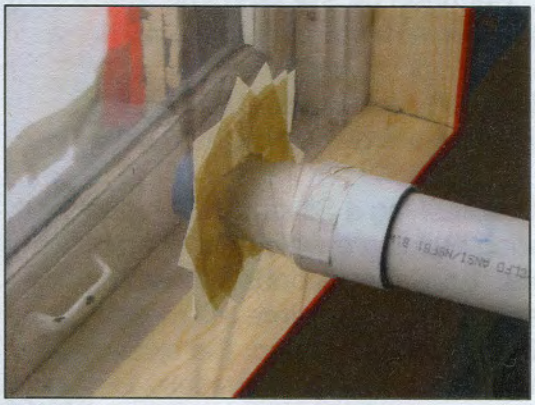


Figure 3 – Vacuum connection at Window Enclosure

Figure 4 – Window and Equipment Set-up

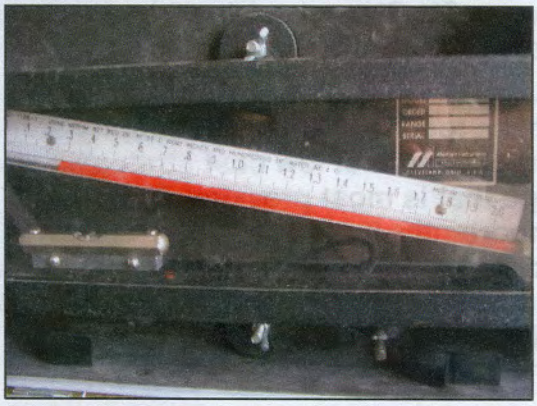


Figure 5 – Inclined Manometer

Sealing the Windows

After setting the baseline infiltration rates, two tests were made with sealant. The first one was made at the joint between the window sash and the window frame plus the gap between the upper and lower sash. (See Figures 6-8, arrow numbered 1.)
A second pass was made at the joint between the wood window frame and the terracotta masonry. (Figures 6-8, arrow numbered 2)

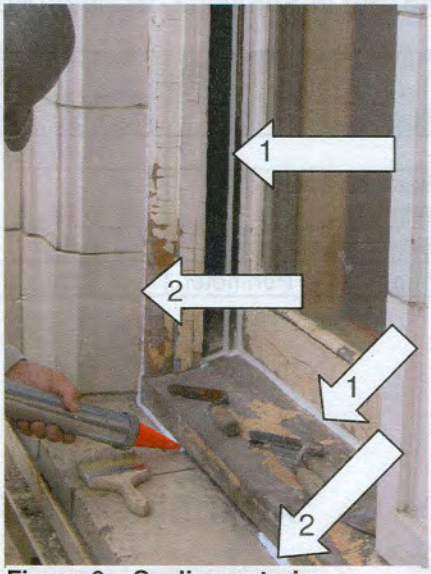


Figure 6 – Sealing exterior window.

Dramatic Results

As soon as the carpenters began applying sealant at the lower window sash and parting rail between the two window sashes (arrows No. 1), the gauges instantly began to fall. Noticing that the trim serving as a stop, or guide was also loose, the carpenter made a pass on either side at the jambs.

The second reading from the report measured sealant at the window frame perimeter (arrows No. 2). Closing this joint any further does not show a measurable difference, therefore the additional effort would not prove economical. The construction team believes the reason lies in the fact that the terra cotta is backed by masonry and solid grouted around the window openings, thereby rendering them relatively resistant to infiltration.

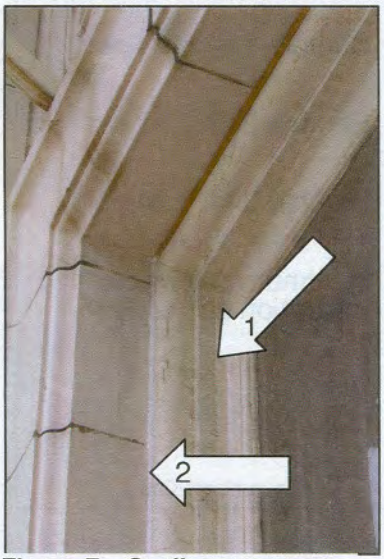


Figure 7 – Sealing at upper sash (1) and frame (2).

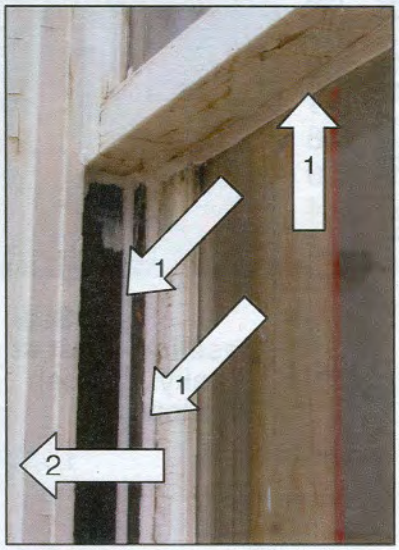
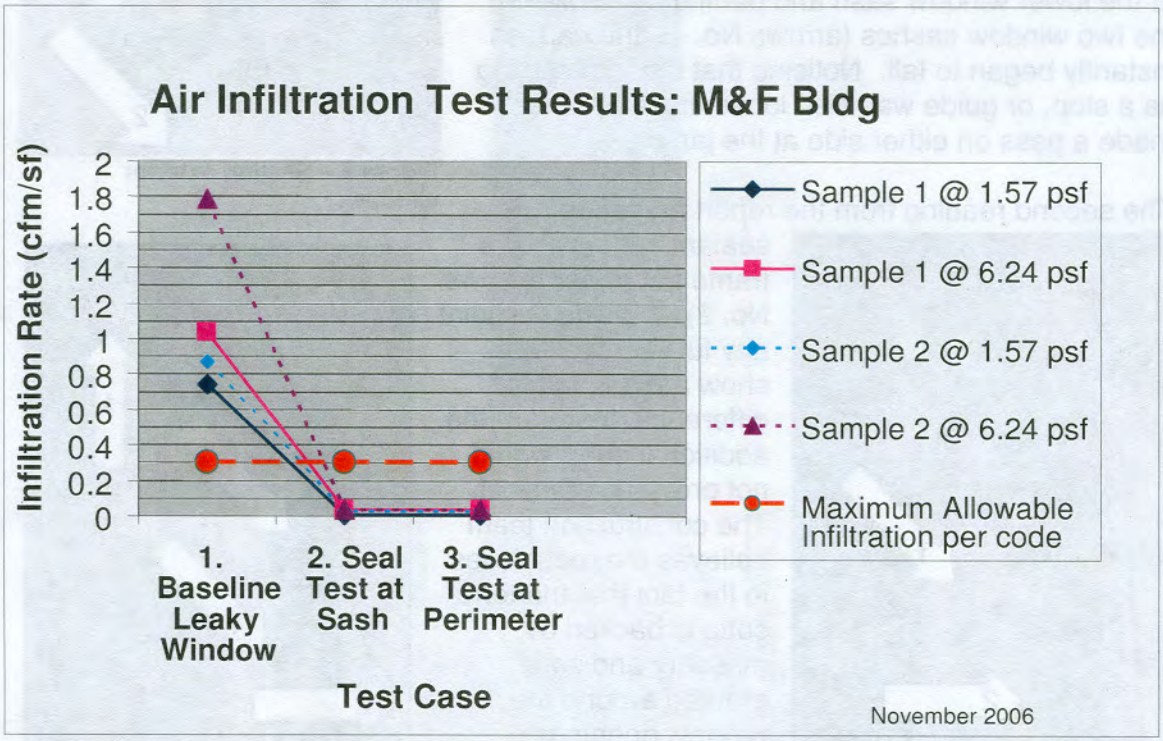


Figure 8 – Sealing at lower sash (1) and frame (2).

The Numbers

Note that in Sample 2, the improvement in air infiltration was 4400%.

Test Case	Sample 1 @ 1.57 psf	Sample 1 @ 6.24 psf	Sample 2 @ 1.57 psf	Sample 2 @ 6.24 psf	Maximum Allowable Infiltration
	NUMBERS EXPRESSED IN CUBIC FEET / MINUTE / SQUARE FOOT				
Baseline Leaky Window	0.74	1.04	0.87	1.79	0.3
Seal Test at Sash	0.01	0.04	0.03	0.04	0.3
Seal Test at Perimeter	0.01	0.04	0.03	0.04	0.3



Attachments

1) Water Leakage Field Test Report #FT2006-450, dated 6/16/06 from Quality Testing, Inc, FT2006-450., 3310 Hill Ave., Everett, WA 98201, ph. (425) 259-6799.
2) ASTM Standard E1827-96
3) ASHRAE Manual – Air Leakage Measurement
4) Narrative LEED –EA Credit 1 – Optimize Energy Performance, PAE Consulting Engineers, October 16, 2006.

WATER LEAKAGE FIELD TEST REPORT

FT2006-450

REPORT TO: SERA ARCHITECTURE
338 NW 5TH AVE.
PORTLAND, OR 97209

ORIGINAL REPORT NUMBER: FT2006-450
ORIGINAL REPORT DATE: 06/26/2006

PRODUCTS: TWO WOOD HUNG WINDOW SYSTEMS AS INSTALLED IN MEIER & FRANK DEPARTMENT STORE PROJECT LOCATED IN PORTLAND, OR

DRAFT

REPORT TO:	SERA Architecture 338 NW 5th Ave. Portland, OR 97209
TEST DATES:	06/15/2006 & 06/16/06
TEST STANDARDS/METHODS:	ASTM E 783-93 Standard Test Method for Field Measurement of Air Leakage Through Installed Exterior Windows and Doors.
TEST PURPOSE:	Air infiltration and post remedial air infiltration testing was performed on two installed wood window systems at the Meier & Frank department store project located in the Portland, OR.
TEST CONDITIONS:	Conditions during testing were partly cloudy skies, periods of light precipitation, wind conditions calm with the outside ambient air temperature from 60° to 70° Fahrenheit.

ASTM E 783-93 EQUIPMENT: The air infiltration was measured using a laminar flow element (LFE) with 20" of 2" straight pipe coupled to the LFE on both sides. The LFE is connected to the test chamber along with a Dwyer inclined manometer, and a blower motor to create and measure the static pressure differentials in addition, a Meriam digital manometer was connected to the LFE, this was used to measure the air infiltration rate. The blower motor is controlled using a power output controller. The exterior of the window systems were completely sealed with 4 Mil plastic sheeting sealed with tape to the perimeter of the window systems. Using the power output controller and blower motor static pressure differentials of 1.57 PSF and 6.24 PSF were applied to the interior test chamber, with the exterior of the window systems sealed. The first measurement, chamber air leakage was recorded, the plastic sheet was removed from the exterior of the window systems and the total air leakage was recorded. Subtracting the chamber leakage from the total leakage gave air leakage though just the window systems. The window air leakage is then divided by the window area resulting in CFM/FT^2.

EQUIPMENT CALIBRATION: The calibration of all equipment used was in full compliance with the calibration requirements of ASTM E 783-93 at the time of testing.

TEST SAMPLE DESCRIPTIONS AND RESULTS

TEST SAMPLE #1:

SIZE: 78" wide by 101 1/2" high

CONFIGURATION: O/X Wood Single Hung Window System

LOCATION: 12th floor, west elevation, larger window system located in the middle.

ASTM 783-93 RESULTS: (AS IS) Measured @ 1.57 PSF (25 MPH) = 0.74 CFM/Ft^2
ASTM 783-93 RESULTS: (AS IS) Measured @ 6.24 PSF (50 MPH) = 1.04 CFM/Ft^2

Post remedial testing:
The entire perimeter of both the top and bottom fixed and sliding sashes including the meeting rails were sealed with sealant:

ASTM 783-93 RESULTS: Measured @ 1.57 PSF (25 MPH) = 0.01 CFM/Ft^2
ASTM 783-93 RESULTS: Measured @ 6.24 PSF (50 MPH) = 0.04 CFM/Ft^2

Post remedial testing:
In addition to sealing the fixed and sliding sashes, the exterior perimeter of the frame was sealed to the building facade:

ASTM 783-93 RESULTS: Measured @ 1.57 PSF (25 MPH) = 0.01 CFM/Ft^2
ASTM 783-93 RESULTS: Measured @ 6.24 PSF (50 MPH) = 0.04 CFM/Ft^2

No change in air flow through the window system when the perimeter is sealed however, the laboratory recommends that this joint be sealed due to the possibility of air infiltration and water penetration into the wall cavity and leaking through other interior wall penetrations

TEST SAMPLE #2:

SIZE: 51 1/2" wide by 101 1/2" high

CONFIGURATION: O/X Wood Single Hung Window System

LOCATION: 12th floor, west elevation, smaller window system located on the right.

ASTM 783-93 RESULTS: (AS IS) Measured @ 1.57 PSF (25 MPH) = 0.87 CFM/Ft^2
ASTM 783-93 RESULTS: (AS IS) Measured @ 6.24 PSF (50 MPH) = 1.79 CFM/Ft^2

Post remedial testing:
The entire perimeter of both the top and bottom fixed and sliding sashes including the meeting rails were sealed with sealant:

ASTM 783-93 RESULTS: Measured @ 1.57 PSF (25 MPH) = 0.03 CFM/Ft^2
ASTM 783-93 RESULTS: Measured @ 6.24 PSF (50 MPH) = 0.04 CFM/Ft^2

Post remedial testing:
In addition to sealing the fixed and sliding sashes, the exterior perimeter of the frame was sealed to the building facade:

ASTM 783-93 RESULTS: Measured @ 1.57 PSF (25 MPH) = 0.03 CFM/Ft^2
ASTM 783-93 RESULTS: Measured @ 6.24 PSF (50 MPH) = 0.04 CFM/Ft^2

No change in air flow through the window system when the perimeter is sealed however, the laboratory recommends that this joint be sealed due to the possibility of air infiltration and water penetration into the wall cavity and leaking through other interior wall penetrations

Per industry standards: AAMA/WDMA/CSA 101/I.S.2/A440-05 Standard/Specification for Windows, Doors, and Unit Skylight, page 52, table 6, the maximum allowable air leakage = 0.3 CFM/Ft^2. As the test results show the air infiltration testing "AS IS" is much greater than the allowable, with the sealing of all sash joint the air infiltration rate is sufficiently less than the allowable. Sealing the exterior frame perimeter to the building facade did not have an effect on the air infiltration rate through the windows however, this does not mean that air isn't penetrating into this joint and leaking through other interior wall penetrations.

The results within this report were secured by using the designated test methods. The above test results indicate compliance with the above referenced test methods. This report does not constitute certification of this/these product(s), which may only be granted by the Administrator of the Certification Program.

No test can wholly eliminate uncertainty regarding the potential for water penetration. Our test is intended to reduce, but not eliminate, uncertainty regarding the potential for water penetration at a designated site. This report is based on conditions that existed at the time the test was performed. The findings and conclusions of this report may be affected by the passage of time and by events such as weathering, vibration, expansion, and contraction. Our services have been executed in accordance with generally accepted practices for this type of test that are in effect at the time this report was prepared. No warranty or other conditions, express or implied, should be understood."

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Randal J. Van Voorst
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Laboratory/Field Manager

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E1827-96(2002) Standard Test Methods for Determining Airtightness of Buildings Using an Orifice BLOWER DOOR

Developed by Subcommittee: E06.41
See Related Work by this Subcommittee
Adoptions: ANSI Approved
Book of Standards Volume: 04.12

1. Scope

1.1 These test methods describe two techniques for measuring air leakage rates through a building envelope in buildings that may be configured to a single zone. Both techniques use orifice **BLOWER DOOR** to induce pressure differences across the building envelope and to measure those pressure differences and the resulting airflows. The measurements of pressu differences and airflows are used to determine airtightness and other leakage characteristic the envelope.

1.2 These test methods allow testing under depressurization and pressurization.

1.3 These test methods are applicable to small indoor-outdoor temperature differentials anc low wind pressure conditions; the uncertainty in the measured results increases with increa wind speeds and temperature differentials.

1.4 These test methods do not measure air change rate under normal conditions of weathei and building operation. To measure air change rate directly, use Test Methods E 741.

1.5 The text of these methods reference notes and footnotes that provide explanatory mate These notes and footnotes, excluding those in tables and figures, shall not be considered as requirements of the standard.

1.6 *This standard does not purport to address all of the safety concerns, if any, associated its use. It is the responsibility of the user of this standard to establish appropriate safety an health practices and determine the applicability of regulatory limitations prior to use.* For specific hazard statements see Section 7.

2. Referenced Documents

E456 Terminology Relating to Quality and Statistics
E631 Terminology of Building Constructions
E741 Test Methods for Determining Air Change in a Single Zone by Means of Tracer Gas Dilution
E779 Test Method for Determining Air Leakage Rate by Fan Pressurization
E1186 Practice for Air Leakage Site Detection in Building Envelopes
E1258 Test Method for Airflow Calibration of Fan Pressurization Devices
ISO 9972 Thermal Insulation-Determination of Building Airtightness-Fan Pressurization Metl
ANSI/ASME PTC 19.1-Part 1, Measurement Uncertainty, Instruments, and Apparatus

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Index Terms

air leakage; **BLOWER DOOR**; building envelope; field method; pressurization; 91.010.30

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E783-02 Standard Test Method for Field Measurement of Air Leakage Through Installed Exterior Windows and Doors

Developed by Subcommittee: E06.51
See Related Work by this Subcommittee
Adoptions: Building Codes; ANSI Approved
Book of Standards Volume: 04.11

1. Scope

1.1 This test method provides a field procedure for determining the air leakage rates of installed exterior windows and doors.

1.2 This test method is applicable to exterior windows and doors and is intended to measur only such leakage associated with the assembly and not the leakage through openings between the assemblies and adjacent construction. The test method can be adapted for the latter purpose, provided the potential paths of air movement and the sources of infiltration exfiltration can be identified, controlled, or eliminated.

1.3 This test method attempts to create and given set of natural environmental conditions. There is a strong possibility that the test method or the test apparatus may, by virtue of th design and use, induce air leakage that does not occur under natural environmental exposu

1.4 This test method is intended for the field testing of installed exterior windows or doors. Persons interested in laboratory testing of fenestration products should reference Test Meth E283.

1.5 Persons using this procedure should be knowledgeable in the area of fluid mechanics an instrumentation practices, and shall have a general understanding of fenestration products components.

1.6 Throughout this test method, SI units are listed first in accordance with E-6 metric polic and shall be considered the primary units. Non-SI units are provided in parenthesis.

1.7 *This standard does not purport to address all of the safety problems, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safe and health practices and determine the applicability of regulatory limitations prior to use.* F specific precautionary statements, see Section 7.

2. Referenced Documents

E283 Test Method for Determining the Rate of Air Leakage Through Exterior Windows, Curt Walls, and Doors Under Specified Pressure Differences Across the Specimen
E631 Terminology of Building Constructions

Index Terms

air leakage; doors; fenestration; field method; static pressure chamber; test method; wind

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E741-00 Standard Test Method for Determining Air Change in a Single Zone by Means o Tracer Gas Dilution

Developed by Subcommittee: E06.41
See Related Work by this Subcommittee
Adoptions: ANSI Approved
Book of Standards Volume: 04.11

1. Scope

1.1 This test method describes techniques using tracer gas dilution for determining a single zone's air change with the outdoors, as induced by weather conditions and by mechanical ventilation. These techniques are: (1) concentration decay, (2) constant injection, and (3) constant concentration.

1.2 This test method is restricted to any single tracer gas. The associated data analysis assumes that one can characterize the tracer gas concentration within the zone with a singl value. The zone shall be a building, vehicle, test cell, or any conforming enclosure.

1.3 Use of this test method requires a knowledge of the principles of gas analysis and instrumentation. Correct use of the formulas presented here requires consistent use of unit especially those of time.

1.4 Determination of the contribution to air change by individual components of the zone enclosure is beyond the scope of this test method.

1.5 The results from this test method pertain only to those conditions of weather and zonal operation that prevailed during the measurement. The use of the results from this test to predict air change under other conditions is beyond the scope of this test method.

1.6 The text of this test method references notes and footnotes which provide explanatory material. These notes and footnotes (excluding those in tables and figures) shall not be considered requirements of this test method.

1.7 *This standard does not purport to address all of the safety concerns, if any, associated its use. It is the responsibility of the user of this standard to establish appropriate safety an health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

E260 Practice for Packed Column Gas Chromatography
E779 Test Method for Determining Air Leakage Rate by Fan Pressurization
E1186 Practice for Air Leakage Site Detection in Building Envelopes
D4480 Test Method for Measuring Surface Wind by Means of Wind Vanes and Rotating Anemometers
, Chapter 23

Index Terms

air change; air change flow; air change rate; air changes per hour; air exchange; air leakag

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E779-03 Standard Test Method for Determining Air Leakage Rate by Fan Pressurization

Developed by Subcommittee: E06.41
See Related Work by this Subcommittee
Adoptions: Building Codes;
Book of Standards Volume: 04.11

1. Scope

1.1 This test method covers a standardized technique for measuring air-leakage rates throu a building envelope under controlled pressurization and de-pressurization.

1.2 This test method is applicable to small temperature differentials and low-wind pressure conditions. For tests conducted in the field, it must be recognized that field conditions may less than ideal. Nevertheless, strong winds and large indoor-outdoor temperature differenti should be avoided.

1.3 This test method is intended to produce a measure of air tightness of a building envelop This test method does not measure air leakage rates under normal conditions of weather ar building operation. To measure air-change rate directly, use the tracer gas dilution method (see Test Method E 741).

1.4 This test method is intended for the measurement of the airtightness of building envelo of single-zone buildings. For the purpose of this test method, many multi-zone buildings ca treated as single-zone buildings by opening interior doors or by inducing equal pressures in adjacent zones.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated its use. It is the responsibility of the user of this standard to establish appropriate safety an health practices and determine the applicability of regulatory limitations prior to use.* For specific hazard statements see Section 7.

2. Referenced Documents

E741 Test Method for Determining Air Change in a Single Zone by Means of a Tracer Gas Dilution.
E1258 Test Method for Airflow Calibration of Fan Pressurization Devices

Index Terms

air leakage; air-leakage rates; blower-door test; building envelope; depressurization; energ conservation; fan pressurization testing; infiltration; pressurization; ventilation; 91.140.30

Citing ASTM Standards

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ASTMCOLLECTION ACTIVE E779 DESIGNATION E779 DESIGNATION E779 DESIGNATION E779 DESIGNATION E779 E779 E779 E779 E779 E779 E779 E779 E779 E779

smaller than the inlet creates lower but more uniform airspeed through the room.

12. Openings with areas much larger than calculated are sometimes desirable when anticipating increased occupancy or very hot weather.
13. Horizontal windows are generally better than square or vertical windows. They produce more airflow over a wider range of wind directions and are most beneficial in locations where prevailing wind patterns shift.
14. Window openings should be accessible to and operable by occupants.
15. Inlet openings should not be obstructed by indoor partitions. Partitions can be placed to split and redirect airflow but should not restrict flow between the building's inlets and outlets.
16. Vertical airshafts or open staircases can be used to increase and take advantage of stack effects. However, enclosed staircases intended for evacuation during a fire should not be used for ventilation.

RESIDENTIAL AIR LEAKAGE

Most infiltration in residential buildings in the U.S. is dominated by envelope leakage. However, trends in new construction are towards tighter envelopes such that envelope leakage is reduced in newer housing.

Envelope Leakage Measurement

Envelope leakage of a building can be measured with **pressurization testing** (commonly called a **blower-door test**). Fan pressurization is relatively quick and inexpensive, and it characterizes building envelope airtightness independent of weather conditions. In this procedure, a large fan or blower is mounted in a door or window and induces a large and roughly uniform pressure difference across the building shell (ASTM *Standards* E779 and E1827; CGSB *Standard* 149.10; ISO *Standard* 9972). The airflow required to maintain this pressure difference is then measured. The leakier the building is, the more airflow is necessary to induce a specific indoor-outdoor pressure difference. The airflow rate is generally measured at a series of pressure differences ranging from about 0.04 to 0.30 in. of water.

The results of a pressurization test, therefore, consist of several combinations of pressure difference and airflow rate data. An example of typical data is shown in Figure 8. These data points characterize the air leakage of a building and are generally converted to a single value that serves as a measure of the building's airtightness. There are several different measures of airtightness, most of which involve fitting the data to a curve describing the relationship between the airflow Q through an opening in the building envelope and the pressure difference Δp across it. This relationship is called the **leakage function** of the opening. The form of the leakage function depends on the geometry of the opening. Background theoretical material relevant to leakage functions may be found in Chastain et al. (1987), Etheridge (1977), Hopkins and Hansford (1974), Kronvall (1980), and Walker et al. (1997).

The openings in a building envelope are not uniform in geometry and, generally, the flow never becomes fully developed. Each opening in the building envelope can be described by Equation (32), commonly called the **power law equation**:

$$Q = c(\Delta p)^n \tag{32}$$

where

Q = airflow through opening, cfm
c = flow coefficient, cfm/(in. of water)^n
n = pressure exponent, dimensionless

Sherman (1992b) showed how the power law can be developed analytically by looking at developing laminar flow in short pipes. Equation (32) only approximates the relationship between Q and Δp. Measurements of single cracks (Honma 1975; Krieth and Eisenstadt 1957) have shown that n can vary if Δp changes over a wide range. Additional investigation of pressure/flow data for simple cracks by Chastain et al. (1987) further indicated the importance of adequately characterizing the three-dimensional geometry of openings and the entrance and exit effects. Walker et al. (1997) showed that for the arrays of cracks in a building envelope over the range of pressures acting during infiltration, n is constant. A typical value for n is about 0.65. Values for c and n can be determined for a building by using fan pressurization testing.

Airtightness Ratings

In some cases, the predicted airflow rate is converted to an equivalent or effective air leakage area as follows:

$$A_L = C_5 Q_r \frac{\sqrt{\rho / 2\Delta p_r}}{C_D} \tag{33}$$

where

A_L = equivalent or effective air leakage area, in^2
Q_r = predicted airflow rate at Δp_r (from curve fit to pressurization test data), cfm
ρ = air density, lb$_m$/ft^3
Δp_r = reference pressure difference, in. of water
C_D = discharge coefficient
C_5 = unit conversion factor = 0.186

All the openings in the building shell are combined into an overall opening area and discharge coefficient for the building when the equivalent or effective air leakage area is calculated. Some users of the leakage area approach set $C_D = 1$. Others set $C_D \approx 0.6$ (i.e., the discharge coefficient for a sharp-edged orifice). The air leakage area of a building is, therefore, the area of an orifice (with an assumed value of C_D) that would produce the same amount of leakage as the building envelope at the reference pressure.

An airtightness rating, whether based on an air leakage area or a predicted airflow rate, is generally normalized by some factor to account for building size. Normalization factors include floor area, exterior envelope area, and building volume.

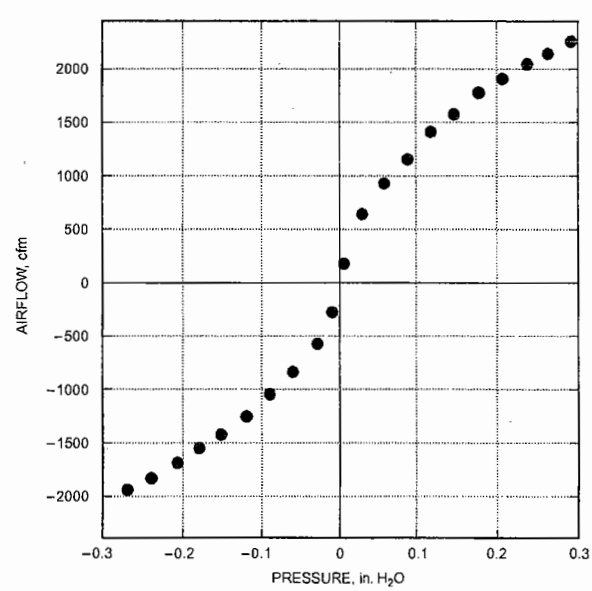

Fig. 8 Airflow Rate Versus Pressure Difference Data from Whole-House Pressurization Test

With the wide variety of possible approaches to normalization and reference pressure difference, and the use of the air leakage area concept, many different airtightness ratings are being used. Reference pressure differences include 0.016, 0.04, 0.10, 0.20, and 0.30 in. of water. Reference pressure differences of 0.016 and 0.04 in. of water are advocated because they are closer to the pressure differences that actually induce air exchange and, therefore, better model the flow characteristics of the openings. While this may be true, they are outside the range of measured values in the test; therefore, the predicted airflow rates at 0.016 and 0.04 in. of water are subject to significant uncertainty. The uncertainty in these predicted airflow rates and the implications for quantifying airtightness are discussed in Chastain (1987), Modera and Wilson (1990), and Persily and Grot (1985b). Round robin tests by Murphy et al. (1991) to determine the repeatability and reproducibility of fan pressurization devices found that subtle errors in fan calibration or operator technique are greatly exaggerated when extrapolating the pressure versus flow curve out to 0.016 in. of water, with errors as great as ±40%, mainly due to the fan calibration errors at low flow.

Some common airtightness ratings include the effective air leakage area at 0.016 in. of water assuming $C_D = 1.0$ (Sherman and Grimsrud 1980); the equivalent air leakage area at 0.04 in. of water assuming $C_D = 0.611$ (CGSB *Standard* 149.10); and the airflow rate at 0.20 in. of water, divided by the building volume to give units of air changes per hour (Blomsterberg and Harrje 1979).

Conversion Between Ratings

Air leakage areas at one reference pressure difference can be converted to air leakage areas at an other reference pressure difference according to:

$$A_{r,2} = A_{r,1}\left(\frac{C_{D,1}}{C_{D,2}}\right)\left(\frac{\Delta p_{r,2}}{\Delta p_{r,1}}\right)^{n-0.5} \tag{34}$$

where

$A_{r,1}$ = air leakage area at reference pressure difference $\Delta p_{r,1}$, in^2
$A_{r,2}$ = air leakage area at reference pressure difference $\Delta p_{r,2}$, in^2
$C_{D,1}$ = discharge coefficient used to calculate $A_{r,1}$
$C_{D,2}$ = discharge coefficient used to calculate $A_{r,2}$
n = pressure exponent from Equation (32)

An air leakage area at one reference pressure difference can be converted to an airflow rate at some other reference pressure difference according to

$$Q_{r,2} = C_6 C_{D,1} A_{r,1}\sqrt{\frac{2}{\rho}}\,(\Delta p_{r,1})^{0.5-n}(\Delta p_{r,2})^{n} \tag{35}$$

where

$Q_{r,2}$ = airflow rate at reference pressure difference $\Delta p_{r,2}$, cfm
C_6 = unit conversion factor = 5.39

The flow coefficient c in Equation (32) may be converted to an air leakage area according to

$$A_L = \frac{c}{C_6 C_D}\sqrt{\frac{\rho}{2}}\,\Delta p_r^{(n-0.5)} \tag{36}$$

Finally, an air leakage area may be converted to the flow coefficient c in Equation (32) according to

$$c = C_6 C_D A_L\sqrt{\frac{\rho}{2}}\,(\Delta p_r)^{0.5-n} \tag{37}$$

Equations (34) through (37) require the assumption of a value of n, unless it is reported with the measurement results. When whole-building pressurization test data are fitted to Equation (32), the value of n generally lies between 0.6 and 0.7. Therefore, using a value of n in this range is reasonable.

Building Air Leakage Data

Fan pressurization measures a building property that ideally varies little with time and weather conditions. In reality, unless the wind and temperature differences during the measurement period are sufficiently mild, the pressure differences they induce during the test will interfere with the test pressures and cause measurement errors. Persily (1982) and Modera and Wilson (1990) studied the effects of wind speed on pressurization test results. Several experimental studies have also shown variations on the order of 20 to 40% over a year in the measured airtightness in homes (Kim and Shaw 1986; Persily 1982; Warren and Webb 1986).

Figure 9 summarizes envelope leakage measured North American housing (Sherman and Dickerhoff 1998) and from several European and Canadian sources (AIVC 1994). This figure shows the large range of measured envelope tightness but can still be used to illustrate typical and extreme values in the housing stock.

ASHRAE *Standard* 119 establishes air leakage performance levels for residential buildings. These levels are in terms of the normalized leakage area A_n:

$$A_n = 6.944\left(\frac{A_L}{A_f}\right)\left(\frac{H}{H_o}\right)^{0.3} \tag{38}$$

where

A_n = normalized leakage area, dimensionless
A_L = effective leakage area at 0.016 in. of water ($C_D = 1.0$), in^2
A_f = gross floor area (within exterior walls), ft^2
H = building height, ft
H_o = reference height of one-story building = 8 ft

Air Leakage of Building Components

The fan pressurization procedure discussed in the section on Envelope Leakage Measurement enables the measurement of whole-building air leakage. The location and size of individual openings in building envelopes are extremely important because they influence the air infiltration rate of a building as well as the heat and moisture transfer characteristics of the envelope. Additional test procedures exist for pressure-testing individual building components such as windows, walls, and doors; they are discussed in ASTM *Standards* E283 and E783 for laboratory and field tests, respectively.

Leakage Distribution

Dickerhoff et al. (1982) and Harrje and Born (1982) studied the air leakage of individual building components and systems. The following points summarize the percentages of whole-building air leakage area associated with various components and systems. The values in parentheses include the range determined for each component and the mean of the range.

Walls (18 to 50%; 35%). Both interior and exterior walls contribute to the leakage of the structure. Leakage between the sill plate and the foundation, cracks below the bottom of the gypsum wallboard, electrical outlets, plumbing penetrations, and leaks into the attic at the top plates of walls all occur.

Ceiling details (3 to 30%; 18%). Leakage across the top ceiling of the heated space is particularly insidious because it reduces the effectiveness of insulation on the attic floor and contributes to infiltration heat loss. Ceiling leakage also reduces the effectiveness of ceiling insulation in buildings without attics. Recessed lighting, plumbing, and electrical penetrations leading to the attic are some particular areas of concern.

Forced-air heating and/or cooling systems (3 to 28%; 18%). The location of the heating or cooling equipment, air handler, or ductwork in conditioned or unconditioned spaces; the venting

arrangement of a fuel-burning device; and the existence and location of a combustion air supply all affect leakage. Modera et al. (1991) and Robison and Lambert (1989), among others, have shown that the variability of leakage in ducts passing through unconditioned spaces is high, the coefficient of variation being on the order of 50%. Field studies have also shown that in-situ repairs can eliminate one-quarter to two-thirds of the observed leakage (Cummings and Tooley 1989; Cummings et al. 1990; Jump et al. 1996; Robison and Lambert 1989). The 18% contribution of ducts to total leakage significantly underestimates their impact because during system operation, the pressure differentials across the duct leaks are approximately ten times higher than typical pressure differences across the envelope leaks (Modera 1989; Modera et al. 1991) and result in large (factors of two to three) changes in ventilation rate (Cummings et al. 1990; Walker 1999; Walker et al. 1999).

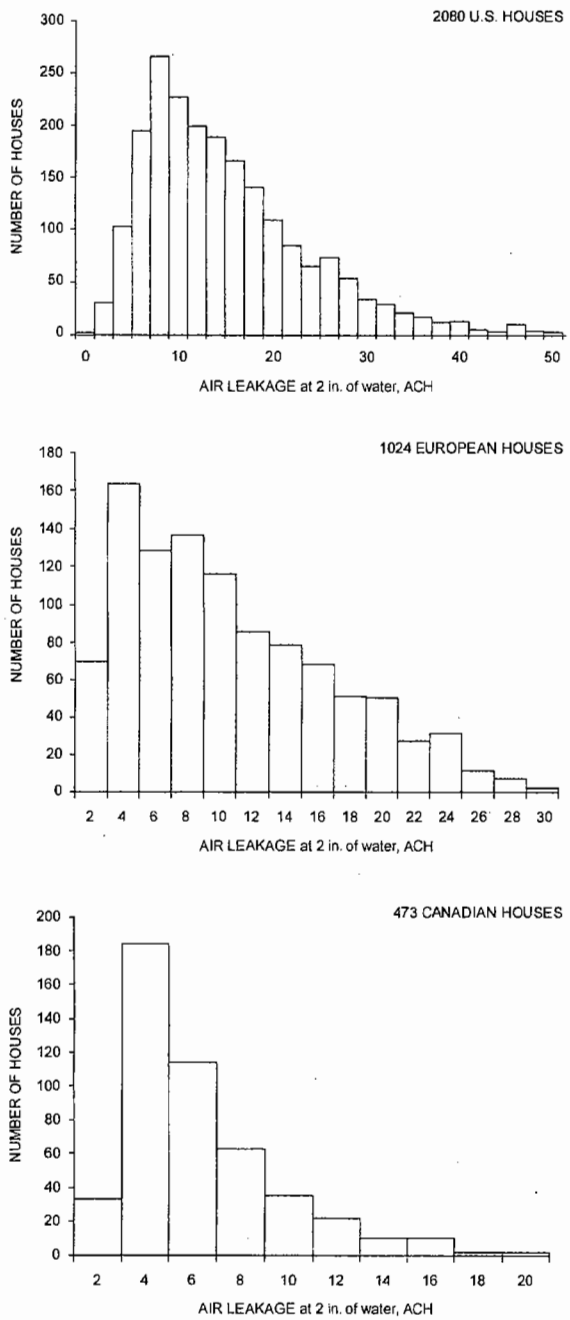

Fig. 9 Envelope Leakage Measurements

Windows and doors (6 to 22%; 15%). More variation in window leakage is seen among window types (e.g., casement versus double-hung) than among new windows of the same type from different manufacturers (Weidt et al. 1979). Windows that seal by compressing the weather strip (casements, awnings) show significantly lower leakage than windows with sliding seals.

Fireplaces (0 to 30%; 12%). When a fireplace is not in use, poorly fitting dampers allow air to escape. Glass doors reduce excess air while a fire is burning but rarely seal the fireplace structure more tightly than a closed damper does. Chimney caps or fireplace plugs (with signs that warn they are in place) effectively reduce leakage through a cold fireplace.

Vents in conditioned spaces (2 to 12%; 5%). Exhaust vents in conditioned spaces frequently have either no dampers or dampers that do not close properly.

Diffusion through walls (<1%). Diffusion, in comparison to infiltration through holes and other openings in the structure, is not an important flow mechanism. At 0.02 in. of water, the permeability of building materials produces an air exchange rate of less than 0.01 ACH by wall diffusion in a typical house.

Component leakage areas. Individual building component leakage areas vary widely from house to house. Typical variability for an individual component such as a door about a factor of 10, depending on the component's construction and installation. Testing should be used to establish the installed leakage of a component in applications where leakage is critical to building performance.

Multifamily Building Leakage

Leakage distribution is particularly important in multifamily apartment buildings. These buildings often cannot be treated as single zones due to the internal resistance between apartments. Moreover, the leakage between apartments varies widely, tending to be small in modern construction, and ranging as high as 60% of the total apartment leakage in turn-of-the-century brick walk-up apartment buildings (Diamond et al. 1986; Modera et al. 1991). Little information on interzonal leakage has been reported because of the difficulty and expense of these measurements.

Controlling Air Leakage

New Buildings. It is much easier to build a tight building than to tighten an existing building. Elmroth and Levin (1983), Eyre and Jennings (1983), Marbek Resource Consultants (1984), and Nelson et al. (1985) provide information and construction details on airtight building design for houses.

A continuous air infiltration retarder is one of the most effective means of reducing air leakage through walls, around window and door frames, and at joints between major building elements. Particular care must be taken to ensure its continuity at all wall, floor, and ceiling joints; at window and door frames; and at all penetrations of the retarder, such as electrical outlets and switches, plumbing connections, and utility service penetrations. Joints in the **air-vapor retarder** must be lapped and sealed. Plastic vapor retarders installed in the ceiling should be tightly sealed with the vapor retarder in the outside walls and should be continuous over the partition walls. A seal at the top of the partition walls prevents leakage into the attic; a plate on top of the studs generally gives a poor seal. The air infiltration retarder can be installed either on the inside of the wall framing, in which case it usually functions as a vapor retarder as well, or on the outside of the wall framing, in which case it should have a permeance rating high enough to permit diffusion of water

vapor from the wall. For a discussion of moisture transfer in building envelopes, see Chapters 23 and 24.

A continuous air infiltration retarder installed on the outside of wall framing can cover many difficult construction details associated with the installation of continuous air-vapor retarders. Interior air-vapor retarders must be lapped and sealed at electrical outlets and switches, at joints between walls and floors and between walls and ceilings, and at plumbing connections penetrating the wall's interior finish. The exterior air infiltration retarder can cover these problem areas continuously. Joints in the air infiltration retarder should be lapped and sealed or taped. Exterior air infiltration retarders are generally made of a material stronger than plastic film and are more likely to withstand damage during construction. Sealing the wall against air leakage at the exterior of the insulation also cuts down on convection currents within the wall cavity, allowing insulation to retain more of its effectiveness.

Existing Buildings. The air leakage sites must first be located in order to tighten the envelope of an existing building. As discussed earlier, air leakage in buildings is due not only to windows and doors, but to a wide range of unexpected and unobvious construction defects. Many important leakage sites can be very difficult to find. A variety of techniques developed to locate leakage sites are described in ASTM *Standard* E1186 and Charlesworth (1988).

Once leakage sites are located, they can be repaired with materials and techniques appropriate to the size and location of the leak. Diamond et al. (1982), Energy Resource Center (1982), and Harrje et al. (1979) include information on airtightening in existing residential buildings. With these procedures, the air leakage of residential buildings can be reduced dramatically. Depending on the extent of the tightening effort and the experience of those doing the work, residential buildings can be tightened anywhere from 5% to more than 50% (Blomsterberg and Harrje 1979; Giesbrecht and Proskiw 1986; Harrje and Mills 1980; Jacobson et al. 1986; Verschoor and Collins 1986). Much less information is available for airtightening large, commercial buildings, but the same general principles apply (Parekh et al. 1991; Persily 1991).

Safe Havens

Although there is generally a need to ventilate buildings to dilute contaminants generated indoors, there may be occasions when outdoor air quality is susbstaintially worse that indoor air quality. In these cases, it is better to decrease ventilation. See the sections on Shelter in Place and Safe Havens for information on these situations.

RESIDENTIAL VENTILATION

Typical infiltration values in housing in North America vary by a factor of about ten, from tightly constructed housing with seasonal average air exchange rates of about 0.2 air changes per hour (ACH) to loosely constructed housing with air exchange rates as great as 2.0 ACH. Figure 10 and Figure 11 show histograms of infiltration rates measured in two different samples of North American housing (Grimsrud et al. 1982; Grot and Clark 1979). Figure 10 shows the average seasonal infiltration of 312 houses located in different areas in North America. The median infiltration value of this sample is 0.5 ACH. Figure 11 represents measurements in 266 houses located in 16 cities in the United States. The median value of this sample is 0.9 ACH. The group of houses contained in the Figure 10 sample is biased toward new, energy-efficient houses, while the group in Figure 11 represents older, low-income housing in the United States.

Additional studies have found average values for houses in regional areas. Palmiter and Brown (1989) and Parker et al. (1990) found a heating season average of 0.40 ACH (range: 0.13 to 1.11 ACH) for 134 houses in the Pacific Northwest. In a comparison of 292 houses incorporating energy-efficient features (including measures to reduce air infiltration and provide ventilation heat recovery) with 331 control houses, Parker et al. (1990) found an average of about 0.25 ACH (range: 0.02 to 1.63 ACH) for the energy-efficient houses versus 0.49 (range: 0.05 to 1.63 ACH) for the control. Ek et al. (1990) found an average of 0.5 ACH (range: 0.26 to 1.09) for 93 double-wide manufactured homes also in the Pacific Northwest. Canadian housing stock has been characterized by Riley (1990) and Yuill and Comeau (1989). While these studies do not represent random samples of North American housing, they indicate the distribution of infiltration rates expected in a group of buildings.

Occupancy influences have not been measured directly and vary widely. Desrochers and Scott (1985) estimated that they add an average of 0.10 to 0.15 ACH to unoccupied values. Kvisgaard and Collet (1990) found that in 16 Danish dwellings, the users on average provided 63% of the total air exchange rate.

Ventilation air requirements for houses in the U.S. have traditionally been met on the assumption that the building envelope is leaky enough that infiltration will suffice. Possible difficulties with this approach include low infiltration when natural forces (temperature difference and wind) are weak, unnecessary energy consumption when such forces are strong, drafts in cold climates, lack of control of ventilation rates to meet changing needs, poor humidity control, potential for interstitial condensation from exfiltration in cold climates or infiltration in hot humid climates, and lack of opportunity to recover the energy used to condition the ventilation air. The solution

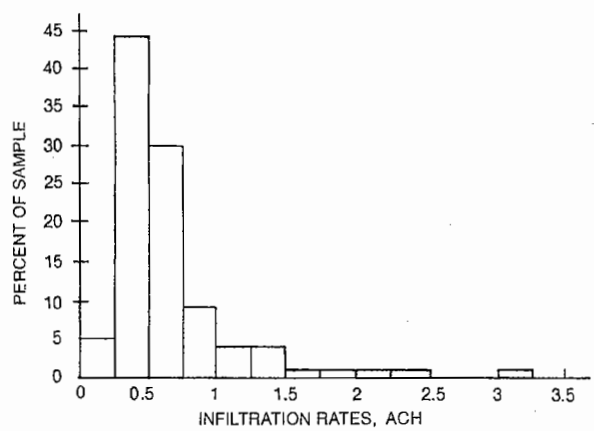

Fig. 10 Histogram of Infiltration Values—New Construction

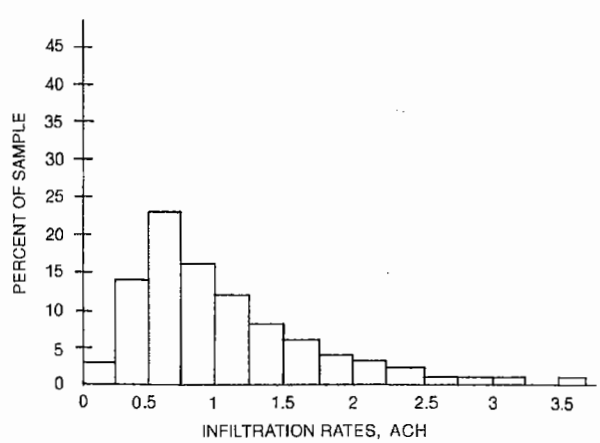

Fig. 11 Histogram of Infiltration Values—Low-Income Housing

Combining Residential Infiltration and Mechanical Ventilation

Significant infiltration and mechanical ventilation often occur simultaneously in residences. The pressure difference from Equation (24) can be used for each building leak, and the flow network (including mechanical ventilation) for the building can be solved to find the flow through all the leaks while accounting for the effect of the mechanical ventilation. However, for simplified models, the natural infiltration and mechanical ventilation are usually determined separately and require a superposition method to combine the flow rates.

Sherman (1992a) compares various superposition procedures and derives a generalized superposition equation that involves some simple leakage distribution parameters. He shows that the result is always subadditive. For small unbalanced fans, typically only half the flow contributes to the total, but this fraction can be anywhere between 0% and 100% depending on the leakage distribution. When the fan flow becomes large, infiltration may be ignored.

In special cases when the leakage distribution is known and highly skewed, it may be necessary to work through the superposition method in more detail. For example, in a wind-dominated situation, a supply fan will have a much bigger effect than an exhaust fan on changing the total ventilation rate; the same situation holds for houses having high neutral levels in cold climates. For the general case, when the details are not known or can be assumed to be broad and typical, the following superposition gives good results:

$$Q_{comb} = Q_{bal} + \sqrt{Q_{unbal}^2 + Q_{infiltration}^2} \tag{43}$$

NONRESIDENTIAL AIR LEAKAGE

Commercial Building Envelope Leakage

There is currently only one industry standard for the measurement of envelope leakage in tall buildings: CGSB *Standard* 149.15. It utilizes the building's own air handlers. ASTM *Standard* E779 and CGSB *Standard* 149.10 are intended for small detached buildings such as houses and provide no guidelines for dealing with problems arising in tall buildings, such as stack and wind effects. Tall buildings require refinement and extensions of established procedures because of obstacles to accurate measurement not present in small buildings, including large envelope leakage area, interfloor leakage, vertical shafts, and large wind and stack pressures. Recent work by Bahnfleth et al. (1999) also shows how to deal with some of these issues.

The building envelopes of large commercial buildings are often thought to be quite airtight. The National Association of Architectural Metal Manufacturers specifies a maximum leakage per unit of exterior wall area of 0.060 cfm/ft^2 at a pressure difference of 0.30 in. of water exclusive of leakage through operable windows. Tamura and Shaw (1976a) found that, assuming a flow exponent n of 0.65 in Equation (32), air leakage measurements in eight Canadian office buildings with sealed windows ranged from 0.120 to 0.480 cfm/ft^2. Persily and Grot (1986) ran whole-building pressurization tests in large office buildings that showed that pressurization airflow rate divided by building volume is relatively low compared to that of houses. However, if these airflow rates are normalized by building envelope area instead of by volume, the results indicate envelope airtightness levels similar to those in typical American houses. In a study of eight U.S. office buildings, Persily and Grot (1986) found air leakage ranging from 0.213 to 1.028 cfm/ft^2 at 0.30 in. of water. This means that office building envelopes are leakier than expected. Typical air leakage values per unit wall area at 0.30 in. of water are 0.10, 0.30, and 0.60 cfm/ft^2 for tight, average, and leaky walls, respectively (Tamura and Shaw 1976a).

Grot and Persily (1986) also found that eight recently constructed office buildings had infiltration rates ranging from 0.1 to 0.6 ACH with no outdoor air intake. The infiltration rates of these buildings exhibited varying degrees of weather dependence, generally much lower than that measured in houses.

Air Leakage Through Internal Partitions

In large buildings, the air leakage associated with internal partitions becomes very important. Elevator, stair, and service shaft walls; floors; and other interior partitions are the major separations of concern in these buildings. Their leakage characteristics are needed to determine infiltration through exterior walls and airflow patterns within a building. These internal resistances are also important in the event of a fire to predict smoke movement patterns and evaluate smoke management systems.

Table 10 gives air leakage areas (calculated at 0.30 in. of water with C_D = 0.65) for different internal partitions of commercial buildings (Klote and Milke 2002). Figure 13 presents examples of measured air leakage rates of elevator shaft walls (Tamura and Shaw 1976b), the type of data used to derive the values in Table 10. Chapter 52 of the 2003 *ASHRAE Handbook—HVAC Applications* should be consulted for performance models and applications of smoke management systems.

Leakage openings at the top of elevator shafts are equivalent to orifice areas of 620 to 1550 in^2. Air leakage rates through stair shaft and elevator doors are shown in Figure 14 as a function of average crack width around the door. The air leakage areas associated with other openings within commercial buildings are also important for air movement calculations. These include interior doors and partitions, suspended ceilings in buildings where the space above the ceiling is used in the air distribution system, and other components of the air distribution system.

Air Leakage Through Exterior Doors

Door infiltration depends on the type of door, room, and building. In residences and small buildings where doors are used infrequently, the air exchange associated with a door can be estimated based on air leakage through cracks between the door and the frame. A frequently opened single door, as in a small retail store, has a much larger amount of airflow than a closed door.

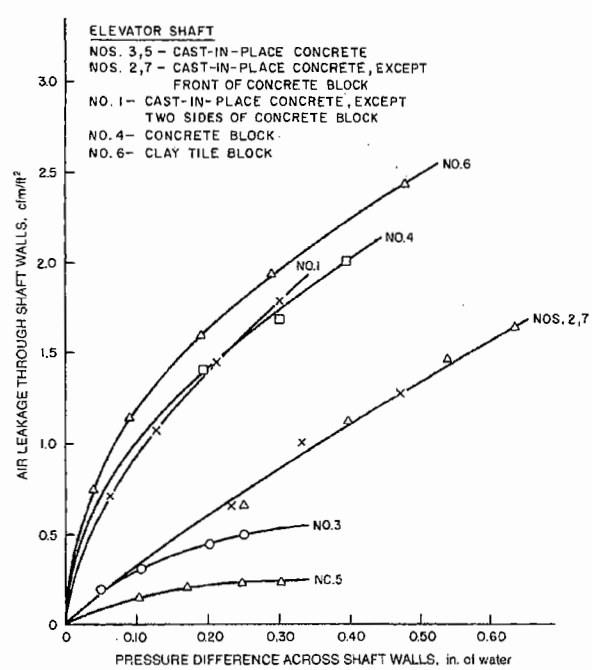

Fig. 13 Air Leakage Rates of Elevator Shaft Walls

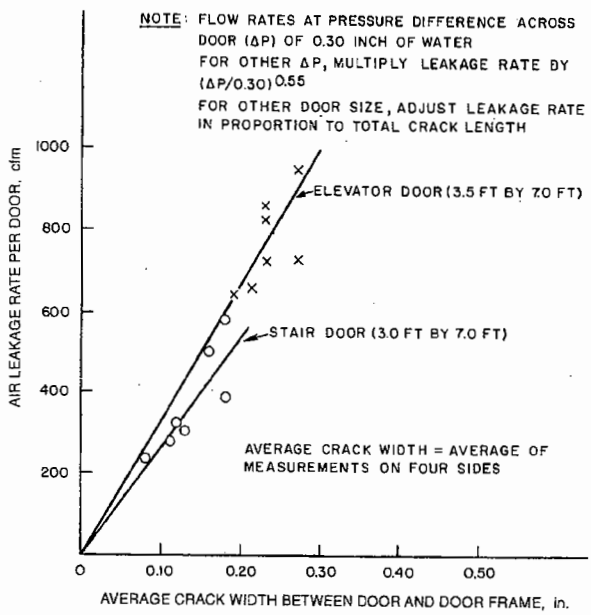

Fig. 14 Air Leakage Rate of Door Versus Average Crack Width

Table 10 Air Leakage Areas for Internal Partitions in Commercial Buildings (at 0.30 in. of water and $C_D = 0.65$)

Construction Element	Wall Tightness	Area Ratio
		A_L/A_w
Stairwell walls	Tight	0.14×10^{-4}
	Average	0.11×10^{-3}
	Loose	0.35×10^{-3}
Elevator shaft walls	Tight	0.18×10^{-3}
	Average	0.84×10^{-3}
	Loose	0.18×10^{-2}
		A_L/A_f
Floors	Average	0.52×10^{-4}

A_L = air leakage area A_w = wall area A_f = floor area

Air Leakage Through Automatic Doors

Automatic doors are a major source of air leakage in buildings. They are normally installed in locations where large numbers of people use the doors. They stay open longer with each use than manual doors. The air leakage through automatic doors can be reduced by the installation of a vestibule. However, pairs of automatic doors on the inside and outside of a vestibule normally have overlapping open periods, even when used by only one person at a time. Therefore, it is important that designers take into account the airflow through automatic doors when calculating the heating and cooling loads in the spaces next to them.

To calculate the average airflow rate through an automatic door, the designer must take into account the area of the door, the pressure difference across it, the discharge coefficient of the door when it is open, and the fraction of time that it is open. Obtaining the discharge coefficient is complicated by the fact that it changes as the door opens and closes.

To simplify this calculation, Figure 15 has been developed (Yuill 1996) to combine the discharge coefficients of doors as they open and close with the fraction of time that doors are open at a particular level of use. This figure presents an overall airflow coefficient as a function of the people using a door per hour. To obtain the average infiltration rate through an automatic door, the user must multiply

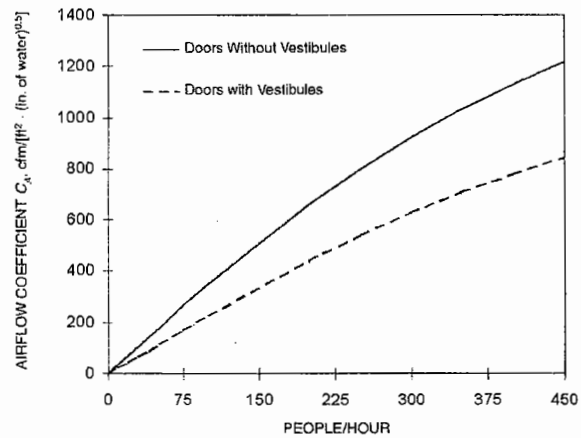

Fig. 15 Airflow Coefficient for Automatic Doors

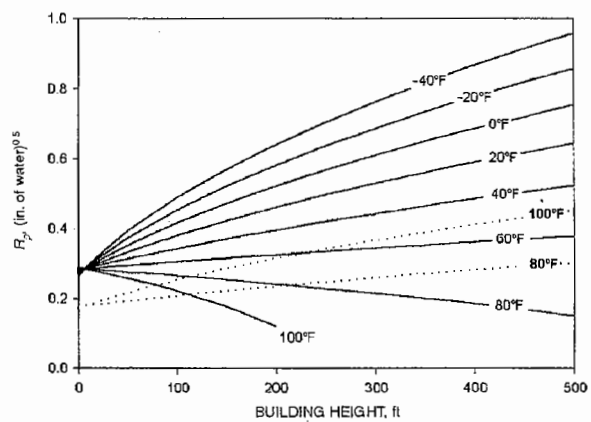

Fig. 16 Pressure Factor for Automatic Doors

this coefficient by the opening area of the door and by the square root of the pressure difference between the outdoor air and the indoor air at the location of the door. The pressure difference across a door in a building depends on the wind pressure on the building, the stack effect due to the indoor-outdoor temperature difference, and the effect of the operation of the air-handling system. It also depends on the leakage characteristics of the exterior walls of the building and of internal partitions.

Two simple methods are presented here. The first method uses simplifying assumptions to determine design values for R_p, the square root of the pressure difference across the automatic door, given in Figure 16. The second method requires explicit calculation of envelope pressures.

In Figure 16, the airflows shown for ambient temperatures of 80 and 100°F, represented by dotted lines, are outward flows. They intercept the vertical axis at a lower point than the other lines because the wind pressure coefficients on the downwind face of the building (where the greatest outward flows will occur) are lower than on the upward face. In many buildings, the pressure in the building is controlled by varying the flow rate through the return fan(s) or by controlling the relief air dampers. These systems are usually set to maintain a pressure above ambient in the lobby. Subtracting the interior pressure maintained in the lobby from the wind pressure gives the net pressure for estimating airflow through the door.

Method 1. For the first method, the infiltration rate through the automatic door is given by

$$Q = C_A A R_p \tag{44}$$

where

Q = airflow rate, cfm
C_A = airflow coefficient from Figure 15, cfm/[ft^2(in. of water)$^{0.5}$]
A = area of the door opening, ft^2
R_p = pressure factor from Figure 16, (in. of water)$^{0.5}$

Method 2. The airflow Q is given by

$$Q = C_A A \sqrt{\Delta p} \tag{45}$$

where

Q = airflow rate, cfm
C_A = airflow coefficient from Figure 15, cfm/[ft^2(in. of water)$^{0.5}$]
A = area of the door opening, ft^2
Δp = pressure difference across the door, in. of water

To find Δp, it is necessary to find the pressure differential due to wind and that due to the stack effect. In order to give the largest possible pressure difference across the door, there are no interactions between the two natural pressures:

$$\Delta p = p_w - \Delta p_s \tag{46}$$

where

p_w = wind-induced surface pressure relative to static pressure, in. of water
Δp_s = pressure difference due to stack effect, in. of water

Example Calculations

It is desired to find the maximum possible infiltration through an automatic door located on the ground floor of a 20-story building. The area of the door is 36 × 84 in. = 3024 in^2 = 21 ft^2. Each floor is 13 ft high. Approximately 300 people per hour pass through the door. The design wind conditions are 15 mph, the indoor temperature is 70°F, and the outdoor temperature is 20°F. The airflow coefficient from Figure 15 (using the line for doors without vestibules) is approximately 920 cfm/[ft^2(in. of water)$^{0.5}$].

Method 1:

The pressure factor from Figure 16 is 0.5 (in. of water)$^{0.5}$. Equation (44) gives the door flow as

$$Q = 920(21)0.5 = 9660 \text{ cfm}$$

Method 2:

The worst possible case for the wind surface pressure coefficient C_p at any point and in any position on the ground floor of the building is inferred from figures in Chapter 16 to be about 0.75. Using this in Equation (18), together with the specified wind speed, results in $p_w = 0.082$ in. of water. Assume that H is one-half the height of the door (42 in.). In order to have the maximum pressure across the door, assume the neutral pressure plane is located halfway up the building such that

$$H_{\text{NPL}} = \frac{1}{2}(20 \text{ stories})\frac{13 \text{ ft}}{\text{story}} = 130 \text{ ft}$$

Substituting these values into Equation (17) gives $\Delta p_s = -0.19$ in. of water. This is the maximum stack pressure difference given no internal resistance to airflow. To find the actual stack pressure difference, it is necessary to multiply this by a draft coefficient. We will assume that this coefficient is 0.9, which is the highest value that has been found for tall buildings. Therefore, $\Delta p_s = 0.9(-0.19 \text{ in. of water}) = -0.17$ in. of water. The total pressure is then $\Delta p = 0.082 - (-0.17) = 0.252$ in. of water. Substituting into Equation (45),

$$Q = 920(21)\sqrt{0.252} = 9700 \text{ cfm}$$

If the building had a vestibule, the airflow coefficient would be read from Figure 15 using the line for doors with vestibules, and it would be approximately 626 cfm/[ft^2(in. of water)$^{0.5}$], reducing the airflow to 6600 cfm into the building.

NONRESIDENTIAL VENTILATION

Commercial and institutional building ventilation systems are typically designed to provide a slight pressurization to minimize infiltration. This pressurization is achieved by having the outside or makeup airflow rate higher than the exhaust or relief airflow rate. In these buildings, infiltration is usually neglected except in areas such as lobbies, where infiltration can be important due to doors. As discussed in the section on Driving Mechanisms for Ventilation and Infiltration, wind and the stack effect can also cause significant infiltration and exfiltration. Ventilation airflow rates for commercial and institutional buildings are typically determined using procedures in ASHRAE *Standard* 62.1. In these procedures for designing forced ventilation systems, no credit is given for infiltration. However, weather-driven pressure differentials may be significant and need to be considered when designing the ventilation system.

ASHRAE *Standard* 62.1 includes two procedures for obtaining acceptable indoor air quality: the Ventilation Rate Procedure and the Indoor Air Quality Procedure. The Ventilation Rate Procedure is by far the more commonly used.

Ventilation Rate Procedure

In the Ventilation Rate Procedure, the design ventilation rate is determined based on a table of minimum ventilation requirements for different space types. These requirements are expressed as an outdoor airflow rate per occupant or per unit floor area, depending on the space type. These ventilation rates are based on air pollutants generated by people, activities, and building materials and furnishings.

The HVAC designer faces several challenges in designing an air distribution system to deliver outdoor air to the occupants of a building. The first is to determine whether the outdoor air is acceptable for use and to design a system for cleaning the air if it is not acceptable. A second goal is to design an air intake and distribution system that will deliver the required level of outdoor air to the occupied portions of the building. This outdoor air must be delivered not only at the design conditions, but throughout the year. The task is complicated by weather-related variations in indoor-outdoor pressure difference. Other complications include pressure variations due to building components such as exhaust fans or dirty filters, and probably most significantly by supply flow variations associated with the operation of variable air volume (VAV) systems (Janu et al. 1995; Mumma and Wong 1990). After the design level of outdoor air is brought into the building, it must then be delivered to the occupants. This issue is related to the discussion in the section on Air Change Effectiveness presented earlier in this chapter.

TRACER GAS MEASUREMENTS

The only reliable way to determine the air exchange rate of an existing building is to measure it. Several tracer gas measurement procedures exist (including a standard test method: ASTM *Standard* E741), all involving an inert or nonreactive gas used to label the indoor air (Charlesworth 1988; Dietz et al. 1986; Fisk et al. 1989; Fortmann et al. 1990; Harrje et al. 1981,1990; Hunt 1980; Lagus 1989; Lagus and Persily 1985; Persily 1988; Persily and Axley 1990; Sherman 1989a, 1989b, 1990; Sherman et al. 1980). The tracer is released into the building in a specified manner, and the concentration of the tracer within the building is monitored and related to the building's air exchange rate. A variety of tracer gases and associated concentration detection devices have been used. Desirable qualities of a tracer gas are detectability, nonreactivity, nontoxicity, neutral buoyancy, relatively low concentration in ambient air, and low cost (Hunt 1980).

All tracer gas measurement techniques are based on a mass balance of the tracer gas within the building. Assuming the outdoor concentration is zero and the indoor air is well mixed, this total balance takes the following form:

$$V\left(\frac{dC}{d\theta}\right) = F(\theta) - Q(\theta)C(\theta) \tag{47}$$

where

V = volume of space being tested, ft^3
$C(\theta)$ = tracer gas concentration at time θ
$dC/d\theta$ = time rate of change of concentration, min^{-1}
$F(\theta)$ = tracer gas injection rate at time θ, cfm
$Q(\theta)$ = airflow rate out of building at time θ, cfm
θ = time, min

In Equation (47), density differences between indoor and outdoor air are generally ignored for moderate climates; therefore, Q also refers to the airflow rate into the building. While Q is often referred to as the infiltration rate, any measurement includes both mechanical and natural ventilation in addition to infiltration. The ratio of Q to the volume V being tested has units of 1/time (often converted to ACH) and is the air exchange rate I.

Equation (47) is based on the assumptions that (1) no unknown tracer gas sources exist; (2) the airflow out of the building is the dominant means of removing the tracer gas from the space (i.e., the tracer gas does not react chemically within the space and/or is not adsorbed onto or by interior surfaces), and (3) the tracer gas concentration within the building can be represented by a single value (i.e., the tracer gas is uniformly mixed within the space).

Three different tracer gas procedures are used to measure air exchange rates: (1) decay or growth, (2) constant concentration, and (3) constant injection.

Decay or Growth

Decay. The simplest tracer gas measurement technique is the decay method (also known as the step-down method). A small amount of tracer gas is injected into the space and is allowed to mix with the interior air. After the injection, $F = 0$ and then the solution to Equation (47) is

$$C(\theta) = C_o e^{-I\theta} \tag{48}$$

where C_o is the concentration of the tracer in the space at $\theta = 0$.

Equation (48) is generally used to solve for I by measuring the tracer gas concentration periodically during the decay and fitting the data to the logarithmic form of Equation (48):

$$\ln C(\theta) = \ln C_o - I\theta \tag{49}$$

Like all tracer gas techniques, the decay method has advantages and disadvantages. One advantage is that because logarithms of concentration are taken, only relative concentrations are needed, which can simplify the calibration of the concentration-measuring equipment. Also, the tracer gas injection rate need not be measured, although it must be controlled so that the tracer gas concentrations are within the range of the concentration-measuring device. The concentration-measuring equipment can be located on site, or building samples can be collected in suitable containers and analyzed elsewhere.

The most serious problem with the decay technique is imperfect mixing of the tracer gas with the interior air, both at initial injection and during the decay. Equations (47) and (48) employ the assumption that the tracer gas concentration within the building is uniform. If the tracer is not well mixed, this assumption is not appropriate and the determination of I will be subject to errors. It is difficult to estimate the magnitude of the errors due to poor mixing, and little analysis of this problem has been performed.

Growth. The growth or step-up method is similar to the decay method except that the initial tracer gas concentration is low and is increased during the test.

Constant Concentration

In the constant concentration technique, the tracer gas injection rate is adjusted to maintain a constant concentration within the building. If the concentration is truly constant, then Equation (47) reduces to

$$Q(\theta) = F(\theta)/C \tag{50}$$

There is less experience with this technique than with the decay procedure, but an increasing number of applications exist (Bohac et al. 1985; Collet 1981; Fortmann et al. 1990; Kumar et al. 1979; Walker and Forest 1995; Walker and Wilson 1998; Wilson and Walker 1993).

Because the tracer gas injection is continuous, no initial mixing period is required. Another advantage is that the tracer gas injection into each zone of the building can be separately controlled; thus, the amount of outdoor air flowing into each zone can be determined. This procedure is best suited for longer term continuous monitoring of fluctuating infiltration rates. This procedure has the disadvantage of requiring the measurement of absolute tracer concentrations and injection rates. Also, imperfect mixing of the tracer and the interior air causes a delay in the response of the concentration to changes in the injection rate.

Constant Injection

In the constant injection procedure, the tracer is injected at a constant rate, and the solution to Equation (47) becomes

$$C(\theta) = (F/Q)(1 - e^{-I\theta}) \tag{51}$$

After sufficient time, the transient term reduces to zero, the concentration attains equilibrium, and Equation (51) reduces to

$$Q = F/C \tag{52}$$

Equation (52) is valid only when air exchange rate I and airflow rate Q are constant; thus, this technique is only appropriate for systems at or near equilibrium. It is particularly useful in spaces with mechanical ventilation or with high air exchange rates. Constant injection requires the measurement of absolute concentrations and injection rates.

Dietz et al. (1986) used a special case of the constant injection technique. This technique uses permeation tubes as a tracer gas source. The tubes release the tracer at an ideally constant rate into the building being tested. A sampling tube packed with an adsorbent collects the tracer from the interior air at a constant rate by diffusion. After a sampling period of one week or more, the sampler is removed and analyzed to determine the average tracer gas concentration within the building during the sampling period.

Solving Equation (47) for C and taking the time average gives

$$\langle C \rangle = \langle F/Q \rangle = F\langle 1/Q \rangle \tag{53}$$

where $\langle \ldots \rangle$ denotes time average. (Note that the time average of $dC/d\theta$ is assumed to equal zero.)

Equation (53) shows that the average tracer concentration $\langle C \rangle$ and the injection rate F can be used to calculate the average of the inverse airflow rate. The average of the inverse is less than the inverse of the actual average, with the magnitude of this difference depending on the distribution of airflow rates during the measurement period. Sherman and Wilson (1986) calculated these differences to be about 20% for one-month averaging periods. Differences greater than 30% have been measured when there were large changes in air exchange rate due to occupant airing of houses; errors from 5 to 30% were measured when the variation was due to weather effects (Bohac et al. 1987). Longer averaging periods and large changes in air exchange rates during the measurement periods

generally lead to larger differences between the average inverse exchange rate and the inverse of the actual average rate.

Multizone Air Exchange Measurement

Equation (47) is based on the assumption of a single, well-mixed enclosure, and the techniques described are for single-zone measurements. Airflow between internal zones and between the exterior and individual internal zones has led to the development of multizone measurement techniques (Fortmann et al. 1990; Harrje et al. 1985; Harrje et al. 1990; Sherman and Dickerhoff 1989). These techniques are important when considering the transport of pollutants from one room of a building to another. For a theoretical development, see Sinden (1978b). Multizone measurements typically use either multiple tracer gases for the different zones or the constant concentration technique. A proper error analysis is essential in all multizone flow determination (Charlesworth 1988; D'Ottavio et al. 1988).

SYMBOLS

A = area, ft^2 or in^2
c = flow coefficient, cfm/(in. of water)^n
c_p = specific heat, Btu/lb·°F
C = concentration, ppm
$\overline{C}$ = time averaged concentration
C_A = airflow coefficient for automatic doors, cfm/[ft^2 (in. of water)$^{0.5}$]
C_D = discharge coefficient
C_p = pressure coefficient
C_s = stack flow coefficient, cfm^2/(in^4·°F) or (in. of water/°F)^n
C_v = effectiveness of openings
C_w = wind flow coefficient, cfm^2/(in^4·mph^2) or (in. of water/mph^2)^n
F = tracer gas injection rate, cfm
$\overline{F}$ = time-averaged contaminant source strength, cfm
f = fractional on-time
g = gravitational acceleration, ft/s^2
G = wind speed multiplier, Table 7
h = specific enthalpy, Btu/lb
H = height, ft
i = hour of year
I = air exchange rate, 1/time
I_i = instantaneous air exchange rate, 1/time
I_m = effective air exchange rate, 1/time
IDD = infiltration degree-days, °F
n = pressure exponent
N = number of discrete time periods in period of interest
p = pressure, in. of water
P = parameter
q = heat rate, Btu/h
Q = volumetric flow rate, cfm
$\overline{Q}$ = effective volumetric flow rate, cfm
s = shelter factor
S = source strength, cfm
t = relative temperature, °F
T = absolute temperature, °R
U = wind speed, mph
V = volume, ft^3
W = humidity ratio, lb$_m$ water/lb$_m$ dry air
ε_I = air change effectiveness
ϕ = wind angle, degrees
ρ = air density, lb$_m$/ft^3
θ = time
θ_{age} = age of air
τ = time constant

Subscripts

b = base
ba = bypass air
c = calculated
ca = recirculated air
e = effective
ea = exhaust air
f = floor
i = indoor or time counter for summation (instantaneous)
H = building height, eaves or roof
ka = makeup air
l = latent
la = relief air
L = leakage or local
ma = mixed air
met = meteorological station location
n = normalized
N = nominal
NPL = neutral pressure level
o = outdoor, initial condition, or reference
oa = outside air
p = pressure
r = reference
s = sensible or stack
sa = supply air
S = space or source
w = wind

REFERENCES

ACGIH. 2001. *Industrial ventilation: A manual of recommended practice*, 24th ed. American Conference of Governmental Industrial Hygienists, Lansing, MI.

AIVC. 1994. *An analysis and data summary of the AIVC's numerical database*. AIVC *Technical Note* 44. International Energy Agency Air Infiltration and Ventilation Centre, Coventry, U.K.

Akins, R.E., J.A. Peterka, and J.E. Cermak. 1979. Averaged pressure coefficients for rectangular buildings. Vol.1, *Proceedings of the Fifth International Wind Engineering Conference*, Fort Collins, U.S., July, pp. 369-380.

Allard, F. and M. Herrlin. 1989. Wind-induced ventilation. *ASHRAE Transactions* 95(2):722-728.

ASHRAE. 1999. Method of testing general ventilation air cleaning devices for removal efficiency by particle size. ANSI/ASHRAE *Standard* 52.2-1999.

ASHRAE. 2004. Thermal environmental conditions for human occupancy. ASHRAE *Standard* 55-2004.

ASHRAE. 2004. Ventilation for acceptable indoor air quality. ANSI/ASHRAE *Standard* 62.1-2004.

ASHRAE. 2003. Ventilation and acceptable indoor air quality in low-rise residential buildings. ANSI/ASHRAE *Standard* 62.2-2003.

ASHRAE. 1988. Air leakage performance for detached single-family residential buildings. ANSI/ASHRAE *Standard* 119-1988 (RA 1994).

ASHRAE. 1997. Measuring air change effectiveness. ANSI/ASHRAE *Standard* 129-97 (RA 2002).

ASHRAE. 1993. A method of determining air change rates in detached dwellings. ANSI/ASHRAE *Standard* 136-1993 (RA 2001).

ASTM. 1991. Test method for determining the rate of air leakage through exterior windows, curtain walls, and doors under specified pressure differences across the specimen. *Standard* E283-91.

ASTM. 1993. Test methods for determining air change in a single zone by means of a tracer gas dilution. *Standard* E741-93.

ASTM. 1999. Measuring air leakage by the fan pressurization method. *Standard* E779-99.

ASTM. 1993. Test method for field measurement of air leakage through installed exterior windows and doors. *Standard* E783-93.

ASTM. 1987. Practices for air leakage site detection in building envelopes. *Standard* E1186-87(R 1992). American Society for Testing and Materials, West Conshohocken, PA.

ASTM. 1996. Standard test methods for determining airtightness of buildings using an orifice blower door. *Standard* E1827-96.

ASTM. 1999. Standard guide for assessing depressurization-induced backdrafting and spillage from vented combustion appliances. *Standard* E1998-99.

Bahnfleth, W.P., G.K. Yuill, and B.W. Lee. 1999. Protocol for field testing of tall buildings to determine envelope air leakage rates. *ASHRAE Transactions* 105(2).

Bankvall, C.G. 1987. Air movements and thermal performance of the building envelope. In *Thermal insulation: Materials and systems*, F.J. Powell and S.L. Mathews, eds. ASTM, Philadelphia, pp. 124-131.

Berg-Munch, B., G. Clausen, and P.O. Fanger. 1986. Ventilation requirements for the control of body odor in spaces occupied by women. *Environmental International* 12(1-4):195.

PAE CONSULTING ENGINEERS, INC.

EAc1 - Narrative

Date: October 16, 2006

Project Name: "The Nines" - Sage/Meier & Frank

Subject: LEED – EA Credit 1 – Optimize Energy Performance

"The Nines" performs 27.47% better than ASHRAE 90.1-1999 requirements using the LEED Energy Cost Budget methodology. This earns 5 LEED points based on the attached interpolation table.

The project includes remodeling of an existing historical building built in 1908 and located in downtown Portland, Oregon. The completed project will consist of approximately 250,000 square feet operating Meier and Frank Department Store that will occupy the first five levels of the building, and approximately 320,000 square feet of "The Nines" hotel that will be located on the sixth through fifteenth floor and the basement of the building. The extent of the energy study is limited to the hotel only.

The majority of the fourteenth floor and all of the fifteenth floor will be new construction. The ratio of the new construction to the total building occupied by the hotel is 18.5%.

The Nines includes two restaurants, 331 guest rooms, a fitness center, laundry facility, grand ballroom, conference rooms, three kitchens, and several mechanical and electrical rooms.

The new addition on the fourteenth and fifteenth floors are steel-framed construction. The existing walls consist of external stucco layer, frame without insulation, and gyp board. All windows in the existing walls will be sealed to reduce the infiltration rate. The overall window to wall ratio is 32.4%. The building's roof will be replaced with a new steel-framed roof with 17.7% skylight to roof ratio.

Hotel guest rooms will use fan coil units with hydronic heating and chilled water coils. Ventilation air to the guestrooms, corridors, meeting rooms, and service areas will be supplied by a dedicated air handling equipment using energy recovery. The heat source space heating water consists of multiple high-efficiency condensing boilers located at the roof level. Domestic water will be heated by a heat exchanger connected to a secondary heating water loop. Public areas will be completely air-conditioned using chilled water from a central plant consisting of two chillers located at the roof level. Two air-cooled chillers will be configured in a primary-secondary system with separate secondary loops for the guestrooms, and public area. The guestroom fan coils will use the "pumped-mono-flow" concept for piping and control. Heating and cooling recovery from exhaust air leaving the guestrooms will be used to temper the ventilation air supplied to the guestrooms.

The energy analysis for "The Nines" was performed using standard engineering calculation procedures and the DOE2.2 and eQuest computer analysis programs. Both the Budget and Design energy cases were modeled using the eQuest interface for the DOE2.2 simulation engine, developed by James J. Hirsch &

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Associates. The program calculates heating and cooling loads, as well as building energy use for each hour of the year.

Climate data used for the analysis was for Portland, Oregon (Table D-1 of ASHRAE 90.1-1999), with corresponding building envelope requirements prescribed by Table B-14 of ASHRAE 90.1-1999. A TMY2 weather file for Portland, Oregon was used for the hourly energy use analysis.

The utility rates used for both the budget proposed design building were based on local utility rates. The electricity rates were from Pacific Power *Schedule 48*, and natural gas rates were from Northwest Natural *Rate Schedule 31*.

Building Energy Efficiency Measures:

1. High Performance Glazing for New Constructions: The shading and thermal performance of a building's glazing is in excess of minimum requirements listed in ASHRAE 90.1-1999 Table B-14 for window to wall ratio of over 30.1%.
2. Increased Wall and Roof Insulation: The overall U-values of the walls and roof in the proposed buildings outperform ASHRAE 90.1-1999 requirements for nonresidential building.
3. High Efficiency Lighting: Lighting power densities in proposed buildings are substantially lower then the lighting power densities allowed by ASHRAE 90.1-1999 using the Building Area Method for hotel.
4. Daylighting Controls: Lighting fixtures in the Atrium controlled with photo sensors.
5. High Efficiency Boilers: Heating water system uses high efficiency condensing boilers.
6. Energy Recovery: Using a run-around loop, exhaust air leaving the guestrooms is used to temper the fresh air supplied to the guestrooms and public area.
7. Mechanical Equipment Efficiency: The specified air-cooled chillers are more efficient than the minimum efficiency requirements of ASHRAE 90.1-1999.
8. The exceptional calculation method of ASHRAE 90.1-1999 ECB method was used for three calculations, described in detail below: reduced building air leakage, demand control ventilation, and reduced domestic water heating by use of low flow fixtures.

Exceptional Calculation Method – Energy Efficiency Measures:

Exceptional Calculation Method 1 (ECM1) – Reduced Building Air Leakage:
A credit ruling posted on 03/11/2003 indicates that improved energy performance for reduction in building air leakage may be considered for savings under EAc1 credit requirements.

Most of "The Nines" building is making use of an existing building envelope and structure. Observation of the building during its former occupancy indicated that the building is quite leaky relative to new construction standards. For this reason, the project team determined a method to reduce building air leakage, while working within the constraints of preserving the historically significant

building façade. Air leakage testing was performed using ASTM E 783-93 on two typical existing window areas (the two typical window sizes for the project). The report containing test results, and describing test procedure is attached. Of two potential window treatments that could be applied to the building, only one proved particularly effective in reducing air leakage. The effective strategy was sealing (with sealant) the entire perimeter of both the top and bottom fixed and sliding sashes, including the rails. The reduction in air leakage was from 0.74 CFM/sf to 0.01 CFM/sf at 1.57 PSF (0.30" w.g.) for the more common window size (Note, that the reduction was greater in the less common window size, but, to be conservative in credit savings, the smaller and more common reduction was applied for ECM savings).

As the test method did not measure the air leakage for the entire wall area, we assumed an overall value of air leakage for the existing wall (this value is 0.60 CFM/sf at 0.30" w.g. from ASHRAE Fundamentals for leaky construction). An area weighted average of window to wall ratio was used to estimate the portion of air leakage contributed by the window area, and the portion contributed by the net exterior wall area. In order to determine the reduced air leakage rate, only that portion of air leakage contributed by the windows were reduced (leaving the net exterior wall portion of air leakage constant). These calculations, including the resulting reduction in air leakage over the total wall area are attached.

The building air leakage was reduced by 34% on existing walls due to this window treatment (see attached calculations). According to ASHRAE 90.1-1999 section 4.1.2 Existing Buildings, and 4.1.2.2 Alterations to existing buildings, measures relating to air leakage were not required for this project.

The air leakage reduction has been applied only to spaces enclosed by the existing building envelope. All new construction portions of the building are treated identically in the design and budget cases. A new DOE2.2 file was created with all inputs equal to the proposed design case except for the infiltration rates as described above. In this way, the energy savings associated with this measure has been isolated. The spreadsheet containing the Design building Energy Cost contains a separate line item for this exceptional calculation method. (See LEED CIR for EAc1 ruling 3/11/03)

<u>Exceptional Calculation Method 2 (ECM2) – Demand Control Ventilation:</u>
CO2 sensors are used to lower the outside air rate supplied to the building when occupancy is low. A calculation is attached showing the average occupancy schedule for the spaces served by the Rooftop units that employ demand control ventilation. The design minimum outside air rate for those AHUs is 7,100 CFM at full occupancy. The fractional hourly occupancy schedule was used to determine the average occupancy rate when the AHUs supply fans are scheduled to be on. This fractional occupancy is 32%. The outside air was therefore reduced to 32% of the peak, or 2,272 CFM. A new DOE2.2 file was created with all inputs equal to the proposed design case except the OSA CFM on AHUs, as described above. The total electric and natural gas savings for this DOE2.2 model have been applied to the ECB calculation method for the DEC'

case under Exceptional Calculation Method 2, as indicated in attached calculation. (See LEED CIR for EAc1 ruling 1/20/02)

Exceptional Calculation Method (ECM3) Low flow fixtures:
Reduction in domestic hot water use due to low flow showers, low flow lavatories, and low flow kitchen sink. Calculations are attached and described further below. Savings were calculated using the WEc3 Baseline fixture flow rates and total water use in gallons/day from the Energy Policy Act of 1992, and the specified design fixture flow rates. Energy to heat domestic water was reduced by ~5,500 therms, as indicated in attached calculation. The total energy savings for this calculation has been applied to the ECB calculation method for the DEC' case under Exceptional Calculation Method 3, as indicated in attached calculation. (See LEED CIR for EAc1 ruling 6/27/01)

Comparison of Design Energy Case versus Budget Energy Case
Descriptions of the differences between the DEC and ECB models are provided in Table 1, below. Items are modeled equivalently in each case if they are not discussed explicitly below in Table 1. Equivalently modeled items include, but are not limited to: occupancy, plug loads, minimum OSA, all schedules, and HVAC systems where not designed (e.g. 15th floor kitchen area, and un-conditioned spaces in actual building design).

Although modeled equivalently, and therefore not presented in the Table 1 below, there are a couple of HVAC systems that warrant discussion. There is a future kitchen and storage space located on the fifteenth floor. In the actual building design, this area is a shell space only, and is not provided with an HVAC system. Therefore, in both the DEC case and ECB cases, the space was modeled with an air-cooled single zone system with natural gas furnace heating, following ASHRAE 90.1-1999 11.3.5.c&d.

Mechanical rooms and semi-conditioned storage area that by the local code can not be used as occupied space are tempered with cabinet unit heaters and unit heaters to keep the rooms above freezing. Thermostat set point in these rooms is 45 °F. The actual heating capacity of these units is modeled in both the DEC case and ECB case.

All power densities and schedules for equipment loads, including task lighting, were modeled equivalently in both the design and budget cases. The power densities chosen reflect what is expected in the actual building. The direct energy use is treated as unregulated load in the ECB method calculation, as indicated in attached calculation.

Table 1, below, summarizes the differences between the Design and Budget models.

Table 1: Summary of Differences between DEC and ECB models

Building Element	**Design Building (DEC model)**	**Budget Building (ECB model)**
B u i l d i n g E n v e l o p e		
Walls	Existing Walls: Un-insulated stucco wall, air space and gyp board. U-factor = 0.402 New Construction: Steel frame wall (studs spaced 16" o.c.) with R-19 insulation. U-factor = 0.109	Existing Walls: Same as Design Building New Construction: Steel frame wall with R-13 insulation. U-factor = 0.124 (See Table B-14 ASHRAE 90.1-1999)
Roof	Built-up Roof with R-30 insulation. U-factor = 0.029	Built-up Roof. U-factor = 0.063 (See Table B-14 ASHRAE 90.1-1999)
Vertical Glazing	Existing Windows: Single glazing, Aluminum framing, - U-factor = 1.13 - SHGC = 0.77 - 32.4 % Glazing (includes glass doors and window frames) New Windows: - Thermally broken Aluminum framing, Double-pane, low-E - window U-factor = 0.41 - SHGC = 0.38	Existing Windows: Same as Design Building New Windows: - window U-factor = 0.57 - SHGC = 0.49 (North) - SHGC = 0.39 (non-North) (See Table B-14 ASHRAE 90.1-1999)
Skylight without a curb	17.7% of roof area - Thermally broken Aluminum framing, Double-pane, low-E - skylight U-factor = 0.6 - SHGC = 0.28	5% of roof area - skylight U-factor = 0.69 - SHGC = 0.39 (See Table B-14 ASHRAE 90.1-1999)
L i g h t i n g		
Lighting Power Density	Average = 1.0 W/sf	1.7 W/sf for Hotel (See Building Area Method – Table 9.3.1.1 ASHRAE 90.1-1999)
Daylighting	Continuous dimming control of the lighting in the Atrium.	Not modeled.
D o m e s t i c W a t e r H e a t i n g		
Water Heater Efficiency	Domestic water is heated through the heat exchanger attached to the secondary hot water loop. In the DEC domestic hot water loop is modeled with a high efficiency (92%) condensing domestic water heater with part load curve.	Domestic water is heated through the heat exchanger attached to the secondary hot water loop. In the ECB domestic hot water loop is modeled with a standard efficiency (80%) domestic water heater with part load curve; natural gas fuel source.

HVAC		
System Type (Variable Air Volume)	AHU-1, AHU-2, AHU-7, AHU-9, AHU-11: VAV Air handling units with heating water and chilled water coils. Heating and cooling capacities and air flow rates were modeled as provided on the actual cut sheets. Actual total increase in air pressure across the supply air fan (at the design flow rate) and fan efficiency were included in the model. Systems were modeled with 100% outside air economizer.	AHU-1, AHU-2, AHU-7, AHU-9, AHU-11: System 4 in Table 11.4.3A Packaged VAV air handling units with reheat, DX cooling coils, and hot water heating coils. Systems were modeled with 100% outside air economizer.
System Type continue: (Constant Air Volume)	AHU-3, AHU-4, AHU-5: Single-Zone Reheat Fan Systems providing constant volume, forced-air heating and cooling for a single zone plus sub zones. Heating and cooling capacities and air flow rates were modeled as provided on the actual cut sheets. Actual total increase in air pressure across the supply air fan (at the design flow rate) and fan efficiency were included in the model. Systems were modeled with 100% outside air economizer. RTU-1, RTU-2, RTU-3, RTU-4, RTU-5: Packaged single zone, constant volume air handling units with gas heat provided by 80% efficient furnace. Heating and cooling capacities and air flow rates were modeled as provided on the actual cut sheets. Actual total increase in air pressure across the supply air fan (at the design flow rate) and fan efficiency were included in the model. Systems were modeled with 100% outside air economizer. Fan Coil Units: Fan coil units serving guest rooms were attached to modeled fan coil chilled water loop. Air side economizer was disabled. MAU-1; MAU-2 100% outside air makeup air units for the kitchens on sixth and eight floors. These units have heating capability only, and they are used when kitchen exhaust fans are operating. These units were modeled as single-zone reheat fan systems. Two additional zones were created with no internal and no external loads and temperature set points of 99 °F for cooling and 60 °F for heating. The supply air temperature of the MAU was set at 60 °F. The actual volume flow rate of the supply air and total increase in air pressure across the supply air fan (at the design flow rate) and fan efficiency were included in the model. Note: AHU-9 is the air handling unit serving air conditioning needs of the two kitchens (described above under Variable Air Volume Systems).	AHU-3, AHU-4, AHU-5: System 11 in Table 11.4.3A Packaged rooftop air conditioner, DX cooling coils, hot water heating coils, and constant volume air flow. Systems were modeled with 100% outside air economizer. RTU-1, RTU-2, RTU-3, RTU-4, RTU-5: System 11 in Table 11.4.3A Packaged rooftop air conditioner, DX cooling coils, with gas heat provided by 80% efficient furnace, and constant volume air flow. Systems were modeled with 100% outside air economizer. Fan Coil Units: System 10 in Table 11.4.3A Packaged terminal air conditioner, DX cooling coils, hot water heating coils, and constant volume air flow. MAU-1; MAU-2 System 11 in Table 11.4.3A Packaged rooftop air conditioner, DX cooling coils, with gas heat provided by 80% efficient furnace, and constant volume air flow. Two additional zones were created with no internal and no external loads and temperature set points of 99 °F for cooling and 60 °F for heating. The outside air rate for this system is equal to that for make-up air in the design building. The supply air temperature of the MAU was set at 60 °F.
Exhaust Air Heat Recovery	50% efficient heat recovery run-around loop was modeled on AHU -3 (15,000 cfm supply air, and 1000 cfm outside air), AHU-4 (13,230	No heat recovery savings applied. Per Section 6.3.6 "Energy Recovery" of the ASHRAE 90.1-1999, AHU-3 and

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	cfm supply air, and 6,770 cfm outside air), and AHU-5 (16,850 cfm 100% outside air).	AHU-4 do not need to be modeled with heat recovery. Per Exception 6.3.6.1 of ASHRAE 90.1-1999 as elaborated in the User's Manual: systems where the largest single exhaust source is less than 75% of the design outdoor airflow do not need to be modeled with heat recovery. In the design building, exhaust heat is recovered through multiple toilet exhausts from the 331 guest rooms.
Cooling Plant	Two 3.0 MBtu/h air cooled chiller: COP = 2.98 IPLV = 13.6 Chilled water temperature is 42 °F with the loop design delta T of 12 °F. One speed, premium efficiency pumps serving primary and fan coil secondary chilled water loops. Variable flow rate is modeled in the secondary chilled water loop serving AHU.	No central cooling plant (See descriptions above of Table 11.4.3.A required systems)
Heating Plant	Heating water system uses three 3.0 MBtu/h high efficiency condensing boilers. Design hot water temperature is 145 °F with loop delta T of 40 °F.	Two 80% efficient gas fired boilers were modeled in baseline building. The hot water supply temperature is 180 °F and return temperature is 130 °F.
Exceptional Calculation Method		
ECM 1: Reduced Building Air Leakage	34% reduction in air leakage rate due to the window treatment on the existing portion of the building. (See LEED CIR for EAc1 ruling 3/11/03)	No reduced infiltration savings applied
ECM 2: Demand Control Ventilation	32% reduction in minimum outside air rate for roof top units serving 15th floor restaurant, bar and lounge areas based on CO_2 sensor control. (See LEED CIR for EAc1 ruling 1/20/02)	No reduction in minimum OSA rate
ECM 2: Demand Control Ventilation	~5,500 Therms were saved using low flow shower heads. (See LEED CIR for EAc1 ruling 6/27/01)	No reduction in energy used for heating domestic hot water.

Attachments to this narrative include:
- Interpolation Table adjusting EAc1 points based on weighted average of Existing and New Construction portions of the building
- Calculation of Energy Cost Budget savings
- Simulation output reports for DEC and ECB models
- Exceptional Calculation Method (1, 2 & 3) documentation and calculations.

Sincerely,

Steve Reidy, PE

NB/KT

PAE CONSULTING ENGINEERS, INC.

Project: Sage/Meier & Frank 11/15/2005
Job: 04-1177 KT

LEED-NC 2.1 Interpolation table - modifications for Sage/M&F

New Construction Area	**59,630**	**(SF)**
Existing/Renovation Area	**262,901**	**(SF)**
Total Final SF	**322,531**	**(SF)**

Sage Percent New Construction: 18.49%

Modified Point Interpolation Table

EAc1	Sage Design Building	
points	Low	High
1	4.35%	9.35%
2	9.36%	14.35%
3	14.36%	19.35%
4	19.36%	24.35%
5	24.36%	29.35%
6	29.36%	34.35%
7	34.36%	39.35%
8	39.36%	44.35%
9	44.36%	49.35%

EAc1 Point Interpolation Table*

New Construction		Existing Buildings	
Low	High	Low	High
12.50%	17.50%	2.50%	7.50%
17.51%	22.50%	7.51%	12.50%
22.51%	27.50%	12.51%	17.50%
27.51%	32.50%	17.51%	22.50%
32.51%	37.50%	22.51%	27.50%
37.51%	42.50%	27.51%	32.50%
42.51%	47.50%	32.51%	37.50%
47.51%	52.50%	37.51%	42.50%
52.51%	57.50%	42.51%	47.50%

* from USGBC

Table 1: Budget Case - SAGE

End Use	Energy Type	Electric (kWh)	Virtual Elec Rate ($/kWh)	Gas (Therms)	Virtual Gas Rate ($/therm)	Energy Use (kBTU)	Cost ($)
Regulated							
Lighting	Electric	2,527,170	$0.0463		$1.0397	8,622,704	$117,008
Space Heating	Gas & Electric	37,209	$0.0463	173,193	$1.0397	17,446,257	$181,792
Space Cooling	Electric	834,918	$0.0463		$1.0397	2,848,740	$38,657
Heat Rejection	Electric	0	$0.0463		$1.0397	0	$0
Pumps & Aux	Electric	49,433	$0.0463	0	$1.0397	168,665	$2,289
Vent Fans	Electric	556,143	$0.0463		$1.0397	1,897,560	$25,749
Domestic Hot Water	Natural Gas		$0.0463	27,043	$1.0397	2,704,300	$28,117
Subtotal Regulated (ECB')		4,004,873		200,236		33,688,227	$393,611
Non-Regulated							
Equipment (note 1)	Electric	1,134,463	$0.0463	0	$1.0397	3,870,788	$52,526
Subtotal Non-Regulated		1,134,463		0		3,870,788	$52,526
Total Building		**5,139,336**		**200,236**		**37,559,014**	**$446,137**
Subtotal Regulated (ECB')		4,004,873		200,236		33,688,227	$393,611
ECB'		**4,004,873**		**200,236**		**33,688,227**	**$393,611**

Notes:

1. Equipment refers to all plug loads in the building

PAE Consulting Engineers, Inc.

Table 1: Design Case - SAGE

End Use	Energy Type	Electric (kWh)	Virtual Elec Rate ($/kWh)	Gas (Therms)	Virtual Gas Rate ($/therm)	Energy Use (kBTU)	Cost ($)
Regulated							
Lighting	Electric	1,474,192	$0.0455		$1.0468	5,029,943	$67,076
Space Heating	Gas & Electric	47,523	$0.0455	127,366	$1.0468	12,898,748	$135,489
Space Cooling	Electric	637,856	$0.0455		$1.0468	2,176,365	$29,022
Heat Rejection	Electric	0	$0.0455		$1.0468	0	$0
Pumps & Aux	Electric	353,234	$0.0455	0	$1.0468	1,205,234	$16,072
Vent Fans	Electric	1,109,569	$0.0455		$1.0468	3,785,849	$50,485
Domestic Hot Water	Natural Gas		$0.0455	22,977	$1.0468	2,297,700	$24,052
ECM 1 - Reduced Air Leakage	*Gas & Electric*	*-38,825*	*$0.0455*	*-20,029*	*$1.0468*	*-2,135,371*	*-$22,733*
ECM 2 - Demand control ventilation	*Gas & Electric*	*-150*	*$0.0455*	*-7,769*	*$1.0468*	*-777,412*	*-$8,139*
ECM 3 - DHW low flow fixture	*Natural Gas*		*$0.0455*	*-5,587*	*$1.0468*	*-558,700*	*-$5,848*
Subtotal Regulated (DEC')		3,583,399		116,958		23,922,357	$285,476
Non-Regulated							
Equipment (note 1)	Electric	1,134,463	$0.0455	0	$1.0468	3,870,788	$51,618
Subtotal Non-Regulated		1,134,463		0		3,870,788	$51,618
Total Building		**4,717,862**		**116,958**		**27,793,145**	**$337,094**
Subtotal Regulated (DEC')		3,583,399	$0.0455	116,958	$1.0468	23,922,357	$285,476
On-site Renewables (PV System)			$0.0455	0	$1.0468	0	$0
DEC"		**3,583,399**		**116,958**		**23,922,357**	**$285,476**
Percentage Cost ($) Savings over ECB'							**27.47%**

Notes:

1. Equipment refers to all plug loads in the building
2. Exceptional Calculation Method 1 - Recuded Building Air Leakage. See attached test report, calculations, and LEED 2.0/2.1 Credit Ruling for EAc1 dated 03/11/03.
3. Exceptional Calculation Method 2 - Demand Control Ventilation. See attached calculations, and LEED 2.0/2.1 Credit Ruling for EAc1 dated 01/20/02.
4. Exceptional Calculation Method 3 - Low Flow Fixtures applying to energy savings in Domestic Hot Water. See LEED 2.0/2.1 CIR for EAc1 dated 6/21/03

REPORT- BEPU Building Utility Performance WEATHER FILE- Portland OR TMY2

	LIGHTS	TASK LIGHTS	MISC EQUIP	SPACE HEATING	SPACE COOLING	HEAT REJECT	PUMPS & AUX	VENT FANS	REFRIG DISPLAY	HT PUMP SUPPLEM	DOMEST HOT WTR	EXT USAGE	TOTAL
EM1 ELECTRICITY													
KWH	2527170.	0.	1134463.	37209.	834918.	0.	49433.	556143.	0.	0.	0.	0.	5139342.
FM1 NATURAL-GAS													
THERM	0.	0.	0.	173193.	0.	0.	0.	0.	0.	0.	27043.	0.	200236.

TOTAL ELECTRICITY 5139342. KWH 16.981 KWH /SQFT-YR GROSS-AREA 16.981 KWH /SQFT-YR NET-AREA
TOTAL NATURAL-GAS 200236. THERM 0.662 THERM /SQFT-YR GROSS-AREA 0.662 THERM /SQFT-YR NET-AREA

PERCENT OF HOURS ANY SYSTEM ZONE OUTSIDE OF THROTTLING RANGE = 1.7
PERCENT OF HOURS ANY PLANT LOAD NOT SATISFIED = 0.0

NOTE: ENERGY IS APPORTIONED HOURLY TO ALL END-USE CATEGORIES.

EAc1 - Sage/Meier&Frank "The Nines"

Simulation Output Report - BUDGET building (ECB)

Marriott Renaissance DOE-2.2-44c7 10/17/2006 7:33:53 BDL RUN 1

REPORT- BEPU Building Utility Performance WEATHER FILE- Portland OR TMY2

	LIGHTS	TASK LIGHTS	MISC EQUIP	SPACE HEATING	SPACE COOLING	HEAT REJECT	PUMPS & AUX	VENT FANS	REFRIG DISPLAY	HT PUMP SUPPLEM	DOMEST HOT WTR	EXT USAGE	TOTAL
EM1 ELECTRICITY													
KWH	1474192.	0.	1134463.	47523.	637856.	0.	353234.	1109569.	0.	0.	0.	0.	4756837.
FM1 NATURAL-GAS													
THERM	0.	0.	0.	127366.	0.	0.	0.	0.	0.	0.	22977.	0.	150343.

TOTAL ELECTRICITY 4756837. KWH 15.717 KWH /SQFT-YR GROSS-AREA 15.717 KWH /SQFT-YR NET-AREA
TOTAL NATURAL-GAS 150343. THERM 0.497 THERM /SQFT-YR GROSS-AREA 0.497 THERM /SQFT-YR NET-AREA

PERCENT OF HOURS ANY SYSTEM ZONE OUTSIDE OF THROTTLING RANGE = 0.6
PERCENT OF HOURS ANY PLANT LOAD NOT SATISFIED = 0.0

NOTE: ENERGY IS APPORTIONED HOURLY TO ALL END-USE CATEGORIES.

EAc1 - Sage/Meier&Frank "The Nines"

Simulation Output Report - DESIGN building (DEC)
Note: results of exceptional calculation methods not included

Marriott Renaissance DOE-2.2-44c7 10/17/2006 7:28:10 BDL RUN 1

REPORT- BEPU Building Utility Performance WEATHER FILE- Portland OR TMY2

	LIGHTS	TASK LIGHTS	MISC EQUIP	SPACE HEATING	SPACE COOLING	HEAT REJECT	PUMPS & AUX	VENT FANS	REFRIG DISPLAY	HT PUMP SUPPLEM	DOMEST HOT WTR	EXT USAGE	TOTAL
EM1 ELECTRICITY													
KWH	1474192.	0.	1134463.	37688.	644182.	0.	343615.	1083872.	0.	0.	0.	0.	4718013.
FM1 NATURAL-GAS													
THERM	0.	0.	0.	107337.	0.	0.	0.	0.	0.	0.	22977.	0.	130313.

TOTAL ELECTRICITY 4718013. KWH 15.589 KWH /SQFT-YR GROSS-AREA 15.589 KWH /SQFT-YR NET-AREA
TOTAL NATURAL-GAS 130313. THERM 0.431 THERM /SQFT-YR GROSS-AREA 0.431 THERM /SQFT-YR NET-AREA

PERCENT OF HOURS ANY SYSTEM ZONE OUTSIDE OF THROTTLING RANGE = 0.0
PERCENT OF HOURS ANY PLANT LOAD NOT SATISFIED = 0.0

NOTE: ENERGY IS APPORTIONED HOURLY TO ALL END-USE CATEGORIES.

EAc1 - Sage/Meier&Frank "The Nines"

Simulation Output Report - DESIGN building (DEC) - ECM1
Output for Exceptional Calculation Method 1 - Reduced Building Air Leakage

Marriott Renaissance DOE-2.2-44c7 10/17/2006 9:55:21 BDL RUN 1

REPORT- BEPU Building Utility Performance WEATHER FILE- Portland OR TMY2

	LIGHTS	TASK LIGHTS	MISC EQUIP	SPACE HEATING	SPACE COOLING	HEAT REJECT	PUMPS & AUX	VENT FANS	REFRIG DISPLAY	HT PUMP SUPPLEM	DOMEST HOT WTR	EXT USAGE	TOTAL
EM1 ELECTRICITY													
KWH	1474192.	0.	1134463.	47523.	637706.	0.	353234.	1109569.	0.	0.	0.	0.	4756688.
FM1 NATURAL-GAS													
THERM	0.	0.	0.	119597.	0.	0.	0.	0.	0.	0.	22977.	0.	142574.

TOTAL ELECTRICITY 4756688. KWH 15.717 KWH /SQFT-YR GROSS-AREA 15.717 KWH /SQFT-YR NET-AREA
TOTAL NATURAL-GAS 142574. THERM 0.471 THERM /SQFT-YR GROSS-AREA 0.471 THERM /SQFT-YR NET-AREA

PERCENT OF HOURS ANY SYSTEM ZONE OUTSIDE OF THROTTLING RANGE = 0.6
PERCENT OF HOURS ANY PLANT LOAD NOT SATISFIED = 0.0

NOTE: ENERGY IS APPORTIONED HOURLY TO ALL END-USE CATEGORIES.

EAc1 - Sage/Meier&Frank "The Nines"

Simulation Output Report - DESIGN building (DEC) - ECM2
Output for Exceptional Calculation Method 2 - Demand Control Ventilation

PAE CONSULTING ENGINEERS, INC.

Project: Sage/Meier & Frank
Job: 04-1177

10/16/2006
KT

EAc1 - Exceptional Calculation Method 1: Air Leakage Reduction

Existing Portion of Building	
Total Existing Window	19,402
Total Existing Wall	69,835
Window as % of Wall	**27.8%**

Before Window Treatment - ORIGINAL AIR LEAKAGE

Air Leakage Rates	CFM/SF wall
Air Leakage Rate across Total Wall Area (ASHRAE value for a very leaky building; at 0.30" w.g.)	**0.60**
Air Leakage across Existing Window Area by Air Leakage Testing (ASTM E 783-93) at 1.57 psf (0.30" w.g.)	0.74
Existing Exterior Wall Estimate of Air Leakage (by weighted average of areas, extrapolated from values above)	0.55

After Window Treatment - REDUCED AIR LEAKAGE

Original Air Leakage Rates	CFM/SF wall
Existing Exterior Wall Estimate of Air Leakage (Remains Constant, from above)	0.55
Air Leakage across Existing Window Area by Air Leakage Testing (ASTM E 783-93) at 1.57 psf (0.30" w.g.)	0.01
Air Leakage Rate across Total Wall Area (by weighted average of window to wall areas)	**0.40**

Percentage Reduction in Air Leakage Rate **34%**
applied to Total Existing Wall Area

PAE CONSULTING ENGINEERS, INC.

Project: Sage/Meier & Frank
Job: 04-1177

10/16/2006
KT

EAc1 - Exceptional Calculation Method 1: Air Leakage Reduction

Existing Window/Wall Area Calculations for Air Leakage Reduction
ECM1 calculation continued.... (pg 2 of 2)

Level 6, 7, 8, 11 & 12 Window Area	
Large Window area	54.98
Small Window area	36.30
Bays per floor/façade	9
façades per floor	4
floors	5
Total Window Area	16,430
New Window Area	2,240
Existing Window Area	14,190

Level 9 & 10 Window Area	
Large Window area	43.60
Small Window area	28.79
Bays per floor/façade	9
façades per floor	4
floors	2
Total Window Area	5,212
New Window Area	0
Existing Window Area	5,212

Level 9 to 12 - Wall Area	
Total Wall Area	76,400
New Wall Area	6,565
Existing Wall Area	69,835

Sage/Meier&Frank - "The Nines"
04-1177

17-Oct
NB

EAc1 - Exceptional Calculation Method 2 (ECM2) - Demand Control Ventilation

Calculation of Reduced Outside Air due to Demand Control Ventilation

Ending Month	Ending Day	Week Schedule	days
12	31	Rest Occup Wk	365

S1 total days	261
S2 total days	52
S3 total days	52
Total days	**365**

ACAD OCCUPANCY SCHEDULE

	S1 WD	S2 Sut	S3 Sun	
1:00 AM	0.05	0.2	0.2	NO FAN
2:00 AM	0.05	0.15	0.2	NO FAN
3:00 AM	0.05	0.05	0.05	NO FAN
4:00 AM	0	0	0	NO FAN
5:00 AM	0	0	0	NO FAN
6:00 AM	0	0	0	NO FAN
7:00 AM	0	0	0	FAN
8:00 AM	0.05	0	0	FAN
9:00 AM	0.05	0	0	FAN
10:00 AM	0.05	0.05	0	FAN
11:00 AM	0.1	0.1	0.1	FAN
12:00 PM	0.4	0.35	0.2	FAN
1:00 PM	0.7	0.4	0.25	FAN
2:00 PM	0.6	0.4	0.25	FAN
3:00 PM	0.3	0.25	0.15	FAN
4:00 PM	0.1	0.2	0.2	FAN
5:00 PM	0.15	0.2	0.25	FAN
6:00 PM	0.4	0.2	0.35	FAN
7:00 PM	0.7	0.6	0.55	FAN
8:00 PM	0.7	0.7	0.65	FAN
9:00 PM	0.7	0.6	0.7	FAN
10:00 PM	0.4	0.55	0.35	FAN
11:00 PM	0.25	0.45	0.2	FAN
12:00 AM	0.1	0.25	0.2	FAN
* Average	0.33	0.30	0.25	* Only when Fans On
Total Days	261	52	52	

Weighted Average Fraction	**0.32**

Units	Design OSA (CFM)	Demand Control OSA (CFM)	Space (Level 15)
RTU-1	3300	1040.1	Bar
RTU-2	3300	1040.1	Lounge
RTU-3	500	157.6	South Bar
Total	7100	2237.7	

Baseline Case

Flush Fixture	Daily Uses	Flow Rate [GPF]	Duration [flush]	Occupant users	Sewage Generation [gal]

Male		0.0	1.0		0
Female		0.0	1.0		0

Male		0.0	1.0		0
Female		0.0	1.0		0

Male		0.0	1.0		0
Female		0.0	1.0		0

Male		0.0	1.0		0
Female		0.0	1.0		0

Male		0.0	1.0		0
Female		0.0	1.0		0

Flow Fixture	Daily Uses	Flow Rate [GPM]	Duration [sec]	Occupant users	Sewage Generation [gal]
Shower	1	2.5	300	465	4359.375
Conventional Lavatory	5	2.5	15	465	1453.125
Shower	0	2.5	300	150	187.5
Conventional Lavatory	3	2.5	15	550	1031.25
Kitchen Sink	2	2.5	15	150	187.5
---		0.0	0		0
---		0.0	0		0
---		0.0	0		0
				Total uses by all occupants	4638.75
				Total Daily Volume [gal]	7,219
				· Annual Work Days	365
				Total Annual Volume [gal]	**2,634,844**

Water Use Reduction **28.83%**

	Points Documented
WE Cr 3.1 (1 point): Water Use Reduction, 20% Reduction	1
WE Cr 3.2 (1 additional point): Water Use Reduction, 30% Reduction	0
Total Points Documented	1

Name: Steve Reidy, PE

Organization: PAE Consulting Engineers, Inc.

Role in project: HVAC Engineer

Signature:

Date: 10/17/2006

WE Credit 3: Water Use Reduction

EITHER

(Tenant, Project Manager, HVAC Engineer, Civil Engineer or Responsible Party)
I, Steve Reidy, PE, declare that the project uses at least 20% less water than baseline fixture performance requirements of the Energy Policy Act of 1992.

Flow Fixture Chart

	Flow Fixture Type	Water Use [GPM]	Duration [sec]
	Conventional Lavatory	2.5	15
*	Low-Flow Lavatory	1.0	15
	Kitchen Sink	2.5	15
*	Low-Flow Kitchen Sink	2.0	15
	Shower	2.5	300
*	Low-Flow Shower	2.5	300
	Janitor Sink	2.5	15
	Hand Wash Fountain	0.5	15
*	Kitchen sink, S-3	2.2	15
*	Ultra Low-Flow Lavatory	0.5	15
*	Ultra Low-Flow Shower	1.8	300

Flush Fixture Chart

Flush Fixture Type	Water Use [GPF]	
Conventional Water Closet	1.6	
Low-Flow Water Closet	1.3	**
Ultra Low-Flow Water Closet	0.8	
Composting Toilet	0.0	
Conventional Urinal	1.0	
Waterless Urinal	0.0	
Dual-flush High	1.6	**
Dual-flush Low	0.8	**
Flush-valve Low	1.1	**

Design Case

Flush Fixture	Daily Uses	Flow Rate [GPF]	Duration [flush]	Occupant users	Sewage Generation [gal]

Male		0.0	1.0		0
Female		0.0	1.0		0

Male		0.0	1.0		0
Female		0.0	1.0		0

Male		0.0	1.0		0
Female		0.0	1.0		0

Male		0.0	1.0		0
Female		0.0	1.0		0

Male		0.0	1.0		0
Female		0.0	1.0		0

Flow Fixture	Daily Uses	Flow Rate [GPM]	Duration [sec]	Occupant users	Sewage Generation [gal]
Low-Flow Shower	0.75	2.5	300	465	4359.375
Ultra Low-Flow Lavatory	5	0.5	15	465	290.625
Ultra Low-Flow Shower	0.1	1.8	300	150	131.25
Ultra Low-Flow Lavatory	3	0.5	15	550	206.25
Low-Flow Kitchen Sink	2	2.0	15	150	150
---		0.0	0		0
---		0.0	0		0
---		0.0	0		0

Total uses by all occupants	4638.75
Total Daily Volume [gal]	5,138
Annual Work Days	365
Annual Volume [gal]	1,875,188
Graywater or Stormwater Reuse Volume [gal]	0
Total Annual Volume [gal]	**1,875,188**

PAE CONSULTING ENGINEERS, INC.

Sage/Meir & Frank
LEED - Energy Study - EAc1

Date: 16-Oct-06
By: KT

Exceptional Calculation Method (3) - Low Flow Fixtures, Reduction in Domestic Hot Water Use

Fixture Savings - see Water Efficiency Credit 3

	Fixture type	Baseline Flow Rate (gpm)	Design Flow Rate (gpm)	**% SAVINGS Flow Rate (gpm)**	Baseline Water Use Gal/Day	Water Temp. at Fixture (°F)	Baseline Gal/Day @ 120°F	**Saved Gallons/day @ 120°F**
Staff & Public Area	Shower	2.5	1.75	**30.0%**	4359.4	110	3689	**1107**
	Lavatory	2.5	0.5	**80.0%**	1453.1	105	1118	**894**
	Kitchen Sink	2.5	2	**20.0%**	187.5	110	159	**32**
Guestroom	Shower	2.5	2.5	**0.0%**	187.5	110	159	**0**
	Lavatory	2.5	0.5	**80.0%**	1031.3	105	793	**635**
Total								**2667**

Annual DHW Savings

Gallons Saved/Day	**2667**
Days/Year Occupied	365
Cold Water Temp (°F)	55
Heated Water Temp (°F)	120
BTU's to heat water	525,215,895
Therms to heat water	**5,252.16**

DHW Low Flow Fixture Savings	
Total Therms to Heat Water	5,252.16
DEC nominal heater efficiency	94%
Heating Therms for Reduced DHW	**5,587**