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FINAL REPORT

ASHRAE RESEARCH PROJECT 438-RP

EVALUATION OF THE TECHNIQUES FOR THE MEASUREMENT OF AIR LEAKAGE OF BUILDING COMPONENTS

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INTRODUCTION

Knowledge of the amount of air leaking into a building through the various building components is important for a wide variety of reasons. Initially the interest in these values was so that estimates could be made on the amount of energy to be added or removed to heat or cool air that was infiltrating into the structure. Selection of new and replacement building materials was done partially on the amount of energy costs that would be saved by the selection of that component.

More recently however as structures are being built to tighter standards in order to conserve energy, there has been an increasing interest in determining the air flow though building components in order to predict the amount of outside air entering the structure through the building envelope. There is a need to be able to estimate the air leakage in a building envelope in order to estimate the forced ventilation which might be required in the structure. These values are also used by designers as they locate the leakage for ventilation purposes. Rather than sealing the structure airtight and going back and installing openings at the desired locations, if we were able to accurately predict the leakage it would be possible to design the envelope with sufficient (but not excessive) leakage.

As more locations have energy and indoor air quality codes and standards being applied to buildings in their jurisdiction, it will be even more critical to have good estimation methods to predict the amount of leakage in a structure. This will be important not only for the code enforcement official who might be applying a performance based code but also for designers and builders attempting to meet performance requirements. It is even more important for those developing prescriptive codes and standards since they must know a-priori that their specifications will meet or exceed the desired leakage recommendations.

The establishment of the appropriate air leakage value to use for the various components is not an easy task. There has been much discussion about testing techniques, values to be used and the accuracy of the data. The problem is confounded even further when it is considered that many of the air leakage components or sites are manufactured on the construction site and not on an assembly line where quality control can be maintained.

Therefore the goal of this research was to evaluate the existing data of component leakage and determine an appropriate technique to enable the estimation of potential rates of air leakage through various building components.

RESEARCH OBJECTIVES

The objectives of this research were:

1. Compile and catalog from the recent available literature, the available data on leakage areas of building components commonly used in North America in residential construction,

2. Assess the adequacy of the component ELA concept and develop and test alternates which would be based on the fundamental principles governing flow through openings,

3. Evaluate the different methods of reporting the air leakage, and

4. Recommend a system of reporting air leakage for components.

CHAPTER 3 - BACKGROUND

The concept of a term which can be used to describe the flow of air into a structure is an commendable one. A method is needed to estimate the leakage of a structure before it is built. The development of a term to accurately predict the leakage of the structure over varying weather conditions would also be helpful so that evaluations such as the blower door test would not have to be run on the structure.

3.1 Definition of Airleakage, Airtightness, Air Infiltration

Several key terms which oftentimes are used interchangeably in the building industry need to be discussed and differentiated between in order to understand the research being reported.

Airleakage refers to the movement of air across or through the building envelope due to some differential pressure. In this report the term airleakage will be referring to the case in which testing is being done where the differential pressure is artificially imposed at levels above those found due to weather conditions and typical operation. When testing for airleakage, this pressure is artificially imposed by some device such as a fan and the measured flow required to maintain that pressure is considered to be the airleakage.

Airtightness refers to the ability of the envelope of the structure to resist the flow of air through it. The more airtight a structure, the higher the pressure must be to maintain flow of air through it. Airtightness can be thought of as the resistance of an enclosure to allow air to cross its boundaries. It is the inverse of airleakage. Typical units of airtightness are volumetric flow rate per unit of surface at some stated constant differential pressure.

Air infiltration refers to the naturally occurring flow of air across the building envelope due to differential pressures naturally occurring during the operation of the building such as weather effects (stack and wind), occupant effects (opening and closing doors) and equipment effects (vented combustion equipment, vents, etc). Air infiltration varies depending upon the response of the building to these effects. It is not constant over time and therefore the value must be time-averaged or the rate stated for some given condition such as the differential pressure. Typically air infiltration will be quoted in units of volume per unit time.

In order to completely evaluate the leakage performance of a building or its components it is necessary to eliminate the other variables which influence infiltration and evaluate the air leakage characteristics of the building envelope and its components only.

3.2 Methods of Measuring Air Tightness/Leakage

The measurement of either the building leakage or air tightness is done to describe the building envelope without weather, equipment or operator influence. Since one is basically the inverse of the other, only one of the parameters needs to be measured. Two major approaches have been used to determine the airtightness; DC pressurization and AC pressurization. DC pressurization is the predominate technique used.

3.2.1 DC Pressurization

DC pressurization has been used for many years, studied considerably and there are several commercially available units available (ASTM, 1987; CGSB, 1986; Gadsby and Harrje, 1985; and Murphy et al 1991). Commonly called the "blower door" or "fan pressurization device (FPD)", it serves as the basis for several national standards and is used by both researchers and field personnel to identify the airflow-pressurization characteristics of buildings and/or locating sources of air flowing through the building skin. The majority of the air leakage data reported in the literature were obtained with this technique. It can be assumed that the data from the literature reported in this work was obtained using this technique unless stated otherwise.

The technique involves placing a powerful variable speed fan in an opening in the building envelope (usually by replacing a door or window) through which air is blown into (pressurization) or out of (depressurization) the building. A uniform, artificial, static pressure is imposed across the entire building envelope and the amount of air being moved by the fan to create this pressure differential is determined. A relationship between the imposed pressure difference and flow rate through the fan may then be determined. The amount of air leakage or building tightness is determined from this relationship.

The air flow rate through the fan is usually determined from: a) measurements of the pressure drop across a known flow restriction, or b) the fan rotational speed and calibration curve. The differential pressure across the building shell is determined from internal and external static pressure taps and a differential pressure transducer.

There are several standards which use the FPD (Canadian Standard CAN/CGSB 149.10 M86, ASTM E 779-87, ASTM E 783-84 and ISO DP 9972). All these standards use the DC pressurization technique, however they differ in salient points such as: pressurization/depressurization, pressure tap location, differential pressure range, limiting weather conditions (wind and temperature differences), expression of results and stated accuracy (Charlesworth, 1988). A summary of comparison between the ASTM 779 and CAN/CGSB 149.10 is

Table 3-1 A Comparison Between Air Tightness Measurement Standards

(From Charlesworth, 1988)

Standard	Pressure Tap Location	Differential Pressure Range	Number of Readings	Preparation of Openings	Results	Equation for Linear Least Squares Regression	Limiting Conditions
CAN/CGSB 149.10 - M86	Minimum of four taps - located around building connected to an averaging container to dampen flucutations	15-50 Pa - depressurization	Every 5 Pa from high to low	Detailed instructions as to position of dampers and sealing of vents	Equivalent Leakage Area at 10 Pa, Cd = 0.611	Log transformation of flow weighted by flow squared	Wind speed < 5.6 m/s
ASTM E 779-87	One tap - location not specified	12.5-75 Pa - pressurization or depressurization	Every 12.5 Pa	Dampers closed - other openings as normal operation	Effective Leakage area at 4 Pa, Cd = 1.0	Log transformation - no weighting for equal spacing	Wind speed < 2 m/s Temperature 5-35°C

given in Table 3.1. There have been no direct comparisons between the various standards so there are no recommendations as to validity of one over the other or standard calibrations for converting the data between them. The 1989 ASHRAE *Handbook - Fundamentals* gives equations to make conversions between leakage and flows given different discharge coefficients and reference pressures.

It has been assumed that the air leakage of the structure when it is under pressurization (air being blown in) is different than when it is being depressurized (air being blown out of the structure) because many times the two curves do not look the same. It has also been assumed that this nonreversibility is due to some building element (such as the vapor retarder) acting as a flap valve, the asymmetric geometry of some of the cracks or the presence of wind and stack pressures during the measurement. In a study of pressurization/ depressurization measurements on 196 houses, Sherman et al. 1986, found that there were no significant differences (i.e. the differences are within the measurement errors) in either the flow exponent or leakage area or a systematic difference between pressurization and depressurization but that significant uncertainty is associated with an individual measurements.

In addition it has been found (Murphy et al. 1991) that there can be substantial differences between different FPDs on the same house with the same operators and data analysis technique. It was found that ordinary use of FPDs by typical operators to determine envelope airtightness levels in existing houses may do little better than ±25% accuracy.

Therefore there are substantial difficulties in attempting to make subtle comparisons between data in the literature which has been collected from different sources using different equipment.

3.2.2 AC Pressurization

The AC pressurization technique is another technique which has been used to examine building air leakage (Modera and Sherman, 1985). While the quantity of data collected with this technique is very small, the technique used is substantially different and merits mentioning. It was developed for determining air tightness directly at the small pressure differences typically found in natural infiltration conditions without introducing large flows through the building envelope or introducing atypical pressure differences (and thus atypical flow regimes [turbulent rather than laminar] through the openings).

AC pressurization creates a periodic pressure difference across the building envelope that can be distinguished from the naturally occurring pressure fluctuations. This pressure change with its amplitude and phase cause a corresponding volume change. The flow through the envelope can then be determined from the continuity equation for a compressible medium, provided accurate estimates are provided of the building's capacity, internal pressure and its derivative.

3.3 Methods of Measuring Air Infiltration

There are several methods which have been used to determine the air infiltration characteristics of a structure. All the most common ones use some form of gas tracing. Gas tracing is the addition of a detectable gas into an airstream or air volume for the purpose of tracking the mass movement of air; or, more typically, the determination of the amount of exchange of air contaminated with the tracer with non-contaminated air. The tagging of air with tracers is usually done by inserting the tracer gas or volatile liquid into the air and then quantitatively detecting or tracing its presence over time.

There are three major techniques of determining the air infiltration rates using gas tracers: a) slug injection/exponential decay (concentration decay), b) variable injection to achieve constant concentration and c) constant emission/ injection. The general governing mass balance equation is the same for all three techniques.

The concentration decay is the most straightforward technique of the three. In this method the tracer is released into the space, time is allowed for it to thoroughly mix with all the air volume and then periodically the decay of the concentration is measured (Hunt, 1980). The decay is due to the dilution of the tagged air with incoming fresh air not containing the tracer. The faster the decay, the higher the input rate of fresh air. This technique is commonly used when large numbers of samples or structures need to be tested with minimal equipment setup or on-site maintenance. Grab bag sampling is often used.

The second major technique varies the source generation or injection to achieve constant concentration. A direct-feedback, automated control system is required for this technique. The infiltration rate becomes directly proportional to the tracer gas generation/release rate. This technique can detect short term variations in infiltration rates and can do multizone measurements. It can only be used when the injection is controlled automatically and typically is used only on structures requiring elaborate testing. Examples of this type technique are Princeton's CCTG and Lawrence Berkeley Laboratory's MTMS systems.

In the constant emission technique, the tracer is released at a constant known rate and the concentration is monitored over time. After steady state is reached, the average concentration may be used to determine the average air exchange over the time period the sampler was exposed. Thus this technique corrects for variations of air exchange over time due to fluctuations in weather conditions, operator effects or equipment effects. Multiple tracers which do not interfere with each other may be used for multizone applications. The Brookhaven PFT method is an example of this technique.

The result of all these techniques is an estimation of the amount of outside air that has infiltrated into the building envelope through openings due to the driving pressure forces which existed during the sampling period.

Thus if we were able to determine a) the driving forces and b) the response of the openings in the building envelope to these driving forces we would be able to estimate the air infiltration over time.

3.4 Methods of Reporting Air Leakage/Infiltration

Several different empirical methods of reporting air leakage characteristics have been used previously. This also makes it difficult to make comparisons between different values in the literature. In most fan pressurization measurements, the flow is recorded as a function of the imposed differential pressure for several (5 to 10) different pressures between the range of 10 to 75 Pa. The way the data are reduced after these five to ten data points are found is where there are significant differences, so it is important to identify them and how they are used.

Reporting in situations where there were several replications was usually done by giving the average value and some measure of dispersion. This is usually the maximum and minimum values or the standard deviation value. It was noticed that in some cases when both the max/min values and the standard deviation values were given that the average minus the standard deviation was less than the reported minimum value. It is assumed that this is due to a log normal distribution of the readings rather than the Gaussian distribution commonly associated with the standard deviation term.

3.4.1 Flow Coefficient and Flow Exponent (C and n, dimensionless)

Empirically it has been found that the pressure vs flow data follow a power law relationship. Gabrielesson et al. (1968) proposed the expression:

$$Q = C\,A\,(\Delta P)^n \qquad 3.4.1$$

where:

Q = volumetric flow rate, m^3/h
C = crack flow coefficient, $m^3/h(Pa)^n$
A = crack section flow area, m^3
ΔP = pressure drop across the opening, Pa
n = flow exponent, dimensionless

Shaw (1974) presented another equation on the basis of mass flow rate:

$$F = K\,(\Delta P)^n \qquad 3.4.2$$

where:

F = mass flow rate, kg/h
K = constant, $kg/(hr \bullet Pa^n)$

Warren (1978) considered that the flow length might make a difference and introduced length into the formula:

$$\Delta P = [Q/KL]^{1/n} \qquad 3.4.3$$

where:

K = constant, $m^2(Pa)^n/h$
L = crack length, m.

The most common form of equation to describe air leakage characteristics is the "power law" equation (Irving 1979, Sherman 1980, ASHRAE, 1989):

$$Q = C\,(\Delta P)^n \qquad 3.4.4$$

where:

Q = Air flow, m^3/s
ΔP = Pressure differential, Pa
C = Flow coefficient, (m^3/s at 1 Pa)
n = Flow exponent, dimensionless

The most common way of determining coefficients is to do a log transformation on the data:

$$\ln Q = \ln C + n * \ln(\Delta P) 3.4.5$$

and then do a least squares regression on the linear transformed data to determine the slope (n) and the intercept (C) of the line.

There are no fundamental fluid flow principles for this relationship. We expect that the exponent should lie between 0.5 (approximating orifice flow) and 1.0 (approximating fully developed laminar flow). There is no physical interpretation beyond this explanation. It is commonly assumed that the variations between these two values account for the physical changes which occur between fully developed turbulent flow and fully developed laminar flow. This includes such things as the development of laminar flow and its effect by the entrance/exit losses, the developing length and other minor loss parameters such as bends, area changes, etc.

Etheridge (1977) and Chastain et al. (1987) derived a semi-empirical dimensionless flow equation based on the distribution of total pressure drop in the loss of fully-developed flow in constant area opening and the loss of developing section, inlet-outlet friction, area change and bend effects:

$$\frac{\Delta P}{\frac{1}{2}\rho \bar{V}^2} = \frac{B}{Re}\frac{Z}{D_h} + K \qquad 3.4.6$$

The derivation of this dimensionless crack flow equation and further discussion of this analysis is done in Section 4.2.1.

3.4.2 Air Flow Rate at 50 Pa (Q_{50}, m^3)

Several countries have adopted an air flow rate with 50 Pa imposed differential pressure as a standard when classifying buildings in terms of airtightness (Charlesworth, 1988). This single point reference number can be easily obtained. It is obtained by simply pressurizing or depressurizing the structure to 50 Pa and determining the fan flow rate required to achieve this pressurization (depressurization) or by substitution into Eqn 3.4.1.

3.4.3 Air Change Rate at 50 Pa (N_{50}, ACH or h^{-1})

This term is also commonly used as a single point reference. It is found from the Q_{50} value described above divided by the building volume, V (m^3).

$$N_{50} = Q_{50} / V \qquad (\text{ACH or } h^{-1})\ 3.4.7$$

The major difficulty in determining this number is estimating the applicable building volume. Questions arise about inclusion of closet volume, interior walls, cabinets, etc.

3.4.4 Effective Leakage Area (ELA_4 or EfLA, cm^2 or m^2)

Another popular measure of leakage introduced by Sherman and Grimsrud (1980) is the building *Effective Leakage Area*. They identified that the behavior of the actual leakage curve closely resembles that expected for turbulent flow and could be modeled by the classical flow equation for a sharp-edge orifice if the discharge coefficient is defined to be unity. (See Appendix E for a theoretical derivation from first principles.) Thus they assumed that the flow was proportional to the square-root of the applied pressure:

$$Q_{ref} = A\, C_d\, (2\Delta P_{ref}/\rho)^{0.5} \qquad 3.4.8$$

where:

Q_{ref} = flow at the reference pressure, (m^3/s)
A = effective leakage area (m^2)
C_d = Discharge coefficient (1.0)
ρ = density of the air, (1.22 kg/m^3)

ΔP_{ref} = the applied reference pressure, (4 Pa)

Thus a term which lumps the area and the orifice discharge coefficient together representing the effective area of an orifice (with C_d = 1.0) to produce the same amount of flow at a reference can be described as:

$$ELA_4 \triangleq A\ C_d = A$$

$$ELA_4 = 10{,}000\ Q_{ref}\ (\rho/2\Delta P_{ref})^{0.5} \quad 3.4.9$$

where:

ELA_4 = effective leakage area, (cm^2).

The ELA does not bear any simple relationship to physical opening areas in the building but instead represents the summation of the overall effect of all the openings. One thing to note is that it is the opening area of an effective orifice with a discharge coefficient of one. It should be stressed that the effective leakage area is not the actual leakage area and it should not be confused.

The ELA depends upon which pressure is used to calculate its value. An applied reference pressure of 4 Pa is used to calculate the ELA_4. This value is commonly used in the USA.

3.4.5 Equivalent Leakage Area (ELA_{10} or EqLA, cm^2 or m^2)

Another commonly used term (and often confused with the Effective Leakage Area term) is the *Equivalent Leakage Area*. This also comes from the theoretically derived orifice equation. The derivation of the effective leakage area follows the derivation of the orifice equation with the exception of the assumption of a orifice discharge coefficient of 1.0 is relaxed and replaced with a value of 0.611 (a value found to be representative of the types of openings being described):

$$ELA_{10} \triangleq A\ C_d = A \bullet 0.611$$

$$ELA_{10} = 10{,}000\ (Q_{ref}\ /\ C_d)\ (\rho/2*\Delta P_{ref})^{0.5} \quad 3.4.10$$

where:

ELA_{10} = equivalent leakage area, (cm^2)
Q_{ref} = flowrate at the reference pressure difference, (m^3/s)
C_d = discharge coefficient, 0.611 (dimensionless)
ΔP_{ref} = reference pressure difference, (10 Pa).

The equivalent leakage area is used by several countries in their standards (eg. Canada and the Netherlands). The potential exists for errors to occur by interchanging the ELA_4 and ELA_{10} values. In this report the C_d value will be listed in the data tables to avoid confusion. It will be assumed that reported ELA values from Canada and the Netherlands will be equivalent leakage areas unless otherwise noted.

3.4.6 Specific Leakage Area (SLA_4 or SLA_{10}, cm^2/m^2)

The effective or equivalent leakage area is representative of the total leakage of all the envelope of the building. It is possible that two buildings could have the same leakage yet differ in envelope area. Thus the development of a "normalizing" term which would take into account the size of the building. The specific leakage area is either the ELA_4 or the ELA_{10} divided by the floor area of the building:

$$SLA_{4\ or\ 10} = ELA_{4\ or\ 10} / A_f \qquad 3.4.11$$

where:

A_f = floor area, (m^2)
$ELA_{4\ or\ 10}$ = ELA at reference pressure of 4 or 10 Pa, (cm^2).

The specific leakage area enables the comparison of leakage between buildings. The floor area is chosen as the normalizing term because it is easily obtainable since it is the most distinguishable number to be recalled by the resident. It should be noted that the value used for floor area can be a source of error. Care must be used in determining if this represents net area (outside dimensions less any area for exterior and interior walls, closets, etc.) or it represents the gross floor area (the outside dimensions).

3.4.7 Normalized Leakage Area (NLA_4 or NLA_{10}, cm^2/m^2)

A building's leakage areas are in the building envelope which consists of more than just the floor area. It is possible to have structures to have the same floor area yet differ widely in exposed surface areas. The normalized leakage area term was developed to take into consideration the area of the building envelope which may be exposed to the pressure differentials which drive airflow through the skin of the building. This is all the exposed surfaces above the grade line and includes the walls, ceilings, and floor above grade (but not the floor on a slab in direct contact with the soil). The CGSB standard uses all the envelope area except the basement floor to normalize. Thus the normalized leakage area was defined as:

$$NLA_{4\ or\ 10} = ELA_{4\ or\ 10} / A_e \qquad 3.4.12$$

where:

A_e = exposed envelope surface area, (m^2).

It is assumed that the normalized leakage area is considered to be the most comprehensive, and best representative number of the leakage area for comparison purposes on surfaces.

3.4.8 Leakage per Unit Length (Q/L, l/s-m)

The leakage flow rate per unit length of crack has commonly been given when well defined, easily measured openings are present (eg. window sash or door seal length). It is known in these circumstances that the amount of flow is proportional to the length of the crack - not to the surface area. Thus the leakage is expressed as the flow rate per unit length of opening:

$$Q_{ref} = k_{ref} \qquad 3.4.13$$

where:

Q_{ref} = the flow rate per unit length at the reference pressure, (l/s-m)
ref = reference pressure for the flow determination, (Pa).
k_{ref} = constant at the reference pressure

3.4.9 Percentage of Total Leakage (%)

There are several cases in the literature when the authors reported only the flow through a particular opening relative to the total flow for the entire structure (ie. % of flow). There was not sufficient information to determine the flow rate through the particular opening. This happened most often when the primary interest was in locating and sealing the leaks in the building and not on quantifying the volumetric flow rate.

3.5 Methods of Determining Building Component Air Leakage

The leakage characteristics previously discussed were primarily developed to report the air leakage of entire buildings as determined by pressurizing and/or depressurizing the entire building and analyzing the resulting flow-differential pressure data. The ASTM Standard E779-87 and Canadian CGSB Standard 149.10-M86 standards are commonly applied to whole house testing in North America. The purpose of these two standards is to establish a uniform technique to determine the leakage rates through a building envelope under controlled fan pressurization or depressurization. The leakage characteristics of individual building components can also be determined from on-site measurements (ASTM E1186-87 and others). These techniques will be discussed individually. Charlesworth (1988) should be consulted for more specific in-depth details.

The desire is to determine the leakage characteristics of the building component insitu in order to be able to accurately predict the leakage of individual parts of the building so tradeoffs might be made.

3.5.1 Sealing the Component with a Chamber

This is the simplest form of direct measurement of the component leakage. It consists of putting a chamber over the interior face of the building element; supplying air (pressurization) or pulling air (depressurization) out of the chamber at a rate required to maintain a pressure difference; and then measuring the flow rate required to maintain this pressure. The analysis and data reporting may be done using any of the methods in Section 3.4.

This method can be made more accurate by balancing the pressure in the room containing the chamber with the pressure in the chamber. This is used to assure that the leakage flow being measured is that flowing through the component in question rather than around or through the chamber.

Another technique used to compensate for the chamber flow resistance is the compensating flow rate meter (Phaff, 1987). This measuring device has a resistance compensating device (an integral fan) to make up for any resistance that the chamber placed over the component might add to the flow path. When this device is correctly adjusted the device does not influence the airflow and the rate through the component sealed by the chamber may be directly obtained.

3.5.2 Balanced Fan Pressurization

This technique is used primarily in situations where the component can not be isolated or sealed and it is known that typically the component does not have a pressure differential across it (Shaw, 1980). A prime example is the party wall between two townhouses. The party wall can not be sealed to prevent the air leaking through it when one of the townhouses is pressurized. Thus an erroneously high reading of leakage would be obtained because during normal operations there would not be a significant differential pressure across the party wall. However the pressurization device creates a uniform static pressure in the structure which is "seen" by all surfaces (including the party wall). The balanced fan pressurization technique provides for a compensating pressurization device to be located on the opposite side of the building component not to be included in the test (eg. party wall). The same pressure would be applied to both sides of the component so that there would not be a driving force creating air flow through the component. Thus there would not be additional air flow required of the testing fan (and the component flow measuring device) to blow through the party wall.

3.5.3 Selective Progressive Sealing

Selective progressive sealing is an indirect determination of the air leakage through a building component which has been sealed with an impermeable cover. This technique assumes that all the air flowing through a component can be stopped by sealing and the resulting reduction or subtraction in total air flow in the building can be attributed to stopping the flow penetrating the component which was sealed. The subtraction of the two tests then quantifies the air leakage through the component sealed.

This technique has been commonly used to identify and quantify large leakage sites. In most situations this has involved retrofit applications to quantify the effects of various retrofit options. However a thorough analysis of the errors involved has not been completed. A potential problem has been noted in that usually the accuracy errors involved in readings of the total airflow might make the errors in the differential readings quite large compared to the actual values of the readings. Another item often noted is that there appears to be some hysterisis in the sealing order. The reduction in building leakage does not match the increase in building leakage if the components are unsealed in a different order. This might indicate that the sealing is not independent of what other components are sealed. This could possibly indicate that there is some communication of air between the components being sealed.

3.5.4 Controlled Laboratory Conditions

Building component measurements can also be made under the controlled conditions of a laboratory. A number of standards exist which specify how these measurements are to be made. Usually the test specimens are placed in a test chamber where the airflow and pressures can be carefully monitored. The airflow to and through the specimen and the pressure differentials across the specimen can be accurately monitored and controlled without the influences of wind, stack or occupant induced pressures, drastic humidity changes and equipment calibration errors due to transportation. In addition, replications can be made under similar conditions to get a better understanding of the systematic errors and biases.

It has been noted that laboratory based measurements have produced significantly different results from site measurements of similar components (Charlesworth 1988, Weidt et al. 1979). There may be several factors which contribute to these differences such as installation differences, weathering, workmanship, etc.. However it should be noted that the instruments used in the laboratory typically have much higher accuracies with lower error bands, greater access to calibration standards and there are no effects of climate which may indicate that the field values have more instrument and systematic errors than anticipated.

CHAPTER 4 - METHODS

In order to accomplish the objectives previously stated, the problem was broken down into two major parts: the literature investigation and analysis, and the theoretical and experimental development of a more well defined term(s) to accurately describe the air leakage characteristics of the building component openings.

4.1 LITERATURE INVESTIGATION

4.1.1 Development of Database

A through examination of library records and discussions with internationally recognized air infiltration researchers revealed that the most comprehensive source of air infiltration related literature in the world was held by the Air Infiltration and Ventilation Centre (AIVC) located in Coventry, Great Britain. This centre is Annex V of, and is supported by, the International Energy Agency, Energy Conservation in Buildings and Community Systems Programme. Its purpose is to "provide technical support to those engaged in the study and prediction of air leakage and the consequential losses of energy in buildings. The aim is to promote the understanding of the complex air infiltration processes and to advance the effective application of energy saving measures in both the design of new buildings and the improvement of existing building stock." (General cover statement on their documents.)

The AIVC's library has extensive documentation from the IEA participating countries on many items relating to air infiltration. An electronic database (AIRBASE) covering their extensive library holdings has been developed (Limb, 1989). Each source previously identified was found to also be in this database. A copy of this database was obtained and installed on a PC in our department.

A general search of this database was undertaken using an extensive keyword search including broad topic, narrow topic and related topic terms contained in the AIRBASE thesaurus. This identified approximately 3500 references. Each abstract was then read and evaluated for its potential use as a source of data for this study. Those articles which were not originally in English or did not have an English translation were not investigated further and were dropped from the list. The source list was narrowed to approximately 425 references which included mainly journal articles, books, and technical research reports.

Each of these references was then subjectively rated into five groups on its potential source of useful data. The groupings were based on indications in the abstracts that the paper included information on:

1. Component leakage data
2. Whole buildings leakage or pressurization data
3. Air infiltration data
4. IAQ, moisture or heat transfer data

5. Non-North American or pre-1970 data

Attempts were then made to obtain copies of the papers or in the case of the research reports at least the sections which might have available useful data. Approximately 98% of the articles in the first two groupings were obtained. Each paper obtained was then scanned to see if it contained potential data or additional reference sources. Additional references located in this manner were then included in the active search list and processed like the others.

With the concurrence of the Project Monitoring SubCommittee, it was decided that the scope of the data should be limited to data obtained after 1970, structures in North America, and not include data that was questionable or obtained from public press type articles. These restrictions significantly reduced the amount of information that was available. There were several articles published in the 1920's and 1930's which presented air leakage test values of building components. However the construction appeared to be significantly different from what is common today. The restriction of limiting the data to construction of North America was a more limiting constraint however. There has been much more research in Europe than in North America on measuring the flow of air through specific building components. It is believed however that this restriction is justified due to the differences in construction techniques and materials.

The remaining approximately 175 papers were then read, analyzed and data extracted. Data was pulled from the papers as they were read and put into a database format.

A list of the references included in the database are included in the Bibliography. Since AIRBASE was the primary source of information, the AIRBASE source identification number was also used in this work as the reference number. Part I of the Bibliography is given in numerical order based on the reference code. Part II is given in the traditional reference notation, alphabetized by author.

A major task of the literature search was sorting and grouping the leakage values obtained. The data collected was initially categorized by the source of leakage (ie. component type) based upon the grouping of leakage areas found in Table 3, Chapter 23 of the 1989 *ASHRAE Handbook - Fundamentals*.

As the database grew the classification evolved to that presented in Table 4-1.

Table 4-1. Components Used to Classify Leakage

CG	Ceiling - General
CG	Ceiling - Drop
CH	Chimney
CP	Ceiling Penetrations - Whole House Fans
CP	Ceiling Penetrations - Recessed Lights
CP	Ceiling Penetrations - Ceiling/Flue Vent
CP	Ceiling Penetrations - Surface Mounted Lights
CS	Crawl Space
CS	Crawl Space - 8x16" Vents
DAC	Doors - Attic/Crawl Space
DAFD	Doors - Attic Fold Down
DAG	Doors - Attic from Garage
DD	Doors - Double
DE	Doors - Elevator (passenger)
DFRAME	Door Frame - General
DFRAME	Door Frame - Masonry
DFRAME	Door Frame - Wood
DFRAME	Door Frame - Trim
DFRAME	Door Frame - Jamb
DFRAME	Door Frame - Threshold
DG	Doors - General
DIP	Doors - Interior Pocket
DIS	Doors - Interior Stairs
DMS	Door Mail Slot
DSP	Doors - Sliding Exterior Glass Patio
DSTW	Doors - Storm (difference with/without)
DS	Doors - Single
DV	Doors - Vestibule
EOS	Electrical Outlets/Switches
F	Furnace - Sealed or no combustion
F	Furnace - Retention Head or Stack Damper
F	Furnace - Retention Head and Stack Damper
FLCS	Floors over Crawl Spaces
FWDOC	Fireplace W Damper Open/Closed
FWG	Fireplace with Glass Doors
FWIDOC	Fireplace with Insert & Damper Open/Closed
GWH	Gas Water Heater
J	Joints (general)
JCW	Joints - Ceiling-Wall
JSP	Joints - Sole Plate
JTP	Joints - Top Plate
PPWP	Piping/Plumbing Wiring Penetrations
V	Vents

Table 4-1. Components Used to Classify Leakage (Continued)

VBWDO	Vents - Bathroom With Damper Closed/Open
VDWOD	Vents - Dryer With (O)ut Damper
VKWDO	Vents - Kitchen With Damper Closed/Open
VKWDO	Vents - Kitchen With Tight Gasket
WAEX	Wall Exterior
	Cast-in-place Concrete
	Clay Brick Cavity Wall - Finished
	Continuous Air Infiltration Barrier
	LW Concrete Block - unfinished/finished
	HW Concrete Block - unfinished
	Precast Concrete Panel
	Rigid Sheathing
WIA	Window - Awning
WICA	Window - Casement
WIDH	Windows - Double Hung with/without storm
WIDS	Windows - Double Horizontal Sliders
WIFM	Windows - Framing Masonry
WIFW	Windows - Framing Wood
WIJ	Windows - Jalousie
WIL	Windows - Lumped
WISHS	Windows - Single Horizontal Slider
WISH	Windows - Single Hung
WISILL	Windows - Sill
WIST	Windows - Storm

After going through several papers it was realized that some structure to the information obtained would have to be developed. Data was being reported using several different methods of leakage indication (see Section 3.4). The key methods of reporting air leakage/infiltration were investigated to attempt to structure the information. The parameters to be obtained from the papers were those most commonly given.

It was decided to record the information in Table 4-2 about each test reported (one test per line) if the information was given in the paper. Very few cases provided sufficient information to complete all the fields of a single line. Often there would be multiple lines of data from a single reference due to the reporting of the details of individual tests. For example, if a paper contained the average ELA_4 for 6 windows, the average and range (if given) would be reported as a single entry. If however the values for each of the six windows were given, there would be six lines of information. The exception to this general operational rule was when whole house information was being reported. Although initially detailed information was recorded on the individual houses, this was discontinued in favor of retaining the grouped or averaged data due to the magnitude of the records involved and the inability to obtain sufficient house descriptive information to derive the leakage of individual components.

The data were entered into a Quattro Pro 3.0 spreadsheet running on a 386 DOS machine. Putting the data into a spreadsheet allowed the data to be sorted by columns which was used extensively for error checking, converting to metric units, assuring all data entries for the same reference used a similar reference pressure and discharge coefficient, sorting components, etc.

A copy of the data obtained from the references is contained in Appendix A. The data in fields 7-11 and 13-17 have been converted to metric units using the conversion factors contained in Appendix D.

A metric conversion of the constants C and n were done in order for the result of the equation to be in metric. The following equations were used to make the transformation:

$$C_{S\text{-}I} = C_{I\text{-}P} * (1.572)(1/248.66)^{n_{I\text{-}P}} \qquad 4.1.1$$

$$n_{S\text{-}I} = n_{I\text{-}P} \qquad 4.1.2$$

In several cases pressurization-flow data were presented in graphical or tabular form. If an equation was not given for this data, the data were fit to the power law equation (3.4.4) using a least squares regression on the linearly transformed data. Data points given in graphical format only (ie. graphs only - no numerical data) were digitized using an enlarged photocopy of the graph and a digitizing pad. When observed data points were not indicated on the plot, five equally spaced points along the line were digitized.

Table 4-2. Database Format for Information Recorded From Literature

Field	Item
1	AIRBASE reference number - This is the number assigned to the reference by the AIRBASE literature data base. The complete reference citation is included in the Bibliography
2	Class or category of leakage - An identification of the component or source of the leakage. See Table 4-1 for a listing of the leakage categories. For those cases where it was not possible to get a clear indication of the type of component, were lumped together under "general" by component.
3	Identifier tag or ID number of test - If the reference indicated an identifier for the particular test or site it was included in this field.
4	Number of cases or replications
5	Technique the source used to obtain the data point (See Appendix C for explanation of the code number)
6	Code to identify units and explain how C and n values were obtained (See Appendix C for explanation of the code number)
7	Reported C value - The constant for the power equation
8	Reported n value - The exponent for the power equation
9	Flow value - The flow through the opening at the reference pressure specified. This value included in this column is the value reported in the reference. For situations with multiple samples, this is the average value reported.
10	Minimum flow value - If a range for multiple samples was given the smaller number was assumed to be the minimum flow value.
11	Lower limit sample standard deviation flow - The average value minus the standard deviation when the range of values was given by the standard deviation.
12	Upper limit sample standard deviation flow - The average value plus the standard when the range of values was given by the standard deviation.
13	Maximum flow value - The maximum flow value with multiple replications.
14	Units for flow - Units reported in the reference (conversions to other flow units ie. I-P to S-I are given in Appendix D)
15	Leakage area term - The leakage area reported in the reference, expressed in units as given in column 18. No attempt has been made here to change the discharge coefficient or reference pressure
16	Minimum area value - If a range of values was given the smaller number was assumed to be the minimum area.
17	Area lower limit sample standard deviation - The average value minus the standard deviation when the spread of values was described by the standard deviation
18	Area upper limit sample standard deviation - The average value plus the standard deviation when the spread of values was described by the standard deviation.
19	Maximum area value - The maximum area value reported with multiple replications.
20	Units for area - Units reported in the reference (conversions to other area terms are given in Appendix D)
21	Discharge coefficient - Value reported or assumed. This was not easily determined. A value of 1 was assumed when 4 Pa was the reference pressure.
22	Reference pressure for reported values (Pa) - Reference pressure reported for the flow or area terms.
23	% of total building leakage - Often reported in whole house or selective sealing testing methods.
24	Note # - Notes to aid in further describing the data. A key to the numbers is in Appendix C.
25	Other key or descriptive information - Other brief descriptive information indicated in the reference.

Initially all data was entered into the database. When one paper reported data which was obtained from another source, the data was entered with the original reference in the source field with a notation in the "other" field that this data was reported by the second source. These data were deleted from the data base when it was verified that the original data from the original source was included in the database. There were many cases which were found in which a data value in one reference had propagated to several references. Thus, several times initially it was incorrectly assumed that there were considerable data on a component when in reality it was several duplications of previously reported data.

4.1.2 Transformation to Common Base Pressure and Discharge Coefficient

As previously discussed, the data found in the literature was reported different ways, obtained at several different pressures and used different discharge coefficients. In general however the data could be broken into three main categories:

a. An equation was given for the data (or curves were presented),
b. The flow was given at a particular pressure difference, and/or
c. The leakage area was reported for a given reference pressure and discharge coefficient.

In order to make comparisons between the sources it was necessary to transform the results to a common reference. It was decided to transform all the data to an ELA using 4 Pa as the base and a discharge coefficient of 1.0 since this was the most common format.

When an equation was given for the data, the flow at 4 Pa was calculated. The effective leakage area was then calculated (using a discharge coefficient of 1.0 and a reference pressure of 4 Pa) from (eqn 23.28, HOF):

$$L = (Q_{ref}/C_d)[\rho/(2\Delta P_{ref})]^{0.5} \qquad 4.1.3$$

where:

L = Effective Leakage Area at reference pressure
Q_{ref} = Flow at reference pressure
C_d = Discharge coefficient
ρ = Air density (assumed standard value of 1.2 kg/m^3)
ΔP = Reference pressure

When the source had reported the data in terms of the flow at a given reference pressure and discharge coefficient, the leakage area at the reference pressure was calculated from Eqn 4.1.3. The effective leakage area at 4 Pa was then calculated from (eqn 23.29 HOF):

$$L_{r,2} = L_{r,1}\ (C_{d,1}/C_{d,2})\ [\Delta P_{r,2}/\Delta P_{r,1}]^{n-0.5} \qquad 4.1.4$$

where:

$L_{r,1}$ = area at P_1
$L_{r,2}$ = area at P_2
$C_{d,1}$ = discharge coefficient at 1
$C_{d,2}$ = discharge coefficient at 2 (=1.0)
$\Delta P_{r,1}$ = reference pressure used by literature source
$\Delta P_{r,2}$ = reference pressure used in calculation (4.0 Pa)
n = flow exponent

A value of 0.65 was assumed for the flow exponent if an equation for the data was not given.

When the source reported the data in terms of leakage area, the effective leakage area at the reference pressure of 4 Pa with a discharge coefficient of 1.0 was calculated from Eqn 4.1.4.

The effective leakage area was calculated for each of the values reported for the minimum, average and maximum flows and areas. A single effective leakage area was calculated when the data were reported in the power equation form.

The effective leakage areas thus calculated are found in columns 13-19 in the data contained in Appendix B.

The units for the ela are cm^2 per whatever unit was used by the source. For example, if the source gave the flow in l/sm^2 of component, the ela would be cm^2/m^2 of component area. In some instances for the same component there were units of cm^2 per: entire house, unit (eg. door), m^2 of floor area, and/or per linear unit (m) of crack or sash.

Weidt et al (1979) indicated that varying the expression of air leakage rate between crack length, sash area and free ventilating area dramatically shifts the relative performance of the tested window operation type. Data concerning the area of the component were included in the "other" field when it was available, however only limited attempts (when sufficient information was given) were made to transform the data from one set of ela units to another (eg. cm^2/m^2 to cm^2/lmc). When this was done it was indicated in the "other" field.

The selection of the ela to represent a component was made by selecting the minimum and maximum elas and then attempting to subjectively determine a weighted average for the overall average ela. The weighing was based upon: the number of samples, the source of data, the age of data, and the grouping of independent data.

There was a large number of references which reported whole house or ductwork leakage values without supplying sufficient information about the structures to separate the component values from the data. It was determined that cataloging of this data was not going to yield usable information for the project and was beyond the scope of this project. In addition it is known that there are currently several significant

projects underway to obtain the leakage of ductwork. Since these data were not available, they could not be included in this report. Therefore the whole house and ductwork data were not included in the database.

4.2 THEORETICAL/EXPERIMENTAL INVESTIGATION

4.2.1.1 Theoretical Analysis - Single Openings

As discussed in a previous section, there are three major ways to deal with the Q-Δp relation. These are:

1) Power equation,
2) Orifice equation, and
3) Dimensionless crack flow equation.

It is convenient to use the power equation for any shaped crack when the dimensions of the cracks are not known. However C and n are the products of regression only and they have no corresponding physical meaning since the equation is not theoretically derived. A further disadvantage is that the equation lacks generality because it is not dimensional homogenous. Hence its application is mainly because it is easy to use and it statistically fits data well. There is no theoretical basis involved.

The orifice equation is theoretically derived from the Bernoulli equation. The constants C_d, A_0 and ρ have clear physical meanings. However the relation that Q is proportional to the square root of ΔP is restrictive because it neglects minor losses.

Using the dimensionless crack flow equation is an improvement; however, there are still restrictions in its application: a) the cross-section area of crack needs to be known to calculate the average velocity, $\bar{V}$, thus it is difficult to calculate for cracks with irregular or unknown shapes, and b) there is not an easily solved relationship which can be derived from a pressurization test.

In general, it can be seen that using the dimensionless crack flow equation is a better approach. However the restrictions need to be loosened before it can be used. If the dimensionless crack flow equation can be arranged so as to have Q as a function of ΔP, then the equation developed will have the benefits of the power equation and the orifice equation. Besides, if an approximate cross-sectional area of a crack can be determined automatically and statistically with original data sets rather than using an assumed dimension as an input, this will be a great improvement.

The dimensionless crack equation has been derived from first principles for idealized openings in Appendix E in the form of:

$$\frac{\Delta P}{\frac{1}{2}\rho \bar{V}^2} - \frac{B}{Re}\frac{Z}{D_h} + K \qquad 4.1$$

The volumetric flow rate $Q = \bar{V} * A$, and D_h is the hydraulic diameter of cracks. After obtaining a new equation, it will be expanded to irregular cracks in a later section.

Substituting for velocity and the Reynolds Number into equation [4.1],

$$\frac{\Delta P}{\frac{1}{2}\rho(\frac{Q}{A})^2} = \frac{B}{(\frac{Q D_h}{A\nu})}\frac{Z}{D_h} + K$$

and simplifying, yields:

$$\frac{2\Delta P A^2}{\rho Q^2} = \frac{BZ\nu A}{Q D_h^2} + K$$

Multiplying Q^2/K to both sides of the above equation and rearranging in the form of a quadratic equation, it can be solved (only the positive root is meaningful) as:

$$Q^2 + \frac{BZ\nu A}{KD_h^2}Q - \frac{2\Delta P A^2}{K\rho} = 0$$

$$Q = A\left[\sqrt{\left(\frac{BZ\nu}{2KD_h^2}\right)^2 + \frac{2\Delta P}{K\rho}} - \frac{BZ\nu}{2KD_h^2}\right] \qquad 4.2$$

This Q-ΔP expression is derived from the dimensionless crack flow equation and is still based on the Q-ΔP data obtained from blower door tests. Each parameter or constant has a clear meaning. Now the question is can the equation be expanded to also include openings with irregular shapes and sizes?

Equation 4.2 may be rewritten in simplified form:

$$Q = C_1\left[(C_2^2 + C_3\Delta P)^{0.5} - C_2\right] \qquad 4.3$$

where:

$C_1 = A$	m^2
$C_2 = BZ\nu/2KD_h$	m/s
$C_3 = 2/K\rho$	m^3/kg

For well-defined openings, it is not difficult to use the above equation because each geometric term has a clear meaning. For irregular cracks, where the sectional area, A, is variable, we can still use equation (4.3) to get an area value, but it will be the equivalent sectional area. D_h may be approximately defined as:

$$D_h = \sqrt{\frac{4A}{\pi}}$$

which is derived from $A = \pi D_h^2/4$. Based on this definition, D_h will be the equivalent diameter of the crack.

Thus the three geometric parameters C_1, C_2, and C_3 may be determined from dimensional measurements for well defined openings. (It can be shown that Eqn 4.3 reduces to the orifice equation for a flow length equal to zero.) A problem however occurs with openings where B, Z, D_h, and K are not well defined and there is not a single solution to the set of equations.

Nonlinear regression techniques were used to determine values for the constants which minimized the error between the prediction equation and the data obtained from the fan pressurization tests.

It is known that the coefficients have some physical limits, so bounds were placed on the range the coefficients could assume so that physically infeasible solutions would not be provided.

Let's consider coefficient C_3. The density of air, ρ, has a limit on the variation of its value. If the test is conducted at sea-level atmosphere pressure (101,325 Pa), and temperature of air is in range of -30°C to +40°C, the variation of air density is about 1.453 to 1.128 kg/m^3. The minor loss coefficient, K, also has a limited variation (1.2-2.3) as shown in previous literature (Etheridge 1977 and Chastain et al.1987). Therefore it is not difficult for us to estimate the C_3 range, and provide bounds on C_3 in the regression routine.

It is also clear that $C_1 > 0$ and $C_2 > 0$. Therefore, let C_3 be a bounded-coefficient and C_1, C_2 be semi-free coefficients to be determined in regression.

There are several nonlinear statistical packages available. The routine selected for this work was the SAS procedure NLIN (SAS, 1985). This procedure produces least squares estimates of the parameters of a nonlinear model. The form of the equation, initial estimates of parameter starting values, and derivatives of the model with respect to the parameters are required inputs. It evaluates the residual sum of squares at each combination of initial parameter values over the range provided to determine the best set of values to start the iterative algorithm. The Marquardt method of iteration was used. This method regresses the residuals onto the partial derivative of the model with respect to the parameters until the iterations converge.

The three coefficients C_1,C_2 and C_3 obtained from the regression analysis can then be used to estimate the parameters of the openings. If the air density value in the test was known, a value of the minor loss, K, can be calculated from C_3 directly. (It should be noted that this minor loss value is just an average value.) Then by substituting C_1, C_2 and C_3 values, we can obtain the $B \cdot Z/(Re \cdot D_h)$ vs. $\Delta P/(\frac{1}{2}\rho \bar{V}^2)$ relationship which is the dimensionless crack equation representation of the Q-ΔP data set:

$$\frac{BZ}{ReD_h} - \frac{BZ}{\left(\frac{\bar{V}D_h}{\nu}\right)D_h} - \frac{\frac{BZ\nu}{D_h^2}}{\frac{Q}{A}} - \frac{A\frac{BZ\nu}{2KD_h^2}}{\frac{2}{k\rho}}\frac{4}{\rho Q} - \frac{C_1 C_2}{C_3}\frac{4}{\rho Q}$$

$$\frac{\Delta P}{\frac{1}{2}\rho\bar{V}^2} - \frac{2\Delta P}{\rho(\frac{Q}{A})^2} - A^2\frac{2\Delta P}{\rho Q^2} - C_1^2\frac{2\Delta P}{\rho Q^2}$$

This means each $\Delta P/(\frac{1}{2}\rho\bar{V}^2)$ value and the corresponding $B{\cdot}Z/(Re{\cdot}D_h)$ value can be obtained directly from the Q-ΔP data set and the nonlinear regression products C_1, C_2 and C_3. In this technique there is no need to make further assumptions or provide the dimensions of the crack to get the $B{\cdot}Z/(Re{\cdot}D_h)$ and $\Delta P/(\frac{1}{2}\rho\bar{V}^2)$ values. This is a significant improvement over the previous methods of evaluating the physical based models (Etheridge 1977, Chastain et.al 1987).

From equation (4.1), it can be shown that the minor loss is the difference between the total pressure and the major loss (all three terms have dimensionless units):

$$K - \frac{\Delta P}{\frac{1}{2}\rho\bar{V}^2} - \frac{BZ}{ReD_h} \qquad 4.4$$

It can be seen that as ΔP changes, the K value is not a constant after the above subtraction for each data point. We know that for a certain crack; D_h, Z and B are constants, leaving only the variables, ΔP, Q or Re to account for the change in K. Actually Re is a function of Q only for a certain crack, while ΔP is independent of Q. Hence one ΔP is exactly corresponding to one Q or Re; they are not independent of each other and have some functional relationship. For most air leakage studies, ΔP is used as the independent variable, hence we define:

$$K(\Delta P) - K(Q) - K(Re) - \frac{\Delta P}{\frac{1}{2}\rho\bar{V}^2} - \frac{BZ}{ReD_h} \qquad [4.5]$$

The original minor loss coefficient, K, was previously taken as a constant. It is actually the average residual between the total and major loss:

$$\bar{K} = \frac{\sum_{i=1}^{n} K(\Delta P_i)}{n} \qquad [4.6]$$

Where n is the number of data points.

A number of different functional forms may be regressed to get the $K(\Delta P)$ expression. If the scatter plot of $K(\Delta P)$-ΔP appears linear, we may use a simple linear approximation:

$$K(\Delta P) = a(\Delta P - b) + \bar{K} \qquad [4.7a]$$

Or if the scatter points fits a curve, a quadratic approximation may be applied.

$$K(\Delta P) = a(\Delta P - b)^m + \bar{K} \qquad [4.7b]$$

Theoretically describing the functional form of the minor loss is beyond the scope of this project. From the $K(\Delta P)$-ΔP relation, in practice, we can regress and predict to get a $K(\Delta P)$ to substitute into equation (4.1) and (4.3), where constants a and b, or a, b and m can be determined consequently. For a simple calculation, the linear approximation may be suggested as a better choice:

$$Q = A\left[\sqrt{\left(\frac{BZ\nu}{2K(\Delta P)\,D_h^2}\right)^2 + \frac{2\Delta P}{K(\Delta P)\rho}} - \frac{BZ\nu}{2K(\Delta P)\,D_h^2}\right] \qquad [4.8]$$

where $K(\Delta P)$ is defined by [4.7a].

The orifice equation previously discussed is a special case of this equation. For the dimensionless crack flow equation, if Z/D_h^2 is close to zero (flow length approximating zero), then $C_2 = BZ\nu/(2K(\Delta P)D_h^2)$ will approach zero also. Equation [4.8] reduces to:

$$Q = A\sqrt{\frac{2\Delta P}{K(\Delta P)\rho}} = \frac{A}{\sqrt{K(\Delta P)}}\sqrt{\frac{2\Delta P}{\rho}}$$

Comparison with the orifice equation in which flow length Z=0, and EQLA=A yields:

$$Q = EQLA\, C_d \sqrt{\frac{2\Delta P}{\rho}} = A\, C_d \sqrt{\frac{2\Delta P}{\rho}}$$

Hence another discharge coefficient expression for the orifice is:

$$C_d = \frac{1}{\sqrt{K(\Delta P)}} \qquad [4.9]$$

This indicates that the orifice equation is just a special case for the derived dimensionless crack flow equation. On the other hand, we find that the curve performance of the new model is very close to that of the power equation for different kind of cracks. That is, it is a theoretical derivation of the orifice equation and yields statistical results as good as the power equation. Therefore the new equation has the benefits of the power and the orifice equations plus sufficient parameters to make judgement on how the air is flowing in complex flow paths.

It can also be shown that the ELA and C_d are dependent on ΔP in the general case. By definition, ELA is:

$$ELA = \frac{Q}{\sqrt{\frac{2\Delta P}{\rho}}} = C_d\, EQLA$$

substituting for Q of equation [4.8] yields:

$$ELA = A\left[\sqrt{\left(\frac{C_2}{\sqrt{\frac{2\Delta P}{\rho}}}\right)^2 + \frac{1}{K(\Delta P)}} - \frac{C_2}{\sqrt{\frac{2\Delta P}{\rho}}}\right] \qquad [4.10]$$

Thus the importance of treating K as a function rather than a constant can be shown by looking at the change in the discharge coefficient:

$$C_d = \sqrt{\left(\frac{C_2}{\sqrt{\frac{2\Delta P}{\rho}}}\right)^2 + \frac{1}{K(\Delta P)}} - \frac{C_2}{\sqrt{\frac{2\Delta P}{\rho}}} \qquad [4.11]$$

4.2.1.2 Theoretical Analysis - Multiple Openings Connected in Series or Parallel

Crack flow resistance was defined previously as the inverse of the flow coefficient of the empirically regressed power equation (Cale and Zawacki 1980, Bassett 1986). That is,

$$Q = C(\Delta P)^n = (\frac{1}{R})(\Delta P)^n$$

where $R = 1/C$ and is called the "resistance to crack flow" with units of $Pa^n \cdot S/m^3$.

There is limited literature which gives the definition of resistance of crack flow, and there is no theoretical derivation. The basic idea for the concept should be:

1) crack flow resistance is the ratio of the driving force and the transfer rate.
2) it is necessary to satisfy the "parallel and series theorem", i.e, for parallel path flow, $R_{total} = 1/\Sigma(1/R_i)$; for series path flow, $R_{total} = \Sigma R_i$.

Figures 4-1 and 4-2 illustrate the cracks in parallel and series connections with their resistance relationships.

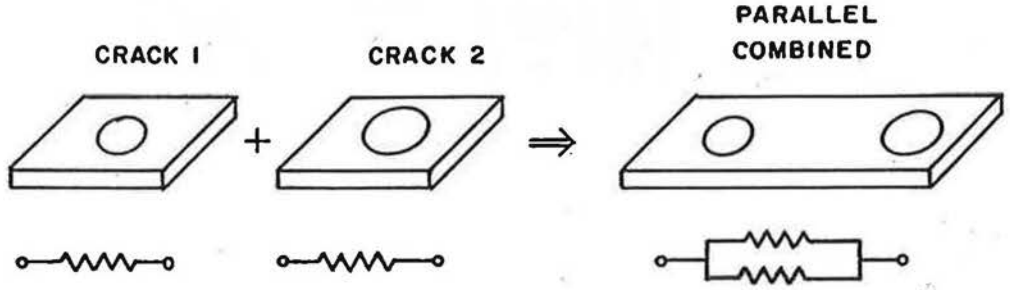


Figure 4-1. Crack parallel connection

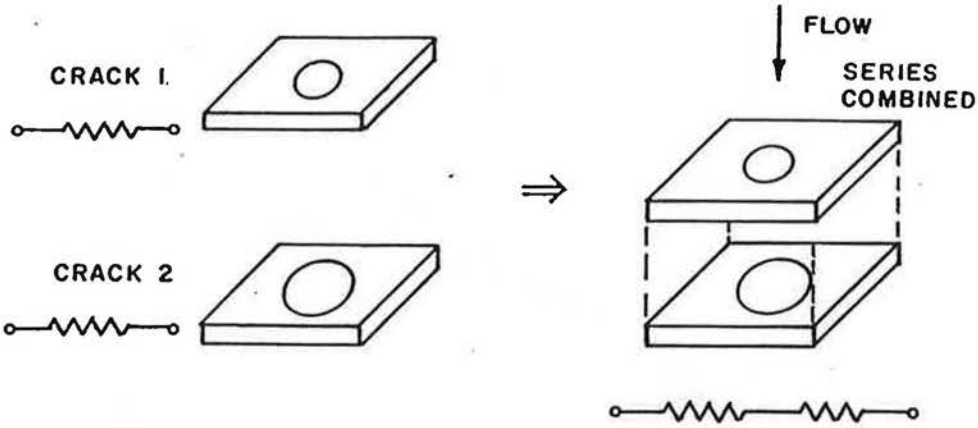


Figure 4-2. Crack series connection

An analogy can be made between the concepts of resistance in electrical circuits and heat conduction and crack flow resistance.

In electrical circuits:

$$I - \frac{V}{R}$$

In heat conduction:

$$q - \lambda \Delta T - \frac{\Delta T}{R}$$

where I and q are the transfer rates, called current intensity and heat flux respectively, V and ΔT are the driving forces, called voltage and temperature difference respectively.

The relationship between the driving force and transfer rate depends on the characteristic of the resistance. If the electrical resistance R and heat resistance R are constant, the I-V and q-ΔT relationships should be linear, otherwise, they will be nonlinear for nonconstant R.

In the problem of flow through cracks, ΔP or some term involving ΔP, is the driving force and Q is the transfer rate. Before trying to make judgement on the validation of the previous concept of the crack flow resistance, we look at an example to explore some of the problems involved in the previous definition.

In Figure 4-3 two power equations are presented which were fit to fan pressurization test data on two different cracks.

Crack 1: $Q = C \cdot (\Delta P)^{0.5}$
Crack 2: $Q = C \cdot (\Delta P)^{1.0}$

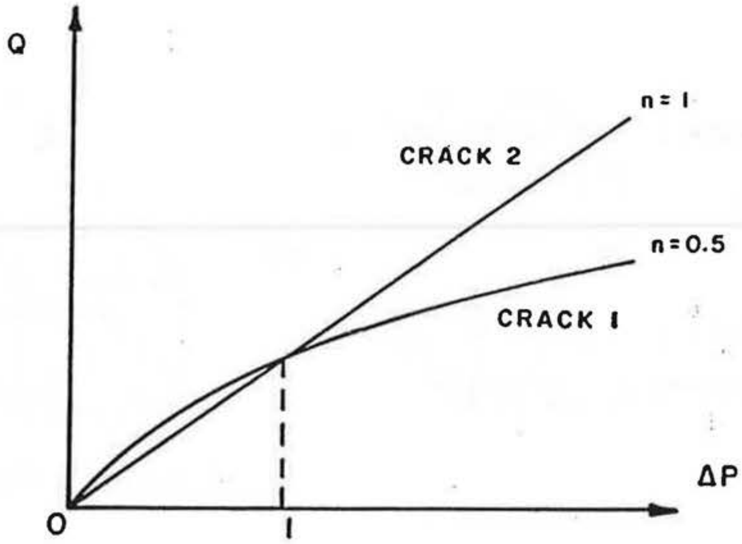


Figure 4-3. Two power equations with n = 1 and n = 0.5

On the basis of the previous definition, if the values of flow coefficients are identical then the flow resistances for the two cracks will be the same. That is,

$$R_1 = \frac{1}{C} = R_2$$

However, when these two curves are plotted, it can be seen that:

a) When $\Delta P < 1$ Pa, crack 1 allows more flow than crack 2 for the same pressure difference, thus, $R_1 < R_2$ and

b) When $\Delta P > 1$ Pa, $R_1 > R_2$ for the same reason.

Unfortunately there is only one point, $\Delta P = 1$ Pa which satisfies $R_1 = R_2$.

This example illustrates the fallacy the original definition of crack flow resistance being the inverse of the regression coefficient C.

Another proposed definition is based on the effective leakage area (ELA) which characterizes the air leakage. The resistance of crack flow with units of m^{-2} can be defined as:

$$R = \frac{1}{ELA}$$

Based on the ELA definition formula:

$$Q = \frac{1}{R}\sqrt{\frac{2\Delta P}{\rho}}$$

where $\sqrt{\frac{2\Delta P}{\rho}}$ is considered as a driving force.

These two definitions create different formulas for the resistance of flow through openings which are in parallel and series connections. Table 4-3 presents the difference between these resistance definitions. Examples to test if there is any improvement in prediction due to the use of the new definition will be given in the Results Section.

Table 4-3. Crack flow resistance definition

	Previous definition: $R = 1/C$	New definition: $R = 1/ELA$
Parallel path	$\frac{1}{R_{total}} - \sum\left(\frac{1}{R_i}\right)$ $\leftrightarrow C_{total} - \sum C_i$	$\frac{1}{R_{total}} - \sum\left(\frac{1}{R_i}\right)$ $\leftrightarrow ELA_{total} - \sum ELA_i$
Series path	$R_{total} - \sum R_i$ $\leftrightarrow \frac{1}{C_{total}} - \sum(\frac{1}{C_i})$	$R_{total} - \sum R_i$ $\leftrightarrow \frac{1}{ELA_{total}} - \sum(\frac{1}{ELA_i})$

4.2.2 Experimental Procedure

A series of experiments were run in order to verify and validate the theoretical developments of the previous section and to gather additional information about the parameters for actual building components. A series of pressure-flow data were taken in the laboratory over a wide pressure range for:

a) a number of geometrically well defined, straight opening specimens tested individually,
b) pairs of well defined openings placed in parallel such that flow would go through them independently,
c) pairs of well defined openings placed in series so that the air would have to travel through both of them, and
d) a number of building components mounted in 2.44X2.44m (8'x8') wood frame wall sections.

The basic idea for this experiment was to use well-defined openings (openings with straight walls and a flow path with known dimensions) with known C_1 values to find the other two opening flow characteristics C_2 and C_3, and the n values from the power equation, to establish a numerical transform formula. Secondly, based on the established formula (Equation [4.3]), the constant C_2 was determined and the other two constants obtained for several building components. The quality of the new fitted model for analyzing building components was then statistically tested.

In addition to model calibration and validation there were other reasons to test the equation. There was a desire to check some of the coefficients to determine:

a) if there was a difference between the goodness-of-fit of this equation compared to the power or orifice equations over the range of the data taken, and
b) if any difference could be shown between the equation types between the flow and predictions at 5 Pa (Q_4 was not chosen because data were not taken at that pressure difference).

4.2.2.1 Test Apparatus

A system to produce and sense a differential pressure across the specimen was constructed in the Energy and Environment laboratory in the Agricultural Engineering Department. This system consisted of: a variable speed fan to produce the airflow and differential pressures; an airflow monitoring chamber to measure airflow; an air distribution and straightening plenum; a specimen and building component holder; temperature, and barometric and differential pressure transducers and the necessary electronics for data acquisition. A schematic of the test apparatus is given in Figure 4.2.1.

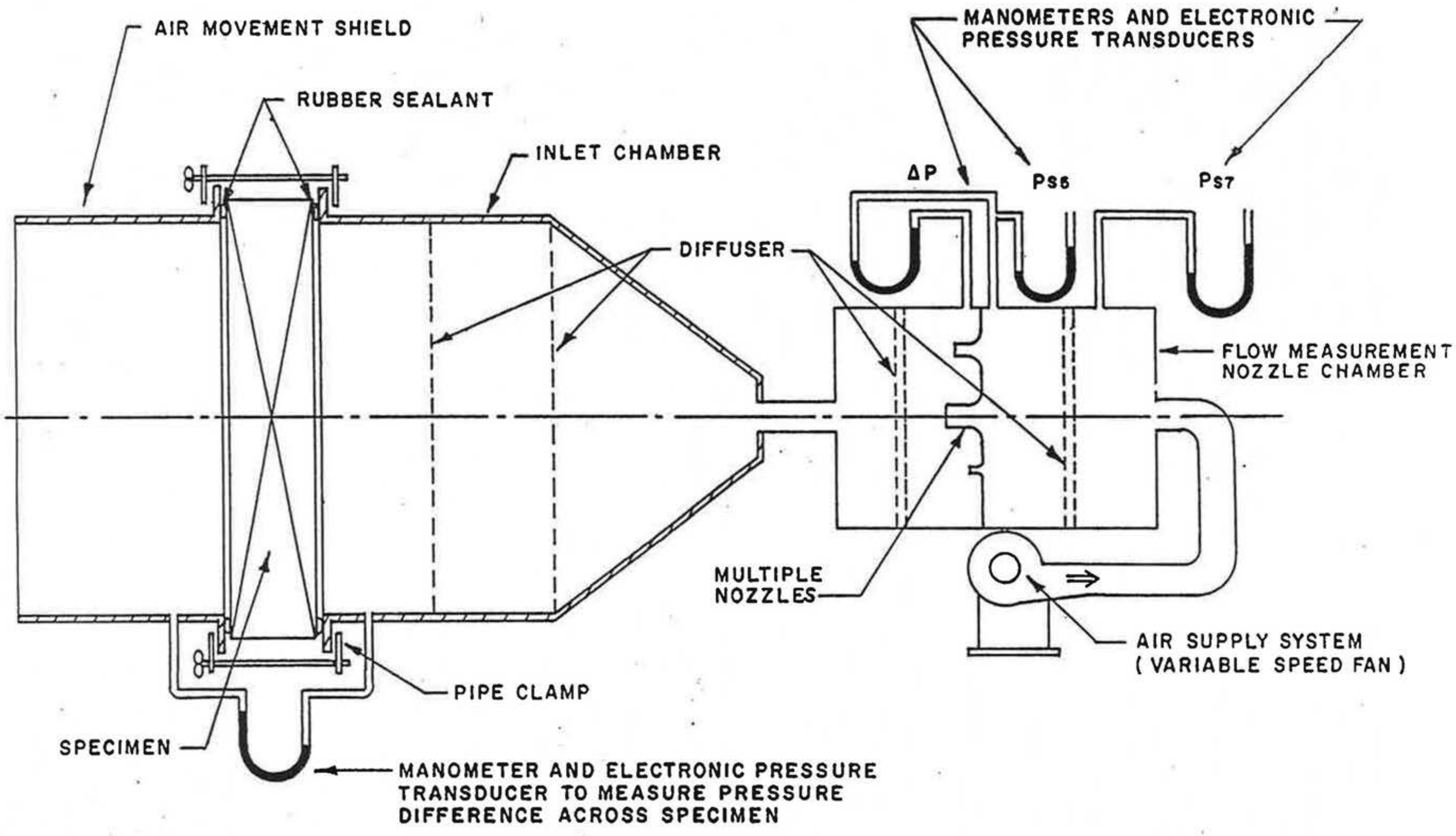


Figure 4.2.1 A schematic of the air leakage measurement system for testing the well defined cracks and building components.

Fan

A variable speed, six radial blade fan with a 26.8 cm (10 9/16") wheel was used to generate the pressure and airflow. The fan shaft was attached to a 1.5 kW (2 hp) variable speed DC motor via belt with 2:1 sheave ratio. The rotational speed of the fan was sensed with a permanently installed tachometer detecting light bouncing off a reflective tape strip attached to the fan shaft. The output of the tachometer was taken to a 4 digit LED display. Correct operation of the tachometer was checked at the beginning of the study. The DC motor speed was controlled with a variable 0-10V input which was adjusted with a 10 turn 5K ohm potentiometer. The speed controller specifications indicated a time constant of 6 seconds and a very stable long term speed control (within +/- 1%). Observation of the digital fan speed indicator showed the fan speed to be very stable. The fan was rated at 140 l/s (300 cfm) output at 17.8 cm (7") static pressure and 3500 rpm.

Airflow Measuring Station

The airflow was measured using a multiple nozzle outlet chamber built to the specifications of ANSI/ASHRAE Standard 51-1985 (ANSI/AMCA Standard 210-85). (See Figure 12 in Standard 51.) The chamber was 122x122x305 cm (48x48x120"), made with 2.54cm square steel tubing frame and covered with 18 gage steel sheets. The sheet metal was attached to the outside of the tubing frame with metal bonding, double-faced adhesive tape and blind pop rivets. All joints were sealed inside and out with a high grade silicone caulk. Access was provided to the inside of the chamber with a 45x45cm metal plate door on either side of the nozzle plane. A seal was produced at the edges of the doors where they overlapped the frame. Each door was held tightly closed with eight fasteners. The settling means was provided at the locations specified in the standard with one layer each of 40% and 60% open, 24 gage metal sheets attached to cross bracing on the interior of the chamber. Velocity readings were taken during system testing on a 10cm grid across the face of the settling mesh and indicated a uniform flow. Ten aluminum spun nozzles without throat taps (L=0.6D), (D=12.7, 17.5, 25.4, 40.6, 50.8, 63.5, 76.2, 101.6, 127, and 152.4mm) were installed on the nozzle plane inside the chamber. The nozzles were located relative to each other on the plane so any combination of nozzles could be operated simultaneously. Static pressure taps constructed as specified in the standard (0.16cm diameter) were placed in the chamber as specified.

Differential pressure across the nozzles was measured with a 25cm WG f.s. variable capacitance diaphragm transducer (accuracy= < ± 1.0%fs, repeatability= <0.3%fs). All output voltages were obtained from 4 1/2 digit voltmeters with an RMS averaging function. Averaging time windows were approximately 30 seconds. Static pressure upstream of the nozzles was measured similarly with one side of the differential transducer being open to the room atmosphere. Barometric pressure was measured in the room with a mercury barometer with 0.1 mm resolution. Dry bulb room temperature was determined with a mercury thermometer and relative humidity was read from a recording hydrothermograph (± 5%rh). Incline manometers (resolution 0.05" wg) were piped in parallel to the electronic transducers to enable a quick periodic check on the electronic devices.

During data analysis an error was found which indicated that there was a significant systematic error in the measuring chamber. After considerable investigation with smoke pencils, it was found that there were some leaks across the nozzle plane through the structural tubing due to leakage through a weld. Substantial effort was spent calibrating this additional leakage across the nozzle plane. (See Section 4.2.2.3.1 Overall System and Chamber Background Leaks Correction.) These calibration data were obtained before the leakage was stopped thus calibration could be done on the original data. This systematic error will be referred to in the Results Section as the system and chamber background leakage.

Equations specified in the ASHRAE Standard 51-1985 were used to calculate the airflow at standard temperature and pressure.

Air Plenum

The output from the airflow monitoring chamber was ducted to a wooden plenum chamber which expanded from the 15cm (6") outlet to the 2.44x2.44m testing face. This expansion chamber was made of marine grade plywood, had two coats of varnish applied to the inside and outside surfaces, and was caulked extensively. The unit was checked for leaks with a smoke stick when the unit was pressurized to four times the maximum operating pressure.

Two planes of 6.3mm pegboard were installed between the inlet and exit to create backpressure and assure uniform air distribution at the testing face of the unit. Uniform air flow across the face of the pegboard was checked by taking air velocity readings with a hot wire anemometer on a 15cm grid at the face of the pegboard plane closest to the test face.

Static pressure taps for the high pressure side ("interior") of the differential pressure to be applied across the openings to be tested were mounted on the straight section sides of the plenum approximately 60 cm from the face of the test section.

The direction of airflow was always to the exterior, simulating building pressurization. Depressurization tests were not run.

Downstream Air Wind Shield

A shield was built to be placed downstream of the test specimen so the "outside" surface of the test specimens and the "exterior" static pressure taps would be shielded from any air currents produced by the diffusers of the building HVAC system. The shield had 1.22X2.44m top, bottom and two sides perpendicular to the specimen. After the specimen holder was put in place the shield would be rolled to meet with the specimen holder. Static pressure taps were mounted on the inside of each of the four sides of the shield for the low side of the differential pressure transducer across the specimen.

Specimen Holder

A wooden frame was built to mount the well defined cracks (Figs 4.2.2a-b). This frame was designed to be able to hold the openings individually, two in parallel or

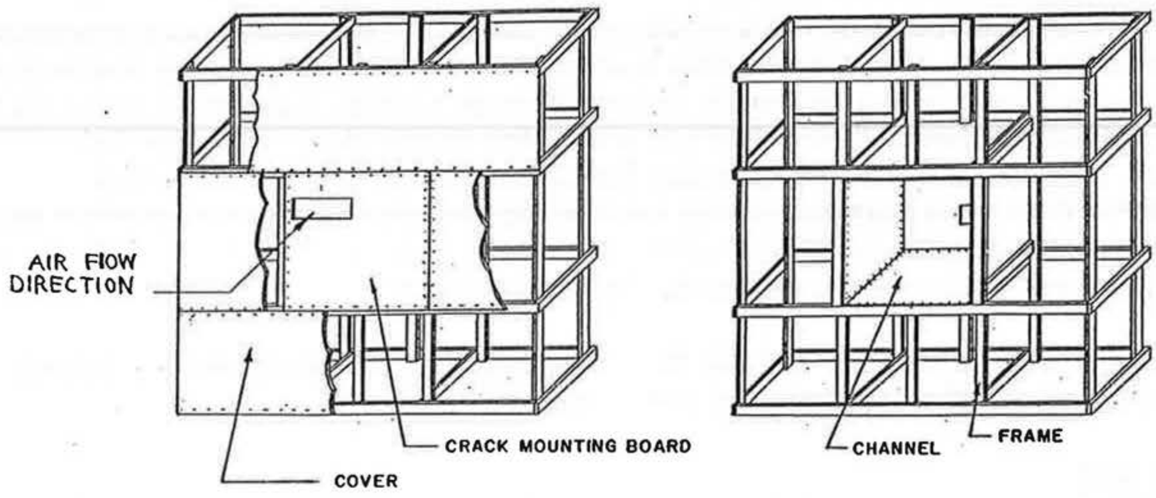


Figure 4.2.2a Specimen Crack Holder Frame

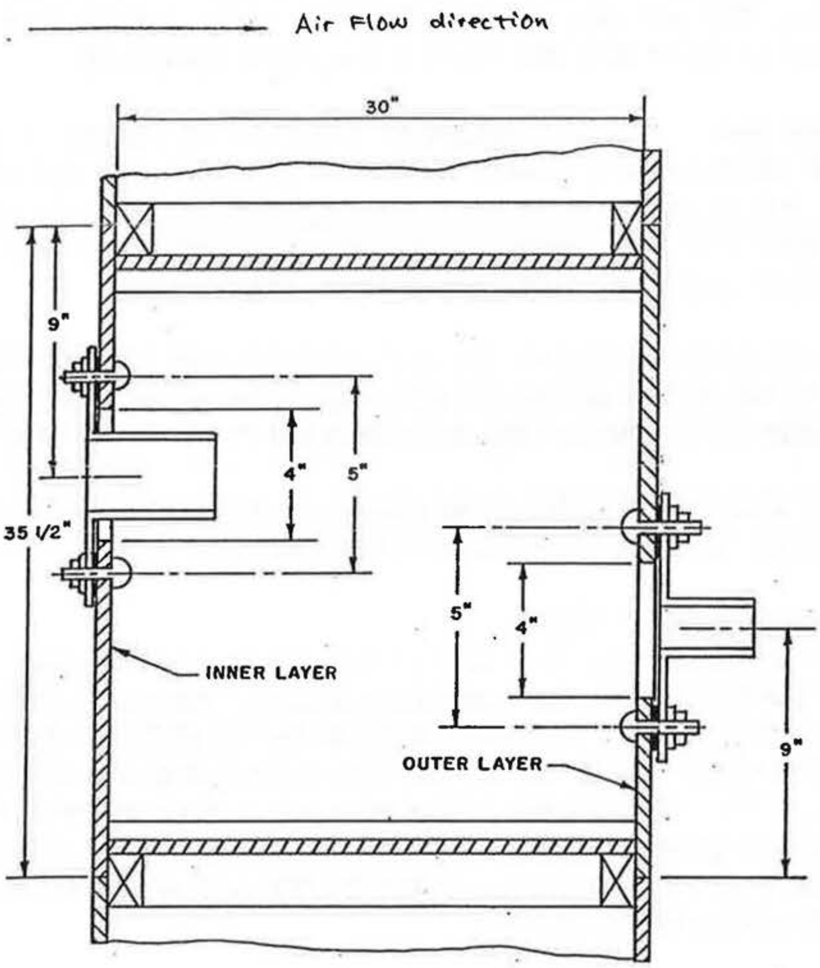


Figure 4.2.2b Cross section of two cracks in series mounted on the outer and inner layers of the frame

two in series. The effective open face on the specimen holder was 91x122cm. The unit was sandwiched between the plenum and the air shield and pipe clamps were used to hold the three pieces together. It was recognized that these joints had the potential for creating a systematic error. Therefore extraordinary effort was expended putting in seals between the plenum and the specimen holder and/or wall sections to prevent air from leaking out around the joint. Pipe clamps were used extensively to apply pressure on the seals to prevent them from leaking. Attempts were made to tighten the clamps to the same pressure each time and the joints were checked to locate and fix any obvious leaks.

Well Defined Openings

Several well defined straight-through openings had been previously used in a study of determining the discharge coefficients for laminar flow in rectangular openings (Chastain and Colliver, 1987). These openings (See Figure 4.2.3) were thin rectangular openings with straight walls and square edged openings which were manufactured to very tight tolerances. They were made from 6mm clear acrylic plastic sheet. Six of these openings which varied in open cross sectional area by a factor of approximately 16, varied in flow length by a factor of 3 1/2 and opening height were selected. There were two geometries which had two crack specimens each which were used as replicates. The specifications for the openings are given in Table 4.4.

Building Component Wall Sections

A number of building components and wall penetrations were tested in 2.44x2.44m wall sections (Table 4.5). A separate 2x4 wood frame wall was constructed for each type component tested (with exception of things which could be changed without disturbing the wall such as outlet or switch gaskets). Typical single bottom plate, double top plate, 400mm (16") O.C. 50x100mm (2X4") SYP (southern yellow pine) stud walls were constructed by a summer student worker with supervision given by a carpenter. The side representing the interior wall surface was covered with 13mm gypsum board drywall which was tapped and mudded. The exterior side was covered with 13mm foil backed polyisosynurate insulating board fastened with 32mm drywall nails approximately every 150mm on the edges and 200mm on the interior. No vapor barrier was installed. Several components such as premium awning, premium double hung, economy double hung, premium casement, economy casement, copper pipes and electric outlets and switches were installed in wall sections made like the base wall. Six outlets/switches were installed on one wall with each plastic switch box in an individual wall cavity between the studs. Wire penetrations went through the top plate. (Airflow through penetrations in the top and bottom plates was not blocked by the experimental apparatus and was exposed to the same pressures as the "exterior" side of the wall.) There were no wire holes between the vertical studs. 1/2" copper water pipe was used in the 1" holes in the bottom plate between each stud space to represent water pipe penetrations. A list of the components tested is given in Table 4.5. Several different types of windows were tested. For each test case two windows from the same manufacturer of the same type, style and size were installed in a wall section constructed like Case A. The values presented are for the entire test section unless otherwise indicated.

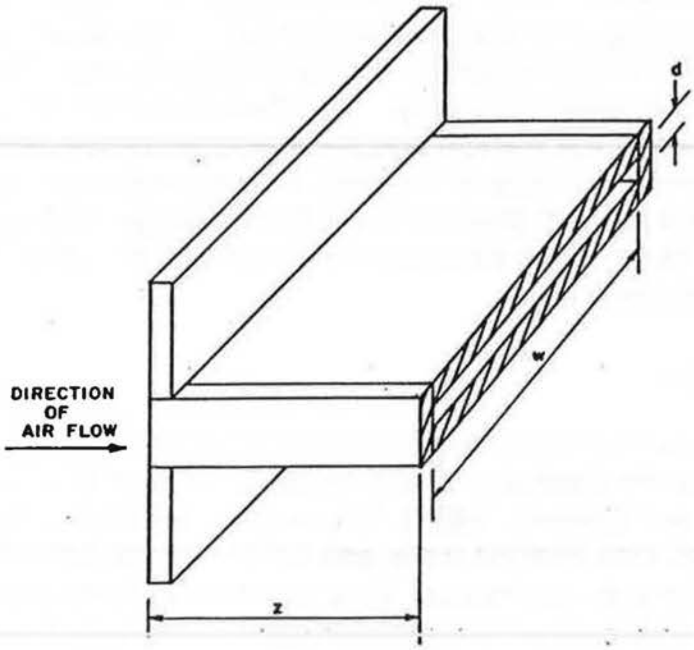


Figure 4.2.3 A typical rectangular crack (opening)

Crack	Section Area	d	Z	W
A	400	0.8	25.4	500.1
B1, B2	850	1.7	50.8	500.1
E	3145	6.3	88.9	499.3
F1, F2	6431	12.9	50.8	498.5
(Unit)	(mm^2)	(mm)	(mm)	(mm)

Table 4.4 Crack Geometry Specifications

Table 4.5 List of the Building Components Tested

CO-1	Exterior Frame: Gypsum Board (Base Case A - no penetrations)
CO-2	Exterior Frame: Insulating Board (Base Case B - no penetrations)
CO-3	Wall Penetration: 6 Outlets with No Wire Holes in Studs, or Top and Bottom Plates
CO-4	Wall Penetration: 6 Outlets with Gaskets and No Wire Holes
CO-5	Wall Penetration: 6 Outlets, Wire Holes in Top Plate
CO-6	Wall Penetration: 6 Outlets, Top Wire Holes Sealed
CO-7	Wall Penetration: 6 Outlets with Gaskets, Top Plate Wire Holes Not Sealed
CO-8	Wall Penetration: 6 Outlets with Gaskets, Top Plate Wire Holes Sealed
CO-9	Wall Penetration: 6 Copper Water Lines through Bottom Plate
CO-10	Wall Penetration: 6 Switches, Wire Holes in Top Plate
CO-11	Wall Penetration: 6 Switches, Top Plate Wire Holes Sealed
CO-12	Wall Penetration: 6 Switches with Gaskets, Top Plate Wire Holes Sealed
CO-13	Wall Penetration: 6 Switches with Gaskets, Top Plate Wire Holes Not Sealed
CO-14	2 Premium Awning windows installed in Base Case Wall
CO-15	2 Premium Double Hung windows installed in Base Case Wall
CO-16	2 Economy Double Hung windows installed in Base Case Wall
CO-17	2 Premium Casement windows installed in Base Case Wall
CO-18	2 Economy Casement windows installed in Base Case Wall

Specimen Differential Pressure Measurement

The differential pressure across a test specimen was measured using the same equipment as the differential pressure across the nozzles with the exception that the full scale range of the transducer was 65Pa for low range and 625Pa for high pressure measurements.

4.2.2.2 Experimental Design

To verify and validate the proposed equation, several applications of the same experiment were run. This involved obtaining data for flow versus differential pressure across an opening(s) for several points between 5 and 125 Pa. A description of the experiment and the application of this experimental procedure to the test cases will be presented.

Experimental Procedure

Each experiment involved placing an opening(s) in the specimen holder (for the case of the well defined cracks) or a wall section (in the case of building components) in the test apparatus and tightening the sandwich of plenum/specimen holder/air shield with pipe clamps. The seals around the joints were checked for leakage.

The fan would then be adjusted to produce at least 125 Pa across the specimen. Nozzles in the airflow chamber would then be opened or closed (and speed readjusted) to obtain the smallest nozzle which would allow the fan capacity to create sufficient airflow to provide the necessary 125 Pa. This procedure was done in an attempt to provide maximum resolution of airflow measurement.

Data would then be taken on the room air conditions (barometric pressure, dry bulb temperature, relative humidity) and transducers (S/N's and offset voltage with no pressure differential) being used. The wet bulb temperature used in the calculation of air density was obtained from a psychrometric program used in teaching the undergraduate environmental design classes.

The fan speed would then be adjusted to create a differential pressure of 5Pa across the specimen. After approximately 30 seconds, if the pressure had stabilized, a pressure reading across the nozzle would be initiated (ie. the RMS averaging function on the voltmeter turned on). The voltmeter would integrate the voltage signal coming in and output a time running average of the signal. The differential pressure across the nozzle would thus be averaged for approximately 30 seconds before the reading was recorded. (This averaging was necessary because there was a small, low frequency [approximately 0.5-1.0 hz as determined from a digital spectrum analyzer] signal that was superimposed on the transducer signal. It was concluded that this signal was coming from changes in the internal pressures of the airflow chamber due to the diaphragm action of the chamber walls moving very slightly. This conclusion was reached by noting the frequency of the movement of the walls.) The actual pressure readings across the test specimen and the static pressure on the upstream side of the nozzles would be taken during the time the nozzle pressure reading was being averaged. (The specimen pressures were stable and did not require any time averaging.) This process was repeated for each pressure/flow data point taken.

The actual pressure readings ($\pm$0.25 Pa) across the test specimen and nozzle were thus taken for pressures from 5 to 125 Pa in nominal increments of 5 Pa.

The temperature, relative humidity and barometric pressure readings taken at the beginning of the test were retaken at the conclusion of each test. The starting and ending conditions were then averaged (if the temperature had changed) to estimate the air state points.

No test was accepted unless the entire pressure range could be completed at one time.

A series of tests was initially run to determine if there was any hysteresis in the system. No significant differences were found in the readings if the order of pressures was increasing from 5 to 125 or if the data were collected with the setpoint pressures decreasing from 125 to 5. Therefore the tests only used the pressure increasing from 5 to 125 with increments of 5 Pa. Only the data between 5 and 75 Pa were used in the data analysis for this project since this is the range commonly used with blower door testing. A comparison of analysis techniques using the range of data collected as one of the parameters to be investigated is being planned for future work. The wide data range was collected for use in that project.

Experiments Performed

Four groups of tests were run using this method. They will be referred to as: individual openings, parallel, series and component openings. An identification of the cracks used for the various experiments and the experiment ID codes are presented in Appendix F.

Individual Openings

The purpose of this test was to obtain pressure-flow data on the well defined, simple geometry, straight-through cracks previously described (Table 4.1) when they were mounted in the specimen holder. The openings and flow covered a range of openings sizes and flow ranging from laminar to turbulent flow. There were two geometries which had two "identical" cracks each for replication purposes. Thus there were four different geometries tested.

An additional feature was added by testing the effects of mounting location on each of the four geometries. They were first tested mounted on the inner layer of the specimen holder (with only the mounting plate on the outer layer) and then mounted on the outer layer (with only the mounting plate on the inner layer). When there were no cracks installed on the outer layer there were two large openings (≈100X520mm) for placement of the cracks in the mounting plate; thus it was possible for this plate to have some effect on the flow. The same is true for when the cracks were mounted on the outer plate with no cracks mounted on the inner plate.

Each test had three replications. The order of testing for the individual, parallel and series openings was determined from a random number table. If two tests of the same opening were in order, the crack was taken out and remounted.

Parallel Openings

The purpose of this test was to obtain the pressure-flow data on the well defined cracks when the air would be going through them in parallel. This would be a test to see how the flow coefficients for individual cracks would combine when there were multiple openings such as the case when there are many different components acting independently to the total static pressure which is applied to all surfaces in whole house testing.

The combination of cracks chosen for testing is presented in Appendix F. These combinations included pairs of "identical" cracks to see if the predicted area coefficient, C_1, doubled; and all possible combinations of the remaining geometries. Three replications were run on each test.

Series Openings

The purpose of this test was to obtain the pressure-flow data on the well-defined cracks when the air would be going through them in series. This would be a check to see how the coefficients would combine when the air would be flowing through multiple restrictions. An example would be the case when the air goes into the electrical outlet, through the box, up the cavity space and then out the hole in the top plate cut for the electrical wire.

The combinations used in this series of tests was to place the largest opening at the inner mounting position and then place all the other geometries individually on the outer plate. This would simulate air flowing through a large hole first and then smaller holes. Tests were also made on the reverse placement (large on outside and smaller on inside). Three replications were made of each test.

Building Components

The purpose of this test was to determine the flow coefficients for some typical building components ranging in quality from construction/economy grade units used in lower cost construction to premium grade, high quality units. In addition to the previous differences determined for the other groups of tests, there were additional differences to be investigated:

a) Could any physical difference be shown by the coefficients (eg. Is the flow through one large leak or many small ones?), and
b) Was there a general trend in the coefficients among the components?

A list of the building components tested was presented in Table 4.5. Tests were conducted on blank frame walls, a series of combinations of electrical outlets/switches and openings for the wire, and various types and quality of commercially available residential windows.

The building component tests were not completely randomized. All tests on a wall section that did not require sealing were run before caulking was applied to the openings. Sealing was done with high quality silicone caulk.

4.2.2.3 Experimental Data Analysis

4.2.2.3.1 Overall system and chamber background leaks correction

The measurement system was carefully sealed to prevent air leakage however calibration tests indicated that some air leakage existed in the system. The "overall system background leak" refers to the air leaks from the wooden collection chamber as well as from the frame holding the well-defined cracks. This term is only associated with testing the well-defined cracks.

The term "chamber background leak" refers to the leakage from the wooden collection chamber only, without including the leakage from the frame which holds the cracks. The chamber background leak is only for component testing.

Two leakage correction equations were used to deduct the air leakage from the data sets of flow measurements for well-defined cracks and building components individually. This correction procedure was included in the pressurization data of Appendices G-J. See the "Flow Rate" columns in the tables in Appendices G-J. The data in the replication column are the uncorrected values. The "System Leak" or the "Chamber Leak" refers to the "overall system background leak" or the "chamber background leak" respectively. The "Corrected Mean" values were obtained by subtracting the leak terms from the average values of the uncorrected three replications. Thus the "Corrected Mean" values are the actual flows entering the specimen being tested.

4.2.2.3.2 Nozzle chamber corrections

There were two problems in the air flow measuring system. The first was the Reynolds number test range for flow through the nozzles. Since the system was based on ANSI/ASHRAE Standard 51-1985, the Re through the nozzle should be greater than 12,000 for the minimum flow as a criteria in this Standard. (The formula used to calculate the discharge coefficient, Cd, was for Re greater than 12,000.) However due to low flow rates at the lower pressures, some of the measurements always occurred below the minimum Re specified even for the smallest nozzle (1/2"). To find a calibration method, the Cd curve produced by the equation given in the Standard with $\beta=0$ (β is the ratio of the nozzle exit diameter to the approach duct diameter) at lower Reynolds numbers was compared with another Cd curve with $\beta=0.2$ (ASME 1959). This was applicable for a Reynolds number range of 2500 to 12,000. It was found that these two curves are very close in the Re range of 2500 to 12,000 as shown in Figure 4.2.6. Therefore the error introduced by extending the previous curve to the lower Reynolds number range is not very significant (about 2% difference at most) compared to the second problem.

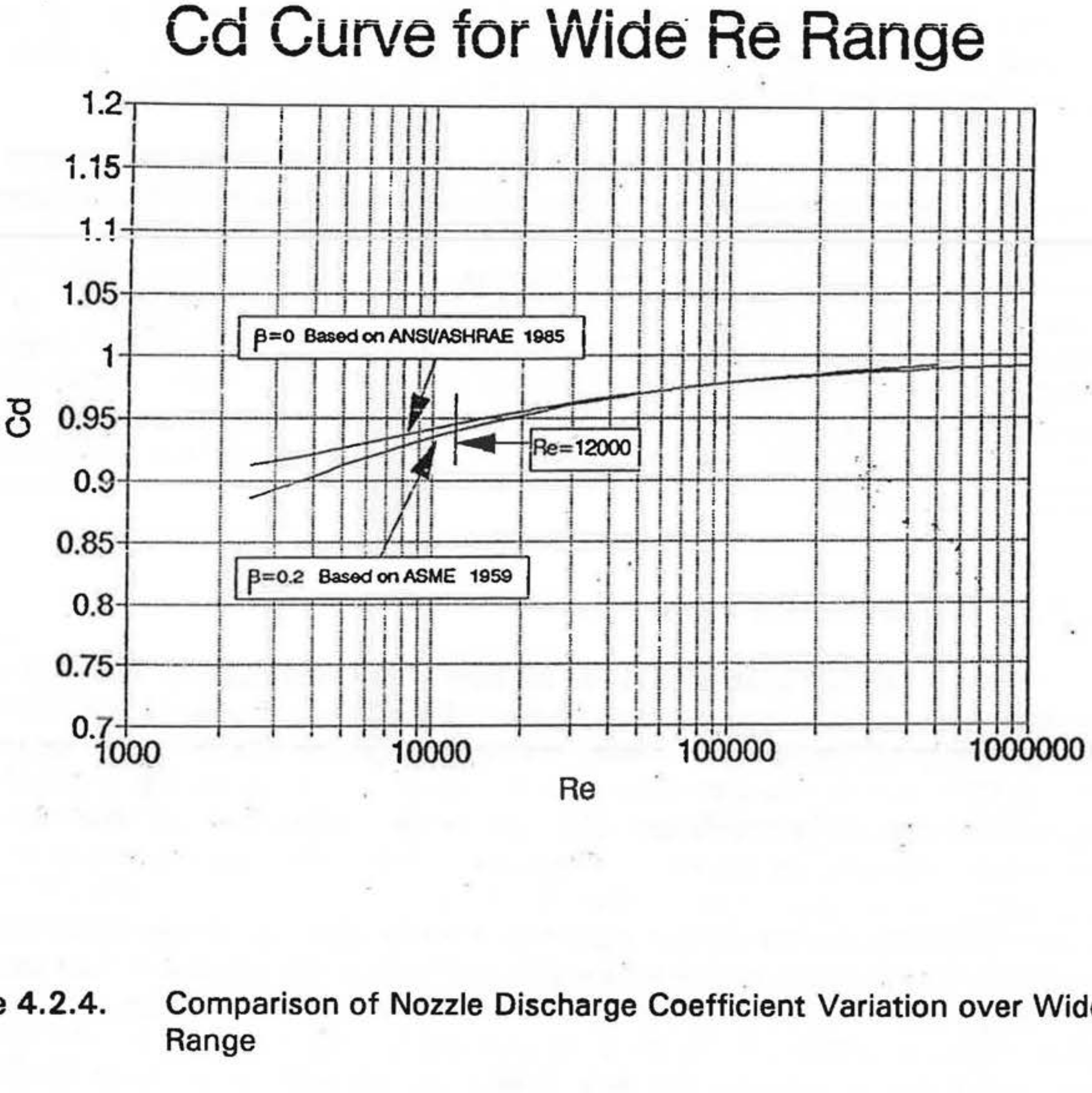


Figure 4.2.4. Comparison of Nozzle Discharge Coefficient Variation over Wide Re Range

Note: Extrapolating the Cd curve (for chamber $\beta = 0$) for Re > 12000 range into lower Re range (Re < 12000) would not introduce significant error since it is very close to another Cd curve with $\beta = 0.2$ which is applicable over the lower Re range.

The second problem involved leaks in and through the metal nozzle chamber. A group of rotameters (Dwyer RMC-102&103, +-2% accuracy) was used to check the flow rate of the nozzle chamber outlet. There were significant differences between the nozzle readings and the rotameter readings especially for the smaller nozzles. The problem was later found to be caused by two leaks in the nozzle chamber. One was an "external leak", denoted Q_{el}, which occurred at the corners of the chamber where an airtight seal had not been produced. The second one called the "internal leak", denoted Q_{il}, was caused by leakage through the foam plugs which were used to seal the nozzles not being used and by leakage through a defect in a weld in the metal chamber. Thus the data previously obtained could not be used until the error from the flow through these leaks could be determined and taken into account.

It was assumed that these two leaks could be modeled by the power law, which led us to use pressurization tests on the two openings individually. Figure 4.2.5 contains data used in the calibration of these two leaks. The external leak, Q_{el}, is a function of the pressure difference, P_{el}, between the chamber on the downstream side of the nozzle and the room pressure. The expression to represent this leakage is:

$$Q_{el} = 0.6314*P_{el}^{0.6445}$$

with $r^2=0.9593$ and C.V.=6.2796% (Q unit is cfm, P unit is in.wg). The internal leak Q_{il}, is a function of pressure drop, P_n, across the testing nozzle plane. This leakage was represented by the relationship:

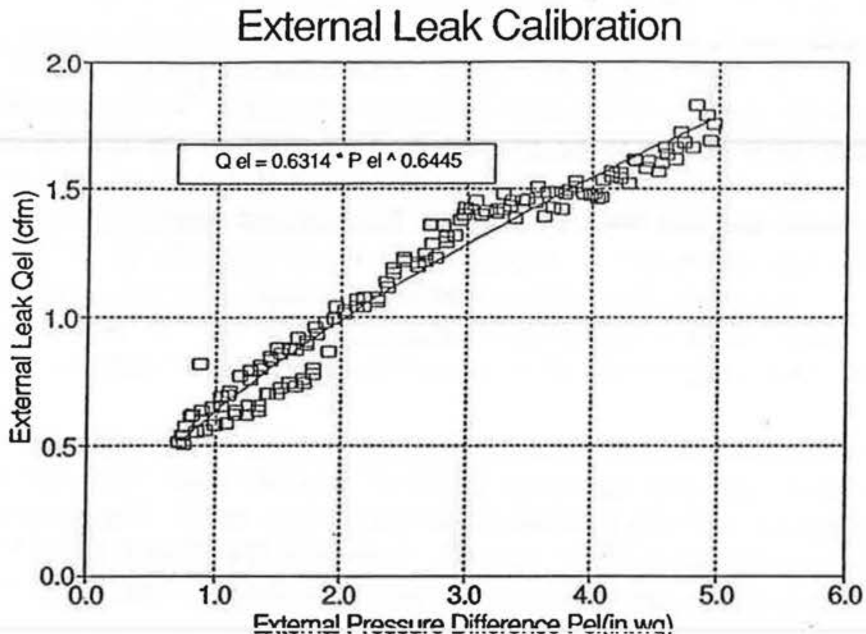
$$Q_{il} = 15.782*P_n^{0.8734}$$

with $r^2=0.9935$ and C.V.=3.789%.

The relationship between the uncorrected nozzle flow, Q_n, rotameter flow, Q_r, (which is the actual flow amount entering the air plenum) and the "external" and "internal" leaks Q_{il} and Q_{el} is:

$$Q_r - Q_n|_{\Delta P_{nozzle}} + Q_{il}|_{\Delta P_{nozzle}} - Q_{el}|_{\Delta P_{el}}$$

These two leaks should be individually included in data corrections according to the referred pressure drop. All the pressurization flow data in Appendices G-J have been corrected for these two leaks.



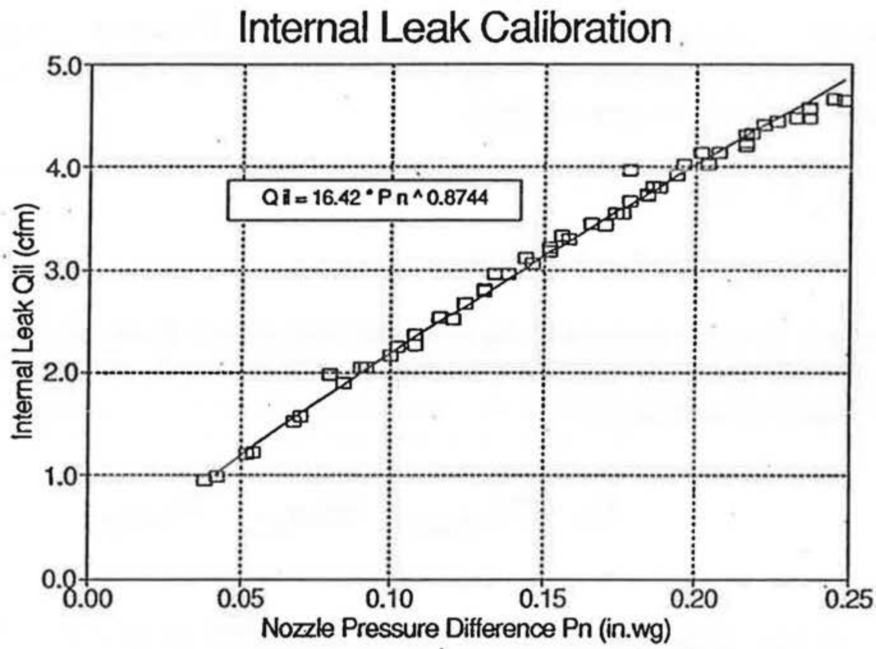


Figure 4.2.5 External and internal leak calibrations of the nozzle flow measuring chamber

4.2.2.3.3 Statistical Techniques

The data collected were fit to the theoretical nonlinear model:

$$Q = C_1 \cdot [\sqrt{C_2^2 + C_3 \cdot \Delta P} - C_2] \qquad [4.3]$$

where:

$C_1 = A$ m^2
$C_2 = BZv/2KD_h^2$ m/s
$C_3 = 2/K\rho$ m^3/kg

Each coefficient has a clear physical meaning in the model. The C_1 is the equivalent sectional area, C_2 is a constant involving geometry and minor loss K, and C_3 is proportional to the inverse of K, which may be thought as a friction indicator.

The flow, Q, and the pressure drop, ΔP, were used as the dependent and independent variables respectively to statistically determine the three coefficients. It is obvious that these three coefficients (parameters) have a nonlinear relationship.

The statistical technique used to solve the nonlinear regression was the SAS NLIN method (SAS 1985, section of NLIN) with the Marquardt option. This option was chosen because it is one which appears to work well in many circumstances and was a practical choice (Draper and Smith 1966, pp. 263-273; SAS 1985, section of NLIN). In this nonlinear regression package, the grid ranges for the relevant parameters need to be provided. The grid for C_2 was set from 0 to 10 by a step of 0.2, and C_3 from 0.6 to 1.7 by a step of 0.05. Different ranges and steps were tested. The results produced after these changes insignificantly different. This indicated that once the dependency problem was solved, the results were unique. Discussion about the dependency problem is contained in the Results section. A similar technique was used to determine the constants C_1 and C_3 for the building component testing.

CHAPTER 5 - RESULTS / DISCUSSION / CONCLUSIONS

5.1 LITERATURE DATABASE

The data from the literature were grouped by components and the effective leakage area for each citation was calculated as described in Section 4.1 at 4 Pa using a discharge coefficient of 1.0. The ela data and supporting material for each citation are contained in Appendix B. (A general shorthand notation throughout the project was used to identify the components and if there was weatherstripping applied. A "W" as the last letter in the component label indicates the presence of weatherstripping and "NW" indicates no weatherstripping.)

The minimum, maximum and best estimate ela values were determined for each component. A summary of the data is contained in Table 5-1. There was considerable variation in the units which were used to provide the basis for the flow or areas reported (eg. cm^2 per: house, each unit, meter of sash, meter of crack, m^2 of component area). Conversions between these units were not attempted unless there was sufficient information given in the reference to make a conversion. In general the units used in the summary were those used by the majority of the data sources.

The best estimate selected from the data was a weighted estimate based upon the number of samples, the age of the data, the "quality" of data (a "best estimate" versus a measured value), and if independent sources predicted similar values. There was somewhat of a problem in determining the best estimate for some of the components since there was considerable overlap of the sources with no independent replication. For several of the cases the "best estimate" was taken as that assumed by the original source.

The best estimate for cases in which there were values given before and after sealing (eg. chimney) was assumed to be an average of multiple replications of the differences and/or direct measurements.

Also contained in Table 5-1 are the values in the 1989 ASHRAE *Handbook - Fundamentals* Chapter 23 Table 3 Effective Leakage Area of Building Components also calculated at a reference pressure of 4 Pa. The new table greatly expands the table in the HOF. There is considerable similarity between the best estimate values selected from the two sources. The selection of the best estimate values to report were made without observation of the values contained in the ASHRAE *Handbook - Fundamentals* and thus were Independent of those numbers. The similarity of the two sets of data is indicative of the use of the same data and in many cases the data were identical. It should be noted that although many entries in the table are unchanged, they have been rigorously reviewed and checked for quality and consistency.

One of the most significant differences is in the data for windows. This is due to the units used as a basis for the ela. A major project to investigate the air leakage of installed windows was done by Weidt et al (1979). The variation of the performance of a number of windows was demonstrated based upon the air leakage. Large shifts in relative performance of different types of windows was identified based on which expression of leakage was used. The air leakage rates were calculated using three different ways: per linear foot of crack, per square foot of window sash area, and per square foot of ventilating area. Since standards and specifications are based on a per linear measure of crack calculation this unit was the basis used for this project. Exceptions to this are the cases of the awning windows and window framing in which there was insufficient information to determine the leakage based upon a length of crack.

It was initially anticipated that there would be some differences that could be identified between the different methods of reporting air leakage, the reference pressures and discharge coefficients selected for the testing and the different testing methods. No significant differences could be detected due to the scatter and insufficient number of data. While this scatter may be due to the anticipated differences in testing and reporting, the results of the round robin testing of the fan pressurization devices suggests that the errors in the devices introduce similar or greater errors.

It should be noted that although the number of different building components listed in the table is greater than previously identified, there are still gaps in the data for some groupings of components which need estimates (or better estimates) of leakage values. There are currently several significant projects underway to obtain the leakage of ductwork. Since these data were not available, they were not included in this report. Other components which need data (or better additional data) include: building construction joints (joints of dissimilar materials like masonry and wood or insulating board and wood; sole plate/baseboard; band joists; building corner joints; butt joints of sheathing, etc), window and door framing in masonry and wood wall construction, and the combined effects of air infiltration barriers and vapor retarders.

TABLE 5-1 Summary of Effective Leakage Areas from Literature (cm2 at 4 Pa, Cd=1)

	Units	RP - 438			Chapter 23 - Table 3 1989 HOF			
		Best Estimate	Minimum	Maximum	Best Estimate	Minimum	Maximum	Units if Different
CG Ceiling - General	cm2/m2	1.8	0.79	2.8				
CG Ceiling - Drop	cm2/m2	0.19	0.046	0.19				
CH Chimney	cm2/ea	29	21	36				
CP Ceiling Pentrations - whole house fans	cm2/ea	20	1.6	21				
CP Ceiling Pentrations - recessed lights	cm2/ea	10	1.5	21	10	10	20	
CP Ceiling Penetrations - ceiling/flue vent	cm2/ea	31	28	31				
CP Ceiling Penetrations - surface mounted lights	cm2/ea	0.82						
CS Crawl Space	cm2/m2	10	8	17				
CS Crawl Space - 8x16" vents	cm2/ea	129						
DACW Doors - Attic/Crawl Space - NonWS	cm2/ea	30	10	37	30	10	30	
DACW Doors - Attic/Crawl Space - WS	cm2/ea	18	8	18.5	18	8	18	
DAFDW Door - Attic Fold Down - NonWS	cm2/ea	44	23	86				
DAFDW Door - Attic Fold Down - WS	cm2/ea	22	14	43				
DAFDW Door - Attic Fold Down - w insulated box	cm2/ea	4						
DAG Doors - Attic from Garage - unconditioned space	cm2/ea	0	0	0				
DD Doors - Double - Not Weatherstripped	cm2/m2	11	7	22	11	7	22	
DD Doors - Double - Weatherstripped	cm2/m2	8	3	23	8	3	15	
DE Doors - Elevator (passenger)	cm2/ea	0.26	0.14	0.35				
DFRAME Door Frame - General	cm2/ea	12	2.4	25				
DFRAME Door Frame - Masonry - Not Caulked	cm2/m2	5	1.7	5	5	1.7	5	
DFRAME Door Frame - Masonry - Caulked	cm2/m2	1	0.3	1	1	0.3	1	
DFRAME Door Frame - Wood - Not Caulked	cm2/m2	1.7	0.6	1.7	1.7	0.6	1.7	
DFRAME Door Frame - Wood - Caulked	cm2/m2	0.3	0.1	0.3	0.3	0.1	0.3	
DFRAME Door Frame - trim	cm2/m	1						
DFRAME Door Frame - jamb	cm2/m	8	7	10				
DFRAME Door Frame - threshold	cm2/m	2	1.2	24				
DG Doors - General - average	cm2/lmc	0.31	0.23	0.45				
DIP Doors - Interior (Pocket) (on top floor)	cm2/ea	14						
DIS Doors - Interior (Stairs)	cm2/m	0.9	0.25	1.5				
DMS Doors - Mail Slot	cm2/m	4						
DSP Doors - Sliding Exterior Glass Patio	cm2/ea	22	3	60				
DSP Doors - Sliding Exterior Glass Patio	cm2/m2	5.5	0.6	15				
DSTM Doors - Storm (difference between with/without)	cm2/ea	6	3	6.2				
DS Doors - Single - Not Weatherstripped	cm2/ea	21	12	53	11	6	17	cm2/m2
DS Doors - Single - Weatherstripped	cm2/ea	12	4	27	8	3	15	cm2/m2
DV Doors - Vestibule (subtract per each location)	cm2/ea	10						
ESO Electrical Outlets/Switches (No gaskets)	cm2/ea	2.5	0.5	6.2	0.5	0	1	
ESO Electrical Outlets/Switches (w gaskets)	cm2/ea	0.15	0.08	3.5	0	0	0	
F Furnace - Sealed (or no) combustion	cm2/ea	0	0	0	0	0	0	
F Furnace - Retention head or stack damper	cm2/ea	30	20	30	30	20	30	
F Furnace - Retention head & stack damper	cm2/ea	24	18	30	24	18	30	
FLCS Floors over Crawl Spaces	cm2/m2	2.2	0.4	4.9				
FLCS Fls over CS w/o ductwork in C.S.	cm2/m2	1.98						
FLCS Fls over CS with ductwork in C.S.	cm2/m2	2.25						
FWDOC Fireplace W Damper Closed	cm2/m2	43	10	92	69	54	84	
FWDOC Fireplace W Damper Open	cm2/m2	350	145	380	350	320	380	
FWG Fireplace W Glass Doors	cm2/m2	40	4	40				
FWIDOC Fireplace w Insert & Damper Closed	cm2/m2	36	26	46	36	26	46	
FWIDOC Fireplace w Insert & Damper Open	cm2/m2	65	40	90	65	40	90	
GWH Gas Water Heater	cm2/ea	20	15	25	20	15	25	
JCW Joints: Ceiling-Wall	cm2/m	1.5	0.16	2.5	1.5	0.5	2.5	
JSP Joints: Sole Plate, floor/wall - uncaulked	cm2/m	4	0.38	5.6	4	1	4	
JSP Joints: Sole Plate, floor/wall - caulked	cm2/m	0.8	0.075	1.2	0.8	0.4	1.2	
JTPO Joints: Top Plate - Band Joist	cm2/m	0.1	0.075	0.38				
PPWP Piping/Plb/Wiring Penetrations uncaulked	cm2/ea	6	2	24	6	2	10	
PPWP P/Plumbing/Wiring Penetrations caulked	cm2/ea	2	1	2	1	0	2	
VBWDC Vents: Bathrm W Damper Closed	cm2/ea	10	2.5	20	11	10	12	
VBWDO Vents: Bathrm W Damper Open	cm2/ea	20	6.1	22	20	18	22	
VDWD Vents: Dryer With Damper	cm2/ea	3	2.9	7	3	0	6	
VDWOD Vents: Dryer Without Damper	cm2/ea	15	12	34				
VKWDO Vents: Kitchen With Damper Open	cm2/ea	40	14	72	39	36	42	
VKWDC Vents: Kitchen With Damper Closed	cm2/ea	5	1	7	5	3	7	
VKWDO Vents: Kitchen With Tight Gasket	cm2/ea	1						
WAEX Wall: Exterior								
Cast In Place Concrete	cm2/m2	0.5	0.049	1.8				
L W Concrete Block - unfinished	cm2/m2	3.5	1.3	4				
L W Concrete Block - painted or stucco	cm2/m2	1.1	0.52	1.1				
H W Concrete Block - unfinished	cm2/m2	0.25						
Continuous Air Infiltration Barrier	cm2/m2	0.15	0.055	0.21				
Rigid Sheathing	cm2/m2	0.35	0.29	0.41				

TABLE 5-1 Summary of Effective Leakage Areas from Literature (cm2 at 4 Pa, Cd=1)

	Units	RP - 438			Chapter 23 - Table 3 1989 HOF			
		Best Estimate	Minimum	Maximum	Best Estimate	Minimum	Maximum	Units if Different
Clay Brick cavity wall - finished	cm2/m2	0.68	0.05	2.3				
Precast Concrete Panel	cm2/m2	1.2	0.28	1.65				
WIANW Window: Awning NotWS	cm2/m2	1.6	0.8	2.4	1.6	0.8	2.4	
WIAW Window: Awning w weatherstripping	cm2/m2	0.8	0.4	1.2	0.8	0.4	1.2	
WICW Windows: Casement w weatherstripping	cm2/lmc	0.24	0.1	3	0.8	0.4	1.2	cm2/m2
WICW Windows: Casement w/o ws	cm2/lmc	0.28			1.6	0.8	2.4	cm2/m2
WIDHSW Windows: Double Horiz Slider w/o ws	cm2/lmc	1.1	0.019	3.4	5.2	2.8	7.6	cm2/m2
WIDHSW Windows: Dbl Hor Sldr - wood w w/s	cm2/lmc	0.55	0.15	1.72	2.6	3.8	1.4	cm2/m2
WIDHSW Windows: Dbl Hor Sldr - al w w/s	cm2/lmc	0.72	0.58	0.8				
WIDHW Windows: Double Hung w/o ws	cm2/lmc	2.5	0.86	6.1	6	3.2	8.8	cm2/m2
WIDHW Windows: Double Hung w ws	cm2/lmc	0.65	0.2	1.9	3	1.6	4.4	cm2/m2
WIDHW Wdows: Dbl Hung w/o ws, w storm	cm2/lmc	0.97	0.48	1.7				
WIDHW Wdows: Dbl Hung w ws, w storm	cm2/lmc	0.79	0.44	1				
WIDHW Wdows: Dbl Hung w ws, w pressurized trackst	cm2/lmc	0.48	0.39	0.56				
WIFM Windows: Framing - Masonary - uncaulked	cm2/m2	6.5	5.7	10.3	6.5	5.7	10.3	
WIFM Windows: Framing - Masonary - caulked	cm2/m2	1.3	1.1	2.1	1.3	1.1	2.1	
WIFW Windows: Framing - Wood - uncaulked	cm2/m2	1.7	1.5	2.7	1.7	1.5	2.7	
WIFW Windows: Framing - Wood - caulked	cm2/m2	0.3	0.3	0.5	0.3	0.3	0.5	
WIJ Windows: Jalousie	cm2/louvre	3.38						
WIL Windows: Lumped	cm2/lms	0.471	0.009	2.06				
WISHSW Windows: Single Horizontal Slider	cm2/lms	0.67	0.2	2.06	1.8	0.9	2.7	cm2/m2
WISHSW Windows: Single Horizontal Slider w/o ws					3.6	1.8	5.4	cm2/m2
WISHSW Windows: Single Hor Slider - aluminum	cm2/lms	0.8	0.27	2.06				
WISHSW Windows: Single Hor Sldr - wood	cm2/lms	0.44	0.27	0.99				
WISHSW Windows: Single Hor Sldr - wood clad	cm2/lms	0.64	0.54	0.81				
WISHW Windows: Single Hung - WS	cm2/lms	0.87	0.62	1.24	2.2	1.8	2.9	cm2/m2
WISHW Windows: Single Hung - non ws					4.4	3.6	5.8	cm2/m2
WISILL Windows: Sill	cm2/lmc	0.21	0.139	0.212				
WIST Windows: Storm Inside - heat shrink	cm2/lms	0.018	0.009	0.018				
WIST Windows: Storm Inside - rigid w magnetic seals	cm2/lms	0.12	0.018	0.24				
WIST Windows: Storm Inside - flex sheets w mech seals	cm2/lms	0.154	0.018	0.833				
WIST Windows: Storm Inside - rigid w mechanical seals	cm2/lms	0.4	0.045	0.833				
WISTM Windows - Storm Outside (Storm only)								
WISTM Windows - Storm Outside - pressurized track	cm2/lmc	0.528						
WISTM Windows - Storm Outside 2 track	cm2/lmc	1.23						
WISTM Windows - Storm Outside - 3 track	cm2/lmc	2.46						

NOTE: Units are cm2 per
m2 = square meters of surface area
lmc = lineal meter of crack
lms = lineal meter of sash
m = lineal meter

5.2 DETERMINATION OF INDEPENDENT C_1, C_2 AND C_3 PARAMETERS

Initially the statistical technique attempted was to make a direct nonlinear regression based on equation [4.3]. The three-parameter nonlinear regression results showed that the estimated constants were not stable as different grids (and therefore search starting points) were selected. In addition, the standard error for one of the parameters always went to zero. This numerical instability indicated that the direct three-parameter regression was over parameterized. When the model was mathematically analyzed further it was recognized that the constants are not independent of each other and actually only two independent parameters existed as in the following form:

$$Q = \sqrt{(C_1C_2)^2 + C_1^2C_3\,\Delta P} - C_1C_2 \qquad 5.1$$

Thus there was a problem in attempting to determine the values for C_1, C_2 and C_3 when there were only two independent parameters.

For well-defined cracks the section area of the crack is known. If the area is treated as an input, the model in the form [4.3] will automatically be reduced to a two-parameter non-linear regression model. When this was done for the well-defined cracks the resulting values of C_2 and C_3 were very stable. This is a significant improvement over a previous approach which needed the assumption of $K=1.5$ (Chastain et al.1987).

The original desire was to apply the model to openings in real building components with unknown crack geometries. None of the three parameters would be known in this case. Therefore a relationship was needed to find one of the three coefficients either theoretically or numerically. It was found that the theoretical relationship(s) derived from equation [4.3] are dependent on the equation and therefore the dependency problem could not be solved.

Thus an attempt was made to determine a numerical relationship between the parameters.

The power equation is presently the most common expression used to represent the Q-ΔP curve. It is also independent of the KY model since it is not theoretically based. Therefore it is a good reference to numerically relate the constants in the new model. The relationship of C_2 in the KY model and the n in the power model were investigated.

<u>For the KY model case</u>:

The model is defined by Eqn 4.3

$$Q = C_1\left[(C_2^2 + C_3\Delta P)^{0.5} - C_2\right]$$

where:

$C_1 = A$ $\quad m^2$

$C_2 = BZv/2KD_h$ $\quad m/s$

$C_3 = 2/K\rho$ $\quad m^3/kg$

When $C_2 = 0$ (i.e. flow length, $Z = 0$), the equation reduces to:

$$Q = C_1 \sqrt{C_3 \Delta P}$$

and therefore $Q \propto \sqrt{\Delta P}$.

The first derivative, $dQ/d\Delta P$ for the model is given by:

$$\frac{dQ}{d\Delta P} = \frac{C_1 C_3}{2\sqrt{C_2^2 + C_3 \Delta P}} \qquad 5.2$$

Figure 5.1 illustrates a typical plot of $dQ/d\Delta P$ vs. ΔP. When C_2 is increasing, the derivative term, $dQ/d\Delta P$, is approaching a constant. When C_2 increases to a large number, say $C_2 > 10$ m/s in this plot, it can be assumed that the derivative $dQ/d\Delta P$ will not significantly change with ΔP. This means that the slope of Q vs. ΔP is approaching to a constant, that is,

$$\text{When } C_2^2 > C_3 \Delta P, \quad \frac{dQ}{d\Delta P} \approx \text{constant} \quad \therefore \quad Q \propto \Delta P$$

<u>For the power model case</u>:

$$Q = C\,\Delta P^n$$

$$\text{When } n = 0.5, \quad Q = C\sqrt{\Delta P} \quad Q \propto \sqrt{\Delta P}$$

$$\text{When } n = 1, \quad Q = C\,\Delta P, \quad Q \propto \Delta P$$

Comparing these two model cases suggests that the function of n in the power model plays a similar role as C_2 in the new model. This observation implies that there may be a numerical relationship between the C_2 and n.

Using data from well-defined cracks enabled the establishment of this calibration relationship since the sectional area of crack, C_1, was known and stable C_2 and C_3 values could be obtained by the two-parameter regression. Meanwhile the power model was also applied to fit the Q-ΔP data from the same well-defined cracks to produce the corresponding C and n. Figure 5.2 is the plot of C_2 vs. n for 19 well-defined cracks. This demonstrates a strong linear correlation between C_2 and n represented by:

$$C_2 - 11.85(n-0.5) \qquad 5.3$$

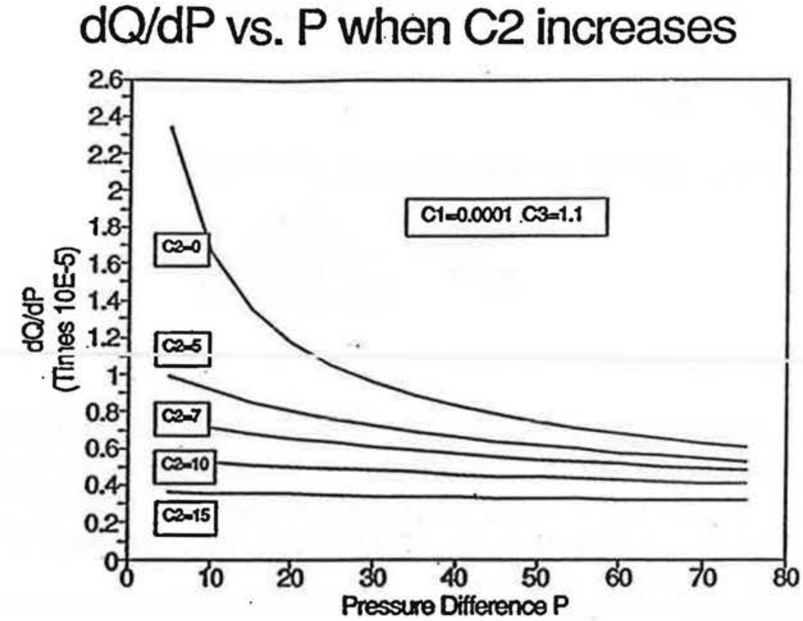


Figure 5.1 dQ/dΔP vs. ΔP relationship in the KY model

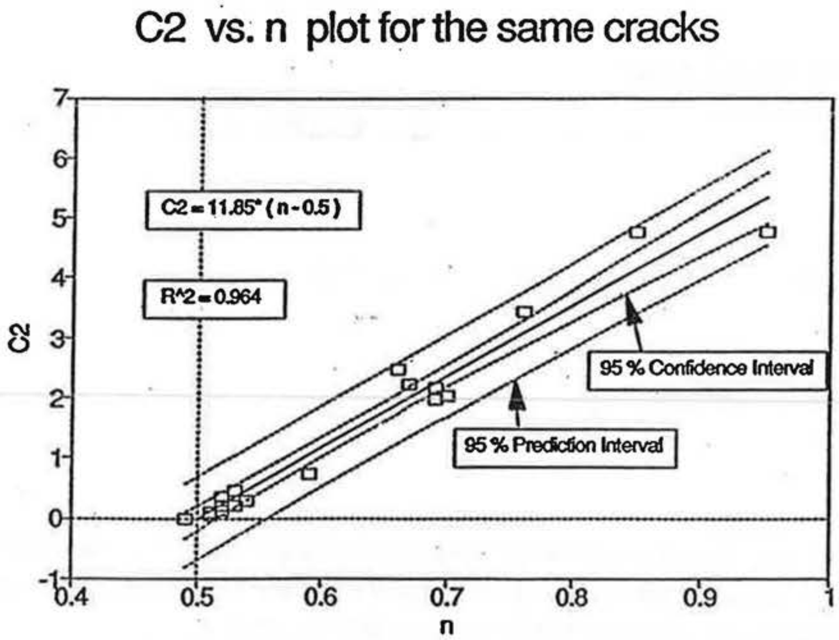


Figure 5.2 C_2 in the KY model vs. n in the power model

It is recognized that an assumption is needed in order to apply this numerical relationship to real building components. It is assumed that there is no significant difference in the Q-ΔP relationship between the well-defined cracks and building components. This assumption had been recognized and used in previous research (Hopkins and Hansford 1974, Etheridge 1977 and Chastain et al.1987).

It is now easy to apply the model to evaluate the leakage performance of real building components. In summary, the following are the procedures for well-defined cracks and building components respectively:

<u>For well-defined cracks</u>:

Input the known crack sectional area C_1 into the model equation [4.3] to obtain the other two constants C_2 and C_3 by a two-parameter nonlinear regression.

<u>For building components</u>:

1) Obtain the regression exponent n based on the power model.
2) Calculate the C_2 from the numerical relation of equation 5.3.
3) Substitute the C_2 value into the new model [4.3] to obtain the other two constants C_1 and C_3 by a two-parameter nonlinear regression.

To determine the two estimated parameters, the least squares concept is still used. The error sum of squares, $\Phi(C_2,C_3)$ or $\Phi(C_1,C_3)$ for the nonlinear model and the given data is:

$$\phi(C_2,C_3) - \sum_{K-1}^{m}\left[Q_K - \hat{C}_1\left(\sqrt{C_2^{\,2}+C_3\Delta P_K}-C_2\right)\right]^2$$

$$\phi(C_1,C_3) - \sum_{K-1}^{m}\left[Q_K - C_1\left(\sqrt{\hat{C}_2^{\,2}+C_3\Delta P_K}-\hat{C}_2\right)\right]^2$$

Where $(Q_K, \Delta P_K)$ is a group of m observations and $1 \le K \le m$. The parameter with "^" means that the parameter is known.

For example, take the equation of $\Phi(C_2,C_3)$ to obtain the least squares estimates of C_2 and C_3. We need to differentiate this equation with respect to C_2 and C_3 respectively. This procedure provides a system of equations with two independent equations and two unknown parameters to be estimated. The equation for $\Phi(C_1,C_3)$ can be handled in a similar way. Finding the estimates by solving the system of equations is very complicated and iterative methods must be employed. There are several methods available for obtaining the parameters by routine computer calculations. The Marquardt's method is one which appears to work well in many circumstances thus it is a practical choice (Draper and Smith 1966, pp. 263-273). The detailed information about the detail of solving the system of equations involving the Marquardt iterative methods can be found in Draper and Smith (1966). Commercial computer software is also available to solve nonlinear regressions. The SAS NLIN programs are very powerful in handling nonlinear regression (SAS 1985). This program was chosen with the Marquardt's method option to estimate the two parameters in this study.

All iterative procedures require initial values of the parameters to be selected. Applying different grids in these cases should not significantly impact the results. It is also clear from their physical meanings that $C_1>0$, $C_2>0$ and $C_3>0$. Hence these constants are set to be semi-free-positive coefficients to be determined by the regression.

From the regression of a specified Q-ΔP data set for building components, the three coefficients C_1, C_2 and C_3 are then obtained. If the air density value in the test is known, the K value can be calculated from C_3 directly. The $B{\cdot}Z/(Re{\cdot}D_h)$ vs. $\Delta P/(\frac{1}{2}\rho \bar{V}^2)$ relationship can also be determined by using the original Q-ΔP data set and the corresponding regression results of C_1, C_2 and C_3, i.e.

$$\frac{BZ}{ReD_h} = \frac{BZ}{\left(\frac{\bar{V}D_h}{\nu}\right)D_h} = \frac{\frac{BZ\nu}{D_h^2}}{\frac{Q}{A}} = \frac{A\frac{BZ\nu}{2KD_h^2}}{\frac{2}{k\rho}}\frac{4}{\rho Q} = \frac{C_1 C_2}{C_3}\frac{4}{\rho Q}$$

$$\frac{\Delta P}{\frac{1}{2}\rho\bar{V}^2} = \frac{2\Delta P}{\rho(\frac{Q}{A})^2} = A^2\frac{2\Delta P}{\rho Q^2} = C_1^2\frac{2\Delta P}{\rho Q^2}$$

This means each $\Delta P/(\frac{1}{2}\rho \bar{V}^2)$ value and the corresponding $B{\cdot}Z/(Re{\cdot}D_h)$ value can be obtained directly from the Q-ΔP data set using the calculation and regression products C_1, C_2 and C_3. In this technique, no assumption has to be made about the dimensions of the crack in order to get $B{\cdot}Z/(Re{\cdot}D_h)$ and $\Delta P/(\frac{1}{2}\rho \bar{V}^2)$ values. This is a significant improvement over the previous methods of Etheridge (1977) and Chastain et.al (1987).

5.3 FIT OF NEW EQUATION

5.3.1 Measure of Goodness-of-Fit

When a new model is proposed, it is essential to quantify how good it fits measured data. The power model is based on a linear regression of a log-transform of the Q-ΔP data. The KY model is derived from the nonlinear Q-ΔP relationship. Therefore a common measure should be chosen to judge their statistical performance.

Often the success of the analytical exercise depends on the proper choice of the quantitative criteria used to determine the quality of the fitted model. The coefficient of determination, R^2, is a commonly used measure; however it is often used improperly and is frequently misunderstood as a measure of the fit of the regression line (Raymond 1990). By definition,

$$R^2 = \frac{SS_{Reg}}{SS_{Total}} = \frac{\sum_{i=1}^{n} (\hat{y}_i-\bar{y})^2}{\sum_{i=1}^{n} (y_i-\bar{y})^2} = 1-\frac{SS_{Res}}{SS_{Total}}$$

where:

SS_{Reg}	is the regression sum of square,
SS_{Res}	is the residual sum of square,
SS_{Total}	is the total sum of square,
y_i	is the predicted y for the corresponding independent variable x_i.

This coefficient of determination represents the proportion of variation in the response data that is explained by the model. Clearly $0 \leq R^2 \leq 1$. Raymond (1990) illustrated that R^2 can appear to be artificially high either because the slope of the regression is large or because the spread of the regressor data x_1, x_2, ... x_n is great.

The coefficient of variation, CV, is a less common criterion but is a reasonable one for representing quality of fit and measuring spread of noise around the regression line. The CV is defined as:

$$CV = \frac{\sqrt{\frac{\sum_{i=1}^{n}(y_i-\hat{y}_i)^2}{n-2}}}{\bar{y}} \times 100$$

where n is the number of observations.

The CV is interpreted as the residual estimate of error standard deviation, measured as a percent of the average response values. The CV was chosen to be the criterion used for the comparison of the models.

5.3.2 Overall Fit

A summary of the results of the unweighted power model and the KY model applied to the data obtained from the well-defined cracks and building components are presented in Table 5.3.1 and Table 5.3.2 respectively. The arithmetic average CV value is 1.86% for the power model and 0.92% for the KY model for the same well-defined cracks. The CV value was lower for the new model in 22 of the 26 cases tested. For the building components tests, the CV is 2.63% based on the power model and 1.93% on the KY model. The CV was lower for the new model in 10 of the 18 cases tested.

These results indicate that the KY model statistically fits as well as the power model. However the efficacy of the new equation is measured in the ability to determine additional information about the openings. The model can predict the actual equivalent sectional area of any type of crack or openings in building components and other parameters such as the minor loss coefficient. This is considered as another factor that measures and describes the crack leakage performance. In other words, the model should provide a reasonable prediction of the sectional area chracteristics of the opening. The summary table of well-defined cracks also indicates that the average relative error between the predicted section areas and the section areas is 5.98%.

It should be noted that the five K values predicted which are out of the range previously suggested for well defined openings (1.2-2.3) are for component wall sections. This indicates that as expected the minor losses for complex openings is larger than well defined openings. Four of the five cases are associated with cases which substantially underestimate the flow at 5 Pa. This indicates that further investigation is needed on the relationship between C_2 and n. The equation developed relating these two was taken from data obtained from the well defined openings.

Comparisons were also made between the observed air flow at 5 Pa and the flow predicted for that pressure difference by both models. The predicted air flow using the new model was closer in 6 of the 26 well-defined crack cases and 3 of the 18 building component cases. It should be noted here that the measurement and computation of the observed air flow at 5 Pa has the following problems: 1) It has a higher inaccuracy of flow measurement than the higher pressure difference readings. 2) For most crack flow measurements, the 5 Pa pressure drop corresponds to the lowest Re (which is often lower than 12,000), therefore the discharge coefficient, C_d, which had the largest error had to be chosen to compute the flow. 3) Its reading may also be easily influenced by the surroundings (especially in field measurements). Because of these reasons, a wide pressure range from 5 Pa to 75 Pa is used to include more high accuracy data in order to obtain a general regression equation to extrapolate to the lower pressure data. Therefore the errors between the observed and the predicted data at 5 Pa are sometimes higher in the new model than that in the

Table 5.3.1 - Summary of Well Defined Cracks

Crack		Power Model							New Model								
		C (m^3/(s*Pa^n))	n	C.V. (%)	ELA (at 4 Pa) (m^2)	Q predi. (at 5 Pa) (m^3/sec.)	Q measured (at 5 Pa) (m^3/sec.)	Error of Q (at 5 Pa) (%)	C1 (m^2)	C2 (m/s)	C3 (m^3/kg)	C.V. (%)	ELA (at 4 Pa) (m^2)	Q predi. (at 5 Pa) (m^3/sec.)	Error of Q (at 5 Pa) (%)	A predi. (cm^2)	K
Individual Crack	A-1	5.700E-05	0.8489	2.649	7.17E-05	2.23E-04	0.00022	1.58	4.000E-04	4.77	1.07	0.652	6.66E-05	2.12E-04	-3.42		1.56
	A-2	3.300E-05	0.9455	8.070	4.74E-05	1.51E-04	0.00012	25.95	4.000E-04	4.76	0.83	2.012	5.22E-05	1.67E-04	39.20		2.00
	B1-1	3.660E-04	0.6749	0.820	3.62E-04	1.08E-03	0.00106	2.31	8.500E-04	2.23	1.28	1.507	3.12E-04	9.71E-04	-8.39		1.30
	B1-2	3.180E-04	0.6852	1.905	3.19E-04	9.58E-04	0.00093	3.01	8.500E-04	1.96	1.03	1.009	2.84E-04	8.83E-04	-5.07		1.62
	B2-1	3.060E-04	0.6897	1.021	3.09E-04	9.29E-04	0.00090	3.17	8.500E-04	2.17	1.04	0.922	2.66E-04	8.31E-04	-7.65		1.60
	B2-2	2.800E-04	0.7025	2.223	2.87E-04	8.67E-04	0.00083	4.50	8.500E-04	2.03	0.95	0.639	2.58E-04	8.06E-04	-2.87		1.75
	E-1	2.640E-03	0.5313	1.093	2.14E-03	6.21E-03	0.00601	3.30	3.145E-03	0.21	0.95	0.585	2.13E-03	6.23E-03	3.59		1.75
	E-2	2.440E-03	0.5441	1.506	2.01E-03	5.86E-03	0.00565	3.67	3.145E-03	0.29	0.92	0.791	2.01E-03	5.89E-03	4.33		1.81
	F1-1	6.410E-03	0.5217	0.670	5.12E-03	1.48E-02	0.01457	1.87	6.431E-03	0.17	1.23	0.364	5.12E-03	1.49E-02	2.21		1.35
	F1-2	6.710E-03	0.5082	0.704	5.26E-03	1.52E-02	0.01482	2.59	6.431E-03	0.03	1.16	0.589	5.30E-03	1.53E-02	3.21		1.43
	F2-1	6.240E-03	0.5297	1.085	5.04E-03	1.46E-02	0.01411	3.73	6.431E-03	0.22	1.25	0.571	5.05E-03	1.47E-02	4.36		1.33
	F2-2	7.340E-03	0.4865	0.250	5.58E-03	1.61E-02	0.01615	-0.56	6.431E-03	0.00	1.18	0.740	5.42E-03	1.56E-02	-3.28		1.41
Parallel Crack	A@B1	3.210E-04	0.7597	1.613	3.57E-04	1.09E-03	0.00103	5.85	1.250E-03	3.45	1.20	1.184	3.09E-04	9.76E-04	-5.20		1.39
	A@E	2.900E-03	0.5197	0.648	2.31E-03	6.69E-03	0.00684	-2.14	3.545E-03	0.21	0.84	0.688	2.25E-03	6.56E-03	-4.11		1.98
	A@F1	6.790E-03	0.5143	0.487	5.37E-03	1.55E-02	0.01529	1.61	6.831E-03	0.11	1.14	0.366	5.37E-03	1.56E-02	1.86		1.46
	B1@B2	7.770E-04	0.6624	1.115	7.54E-04	2.26E-03	0.00237	-4.79	1.700E-03	2.46	1.36	1.990	6.13E-04	1.91E-03	-19.31		1.22
	B1@E	2.640E-03	0.5862	1.608	2.31E-03	6.78E-03	0.00643	5.47	3.995E-03	0.73	1.05	0.486	2.24E-03	6.69E-03	4.05		1.58
	B1@F1	7.330E-03	0.5154	0.421	5.81E-03	1.68E-02	0.01655	1.52	7.281E-03	0.13	1.18	0.315	5.78E-03	1.68E-02	1.29		1.41
	F1@F2	1.392E-02	0.5055	0.349	1.09E-02	3.14E-02	0.03127	0.42	1.286E-02	0.04	1.23	0.365	1.09E-02	3.14E-02	0.37		1.35
Series Crack	A~B1	3.120E-05	0.9333	6.088	4.41E-05	1.40E-04	0.00012	16.77	3.606E-04	5.10	0.89	1.897	4.72E-05	1.51E-04	25.93	3.61	1.87
	B1~A	3.580E-05	0.9511	6.797	5.19E-05	1.65E-04	0.00013	27.27	4.262E-04	5.33	0.97	1.875	5.82E-05	1.86E-04	43.29	4.26	1.72
	B1~E	3.400E-04	0.6628	1.633	3.30E-04	9.88E-04	0.00095	4.00	7.269E-04	1.90	1.25	0.916	2.91E-04	9.01E-04	-5.12	7.27	1.33
	E~B1	3.080E-04	0.6913	1.136	3.11E-04	9.37E-04	0.00090	4.11	8.444E-04	2.25	1.09	1.320	2.68E-04	8.38E-04	-6.90	8.44	1.53
	E~F1	2.150E-03	0.5534	1.572	1.79E-03	5.24E-03	0.00499	4.99	1.808E-03	0.59	2.39	0.735	1.79E-03	5.27E-03	5.69	18.08	0.70
	F1~B1	3.170E-04	0.6950	1.470	3.22E-04	9.70E-04	0.00092	5.45	8.142E-04	2.37	1.26	0.770	2.82E-04	8.81E-04	-4.24	8.14	1.32
	F1~E	2.180E-03	0.5504	1.365	1.81E-03	5.29E-03	0.00502	5.31	1.750E-03	0.59	2.55	0.642	1.80E-03	5.30E-03	5.60	17.50	0.65
(Average)				1.857								0.920					1.48

Table 5.3.2 - Summary of Building Components

Component	Power Model: C (m^3/(s*Pa^n))	n	C.V. (%)	ELA (at 4 Pa) (m^2)	Q predi. (at 5 Pa) (m^3/sec.)	Q measured (at 5 Pa) (m^3/sec.)	Error of Q (at 5 Pa) (%)	New Model: C1 (m^2)	C2 (m/s)	C3 (m^3/kg)	C.V. (%)	ELA (at 4 Pa) (m^2)	Q predi. (at 5 Pa) (m^3/sec.)	Error of Q (at 5 Pa) (%)	A predi. (cm^2)	K
CO-1	1.01E-05	1.0145	10.521	1.60E-05	5.17E-05	0.00004	29.23	1.260E-04	6.04	1.35	2.909	2.11E-05	6.74E-05	68.55	1.26	1.23
CO-2	8.19E-04	0.5554	3.469	6.86E-04	2.00E-03	0.00189	5.93	3.940E-04	0.71	7.11	2.446	7.13E-04	2.09E-03	10.37	3.94	0.23
CO-3	3.12E-04	0.6720	0.935	3.07E-04	9.20E-04	0.00090	2.24	7.800E-04	2.01	1.07	1.159	2.64E-04	8.22E-04	-8.62	7.80	1.56
CO-4	2.74E-04	0.6879	2.237	2.68E-04	8.03E-04	0.00078	2.92	5.810E-04	2.01	1.35	1.803	2.39E-04	7.41E-04	-5.04	5.81	1.23
CO-5	3.49E-04	0.6459	0.678	3.31E-04	9.87E-04	0.00098	0.71	7.730E-04	1.78	1.05	1.770	2.80E-04	8.67E-04	-11.54	7.73	1.58
CO-6	2.12E-04	0.7167	0.534	2.22E-04	6.72E-04	0.00066	1.80	7.590E-04	2.61	0.91	1.557	1.83E-04	5.77E-04	-12.51	7.59	1.83
CO-7	2.29E-04	0.7061	0.777	2.36E-04	7.13E-04	0.00070	1.92	7.210E-04	2.49	1.01	1.450	1.98E-04	6.23E-04	-11.00	7.21	1.65
CO-8	1.70E-04	0.7047	1.287	1.75E-04	5.28E-04	0.00050	5.69	5.000E-04	2.37	1.09	0.926	1.53E-04	4.78E-04	-4.33	5.00	1.53
CO-9	1.67E-05	0.8518	5.119	2.11E-05	6.58E-05	0.00005	31.56	1.080E-04	4.15	1.10	2.771	2.09E-05	6.66E-05	33.23	1.08	1.51
CO-10	2.22E-04	0.7393	1.649	2.40E-04	7.30E-04	0.00068	7.30	8.040E-04	2.84	1.06	1.315	2.08E-04	6.56E-04	-3.53	8.04	1.57
CO-11	1.48E-04	0.7318	1.811	1.58E-04	4.81E-04	0.00045	6.80	5.130E-04	2.73	1.06	1.337	1.37E-04	4.31E-04	-4.11	5.13	1.57
CO-12	9.33E-05	0.6758	1.004	9.23E-05	2.77E-04	0.00028	-1.12	2.620E-04	2.13	0.94	1.795	7.62E-05	2.38E-04	-14.92	2.62	1.77
CO-13	6.62E-05	0.8962	5.858	8.89E-05	2.80E-04	0.00022	27.31	5.150E-04	4.74	1.17	1.466	9.39E-05	2.99E-04	36.11	5.15	1.42
CO-14	3.81E-04	0.7687	1.741	4.29E-04	1.31E-03	0.00131	0.22	2.567E-03	3.20	0.57	2.685	3.37E-04	1.07E-03	-18.09	25.67	2.92
CO-15	6.00E-04	0.7577	1.807	6.65E-04	2.03E-03	0.00211	-3.73	3.982E-03	3.08	0.54	2.581	5.13E-04	1.64E-03	-22.45	39.82	3.08
CO-16	5.05E-03	0.6222	0.821	4.64E-03	1.37E-02	0.01334	3.05	8.463E-03	1.42	1.32	0.725	4.20E-03	1.28E-02	-3.86	84.63	1.26
CO-17	7.77E-04	0.7721	2.349	8.78E-04	2.69E-03	0.00299	-9.96	6.701E-03	3.20	0.43	2.648	6.71E-04	2.14E-03	-28.30	67.01	3.87
CO-18	1.10E-03	0.7745	4.713	1.25E-03	3.83E-03	0.00416	-8.03	1.416E-02	3.20	0.26	4.033	8.70E-04	2.79E-03	-32.92	141.60	6.40
(Average)			2.628								1.965					2.01

power model.

The plots in Figures 5-3-3 through 5-3-11 illustrate the curve performances of the power equation and the new dimensional flow equation. The pressurization data sets of the 18 building components are used as a sample. The conclusion gained from these plots is that the KY model curve fits the data as well and is very close to the power equation model.

The following symbols are used in Figure 5-3-3 to Figure 5-3-11:

****	1:	Average value of the three observed data points
-------	2:	Power model predicted curve
——	3:	New model predicted curve

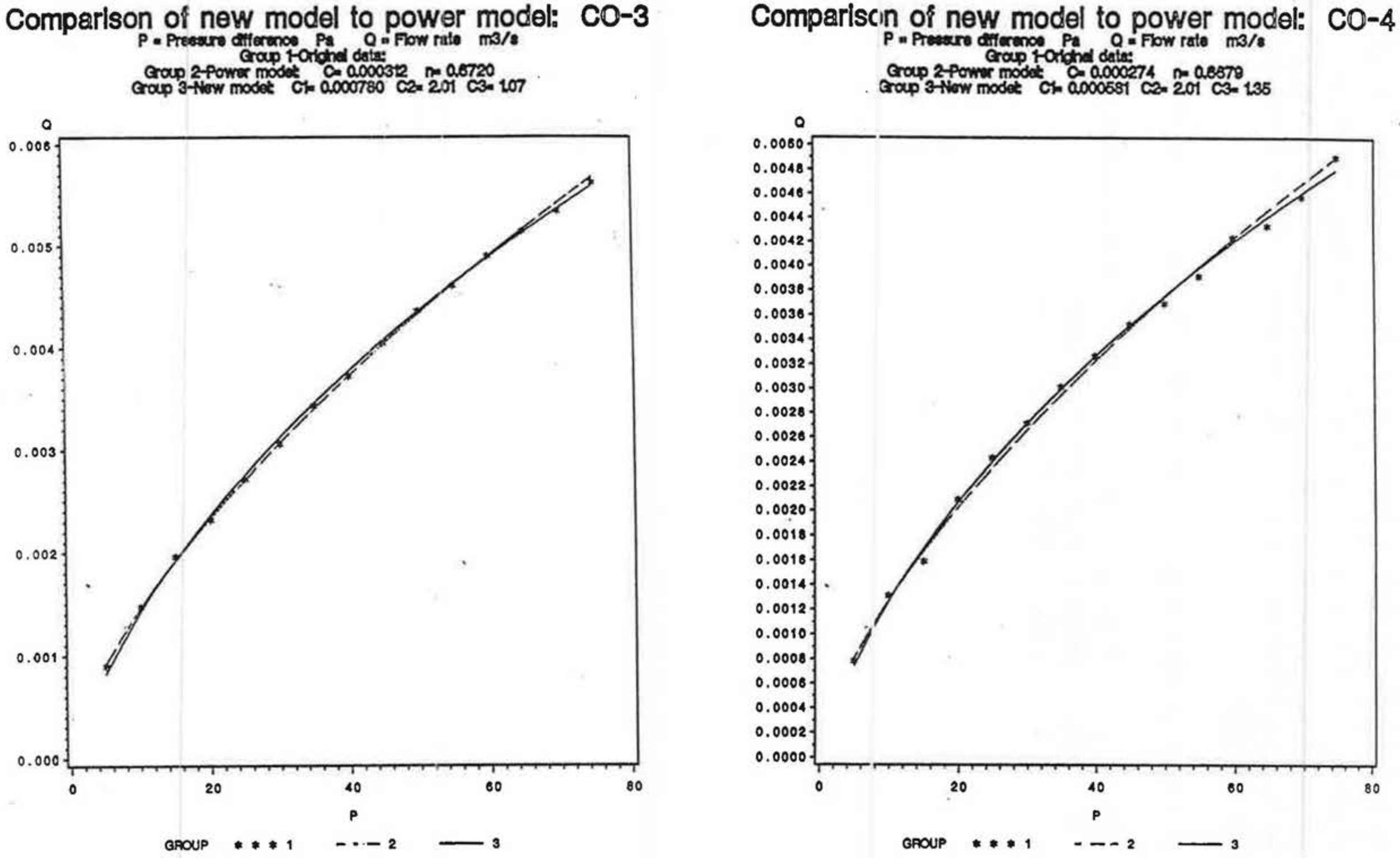


Figure 5-3-4. Model comparison on component 3 and 4

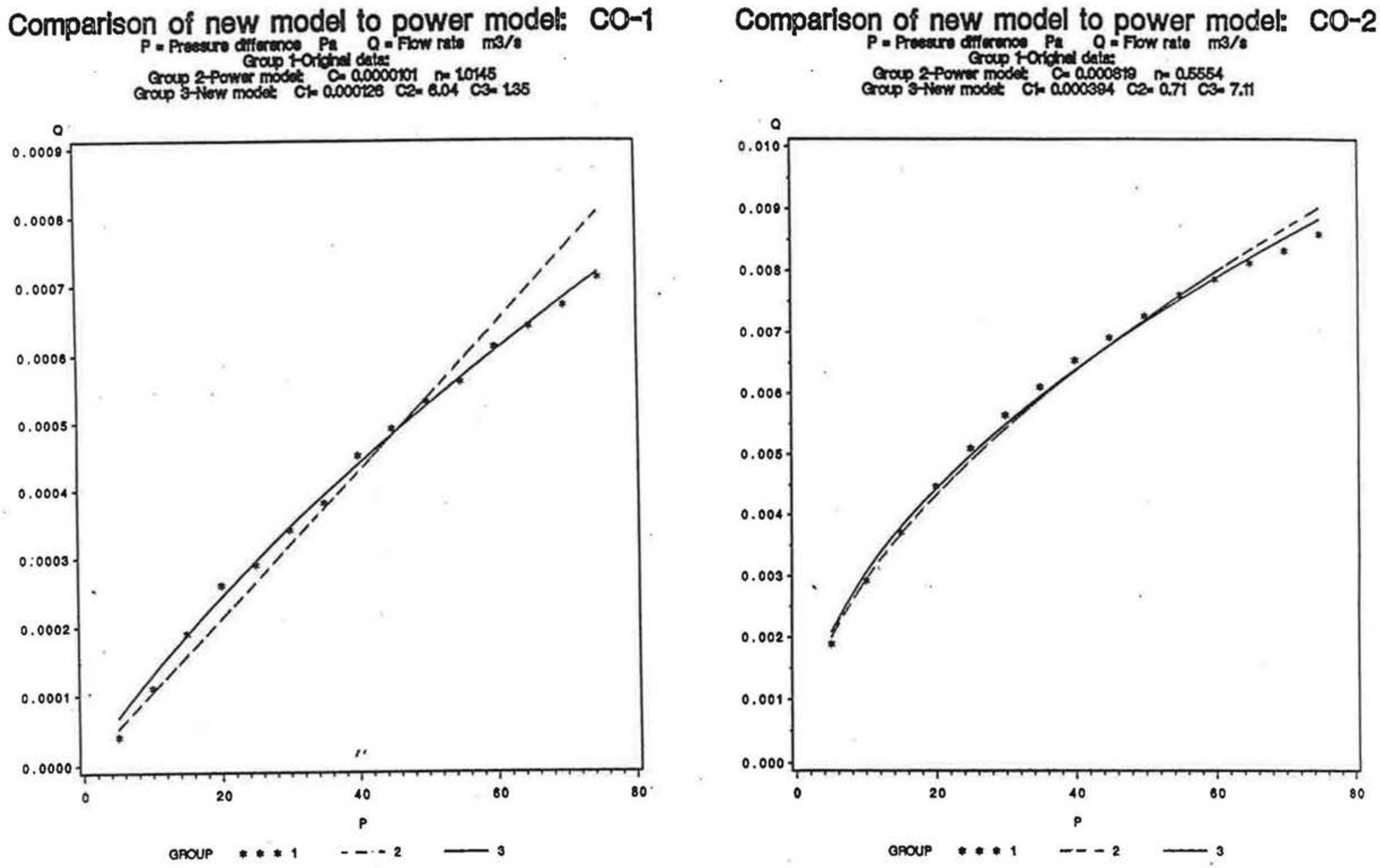


Figure 5-3-3. Model comparison on component 1 and 2

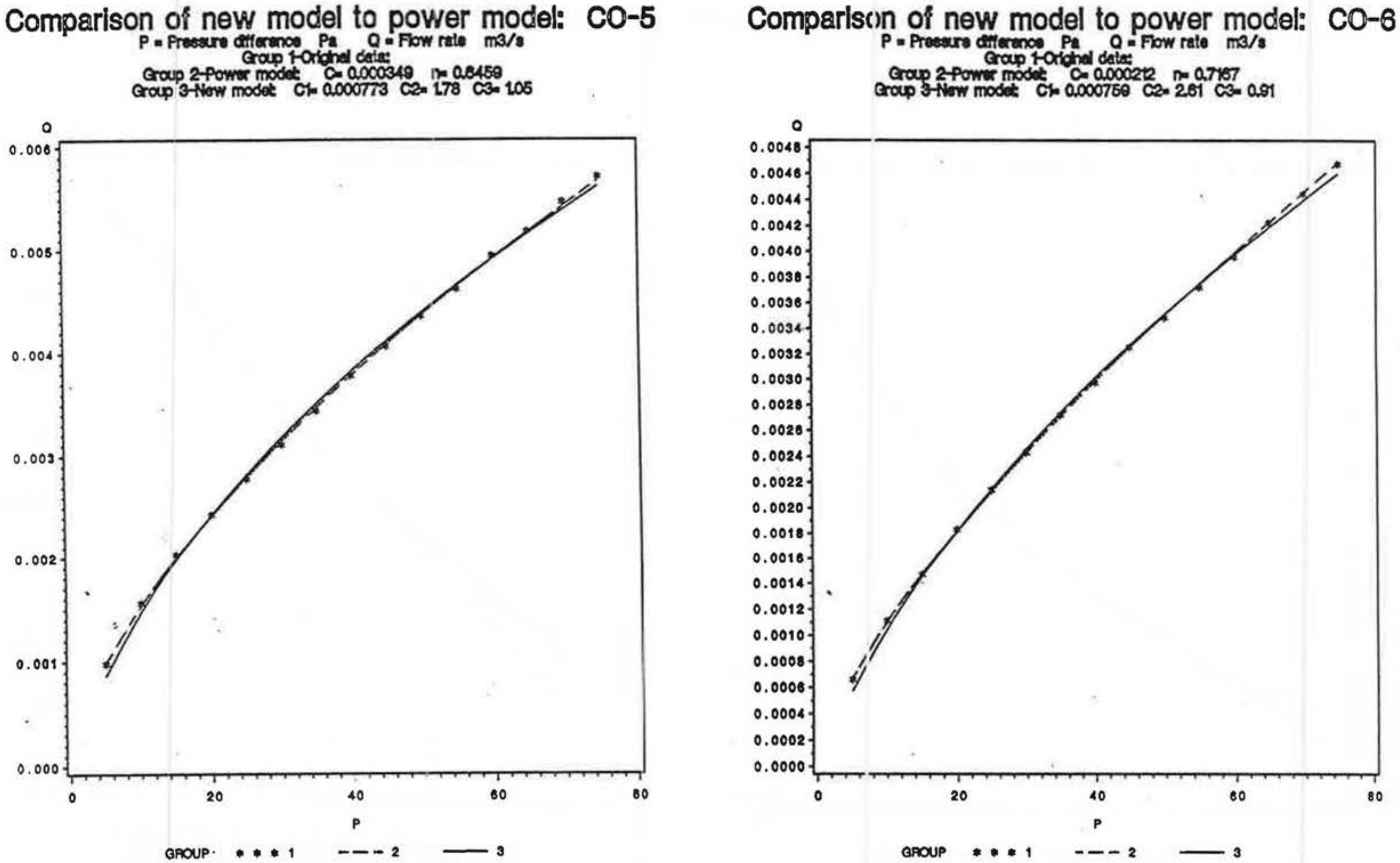


Figure 5-3-5. Model comparison on component 5 and 6

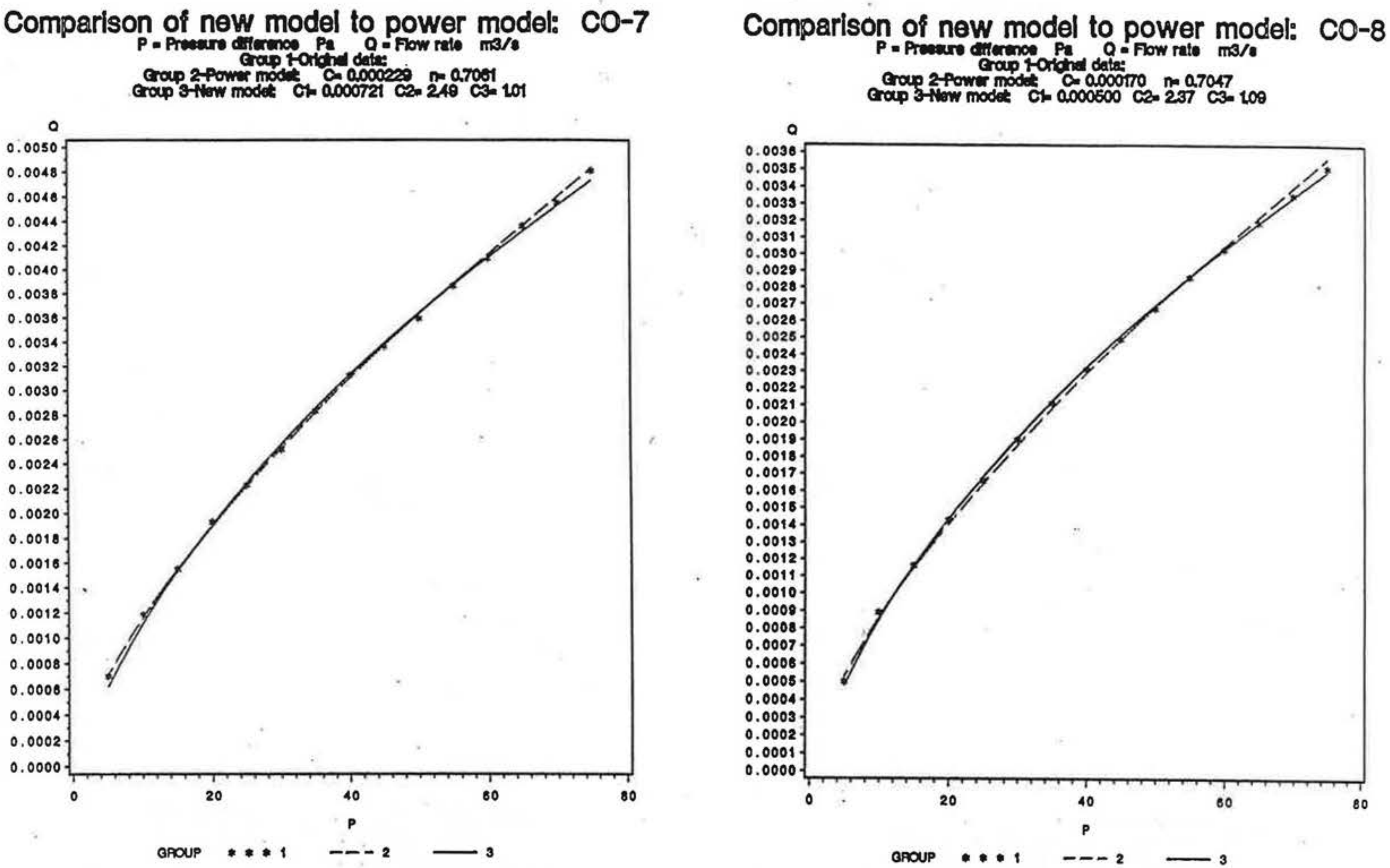


Figure 5-3-6. Model comparison on component 7 and 8

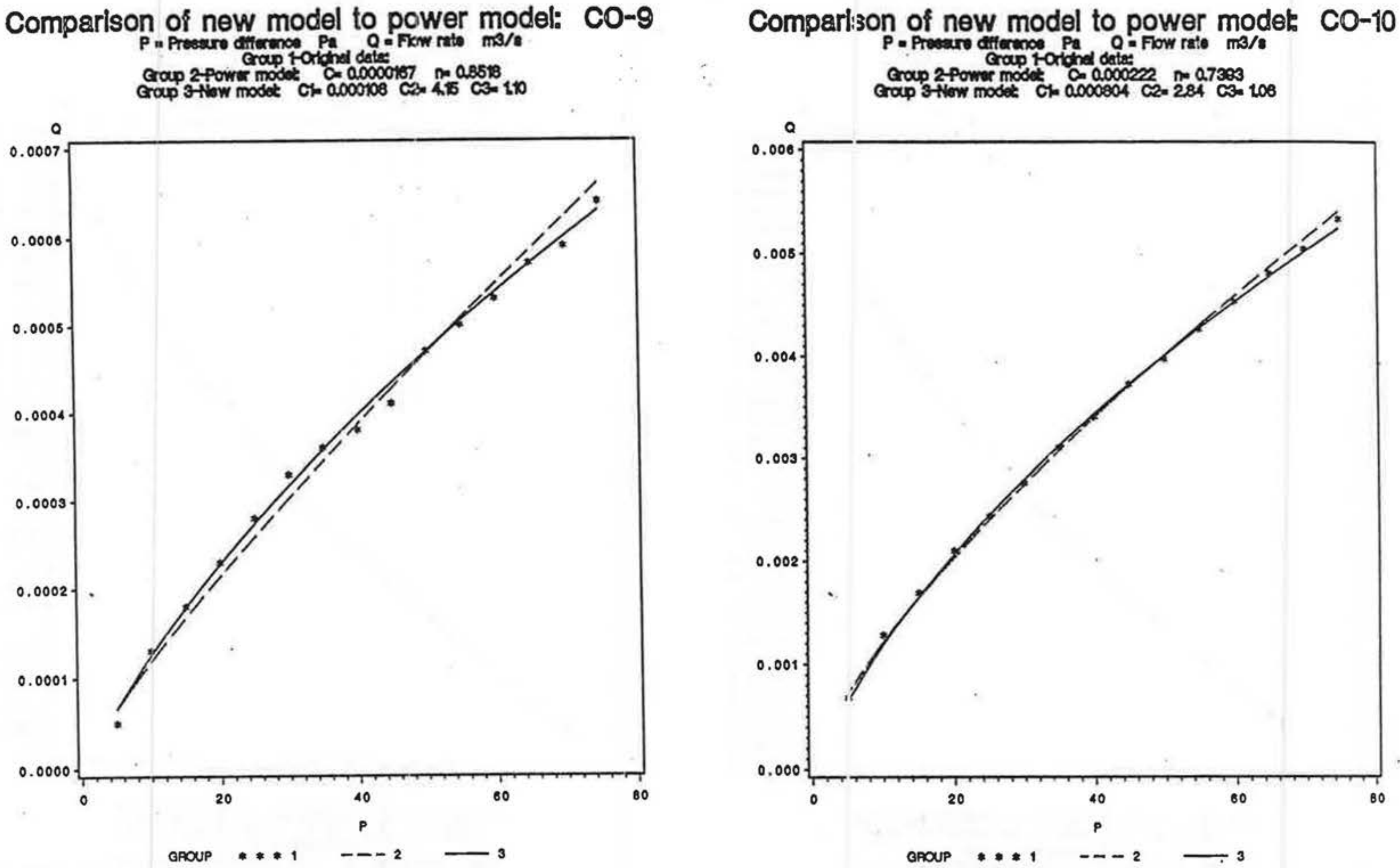


Figure 5-3-7. Model comparison on component 9 and 10

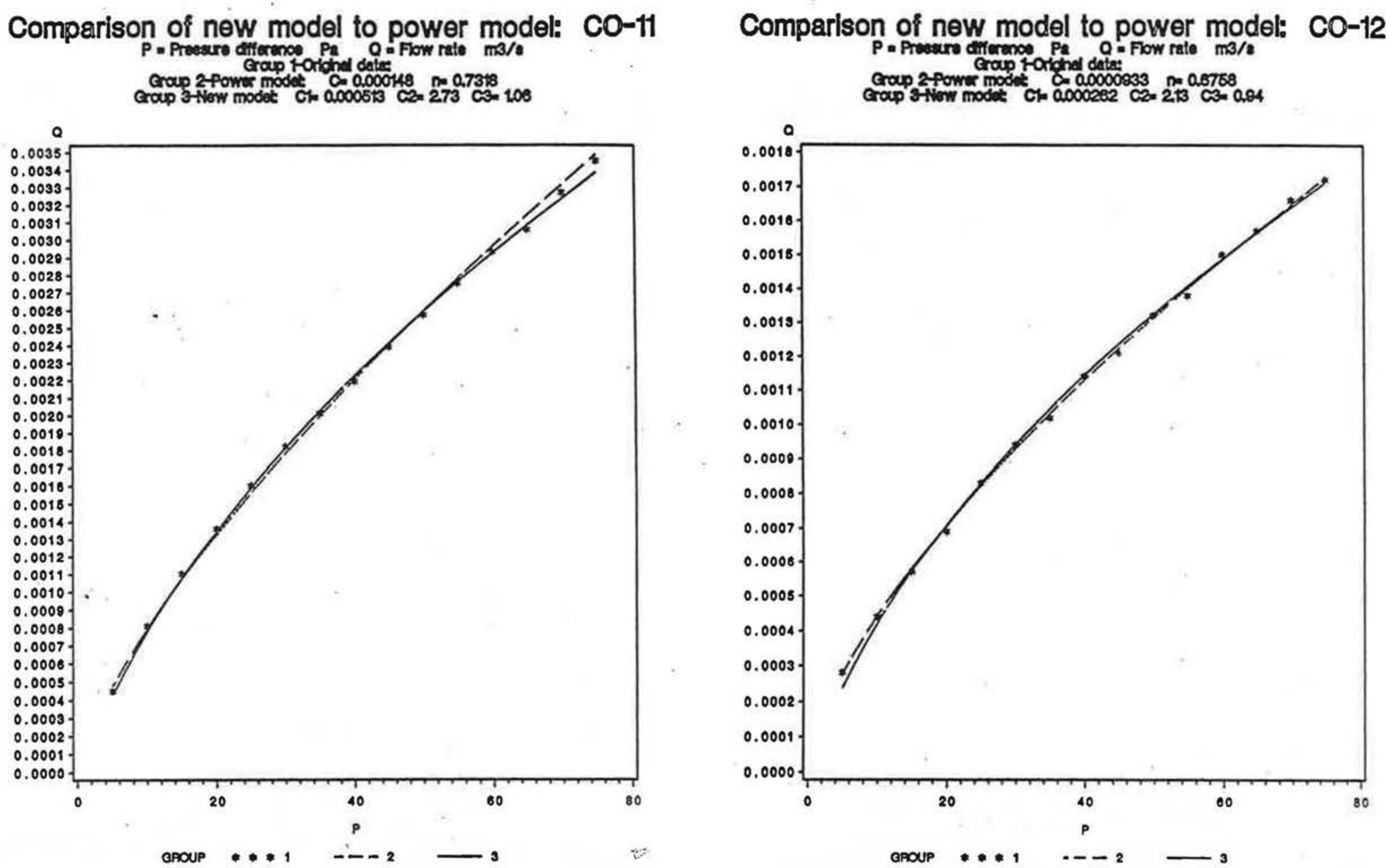


Figure 5-3-8. Model comparison on component 11 and 12

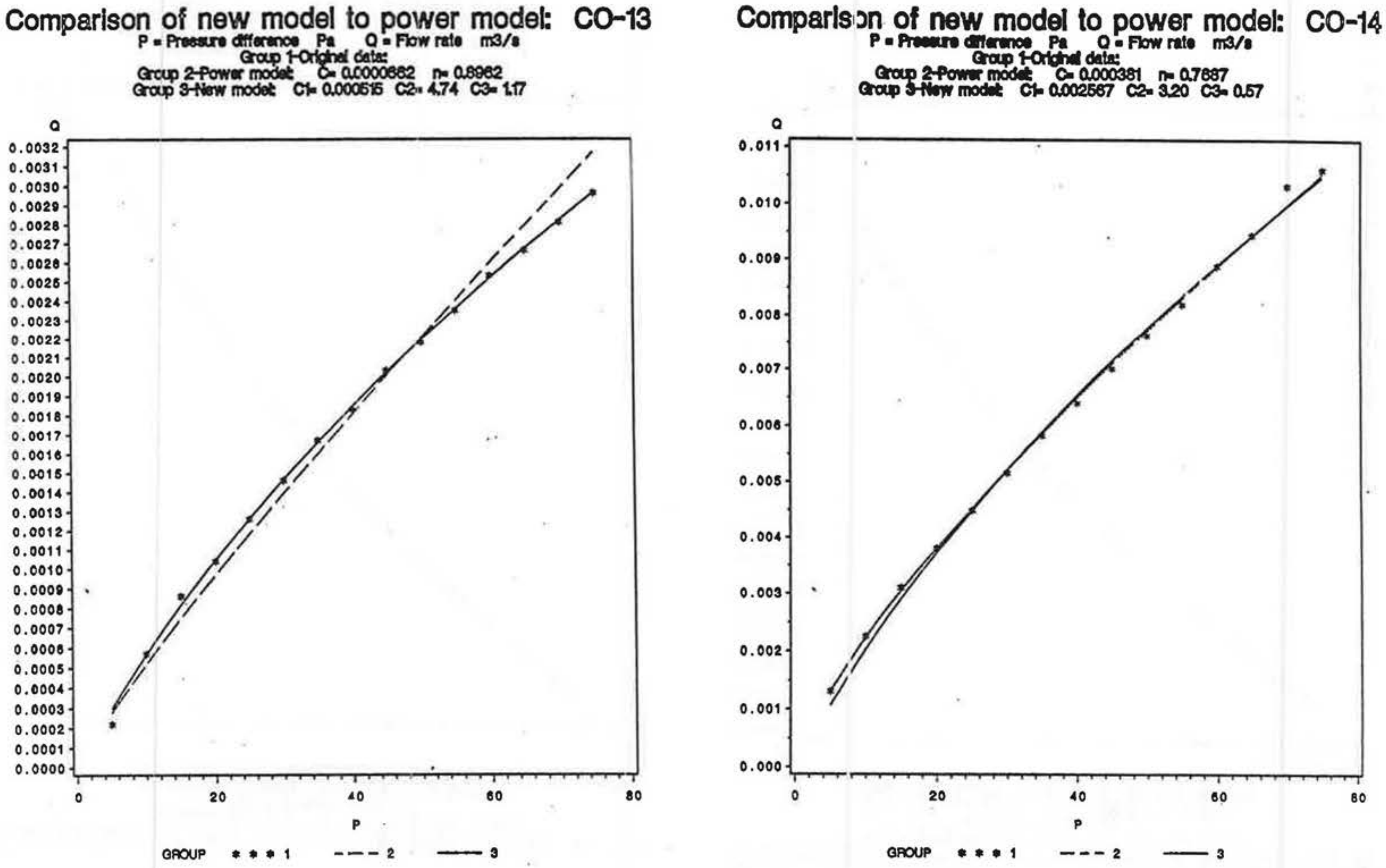
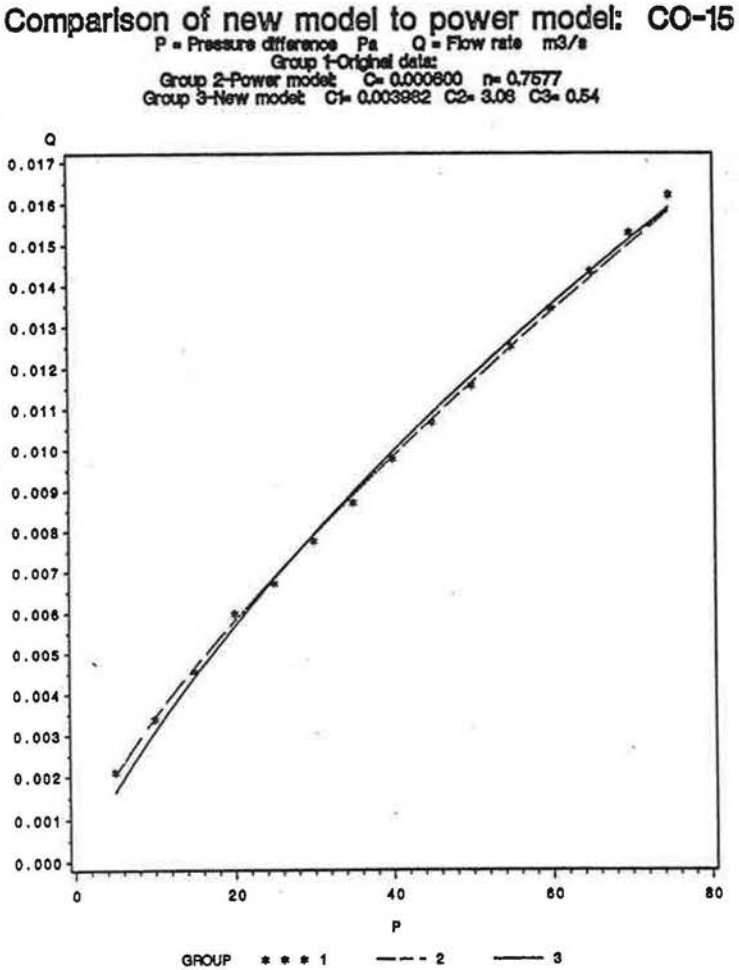


Figure 5-3-9. Model comparison on component 13 and 14



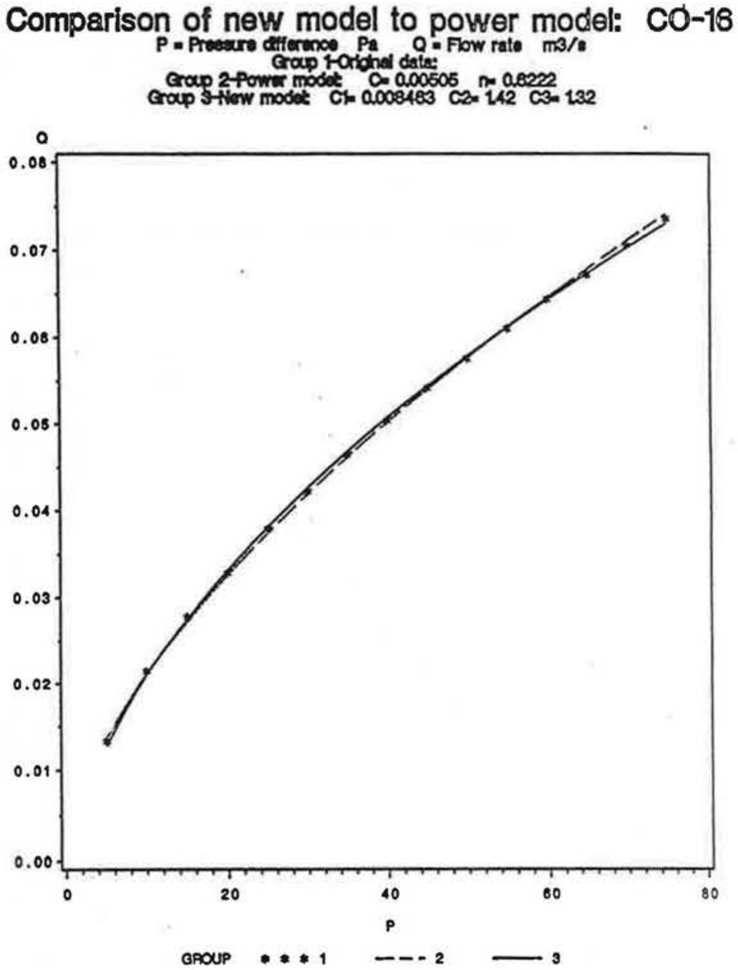


Figure 5-3-10. Model comparison on component 15 and 16

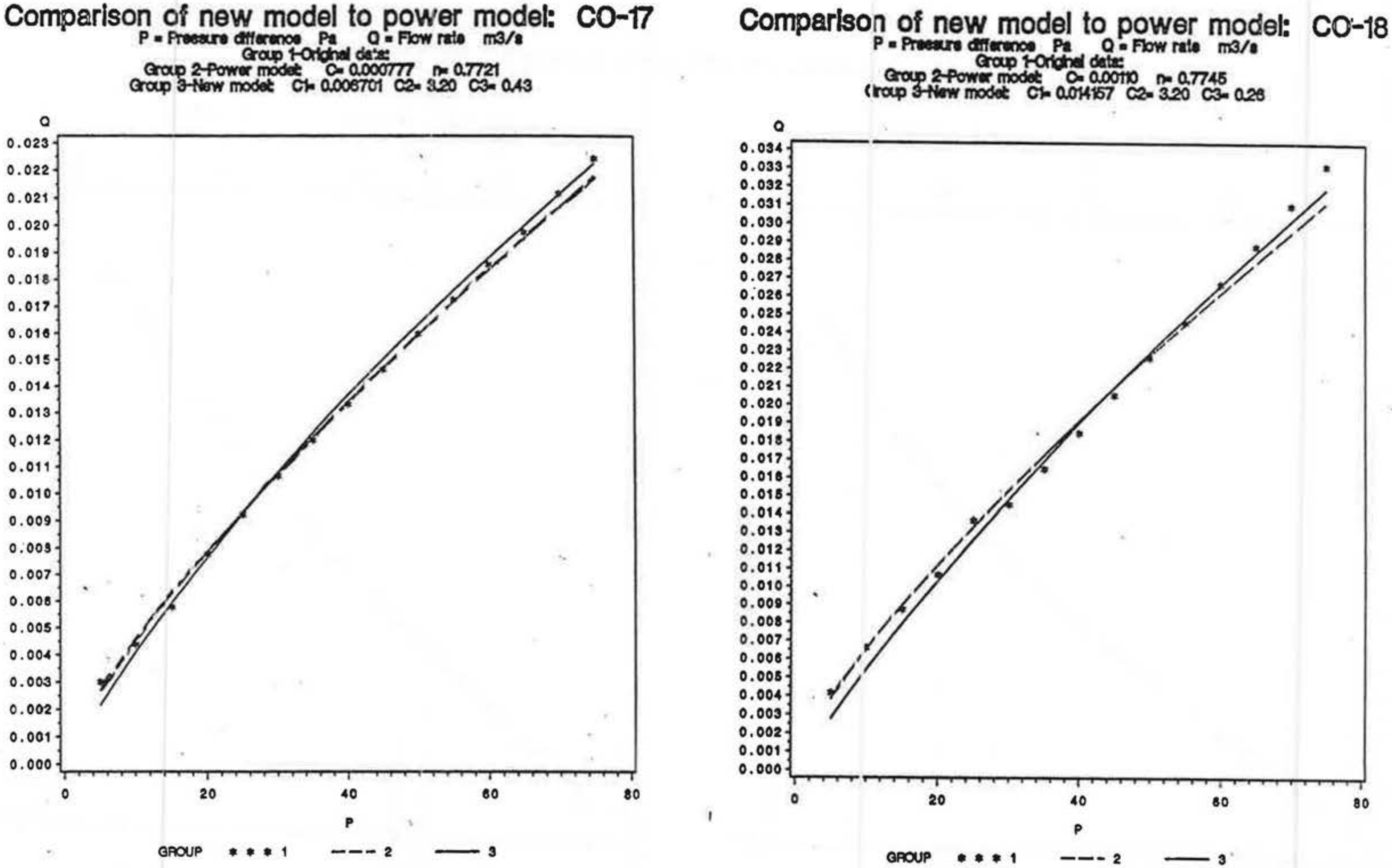


Figure 5-3-11. Model comparison on component 17 and 18

5.3.3 Parallel and series analysis based on well-defined cracks

A comparison was made between two definitions given in Table 4-3 for the resistance to airflow: a) the inverse of the ELA (based on Pa = 4) and b) the inverse of the power regression equation coefficient C. The data obtained from the well-defined cracks were used to test the new and previous definitions to see which one worked better. The values of the ELA and C are from Table 5-3-1. (It should be recognized that the coefficients of leakage curves with different n values have to be added to apply the parallel and series analogy. This incompatibility further reflects the problem of using nonhomogeneous equations however it is necessary in order to make these comparisons.)

In Table 5.3.3 the previous definition of crack resistance is used to compare the parallel flow theory based on the power equation model coefficient C. In Table 5.3.4 and Table 5.3.5 the new definition of resistance to airflow being the inverse of the ELA is used for checking parallel flow based on the ELA values calculated from the power and KY models respectively. The comparison between combining the two C coefficients versus the value of C obtained from the combined flow indicates a 12.5% overall average difference between them. This value is reduced to 8.7% and 8% when the ELA values from the power model or KY model respectively are used. The ELA and C values used for each crack in these equations are those obtained from tests where each crack was run separately. Tables 5.3.6, 5.3.7 and 5.3.8 are similar to the previous three tables while being applied to the series flow application. The average differences are 13.8, 12.2 and 10.7% for the series application. From these six tables it is obvious that defining the inverse of the ELA as a first approximation of the crack resistance is more effective and yields a satisfactory prediction of parallel and series flow through cracks. Secondly, these examples show that the ELA value from the KY model is slightly more accurate than that from power model.

This theory may also be used to analyze the leakage performance of various building components which may have parallel or series connections as well as whole building structures.

Table 5.3.3 Using R = 1/C as definition of crack resistance to check the parallel flow theory based on the power model coefficient C (C units: $m^3/h(Pa)^n$)

Cracks connected in parallel	C ⇔ C1 + C2 (× 10^{-4})	Relative error (%)
A@B1	3.21 ⇔ 0.57+3.66=4.23	31.8
A@E	29 ⇔ 0.57+26.4=26.97	-7.0
A@F1	67.9 ⇔ 0.57+64.1=64.67	-4.8
B1@B2	7.77 ⇔ 3.66+3.06=6.72	-13.5
B1@E	26.4 ⇔ 3.66+26.4=30.06	13.9
B1@F1	73.3 ⇔ 3.66+64.1=67.76	-7.6
F1@F2	139.2 ⇔ 64.1+62.4=126.5	-9.1
Absolute Average		12.5

Note: C = Coefficient from the power equation using the total flow through both cracks mounted in parallel.
C1 = Coefficient from power equation for crack 1 determined individually
C2 = Coefficient from power equation for crack 2 determined individually

$$\text{Relative Er.} = \frac{C-(C1+C2)}{C} * 100$$

Table 5.3.4 Using R = 1/ELA as definition of crack resistance to check the parallel flow based on ELA values at 4 Pa from the power model (ELA units: m^2)

Cracks connected in parallel	$ELA \Leftrightarrow ELA_1 + ELA_2$ ($\times 10^{-4}$)	Relative error (%)
A@B1	3.57 ⇔ 0.72+3.62=4.34	21.6
A@E	23.1 ⇔ 0.72+21.4=22.12	-4.2
A@F1	53.7 ⇔ 0.72+51.2=51.92	-3.3
B1@B2	7.54 ⇔ 3.62+3.09=6.71	-11
B1@E	23.1 ⇔ 3.62+21.4=25.02	8.3
B1@F1	58.1 ⇔ 3.62+51.2=54.82	-5.6
F1@F2	109 ⇔ 51.2+50.4=101.6	-6.8
Absolute Average		8.7

Note: ELA_1 is quoted from Table 5-3-1 for the power model with flow through crack 1.

ELA_2 is quoted from Table 5-3-1 for power model with flow through crack 2.

ELA was determined for flow through both the two cracks mounted in parallel.

Table 5.3.5 Using R = 1/ELA as definition of crack resistance to check the parallel theory based on the KY model ELA values at 4 Pa. (ELA units: m^2)

Cracks connected in parallel	ELA ⇔ ELA_1 + ELA_2 ($\times 10^{-4}$)	Relative error (%)
A@B1	3.09 ⇔ 0.67+3.12=3.79	22.7
A@E	22.5 ⇔ 0.67+21.3=21.97	-2.4
A@F1	53.7 ⇔ 0.67+51.2=51.87	-3.4
B1@B2	6.13 ⇔ 3.12+2.66=5.78	-5.7
B1@E	22.4 ⇔ 3.12+21.3=24.42	9.0
B1@F1	57.8 ⇔ 3.12+51.2=54.32	-6.0
F1@F2	109 ⇔ 51.0+50.5=101.5	-6.9
Absolute Average		8.0

Table 5.3.6 Using R = 1/C as definition of crack resistance to check the series theory based on power model coefficient C. (C units: $m^3/h(Pa)^n$)

Cracks connected in series	$\frac{1}{C_{Total}} - \Sigma(\frac{1}{C_i})$ $(\times 10^4)$	Re. error (%)
A ~ B1	$\frac{1}{0.312} - 3.21 \leftrightarrow (\frac{1}{0.33} + \frac{1}{3.66}) - 3.3$	2.8
B1 ~ A	$\frac{1}{0.358} - 2.79 \leftrightarrow (\frac{1}{3.18} + \frac{1}{0.57}) - 2.07$	-25.8
B1 ~ E	$\frac{1}{3.40} - 0.29 \leftrightarrow (\frac{1}{3.18} + \frac{1}{26.4}) - 0.352$	21.4
E ~ B1	$\frac{1}{3.08} - 0.32 \leftrightarrow (\frac{1}{24.4} + \frac{1}{3.66}) - 0.314$	-1.9
E ~ F1	$\frac{1}{21.5} - 0.0465 \leftrightarrow (\frac{1}{24.4} + \frac{1}{64.1}) - 0.0566$	21.7
F1 ~ B1	$\frac{1}{3.17} - 0.315 \leftrightarrow (\frac{1}{67.1} + \frac{1}{3.66}) - 0.288$	-8.5
F1 ~ E	$\frac{1}{21.8} - 0.0459 \leftrightarrow (\frac{1}{67.1} + \frac{1}{26.4}) - 0.0528$	15.0
Absolute Average		13.8

Table 5.3.7 Using R = 1/ELA as definition of crack resistance to check the series theory based on ELA from power model at 4 Pa. (ELA units: m^2)

Cracks connected in series	$\frac{1}{ELA_{Total}} \sim \Sigma(\frac{1}{ELA_i})$ $(\times 10^4)$	Re. error (%)
A ~ B1	$\frac{1}{0.441} - 2.27 \leftrightarrow (\frac{1}{0.474} + \frac{1}{3.62}) - 2.39$	5.3
B1 ~ A	$\frac{1}{0.519} - 1.93 \leftrightarrow (\frac{1}{3.19} + \frac{1}{0.717}) - 1.71$	-11.4
B1 ~ E	$\frac{1}{3.3} - 0.303 \leftrightarrow (\frac{1}{3.19} + \frac{1}{21.4}) - 0.36$	18.8
E ~ B1	$\frac{1}{3.11} - 0.322 \leftrightarrow (\frac{1}{20.1} + \frac{1}{3.62}) - 0.326$	1.2
E ~ F1	$\frac{1}{17.9} - 0.0559 \leftrightarrow (\frac{1}{20.1} + \frac{1}{51.2}) - 0.0693$	24.0
F1 ~ B1	$\frac{1}{3.22} - 0.311 \leftrightarrow (\frac{1}{51.2} + \frac{1}{3.62}) - 0.296$	-4.8
F1 ~ E	$\frac{1}{18.1} - 0.0552 \leftrightarrow (\frac{1}{51.2} + \frac{1}{21.4}) - 0.0663$	20.1
Absolute Average		12.23

Table 5.3.8 Using R = 1/ELA as definition of crack resistance to check the series theory based on ELA from KY model at 4 Pa. (ELA units: m^2)

Cracks connected in series	$\frac{1}{ELA_{Total}} - \Sigma(\frac{1}{ELA_i})$ $(\times 10^4)$	Re. error (%)
A ~ B1	$\frac{1}{0.472} - 2.12 \leftrightarrow (\frac{1}{0.522} + \frac{1}{3.12}) - 2.24$	5.7
B1 ~ A	$\frac{1}{0.582} - 1.72 \leftrightarrow (\frac{1}{2.84} + \frac{1}{0.667}) - 1.85$	7.6
B1 ~ E	$\frac{1}{2.91} - 0.34 \leftrightarrow (\frac{1}{2.84} + \frac{1}{21.3}) - 0.40$	17.6
E ~ B1	$\frac{1}{2.68} - 0.37 \leftrightarrow (\frac{1}{20.1} + \frac{1}{3.12}) - 0.37$	0
E ~ F1	$\frac{1}{17.9} - 0.056 \leftrightarrow (\frac{1}{20.1} + \frac{1}{51.2}) - 0.069$	23.2
F1 ~ B1	$\frac{1}{2.82} - 0.35 \leftrightarrow (\frac{1}{53} + \frac{1}{3.12}) - 0.34$	-2.9
F1 ~ E	$\frac{1}{18.0} - 0.056 \leftrightarrow (\frac{1}{53} + \frac{1}{21.3}) - 0.066$	17.9
Absolute Average		10.7

5.3.4 Building component analysis

Various openings of building components may work as cracks which are connected in parallel and/or series. The Q—ΔP relationships and ELAs have been measured and calculated for 18 building components. Among the 18 components there are two useful groups which have identifiable series/parallel flow paths. These are the test wall sections which contain electrical switches, duplex outlets and/or wire holes through the top plate with or without sealing of the holes and with or without switch/outlet gaskets. These examples will be used to analyze the flow path details, where the ELA values are produced from the new model.

The ELA values determined for combinations of these test cases are presented in Table 5.3.9. Note that the ELA values are for the total of the six boxes (switches or outlets) in a single test wall.

The following symbols are used to represent the combinations:

S --- Electrical switch, coverplate and box in the wall, no wiring hole penetrations through the studs or the top plate
O --- Electrical duplex outlet, cover plate and box in the wall, no wiring hole penetrations through the studs or the top plate
G --- Gasket (foam) on the switch or outlet
T/O -- Wire hole opening (1") in the top plate of the wall section with 12/3 romex wire run through each hole
Seal - Top plate wire hole sealed with caulking

Table 5.3.9 Crack leakage resistance of the switch group

Component	Connection	ELA (cm^2)	R (=1/ELA)
CO-10	S+T/O	2.08	0.48
CO-11	S+T/O+Seal	1.37	0.73
CO-12	S+T/O+G+Seal	0.762	1.31
CO-13	S+T/O+G	0.939	1.06

If it is considered that applying a gasket or sealing the wire hole works as connecting a resistance in series (Figure 5-3-12), a value of R=0.58 (cm^{-2}) is obtained for applying the gaskets between CO-10 and CO-13 or between CO-11 and CO-12. A value of R=0.25 (cm^{-2}) is found for sealing the top hole between CO-10 and CO-11 or CO-12 and CO-13. These values demonstrate the application of the series resistance theory.

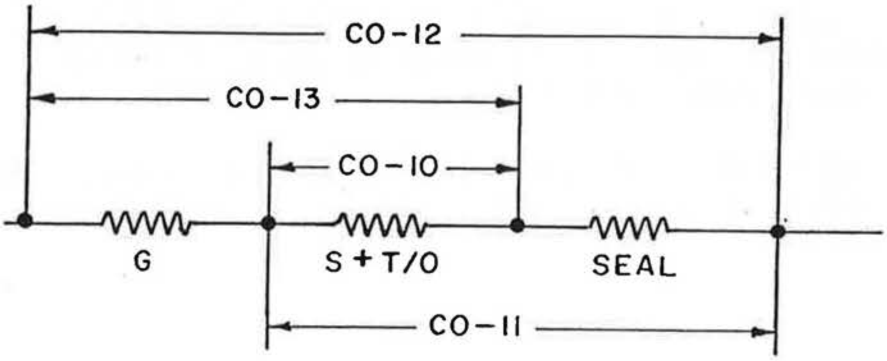


Figure 5-3-12. Switch group resistance analysis

Table 5.3.10 contains the results of applying gaskets or sealing the top holes for the walls containing outlets. If we assume these work as connecting a resistance in series, we obtain R=0.04 (cm^{-2}), 0.15 (cm^{-2}) and 0.10 (cm^{-2}) between CO-3 and CO-4, between CO-5 and CO-7 and between CO-6 and CO-8 respectively. The average total resistance value for the six gaskets is 0.10 (cm^{-2}). (Note that there is not a dramatic difference in the order in which it is applied. This implies that there are significant other leaks.) The resistance values for the seal equal to 0.19 (cm^{-2}) and 0.14 (cm^{-2}) between CO-5 and CO-6 and CO-7 and CO-8 respectively. Therefore the average total resistance value for sealing the six top holes is 0.17 (cm^{-2}).

Table 5.3.10 Crack leakage resistance of the outlet group

Component	Connection	ELA (cm^2)	R (=1/ELA)
CO-3	O	2.64	0.38
CO-4	O+G	2.39	0.42
CO-5	O+T/O	2.80	0.36
CO-6	O+T/O+Seal	1.83	0.55
CO-7	O+T/O+G	1.98	0.51
CO-8	O+T/O+G+Seal	1.53	0.65

There is a problem in attempting to determine the resistance of the T/O (Top plate wire hole) by subtracting the resistance of CO-3 from the resistance of CO-5. If we assume that O (outlet on the wall) and T/O (top hole) are connected in series, the resistance of CO-5 should be higher than the resistance of CO-3, while the result shows the resistance of CO-5 is lower than that of CO-3. This indicates that the function of having a wire hole in the top plate with an outlet may work in neither simple parallel nor simple series, it work as a combination of parallel and series.

Overall the definition presented of crack resistance and parallel/series flow theory describes the component leakage well.

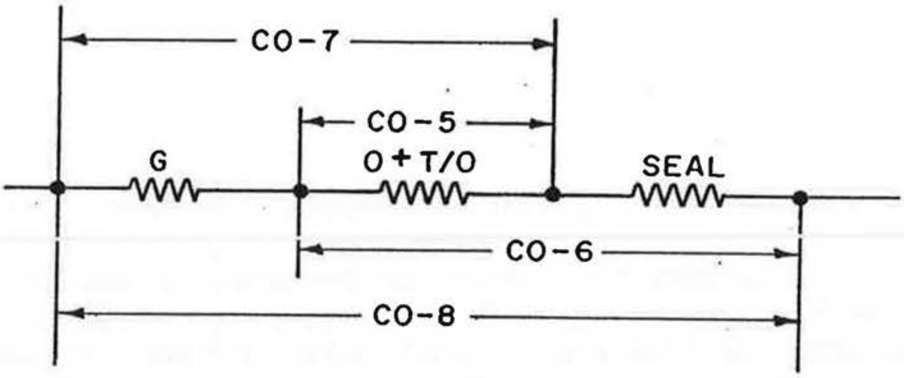


Figure 5-3-13. Outlet group resistance analysis

5.4 ELA and C_d Curves Analysis

In previous air leakage studies, researchers set ELA and C_d as constants evaluated at 4, 10, 50 or 75 Pa. The results from the FPD tests use these standard values for simplicity since the flow is not simple orifice flow. Actually they are functions of the pressure difference, ΔP. In this analysis, the ELA and C_d are calculated based on their original definitions. The ELA curves in Figures 5-4-1 and 5-4-2 are based on the derived equation 4-10 for the 18 building components. They illustrate what has been previously known. That is that ELA has a significant variation as ΔP changes, which means that the choice of reference pressure drops (4 Pa or 10 Pa) affects the ELA results. The C_d curves in Figure 5-4-3 are based on equation 4-11 with five different C_2 values, which illustrate the significant errors by setting $C_d=1.0$ (ASTM 1984, 1987) or $C_d=0.611$ (CGSB 1986) for the calculation of any crack leakage. Figure 5-4-4 presents the C_d charts for the KY model at 4 Pa and 10 Pa. These three dimensional contours illustrate how C_d values vary instead of previously assumed constant settings of $C_d=0.611$ or $C_d=1.0$. This chart is created for calculation purposes especially for the situation of computing the EQLA values. In this chart of typical values (input $K=1.5$ as a known value), we find that the C_d values change dramatically for low pressure difference rather than being a constant. Hence the C_d value at low pressures is more sensitive.

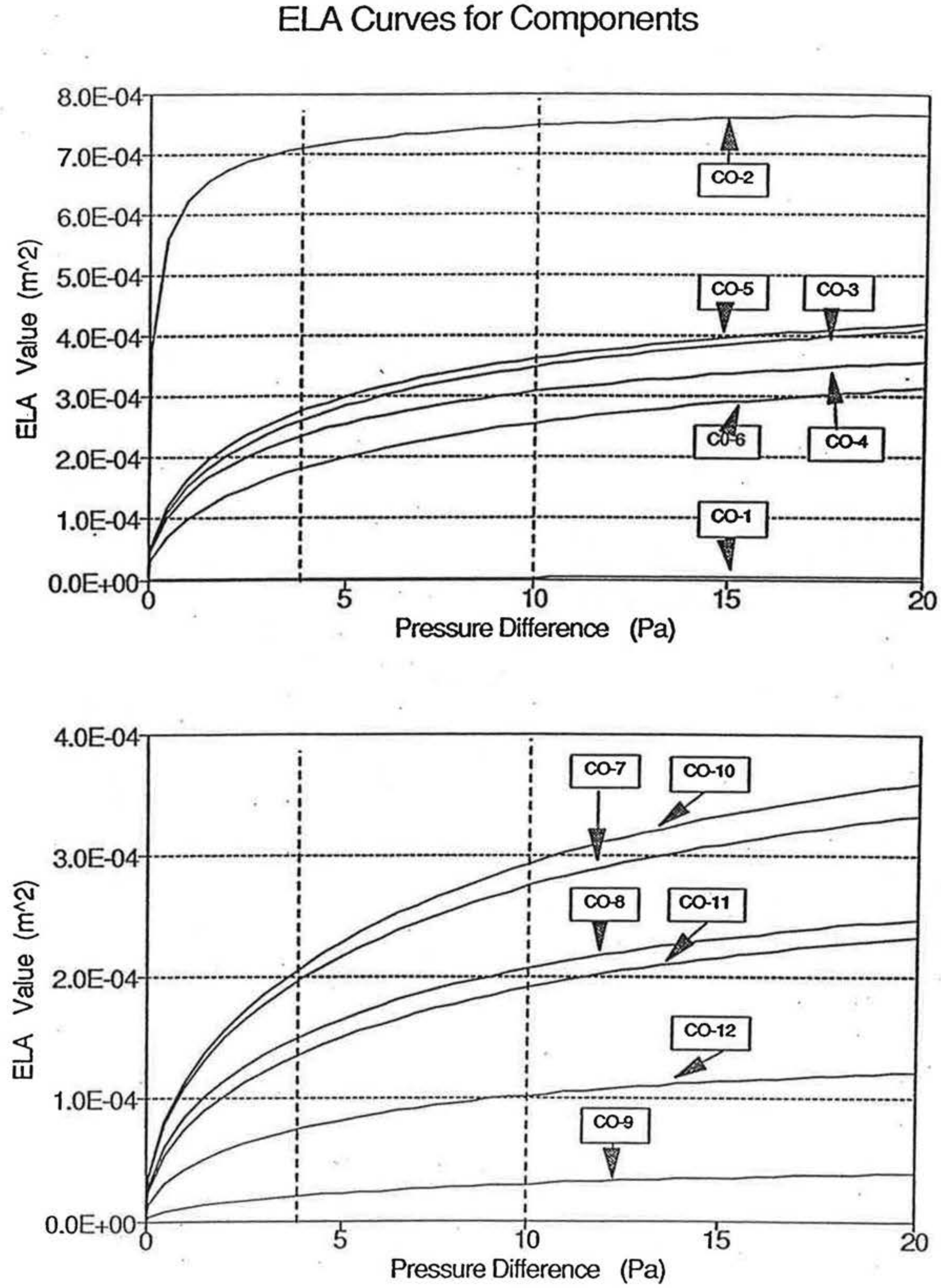


Figure 5-4-1. ELA curves for building components 1 to 12

difference between the minimum and maximum values recorded for several components was much larger. This it to be expected since there were more sources of data with a greater variability between the different sources. It was often found that the variability between the "same" component between two sources using the same reporting format was greater than the variation between component types from the same source.

It should be noted that although the number of different building components listed in the table is greater than previously identified, there are still gaps in the data for some groupings of components which need estimates (or better estimates) of leakage values. There are currently several significant projects underway to obtain the leakage of ductwork. Since these data were not available, they were not included in this report. Other components which need data (or better additional data) include: building construction joints (joints of dissimilar materials like masonry and wood or insulating board and wood; sole plate/baseboard; band joists; building corner joints; butt joints of sheathing, etc), window and door framing in masonry and wood wall construction, and the combined effects of air infiltration barriers and vapor retarders.

Evaluate and Give Alternatives to the ELA Concept:

A comparison of the predicted effective leakage areas using the commonly used reference pressures and discharge coefficients was done for the building components tested in the laboratory. As is commonly known, the ELA varies with the reference pressures selected. These differences were significant (30%) in the ELA predicted using 4 Pa and 10 Pa as the reference pressures for the components tested. Curves were also produced to illustrate the significant variations introduced by selecting different discharge coefficients. In addition to these variations, the known correlation which exists between n and C propagate variations which are not readily apparent. These type of variations cause confusion when comparisons are attempted between reported values when different authors use different reference values and discharge coefficients, especially when these values and the C and n are not stated.

A theoretically-based air leakage model to define the flow rate versus the pressure differential across building components was derived from the dimensionless crack equation. It was validated and compared to commonly accepted ELA calculation techniques using a number of well-defined cracks which were experimentally tested. It was found that the three-parameter model developed describes the flow versus pressure relationship accurately however it is not as easy to use. It requires a nonlinear regression solution technique and has a numerical restriction from the power model. A benefit of the model developed is that the coefficients obtained represent physical parameters describing the characteristics of the opening tested.

Experiments were also run to test the model developed for situations where the air may be flowing in a series path through several openings or in parallel across different openings. The new model was able to fit the flow versus pressure data as well as the commonly used techniques. It was also demonstrated that the physical parameters obtained independently with the new model on each opening could be combined to predict the total resistance when the openings were combined in series.

Evaluate Different Methods and Recommend a Method of Reporting Leakage:

There were no direct comparisons found in the literature between the various DC pressurization standards so there are no recommendations as to the validity of one over the other or standard calibrations for converting the data between them.

Several different methods of reporting leakage were observed. It was observed that the leakage data obtained in the available literature were given in three main ways: constants for the fit of the data to the power equation, the flow at a given differential pressure across the component, or the equivalent/effective leakage area. These methods were evaluated in order to make the transformations to compare components tested by different sources. It was not possible to get ELA values from some of the techniques such as those which gave leakage as a percentage of the total leakage of the structure. The most common technique of giving a C and n value for the component was adequate provided the value used for the discharge coefficient and the unit of area or length was known. There was some confusion in the literature between effective and equivalent leakage areas. It is critical that leakage reports give sufficient information to avoid this confusion.

It was recognized that there are advantages to using the power and/or orifice equations such as ease of use and generally having a good fit. Disadvantages to these techniques were also identified (e.g. dimensionally nonhomogeneous, constants have no physical basis, not theoretically based and incompatibility for use in series/parallel flow analysis).

It was found that there were several key parameters to successfully reporting sufficient information about leakage in order to make comparisons. In the ideal case the following need to be included: the actual flow/pressure difference values for the test points; the area over which the pressure is being maintained and flow is being measured (or the length of the crack which is exposed to the pressure difference); and other conditions which influence the flow such as type of weatherstripping, etc. If the actual data points cannot be reported, the coefficients (C_1, C_2, C_3 or C&n) and the range of pressures used for testing should be reported in addition to the others indicated.

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APPENDIX A

Listing of Literature Leakage Values

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	ref #	class	ref id #	# case	D A T	C & n	C value Mixed	n value	flow (avg) S-I	flow variation min S-I	flow variation -s.d. S-I	flow variation + s.d. S-I	flow variation max S-I	flow units	area S-I	area variation min S-I	area variation - s.d. S-I	area variation + s.d. S-I	area variation max S-I	area units	C d	ref. press	% total	Note #'s	other	
1	646	CG	1	1	3b																	30	12		ceiling	1
2	1514	CG	IW11		3										0.02					cm2/m2	0.6	50		113		2
3	1514	CG	CR2		3										0.046					cm2/m2	0.6	50		113	dropped ceiling w/ plastic sheet (EW-6)	3
4	1514	CG	CR5		3										0.465					cm2/m2	0.6	50		113	dropped ceiling w/o plastic sheet	4
5	40	CG	h5	1	1				1.37					l/sm2							1	75	8	314	area term refers to ceiling area 0.03in2/ft2	5
6	40	CG	h6	1	1				1.88					l/sm2							1	75	11	314	area term refers to ceiling area 0.04 in2/ft2	6
7	40	CG	h3	1	1				1.88					l/sm2							1	75	16	314	area term refers to ceiling area 0.04 in2/ft2	7
8	40	CG	h2	1	1				3.81					l/sm2							1	75	67	314	area term refers to ceiling area 0.085 in2/ft2	8
9	40	CG	h4	1	1				4.57					l/sm2							1	75	34	314	area term refers to ceiling area 0.1in2/ft2	9
10	40	CG	h1	1	1				4.83					l/sm2							1	75	65	314	area term refers to ceiling area 0.1 in2/ft2	10
11	466	CG							0.25					l/sm2									50		assumes % to get flow (.75 ach house)	11
12	466	CG							0.13					l/sm2									25		assumes % to get flow (.75 ach house)	12
13	91	CG	2	1	1				0.18					m3/s							1	75	16		(need area terms)	13
14	91	CG	1	1	1				0.35					m3/s							1	75	65		(need area terms)	14
15	D3	CH	diff	1	5										28					cm2	1	4		5,303	depressurization (flue), efla difference	15
16	D3	CH	diff	1	5										33					cm2	1	4		5,303	pressurization(flue), efla difference	16
17	1008	CH	diff	1	4	1	2.05	0.71						l/s										5,201	difference, entire house	17
18	1008	CH	measur	1	4	6	4.31	0.56						l/s								0-50		2,201	measured directly	18
19	1008	CH	open	1	4	1	24.4	0.71						l/s									9	4,201	chimney uncapped, entire house	19
20	1008	CH	capped	1	4	1	22.3	0.71						l/s										4,201	chimney capped, entire house	20
21	1514	CP	C/R16		3										2					cm2 ea	0.6	50		113	ceiling mounted lights	21
22	1514	CP	C/R3		3										4					cm2 ea	0.6	50		113	(whole house fans w/ w/s cover)	22
23	1514	CP	C/R11		3										5					cm2 ea	0.6	50		113	(recessed light-caulked at edges)	23
24	1261	CP													10	10			20	cm2 ea	1	4			recessed light fixtures	24
25	1514	CP	C/R12		3										25					cm2 ea	0.6	50		113	recessed light	25
26	1514	CP	C/R4		3										50					cm2 ea	0.6	50		113	(whole house fans) w/ closed louver	26
27	92	CP	h43	1	2				11.8					l/s ea							1	62			super energy construction, recessed ceiling spots	27
28	92	CP		50	2				15.6	2.36			26.4	l/s ea							1	62	5.2%		recessed ceiling spots	28
29	92	CP	h43	1	2				24.5					l/s ea							1	62			super energy construction, recessed ceiling spots	29
30	339	CP	mobile	1					41.5	37.8			41.5	l/s-house							1	50	8		joint between ceiling and flue vent, sealing sequence 3	30
31	D4	CS		1	6										129					cm2	1	4			crawl space vent-8x16 each	31
32	D4	CS		9	6										1690	1277			2735	cm2	1	4			ELA, vents closed, entire crawl space	32
33	D4	CS		9	6										10.3	7.8			16.6	cm2/m2	1	4			SELA vents closed	33
34	1261	DACNW													30	10			30	cm2 ea	1	4				34
35	1514	DACNW	C/R14		3										90					cm2 ea	0.6	50		113	(attic into conditioned space)	35
36	1261	DACW													18	8			18	cm2 ea	1	4			weatherstripped	36
37	1514	DACW	C/R13		3										45					cm2 ea	0.6	50		113	(attic into conditioned space)	37
38	1514	DAFD	D10		3										10					cm2 ea	0.6	50		113	w/ insulated box	38
39	1514	DAFDNW	D8		3										108	55			210	cm2 ea	0.6	50		113	w/o w/s, 3x6' door (1-4mm crack)	39
40	1514	DAFDW	D9		3										54	35			105	cm2 ea	0.6	50		113	w/ w/s (50% of D-8)	40
41	1514	DAG	C/R15		3															cm2 ea	0.6	50		113	(into unconditioned space)	41
42	1261	DDNW													11	7			22	cm2/m2	1	4				42
43	1261	DDW													8	3			15	cm2/m2	1	4				43
44	1514	DDW	D7		3										27.3	18.2			56.1	cm2/m2	0.6	50		113	3x6 door (.7-2mm crack) (RP438 changed units to per m2)	44
45	92	DFRAME		50	2				1.69					l/s ea							1	62			via threshold, 9% of door leakage	45
46	92	DFRAME		50	2				6.61					l/s ea							1	62			via weatherstripping on the 3 edges, 37% of door leakage	46
47	92	DFRAME		50	2				9.91					l/s ea							1	62			door frame & facing, 54% of total	47
48	92	DFRAME		50	2				18.4	3.78			37.8	l/s ea							1	62	5%		37% via w/s, 9% threshold, 54% wallframe joint	48
49	208	DFRAME	lab	1	4	8	2.55	0.68	1.73					l/sm							1	75			frame trim, outer & inner 3 sides, 33.25 ft	49
50	208	DFRAME	lab	1	4	8	2.14	0.62	1.57					l/sm							1	75			frame trim, outer 3 sides, 16.75 ft	50
51	208	DFRAME	lab	1	4	8	15.6	0.63	11.8					l/sm							1	75			jamb except for threshold, held closed, 16 ft	51
52	208	DFRAME	lab	1	4	8	19.8	0.59	15.2					l/sm							1	75			jamb except threshold, free, 16 ft (cfm-in wg)	52
53	208	DFRAME	lab	1	4	8	42.7	0.57	33.6					l/sm							1	75			under threshold	53
54	1261	DFRAMEM													1	0.3			1	cm2/m2	1	4			w/ caulking	54
55	1261	DFRAMEM													5	1.7			5	cm2/m2	1	4			w/o caulking	55
56	1261	DFRAMEW													0.3	0.1			0.3	cm2/m2	1	4			w/ caulking	56
57	1261	DFRAMEW													1.7	0.6			1.7	cm2/m2	1	4			w/o caulking	57
58	1261	DG		19																	1	4	11		(a3313) w fireplace	58

	ref #	class	ref id #	# case	D A T	C & n	C value Mixed	n value	flow (avg) S-I	flow variation min S-I	flow variation -s.d. S-I	flow variation + s.d. S-I	flow variation max S-I	flow units	area S-I	area variation min S-I	area variation - s.d. S-I	area variation + s.d. S-I	area variation max S-I	area units	C d	ref. press	% total	Note #'s	other	
59	1261	DG		11																	1	4	10		(a3313) w/o fireplace	59
60	1514	DG	D13		3										0.488					cm2/lmc	0.6	50		113	average (new)	60
61	1514	DG	D13		3										0.549					cm2/lmc	0.6	50		113	well fitted	61
62	1514	DG	D13		3										0.762	C.55			1.07	cm2/lmc	0.6	50		113	average	62
63	1514	DG	D13		3										1.097					cm2/lmc	0.6	50		113	poorly fitted	63
64	299	DGE	No5	1		6	0.05	0.46						m3/s											elevator door, 6.8 mm crack, door opening 1.07x2.13m	64
65	299	DGE	No6	1		6	0.03	0.53						m3/s											elevator door, 4.8 mm crack, door opening 1.07x2.13m	65
66	299	DGE	No4	1		6	0.01	0.72						m3/s											elevator door, 5.3 mm crack, door opening 1.07x2.13m	66
67	299	DGE	No2	1		6	0.01	0.83						m3/s											elevator door, 5.8 mm crack, door opening 1.22x2.13m	67
68	299	DGE	No1	1		6	0.04	0.52						m3/s											elevator door, 5.8 mm crack, door opening 1.07x2.13m	68
69	299	DGE	No3	1		6	0.04	0.49						m3/s											elevator door, 5.8 mm crack, door opening 1.00x2.13m	69
70	1514	DIP	lw7		3										35					cm2 ea	0.6	50		113	(located on upper floor)	70
71	1514	DIP	lw7		3										1.829					cm2/lmc	0.6	50		113	(located on upper floor)	71
72	1514	DIS	d-14		3										1.829	C.61			1.83	cm2/lmc	0.6	50		113	(2mm crack)	72
73	1514	DIS	d-14		3										2.743	1.83			3.66	cm2/lmc	0.6	50		113	(4mm crack)	73
74	208	DMS	lab	1	4	8	2.23	0.3	2.52					l/sm							1	75			2.3 ft slot, (cfm-in wg)	74
75	1514	DSP	D6		3										100	60			260	cm2 ea	0.6	50		113		75
76	1357	DSP		10	3				43	24			80	l/s							1	50			alum. ranch - slider doors	76
77	92	DSP		50	2				20.3	4.72			35.4	l/s ea							1	62	1.7			77
78	HOF	DSP							2.54					l/sm2							1	300			SGD-B2, SGD-A2, SGD-A3	78
79	HOF	DSP							2.54					l/sm2							1	75			Fed MHC&SS 280.403 ALL TYPES WINDO & S. GLASS DO	79
80	HOF	DSP							2.54					l/sm2							1	75			ANSI A200.2 SGD wood	80
81	HOF	DSP							5.08					l/sm2							1	75			fed MHC&SS 280.405 ALL TYPES VERTICAL ENTRANCES	81
82	HOF	DSP							5.08					l/sm2							1	75			ANSIa134.2(al, sliding glass door-SGD-B1)	82
83	311	DSP	Tpe 1-7	1	4	6	0.1	0.68						l/sm2											3 panels, 2 of them slide	83
84	311	DSP	Tpe 2-2	1	4	6	0.13	0.7						l/sm2											2 panels, one slides	84
85	311	DSP	Tpe 2-3	1	4	6	0.11	0.72						l/sm2											2 panels, one slides	85
86	311	DSP	Tpe 1-1	1	4	6	0.28	0.56						l/sm2											3 panels, 2 of them slide (numbers are from top to bot on Fi	86
87	311	DSP	Tpe 1-5	1	4	6	0.11	0.67						l/sm2											3 panels, 2 of them slide	87
88	311	DSP	Tpe 2-6	1	4	6	0.16	0.59						l/sm2											2 panels, one slides	88
89	311	DSP	Tpe 1-4	1	4	6	0.1	0.73						l/sm2											3 panels, 2 of them slide	89
90	311	DSP	Tpe 1-6	1	4	6	0.09	0.69						l/sm2											3 panels, 2 of them slide	90
91	1514	DSTM/W			3																0.6	50		113	storm door = 35% reduction	91
92	1514	DSTM/W	D2		3										20					cm2 ea	0.6	50		113	subtract 20 cm2	92
93	1065	DSTM/W		7											62					cm2 tot	1	4			average difference after appling storm windows & doors	93
94	1065	DSTM/W		7											0.005					cm2/m2	1	4			per sq ft of floor area	94
95	40	DSTM/W	h5	2	1				0.83					l/smc							1	75			w/ storm door	95
96	40	DSTM/W	h6	2	1				0.83					l/smc							1	75			w/storm door	96
97	40	DSTM/W	h6	2	1				1.23					l/smc							1	75			w/o storm door	97
98	40	DSTM/W	h5	2	1				1.45					l/smc							1	75			w/o storm door	98
99	1514	DSW	D3		3										25	15			40	cm2 ea	0.6	50		113	weatherstripped, magnetic seals	99
100	1514	DSW	D5		3										36	25			65	cm2 ea	0.6	50		113	weatherstripped	100
101	1261	DSW													8	3			15	cm2/m2	1	4				101
102	40	DSW	hs#5	2	1				0.83					l/smc							1	75			with-42% reduction - w/s fair to poor	102
103	40	DSW	hs#6	2	1				0.83					l/smc							1	75			with-32% reduction - w/s fair to poor	103
104	40	DSW	hs#6	2	1				1.23					l/smc							1	75			without storm - w/s fair to poor	104
105	40	DSW	hs#5	2	1				1.45					l/smc							1	75			without storm-weatherstripping fair to poor	105
106	40	DSW	hs#2	2	1				2.15					l/smc							1	75			(with storm - w/s fair to poor)	106
107	40	DSW	hs#3	2	1				3.22					l/smc							1	75			(without storm-weatherstripping fair to poor)	107
108	40	DSW	hs#1	2	1				4.79					l/smc							1	75			(without storm-weatherstripping fair to poor)	108
109	40	DSW	hs#4	2	1				6.18					l/smc							1	75			(without storm - w/s fair to poor)	109
110	1514	DSWN	D4		3										50	30			130	cm2 ea	0.6	50		113	up to 2mm avg crack	110
111	1261	DSWN													11	6			17	cm2/m2	1	4				111
112	1514	DV	D1		3										25					cm2/hs	0.6	50		113	subtract 25 cm2 per vestibule	112
113	1261	EO		19																	1	4	2		(A3313) w/ fireplace	113
114	646	EO		1	3b																	16	3.1		exterior walls	114
115	646	EO		1	3b																	32	1.3		party wall	115
116	1261	EO		11																	1	4	4		(A3313) w/o fplace	116
117	1514	EO	IW-2		3										0.2					cm2 ea	0.6	50		113	w gaskets	117

	ref #	class	ref id #	# case	D A T	C & n	C value Mixed	n value	flow (avg) S-I	flow variation min S-I	flow variation -s.d. S-I	flow variation + s.d. S-I	flow variation max S-I	flow units	area S-I	area variation min S-I	area variation - s.d. S-I	area variation + s.d. S-I	area variation max S-I	area units	Cd	ref. press	% total	Note #'s	other	
118	1514	EO	EW-2		3										0.2					cm2 ea	0.6	50		113	w/ gaskets	118
119	1261	EO													0.5				1	cm2 ea	1	4			not gasketed	119
120	1514	EO	IW-1		3										1.5					cm2 ea	0.6	50		113	w/o gaskets	120
121	1157	EO		12hs											6			10		cm2 total	1	4	1 +/-	313	1982 USA frame res red, with gaskets, % is w or w/o fp dam	121
122	92	EO		50	2				0.24					l/s ea							1	62			w/ gaskets(7% of original)	122
123	92	EO		50	2				3.78				7.08	l/s ea							1	62	20		w/o gaskets	123
124	208	EO		1	1				5.29					l/s ea							1	75			duplex outlet in insulated test wall	124
125	208	EO		1	1				6.13					l/s ea							1	75			duplex outlet-uninsulated test wall	125
126	339	EO		1					8.97	8.02			8.97	l/s-house							1	50	<2		total for all exterior outlets and switches	126
127	1514	ES	IW-3		3										1.5					cm2 ea	0.6	50		113	no gaskets	127
128	1514	ES	EW-1		3										15				15	cm2 ea	0.6	50		113	no gaskets	128
129	1514	F	H4		3															cm2 ea	0.6	50		113	sealed combustion furnance	129
130	1261	F																		cm2 ea	1	4		302	sealed combustion furnace	130
131	1514	F	H8		3										30					cm2 ea	0.6	50		113	no ducts-resistance or water (hydronic) system	131
132	1261	F													24	18			30	cm2 ea	1	4		302	retention head & stack damper	132
133	1514	F	H6		3										60					cm2 ea	0.6	50		113	retention head plus stack damper	133
134	1261	F													30	20			40	cm2 ea	1	4		302	furnace w/ stack damper	134
135	1261	F													30	20			40	cm2 ea	1	4		302	retention head burner furnace	135
136	1514	F	H5		3										75					cm2 ea	0.6	50		113	retention head burner furnance	136
137	1514	F	H7		3										75					cm2 ea	0.6	50		113	stack damper on furnance	137
138	D4	FLCS		9	6										355	65			806	cm2	1	4			ELA	138
139	D4	FLCS	wodw	5	6										1.98					cm2/m2	1	4			houses w/o ductwork in crawl space	139
140	D4	FLCS		9	6										2.2	0.4			4.9	cm2/m2	1	4			SELA	140
141	D4	FLCS	wdw	4	6										2.25					cm2/m2	1	4			houses w/ ductwork in crawl space	141
142	1870	FWDC	hc	1											26					cm2	1	4		317	fireplace covered w/ plastic	142
143	1514	FWDC	F-7		3										30					cm2 ea	0.6	50		113	tight damper	143
144	1514	FWDC	F-3		3										60	50			85	cm2 ea	0.6	50		113	average damper	144
145	1261	FWDC													69	54			84	cm2 ea	1	4				145
146	1157	FWDC		5											69		54	84		cm2 ea	1	4	9		% +/-2, w/ dampers closed ,1982 frame res	146
147	1357	FWDC		1	3								120	l/s							1	50			brick chimney & open fireplace	147
148	40	FWDC	H#6	1	1				33					l/s ea							1	75			1950 Ottawa	148
149	40	FWDC	H#3	1	1				37.6					l/s ea							1	75			1950 Ottawa	149
150	92	FWDC		1	2				38.7					l/s ea							1	62			spring loaded damper on top of chimney	150
151	40	FWDC	H#4	1	1				51.9					l/s ea							1	75			1950 Ottawa	151
152	92	FWDC	h43	2	2				56.6					l/s ea							1	62			super energy construction	152
153	92	FWDC		21	2				62.8					l/s ea							1	62			located on interior wall	153
154	92	FWDC		40	2				65.6	15.1			142	l/s ea							1	62	5.5%		overall number (damper closed)	154
155	92	FWDC		18	2				69.4					l/s ea							1	62			located on exterior wall	155
156	92	FWDC		1	2				77.4					l/s ea							1	62			typ cast iron damper-observation	156
157	1514	FWDC	F-1		3									l/s ea						cm2 ea	0.6	75		113	fireplace w/ sealed combustion	157
158	1514	FWDO	F-2		3										350					cm2 ea	0.6	50		113	fireplace w/o damper or cover	158
159	1261	FWDO													350	320			380	cm2 ea	1	4			each	159
160	1157	FWDO		13											350		320	380		cm2 ea	1	4	24		% +/-4, w/o dampers, 1982 USA Frame residence	160
161	3019	FWG													100					cm2	1	4				161
162	1514	FWG	F-5		3										10					cm2 ea	0.6	50		113	fireplace,glass door,stove	162
163	92	FWG		1	2				26					l/s ea							1	62				163
164	92	FWG		1	2				33					l/s ea							1	62				164
165	1514	FWIDC	F-6		3										35	25			45	cm2 ea	0.6	50		113		165
166	1261	FWIDC													36	26			46	cm2 ea	1	4				166
167	1157	FWIDC		3											36		26	46		cm2 ea	1	4	8		% +/- 1	167
168	1157	FWIDC		7											65		40	90		cm2 ea	1	4	13		% +/-3, question if not glass doors	168
169	1514	FWIDO	F-6		3										65	50			80	cm2 ea	0.6	50		113		169
170	1261	FWIDO													65	40			90	cm2 ea	1	4				170
171	1261	GWH													20	15			25	cm2 ea	1	4				171
172	1514	GWH	H9		3										50					cm2 ea	0.6	50		113	domestic hot water heater exhaust stack	172
173	339	J							36.3	35.9			36.3	l/s-house							1	50	6		paneling side joints	173
174	1514	JCW	IW-10		3										0.381					cm2/m	0.6	50		113	Wall/ceiling crack	174
175	1261	JCW													1.5	0.5			2.5	cm2/m	1	4			ceiling/wall joint w/o taped, plastered or wrapped V.B.	175
176	339	JCW							65.1	42.5			65.1	l/s-house							1	50	14		wall/ceiling mobile	176

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	ref #	class	ref id #	# case	DAT	C & n	C value Mixed	n value	flow (avg) S-I	flow variation min S-I	flow variation -s.d. S-I	flow variation + s.d. S-I	flow variation max S-I	flow units	area S-I	area variation min S-I	area variation - s.d. S-I	area variation + s.d. S-I	area variation max S-I	area units	C d	ref. press	% total	Note #'s	other	
177	646	JSP		1	3b																	16	23		floor/wall interface	177
178	1261	JSP	&JTP																		1	4	42		(A3313) w/ fireplace	178
179	1261	JSP	& JTP																		1	4	31		(A313)sill plate & w/ceil j w/fireplace	179
180	942	JSP																					60		(A3313)	180
181	92	JSP																					60%		reduction due to caulking	181
182	1514	JSP	EW-7		3										0.183					cm2/m	0.6	50		113	caulked sill & final caulk	182
183	1514	JSP	IW-10		3										0.381					cm2/m	0.6	50		113	wall/floor or wall/ceiling	183
184	1514	JSP	EW-8		3										0.914					cm2/m	0.6	50		113	uncaulked sill	184
185	1514	JSP	EW-5		3										0.914					cm2/m	0.6	50		113	caulked or fiber mat behind molding	185
186	1261	JSP													0.8	0.4			1.2	cm2/m	1	4			sill caulked per m of perimeter	186
187	1261	JSP													4	1			4	cm2/m	1	4			sill, not caulked	187
188	208	JSP	lab	1					0.75					l/sm							1	75			sill plate-top of trim; plate and solid concrete block foundati	188
189	208	JSP	lab	1					1.49					l/sm							1	75			sill plate-bottom of trim; plate and solid concrete block foun	189
190	311	JSP	indirct-	1	4	6	0.07	0.61						l/sm									50%		floor-wall joint (indirect measurement w pressure balancing)	190
191	311	JSP	direct	1	4	6	0.14	0.64						l/sm											floor-wall joint (direct measurement w pressure balancing)	191
192	92	JSP		50	2				5.66				8.65	l/smc							1	62	24.6		not caulked	192
193	1514	JTPO	EW-13		3										0.183					cm2/m	0.6	50		113	Band Joist-ins w/ internal partitions return air (caulked)	193
194	1514	JTPO	EW-12		3										0.914					cm2/m	0.6	50		113	Band joist - unins w/ internal partitions as return air	194
195	1261	PPWP		19																	1	4	13		(A3313) wfp	195
196	1261	PPWP		11																	1	4	12		(A3313) w/o fp	196
197	1261	PPWP													1				2	cm2 ea	1	4			caulked	197
198	1261	PPWP													1.6				1.6	cm2 ea	1	4			sealed or with continuous v.b., duct pentrations	198
199	1261	PPWP													6	2			10	cm2 ea	1	4			not sealed	199
200	1261	PPWP													24	14			24	cm2 ea	1	4			each, unsealed or w/o v.b., duct pentrations	200
201	1514	PPWP			3										60					cm2/du	0.6	50		113	duct in wall	201
202	1514	PPWP			3										15					cm2/pip	0.6	50		113	(IW-4,IW-5) vs no piping/wiring, see notes	202
203	1514	PPWP	EW-3		3										15					cm2/pip	0.6	50		113	piping & wiring in walls	203
204	339	PPWP		2					9.2					l/s ea							1	50	4%		mobile home (plumbing holes in floor)	204
205	1357	PPWP		3	3				38	11			71	l/s ea							1	50			plumbing to bath w/ bath enclosed	205
206	1514	VBWDC	V2		3										6	6			12	cm2 ea	0.6	50		113		206
207	1157	VBWDC		6											11		10	12		cm2 ea	1	4	2		% +/-0.1	207
208	1261	VBWDC													11	10			12	cm2 ea	1	4				208
209	92	VBWDC		50	2				15.6	9.44			30.7	l/s ea							1	62	1.3%		unknown about damper position	209
210	1514	VBWDO	V-3		3										20	15			25	cm2 ea	0.6	50		113		210
211	1261	VBWDO													20	18			22	cm2 ea	1	4				211
212	1157	VBWDO		9											20		18	22		cm2 ea	1	4	3		% +/-0.3	212
213	92	VBWDO	H1	1	2				14.2					l/s ea							1	62				213
214	339	VBWDO	mobile 1						73.6	71.3			73.6	l/s-house							1	50	14%		11th to be unsealed, not sure if damper open or not	214
215	1339	VD		1					3.49					m3/m											elect clo dryer operating w/ 2m of .1m flex plastic tubing	215
216	1514	VDWD	V-8		3										7					cm2 ea	0.6	50		113		216
217	1261	VDWD													3				6	cm2 ea	1	4				217
218	1514	VDWOD	V-9		3										30					cm2 ea	0.6	50		113		218
219	92	VDWOD		50	2				33.5	17.9			52.9	l/s ea							1	62	3%			219
220	1514	VKWDC	V-7		3										2					cm2 ea	0.6	50		113	tight gasket	220
221	1514	VKWDC	V-5		3										10	5			10	cm2 ea	0.6	50		113		221
222	1261	VKWDC													5	3			7	cm2 ea	1	4				222
223	1157	VKWDC		7											5		3	7		cm2 ea	1	4	1		% +/-0.3	223
224	1514	VKWDO	V-6		3										55	35			75	cm2 ea	0.6	50		113		224
225	1157	VKWDO		12											39		36	42		cm2 ea	1	4	6		% +/-0.4	225
226	1261	VKWDO													39	36			42	cm2 ea	1	4				226
227	92	VKWDO	H1	1	2				61.3					l/s ea							1	62			vent-a-hood, 6" round	227
228	92	VKWDO		50	2				62.3				110	l/s ea							1	62	5.2%		6" round vent pipe	228
229	299	WAEL	No4	1		6	0.46	0.46						m3/s100										318	concrete block	229
230	299	WAEL	No2,7	1		6	0.07	0.95						m3/s100										318	cast inplace concrete, front of concrete block	230
231	299	WAEL	No1	1		6	0.61	0.63						m3/s100										318	cast in place concrete, two sides concrete block	231
232	299	WAEL	No6	1		6	1.14	0.5						m3/s100										318	clay tile block	232
233	299	WAEL	No3	1		6	0.2	0.61						m3/s100										318	cast in place concrete	233
234	299	WAEL	No5	1		6	0.17	0.45						m3/s100										318	cast in place concrete	234
235	646	WAEX		1	3b																	32	4.5		party wall	235

	ref #	class	ref id #	# case	D A T	C & n	C value Mixed	n value	flow (avg) S-I	flow variation min S-I	-s.d. S-I	+ s.d. S-I	max S-I	flow units	area S-I	area variation min S-I	-s.d. S-I	+ s.d. S-I	max S-I	area units	C d	ref. press	% total	Note #'s	other	
236	1381	WAEX																				50	35		(A3313)	236
237	646	WAEX		1	3b																	30	28		2x4 brick veneer	237
238	1514	WAEX	EW-14		3										0.54				5.4	cm/m2	0.6	50		113	subtract for plastering, oil paint, cld water paint	238
239	1261	WAEX													24					cm2 ea	1	4			wall/window air conditioner	239
240	1514	WAEX	EW-10		3										100					cm2/hs	0.6	50		113	cm2 subtract for polystrene sheath calk @ jnts (EW-10,EW-	240
241	1514	WAEX	EW-6		3										700					cm2/hs	0.6	50		113	cm2 subtract for continuous polyethylene vapor barrier	241
242	3034	WAEX		5	5										0.15	0.06			0.21	cm2/m2	1	4			continous air infiltration barriers	242
243	3034	WAEX		1	5										0.252					cm2/m2	1	4			laminated fiberboard/ foil	243
244	3034	WAEX		5	5										0.349	0.29			0.41	cm2/m2	1	4			rigid sheathings	244
245	3034	WAEX		6	5										0.732	0.52			0.92	cm2/m2	1	4			paper & foil sheathings or none	245
246	339	WAEX		1					36.3	35.9			36.3	l/s-house							1	50	8%		mobile, sealing plywood paneling butt joints	246
247	177	WAEX	ASH2						0.02					l/sm2							1	45			ashrae lab values 8.5" brick wall-plaster inside	247
248	597	WAEX	6-2	1	5	5	0.00	1.07	0.09					l/sm2							1	50		3,106	6-1 + 3 coats plaster inside	248
249	597	WAEX	7-2	1	5	5	0.00	1	0.17					l/sm2							1	50		3,106	7-1 + 3 coats plaster inside	249
250	597	WAEX	9	1	5	5	0.01	0.87	0.34					l/sm2							1	50		3,108	SCR brick w/ interior finish unvented air space	250
251	597	WAEX	8	1	5	5	0.02	0.81	0.42					l/sm2							1	50		3,107	SCR brick w/ interior finish, vented air space	251
252	597	WAEX	5-1	1	5	5	0.02	0.94	0.68					l/sm2							1	50		3,105	h.w. concrete block (3 core) unfinished w/ expanded mica	252
253	177	WAEX	NAAM	1					0.3					l/sm2							1	45			NAAMM metal curtain wall std	253
254	597	WAEX	5-2	1	5	5	0.02	0.86	0.59					l/sm2							1	50		3,105	5-2 + one coat latex paint inside	254
255	597	WAEX	7-1	1	5	5	0.02	0.81	0.59					l/sm2							1	50		3,106	claybrick cavity wall (unvented) w/ granulated	255
256	597	WAEX	6-1	1	5	5	0.02	0.81	0.59					l/sm2							1	50		3,106	clay brick cavity wall (unvented) w/ expanded mica	256
257	91	WAEX	1	1	1				0.74					l/sm2							1	75	15		108 m2 wall area	257
258	597	WAEX	1-3	1	5	5	0.04	0.85	1.19					l/sm2							1	50		3,103	1-2 + two coats stucco + 1 coat paint ext	258
259	159	WAEX	C	1		1	0.05	0.74	0.95					l/sm2							1	50		1,102	precast concrete panel	259
260	159	WAEX	PB	1		1	0.06	0.76	1.2					l/sm2							1	50		1,102	0.33m plain brick wall	260
261	159	WAEX	D	1		1	0.08	0.69	1.24					l/sm2							1	50		1,102	hollow steel panel	261
262	597	WAEX	4-2	1	5	5	0.09	0.79	1.86					l/sm2							1	50		3,104	4-1 + three coats stucco outside	262
263	177	WAEX	4	1					1.27					l/sm2							1	45			concrete, space, insul, parge, black, plaster	263
264	597	WAEX	1-2	1	5	5	0.11	0.73	1.78					l/sm2							1	50		3,103	1-1 + two coats paint on inside	264
265	159	WAEX	A	1		1	0.11	0.72	1.85					l/sm2							1	50		1,102	precast concrete panel	265
266	177	WAEX	3	1					1.57					l/sm2							1	45			steel,space, insul	266
267	597	WAEX	3	1	5	5	0.09	0.97	3.89					l/sm2							1	50		3,103	l.w. c block wall (unfinished) w/ expanded mica fill	267
268	597	WAEX	4-1	1	5	5	0.1	0.89	3.3					l/sm2							1	50		3,104	l.w.c.b.w. (unfinished) 3 core	268
269	177	WAEX	2	1					1.93					l/sm2							1	45			concrete insulation	269
270	177	WAEX	ASH1	1					2.03					l/sm2							1	45			ashrae lab values 8.5" brick wall-plain	270
271	159	WAEX	B	1		1	0.21	0.52	1.6					l/sm2							1	50		1,102	precast concrete panel	271
272	597	WAEX	2-2	1	5	5	0.14	0.84	3.81					l/sm2							1	50		3,103	2-1 + volcanic dust fill insulation	272
273	177	WAEX	1	1					2.44					l/sm2							1	45			concrete, tile, ins, space, tile, plaster	273
274	91	WAEX	2	1	1				5.84					l/sm2							1	75	65		126 m2 wall area	274
275	597	WAEX	2-1	1	5	5			2.88					l/sm2							1	25		3,103	lw concrete block wall (unfinished)	275
276	597	WAEX	1-1	1					3.39					l/sm2							1	25		3,103	lw concrete block wall, 2 core (no finish)	276
277	311	WAEX	Bldg C	1	4	6	0.04	0.86						l/sm2											Conc brick, rigid insulation, dry wall	277
278	311	WAEX	Ref	1	4	6	0.05	0.81						l/sm2											13" Plain brick wall - 1977 HOF	278
279	311	WAEX	Bldg V	1	4	6	0.07	0.69						l/sm2											F. brk, conc blk, parging, rigid ins, gypsum board	279
280	311	WAEX	Bldg M	1	4	6	0.25	0.63						l/sm2											Brick, VB, plaster	280
281	311	WAEX	Bldg V	1	4	6	0.1	0.69						l/sm2											F. brk, conc blk, parging, rigid ins, gypsum board	281
282	311	WAEX	Bldg T	1	4	6	0.02	0.91						l/sm2											prepour conc spandrel panel, insulation, VB, dry wall	282
283	311	WAEX	Bldg A	1	4	6	0.06	0.76						l/sm2											Clay brk, con blk, parging, bld paper, bat ins, VB, gyp bd	283
284	311	WAEX	Bldg C	1	4	6	0.14	0.66						l/sm2											Conc brick, rigid insulation, dry wall	284
285	86	WAEX	1	1	4	6	0.48	0.5						l/sm2										101	expanded polystyrene bead board (1"thick, 1pcf)	285
286	40	WAEX	h1	1	1				0.76					l/sm2	1.111					cm2/m2	1	75	15	314	0.016 in2/ft2 wall area (includes windows)	286
287	40	WAEX	h2	1	1				1.02					l/sm2	1.528					cm2/m2	1	75	21	314	0.022 in2/ft2	287
288	40	WAEX	h6	1	1				3.4					l/sm2	4.93					cm2/m2	1	75	66	314	0.071 in2/ft2	288
289	40	WAEX	h4	1	1				4.98					l/sm2	7.291					cm2/m2	1	75	42	314	0.105 in2/ft2	289
290	40	WAEX	h5	1	1				5.08					l/sm2	7.638					cm2/m2	1	75	77	314	0.11 in2/ft2	290
291	40	WAEX	h3	1	1				6.2					l/sm2	9.027					cm2/m2	1	75	65	314	0.13 in2/ft2	291
292	299	WAST	No1	1		6	0.04	0.68						m3/s100										318	cast in place concrete, parged	292
293	299	WAST	No6	1		6	0.23	0.54						m3/s100										318	cast in place concrete, parged	293
294	299	WAST	No2	1		6	0.00	0.79						m3/s100										318	cast in place concrete, parged	294

	ref #	class	ref id #	# case	D A T	C & n	C value Mixed	n value	flow (avg) S-I	flow variation min S-I	- s.d. S-I	+ s.d. S-I	max S-I	flow units	area S-I	area variation min S-I	- s.d. S-I	+ s.d. S-I	max S-I	area units	C d	ref. press	% total	Note #'s	other	
295	299	WAST	No8	1		6	0.03	0.69						m3/s100										318	cast in place concrete, parged except door side of clay tile b	295
296	299	WAST	No3	1		6	*****	0.83						m3/s100										318	cast in place concrete, parged	296
297	299	WAST	No7	1		6	0.02	0.98						m3/s100										318	clay tile block, plastered	297
298	299	WAST	No4	1		6	0.03	0.72						m3/s100										318	cast in place concrete, parged	298
299	299	WAST	No5	1		6	0.04	0.53						m3/s100										318	cast in place concrete, parged except front and back con bl	299
300	648	WDL		1	3b																	27	4.5		windows and doors	300
301	40	WDL		6																	1	75	15-2			301
302	91	WDL	1	1	1				0.11					m3/s							1	75	20		window & doors lumped - with stm units	302
303	91	WDL	2	1	1				0.22					m3/s							1	75	19		window & doors lumped w/ storm units	303
304	1261	WIANWS													1.6	0.8			2.4	cm2/m2	1	4			awning	304
305	1261	WIAWS													0.8	0.4			1.2	cm2/m2	1	4			awning	305
306	311	WIAWS	type4	2	4	7	0.02	0.73						l/sm											Awning, 2 windows-5.3x5.3' total (includes win frame/wall jo	306
307	1514	WICA	W-13-18		3										0.024	*****			0.06	cm2/lmc	0.6	50		113	(W-18) w w.s. (50% of W13)	307
308	1514	WICA	W-1		3										0.027					cm2/lmc	0.6	50		113	weatherstripped not only wood (50% of W2) (1.2cm2/ea)	308
309	1514	WICA	W-13		3										0.052	0.02			0.13	cm2/lmc	0.6	50		113	w/o weatherstripping	309
310	1514	WICA	W-2		3										0.052					cm2/lmc	0.6	50		113	including awning (2.3 cm2 ea)	310
311	1261	WICA													0.8	0.4			1.2	cm2/m2	1	4			weatherstripped	311
312	1261	WICA													1.6	0.8			2.4	cm2/m2	1	4			non ws	312
313	458	WICA		2	9				0.2	0.16	0.14	0.25	0.24	l/smc							1	75			w/o stm, wood awning	313
314	458	WICA		30	9				0.3	0.02	0.11	0.5	0.77	l/smc							1	75			w/o stm, wood clad casement	314
315	458	WICA		79	9				0.36	0.16	0.17	0.55	0.91	l/smc							1	75			w/o stm, all casements	315
316	458	WICA		47	9				0.41	0.06	0.22	0.58	0.91	l/smc							1	75			w/o stm, wood casement	316
317	119	WICNW	11-77		1				0.49					l/smc							1	75			42x42" wood, two single sash, side by side (12.45 sq ft)	317
318	40	WICW	h4	7	1				1.7					l/smc							1	75		314	w stm (basement) (windows locked)	318
319	40	WICW	h3	5	1				2.2					l/smc							1	75		314	w stm (basement) (windows locked)	319
320	40	WICW	h5	4	1				3.14					l/smc							1	75		314	w/o stm (basement) (windows locked)	320
321	40	WICW	h2	4	1				4.35					l/smc							1	75		314	w stm (basement) (windows locked)	321
322	40	WICW	h6	3	1				5.23					l/smc							1	75		314	w stm (basement) (windows locked) .	322
323	119	WICW	11-77		1				0.3					l/smc							1	75			42x42" wood, two single sash, side by side (12.45 sq ft)	323
324	1514	WIDHW	W-15-18		3										0.079	0.02			0.23	cm2/lmc	0.6	50		113	w/ w/s (50% W15)	324
325	1514	WIDHW	W-7		3										0.107					cm2/lmc	0.6	50		113	w/ w/s (50% W8) (5 cm2/ea)	325
326	1261	WIDHW													3	1.6			4.4	cm2/m2	1	4				326
327	119	WIDHW	10-77		1				0.42					l/smc							1	75			34x48 wood w/ metal jamb liners (11.42 sq ft)	327
328	40	WIDHW	h3	10	1				0.52					l/smc							1	75		314	with storm (44% reduction), windows locked	328
329	119	WIDHW	9-77		1				0.93					l/smc							1	75			37x49 wood w/ vinyl jamb liners (12.78 sq ft)	329
330	40	WIDHW	h3	10	1				0.94					l/smc							1	75		314	w/o storm, windows locked	330
331	113	WIDHW			A				0.55					l/smc							1	27		315	pressurized tracks, w/s	331
332	458	WIDHW		38	9				1.13	0.35	0.49	1.79	3.24	l/smc							1	75			w/o stm, all double hung (wood)	332
333	458	WIDHW		9	9				1.13	0.49	0.52	1.73	2.04	l/smc							1	75			w/o stm, wood clad double hung	333
334	458	WIDHW		29	9				1.13	0.35	0.46	1.82	3.24	l/smc							1	75			w/o stm, wood double hung	334
335	40	WIDHW	h5	13	1				1.54					l/smc							1	75		314	w stm (casement type stm)(26% reduction), windows locked	335
336	40	WIDHW	h5	13	1				2.09					l/smc							1	75		314	w/o storm, windows locked	336
337	113	WIDHW			A				1.13	0.24			3.3	l/smc							1	27		315	w/s, (1967)	337
338	40	WIDHW	h4	10	1				2.36					l/smc							1	75		314	w storm (29% reduction), windows locked	338
339	40	WIDHW	h4	10	1				3.3					l/smc							1	75		314	w/o storm, windows locked	339
340	1721	WIDHW	TBL4-3	1	4	5	0.04	0.71						l/smc								-75			average fit, w/s	340
341	1721	WIDHW	TBL4-2	1	4	5	0.08	0.68						l/smc								-75			average fit, w/o w/s	341
342	1721	WIDHW	TBL4-1	1	4	5	0.28	0.62						l/smc								-75			loose fit, w/o w/s	342
343	1514	WIDHWN	W-15		3										0.158	0.05			0.46	cm2/lmc	0.6	50		113	w/o w/s	343
344	1514	WIDHWN	W-6		3										0.216					cm2/lmc	0.6	50		113	w/o w/s (10 cm2/ea)	344
345	1261	WIDHWN													6	3.2			8.8	cm2/m2	1	4				345
346	208	WIDHWN	lab						1.89					l/sm							1	75			sash only, w/o meeting rail 10.5 ft	346
347	208	WIDHWN	lab						4.72					l/sm							1	75			sash and meeting rail, 12.8 ft crack	347
348	208	WIDHWN	lab						5.34					l/sm							1	75			entire window (including frame) 24.8 ft	348
349	119	WIDHWN	9-77		1				1.49					l/smc							1	75			37x49 wood w/ vinyl jamb liners (12.78 sq ft)	349
350	119	WIDHWN	10-77		1				1.65					l/smc							1	75			34x48 wood w/ metal jamb liners (11.42 sq ft)	350
351	113	WIDHWN			A				2.28	1.32			5.47	l/smc							1	27		315	gives lab test data (<1970), w/o w/s	351
352	1514	WIDSNW	W-14		3										0.137	0.05			0.41	cm2/lmc	0.6	50		113	double slider w/o w/s	352
353	1514	WIDSNW	W-4		3										0.174					cm2/lmc	0.6	50		113	w/o w/s (slider - all lumped) (8cm2/ea)	353

	ref #	class	ref id #	# case	D A T	C & n	C value Mixed	n value	flow (avg) S-I	flow variation min S-I	-s.d. S-I	+ s.d. S-I	max S-I	flow units	area S-I	area variation min S-I	-s.d. S-I	+ s.d. S-I	max S-I	area units	C d	ref. press	% total	Note #'s	other	
354	1261	WIDSNW													5.2	2.8			7.6	cm2/m2	1	4				354
355	1514	WIDSW	W-14-18		3										0.067	0.02			0.21	cm2/lmc	0.6	50		113	double slider w w/s	355
356	1514	WIDSW	W-3		3										0.085					cm2/lmc	0.6	50		113	w w/s (50% of W4) (slider - all lumped) (4 cm2/ea)	356
357	1261	WIDSW													2.6	1.4			3.8	cm2/m2	1	4				357
358	458	WIDSW		27	9				0.9	0.27	0.31	1.48	2.99	l/smc							1	75			w/o stm, wood double sliders	358
359	458	WIDSW		33	9				0.96	0.27	0.42	1.51	2.99	l/smc							1	75			w/o stm, all double sliders	359
360	458	WIDSW		6	9				1.26	1.01	1.12	1.4	1.38	l/smc							1	75			w/o stm, alum. double sliders	360
361	942	WIF																					20		(A3313) window & door perimeters	361
362	1514	WIFM	W-5		3										0.055					cm2/lmc	0.6	50		113	caulking (20% of W-6) (2.4 cm2/ea)	362
363	1514	WIFM	W-6		3										0.271					cm2/lmc	0.6	50		113	no caulking (12 cm2/ea)	363
364	1261	WIFM													1.3	1.1			2.1	cm2/m2	1	4			w/ caulking	364
365	1261	WIFM													6.5	5.7			10.3	cm2/m2	1	4			without caulking	365
366	311	WIFM	cq2	1	4	6	0.02	0.68						l/sm									1-0.1		window & frame wall joint	366
367	1514	WIFW	W-5		3										0.018					cm2/lmc	0.6	50		113	caulked (0.8 cm2/ea)	367
368	1514	WIFW	W-6		3										0.094					cm2/lmc	0.6	50		113	no caulking (4 cm2/ea)	368
369	1261	WIFW													0.3	0.3			0.5	cm2/m2	1	4			w/ caulking	369
370	1261	WIFW													1.7	1.5			2.7	cm2/m2	1	4			without caulking	370
371	208	WIFW	lab 1						39.2					l/s ea							1	75			entire window including frame (24.8 ft)	371
372	339	WIFW	1						113	88.7			113	l/s-house							1	50	18%		mobile, unsealing seq 1, windows and frame	372
373	1261	WIL		19																	1	4	10		wfp	373
374	1261	WIL		11																	1	4	14		w/ofp	374
375	92	WIL		50	2				10.9	3.3			31.6	l/s ea							1	62	11.8		about same for sealed insu glass, stm w, or single glazing fr	375
376	92	WIL	H1	2	2				11.8					l/s ea							1	62				376
377	92	WIL												l/s ea									60%		reduction when caulked frame	377
378	2257	WIL								0.32			7.4	l/sm							1	75	20		federal office bldg.	378
379	1721	WIL			1				0.79					l/sm							1	75			ANSI/AAMA,ANSI/NWMA prime (ft of sash seal)	379
380	176	WIL							0.81					l/sm							1	75			(a2257)	380
381	1721	WIL			1				1.57					l/sm							1	75			exterior storm window stds (ft of sash seal)	381
382	176	WIL			5				0.38	0.19			0.55	l/smc							1	75		316	exterior walls of tall buildings (a2257)	382
383	176	WIL			5				0.5	0.25			0.75	l/smc							1	75		316	exterior walls of tall buildings (a2257)	383
384	458	WIL		192	1				0.82	0.02	0.2	1.45	3.58	l/smc							1	75			all window types	384
385	1357	WIQ	1		3				4.5					l/s							1	50			per louvre on louvre window	385
386	1277	WIQ		1	1				0.79					l/sm							1	75		311	"tight"	386
387	1277	WIQ		1	3a				0.71					l/sm							1	25		310	"leaky", average fit w/o w/s or loose fit w/s	387
388	1277	WIQ		1	3a				2.04					l/sm							1	25		309	"very leaky", loosly fitting window, much worst than average	388
389	706	WIQ	H4	1	4	6	0.13	0.33						l/sm								0-75			either casement or awning	389
390	311	WISHS	Bldg A	1	4	6	0.1	0.74						l/sm											5x4'-one fixed and one h. slider (includes win frame/wall join	390
391	311	WISHS	Bldg A	1	4	6	0.15	0.66						l/sm											5x4'-one fixed and one h. slider (includes win frame/wall join	391
392	311	WISHS	Bldg C	1	4	6	0.02	0.72						l/sm											5.3x5.3'-one fixed & one h. slider (includes win frame/wall jo	392
393	311	WISHS	Bldg A	1	4	6	0.17	0.69						l/sm											5x4'-one fixed and one h. slider (includes win frame/wall join	393
394	311	WISHS	Bldg V	1	4	6	0.07	0.67						l/sm											8.3x5.2'-one small fixed one h. slider (inclds win frm/wall jnt	394
395	311	WISHS	Bldg V	1	4	6	0.1	0.68						l/sm											8.3x5.2'-one small fixed one h. slider (inclds win frm/wall jnt	395
396	311	WISHS	Bldg C	1	4	6	0.03	0.83						l/sm											5.3x5.3'-one fixed & one h. slider (includes win frame/wall jo	396
397	311	WISHS	Bldg C	1	4	6	0.04	0.77						l/sm											5.3x5.3'-one fixed & one h. slider (includes win frame/wall jo	397
398	311	WISHS	Bldg C	1	4	6	0.03	0.72						l/sm											5.3x5.3'-one fixed & one h. slider (includes win frame/wall jo	398
399	311	WISHS	Bldg C	1	4	6	0.01	1.01						l/sm											5.3x5.3'-one fixed & one h. slider (includes win frame/wall jo	399
400	311	WISHS	Bldg A	1	4	6	0.09	0.72						l/sm											5x4'-one fixed and one h. slider (includes win frame/wall join	400
401	311	WISHS	Bldg T	1	4	7	0.06	0.67						l/sm											12.9x4.5'- single hor slider (includes win fm/wall joints)	401
402	311	WISHS	Bldg V	1	4	6	0.05	0.75						l/sm											8.3x5.2'-one small fixed one h. slider (inclds win frm/wall jnt	402
403	311	WISHS	Bldg T	1	4	7	0.03	0.64						l/sm											12.9x4.5'- single hor slider (includes win fm/wall joints)	403
404	311	WISHS	Bldg C	1	4	6	0.03	0.71						l/sm											5.3x5.3'-one fixed & one h. slider (includes win frame/wall jo	404
405	458	WISHS		6	9				0.75	0.47	0.28	1.23	1.71	l/smc							1	75			w/o stm, wood single sliders	405
406	458	WISHS		3	9				1.12	0.94	0.88	1.35	1.4	l/smc							1	75			w/o stm, wood clad single sliders	406
407	458	WISHS		31	9				1.23	0.47	0.6	1.87	3.58	l/smc							1	75			w/o stm, all single sliders	407
408	458	WISHS		22	9				1.38	0.47	0.72	2.03	3.58	l/smc							1	75			w/o stm, alum. single sliders	408
409	1514	WISHSN	W-16		3										0.174	0.08			0.5	cm2/lmc	0.6	50		113	single slider w/o w/s	409
410	1514	WISHSN	W-4		3										2.438					cm2/lmc	0.6	50		113	slider - all lumped, w/s	410
411	1261	WISHSNW													3.6	1.8			5.4	cm2/m2	1	4				411
412	1514	WISHSW	W-16-18		3										0.085	0.04			0.25	cm2/lmc	0.6	50		113	single slider w w/s	412

	ref #	class	ref id #	# case	D A T	C & n	C value Mixed	n value	flow (avg) S-I	flow variation min S-I	-s.d. S-I	+ s.d. S-I	max S-I	flow units
413	1514	WISHSW	W-3		3									
414	1261	WISHSW												
415	40	WISHSW		6hs	3									l/sm
416	40	WISHSW	h1	4	1				0.44					l/smc
417	40	WISHSW	h2	4	1				0.86					l/smc
418	40	WISHSW	h1	4	1				1.54					l/smc
419	40	WISHSW	h2	4	1				2					l/smc
420	40	WISHSW	h6	9	1				2.8					l/smc
421	40	WISHSW	h6	9	1				4.01					l/smc
422	1514	WISHW	W-17-18		3									
423	1514	WISHW	W-17		3									
424	1261	WISHW												
425	458	WISHW		11	9				1.51	1.07	1.07	1.97	2.15	l/sms
426	1261	WISHWN												
427	311	WISILL	direct	1	4	6	0.02	0.82						l/sm
428	311	WISILL	indirct	1	4	6	*****	1.03						l/sm
429	42	WIST			1	8	5170	0.93						l/s-house
430	42	WIST			1	8	3090	0.74						l/s-house
431	526	WIST	lab	1	4	5	28.6	0.69						l/s-house
432	526	WIST	lab	1	4	5	14.3	0.93						l/s-house
433	1721	WIST			1				0.79					l/sm
434	113	WIST			A					0.39			2.66	l/smc
435	113	WIST	2 track		A				0.47					l/smc
436	113	WIST	2 track		A				1.1					l/smc
437	113	WIST	3 track		A				2.2					l/smc
438	1721	WIST	HS		1				0.03	0.02			0.03	l/sms
439	1721	WIST	RG/MAG		1				0.2	0.03			0.42	l/sms
440	1721	WIST	FS/MECH		1				0.27	0.03			1.45	l/sms
441	1721	WIST	RG/MECH		1				0.69	0.08			1.45	l/sms
442	113	WISTDH	p track		A				0.42	0.35			0.5	l/smc
443	113	WISTDH			A				0.71	0.39			0.93	l/smc
444	113	WISTDH			A				0.86	0.42			1.52	l/smc

	area S-I	area variation min S-I	- s.d. S-I	+ s.d. S-I	max S-I	area units	C d	ref. press	% total	Note #'s	other	
413	1.219					cm2/lmc	0.6	50		113	slider - all lumped, w/o w/s	413
414	1.8	0.9			2.7	cm2/m2	1	4				414
415							1	50			l/ms conversion terms in paper 1357	415
416							1	75			w stm	416
417							1	75			w stm	417
418							1	75			w/o stm	418
419							1	75			w/o stm	419
420							1	75			w/ stm	420
421							1	75			w/o stm	421
422	0.107	0.08			0.15	cm2/lmc	0.6	50		113	w/ w/s (50% W-17)	422
423	0.216	0.15			0.3	cm2/lmc	0.6	50		113	w/o w/s single hung	423
424	2.2	1.8			2.9	cm2/m2	1	4				424
425							1	75			w/o stm, alum single hung	425
426	4.4	3.6			5.8	cm2/m2	1	4				426
427									28%		direct measuremetns (fig 4)	427
428											indirect measurements (fig 4)	428
429							0.6				entire house storm windows out	429
430							0.6	75			entire house storm windows in	430
431								0-45		308	mobile in lab, storms in (little difference)	431
432								0-45		308	mobile in lab, storms out (little difference)	432
433							1	75			ANSI/AAMA, interior storm windows (ft of sash seal)	433
434							1	27		315	al or vinyl	434
435							1	27		315	pressurized track, w/s at head, meeting rail and sill	435
436							1	27		315	al or vinyl	436
437							1	27		315	al or vinyl	437
438							1	75			heat shrink films with adhesive or mechanical seals (over av	438
439							1	75			rigid glazing with magnetic seals (over avg prime)	439
440							1	75			flexible sheets with mechanical seals (over avg prime)	440
441							1	75			rigid glazing with mechanical seals (over avg prime)	441
442							1	27		315	pressurized track prime; double, pressurized, 3 track storm	442
443							1	27		315	w.s. prime; double, pressurized, 3 track storm	443
444							1	27		315	w/o W/S prime, double(avg), pressurized(min), 3 track storm	444

APPENDIX B

Listing of Literature Leakage Values
With Calculated ELA using 4 Pa and $C_d = 1$

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	ref #	class	ref id #	# cases	D A T	C & n	C value S-I	n value	flow (avg) S-I	flow variation min S-I	flow variation max S-I	flow units	ela c&n ela cal 4 1	ela from flow min 4 1	ela from flow avg 4 1	ela from flow max 4 1	ela from area min 4 1	ela from area avg 4 1	ela from area max 4 1	area S-I	area variation min S-I	area variation max S-I	area units	C d	ref. press	% total	Note #'s	other	
1	646	CG	1	1	3b																				30	12.3		ceiling	1
2	1514	CG	IW11 .		3													0.006		0.02			cm2/m2	0.6	50		113		2
3	1514	CG	CR2		3													0.019		0.0465			cm2/m2	0.6	50		113	dropped ceiling w/ plastic sheet (EW-6)	3
4	1514	CG	CR5		3													0.191		0.4645			cm2/m2	0.6	50		113	dropped ceiling w/o plastic sheet	4
5	40	CG	h5	1	1				1.372			l/sm2			0.79									1	75	3	314	area term refers to ceiling area 0.03in2/ft2	5
6	40	CG	h6	1	1				1.88			l/sm2			1.083									1	75	11	314	area term refers to ceiling area 0.04 in2/ft2	6
7	40	CG	h3	1	1				1.88			l/sm2			1.083									1	75	16	314	area term refers to ceiling area 0.04 in2/ft2	7
8	40	CG	h2	1	1				3.81			l/sm2			2.195									1	75	67	314	area term refers to ceiling area 0.085 in2/ft2	8
9	40	CG	h4	1	1				4.572			l/sm2			2.635									1	75	34	314	area term refers to ceiling area 0.1in2/ft2	9
10	40	CG	h1	1	1				4.626			l/sm2			2.781									1	75	65	314	area term refers to ceiling area 0.1 in2/ft2	10
11	466	CG							0.254			l/sm2														50		assumes % to get flow (.75 ach house)	11
12	466	CG							0.127			l/sm2														25		assumes % to get flow (.75 ach house)	12
13	91	CG	2	1	1				0.164			m3/s			0.106									1	75	16		(need area terms)	13
14	91	CG	1	1	1				0.354			m3/s			0.204									1	75	65		(need area terms)	14
15	D3	CH	diff	1	5													26		28			cm2	1	4		5,303	depressurization (flue), efla difference	15
16	D3	CH	diff	1	5													33		33			cm2	1	4		5,303	pressurization(flue), efla difference	16
17	1006	CH	diff	1	4	1	2.05	0.71				l/s	21.25														5,201	difference, entire house	17
18	1006	CH	measur	1	4	6	4.31	0.56				l/s	36.28												0-50		2,201	measured directly	18
19	1006	CH	open	1	4	1	24.4	0.71				l/s	252.9													9	4,201	chimney uncapped, entire house	19
20	1006	CH	capped	1	4	1	22.34	0.71				l/s	231.5														4,201	chimney capped, entire house	20
21	1514	CP	C/R16		3													0.822		2			cm2 ea	0.6	50		113	ceiling mounted lights	21
22	1514	CP	C/R3		3													1.643		4			cm2 ea	0.6	50		113	(whole house fans w/ w/s cover)	22
23	1514	CP	C/R11		3													2.054		5			cm2 ea	0.6	50		113	(recessed light-caulked at edges)	23
24	1261	CP															10	10	20	10	10	20	cm2 ea	1	4			recessed light fixtures	24
25	1514	CP	C/R12		3													10.27		25			cm2 ea	0.6	50		113	recessed light	25
26	1514	CP	C/R4		3													20.54		50			cm2 ea	0.6	50		113	(whole house fans) w/ closed louver	26
27	92	CP	h43	1	2				11.8			l/s ea			7.693									1	62			super energy construction, recessed ceiling spots	27
28	92	CP		50	2				15.57	2.36	26.43	l/s ea		1.539	10.16	17.23								1	62	5.2%		recessed ceiling spots	28
29	92	CP	h43	1	2				24.54			l/s ea			16									1	62			super energy construction, recessed ceiling spots	29
30	339	CP	mobile	1					41.53	37.75	41.53	l/s-house		28.31	31.14	31.14								1	50	6		joint between ceiling and flue vent, sealing sequence 3	30
31	D4	CS		1	6													129		129			cm2	1	4			crawl space vent-8x16 each	31
32	D4	CS		9	6												1277	1690	2735	1690	1277	2735	cm2	1	4			ELA, vents closed, entire crawl space	32
33	D4	CS		9	6												7.8	10.3	16.6	10.3	7.8	16.6	cm2/m2	1	4			SELA vents closed	33
34	1261	DACNW															10	30	30	30	10	30	cm2 ea	1	4				34
35	1514	DACNW	C/R14		3													36.97		90			cm2 ea	0.6	50		113	(attic into conditioned space)	35
36	1261	DACW															8	18	18	18	8	18	cm2 ea	1	4			weatherstripped	36
37	1514	DACW	C/R13		3													18.49		45			cm2 ea	0.6	50		113	(attic into conditioned space)	37
38	1514	DAFD	D10		3													4.108		10			cm2 ea	0.6	50		113	w/ insulated box	38
39	1514	DAFDNW	D8		3												22.59	44.36	86.26	108	55	210	cm2 ea	0.6	50		113	w/o w/s, 3x8' door (1-4mm crack)	39
40	1514	DAFDW	D9		3												14.38	22.18	43.13	54	35	105	cm2 ea	0.6	50		113	w/ w/s (50% of D-8)	40
41	1514	DAG	C/R15		3																		cm2 ea	0.6	50		113	(into unconditioned space)	41
42	1261	DDNW															7	11	22	11	7	22	cm2/m2	1	4				42
43	1261	DDW															3	8	15	8	3	15	cm2/m2	1	4				43
44	1514	DDW	D7		3												7.476	11.21	23.05	27.3	18.2	56.1	cm2/m2	0.6	50		113	8x6 door (.7-2mm crack) (RP438 changed units to per m2)	44
45	92	DFRAME		50	2				1.888			l/s ea			1.231									1	62			via threshold, 9% of door leakage	45
46	92	DFRAME		50	2				6.607			l/s ea			4.308									1	62			via weatherstripping on the 3 edges, 37% of door leakage	46
47	92	DFRAME		50	2				9.91			l/s ea			6.462									1	62			door frame & facing, 54% of total	47
48	92	DFRAME		50	2				18.4	3.775	37.75	l/s ea		2.462	12	24.62								1	62	5%		37% via w/s, 9% threshold, 54% wallframe joint	48
49	206	DFRAME	lab	1	4	8	0.0949	0.678	1.729			l/sm	0.941		0.918									1	75			frame trim, outer & inner 3 sides, 33.25 ft	49
50	206	DFRAME	lab	1	4	8	0.1097	0.62	1.572			l/sm	1.003		0.989									1	75			frame trim, outer 3 sides, 16.75 ft	50
51	206	DFRAME	lab	1	4	8	0.7597	0.631	11.79			l/sm	7.056		7.183									1	75			jamb except for threshold, held closed, 16 ft	51
52	206	DFRAME	lab	1	4	8	1.1881	0.591	15.25			l/sm	10.44		10.45									1	75			jamb except threshold, free, 16 ft (cfm-in wg)	52
53	206	DFRAME	lab	1	4	8	2.837	0.573	33.8			l/sm	24.32		24.41									1	75			under threshold	53
54	1261	DFRAMEM															0.3	1	1	1	0.3	1	cm2/m2	1	4			w/ caulking	54
55	1261	DFRAMEM															1.7	5	5	5	1.7	5	cm2/m2	1	4			w/o caulking	55
56	1261	DFRAMEW															0.1	0.3	0.3	0.3	0.1	0.3	cm2/m2	1	4			w/ caulking	56
57	1261	DFRAMEW															0.6	1.7	1.7	1.7	0.6	1.7	cm2/m2	1	4			w/o caulking	57
58	1261	DG		19																				1	4	11		(a3313) w fireplace	58
59	1261	DG		11																				1	4	10		(a3313) w/o fireplace	59
60	1514	DG	D13		3													0.2		0.4877			cm2/lnc	0.6	50		113	average (new)	60
61	1514	DG	D13		3													0.225		0.5486			cm2/lnc	0.6	50		113	well fitted	61
62	1514	DG	D13		3												0.225	0.313	0.438	0.762	0.549	1.067	cm2/lnc	0.6	50		113	average	62
63	1514	DG	D13		3													0.451		1.0973			cm2/lnc	0.6	50		113	poorly fitted	63

	ref #	class	ref id #	# cases	D A T	C & n	C value S-I	n value	flow (avg) S-I	flow variation min S-I	flow variation max S-I	flow units	ela c&n ela cal	ela from flow min	ela from flow avg	ela from flow max	ela from area min	ela from area avg	ela from area max	area S-I	area variation min S-I	area variation max S-I	area units	C d	ref. press	% total	Note #'s	other	
													4	4	4	4	4	4	4										
													1	1	1	1	1	1	1										
64	299	DGE	No5	1		6	0.0475	0.462				m3/s	0.349															elevator door, 6.8 mm crack, door opening 1.07x2.13m	64
65	299	DGE	No6	1		6	0.0321	0.53				m3/s	0.259															elevator door, 4.8 mm crack, door opening 1.07x2.13m	65
66	299	DGE	No4	1		6	0.0144	0.716				m3/s	0.15															elevator door, 5.3 mm crack, door opening 1.07x2.13m	66
67	299	DGE	No2	1		6	0.0115	0.829				m3/s	0.141															elevator door, 5.8 mm crack, door opening 1.22x2.13m	67
68	299	DGE	No1	1		6	0.0424	0.517				m3/s	0.336															elevator door, 5.8 mm crack, door opening 1.07x2.13m	68
69	299	DGE	No3	1		6	0.0406	0.491				m3/s	0.312															elevator door, 5.8 mm crack, door opening 1.00x2.13m	69
70	1514	DIP	lw7		3													14.38		35			cm2 ea	0.6	50		113	(located on upper floor)	70
71	1514	DIP	lw7		3													0.751		1.8288			cm2/lmc	0.6	50		113	(located on upper floor)	71
72	1514	DIS	d-14		3												0.25	0.751	0.751	1.8288	0.61	1.829	cm2/lmc	0.6	50		113	(2mm crack)	72
73	1514	DIS	d-14		3												0.751	1.127	1.502	2.7432	1.829	3.658	cm2/lmc	0.6	50		113	(4mm crack)	73
74	206	DMS	lab	1	4	8	0.6839	0.296	2.515			l/sm	3.992		4.091									1	75			2.3 ft slot, (cfm-in wg)	74
75	1514	DSP	D6		3												24.65	41.08	106.8	100	60	260	cm2 ea	0.6	50		113		75
76	1357	DSP		10	3				43	24	80	l/s		18	32.25	60								1	50			alum. ranch - slider doors	76
77	92	DSP		50	2				20.29	4.719	35.39	l/s ea		3.077	13.23	23.08								1	62	1.7			77
78	HOF	DSP							2.54			l/sm2			0.594									1	300			SGD-B2, SGD-A2, SGD-A3	78
79	HOF	DSP							2.54			l/sm2			1.464									1	75			Fed MHC&SS 280.403 ALL TYPES WINDO & S. GLASS DOORS	79
80	HOF	DSP							2.54			l/sm2			1.464									1	75			ANSI A200.2 SGD wood	80
81	HOF	DSP							5.08			l/sm2			2.927									1	75			fed MHC&SS 280.405 ALL TYPES VERTICAL ENTRANCES	81
82	HOF	DSP							5.08			l/sm2			2.927									1	75			ANSIa134.2(a), sliding glass door-SGD-B1)	82
83	311	DSP	Tpe 1-7	1	4	6	0.101	0.68				l/sm2	1.004															3 panels, 2 of them slide	83
84	311	DSP	Tpe 2-2	1	4	6	0.129	0.702				l/sm2	1.322															2 panels, one slides	84
85	311	DSP	Tpe 2-3	1	4	6	0.113	0.718				l/sm2	1.184															2 panels, one slides	85
86	311	DSP	Tpe 1-1	1	4	6	0.277	0.56				l/sm2	2.332															3 panels, 2 of them slide (numbers are from top to bot on Fig 9)	86
87	311	DSP	Tpe 1-5	1	4	6	0.111	0.673				l/sm2	1.093															3 panels, 2 of them slide	87
88	311	DSP	Tpe 2-6	1	4	6	0.161	0.588				l/sm2	1.409															2 panels, one slides	88
89	311	DSP	Tpe 1-4	1	4	6	0.104	0.729				l/sm2	1.107															3 panels, 2 of them slide	89
90	311	DSP	Tpe 1-6	1	4	6	0.092	0.686				l/sm2	0.922															3 panels, 2 of them slide	90
91	1514	DSTM/W			3																			0.6	50		113	storm door = 35% reduction	91
92	1514	DSTM/W	D2		3													6.162		20			cm2 ea	0.6	50		113	subtract 20 cm2	92
93	1065	DSTM/W		7														62		62			cm2 total	1	4			average difference after appling storm windows & doors	93
94	1065	DSTM/W		7														0.005		0.0046			cm2/m2	1	4			per sq ft of floor area	94
95	40	DSTM/W	h5	2	1				0.833			l/smc			0.48									1	75			w/ storm door	95
96	40	DSTM/W	h6	2	1				0.833			l/smc			0.48									1	75			w/storm door	96
97	40	DSTM/W	h6	2	1				1.226			l/smc			0.707									1	75			w/o storm door	97
98	40	DSTM/W	h5	2	1				1.446			l/smc			0.833									1	75			w/o storm door	98
99	1514	DSW	D3		3												6.162	10.27	16.43	25	15	40	cm2 ea	0.6	50		113	weatherstripped, magnetic seals	99
100	1514	DSW	D5		3												10.27	14.79	26.7	36	25	65	cm2 ea	0.6	50		113	weatherstripped	100
101	1261	DSW															3	8	15	8	3	15	cm2/m2	1	4				101
102	40	DSW	hs#5	2	1				0.833			l/smc			0.48									1	75			with-42% reduction - w/s fair to poor	102
103	40	DSW	hs#6	2	1				0.833			l/smc			0.48									1	75			with-32% reduction - w/s fair to poor	103
104	40	DSW	hs#6	2	1				1.226			l/smc			0.707									1	75			without storm - w/s fair to poor	104
105	40	DSW	hs#5	2	1				1.446			l/smc			0.833									1	75			without storm-weatherstripping fair to poor	105
106	40	DSW	hs#2	2	1				2.154			l/smc			1.241									1	75			(with storm - w/s fair to poor)	106
107	40	DSW	hs#3	2	1				3.223			l/smc			1.857									1	75			(without storm-weatherstripping fair to poor)	107
108	40	DSW	hs#1	2	1				4.795			l/smc			2.763									1	75			(without storm-weatherstripping fair to poor)	108
109	40	DSW	hs#4	2	1				6.178			l/smc			3.56									1	75			(without storm - w/s fair to poor)	109
110	1514	DSWN	D4		3												12.32	20.54	53.4	50	30	130	cm2 ea	0.6	50		113	up to 2mm avg crack	110
111	1261	DSWN															6	11	17	11	6	17	cm2/m2	1	4				111
112	1514	DV	D1		3													10.27		25			cm2/hs	0.6	50		113	subtract 25 cm2 per vestibule	112
113	1261	EO		19																				1	4	2		(A3313) w/ fireplace	113
114	646	EO		1	3b																				16	3.1		exterior walls	114
115	646	EO		1	3b																				32	1.3		party wall	115
116	1261	EO		11																				1	4	4		(A3313) w/o fplace	116
117	1514	EO	IW-2		3													0.082		0.2			cm2 ea	0.6	50		113	w gaskets	117
118	1514	EO	EW-2		3													0.082		0.2			cm2 ea	0.6	50		113	w/ gaskets	118
119	1261	EO																0.5	1	0.5		1	cm2 ea	1	4			not gasketed	119
120	1514	EO	IW-1		3													0.616		1.5			cm2 ea	0.6	50		113	w/o gaskets	120
121	1157	EO		12hs														8		8			cm2 total	1	4	1+/-1	313	1982 USA frame res red, with gaskets, % is w or w/o fp dampers	121
122	92	EO		50	2				0.236			l/s ea			0.154									1	62			w/ gaskets(7% of original)	122
123	92	EO		50	2				3.775		7.079	l/s ea			2.462	4.616								1	62	20.3		w/o gaskets	123
124	206	EO		1	1				5.285			l/s ea			3.046									1	75			duplex outlet in insulated test wall	124
125	206	EO		1	1				6.135			l/s ea			3.535									1	75			duplex outlet-uninsulated test wall	125
126	339	EO		1					8.966	8.022	8.966	l/s-house		6.017	6.724	6.724								1	50	<2		total for all exterior outlets and switches	126
127	1514	ES	IW-3		3													0.616		1.5			cm2 ea	0.6	50		113	no gaskets	127

	ref #	class	ref id #	# cases	D A T	C & n	C value S-I	n value	flow (avg) S-I	flow variation min S-I	flow variation max S-I	flow units	ela p&n ela cal 4 1	ela from flow min 4 1	ela from flow avg 4 1	ela from flow max 4 1	ela from area min 4 1	ela from area avg 4 1	ela from area max 4 1	area S-I	area variation min S-I	area variation max S-I	area units	C d	ref. press	% total	note #'s	other	
128	1514	ES	EW-1		3													6.162	6.162	15		15	cm2 ea	0.6	50		113	no gaskets	128
129	1514	F	H4		3																		cm2 ea	0.6	50		113	sealed combustion furnace	129
130	1261	F																					cm2 ea	1	4		302	sealed combustion furnace	130
131	1514	F	H8		3													12.32		30			cm2 ea	0.6	50		113	no ducts-resistance or water (hydronic) system	131
132	1261	F															18	24	30	24	18	30	cm2 ea	1	4		302	retention head & stack damper	132
133	1514	F	H6		3													24.65		60			cm2 ea	0.6	50		113	retention head plus stack damper	133
134	1261	F															20	30	40	30	20	40	cm2 ea	1	4		302	furnace w/ stack damper	134
135	1261	F															20	30	40	30	20	40	cm2 ea	1	4		302	retention head burner furnace	135
136	1514	F	H5		3													30.81		75			cm2 ea	0.6	50		113	retention head burner furnace	136
137	1514	F	H7		3													30.81		75			cm2 ea	0.6	50		113	stack damper on furnace	137
138	D4	FLCS		9	6												65	355	806	355	65	806	cm2	1	4			ELA	138
139	D4	FLCS	wodw	5	6													1.98		1.98			cm2/m2	1	4			houses w/o ductwork in crawl space	139
140	D4	FLCS		9	6												0.4	2.2	4.9	2.2	0.4	4.9	cm2/m2	1	4			SELA	140
141	D4	FLCS	wdw	4	6													2.25		2.25			cm2/m2	1	4			houses w/ ductwork in crawl space	141
142	1870	FWDC	hc	1														26		26			cm2	1	4		317	fireplace covered w/ plastic	142
143	1514	FWDC	F-7		3													12.32		30			cm2 ea	0.6	50		113	tight damper	143
144	1514	FWDC	F-3		3												20.54	24.65	34.92	60	50	85	cm2 ea	0.6	50		113	average damper	144
145	1261	FWDC															54	69	84	69	54	84	cm2 ea	1	4				145
146	1157	FWDC		5														69		69			cm2 ea	1	4	9		% +/-2, w/ dampers closed ,1982 frame res	146
147	1357	FWDC		1	3						120	l/s				90								1	50			brick chimney & open fireplace	147
148	40	FWDC	H#6	1	1				33.03			l/s ea			19.03									1	75			1950 Ottawa	148
149	40	FWDC	H#3	1	1				37.75			l/s ea			21.75									1	75			1950 Ottawa	149
150	92	FWDC		1	2				38.7			l/s ea			25.23									1	62			spring loaded damper on top of chimney	150
151	40	FWDC	H#4	1	1				51.91			l/s ea			29.91									1	75			1950 Ottawa	151
152	92	FWDC	h43	2	2				58.63			l/s ea			36.93									1	62			super energy construction	152
153	92	FWDC		21	2				62.76			l/s ea			40.93									1	62			located on interior wall	153
154	92	FWDC		40	2				65.59	15.1	141.6	l/s ea		9.848	42.78	92.32								1	62	5.5%		overall number (damper closed)	154
155	92	FWDC		16	2				69.37			l/s ea			45.24									1	62			located on exterior wall	155
156	92	FWDC		1	2				77.39			l/s ea			50.47									1	62			typ cast iron damper-observation	156
157	1514	FWDC	F-1		3							l/s ea											cm2 ea	0.6	75		113	fireplace w/ sealed combustion	157
158	1514	FWDO	F-2		3													143.6		350			cm2 ea	0.6	50		113	fireplace w/o damper or cover	158
159	1261	FWDO															320	350	380	350	320	380	cm2 ea	1	4			each	159
160	1157	FWDO		13														350		350			cm2 ea	1	4	24		% +/-4, w/o dampers, 1982 USA Frame residence	160
161	3019	FWG																100		100			cm2	1	4				161
162	1514	FWG	F-5		3													4.108		10			cm2 ea	0.6	50		113	fireplace,glass door,stove	162
163	92	FWG		1	2				25.95			l/s ea			16.93									1	62				163
164	92	FWG		1	2				33.03			l/s ea			21.54									1	62				164
165	1514	FWIDC	F-6		3												10.27	14.38	18.49	35	25	45	cm2 ea	0.6	50		113		165
166	1261	FWIDC															26	36	46	36	26	46	cm2 ea	1	4				166
167	1157	FWIDC		3														36		36			cm2 ea	1	4	8		% +/- 1	167
168	1157	FWIDC		7														65		65			cm2 ea	1	4	13		% +/-3, question if not glass doors	168
169	1514	FWIDO	F-8		3												20.54	26.7	32.86	65	50	80	cm2 ea	0.6	50		113		169
170	1261	FWIDO															40	65	90	65	40	90	cm2 ea	1	4				170
171	1261	GWH															15	20	25	20	15	25	cm2 ea	1	4				171
172	1514	GWH	H9		3													20.54		50			cm2 ea	0.6	50		113	domestic hot water heater exhaust stack	172
173	339	J							36.34	35.86	36.34	l/s-house		26.9	27.25	27.25								1	50	8		paneling side joints	173
174	1514	JCW	IW-10		3													0.157		0.381			cm2/m	0.6	50		113	Wall/ceiling crack	174
175	1261	JCW															0.5	1.5	2.5	1.5	0.5	2.5	cm2/m	1	4			ceiling/wall joint w/o taped, plastered or wrapped V.B.	175
176	339	JCW							65.12	42.47	65.12	l/s-house		31.65	48.84	48.84								1	50	14		wall/ceiling mobile	176
177	646	JSP		1	3b																				16	23.1		floor/wall interface	177
178	1261	JSP	&JTP																					1	4	42		(A3313) w/ fireplace	178
179	1261	JSP	& JTP																					1	4	31		(A313)sill plate & w/ceil | w/fireplace	179
180	942	JSP																								60		(A3313)	180
181	92	JSP																								80%		reduction due to caulking	181
182	1514	JSP	EW-7		3													0.075		0.1829			cm2/m	0.6	50		113	caulked sill & final caulk	182
183	1514	JSP	IW-10		3													0.157		0.361			cm2/m	0.6	50		113	wall/floor or wall/ceiling	183
184	1514	JSP	EW-8		3													0.378		0.9144			cm2/m	0.6	50		113	uncaulked sill	184
185	1514	JSP	EW-5		3													0.378		0.9144			cm2/m	0.6	50		113	caulked or fiber mat behind molding	185
186	1261	JSP															0.4	0.3	1.2	0.8	0.4	1.2	cm2/m	1	4			sill caulked per m of perimeter	186
187	1261	JSP															1	4	4	4	1	4	cm2/m	1	4			sill, not caulked	187
188	208	JSP	lab	1					0.755			l/s-m			0.435									1	75			sill plate-top of trim; plate and solid concrete block foundation	188
189	208	JSP	lab	1					1.493			l/s-m			0.861									1	75			sill plate-bottom of trim; plate and solid concrete block foundatio	189
190	311	JSP	indirect-1	1	4	6	0.0707	0.807				l/s-m	0.636													50%		floor-wall joint (indirect measurement w pressure balancing)	190
191	311	JSP	direct	1	4	6	0.139	0.637				l/s-m	1.302															floor-wall joint (direct measurement w pressure balancing)	191

	ref #	class	ref id #	# cases	D A T	C & n	C value	n value	flow (avg)	flow variation min	flow variation max	flow units	ela c&n ela cal	ela from flow min	ela from flow avg	ela from flow max	ela from area min	ela from area avg	ela from area max	area	area variation min	area variation max	area units	C d	ref. press	% total	Note #'s	other	
													4	4	4	4	4	4	4										
							S-I		S-I	S-I	S-I		1	1	1	1	1	1	1	S-I	S-I	S-I							
192	92	JSP		50	2				5.659		8.646	l/smc			3.69	5.638								1	62	24.6		not caulked	192
193	1514	JTPO	EW-13		3													0.076		0.1829			cm2/m	0.6	50		113	Band Joist-ins w/ internal partitions return air (caulked)	193
194	1514	JTPO	EW-12		3													0.376		0.9144			cm2/m	0.6	50		113	Band joist - unins w/ internal partitions as return air	194
195	1261	PPWP		19																				1	4	13		(A3313) w/fp	195
196	1261	PPWP		11																				1	4	12		(A3313) w/o fp	196
197	1261	PPWP																1	2	1		2	cm2 ea	1	4			caulked	197
198	1261	PPWP																1.6	1.6	1.6		1.6	cm2 ea	1	4			sealed or with continuous v.b., duct pentrations	198
199	1261	PPWP															2	6	10	6	2	10	cm2 ea	1	4			not sealed	199
200	1261	PPWP															14	24	24	24	14	24	cm2 ea	1	4			each, unsealed or w/o v.b., duct pentrations	200
201	1514	PPWP			3													24.65		60			cm2/duct	0.6	50		113	duct in wall	201
202	1514	PPWP			3													6.162		15			cm2/pipe	0.6	50		113	(IW-4,IW-5) vs no piping/wiring, see notes	202
203	1514	PPWP	EW-3		3													6.162		15			cm2/pipe	0.6	50		113	piping & wiring in walls	203
204	339	PPWP		2					9.202			l/s ea			6.901									1	50	4%		mobile home (plumbing holes in floor)	204
205	1357	PPWP		3	3				38	11	71	l/s ea		8.25	28.5	53.25								1	50			plumbing to bath w/ bath enclosed	205
206	1514	VBWDC	V2		3												2.465	2.465	4.929	6	6	12	cm2 ea	0.6	50		113		206
207	1157	VBWDC		6														11		11			cm2 ea	1	4	2		% +/-0.1	207
208	1261	VBWDC															10	11	12	11	10	12	cm2 ea	1	4				208
209	92	VBWDC		50	2				15.57	9.438	30.67	l/s ea		6.155	10.16	20								1	62	1.3%		unknown about damper position	209
210	1514	VBWDO	V-3		3												6.162	8.216	10.27	20	15	25	cm2 ea	0.6	50		113		210
211	1261	VBWDO															18	20	22	20	18	22	cm2 ea	1	4				211
212	1157	VBWDO		9														20		20			cm2 ea	1	4	3		% +/-0.3	212
213	92	VBWDO	H1	1	2				14.16			l/s ea			9.232									1	62				213
214	339	VBWDO	mobile 1						73.62	71.26	73.62	l/s-house		53.44	55.21	55.21								1.	50	14%		11th to be unsealed, not sure if damper open or not	214
215	1339	VD		1					3.49			m3/m																elect clo dryer operating w/ 2m of .1m flex plastic tubing	215
216	1514	VDWD	V-8		3													2.875		7			cm2 ea	0.6	50		113		216
217	1261	VDWD																3	6	3		6	cm2 ea	1	4				217
218	1514	VDWOD	V-9		3													12.32		30			cm2 ea	0.6	50		113		218
219	92	VDWOD		50	2				33.5	17.93	52.65	l/s ea		11.69	21.85	34.47								1	62	3%			219
220	1514	VKWDC	V-7		3													0.822		2			cm2 ea	0.6	50		113	tight gasket	220
221	1514	VKWDC	V-5		3												2.054	4.108	4.108	10	5	10	cm2 ea	0.6	50		113		221
222	1261	VKWDC															3	5	7	5	3	7	cm2 ea	1	4				222
223	1157	VKWDC		7														5		5			cm2 ea	1	4	1		% +/-0.3	223
224	1514	VKWDO	V-6		3												14.38	22.59	30.81	55	35	75	cm2 ea	0.6	50		113		224
225	1157	VKWDO		12														39		39			cm2 ea	1	4	6		% +/-0.4	225
226	1261	VKWDO															36	39	42	39	36	42	cm2 ea	1	4				226
227	92	VKWDO	H1	1	2				61.35			l/s ea			40.01									1	62			vent-a-hood, 6" round	227
228	92	VKWDO		50	2				62.29		110.4	l/s ea			40.62	72.01								1	62	5.2%		6" round vent pipe	228
229	299	WAEL	No4	1		6	0.46	0.46				m3/s1000	3.371														318	concrete block	229
230	299	WAEL	No2,7	1		6	0.0707	0.947				m3/s1000	1.018														318	cast inplace concrete, front of concrete block	230
231	299	WAEL	No1	1		6	0.609	0.625				m3/s1000	5.61														318	cast in place concrete, two sides concrete block	231
232	299	WAEL	No6	1		6	1.138	0.501				m3/s1000	6.827														318	clay tile block	232
233	299	WAEL	No3	1		6	0.201	0.608				m3/s1000	1.808														318	cast in place concrete	233
234	299	WAEL	No5	1		6	0.168	0.454				m3/s1000	1.221														318	cast in place concrete	234
235	646	WAEX		1	3b																				32	4.5		party wall	235
236	1361	WAEX																							50	35		(A3313)	236
237	646	WAEX		1	3b																				30	27.9		2x4 brick veneer	237
238	1514	WAEX	EW-14		3													0.22	2.22	0.54		5.4	cm/m2	0.6	50		113	subtract for plastering, oil paint, cld water paint	238
239	1261	WAEX																24		24			cm2 ea	1	4			wall/window air conditioner	239
240	1514	WAEX	EW-10		3													41.06		100			cm2/hs	0.6	50		113	cm2 subtract for polystrene sheath calk @ jnts (EW-10,EW-11)	240
241	1514	WAEX	EW-6		3													287.5		700			cm2/hs	0.6	50		113	cm2 subtract for continuous polyethylene vapor barrier	241
242	3034	WAEX		5	5												0.055	0.15	0.21	0.15	0.055	0.21	cm2/m2	1	4			continous air infiltration barriers	242
243	3034	WAEX		1	5													0.252		0.252			cm2/m2	1	4			laminated fiberboard/ foil	243
244	3034	WAEX		5	5												0.292	0.349	0.414	0.349	0.292	0.414	cm2/m2	1	4			rigid sheathings	244
245	3034	WAEX		6	5												0.515	0.732	0.918	0.732	0.515	0.918	cm2/m2	1	4			paper & foil sheathings or none	245
246	339	WAEX		1					36.34	35.86	36.34	l/s-house		26.9	27.25	27.25								1	50	5%		mobile, sealing plywood paneling butt joints	246
247	177	WAEX	ASH2						0.015			l/sm2			0.012									1	45			ashrae lab values 8.5" brick wall-plaster inside	247
248	597	WAEX	6-2	1	5	5	0.0013	1.07	0.065			l/sm2	0.023		0.022									1	50		3,106	6-1 + 3 coats plaster inside	248
249	597	WAEX	7-2	1	5	5	0.0034	1	0.169			l/sm2	0.053		0.052									1	50		3,106	7-1 + 3 coats plaster inside	249
250	597	WAEX	9	1	5	5	0.0102	0.87	0.339			l/sm2	0.132		0.146									1	50		3,106	SCR brick w/ interior finish unvented air space	250
251	597	WAEX	8	1	5	5	0.0177	0.807	0.423			l/sm2	0.21		0.213									1	50		3,107	SCR brick w/ interior finish, vented air space	251
252	597	WAEX	5-1	1	5	5	0.0164	0.939	0.677			l/sm2	0.233		0.245									1	50		3,105	h.w. concrete block (3 core) unfinished w/ expanded mica	252
253	177	WAEX	NAAMM	1					0.305			l/sm2			0.245									1	45			NAAMM metal curtain wall std	253
254	597	WAEX	5-2	1	5	5	0.0207	0.86	0.593			l/sm2	0.264		0.262									1	50		3,105	5-2 + one coat latex paint inside	254
255	597	WAEX	7-1	1	5	5	0.0241	0.81	0.593			l/sm2	0.297		0.297									1	50		3,106	claybrick cavity wall (unvented) w/ granulated	255

	ref #	class	ref d #	# cases	D A T	C & n	C value S-I	n value	flow (avg) S-I	flow variation min S-I	flow variation max S-I	flow units	ela c&n ela cal	ela from flow min	ela from flow avg	ela from flow max	ela from area min	ela from area avg	ela from area max	area S-I	area variation min S-I	area variation max S-I	area units	C d	ref. press	% total	Note #'s	other	
													4	4	4	4	4	4	4										
													1	1	1	1	1	1	1										
256	597	WAEX	6-1	1	5	5	0.0241	0.81	0.593			l/sm2	0.287		0.297									1	50		3,106	clay brick cavity wall (unvented) w/ expanded mica	256
257	91	WAEX	1	1	1				0.74			l/sm2			0.426									1	75	15		106 m2 wall area	257
258	597	WAEX	1-3	1	5	5	0.0417	0.851	1.19			l/sm2	0.525		0.537									1	50		3,103	1-2 + two coats stucco + 1 coat paint ext	258
259	159	WAEX	C	1		1	0.053	0.74	0.95			l/sm2	0.573		0.568									1	50		1,102	precast concrete panel	259
260	159	WAEX	PB	1		1	0.061	0.76	1.2			l/sm2	0.678		0.682									1	50		1,102	0.33m plain brick wall	260
261	159	WAEX	D	1		1	0.064	0.69	1.24			l/sm2	0.847		0.841									1	50		1,102	hollow steel panel	261
262	597	WAEX	4-2	1	5	5	0.0652	0.787	1.86			l/sm2	0.962		0.967									1	50		3,104	4-1 + three coats stucco outside	262
263	177	WAEX	4	1					1.27			l/sm2			1.02									1	45			concrete, space, insul, parge, black, plaster	263
264	597	WAEX	1-2	1	5	5	0.105	0.731	1.78			l/sm2	1.12		1.088									1	50		3,103	1-1 + two coats paint on inside	264
265	159	WAEX	A	1		1	0.11	0.723	1.85			l/sm2	1.161		1.154									1	50		1,102	precast concrete panel	265
266	177	WAEX	3	1					1.575			l/sm2			1.265									1	45			steel,space, insul	266
267	597	WAEX	3	1	5	5	0.0686	0.965	3.89			l/sm2	1.308		1.317									1	50		3,103	l.w. c block wall (unfinished) w/ expanded mica fill	267
268	597	WAEX	4-1	1	5	5	0.0991	0.894	3.3			l/sm2	1.325		1.336									1	50		3,104	l.w.c.b.w. (unfinished) 3 core	268
269	177	WAEX	2	1					1.93			l/sm2			1.55									1	45			concrete insulation	269
270	177	WAEX	ASH1	1					2.032			l/sm2			1.632									1	45			ashrae lab values 8.5" brick wall-plain	270
271	159	WAEX	B	1		1	0.207	0.524	1.6			l/sm2	1.656		1.65									1	50		1,102	precast concrete panel	271
272	597	WAEX	2-2	1	5	5	0.142	0.64	3.61			l/sm2	1.762		1.768									1	50		3,103	2-1 + volcanic dust fill insulation	272
273	177	WAEX	1	1					2.438			l/sm2			1.958									1	45			concrete, tile, ins, space, tile, plaster	273
274	91	WAEX	2	1	1				5.84			l/sm2			3.365									1	75	65		126 m2 wall area	274
275	597	WAEX	2-1	1	5	5			2.88			l/sm2			3.389									1	25		3,103	lw concrete block wall (unfinished)	275
276	597	WAEX	1-1	1					3.39			l/sm2			3.99									1	25		3,103	lw concrete block wall, 2 core (no finish)	276
277	311	WAEX	Bldg C	1	4	6	0.0391	0.859				l/sm2	0.498															Conc brick, rigid insulation, dry wall	277
278	311	WAEX	Ref	1	4	6	0.0511	0.813				l/sm2	0.511															13" Plain brick wall - 1977 HOF	278
279	311	WAEX	Bldg V	1	4	6	0.0686	0.694				l/sm2	0.895															F. brk, conc blk, parging, rigid ins, gypsum board	279
280	311	WAEX	Bldg M	1	4	6	0.25	0.625				l/sm2	2.303															Brick, VB, plaster	280
281	311	WAEX	Bldg V	1	4	6	0.102	0.691				l/sm2	1.03															F. brk, conc blk, parging, rigid ins, gypsum board	281
282	311	WAEX	Bldg T	1	4	6	0.0203	0.908				l/sm2	0.277															prepour conc spandrel panel, insulation, VB, dry wall	282
283	311	WAEX	Bldg A	1	4	6	0.0644	0.758				l/sm2	0.713															Clay brk, con blk, parging, bld paper, bat ins, VB, gyp bd	283
284	311	WAEX	Bldg C	1	4	6	0.136	0.661				l/sm2	1.317															Conc brick, rigid insulation, dry wall	284
285	86	WAEX	1	1	4	6	0.4778	0.5				l/sm2	3.701														101	expanded polystyrene bead board (1"thick, 1pcf)	285
286	40	WAEX	h1	1	1				0.762			l/sm2			0.439			0.716		1.111			cm2/m2	1	75	15	314	0.016 in2/ft2 wall area (includes windows)	286
287	40	WAEX	h2	1	1				1.016			l/sm2			0.585			0.984		1.5277			cm2/m2	1	75	21	314	0.022 in2/ft2	287
288	40	WAEX	h6	1	1				3.404			l/sm2			1.961			3.178		4.9302			cm2/m2	1	75	66	314	0.071 in2/ft2	288
289	40	WAEX	h4	1	1				4.978			l/sm2			2.869			4.697		7.2912			cm2/m2	1	75	42	314	0.105 in2/ft2	289
290	40	WAEX	h5	1	1				5.08			l/sm2			2.927			4.921		7.6384			cm2/m2	1	75	77	314	0.11 in2/ft2	290
291	40	WAEX	h3	1	1				6.196			l/sm2			3.571			5.816		9.0272			cm2/m2	1	75	65	314	0.13 in2/ft2	291
292	299	WAST	No1	1		6	0.0438	0.678				m3/s1000	0.434														318	cast in place concrete, parged	292
293	299	WAST	No6	1		6	0.225	0.537				m3/s1000	1.835														318	cast in place concrete, parged	293
294	299	WAST	No2	1		6	0.0042	0.794				m3/s1000	0.049														316	cast in place concrete, parged	294
295	299	WAST	No8	1		6	0.026	0.689				m3/s1000	0.262														318	cast in place concrete, parged except door side of clay tile blk	295
296	299	WAST	No3	1		6	0.0061	0.834				m3/s1000	0.075														318	cast in place concrete, parged	296
297	299	WAST	No7	1		6	0.0186	0.976				m3/s1000	0.279														318	clay tile block, plastered	297
298	299	WAST	No4	1		6	0.0323	0.718				m3/s1000	0.338														318	cast in place concrete, parged	298
299	299	WAST	No5	1		6	0.0423	0.533				m3/s1000	0.343														318	cast in place concrete, parged except front and back con block	299
300	646	WDL		1	3b																				27	4.5		windows and doors	300
301	40	WDL		6																				1	75	15-24			301
302	91	WDL	1	1	1				0.113			m3/s			0.065									1	75	20		window & doors lumped - with stm units	302
303	91	WDL	2	1	1				0.217			m3/s			0.125									1	75	19		window & doors lumped w/ storm units	303
304	1261	WIANWS															0.8	1.6	2.4	1.6	0.8	2.4	cm2/m2	1	4			awning	304
305	1261	WIAWS															0.4	0.8	1.2	0.8	0.4	1.2	cm2/m2	1	4			awning	305
306	311	WIAWS	type4	2	4	7	0.0218	0.733				l/sm	0.233															Awning, 2 windows-5.3x5.3' total (includes win frame/wall joint)	306
307	1514	WICA	W-13-18		3												0.003	0.01	0.025	0.0244	0.006	0.061	cm2/mc	0.6	50		113	(W-18) w w.s. (50% of W13)	307
308	1514	WICA	W-1		3													0.011		0.0274			cm2/mc	0.6	50		113	weatherstripped not only wood (50% of W2) (1.2cm2/ea)	308
309	1514	WICA	W-13		3												0.006	0.021	0.054	0.0515	0.015	0.131	cm2/mc	0.6	50		113	w/o weatherstripping	309
310	1514	WICA	W-2		3													0.021		0.0518			cm2/mc	0.6	50		113	including awning (2.3 cm2 ea)	310
311	1261	WICA															0.4	0.8	1.2	0.8	0.4	1.2	cm2/m2	1	4			weatherstripped	311
312	1261	WICA															0.8	1.6	2.4	1.6	0.8	2.4	cm2/m2	1	4			non ws	312
313	458	WICA		2	9				0.204	0.157	0.236	l/smc		0.091	0.118	0.136								1	75			w/o stm, wood awning	313
314	458	WICA		30	9				0.299	0.016	0.77	l/smc		0.009	0.172	0.444								1	75			w/o stm, wood clad casement	314
315	458	WICA		79	9				0.362	0.157	0.912	l/smc		0.091	0.208	0.525								1	75			w/o stm, all casements	315
316	458	WICA		47	9				0.409	0.063	0.912	l/smc		0.036	0.236	0.525								1	75			w/o stm, wood casement	316
317	119	WICNW	11-77		1				0.487			l/smc			0.281									1	75			42x42" wood, two single sash, side by side (12.45 sq ft)	317
318	40	WICW	h4	7	1				1.696			l/smc			0.978									1	75		314	w stm (basement) (windows locked)	318
319	40	WICW	h3	5	1				2.201			l/smc			1.268									1	75		314	w stm (basement) (windows locked)	319

	ref #	class	ref id #	# cases	D A T	C & n	C value S-I	n value	flow (avg) S-I	flow variation min S-I	flow variation max S-I	flow units	ela c&n ela cal	ela from flow min	ela from flow avg	ela from flow max	ela from area min	ela from area avg	ela from area max	area S-I	area variation min S-I	area variation max S-I	area units	C d	ref. press	% total	Note #'s	other	
													4	4	4	4	4	4	4										
													1	1	1	1	1	1	1										
320	40	WICW	h5	4	1				3.144			l/smc			1.812									1	75		314	w/o stm (basement) (windows locked)	320
321	40	WICW	h2	4	1				4.354			l/smc			2.509									1	75		314	w stm (basement) (windows locked)	321
322	40	WICW	h6	3	1				5.235			l/smc			3.016									1	75		314	w stm (basement) (windows locked)	322
323	119	WICW	11-77		1				0.299			l/smc												1	75			42x42" wood, two single sash, side by side (12.45 sq ft)	323
324	1514	WIDHW	W-15-18		3												0.01	0.033	0.094	0.0792	0.024	0.229	cm2/lmc	0.6	50		113	w/ w/s (50% W15)	324
325	1514	WIDHW	W-7		3													0.044		0.1067			cm2/lmc	0.6	50		113	w/ w/s (50% W8) (5 cm2/ea)	325
326	1261	WIDHW															1.6	3	4.4	3	1.6	4.4	cm2/m2	1	4				326
327	119	WIDHW	10-77		1				0.424			l/smc			0.245									1	75			34x48 wood w/ metal jamb liners (11.42 sq ft)	327
328	40	WIDHW	h3	10	1				0.519			l/smc			0.299									1	75		314	with storm (44% reduction), windows locked	328
329	119	WIDHW	9-77		1				0.927			l/smc			0.534									1	75			37x49 wood w/ vinyl jamb liners (12.78 sq ft)	329
330	40	WIDHW	h3	10	1				0.943			l/smc			0.543									1	75		314	w/o storm, windows locked	330
331	113	WIDHW			A				0.55			l/smc			0.616									1	27		315	pressurized tracks, w/s	331
332	458	WIDHW		38	9				1.132	0.346	3.238	l/smc		0.199	0.652	1.866								1	75			w/o stm, all double hung (wood)	332
333	458	WIDHW		9	9				1.132	0.487	2.044	l/smc		0.281	0.652	1.178								1	75			w/o stm, wood clad double hung	333
334	458	WIDHW		29	9				1.132	0.346	3.238	l/smc		0.199	0.652	1.866								1	75			w/o stm, wood double hung	334
335	40	WIDHW	h5	13	1				1.541			l/smc			0.888									1	75		314	w stm (casement type stm)(26% reduction), windows locked	335
336	40	WIDHW	h5	13	1				2.091			l/smc			1.205									1	75		314	w/o storm, windows locked	336
337	113	WIDHW			A				1.132	0.236	3.301	l/smc		0.264	1.267	3.695								1	27		315	w/s, (1967)	337
338	40	WIDHW	h4	10	1				2.358			l/smc			1.359									1	75		314	w storm (29% reduction), windows locked	338
339	40	WIDHW	h4	10	1				3.301			l/smc			1.902									1	75		314	w/o storm, windows locked	339
340	1721	WIDHW	TBL4-3	1	4	5	0.037	0.709				l/smc	0.363												-75			average fit, w/s	340
341	1721	WIDHW	TBL4-2	1	4	5	0.079	0.68				l/smc	0.785												-75			average fit, w/o w/s	341
342	1721	WIDHW	TBL4-1	1	4	5	0.28	0.615				l/smc	2.544												-75			loose fit, w/o w/s	342
343	1514	WIDHWN	W-15		3												0.019	0.065	0.186	0.1585	0.046	0.457	cm2/lmc	0.6	50		113	w/o w/s	343
344	1514	WIDHWN	W-6		3													0.069		0.2164			cm2/lmc	0.6	50		113	w/o w/s (10 cm2/ea)	344
345	1261	WIDHWN															3.2	6	8.8	6	3.2	8.8	cm2/m2	1	4				345
346	208	WIDHWN	lab						1.886			l/sm			1.087									1	75			sash only, w/o meeting rail 10.5 ft	346
347	208	WIDHWN	lab						4.716			l/sm			2.717									1	75			sash and meeting rail, 12.8 ft crack	347
348	208	WIDHWN	lab						5.345			l/sm			3.08									1	75			entire window (including frame) 24.8 ft	348
349	119	WIDHWN	9-77		1				1.493			l/smc			0.861									1	75			37x49 wood w/ vinyl jamb liners (12.78 sq ft)	349
350	119	WIDHWN	10-77		1				1.651			l/smc			0.951									1	75			34x48 wood w/ metal jamb liners (11.42 sq ft)	350
351	113	WIDHWN			A				2.279	1.32	5.471	l/smc		1.478	2.552	6.124								1	27		315	gives lab test data (<1970), w/o w/s	351
352	1514	WIDSNW	W-14		3												0.019	0.058	0.169	0.1372	0.046	0.411	cm2/lmc	0.6	50		113	double slider w/o w/s	352
353	1514	WIDSNW	W-4		3													0.071		0.1737			cm2/lmc	0.6	50		113	w/o w/s (slider - all lumped) (6cm2/ea)	353
354	1261	WIDSNW															2.8	5.2	7.6	5.2	2.8	7.6	cm2/m2	1	4				354
355	1514	WIDSW	W-14-18		3												0.01	0.028	0.065	0.0671	0.024	0.206	cm2/lmc	0.6	50		113	double slider w w/s	355
356	1514	WIDSW	W-3		3													0.035		0.0853			cm2/lmc	0.6	50		113	w w/s (50% of W4) (slider - all lumped) (4 cm2/ea)	356
357	1261	WIDSW															1.4	2.6	3.8	2.6	1.4	3.8	cm2/m2	1	4				357
358	458	WIDSW		27	9				0.896	0.267	2.987	l/smc		0.154	0.516	1.721								1	75			w/o stm, wood double sliders	358
359	458	WIDSW		33	9				0.959	0.267	2.987	l/smc		0.154	0.553	1.721								1	75			w/o stm, all double sliders	359
360	458	WIDSW		6	9				1.258	1.006	1.383	l/smc		0.58	0.725	0.797								1	75			w/o stm, alum. double sliders	360
361	942	WIF																								20		(A3313) window & door perimeters	361
362	1514	WIFM	W-5		3													0.023		0.0549			cm2/lmc	0.6	50		113	caulking (20% of W-6) (2.4 cm2/ea)	362
363	1514	WIFM	W-6		3													0.111		0.2713			cm2/lmc	0.6	50		113	no caulking (12 cm2/ea)	363
364	1261	WIFM															1.1	1.3	2.1	1.3	1.1	2.1	cm2/m2	1	4			w/ caulking	364
365	1261	WIFM															5.7	6.5	10.3	6.5	5.7	10.3	cm2/m2	1	4			without caulking	365
366	311	WIFM	cq2	1	4	6	0.0184	0.678				l/sm	0.182													1-0.1		window & frame wall joint	366
367	1514	WIFW	W-5		3													0.008		0.0183			cm2/lmc	0.6	50		113	caulked (0.8 cm2/ea)	367
368	1514	WIFW	W-6		3													0.039		0.0945			cm2/lmc	0.6	50		113	no caulking (4 cm2/ea)	368
369	1261	WIFW															0.3	0.3	0.5	0.3	0.3	0.5	cm2/m2	1	4			w/ caulking	369
370	1261	WIFW															1.5	1.7	2.7	1.7	1.5	2.7	cm2/m2	1	4			without caulking	370
371	206	WIFW	lab 1						39.17			l/s ea			22.57									1	75			entire window including frame (24.8 ft)	371
372	339	WIFW	1						113.3	86.72	113.3	l/s-house		66.54	84.94	84.94								1	50	18%		mobile, unsealing seq 1, windows and frame	372
373	1261	WIL		19																				1	4	10		w/fp	373
374	1261	WIL		11																				1	4	14		w/ofp	374
375	92	WIL		50	2				10.85	3.303	31.62	l/s ea		2.154	7.078	20.62								1	62	11.8		about same for sealed insu glass, stm w, or single glazing frm lea	375
376	92	WIL	H1	2	2				11.8			l/s ea			7.693									1	62				376
377	92	WIL										l/s ea														50%		reduction when caulked frame	377
378	2257	WIL								0.32	7.4	l/sm		0.184		4.264								1	75	20		federal office bldg.	378
379	1721	WIL			1				0.786			l/sm			0.453									1	75			ANSI/AAMA,ANSI/NWMA prime (ft of sash seal)	379
380	176	WIL							0.81			l/sm			0.467									1	75			(a2257)	380
381	1721	WIL			1				1.572			l/sm			0.906									1	75			exterior storm window stds (ft of sash seal)	381
382	176	WIL			5				0.377	0.189	0.55	l/smc		0.109	0.217	0.317								1	75		316	exterior walls of tall buildings (a2257)	382
383	176	WIL			5				0.503	0.252	0.755	l/smc		0.145	0.29	0.435								1	75		316	exterior walls of tall buildings (a2257)	383

	ref #	class	ref id #	# cases	D A T	C & n	C value	n value	flow (avg)	flow variation min	flow variation max	flow units	ela c&n ela cal	ela from flow min	ela from flow avg	ela from flow max	ela from area min	ela from area avg	ela from area max	area	area variation min	area variation max	area units	C d	ref. press	% total	Note #'s	other	
													4	4	4	4	4	4	4										
							S-I		S-I	S-I	S-I		1	1	1	1	1	1	1	S-I	S-I	S-I							
384	458	WIL		192	1				0.817	0.016	3.584	l/smc		0.009	0.471	2.065								1	75			all window types	384
385	1357	WIQ	1		3				4.5			l/s			3.375									1	50			per louvre on louvre window	385
386	1277	WIQ		1	1				0.786			l/sm			0.453									1	75		311	"tight"	386
387	1277	WIQ		1	3a				0.707			l/sm			0.832									1	25		310	"leaky", average fit w/o w/s or loose fit w/s	387
388	1277	WIQ		1	3a				2.044			l/sm			2.405									1	25		309	"very leaky", loosly fitting window, much worst than average	388
389	706	WIQ	H4	1	4	6	0.1255	0.333				l/sm	0.771												0-75			either casement or awning	389
390	311	WISHS	Bldg A	1	4	6	0.0969	0.739				l/sm	1.045															5x4'-one fixed and one h. slider (includes win frame/wall joints)	390
391	311	WISHS	Bldg A	1	4	6	0.149	0.657				l/sm	1.435															5x4'-one fixed and one h. slider (includes win frame/wall joints)	391
392	311	WISHS	Bldg C	1	4	6	0.0187	0.719				l/sm	0.196															5.3x5.3'-one fixed & one h. slider (includes win frame/wall joints)	392
393	311	WISHS	Bldg A	1	4	6	0.169	0.693				l/sm	1.711															5x4'-one fixed and one h. slider (includes win frame/wall joints)	393
394	311	WISHS	Bldg V	1	4	6	0.0722	0.673				l/sm	0.711															5.3x5.2'-one small fixed one h. slider (inclds win frm/wall jnts)	394
395	311	WISHS	Bldg V	1	4	6	0.101	0.681				l/sm	1.005															5.3x5.2'-one small fixed one h. slider (inclds win frm/wall jnts)	395
396	311	WISHS	Bldg C	1	4	6	0.0273	0.827				l/sm	0.333															5.3x5.3'-one fixed & one h. slider (includes win frame/wall joints)	396
397	311	WISHS	Bldg C	1	4	6	0.0366	0.766				l/sm	0.41															5.3x5.3'-one fixed & one h. slider (includes win frame/wall joints)	397
398	311	WISHS	Bldg C	1	4	6	0.0261	0.716				l/sm	0.273															5.3x5.3'-one fixed & one h. slider (includes win frame/wall joints)	398
399	311	WISHS	Bldg C	1	4	6	0.0133	1.008				l/sm	0.208															5.3x5.3'-one fixed & one h. slider (includes win frame/wall joints)	399
400	311	WISHS	Bldg A	1	4	6	0.0673	0.72				l/sm	0.917															5x4'-one fixed and one h. slider (includes win frame/wall joints)	400
401	311	WISHS	Bldg T	1	4	7	0.0629	0.668				l/sm	0.615															12.9x4.5'- single hor slider (includes win frn/wall joints)	401
402	311	WISHS	Bldg V	1	4	6	0.053	0.751				l/sm	0.581															5.3x5.2'-one small fixed one h. slider (inclds win frm/wall jnts)	402
403	311	WISHS	Bldg T	1	4	7	0.034	0.64				l/sm	0.32															12.9x4.5'- single hor slider (includes win frn/wall joints)	403
404	311	WISHS	Bldg C	1	4	6	0.0321	0.713				l/sm	0.334															5.3x5.3'-one fixed & one h. slider (includes win frame/wall joints)	404
405	458	WISHS		6	9				0.755	0.472	1.713	l/smc		0.272	0.435	0.967								1	75			w/o stm, wood single sliders	405
406	458	WISHS		3	9				1.116	0.943	1.399	l/smc		0.543	0.643	0.806								1	75			w/o stm, wood clad single sliders	406
407	458	WISHS		31	9				1.226	0.472	3.584	l/smc		0.272	0.707	2.065								1	75			w/o stm, all single sliders	407
408	458	WISHS		22	9				1.383	0.472	3.584	l/smc		0.272	0.797	2.065								1	75			w/o stm, alum. single sliders	408
409	1514	WISHSNW	W-16		3												0.031	0.071	0.207	0.1737	0.076	0.503	cm2/l nc	0.6	50		113	single slider w/o w/s	409
410	1514	WISHSNW	W-4		3													1.002		2.4384			cm2/l nc	0.6	50		113	slider - all lumped, w/s	410
411	1261	WISHSNW															1.8	2.6	5.4	3.6	1.8	5.4	cm2/l n2	1	4				411
412	1514	WISHSW	W-16-18		3												0.016	0.035	0.103	0.0653	0.04	0.251	cm2/l nc	0.6	50		113	single slider w w/s	412
413	1514	WISHSW	W-3		3													0.501		1.2192			cm2/l nc	0.6	50		113	slider - all lumped, w/o w/s	413
414	1261	WISHSW															0.9	1.8	2.7	1.8	0.9	2.7	cm2/l n2	1	4				414
415	40	WISHSW		6hs	3							l/sm												1	50			l/ms conversion terms in paper 1357	415
416	40	WISHSW	h1	4	1				0.44			l/smc			0.254									1	75			w stm	416
417	40	WISHSW	h2	4	1				0.66			l/smc			0.38									1	75			w stm	417
418	40	WISHSW	h1	4	1				1.541			l/smc			0.888									1	75			w/o stm	418
419	40	WISHSW	h2	4	1				1.996			l/smc			1.15									1	75			w/o stm	419
420	40	WISHSW	h6	9	1				2.798			l/smc			1.612									1	75			w/ stm	420
421	40	WISHSW	h6	9	1				4.009			l/smc			2.31									1	75			w/o stm	421
422	1514	WISHW	W-17-18		3												0.031	0.044	0.063	0.1067	0.076	0.152	cm2/l nc	0.6	50		113	w/ w/s (50% W-17)	422
423	1514	WISHW	W-17		3												0.063	0.069	0.125	0.2164	0.152	0.305	cm2/l nc	0.6	50		113	w/o w/s single hung	423
424	1261	WISHW															1.8	2.2	2.9	2.2	1.8	2.9	cm2/l n2	1	4				424
425	458	WISHW		11	9				1.509	1.069	2.154	l/sms		0.616	0.87	1.241								1	75			w/o stm, alum single hung	425
426	1261	WISHWN															3.6	4.4	5.8	4.4	3.6	5.8	cm2/l n2	1	4				426
427	311	WISILL	direct	1	4	6	0.0176	0.819				l/sm	0.212													28%		direct measuremetns (fig 4)	427
428	311	WISILL	indirct	1	4	6	0.0086	1.034				l/sm	0.139															indirect measurements (fig 4)	428
429	42	WIST			1	8	48.112	0.929				l/s-house	675.5											0.6				entire house storm windows out	429
430	42	WIST			1	8	80.305	0.743				l/s-house	871.2											0.6	75			entire house storm windows in	430
431	526	WIST	lab	1	4	5	28.8	0.693				l/s-house	291.5												0-45		306	mobile in lab, storms in (little difference)	431
432	526	WIST	lab	1	4	5	14.3	0.928				l/s-house	200.5												0-45		306	mobile in lab, storms out (little difference)	432
433	1721	WIST			1				0.786			l/sm			0.453									1	75			ANSI/AAMA, interior storm windows (ft of sash seal)	433
434	113	WIST			A					0.388	2.657	l/smc		0.435		2.974								1	27		315	al or vinyl	434
435	113	WIST	2 track		A				0.472			l/smc			0.528									1	27		315	pressurized track, w/s at head, meeting rail and sill	435
436	113	WIST	2 track		A				1.1			l/smc			1.232									1	27		315	al or vinyl	436
437	113	WIST	3 track		A				2.201			l/smc			2.464									1	27		315	al or vinyl	437
438	1721	WIST	HS		1				0.031	0.016	0.031	l/sms		0.009	0.018	0.018								1	75			heat shrink films with adhesive or mechanical seals (over avg pri	438
439	1721	WIST	RG/MAG		1				0.204	0.031	0.424	l/sms		0.018	0.118	0.245								1	75			rigid glazing with magnetic seals (over avg prime)	439
440	1721	WIST	FS/MECH		1				0.267	0.031	1.446	l/sms		0.018	0.154	0.833								1	75			flexible sheets with mechanical seals (over avg prime)	440
441	1721	WIST	RG/MECH		1				0.692	0.079	1.446	l/sms		0.045	0.399	0.833								1	75			rigid glazing with mechanical seals (over avg prime)	441
442	113	WISTDH	p track		A				0.424	0.346	0.503	l/smc		0.387	0.475	0.563								1	27		315	pressurized track prime; double, pressurized, 3 track storm	442
443	113	WISTDH			A				0.707	0.393	0.927	l/smc		0.44	0.792	1.038								1	27		315	w.s. prime; double, pressurized, 3 track storm	443
444	113	WISTDH			A				0.865	0.424	1.525	l/smc		0.475	0.968	1.707								1	27		315	w/o W/S prime, double(avg), pressurized(min), 3 track storm(ma	444

APPENDIX C
Notes to Literature Leakage Tables

Legend for Data Testing Coding - Column 6
(Reported by the source)

1. Single reading at reference pressure - 75 Pa
2. Single reading at reference pressure - 62 Pa
3. Single reading at reference pressure - 50 Pa

3a. Single reading at reference pressure - 26.8 Pa (15 mph)
3b. Single reading at some other reference pressure

4. Multiple readings over a pressure range with eqn for readings
5. Multiple readings over a pressure range - calculated at P_{ref}
6. E779-81
7. CGSB CAN2-149.10
8. ASTM C-236
9. ASTM C-283

A. Multiple readings over a pressure range - data for 26.8 Pa (15 mph)

Legend for C and n Coding - Column 7

1. Equation originally given (SI)
2. Equation given I-P not converted yet
3. Equation given I-P still in I-P
4. Equation comes from subtraction of two equations given
5. Data given - Equation regressed by RP 438
6. Data points shown on graph - digitized and regressed by RP 438
7. Graph given - points selected, digitized and regressed by RP 438
8. Equation converted to SI

Legend for Note #'s - Column 24

1. Data point pulled from graph
2. Data pulled from graph and regress equation
3. Data values given, equation regressed by RP438
4. Data from regression equation given
5. Data from difference between open and closed

101. Lightweight concrete block wall with polystyrene pellets in the cores 12x8x16 (2 core) 2 cores latex on the exterior
102. Fixed glazing area 24% to 38% of wall area
103. Lightweight concrete block (expanded clay aggregate) 2 core (8x8x16)
104. Lightweight concrete block (expanded slag aggregate) 3 core (8x8x16)
105. Concrete block (sand and gravel aggregrate) 3 core (8x8x16)
106. Two rows brick (2 3/8 x 3 3/4 x 8) with 2" cavity
107. Single row SCR brick (2 1/6 x 5 1/2 x 11 1/2) with 3/8 vented furring strips, sheathing paper, furring strips with fiberglass insulation, vapor barrier,

tempered wallboard

108. Same as 107 except 3/8" air space not vented.
109a. Single stud wall conventional vapor barrier location - whole house values
109b. Single stud wall sandwiched vapor barrier location - whole house values
110. Double stud wall conventional vapor barrier locaton - whole house values
111. Double stud wall sandwiched vapor barrier location - whole house values
112. 50 Pa with C_d = 0.611
113. 50 Pa with orifice equation C_d = 0.60

201. $Q = C A (\Delta P)^n$ where A = area of building envelope, 228 m^2

301. Only if in unconditioned space
302. Only if in conditioned space
303. Unheated flue with 0.15 m diameter, 0.075m restriction orfice and rain cap
304. Area, vol, C, n, SLA, ACH_{50}, ACH given for each house (SLA based on envelope area)
305. Fan on - flow is corrected for standard restrictions like 1/4" screening, louvers, elbows, straight duct and grease filter
306. Leakage areas for opaque walls: data values, C, n, r^2 also given in paper, no significant differences between sidings
307. Gives house specifics (including ELA, SLA and average ACH for each) for 312 houses which have been found in literature - big whole house leakage data set
308. Mobile home in lab - storm windows inside louvered jalousie type windows. Window area of 6 m^2
309. "Very leaky" - loosely fitting window, much worst than average (1.3 cfm/ft @ 25 Pa)
310. "Leaky" - Average fit, unweatherstripped or weatherstripped with loose fit (0.45 cfm @ 25 Pa)
311. "Tight" (0.5cfm/ft @ 75 Pa)
312. $A=Q/2400(\Delta P)^{0.5}$
313. Negative values were given in some cases becasue paint seal was broken
314. Exclusive of windows and doors, but including leakage between wall and door and window frames [area term given by $A=Q/(2400(\Delta P0.3")^{0.5})$]
315. Approximately 17 ft crack/window
316. Exterior wall leakage rates on tall buildings
317. Subtraction of registers sealed measurement value from registers unsealed value
318. Units = m^3/s-1000m^2

Note: The numbers are not sequential due to not using and/or combining or deleting some of the raw data.

APPENDIX D
Conversion Factors

Physical Quantity	To convert From	To	Multiply by	To convert From	To	Multiply by
Length in	m	0.0254				
	ft	m	0.3048	m	ft	3.281
Area	ft^2	m^2	0.09294	m^2	ft^2	10.76
	in^2	cm^2	6.452	cm^2	in^2	0.1550
Volume	ft^3	m^3	0.02832	m^3	ft^3	35.32
	ft^3	l	28.32	l	ft^3	0.03531
Mass	lbm	kg	0.4536	kg	lbm	2.205
Density	lbm/ft^3	kg/m^3	16.02	kg/m^3	lbm/ft^3	0.06243
Flow	cfm	m^3/s	$4.719 * 10^{-4}$	m^3/s	cfm	2119
Flow	cfm	l/s	0.4719	l/s	cfm	2.119
Velocity	fpm	m/s	0.00508	m/s	fpm	196.8
	mph	m/s	0.44704	m/s	mph	2.237
	mph	km/h	1.609	km/h	mph	0.6215
Pressure	in wg	Pa	248.66	Pa	in wg	0.004022
	in Hg	Pa	3386.4	Pa	in Hg	0.0002953
Spec Leakage area	in^2/ft^2	cm^2/m^2	69.44	cm^2/m^2	in^2/ft^2	0.0144
	cm^2/ft^2	cm^2/m^2	0.0929	cm^2/m^2	cm^2/ft^2	10.76
	cm^2/ft	cm^2/m	0.3048	cm^2/m	cm^2/ft	3.281
	cm^2/100ft	cm^2/m	30.48	cm^2/m	cm^2/100ft	0.0328
				cm^2/m	in^2/ft	0.5086
Flow per unit leakage area	cfm/in^2	m^3/s-cm^2	0.2632	m^3/s-cm^2	cfm/in^2	3.80
length leakage	cfm/ft	l/sm	1.572	l/sm	cfm/ft	0.636
	cfm/ft	m^3/sm	0.0001439	m^3/sm	cfm/ft	6949.
area surface	cfh/ft^2	l/sm^2	0.08467	l/sm^2	cfh/ft^2	11.81
	cfm/ft^2	l/sm^2	5.080	l/sm^2	cfm/ft^2	0.1969
	cfm/ft^2	m^3/sm^2	0.0050802	m^3/sm^2	cfm/ft^2	196.8

Other Conversions:

$1 \text{ N} = 1 \text{ kg-m/s}^2$

Pressure (in wg) = $0.000482 V^2$ (mph)

Pressure (Pa) = $0.1200575 V^2$ (mph)

Pressure (Pa) = $0.601 V^2$ (m/s)

Pressure (Pa) = $0.601 [(1/3.6) V]^2$ (km/h)

15mph = 27 Pa, 25mph = 75 Pa

Standard Air Density = 0.075 lb/ft^3 = 1.20 kg/m^3

APPENDIX E

Derivation of Dimensionless Crack Flow Equation

From Sun, 1992

CHAPTER 3

THEORY AND DEVELOPMENTS

3.1 Theory Preparation

As mentioned in previous chapters, three basic alternative equations (orifice equation, power equation and dimensionless flow equation) are used in the airtightness literature. It is important to demonstrate their developments and indicate some of the assumptions involved. From these examples we might get some ideas for improvements which will enable us to make equation(s) which more closely describe the natural performance of crack flow.

The fundamental theorem to describe the airtightness problem is the Bernoulli equation. It is widely used in hydrodynamics, especially in one dimensional steady flow problems. The basic point of the Bernoulli equation is the energy balance in which the pressure changes and velocity along a streamline are related. For crack flow, the flow velocity and flow rate have a simple relation. Hence with the help of the Bernoulli equation, we can obtain the pressure and flow relationship which governs airtightness and crack flow problems.

3.1.1 Introduction of the derivation of Bernoulli equation based on energy conservation law

The first law of thermodynamics applies to a thermodynamic, volume system which is originally at rest and after some event, is finally at rest again. Under these conditions, it is stated that the "change in internal energy, due to the event, is equal to the sum of the total work done on the system during the course of the event and any heat which was added " (Currie, 1974). Consider a control volume as shown below:

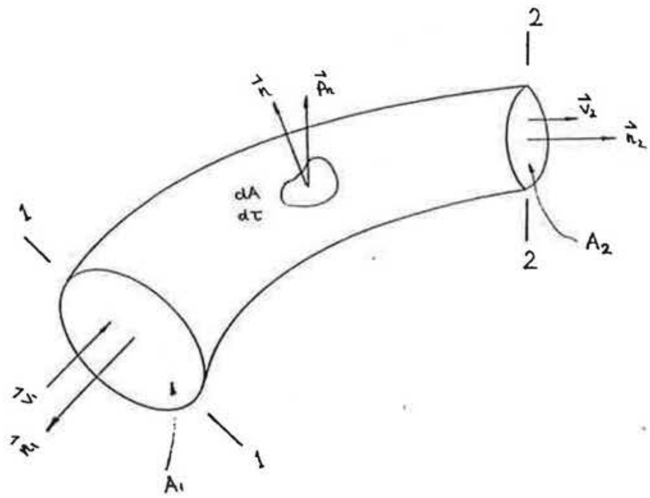

Figure 3-1. Differential controll volume of a flow pipe

dτ-----differential control volume

dA-----differential control surface

$\vec{n}$-----unit normal to the surface of the body

$\vec{v}_1$, $\vec{v}_2$--flow velocity vectors

A_1, A_2--cross sectional areas

Control volume---a finite length mini stream tube which is a region whose sidewalls are made up of streamlines.

The energy of the fluid consists of two parts (on the basis of per unit mass): 1) internal energy, e, and 2) the kinetic energy, $(\vec{v}\cdot\vec{v})/2$. Hence the total energy contained in the control volume will be $\int_\tau \rho(e+((\vec{v}\cdot\vec{v})/2)d\tau$.

Two types of external forces which may act on the fluid mass are the body force and the surface stress. Body force per unit mass is denoted by the vector, $\vec{f}$. Then the total work done due to this body force will be $\int_\tau \vec{v}\cdot\rho\vec{f}d\tau$. The magnitude of the surface stress per unit area is represented by the vector, $\vec{P}_n$. Then the total work done is $\int_A \vec{v}\cdot\vec{P}_n\, dA$. Finally, if the vector $\vec{q}$ denotes the conductive heat flux leaving the control volume, then the quantity of heat leaving the fluid mass per unit time per unit surface area will be $\vec{q}\cdot\vec{n}$, and the net amount of heat leaving the fluid per unit time will be $\int_A \vec{q}\cdot\vec{n}dA$.

The law of energy conservation requires that the rate of change of total energy is equal to the rate at which work is being done plus the rate at which heat is being added, that is:

$$\frac{D}{Dt}\int_\tau \rho\left(e+\frac{1}{2}\vec{v}\cdot\vec{v}\right)d\tau = \oint_A \vec{v}\cdot\vec{P}_n dA + \int_\tau \vec{v}\cdot\rho\vec{f}d\tau - \oint_A \vec{q}\cdot\vec{n}dA \qquad [3.1]$$

where Lagrangian derivatives D/Dt is employed to a specific mass of fluid which is arbitrarily chosen. For the control volume system, we may convert to Eulerian derivatives by use of Reynolds' Transport Theorem, suppose any physical parameter

$\alpha = \alpha(x,y,z,t)$,

$$\frac{D}{Dt}\int_\tau \alpha\, d\tau = \int_\tau\left[\frac{\partial\alpha}{\partial t} + \nabla\cdot(\alpha\vec{v})\right]d\tau$$

Then the left side of equation [3.1] is,

$$\frac{D}{Dt}\int_\tau \rho\,(e+\frac{1}{2}\vec{v}\cdot\vec{v})\, d\tau$$

$$= \int_\tau \frac{\partial}{\partial t}(\rho e+\frac{1}{2}\rho\vec{v}\cdot\vec{v})\, d\tau + \int_\tau \nabla\cdot\left[\rho\vec{v}\,(e+\frac{1}{2}\vec{v}\cdot\vec{v})\right]d\tau$$

$$= \int_\tau \frac{\partial}{\partial t}(\rho e+\frac{1}{2}\rho\vec{v}\cdot\vec{v})\, d\tau + \oint_A \vec{n}\cdot\rho\vec{v}\,(e+\frac{1}{2}\vec{v}\cdot\vec{v})\, dA$$

(using Gauss theorem in the second term)

If we assume,

1) steady flow, $\partial/\partial t=0$, that is, $\partial/\partial t(\rho e+½\rho\vec{v}\cdot\vec{v})=0$

2) no heat transfer involved, $|\vec{q}|=0$

3) body force is conservative, such as gravity, then $\vec{f}$ may be written as the gradient of some scaler function U, that is, $\vec{f}=-\nabla U$

4) inviscid fluid without shear stress to resist deformation, therefore the normal stress is the only stress exerted on the surface, hence $\vec{P}_n=-\vec{n}\cdot P$, which means the surface stress is the pressure in outward normal direction. P is the static pressure.

Then the first term on the right hand side of equation [3.1] is:

$$\oint_A \vec{v}\cdot\vec{P}_n dA = \oint_A \vec{v}\cdot(-\vec{n}P)\,dA$$

$$= -\oint_A \vec{v}\cdot\vec{n}\,P\,dA$$

the second term of the right side is (assuming ρ constant):

$$\int_\tau \vec{v}\cdot(\rho\vec{f}\,)\,d\tau = \int_\tau \rho\vec{v}\cdot\vec{f}\,d\tau$$

$$= \int_\tau \rho\vec{v}\cdot(-\nabla U)\,d\tau = \int_\tau -\rho\,(\vec{v}\cdot\nabla U)\,d\tau$$

$$= \int_\tau -\rho[\nabla\cdot(\vec{v}U) - U\nabla\cdot\vec{v}\,)]\,d\tau$$

$$= -\int_\tau \rho\nabla\cdot(\vec{v}U)\,d\tau + \int_\tau \rho U\nabla\cdot\vec{v}\,d\tau$$

$$= -\int_\tau \rho\nabla\cdot(\vec{v}U)\,d\tau \qquad \text{(continuity: } \nabla\cdot\vec{v} = 0)$$

$$= -\oint_A \rho\,U\,(\vec{v}\cdot\vec{n})\,dA \qquad \text{(Gauss theorm)}$$

and the third term,

$$-\oint_A \vec{q}\cdot\vec{n}\,dA = 0$$

In all, equation [3.1] based on above assumptions reduces to be:

$$\oint_A \vec{n}\cdot\rho\,\vec{v}\,(e+\frac{1}{2}\vec{v}\cdot\vec{v})\,dA = -\oint_A \vec{v}\cdot\vec{n}\,P\,dA - \oint_A \rho\,U\,(\vec{v}\cdot\vec{n})\,dA$$

that is:

$$\oint_A \rho\,\vec{v}\cdot\vec{n}\left[e+\frac{1}{2}\vec{v}\cdot\vec{v}+\frac{P}{\rho}+U\right]dA = 0 \qquad [3.2]$$

Equation [3.2] may be thought of as another energy conservation equation based on the assumptions of: steady flow, no heat transfer, invisicid fluid and body force is conservative, where,

e-------internal energy per unit mass,

$\vec{v}\cdot\vec{v}/2$---kinetic energy per unit mass,

P/ρ-----pressure potential energy per unit mass, and

U-------body force potential energy related with gravity, hence U=gZ which may be called elevation energy per unit mass.

The meaning of equation [3.2] is that the algebraical sum of total energy which is flowing in or out the control surface A is zero during unit time. That is to say, accompanied with fluid flowing in or out of any differential area dA, the net gain of energy flow in all the control surface A is zero during unit time. Where $e + \frac{1}{2}\vec{v}\cdot\vec{v} + P/\rho + gZ$ is considered as total energy per unit mass.

For the following special case, if the control volume can be thought of as a very small stream tube where there is no flow cross the tube surface, except for the section areas 1-1 and 2-2 in Figure 3-1, and also any parameters on these section areas are treated as being uniform, we can obtain from equation [3.2]:

$$\left(\int_{A1} + \int_{A2}\right)\left[\rho\,\vec{v}\cdot\vec{n}\left(e + \frac{1}{2}\vec{v}\cdot\vec{v} + \frac{P}{\rho} + gZ\right)dA\right] = 0$$

That is:

$$\rho\,\vec{v}_1\cdot\vec{n}_1\left(e_1 + \frac{1}{2}\vec{v}_1\cdot\vec{v}_1 + \frac{P_1}{\rho} + gZ_1\right)A_1 + \rho\,\vec{v}_2\cdot\vec{n}_2\left(e_2 + \frac{1}{2}\vec{v}_2\cdot\vec{v}_2 + \frac{P_2}{\rho} + gZ_2\right)A_2 = 0$$

In A_1 section area, $\vec{v}_1\cdot\vec{n}_1 = -V_1$ ($\vec{v}_1, \vec{n}_1$ different directions) and in A_2 section area, $\vec{v}_2\cdot\vec{n}_2 = V_2$ ($\vec{v}_2, \vec{n}_2$ same direction). Where $V_1 = |\vec{v}_1|$, $V_2 = |\vec{v}_2|$. That is, V_1 and V_2 are the magnitude of the vector $\vec{v}_1$ and $\vec{v}_2$ respectively. We know from the continuity condition $A_1\cdot V_1 = A_2\cdot V_2$, therefore, we get the equation commonly called the Bernoulli equation:

$$e_1 + \frac{1}{2}v_1^2 + \frac{P_1}{\rho} + gZ_1 = e_2 + \frac{1}{2}v_2^2 + \frac{P_2}{\rho} + gZ_2$$

This equation can be satisfied at two distinct sectional areas along the stream tube and of course be satisfied at two distinct points along stream line.

We can further assume: internal energy keeps constant because of no heat transfer and friction involved, and there is no (or negligible) elevation change, i.e, $e_1=e_1$, and $Z_1=Z_2$.

Hence we obtain the following result which is important to introduce the orifice flow equation and the dimensional crack flow equation:

$$\frac{1}{2}v_1^2+\frac{P_1}{\rho} = \frac{1}{2}v_2^2+\frac{P_2}{\rho} \qquad [3.3]$$

In summary, to obtain the above equation [3.3], several important assumptions had to be applied to the basic energy conservation equation [3.1]:

(1) steady flow, $\partial/\partial t=0$

(2) incompressible flow, ρ=constant inside the stream tube

(3) frictionless flow, e=constant

(4) no elevation change, Z=constant

(5) no heat transfer involved, $|\vec{q}|=0$

(6) inviscid fluid, $\vec{P}_n=-\vec{P}\cdot n$, sometimes however, it is used to approximate viscid fluid flow, and

(7) uniform parameters at any two distinct sectional areas along small stream tube.

3.1.2. Application of Bernoulli equation to orifice flow

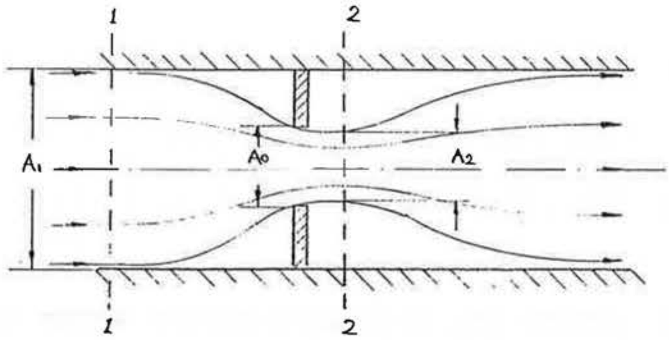

Figure 3-2. Orifice flow

As shown in the figure, the mainstream flow continues to accelerate from the orifice throat to form a vena contracta and then decelerates again to fill the duct. We set section (1) at a uniform flow inlet part. In the vena contracta section, the flow area is minimum, streamlines are essentially straight, and the pressure is uniform across the channel section. Hence section (2) is set at the vena contracta. Then the Bernoulli equation is applied in form of equation (3),

$$\frac{V_1^2}{2} + \frac{P_1}{\rho} = \frac{V_2^2}{2} + \frac{P_2}{\rho}$$

Using the continuity condition $V_1 \cdot A_1 = V_2 \cdot A_2$,

$$V_2 = \sqrt{\frac{2(P_1-P_2)}{\rho\left[1-\left(\frac{A_2}{A_1}\right)^2\right]}}$$

$$Q = A_2\,V_2 = A_2\sqrt{\frac{2(P_1-P_2)}{\rho\left[1-\left(\frac{A_2}{A_1}\right)^2\right]}}$$

There are the following four points which should be mentioned:

The section (2) area A_2 at the vena contracta is hard to measure. The location of the vena contracta section and the section area A_2 vary with flow conditions which might change with different test requirements. In practice, we may use orifice area A_0 instead of A_2.

Secondly, it is difficult to place pressure tap(s) exactly at the location of the vena contracta to measure P_2. The location of the pressure taps influences the empirically determined discharge coefficient C_d. For practical orifice measurement, location of the pressure taps consistent with C_d may be selected (Doebelin 1966, pp.466, Fox and McDonald 1978, pp.453).

Thirdly, we should note that the Bernoulli equation is derived from inviscid flow case. In order to expand it to viscid fluid, the internal friction which might cause actual velocity less than the ideal velocity should be included.

Furthermore, we have to use some coefficient(s) to correct for the differences caused by the above factors. Therefore contributed by these three factors, the discharge coefficient, C_d, may be introduced. The following equation may also be satisfied by C_d adjustment, hence

$$Q = C_d A_0 \sqrt{\frac{2(P_1-P_2)}{\rho\left[1-\left(\frac{A_0}{A_1}\right)^2\right]}} \qquad [3.4a]$$

If and only if $A_0 << A_1$, i.e, orifice area is much smaller than the duct section area, we get a simpler and common expression:

$$Q = C_d A_0 \sqrt{\frac{2\Delta P}{\rho}} \qquad [3.4b]$$

Equation [3.4b] is often called the orifice equation. It is obvious that equation [3.4b] is an approximation from equation [3.4a] by neglecting A_0/A_1. Hence the C_d value in equation [3.4b] is also affected by the value of A_0/A_1 which is neglected.

In conclusion, on the basis of the discussion above, the discharge coefficient C_d based on equation [3.4b] is influenced by:

a) A_2/A_0. In which A_2 varies with flow condition, therefore it is hard to measure

b) location of pressure taps

c) viscid friction

d) A_0/A_1, denoted by β, which can be determined by the structure itself and does not vary with flow condition.

We may write C_d as the following function:

$C_d = f(A_2/A_0, \text{tap location, viscid friction}, \beta)$

If and only if the tap locations have been determined, it can be written as:

$C_d = f(A_2/A_0, \text{viscid friction}, \beta)$,

It is known that the Reynold number, Re, can be written as: $Re=(\bar{V}\cdot D_h)/\nu=(Q\cdot D_h)/(A\cdot \nu)$. It involves the flow condition, the viscid friction and the geometry terms. As noted in point a) above, A_2/A_0 varies with flow condition. Hence a more general expression for C_d is, $C_d=f(Re,\beta)$, if and only if the location of pressure taps has been determined (Fox and McDonald 1978, Doebelin 1966).

D_h is the hydraulic diameter and ν is viscosity.

3.1.3 Application of orifice equation to crack flow

The equation [3-4b], called the orifice equation, is widely applied to crack flow studies and is considered as a fundamental equation, although the power equation is more commonly used (ASHRAE Handbook Fundamentals 1989, pp.23.6 & 23.11). But it is a way for us to treat the crack flow problem more analytically than empirically.

Crack flow is much more complicated than orifice flow either in geometry or in flow model. There are several things which cause the difference. One is that we assume the flow length in orifice flow is zero while in real crack flow it typically is not. Secondly in orifice flow, we neglect the viscid friction and assume $P/\rho+\frac{1}{2}V\cdot V$ is constant along the stream tube, and the friction effect is simply contributed to the C_d term; while in crack flow, the $P/\rho+\frac{1}{2}V\cdot V$ values across the crack might be significantly different and there may be better ways to describe them. Thirdly, the relation that Q is proportional to $\sqrt{\Delta P}$ may be suitable for orifice flow only, but it is really a restriction for crack flow because it just covers a square root relationship of Q-ΔP, it is lack of generality of application.

3.1.4 Application of Bernoulli equation to crack flow

For orifice flow we neglect the effect of friction in the derivation and treat the flow length as zero. But for crack flow we are concerned with the geometry of the crack channel which causes an amount of pressure loss due to friction. It is commonly called "Head loss".

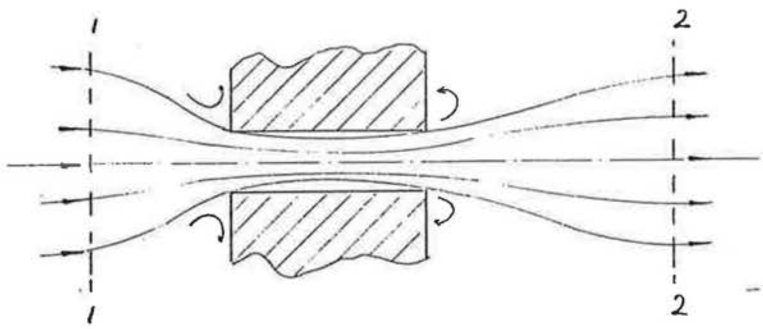

Figure 3-3. Crack flow

To simplify the analysis, the total head loss denoted by h_t may be divided into major loss, denoted by h_m, and minor loss, denoted by h_n. See Figure 3-4 (Fox and McDonald 1978, pp.369), note that the entrance length for the developing section is estimated by the formula of, $L \approx 0.06\ Re \cdot D_h$,

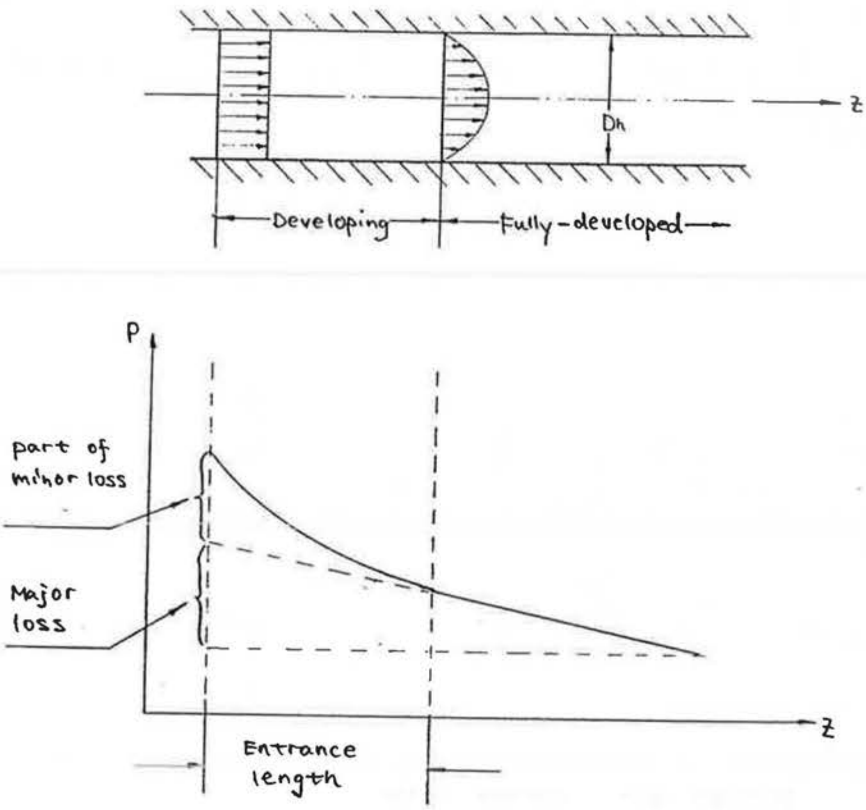

Figure 3-4. Variation of static pressure in a pipe inlet section (From Fox and McDonald 1973)

The major loss h_m is due to friction in fully-developed laminar flow in constant area portions of the system. The minor loss h_n is due to the difference between fully-developed laminar and developing laminar flow, bends, entrance and exit losses, and any other nonconstant area frictional effects. Refer to Figure 3-3, we have:

$$\left(\frac{V_1^2}{2}+\frac{P_1}{\rho}\right)-\left(\frac{V_2^2}{2}+\frac{P_2}{\rho}\right)=h_T=h_m+h_n \qquad [3.5]$$

It is obvious that if we assume no flow length (which means no developing and developed regimes, and no pressure drops on the length), no inlet-outlet and no bends, the total head loss h_t will be zero. Then equation [3.5] reduces to the Bernoulli equation.

Let us first find the major loss expression due to friction in a constant sectional area crack with fully-developed laminar flow, $A_1=A_2$, hence $V_1=V_2$ from continuity, also with $h_n=0$. Therefore, $(P_1-P_2)/\rho=h_t=h_m$ for fully-developed flow in a constant area crack.

Based on this condition, we can easily obtain the h_m expression for fully-developed laminar flow for regular geometry channels such as infinite parallel plate and circular opening flows with the derivation from basic fluid mechanics theory. The following is the derivation for the fully-developed laminar flow for infinite parallel plate with a limited width as shown in Figure 3-5 as the first example, this result can also be applied to the rectangular channel with small aspect ratios:

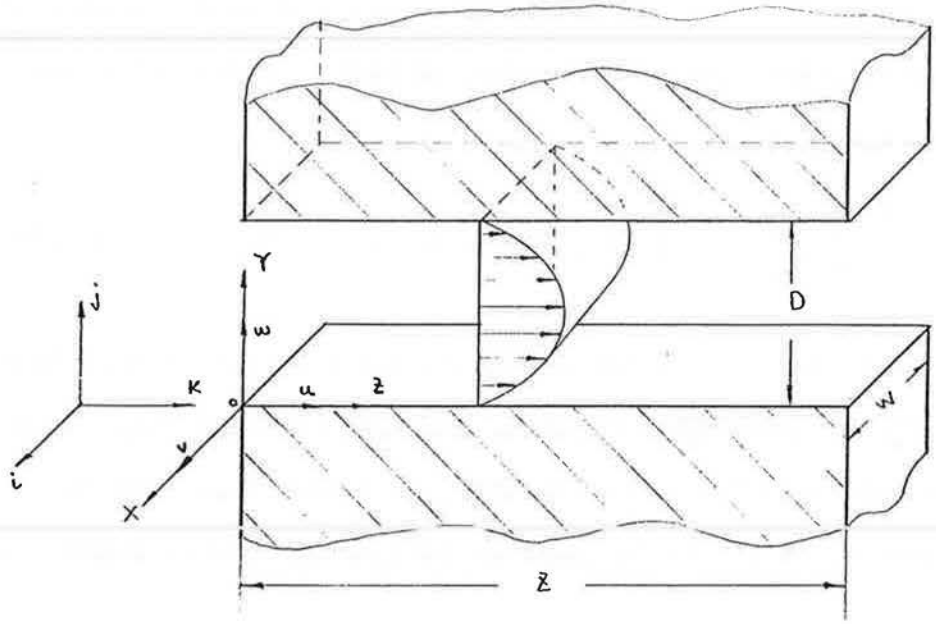

Figure 3-5. Laminar flow between infinite parallel plates

The Navier-Stokes equation for laminar viscid flow is (Currie 1974, pp.220-225):

$$\frac{\partial \vec{V}}{\partial t} + (\vec{V} \cdot \nabla)\vec{V} = -\frac{1}{\rho}\nabla P + \nu \nabla^2 \vec{V} + \vec{f}$$

where

$\vec{V}$---velocity vector

P---pressure

$\vec{f}$---body force ($=-\vec{g}$, gravity vector)

t---time

ρ---air density

μ---dynamic viscosity.

Using the following assumptions:

1) steady flow $\partial/\partial t=0$

2) one dimension flow $\vec{V}=u\vec{k}$,ie, $u=u(y), v=0, w=0$

3) since no flow in x, y directions, $P=P(z)$

4) body force (gravity) is negligible , $|\vec{f}|=0$

5) boundary condition, $u(0)=0,\ u(D)=0$

6) pressure is linear distribution in flow direction,

$dP/dz = -\Delta P/Z$

Hence

$$(\vec{V}\cdot\nabla)\vec{V} = (u\vec{k}\cdot\frac{\partial}{\partial z}\vec{k})\,u\vec{k} = 0 \qquad (\ u=u(y)\ )$$

$$\nabla P = \frac{\partial P}{\partial x}\vec{i} + \frac{\partial P}{\partial y}\vec{j} + \frac{\partial P}{\partial z}\vec{k} = \frac{dP}{dz}\vec{k} \qquad (\ P=P(z)\ )$$

$$\nabla^2\vec{V} = \frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} + \frac{\partial^2 u}{\partial z^2} \qquad (\ \vec{V}=u\vec{k}\ )$$

$$= \frac{d^2u}{dy^2} \qquad (\ u=u(y)\ )$$

$$\frac{\partial\vec{V}}{\partial t} = 0 \qquad (\ \text{Steady flow: } \frac{\partial}{\partial t} = 0\ )$$

Therefore the Navier-Stokes equation reduces to be:

$$0 = \frac{1}{\rho}\left(-\frac{dP}{dz}\right) + \mu\left(\frac{d^2u}{dy^2}\right)$$

By integrating the velocity variable u with respect to y twice, then a fully-developed laminar velocity profile is given:

$$u(y) = \frac{1}{\mu}\frac{dP}{dz}\left(\frac{y^2}{2} + Ay + B\right)$$

Applying the boundary conditions to determine integration constants A and B

$$\begin{cases} u(0) = 0 \quad , B = 0 \\ u(y) = 0 \quad , A = -\left(\frac{D}{2\mu}\right)\frac{dP}{dz} \end{cases}$$

Then,

$$u(y) = \frac{1}{2\mu}\frac{dP}{dz}\, y(y-D)$$

Assuming that the width of the infinite parallel is w, then the volumetric flow rate Q for the rectangular channel with a small ratio is:

$$Q = \int_0^w \int_0^d u(y)\, dy\, dx = -\frac{b^3 w}{12\mu}\frac{dP}{dz} = \frac{D^3 w}{12\mu}\frac{\Delta P}{Z}$$

Average velocity $\bar{V}$:

$$\bar{V} = \frac{Q}{A} = \frac{Q}{wD} = \frac{D^2}{12\mu}\frac{\Delta P}{Z}$$

$$\Delta P = \frac{12\mu Z\bar{V}}{D^2}$$

Applying hydraulic diameter D_h=2D for parallel plates:

$$\Delta P = \frac{48\mu Z\bar{V}}{D_h^2}$$

Using major loss expression $h_m=\Delta P/\rho$

$$h_m = \frac{48\nu Z\bar{V}}{D_h^2} = \frac{96\ Z}{\left(\frac{\bar{V}D_h}{\nu}\right)D_h}\frac{\bar{V}^2}{2} = \frac{96\ Z}{Re\,D_h}\frac{\bar{V}^2}{2}$$

Using a similar method for fully-developed laminar flow in a circular pipe, we obtain:

$$h_m = \frac{64\ Z}{Re\,D_h}\frac{\bar{V}^2}{2}$$

where $D_h=D$ for the circular case.

In general, we find the difference existing in the major loss expression for rectangular or circular openings is the coefficient only. We may define B as friction coefficient and f as friction factor for the fully-developed laminar flow of any type of crack as:

$$h_m = \frac{B}{Re}\frac{Z}{D_h}\frac{\bar{V}^2}{2} = f\frac{Z}{D_h}\frac{\bar{V}^2}{2}$$

This is the form for the major loss for fully-developed laminar flow; where f=B/Re, B=64 for circular pipe, B=96 for rectangular channel and friction factor f is linear with the Re number.

We note that sometimes when the pressure drop across an orifice, pipe or even building components is higher, the Re number may be in the turbulent regime in which case the friction factor, f, will not be linearly related to the Re number. There are several empirical correlations for different cases (Fox and McDonald 1978, pp.467):

For turbulent flow in smooth pipes (Re ≤ 100,000), the Blasius correlation is:

$$f = \frac{0.316}{Re^{0.25}}$$

For turbulent flow in the fully-rough flow regime, the Von Karman correlation is (e/D is the relative roughness, see details in Fox and McDonald 1978 pp. 467):

$$f = \frac{1}{4\left[0.57 - \log_{10}\left(\frac{e}{D}\right)\right]^2}$$

Actually for most medium-roughness pipes, the correlation curves of the friction factor may be found numerically (see Figure 8.12 in Fox and McDonald 1978).

In summary, the general form for the major loss is:

$$h_m = f \frac{Z}{D_h} \frac{\bar{V}^2}{2}$$

Where for fully-developed laminar cases: f=64/Re and f=96/Re for circular and rectangular pipes respectively. For flow in the turbulent regime, f depends on the relative roughness (using Blasius or Von Karman correlations or others) and the Re number.

We then consider minor loss which is due to inlet-outlet loss, hydrodynamic development loss, section area change, the roughness of internal surface and bends. Because it has such a large variation and is affected by so many factors, the minor loss, in practice, is impossible to be theoretically estimated. However, we might express minor head loss as:

$$h_n = K \frac{\bar{V}^2}{2}$$

K is called the minor loss coefficient, which must be determined experimentally for each case or each similar group. Some suggested K values can be found in the literature for pipe entrances, exits, enlargements and contractions, gradual contraction and bends (Fox and McDonald 1978, pp.368-374).

In conclusion

$$\frac{\Delta P}{\rho} = h_T = h_m + h_n = \frac{B}{Re} \frac{Z}{D_h} \frac{\bar{V}^2}{2} + K \frac{\bar{V}^2}{2}$$

An alternative form with dimensionless pressure drop expression of the above equation can be written as:

$$\frac{\Delta P}{\frac{1}{2}\rho \overline{V}^2} = \frac{B}{Re}\frac{Z}{D_h} + K \qquad [3.6]$$

where

$\frac{\Delta P}{\frac{1}{2}\rho \overline{V}^2}$ --- the dimensionless pressure drop

$\frac{BZ}{ReD_h}$ --- the dimensionless major loss coefficient due to frictional effects in fully-developed flow in constant area opening.

K --- the dimensionless minor loss coefficient due to the difference between fully-developed and developing flow, inlet and outlet losses, area changes and bends.

The equation [3.6] is called the dimensionless crack flow equation. The derivation of the equation in this way may be more stringent than other approaches used, such as the power model or the orifice model. A number of researchers have applied this dimensionless crack flow equation (Hopkins and Hansford 1974, Etheridge 1977, Kronvall 1980 and Chastain et al.1987).

APPENDIX F

Definition and Combination of Crack/Position Coding

Definition and Combination of Crack/Position Coding

1) Individual Crack

Crack	A	B1	B2	E	F1	F2
Name (Outer Layer)	A-1	B1-1	B2-1	E-1	F1-1	F2-1
Name (Inner Layer)	A-2	B1-2	B2-2	E-2	F1-2	F2-2

Note: Refer to Figure 4.2.2 for placement location and Table 4.1 for dimensions of the individual cracks.

2) Parallel Connection

Parallel Type	A and B1	A and E	A and F1	B1 and B2	B1 and F1	B1 and E	F1 and F2
Name	A@B1	A@E	A@F1	B1@B2	B1@F1	B1@E	F1@F2

3) Series Connection

Inner	A	B1	B1	E	E	F1	F1
Outer	B1	A	E1	B1	F1	B1	E
Name	A~B1	B1~A	B1~E1	E~B1	E~F1	F1~B1	F1~E

APPENDIX G

Data Tables for Individual Openings

Crack Leakage Calculation By Individual Crack : A-1

Pressure Difference Across Crack		Flow Rate						Power Model Predicted Q	New Model Predicted Q
		Rep.1	Rep.2	Rep.3	System Leak	Corrected Mean			
(in.Wg)	(Pa)	(cfm)	(cfm)	(cfm)	(cfm)	(cfm)	(m^3/sec.)	(m^3/sec.)	(m^3/sec.)
0.02	5	0.82	0.82	0.92	0.40	0.46	0.00022	0.00022	0.00021
0.04	10	1.37	1.38	1.37	0.56	0.82	0.00039	0.00040	0.00041
0.06	15	1.91	1.87	1.98	0.68	1.24	0.00059	0.00057	0.00058
0.08	20	2.35	2.36	2.42	0.78	1.60	0.00075	0.00072	0.00075
0.10	25	2.81	2.75	2.81	0.87	1.92	0.00091	0.00088	0.00091
0.12	30	3.18	3.19	3.18	0.95	2.23	0.00105	0.00102	0.00105
0.14	35	3.54	3.55	3.60	1.03	2.54	0.00120	0.00117	0.00120
0.16	40	3.91	3.92	3.96	1.10	2.83	0.00134	0.00131	0.00133
0.18	45	4.25	4.25	4.30	1.16	3.11	0.00147	0.00144	0.00146
0.20	50	4.53	4.60	4.58	1.22	3.34	0.00158	0.00158	0.00158
0.22	55	4.86	4.87	4.97	1.28	3.62	0.00171	0.00171	0.00171
0.24	60	5.13	5.14	5.23	1.34	3.83	0.00181	0.00184	0.00182
0.26	65	5.45	5.50	5.51	1.39	4.10	0.00193	0.00197	0.00193
0.28	70	5.77	5.78	5.82	1.44	4.34	0.00205	0.00210	0.00204
0.30	75	6.07	6.05	6.12	1.49	4.59	0.00216	0.00223	0.00215
0.32	80	6.28	6.30	6.34	1.54	4.76	0.00225		
0.34	85	6.53	6.55	6.69	1.59	4.97	0.00234		
0.36	90	6.79	6.76	6.88	1.63	5.18	0.00244	C = 5.7E-05	C1 = 4.00E-04
0.38	95	7.04	7.10	7.14	1.68	5.42	0.00256		
0.40	100	7.29	7.31	7.42	1.72	5.62	0.00265		C2 = 4.77
0.42	105	7.57	7.64	7.70	1.76	5.88	0.00277	n = 0.8489	
0.44	110	7.82	7.88	7.87	1.80	6.05	0.00286		C3 = 1.07
0.46	115	8.01	8.11	8.16	1.84	6.25	0.00295		
0.48	120	8.33	8.26	8.35	1.88	6.43	0.00304	C.V.= 2.6485 (%)	C.V.= 0.6518 (%)
0.5	125	8.58	8.59	8.62	1.92	6.68	0.00315		

Crack Leakage Calculation By Individual Crack : A-2

Pressure Difference Across Crack		Flow Rate						Power Model Predicted Q	New Model Predicted Q
		Rep.1	Rep.2	Rep.3	System Leak	Corrected Mean			
(in.Wg)	(Pa)	(cfm)	(cfm)	(cfm)	(cfm)	(cfm)	(m^3/sec.)	(m^3/sec.)	(m^3/sec.)
0.02	5	0.62	0.70	0.62	0.40	0.25	0.00012	0.00015	0.00017
0.04	10	1.22	1.22	1.22	0.56	0.66	0.00031	0.00029	0.00032
0.06	15	1.63	1.71	1.63	0.68	0.98	0.00046	0.00043	0.00047
0.08	20	2.10	2.03	2.03	0.78	1.27	0.00060	0.00056	0.00060
0.10	25	2.51	2.45	2.45	0.87	1.60	0.00075	0.00069	0.00073
0.12	30	2.84	2.80	2.86	0.95	1.88	0.00089	0.00082	0.00085
0.14	35	3.17	3.12	3.13	1.03	2.11	0.00100	0.00095	0.00097
0.16	40	3.33	3.43	3.34	1.10	2.27	0.00107	0.00108	0.00109
0.18	45	3.69	3.73	3.65	1.16	2.52	0.00119	0.00121	0.00119
0.20	50	3.87	4.03	3.89	1.22	2.71	0.00128	0.00133	0.00130
0.22	55	4.23	4.28	4.23	1.28	2.96	0.00140	0.00146	0.00140
0.24	60	4.51	4.56	4.46	1.34	3.17	0.00150	0.00158	0.00150
0.26	65	4.75	4.79	4.74	1.39	3.36	0.00159	0.00171	0.00160
0.28	70	5.02	5.07	5.02	1.44	3.59	0.00170	0.00183	0.00169
0.30	75	5.30	5.29	5.24	1.49	3.78	0.00179	0.00196	0.00178
0.32	80	5.37	5.52	5.37	1.54	3.88	0.00183		
0.34	85	5.69	5.65	5.65	1.59	4.08	0.00192		
0.36	90	6.00	5.91	5.95	1.63	4.32	0.00204	C = 3.3E-05	C1 = 4.00E-04
0.38	95	6.12	6.08	6.13	1.68	4.43	0.00209		
0.40	100	6.29	6.33	6.29	1.72	4.58	0.00216		C2 = 4.76
0.42	105	6.40	6.46	6.42	1.76	4.67	0.00220	n = 0.9455	
0.44	110	6.76	6.76	6.71	1.80	4.94	0.00233		C3 = 0.83
0.46	115	7.01	6.97	6.97	1.84	5.14	0.00243		
0.48	120	7.05	7.17	7.08	1.88	5.22	0.00246	C.V.= 8.0702 (%)	C.V.= 2.0118 (%)
0.5	125	7.29	7.29	7.25	1.92	5.36	0.00253		

Crack Leakage Calculation By Individual Crack : B1-1

Pressure Difference Across Crack (in.Wg)	(Pa)	Flow Rate: Rep.1 (cfm)	Rep.2 (cfm)	Rep.3 (cfm)	System Leak (cfm)	Corrected Mean (cfm)	Corrected Mean (m^3/sec.)	Power Model Predicted Q (m^3/sec.)	New Model Predicted Q (m^3/sec.)
0.02	5	2.52	2.83	2.58	0.40	2.25	0.00106	0.00108	0.00097
0.04	10	4.19	4.31	4.15	0.56	3.66	0.00173	0.00173	0.00169
0.06	15	5.55	5.65	5.47	0.68	4.88	0.00230	0.00228	0.00228
0.08	20	6.68	6.82	6.63	0.78	5.93	0.00280	0.00276	0.00280
0.10	25	7.75	7.91	7.66	0.87	6.90	0.00326	0.00321	0.00327
0.12	30	8.57	8.81	8.53	0.95	7.68	0.00363	0.00363	0.00370
0.14	35	9.56	9.80	9.48	1.03	8.59	0.00405	0.00403	0.00410
0.16	40	10.50	10.57	10.30	1.10	9.36	0.00442	0.00441	0.00448
0.18	45	11.22	11.44	11.14	1.16	10.11	0.00477	0.00478	0.00483
0.20	50	11.93	12.19	11.85	1.22	10.76	0.00508	0.00513	0.00516
0.22	55	12.73	13.13	12.76	1.28	11.59	0.00547	0.00547	0.00548
0.24	60	13.49	13.95	13.46	1.34	12.30	0.00580	0.00580	0.00579
0.26	65	14.06	14.56	14.06	1.39	12.84	0.00606	0.00612	0.00609
0.28	70	14.81	15.26	14.81	1.44	13.51	0.00638	0.00644	0.00637
0.30	75	15.59	15.99	15.61	1.49	14.24	0.00672	0.00674	0.00665
0.32	80	16.05	16.64	16.05	1.54	14.70	0.00694		
0.34	85	16.84	17.39	16.77	1.59	15.41	0.00727		
0.36	90	17.32	17.85	17.34	1.63	15.87	0.00749		
0.38	95	18.01	18.65	17.98	1.68	16.54	0.00780		
0.40	100	18.71	19.28	18.69	1.72	17.17	0.00811		
0.42	105	19.41	19.84	19.37	1.76	17.78	0.00839		
0.44	110	19.96	20.52	19.89	1.80	18.32	0.00865		
0.46	115	20.06	21.20	20.54	1.84	18.76	0.00885		
0.48	120	21.20	21.60	21.08	1.88	19.41	0.00916		
0.5	125	21.70	22.39	21.60	1.92	19.98	0.00943		

Power Model: C = 3.66E-04, n = 0.6749, C.V. = 0.8202 (%)

New Model: C1 = 8.50E-04, C2 = 2.23, C3 = 1.28, C.V. = 1.5074 (%)

Crack Leakage Calculation By Individual Crack : B1-2

Pressure Difference Across Crack (in.Wg)	(Pa)	Flow Rate: Rep.1 (cfm)	Rep.2 (cfm)	Rep.3 (cfm)	System Leak (cfm)	Corrected Mean (cfm)	Corrected Mean (m^3/sec.)	Power Model Predicted Q (m^3/sec.)	New Model Predicted Q (m^3/sec.)
0.02	5	2.33	2.33	2.46	0.40	1.98	0.00093	0.00096	0.00088
0.04	10	3.86	3.18	3.97	0.56	3.11	0.00147	0.00154	0.00153
0.06	15	5.13	5.18	5.23	0.68	4.50	0.00212	0.00203	0.00207
0.08	20	6.14	6.19	6.19	0.78	5.39	0.00254	0.00248	0.00254
0.10	25	7.04	7.13	7.15	0.87	6.24	0.00294	0.00289	0.00296
0.12	30	7.99	8.03	8.08	0.95	7.08	0.00334	0.00327	0.00334
0.14	35	8.83	8.83	8.92	1.03	7.83	0.00370	0.00363	0.00370
0.16	40	9.56	9.67	9.62	1.10	8.52	0.00402	0.00398	0.00404
0.18	45	10.28	10.40	10.40	1.16	9.20	0.00434	0.00432	0.00436
0.20	50	10.86	11.10	11.10	1.22	9.79	0.00462	0.00464	0.00466
0.22	55	11.57	11.65	11.65	1.28	10.34	0.00488	0.00495	0.00494
0.24	60	12.35	12.43	12.47	1.34	11.08	0.00523	0.00526	0.00522
0.26	65	12.97	12.86	12.97	1.39	11.54	0.00545	0.00555	0.00549
0.28	70	13.54	13.80	13.73	1.44	12.24	0.00578	0.00584	0.00574
0.30	75	14.19	14.22	14.26	1.49	12.73	0.00601	0.00613	0.00599
0.32	80	14.88	14.75	14.96	1.54	13.32	0.00629		
0.34	85	15.44	15.41	15.52	1.59	13.87	0.00655		
0.36	90	15.91	15.97	15.93	1.63	14.30	0.00675		
0.38	95	16.54	16.58	16.58	1.68	14.89	0.00703		
0.40	100	17.05	17.08	17.12	1.72	15.36	0.00725		
0.42	105	17.63	17.72	17.70	1.76	15.92	0.00751		
0.44	110	18.05	18.12	18.09	1.80	16.29	0.00769		
0.46	115	18.55	18.75	18.63	1.84	16.80	0.00793		
0.48	120	19.18	19.22	19.25	1.88	17.34	0.00818		
0.5	125	19.54	19.68	19.68	1.92	17.71	0.00836		

Power Model: C = 3.18E-04, n = 0.6852, C.V. = 1.9047 (%)

New Model: Cf = 8.50E-04, C2 = 1.96, C3 = 1.03, C.V. = 1.0089 (%)

Crack Leakage Calculation By Individual Crack : B2-1

Pressure Difference Across Crack (in.Wg)	(Pa)	Flow Rate Rep.1 (cfm)	Rep.2 (cfm)	Rep.3 (cfm)	System Leak (cfm)	Corrected Mean (cfm)	Corrected Mean (m^3/sec.)	Power Model Predicted Q (m^3/sec.)	New Model Predicted Q (m^3/sec.)
0.02	5	2.42	2.36	2.16	0.40	1.92	0.00090	0.00093	0.00083
0.04	10	3.80	3.80	3.63	0.56	3.19	0.00150	0.00150	0.00146
0.06	15	4.99	4.99	4.74	0.68	4.23	0.00200	0.00198	0.00199
0.08	20	6.13	5.99	5.73	0.78	5.17	0.00244	0.00242	0.00245
0.10	25	7.05	7.05	6.80	0.87	6.10	0.00288	0.00282	0.00287
0.12	30	7.89	7.89	7.56	0.95	6.83	0.00322	0.00320	0.00325
0.14	35	8.79	8.62	8.43	1.03	7.59	0.00358	0.00355	0.00361
0.16	40	9.59	9.46	9.06	1.10	8.27	0.00390	0.00390	0.00394
0.18	45	10.28	10.20	9.87	1.16	8.95	0.00423	0.00423	0.00426
0.20	50	11.05	11.01	10.56	1.22	9.65	0.00455	0.00454	0.00456
0.22	55	11.61	11.68	11.26	1.28	10.23	0.00483	0.00485	0.00484
0.24	60	12.35	12.30	12.01	1.34	10.88	0.00514	0.00515	0.00512
0.26	65	13.11	12.99	12.48	1.39	11.47	0.00541	0.00545	0.00538
0.28	70	13.71	13.65	13.06	1.44	12.03	0.00568	0.00573	0.00564
0.30	75	14.29	14.21	13.64	1.49	12.55	0.00592	0.00601	0.00589
0.32	80	[illegible]	[illegible]	14.25	1.54	13.10	0.00618		
0.34	85	15.51	15.47	14.88	1.59	13.70	0.00647		
0.36	90	16.06	16.19	15.50	1.63	14.28	0.00674	C = 3.06E-04	C1 = 8.50E-04
0.38	95	16.68	16.60	15.95	1.68	14.73	0.00695		
0.40	100	17.15	17.17	16.52	1.72	15.23	0.00719		C2 = 2.17
0.42	105	17.79	17.68	17.07	1.76	15.75	0.00743	n = 0.6897	
0.44	110	18.35	18.32	17.64	1.80	16.30	0.00769		C3 = 1.04
0.46	115	18.81	18.91	18.15	1.84	16.78	0.00792		
0.48	120	19.30	19.41	18.58	1.88	17.22	0.00813	C.V.= 1.0208 (%)	C.V.= 0.9215 (%)
0.5	125	20.03	19.90	19.33	1.92	17.84	0.00842		

Crack Leakage Calculation By Individual Crack : B2-2

Pressure Difference Across Crack (in.Wg)	(Pa)	Flow Rate Rep.1 (cfm)	Rep.2 (cfm)	Rep.3 (cfm)	System Leak (cfm)	Corrected Mean (cfm)	Corrected Mean (m^3/sec.)	Power Model Predicted Q (m^3/sec.)	New Model Predicted Q (m^3/sec.)
0.02	5	2.16	2.16	2.16	0.40	1.76	0.00083	0.00087	0.00081
0.04	10	3.63	3.49	3.43	0.56	2.96	0.00140	0.00141	0.00141
0.06	15	4.69	4.69	4.74	0.68	4.03	0.00190	0.00188	0.00192
0.08	20	5.77	5.77	5.78	0.78	4.99	0.00236	0.00230	0.00236
0.10	25	6.71	6.76	6.75	0.87	5.87	0.00277	0.00269	0.00276
0.12	30	7.59	7.51	7.47	0.95	6.57	0.00310	0.00305	0.00313
0.14	35	8.43	8.38	8.34	1.03	7.36	0.00347	0.00340	0.00347
0.16	40	9.10	9.15	9.15	1.10	8.04	0.00379	0.00374	0.00379
0.18	45	9.78	9.87	9.81	1.16	8.66	0.00409	0.00406	0.00409
0.20	50	10.46	10.62	10.63	1.22	9.35	0.00441	0.00437	0.00438
0.22	55	11.04	11.23	11.24	1.28	9.89	0.00467	0.00467	0.00466
0.24	60	11.35	11.75	11.83	1.34	10.30	0.00486	0.00497	0.00492
0.26	65	12.15	12.37	12.41	1.39	10.92	0.00515	0.00526	0.00517
0.28	70	12.92	12.92	12.91	1.44	11.47	0.00541	0.00554	0.00542
0.30	75	13.49	13.53	13.49	1.49	12.01	0.00567	0.00581	0.00565
0.32	80	14.06	14.13	14.13	1.54	12.56	0.00593		
0.34	85	14.66	14.73	14.73	1.59	13.12	0.00619		
0.36	90	15.15	15.33	15.33	1.63	13.64	0.00644	C = 2.80E-04	C1 = 8.50E-04
0.38	95	15.73	15.70	15.70	1.68	14.03	0.00662		
0.40	100	16.25	16.36	16.38	1.72	14.61	0.00690		C2 = 2.03
0.42	105	16.75	16.69	16.72	1.76	14.96	0.00706	n = 0.7025	
0.44	110	17.30	17.23	17.30	1.80	15.47	0.00730		C3 = 0.95
0.46	115	17.77	17.74	17.80	1.84	15.93	0.00752		
0.48	120	18.30	18.29	18.33	1.88	16.43	0.00775	C.V.= 2.2226 (%)	C.V.= 0.6390 (%)
0.5	125	18.72	18.69	18.75	1.92	16.80	0.00793		

Crack Leakage Calculation By Individual Crack : E-1

Pressure Difference Across Crack (in.Wg)	(Pa)	Flow Rate: Rep.1 (cfm)	Rep.2 (cfm)	Rep.3 (cfm)	System Leak (cfm)	Corrected Mean (cfm)	Corrected Mean (m^3/sec.)	Power Model Predicted Q (m^3/sec.)	New Model Predicted Q (m^3/sec.)
0.02	5	13.33	12.48	13.60	0.40	12.74	0.00601	0.00621	0.00623
0.04	10	19.72	19.07	20.30	0.56	19.14	0.00903	0.00897	0.00906
0.06	15	24.41	23.85	25.26	0.68	23.83	0.01125	0.01113	0.01123
0.08	20	28.49	28.15	29.40	0.78	27.90	0.01317	0.01297	0.01306
0.10	25	32.46	31.71	32.88	0.87	31.48	0.01486	0.01460	0.01468
0.12	30	35.32	35.27	35.71	0.95	34.48	0.01627	0.01608	0.01614
0.14	35	38.26	37.86	38.75	1.03	37.26	0.01759	0.01746	0.01749
0.16	40	41.06	40.54	41.29	1.10	39.87	0.01881	0.01874	0.01874
0.18	45	43.62	43.00	43.83	1.16	42.32	0.01997	0.01995	0.01991
0.20	50	45.72	45.68	45.94	1.22	44.56	0.02103	0.02110	0.02103
0.22	55	48.21	47.84	48.62	1.28	46.94	0.02215	0.02220	0.02208
0.24	60	50.30	49.94	50.60	1.34	48.94	0.02310	0.02325	0.02309
0.26	65	52.62	51.87	52.32	1.39	50.88	0.02401	0.02426	0.02406
0.28	70	54.11	54.05	54.39	1.44	52.74	0.02489	0.02523	0.02499
0.30	75	56.32	56.17	56.61	1.49	54.88	0.02590	0.02617	0.02589
0.32	80	58.21	57.87	57.82	1.54	56.42	0.02663		
0.34	85	60.15	59.63	69.76	1.59	58.26	0.02749		
0.36	90	61.77	61.44	61.30	1.63	59.87	0.02826		
0.38	95	63.71	63.13	62.99	1.68	61.60	0.02907		
0.40	100	65.36	64.86	64.90	1.72	63.32	0.02988		
0.42	105	67.08	66.67	66.64	1.76	65.03	0.03069		
0.44	110	68.69	68.28	67.98	1.80	66.52	0.03139		
0.46	115	70.33	69.93	69.65	1.84	68.13	0.03215		
0.48	120	71.88	71.65	71.04	1.88	69.65	0.03287		
0.5	125	73.33	73.02	72.35	1.92	70.98	0.03350		

Power Model			New Model		
C =	0.00264		C1 =	3.145E-03	
			C2 =	0.21	
n =	0.5313				
			C3 =	0.95	
C.V.=	1.0927	(%)	C.V.=	0.5853	(%)

Crack Leakage Calculation By Individual Crack : E-2

Pressure Difference Across Crack (in.Wg)	(Pa)	Flow Rate: Rep.1 (cfm)	Rep.2 (cfm)	Rep.3 (cfm)	System Leak (cfm)	Corrected Mean (cfm)	Corrected Mean (m^3/sec.)	Power Model Predicted Q (m^3/sec.)	New Model Predicted Q (m^3/sec.)
0.02	5	12.16	12.16	12.76	0.40	11.97	0.00565	0.00586	0.00589
0.04	10	18.41	18.62	18.84	0.56	18.06	0.00853	0.00854	0.00867
0.06	15	23.47	23.64	24.00	0.68	23.03	0.01087	0.01065	0.01081
0.08	20	27.67	27.50	27.82	0.78	26.88	0.01269	0.01245	0.01261
0.10	25	31.12	31.40	31.26	0.87	30.39	0.01434	0.01406	0.01420
0.12	30	34.45	34.30	34.58	0.95	33.49	0.01581	0.01553	0.01564
0.14	35	37.32	37.44	37.44	1.03	36.37	0.01717	0.01689	0,01696
0.16	40	39.79	40.03	40.14	1.10	38.89	0.01835	0.01816	0.01819
0.18	45	42.16	42.13	42.39	1.16	41.06	0.01938	0.01936	0.01934
0.20	50	44.54	44.64	44.75	1.22	43.42	0.02049	0.02050	0.02044
0.22	55	46.73	46.72	47.05	1.28	45.55	0.02150	0.02159	0.02148
0.24	60	48.86	49.06	48.85	1.34	47.58	0.02246	0.02264	0.02247
0.26	65	50.71	50.91	51.02	1.39	49.49	0.02336	0.02365	0.02343
0.28	70	52.63	52.82	52.82	1.44	51.31	0.02422	0.02462	0.02434
0.30	75	54.68	54.78	54.88	1.49	53.29	0.02515	0.02556	0.02523
0.32	80	56.69	56.77	56.78	1.54	55.21	0.02606		
0.34	85	58.39	58.37	58.57	1.59	56.85	0.02683		
0.36	90	60.23	60.29	60.31	1.63	58.64	0.02768		
0.38	95	61.75	61.81	62.09	1.68	60.21	0.02842		
0.40	100	63.69	63.58	63.68	1.72	61.93	0.02923		
0.42	105	65.25	65.07	65.50	1.76	63.51	0.02998		
0.44	110	67.15	66.94	67.12	1.80	65.27	0.03080		
0.46	115	68.65	68.28	68.63	1.84	66.68	0.03147		
0.48	120	69.80	69.94	69.88	1.88	67.99	0.03209		
0.5	125	71.60	71.47	71.58	1.92	69.63	0.03286		

Power Model			New Model		
C =	0.00244		C1 =	3.145E-03	
			C2 =	0.29	
n =	0.5441				
			C3 =	0.92	
C.V.=	1.5057	(%)	C.V.=	0.7912	(%)

Crack Leakage Calculation By Individual Crack : F1-1

Pressure Difference Across Crack (in.Wg)	(Pa)	Flow Rate: Rep.1 (cfm)	Rep.2 (cfm)	Rep.3 (cfm)	System Leak (cfm)	Corrected Mean (cfm)	Corrected Mean (m^3/sec.)	Power Model Predicted Q (m^3/sec.)	New Model Predicted Q (m^3/sec.)
0.02	5	34.22	32.43	27.13	0.40	30.86	0.01457	0.01484	0.01489
0.04	10	47.11	47.10	42.95	0.56	45.17	0.02132	0.02131	0.02149
0.06	15	58.89	57.81	54.33	0.68	56.33	0.02659	0.02633	0.02655
0.08	20	67.96	66.98	64.60	0.78	65.73	0.03102	0.03059	0.03082
0.10	25	75.48	74.90	72.12	0.87	73.30	0.03459	0.03437	0.03459
0.12	30	82.69	82.41	79.28	0.95	80.51	0.03800	0.03780	0.03799
0.14	35	89.66	88.89	86.46	1.03	87.31	0.04120	0.04096	0.04112
0.16	40	95.71	94.98	92.43	1.10	93.28	0.04402	0.04392	0.04403
0.18	45	101.00	100.76	98.53	1.16	98.94	0.04669	0.04670	0.04676
0.20	50	106.71	106.04	104.35	1.22	104.48	0.04931	0.04934	0.04935
0.22	55	112.17	111.54	109.06	1.28	109.64	0.05175	0.05186	0.05181
0.24	60	116.84	116.22	114.42	1.34	114.49	0.05403	0.05426	0.05416
0.26	65	121.94	120.76	119.19	1.39	119.24	0.05627	0.05658	0.05642
0.28	70	126.44	125.70	123.61	1.44	123.81	0.05843	0.05881	0.05859
0.30	75	130.69	129.95	128.28	1.49	128.15	0.06048	0.06096	0.06068
0.32	80	135.17	134.27	132.27	1.54	[illegible]	[illegible]		
0.34	85	139.53	138.63	136.33	1.59	136.58	0.06446		
0.36	90	142.77	142.57	140.65	1.63	140.36	0.06624		
0.38	95	146.77	146.57	144.67	1.68	144.33	0.06811		
0.40	100	151.16	150.01	148.14	1.72	148.05	0.06987		
0.42	105	154.67	154.01	152.00	1.76	151.80	0.07164		
0.44	110	158.26	157.62	155.65	1.80	155.38	0.07333		
0.46	115	161.95	161.01	159.06	1.84	158.83	0.07496		
0.48	120	165.87	164.34	162.73	1.88	162.43	0.07666		
0.5	125	168.83	167.92	166.01	1.92	165.67	0.07819		

Power Model	New Model
C = ERR	C1 = 6.431E-03
	C2 = 0.17
n = 0.5217	C3 = 1.23
C.V.= 0.6701 (%)	C.V.= 0.3635 (%)

Crack Leakage Calculation By Individual Crack : F1-2

Pressure Difference Across Crack (in.Wg)	(Pa)	Flow Rate: Rep.1 (cfm)	Rep.2 (cfm)	Rep.3 (cfm)	System Leak (cfm)	Corrected Mean (cfm)	Corrected Mean (m^3/sec.)	Power Model Predicted Q (m^3/sec.)	New Model Predicted Q (m^3/sec.)
0.02	5	31.82	31.79	31.79	0.40	31.41	0.01482	0.01520	0.01530
0.04	10	46.70	46.64	46.64	0.56	46.10	0.02176	0.02162	0.02171
0.06	15	57.46	58.14	58.50	0.68	57.36	0.02707	0.02657	0.02663
0.08	20	66.70	66.62	66.31	0.78	65.77	0.03104	0.03075	0.03078
0.10	25	74.34	74.86	74.56	0.87	73.72	0.03479	0.03445	0.03444
0.12	30	81.65	81.29	81.29	0.95	80.46	0.03797	0.03779	0.03775
0.14	35	87.66	87.58	87.06	1.03	86.41	0.04078	0.04067	0.04078
0.16	40	94.06	93.74	93.72	1.10	92.74	0.04377	0.04374	0.04361
0.18	45	99.43	99.33	99.33	1.16	98.20	0.04635	0.04644	0.04627
0.20	50	105.00	104.46	105.12	1.22	103.64	0.04891	0.04899	0.04878
0.22	55	110.13	109.19	109.60	1.28	108.35	0.05114	0.05143	0.05117
0.24	60	114.65	114.75	114.75	1.34	113.38	0.05351	0.05375	0.05346
0.26	65	119.81	119.71	119.89	1.39	118.41	0.05588	0.05598	0.05565
0.28	70	124.24	124.12	123.93	1.44	122.65	0.05789	0.05813	0.05776
0.30	75	128.35	127.85	127.85	1.49	126.52	0.05971	0.06020	0.05979
0.32	80	132.71	132.40	132.58	1.54	131.02	0.06184		
0.34	85	136.60	136.47	136.47	1.59	134.93	0.06368		
0.36	90	140.75	140.27	140.44	1.63	138.85	0.06553		
0.38	95	144.63	144.49	144.16	1.68	142.75	0.06737		
0.40	100	148.43	147.80	147.63	1.72	146.23	0.06901		
0.42	105	152.15	151.69	151.84	1.76	150.13	0.07086		
0.44	110	155.65	155.17	155.50	1.80	163.64	0.07251		
0.46	115	158.76	158.92	158.77	1.84	156.98	0.07408		
0.48	120	162.74	162.13	162.27	1.88	160.50	0.07575		
0.5	125	165.60	165.29	165.29	1.92	163.47	0.07715		

Power Model	New Model
C = 0.00671	C1 = 6.431E-03
	C2 = 0.03
n = 0.5082	C3 = 1.16
C.V.= 0.7040 (%)	C.V.= 0.5893 (%)

Crack Leakage Calculation By Individual Crack : F2-1

Pressure Difference Across Crack (In.Wg)	(Pa)	Flow Rate Rep.1 (cfm)	Rep.2 (cfm)	Rep.3 (cfm)	System Leak (cfm)	Corrected Mean (cfm)	Corrected Mean (m^3/sec.)	Power Model Predicted Q (m^3/sec.)	New Model Predicted Q (m^3/sec.)
0.02	5	30.09	30.09	30.73	0.40	29.90	0.01411	0.01464	0.01472
0.04	10	45.59	45.59	45.58	0.56	45.03	0.02125	0.02113	0.02137
0.06	15	57.75	57.75	56.63	0.68	56.70	0.02676	0.02619	0.02647
0.08	20	66.71	66.71	66.69	0.78	65.92	0.03111	0.03050	0.03077
0.10	25	74.43	74.43	74.12	0.87	73.46	0.03467	0.03433	0.03456
0.12	30	81.79	81.79	81.22	0.95	80.65	0.03806	0.03781	0.03799
0.14	35	88.37	88.37	88.34	1.03	87.33	0.04122	0.04103	0.04115
0.16	40	94.55	94.55	94.29	1.10	93.37	0.04406	0.04403	0.04408
0.18	45	100.64	100.64	100.38	1.16	99.39	0.04691	0.04687	0.04684
0.20	50	105.99	105.99	106.18	1.22	104.83	0.04947	0.04956	0.04945
0.22	55	111.13	111.13	110.89	1.28	109.76	0.05180	0.05213	0.05193
0.24	60	116.48	116.48	116.24	1.34	115.06	0.05430	0.05458	0.05430
0.26	65	120.65	120.65	121.01	1.39	119.38	0.05634	0.05695	0.05657
0.28	70	125.47	125.47	125.44	1.44	124.02	0.05853	0.05923	0.05876
0.30	75	130.32	130.32	130.11	1.49	128.76	0.06077	0.06143	0.06087
0.32	80	134.50	134.50	134.10	1.54	132.82	0.06269		
0.34	85	137.68	137.68	138.18	1.59	136.26	0.06431		
0.36	90	142.53	142.53	142.50	1.63	140.89	0.06649		
0.38	95	146.25	146.25	146.54	1.68	144.67	0.06828		
0.40	100	150.22	150.22	150.01	1.72	148.43	0.07005		
0.42	105	154.42	154.42	153.90	1.76	152.48	0.07196		
0.44	110	157.90	157.90	157.55	1.80	155.98	0.07362		
0.46	115	161.63	161.63	160.98	1.84	159.57	0.07531		
0.48	120	164.84	164.84	164.65	1.88	162.90	0.07688		
0.5	125	168.15	168.15	167.95	1.92	166.16	0.07842		

Power Model		New Model	
C =	0.00624	C1 =	6.431E-03
		C2 =	0.22
n =	0.5297		
		C3 =	1.25
C.V.=	1.0847 (%)	C.V.=	0.5709 (%)

Crack Leakage Calculation By Individual Crack : F2-2

Pressure Difference Across Crack (In.Wg)	(Pa)	Flow Rate Rep.1 (cfm)	Rep.2 (cfm)	Rep.3 (cfm)	System Leak (cfm)	Corrected Mean (cfm)	Corrected Mean (m^3/sec.)	Power Model Predicted Q (m^3/sec.)	New Model Predicted Q (m^3/sec.)
0.02	5	35.40	33.65	34.77	0.40	34.21	0.01615	0.01606	0.01562
0.04	10	47.62	48.86	47.11	0.56	47.31	0.02233	0.02250	0.02209
0.06	15	58.98	59.27	58.91	0.68	58.38	0.02755	0.02741	0.02706
0.08	20	67.74	67.66	67.66	0.78	66.91	0.03158	0.03152	0.03124
0.10	25	74.44	75.23	75.52	0.87	74.19	0.03502	0.03514	0.03493
0.12	30	82.82	82.47	81.65	0.95	81.36	0.03840	0.03840	0.03826
0.14	35	88.78	88.93	88.15	1.03	87.59	0.04134	0.04139	0.04133
0.16	40	94.17	94.79	94.55	1.10	93.41	0.04408	0.04417	0.04418
0.18	45	100.01	100.58	100.12	1.16	99.08	0.04676	0.04677	0.04686
0.20	50	105.13	106.11	105.23	1.22	104.27	0.04921	0.04923	0.04940
0.22	55	110.05	111.19	110.14	1.28	109.18	0.05153	0.05157	0.05181
0.24	60	115.41	115.89	115.48	1.34	114.25	0.05392	0.05380	0.05411
0.26	65	119.58	121.20	119.64	1.39	118.74	0.05604	0.05593	0.05632
0.28	70	124.20	124.83	124.25	1.44	122.98	0.05804	0.05799	0.05845
0.30	75	128.50	128.92	129.27	1.49	127.41	0.06013	0.05997	0.06050
0.32	80	132.87	133.62	132.72	1.54	131.53	0.06208		
0.34	85	136.77	137.67	137.14	1.59	135.61	0.06400		
0.36	90	140.75	141.45	141.11	1.63	139.47	0.06582		
0.38	95	144.47	145.48	144.98	1.68	143.30	0.06763		
0.40	100	147.11	149.43	148.77	1.72	146.72	0.06924		
0.42	105	152.01	152.97	152.32	1.76	150.67	0.07111		
0.44	110	155.20	156.45	155.81	1.80	154.02	0.07269		
0.46	115	158.95	159.86	159.54	1.84	157.61	0.07438		
0.48	120	162.17	163.36	162.90	1.88	160.93	0.07595		
0.5	125	166.09	166.66	166.22	1.92	164.40	0.07759		

Power Model		New Model	
C =	0.00734	C1 =	6.431E-03
		C2 =	0.00
n =	0.4865		
		C3 =	1.18
C.V.=	0.2495 (%)	C.V.=	0.7401 (%)

APPENDIX H

Data Tables for Openings in Parallel

Parallel Crack Leakage Calculation : (A@B1)

Pressure Difference Across Crack (in.Wg)	(Pa)	Flow Rate Rep.1 (cfm)	Rep.2 (cfm)	Rep.3 (cfm)	System Leak (cfm)	Corrected Mean (cfm)	Corrected Mean (m^3/sec.)	Power Model Predicted Q (m^3/sec.)	New Model Predicted Q (m^3/sec.)
0.02	5	2.58	2.52	2.64	0.40	2.19	0.00103	0.00109	0.00098
0.04	10	4.70	4.50	4.47	0.56	4.00	0.00189	0.00185	0.00180
0.06	15	6.20	5.76	6.20	0.68	5.37	0.00254	0.00251	0.00252
0.08	20	7.54	7.65	7.70	0.78	6.85	0.00323	0.00313	0.00318
0.10	25	8.78	8.93	8.93	0.87	8.01	0.00378	0.00370	0.00378
0.12	30	10.24	10.16	10.13	0.95	9.22	0.00435	0.00425	0.00434
0.14	35	11.16	11.30	11.31	1.03	10.23	0.00483	0.00478	0.00486
0.16	40	12.23	11.87	12.46	1.10	11.09	0.00523	0.00529	0.00536
0.18	45	13.30	13.42	13.52	1.16	12.25	0.00578	0.00579	0.00584
0.20	50	14.40	14.51	14.58	1.22	13.27	0.00626	0.00627	0.00629
0.22	55	15.40	15.40	15.50	1.28	14.15	0.00668	0.00674	0.00672
0.24	60	16.40	16.44	16.53	1.34	15.12	0.00713	0.00720	0.00714
0.26	65	17.32	17.48	17.46	1.39	16.03	0.00756	0.00765	0.00754
0.28	70	18.29	18.40	18.46	1.44	16.94	0.00799	0.00810	0.00793
0.30	75	19.26	19.33	19.15	1.49	17.75	0.00838	0.00853	0.00831
0.32	80	20.18	19.62	20.28	1.54	18.49	0.00872		
0.34	85	20.96	21.04	20.96	1.59	19.40	0.00915		
0.36	90	21.89	21.98	22.08	1.63	20.35	0.00960	C= 3.21E-04	C1= 1.250E-03
0.38	95	22.75	23.00	22.90	1.68	21.21	0.01001		
0.40	100	23.56	23.57	23.66	1.72	21.88	0.01033		C2= 3.45
0.42	105	24.42	24.53	24.60	1.76	22.76	0.01074	n= 0.7597	
0.44	110	25.35	25.25	25.25	1.80	23.48	0.01108		C3= 1.2
0.46	115	26.09	26.24	26.17	1.84	24.32	0.01148		
0.48	120	26.82	26.87	26.97	1.88	25.01	0.01180	C.V.= 1.6127 (%)	C.V.= 1.1842 (%)
0.5	125	28.00	27.61	27.82	1.92	25.89	0.01222		

Parallel Crack Leakage Calculation : (A@E)

Pressure Difference Across Crack (in.Wg)	(Pa)	Flow Rate Rep.1 (cfm)	Rep.2 (cfm)	Rep.3 (cfm)	System Leak (cfm)	Corrected Mean (cfm)	Corrected Mean (m^3/sec.)	Power Model Predicted Q (m^3/sec.)	New Model Predicted Q (m^3/sec.)
0.02	5	14.48	14.98	15.24	0.40	14.50	0.00684	0.00669	0.00656
0.04	10	20.19	20.60	20.80	0.56	19.97	0.00943	0.00960	0.00956
0.06	15	25.16	25.68	25.97	0.68	24.93	0.01176	0.01185	0.01186
0.08	20	29.48	29.94	30.10	0.78	29.06	0.01372	0.01376	0.01380
0.10	25	33.24	33.52	33.80	0.87	32.65	0.01541	0.01545	0.01552
0.12	30	36.59	36.85	36.72	0.95	35.77	0.01688	0.01698	0.01707
0.14	35	40.21	40.70	40.82	1.03	39.55	0.01866	0.01840	0.01849
0.16	40	42.69	43.16	43.28	1.10	41.94	0.01980	0.01972	0.01982
0.18	45	45.28	45.73	45.85	1.16	44.46	0.02098	0.02097	0.02106
0.20	50	48.01	48.44	48.55	1.22	47.11	0.02223	0.02215	0.02224
0.22	55	50.62	51.04	51.14	1.28	49.65	0.02343	0.02327	0.02336
0.24	60	52.75	53.16	53.16	1.34	51.68	0.02439	0.02435	0.02443
0.26	65	54.91	55.20	55.30	1.39	53.75	0.02536	0.02538	0.02546
0.28	70	57.21	57.50	57.60	1.44	56.00	0.02643	0.02638	0.02645
0.30	75	59.35	59.73	59.82	1.49	58.14	0.02744	0.02734	0.02740
0.32	80	61.46	61.82	61.91	1.54	60.19	0.02841		
0.34	85	63.42	63.78	63.87	1.59	62.10	0.02931		
0.36	90	65.33	65.69	65.69	1.63	63.94	0.03017	C= 0.00290	C1= 3.545E-03
0.38	95	67.31	67.66	67.74	1.68	65.89	0.03110		
0.40	100	68.99	69.42	69.51	1.72	67.59	0.03190		C2= 0.21
0.42	105	71.06	71.56	71.73	1.76	69.69	0.03289	n= 0.5197	
0.44	110	72.69	73.18	73.34	1.80	71.27	0.03363		C3= 0.84
0.46	115	74.68	75.17	75.33	1.84	73.22	0.03456		
0.48	120	76.42	76.74	76.90	1.88	74.80	0.03530	C.V.= 0.6479 (%)	C.V.= 0.6876 (%)
0.5	125	77.67	78.06	78.22	1.92	76.07	0.03590		

Parallel Crack Leakage Calculation : (A@F1)

Pressure Difference Across Crack (In.Wg)	(Pa)	Flow Rate: Rep.1 (cfm)	Rep.2 (cfm)	Rep.3 (cfm)	System Leak (cfm)	Corrected Mean (cfm)	Corrected Mean (m^3/sec.)	Power Model Predicted Q (m^3/sec.)	New Model Predicted Q (m^3/sec.)
0.02	5	32.98	32.39	32.99	0.40	32.39	0.01529	0.01554	0.01557
0.04	10	47.91	47.05	48.34	0.56	47.21	0.02228	0.02219	0.02232
0.06	15	59.16	58.81	59.52	0.68	58.49	0.02760	0.02734	0.02751
0.08	20	68.49	68.80	67.86	0.78	67.60	0.03190	0.03169	0.03187
0.10	25	77.36	76.82	76.82	0.87	76.13	0.03593	0.03555	0.03572
0.12	30	83.10	84.17	83.90	0.95	82.77	0.03906	0.03904	0.03920
0.14	35	90.26	90.77	91.02	1.03	89.65	0.04231	0.04227	0.04240
0.16	40	96.97	96.75	96.98	1.10	95.81	0.04522	0.04527	0.04538
0.18	45	103.07	103.09	103.31	1.16	102.00	0.04814	0.04810	0.04818
0.20	50	108.69	108.91	108.92	1.22	107.61	0.05079	0.05078	0.05083
0.22	55	113.66	114.09	114.07	1.28	112.66	0.05317	0.05333	0.05334
0.24	60	119.23	119.45	119.07	1.34	117.91	0.05565	0.05577	0.05575
0.26	65	123.85	124.06	124.06	1.39	122.60	0.05786	0.05811	0.05806
0.28	70	129.24	128.89	129.27	1.44	127.69	0.06026	0.06037	0.06028
0.30	75	133.02	133.22	133.58	1.49	131.78	0.06220	0.06255	0.06242
0.32	80	137.95	138.32	136.32	1.54	[illegible]	[illegible]		
0.34	85	142.90	142.42	142.92	1.59	141.16	0.06662		
0.36	90	146.57	146.58	146.59	1.63	144.94	0.06841		
0.38	95	150.63	150.49	150.32	1.68	148.80	0.07023		
0.40	100	154.93	154.78	154.48	1.72	153.01	0.07221		
0.42	105	158.82	158.70	158.70	1.76	156.98	0.07408		
0.44	110	162.33	162.51	162.51	1.80	160.65	0.07582		
0.46	115	166.37	166.11	165.67	1.84	164.21	0.07750		
0.48	120	169.04	169.81	169.35	1.88	167.52	0.07906		
0.5	125	173.54	173.13	173.13	1.92	171.35	0.08087		

Power Model	New Model
C = 0.00679	C1 = 6.831E-03
n = 0.5143	C2 = 0.11
	C3 = 1.14
C.V.= 0.4866 (%)	C.V.= 0.3658 (%)

Parallel Crack Leakage Calculation : (B1@B2)

Pressure Difference Across Crack (In.Wg)	(Pa)	Flow Rate: Rep.1 (cfm)	Rep.2 (cfm)	Rep.3 (cfm)	System Leak (cfm)	Corrected Mean (cfm)	Corrected Mean (m^3/sec.)	Power Model Predicted Q (m^3/sec.)	New Model Predicted Q (m^3/sec.)
0.02	5	5.35	5.44	5.49	0.40	5.03	0.00237	0.00226	0.00191
0.04	10	7.56	7.74	7.79	0.56	7.14	0.00337	0.00357	0.00335
0.06	15	10.44	10.60	10.69	0.68	9.90	0.00467	0.00467	0.00456
0.08	20	12.49	12.09	12.77	0.78	11.87	0.00560	0.00565	0.00562
0.10	25	14.59	14.74	14.89	0.87	13.87	0.00655	0.00655	0.00658
0.12	30	16.54	16.65	16.76	0.95	15.70	0.00741	0.00739	0.00745
0.14	35	18.14	18.24	18.42	1.03	17.24	0.00814	0.00819	0.00827
0.16	40	19.84	20.01	20.15	1.10	18.90	0.00892	0.00895	0.00904
0.18	45	21.37	21.57	21.78	1.16	20.41	0.00963	0.00967	0.00976
0.20	50	22.91	23.11	23.31	1.22	21.89	0.01033	0.01037	0.01045
0.22	55	24.47	24.67	24.90	1.28	23.40	0.01104	0.01105	0.01110
0.24	60	26.06	26.32	26.55	1.34	24.97	0.01179	0.01170	0.01173
0.26	65	27.63	27.82	28.02	1.39	26.43	0.01247	0.01234	0.01234
0.28	70	28.96	29.12	29.31	1.44	27.69	0.01307	0.01296	0.01292
0.30	75	30.33	30.52	30.74	1.49	29.04	0.01371	0.01357	0.01349
0.32	80	31.63	31.88	32.04	1.54	30.31	0.01431		
0.34	85	33.26	33.48	33.60	1.59	31.86	0.01504		
0.36	90	34.49	34.73	34.88	1.63	33.07	0.01561		
0.38	95	35.68	35.86	35.95	1.68	34.16	0.01612		
0.40	100	37.36	37.60	37.75	1.72	35.85	0.01692		
0.42	105	38.58	38.79	38.91	1.76	37.00	0.01746		
0.44	110	39.70	40.00	40.02	1.80	38.11	0.01798		
0.46	115	41.22	41.51	41.60	1.84	39.60	0.01869		
0.48	120	42.54	42.86	42.97	1.88	40.91	0.01931		
0.5	125	43.69	44.04	44.12	1.92	42.03	0.01984		

Power Model	New Model
C = 7.8E-04	C1 = 1.700E-03
n = 0.6624	C2 = 2.46
	C3 = 1.36
C.V.= 1.1146 (%)	C.V.= 1.9002 (%)

Parallel Crack Leakage Calculation : (B1@E)

Pressure Difference Across Crack (In.Wg)	(Pa)	Flow Rate Rep.1 (cfm)	Rep.2 (cfm)	Rep.3 (cfm)	System Leak (cfm)	Corrected Mean (cfm)	Corrected Mean (m^3/sec.)	Power Model Predicted Q (m^3/sec.)	New Model Predicted Q (m^3/sec.)
0.02	5	14.66	13.56	13.83	0.40	13.62	0.00643	0.00678	0.00669
0.04	10	22.77	22.54	22.16	0.56	21.94	0.01035	0.01018	0.01035
0.06	15	29.21	28.40	28.55	0.68	28.04	0.01323	0.01291	0.01320
0.08	20	34.08	33.88	33.74	0.78	33.12	0.01563	0.01529	0.01562
0.10	25	38.72	38.40	38.14	0.87	37.55	0.01772	0.01742	0.01776
0.12	30	42.88	42.69	42.80	0.95	41.84	0.01975	0.01939	0.01969
0.14	35	47.11	46.36	46.47	1.03	45.62	0.02153	0.02122	0.02148
0.16	40	50.16	50.07	49.75	1.10	48.90	0.02308	0.02295	0.02314
0.18	45	53.48	53.38	53.07	1.16	52.15	0.02461	0.02459	0.02470
0.20	50	57.05	56.28	56.65	1.22	55.44	0.02616	0.02615	0.02618
0.22	55	59.74	59.45	59.26	1.28	58.20	0.02747	0.02766	0.02758
0.24	60	62.45	62.34	62.24	1.34	61.01	0.02879	0.02910	0.02893
0.26	65	65.33	65.22	65.13	1.39	63.83	0.03013	0.03050	0.03022
0.28	70	67.89	67.69	68.01	1.44	66.42	0.03135	0.03186	0.03146
0.30	75	70.54	70.42	70.50	1.49	68.99	0.03256	0.03317	0.03266
0.32	80	73.06	72.86	72.93	1.54	71.41	0.03370		
0.34	85	75.61	75.40	75.22	1.59	73.82	0.03484		
0.36	90	77.86	77.80	77.87	1.63	76.21	0.03597	C= 0.00264	C1= 3.995E-03
0.38	95	80.30	79.56	80.30	1.68	78.37	0.03699		
0.40	100	82.55	82.93	82.77	1.72	81.03	0.03824		C2= 0.73
0.42	105	84.76	85.11	84.74	1.76	83.11	0.03922	n= 0.5862	
0.44	110	87.07	86.92	86.84	1.80	85.14	0.04018		C3= 1.05
0.46	115	89.28	89.27	89.26	1.84	87.42	0.04126		
0.48	120	91.59	91.37	91.14	1.88	89.49	0.04223	C.V.= 1.6083 (%)	C.V.= 0.4862 (%)
0.5	125	93.73	93.51	93.70	1.92	91.73	0.04329		

Parallel Crack Leakage Calculation : (B1@F1)

Pressure Difference Across Crack (In.Wg)	(Pa)	Flow Rate Rep.1 (cfm)	Rep.2 (cfm)	Rep.3 (cfm)	System Leak (cfm)	Corrected Mean (cfm)	Corrected Mean (m^3/sec.)	Power Model Predicted Q (m^3/sec.)	New Model Predicted Q (m^3/sec.)
0.02	5	36.04	36.06	34.31	0.40	35.07	0.01655	0.01680	0.01676
0.04	10	51.09	52.31	51.86	0.56	51.20	0.02416	0.02402	0.02408
0.06	15	63.95	64.63	63.93	0.68	63.49	0.02997	0.02960	0.02970
0.08	20	74.30	74.02	73.38	0.78	73.12	0.03451	0.03433	0.03444
0.10	25	82.45	83.00	83.22	0.87	82.02	0.03871	0.03851	0.03861
0.12	30	91.45	90.97	90.68	0.95	90.08	0.04251	0.04231	0.04238
0.14	35	98.16	98.16	98.57	1.03	97.27	0.04590	0.04581	0.04585
0.16	40	104.70	105.36	104.88	1.10	103.88	0.04903	0.04907	0.04908
0.18	45	111.55	111.56	111.29	1.16	110.30	0.05206	0.05214	0.05212
0.20	50	118.46	117.64	117.60	1.22	116.68	0.05507	0.05505	0.05499
0.22	55	123.90	121.40	124.22	1.28	121.89	0.05753	0.05782	0.05772
0.24	60	128.98	129.53	129.65	1.34	128.05	0.06043	0.06047	0.06033
0.26	65	134.60	135.13	134.89	1.39	133.48	0.06300	0.06302	0.06283
0.28	70	140.02	140.38	139.79	1.44	138.62	0.06542	0.06547	0.06523
0.30	75	144.79	144.79	144.57	1.49	143.22	0.06759	0.06784	0.06756
0.32	80	149.59	150.27	151.00	1.54	148.75	0.07020		
0.34	85	155.23	154.91	154.85	1.59	153.41	0.07240		
0.36	90	159.46	159.31	159.40	1.63	157.76	0.07445	C= 0.00733	C1= 7.281E-03
0.38	95	163.30	163.61	163.39	1.68	161.75	0.07634		
0.40	100	167.66	168.41	167.88	1.72	166.27	0.07847		C2= 0.13
0.42	105	172.08	173.11	172.01	1.76	170.64	0.08053	n= 0.5154	
0.44	110	175.98	176.98	176.20	1.80	174.59	0.08240		C3= 1.18
0.46	115	180.52	181.07	180.58	1.84	178.88	0.08442		
0.48	120	184.41	185.10	184.19	1.88	182.69	0.08622	C.V.= 0.4207 (%)	C.V.= 0.3150 (%)
0.5	125	189.05	188.79	188.29	1.92	186.79	0.08816		

Parallel Crack Leakage Calculation : (F1@F2)

Pressure Difference Across Crack (In.Wg)	Pressure Difference Across Crack (Pa)	Flow Rate: Rep.1 (cfm)	Flow Rate: Rep.2 (cfm)	Flow Rate: Rep.3 (cfm)	Flow Rate: System Leak (cfm)	Flow Rate: Corrected Mean (cfm)	Flow Rate: Corrected Mean (m^3/sec.)	Power Model Predicted Q (m^3/sec.)	New Model Predicted Q (m^3/sec.)
0.02	5	66.04	67.90	66.03	0.40	66.26	0.03127	0.03140	0.03139
0.04	10	95.24	94.80	94.78	0.56	94.38	0.04454	0.04458	0.04460
0.06	15	116.83	117.19	117.19	0.68	116.39	0.05493	0.05472	0.05473
0.08	20	136.63	135.63	135.30	0.78	135.08	0.06375	0.06329	0.06328
0.10	25	150.91	150.89	150.59	0.87	149.93	0.07076	0.07084	0.07081
0.12	30	165.73	165.44	165.72	0.95	164.68	0.07772	0.07768	0.07762
0.14	35	178.95	179.19	178.43	1.03	177.83	0.08393	0.08398	0.08388
0.16	40	191.14	192.57	191.36	1.10	190.59	0.08995	0.08984	0.08970
0.18	45	202.45	203.80	202.18	1.16	201.65	0.09517	0.09535	0.09518
0.20	50	213.88	214.08	214.08	1.22	212.79	0.10043	0.10057	0.10035
0.22	55	224.60	224.80	225.84	1.28	223.80	0.10562	0.10553	0.10528
0.24	60	236.92	234.67	235.49	1.34	234.35	0.11060	0.11028	0.10998
0.26	65	244.06	243.23	242.84	1.39	241.99	0.11420	0.11483	0.11449
0.28	70								
0.30	75								
0.32	80								
0.34	85								
0.36	90								
0.38	95								
0.40	100								
0.42	105								
0.44	110								
0.46	115								
0.48	120								
0.5	125								

Power Model		New Model	
C=	0.01392	C1=	1.28620E-02
		C2=	0.04
n=	0.5055	C3=	1.23
C.V.=	0.3487 (%)	C.V.=	0.3652 (%)

APPENDIX I

Data Tables for Openings in Series

Series Crack Leakage Calculation : (A~B1)

Pressure Difference Across Crack (in.Wg)	(Pa)	Flow Rate Rep.1 (cfm)	Rep.2 (cfm)	Rep.3 (cfm)	System Leak (cfm)	Corrected Mean (cfm)	Corrected Mean (m^3/sec.)	Power Model Predicted Q (m^3/sec.)	New Model Predicted Q (m^3/sec.)
0.02	5	0.62	0.62	0.72	0.40	0.26	0.00012	0.00014	0.00015
0.04	10	1.05	1.13	1.22	0.56	0.58	0.00027	0.00027	0.00029
0.06	15	1.56	1.49	1.63	0.68	0.88	0.00042	0.00039	0.00042
0.08	20	1.90	1.90	1.96	0.78	1.14	0.00054	0.00051	0.00055
0.10	25	2.26	2.32	2.32	0.87	1.43	0.00067	0.00063	0.00067
0.12	30	2.54	2.66	2.60	0.95	1.65	0.00078	0.00075	0.00078
0.14	35	2.94	2.94	3.00	1.03	1.93	0.00091	0.00086	0.00089
0.16	40	3.14	3.27	3.22	1.10	2.11	0.00100	0.00098	0.00099
0.18	45	3.52	3.52	3.58	1.16	2.38	0.00112	0.00109	0.00109
0.20	50	3.76	3.73	3.83	1.22	2.55	0.00120	0.00120	0.00119
0.22	55	4.00	4.07	4.07	1.28	2.77	0.00131	0.00131	0.00128
0.24	60	4.25	4.25	4.30	1.34	2.93	0.00138	0.00142	0.00137
0.26	65	4.50	4.44	4.50	1.39	3.09	0.00146	0.00154	0.00146
0.28	70	4.72	4.67	4.67	1.44	3.25	0.00153	0.00165	0.00155
0.30	75	4.91	4.96	5.01	1.49	3.46	0.00164	0.00175	0.00163
0.32	80	5.14	5.14	5.19	1.54	3.62	0.00171		
0.34	85	5.36	5.31	5.37	1.59	3.76	0.00177		
0.36	90	5.59	5.53	5.54	1.63	3.92	0.00185		
0.38	95	5.85	5.80	5.75	1.68	4.12	0.00195		
0.40	100	5.98	5.98	5.98	1.72	4.26	0.00201		
0.42	105	6.15	6.19	6.19	1.76	4.41	0.00208		
0.44	110	6.40	6.36	6.36	1.80	4.57	0.00216		
0.46	115	6.57	6.65	6.61	1.84	4.77	0.00225		
0.48	120	6.70	6.78	6.78	1.88	4.87	0.00230		
0.5	125	6.81	6.89	6.90	1.92	4.95	0.00234		

Power Model	New Model
C = 3.12E-05	C1 = 3.606E-04
n = 0.9333	C2 = 5.1
	C3 = 0.89
C.V.= 6.0676 (%)	C.V.= 1.8970 (%)

Series Crack Leakage Calculation : (B1~A)

Pressure Difference Across Crack (in.Wg)	(Pa)	Flow Rate Rep.1 (cfm)	Rep.2 (cfm)	Rep.3 (cfm)	System Leak (cfm)	Corrected Mean (cfm)	Corrected Mean (m^3/sec.)	Power Model Predicted Q (m^3/sec.)	New Model Predicted Q (m^3/sec.)
0.02	5	0.70	0.62	0.72	0.40	0.28	0.00013	0.00017	0.00019
0.04	10	1.30	1.30	1.22	0.56	0.71	0.00034	0.00032	0.00036
0.06	15	1.85	1.78	1.78	0.68	1.12	0.00053	0.00047	0.00052
0.08	20	2.21	2.27	2.15	0.78	1.43	0.00067	0.00062	0.00068
0.10	25	2.63	2.63	2.57	0.87	1.74	0.00082	0.00076	0.00082
0.12	30	3.07	3.01	3.02	0.95	2.06	0.00098	0.00091	0.00096
0.14	35	3.33	3.38	3.33	1.03	2.32	0.00109	0.00105	0.00109
0.16	40	3.70	3.70	3.70	1.10	2.60	0.00123	0.00120	0.00122
0.18	45	4.04	3.99	4.04	1.16	2.86	0.00135	0.00134	0.00135
0.20	50	4.38	4.43	4.34	1.22	3.16	0.00149	0.00148	0.00147
0.22	55	4.62	4.57	4.62	1.28	3.32	0.00157	0.00162	0.00158
0.24	60	5.01	4.94	4.96	1.34	3.63	0.00171	0.00176	0.00169
0.26	65	5.08	5.23	5.13	1.39	3.75	0.00177	0.00190	0.00180
0.28	70	5.49	5.44	5.49	1.44	4.03	0.00190	0.00204	0.00191
0.30	75	5.80	5.70	5.80	1.49	4.27	0.00202	0.00217	0.00201
0.32	80	5.96	6.07	5.96	1.54	4.45	0.00210		
0.34	85	6.27	6.27	6.27	1.59	4.69	0.00221		
0.36	90	6.58	6.49	6.58	1.63	4.92	0.00232		
0.38	95	6.78	6.71	6.79	1.68	5.08	0.00240		
0.40	100	7.00	6.91	6.99	1.72	5.24	0.00247		
0.42	105	7.20	7.11	7.20	1.76	5.41	0.00255		
0.44	110	7.53	7.44	7.49	1.80	5.68	0.00268		
0.46	115	7.59	7.69	7.60	1.84	5.79	0.00273		
0.48	120	7.71	7.76	7.72	1.88	5.85	0.00276		
0.5	125	7.96	8.01	7.93	1.92	6.05	0.00285		

Power Model	New Model
C = 3.58E-05	C1 = 4.262E-04
n = 0.9511	C2 = 5.33
	C3 = 0.97
C.V.= 6.7966 (%)	C.V.= 1.8753 (%)

Series Crack Leakage Calculation : (B1~E)

Pressure Difference Across Crack (in.Wg)	(Pa)	Flow Rate Rep.1 (cfm)	Rep.2 (cfm)	Rep.3 (cfm)	System Leak (cfm)	Corrected Mean (cfm)	Corrected Mean (m^3/sec.)	Power Model Predicted Q (m^3/sec.)	New Model Predicted Q (m^3/sec.)
0.02	5	2.40	2.43	2.43	0.40	2.02	0.00095	0.00099	0.00090
0.04	10	3.91	3.91	3.91	0.56	3.36	0.00158	0.00156	0.00154
0.06	15	4.93	5.18	5.08	0.68	4.39	0.00207	0.00205	0.00206
0.08	20	6.05	6.05	6.00	0.78	5.25	0.00248	0.00248	0.00251
0.10	25	7.01	7.01	7.11	0.87	6.17	0.00291	0.00287	0.00291
0.12	30	7.95	7.77	7.86	0.95	6.91	0.00326	0.00324	0.00328
0.14	35	8.69	8.63	8.63	1.03	7.63	0.00360	0.00359	0.00362
0.16	40	9.39	9.31	9.31	1.10	8.24	0.00389	0.00392	0.00394
0.18	45	10.15	10.01	10.05	1.16	8.91	0.00420	0.00424	0.00424
0.20	50	10.83	10.71	10.83	1.22	9.57	0.00452	0.00455	0.00453
0.22	55	11.51	11.47	11.47	1.28	10.20	0.00481	0.00484	0.00480
0.24	60	12.09	12.02	12.05	1.34	10.72	0.00506	0.00513	0.00506
0.26	65	12.76	12.75	12.75	1.39	11.36	0.00536	0.00541	0.00532
0.28	70	13.07	13.34	13.18	1.44	11.75	0.00555	0.00568	0.00556
0.30	75	13.90	13.79	13.83	1.49	12.35	0.00583	0.00595	0.00579
0.32	80	14.46	14.35	14.42	1.54	12.87	0.00607		
0.34	85	15.03	14.99	14.99	1.59	13.42	0.00633		
0.36	90	15.34	15.54	15.51	1.63	13.83	0.00653	C = 3.40E-04	C1 = 7.269E-04
0.38	95	16.06	16.09	16.12	1.68	14.42	0.00680		
0.40	100	16.64	16.61	16.68	1.72	14.92	0.00704		C2 = 1.9
0.42	105	16.87	17.08	16.90	1.76	15.19	0.00717	n = 0.6628	
0.44	110	17.45	17.58	17.37	1.80	15.67	0.00739		C3 = 1.25
0.46	115	18.05	18.12	17.98	1.84	16.21	0.00765		
0.48	120	18.45	18.61	18.51	1.88	16.64	0.00786	C.V.= 1.6334 (%)	C.V.= 0.9164 (%)
0.5	125	19.01	19.01	18.94	1.92	17.07	0.00806		

Series Crack Leakage Calculation : (E~B1)

Pressure Difference Across Crack (in.Wg)	(Pa)	Flow Rate Rep.1 (cfm)	Rep.2 (cfm)	Rep.3 (cfm)	System Leak (cfm)	Corrected Mean (cfm)	Corrected Mean (m^3/sec.)	Power Model Predicted Q (m^3/sec.)	New Model Predicted Q (m^3/sec.)
0.02	5	2.34	2.30	2.30	0.40	1.92	0.00090	0.00094	0.00084
0.04	10	3.69	3.86	3.81	0.56	3.23	0.00153	0.00151	0.00147
0.06	15	5.00	4.99	5.06	0.68	4.34	0.00205	0.00200	0.00201
0.08	20	6.10	6.05	6.17	0.78	5.33	0.00251	0.00244	0.00248
0.10	25	7.02	6.70	7.13	0.87	6.08	0.00287	0.00285	0.00290
0.12	30	7.99	7.91	7.96	0.95	7.00	0.00330	0.00323	0.00329
0.14	35	8.19	8.73	8.77	1.03	7.54	0.00356	0.00360	0.00365
0.16	40	9.34	9.48	9.46	1.10	8.33	0.00393	0.00395	0.00399
0.18	45	10.34	10.22	10.28	1.16	9.12	0.00430	0.00428	0.00431
0.20	50	10.98	10.87	11.04	1.22	9.74	0.00460	0.00460	0.00462
0.22	55	11.68	11.70	11.64	1.28	10.39	0.00490	0.00492	0.00491
0.24	60	12.43	12.40	12.34	1.34	11.05	0.00522	0.00522	0.00519
0.26	65	13.01	12.98	12.96	1.39	11.59	0.00547	0.00552	0.00546
0.28	70	13.73	13.64	13.49	1.44	12.18	0.00575	0.00581	0.00572
0.30	75	14.42	14.30	14.22	1.49	12.82	0.00605	0.00609	0.00597
0.32	80	15.01	14.84	14.77	1.54	13.33	0.00629		
0.34	85	15.46	15.44	15.47	1.59	13.87	0.00655		
0.36	90	16.14	16.13	16.02	1.63	14.46	0.00683	C = 3.08E-04	C1 = 8.444E-04
0.38	95	16.73	16.71	16.63	1.68	15.01	0.00709		
0.40	100	17.34	17.24	17.18	1.72	15.53	0.00733		C2 = 2.25
0.42	105	17.90	17.79	17.75	1.76	16.05	0.00758	n = 0.6913	
0.44	110	18.40	18.25	18.32	1.80	16.52	0.00780		C3 = 1.09
0.46	115	18.86	18.81	18.84	1.84	17.00	0.00802		
0.48	120	19.52	19.27	19.37	1.88	17.51	0.00826	C.V.= 1.1358 (%)	C.V.= 1.3203 (%)
0.5	125	20.08	19.93	19.82	1.92	18.02	0.00851		

Series Crack Leakage Calculation : (E~F1)

Pressure Difference Across Crack		Flow Rate						Power Model Predicted Q	New Model Predicted Q
		Rep.1	Rep.2	Rep.3	System Leak	Corrected Mean			
(in.Wg)	(Pa)	(cfm)	(cfm)	(cfm)	(cfm)	(cfm)	(m^3/sec.)	(m^3/sec.)	(m^3/sec.)
0.02	5	11.29	10.97	10.63	0.40	10.57	0.00499	0.00524	0.00527
0.04	10	17.16	17.40	17.16	0.56	16.68	0.00787	0.00769	0.00784
0.06	15	21.16	21.56	21.36	0.68	20.68	0.00976	0.00962	0.00981
0.08	20	25.17	25.35	25.18	0.78	24.45	0.01154	0.01128	0.01148
0.10	25	28.42	28.75	28.59	0.87	27.72	0.01308	0.01277	0.01295
0.12	30	31.55	31.44	31.27	0.95	30.47	0.01438	0.01412	0.01428
0.14	35	34.21	33.96	33.81	1.03	32.97	0.01556	0.01538	0.01550
0.16	40	36.34	36.62	36.49	1.10	35.39	0.01670	0.01656	0.01664
0.18	45	38.99	38.77	38.65	1.16	37.64	0.01776	0.01767	0.01771
0.20	50	40.94	40.96	41.08	1.22	39.77	0.01877	0.01873	0.01873
0.22	55	42.93	43.07	42.95	1.28	41.70	0.01968	0.01975	0.01969
0.24	60	45.09	45.11	44.99	1.34	43.72	0.02064	0.02072	0.02061
0.26	65	46.40	46.97	46.86	1.39	45.35	0.02140	0.02166	0.02149
0.28	70	48.55	48.57	48.46	1.44	47.09	0.02222	0.02257	0.02234
0.30	75	50.13	50.35	50.25	1.49	48.75	0.02301	0.02345	0.02316
0.32	80	51.96	51.89	51.68	1.54	50.30	0.02374		
0.34	85	53.66	53.59	53.59	1.59	52.02	0.02455		
0.36	90	54.94	55.25	55.35	1.63	53.55	0.02527	C= 0.00215	C1= 1.808E-03
0.38	95	56.67	56.88	56.59	1.68	55.03	0.02597		
0.40	100	58.27	58.11	57.91	1.72	56.38	0.02661		C2= 0.59
0.42	105	59.75	59.78	59.59	1.76	57.94	0.02735	n= 0.5534	
0.44	110	61.11	60.31	60.30	1.80	58.78	0.02774		C3= 2.39
0.46	115	62.56	62.66	62.66	1.84	60.79	0.02869		
0.48	120	63.88	64.18	64.09	1.88	62.17	0.02934	C.V.= 1.5720 (%)	C.V.= 0.7352 (%)
0.5	125	65.45	65.39	65.21	1.92	63.43	0.02994		

Series Crack Leakage Calculation : (F1~B1)

Pressure Difference Across Crack		Flow Rate						Power Model Predicted Q	New Model Predicted Q
		Rep.1	Rep.2	Rep.3	System Leak	Corrected Mean			
(in.Wg)	(Pa)	(cfm)	(cfm)	(cfm)	(cfm)	(cfm)	(m^3/sec.)	(m^3/sec.)	(m^3/sec.)
0.02	5	2.33	2.40	2.33	0.40	1.96	0.00092	0.00097	0.00088
0.04	10	3.97	3.91	3.91	0.56	3.37	0.00159	0.00157	0.00155
0.06	15	5.18	5.18	5.18	0.68	4.50	0.00212	0.00208	0.00210
0.08	20	6.33	6.26	6.28	0.78	5.51	0.00260	0.00254	0.00259
0.10	25	7.27	7.22	7.18	0.87	6.35	0.00300	0.00297	0.00303
0.12	30	8.23	8.15	8.15	0.95	7.22	0.00341	0.00337	0.00344
0.14	35	9.21	9.04	9.00	1.03	8.06	0.00380	0.00375	0.00381
0.16	40	9.87	9.83	9.79	1.10	8.73	0.00412	0.00412	0.00416
0.18	45	10.68	10.60	10.55	1.16	9.45	0.00446	0.00447	0.00450
0.20	50	11.44	11.44	11.36	1.22	10.19	0.00481	0.00481	0.00481
0.22	55	12.17	12.10	12.10	1.28	10.84	0.00512	0.00514	0.00512
0.24	60	12.80	12.84	12.76	1.34	11.46	0.00541	0.00546	0.00541
0.26	65	13.49	13.45	13.41	1.39	12.06	0.00569	0.00577	0.00569
0.28	70	14.13	14.12	14.05	1.44	12.66	0.00597	0.00607	0.00596
0.30	75	14.68	14.79	14.79	1.49	13.26	0.00626	0.00637	0.00622
0.32	80	15.43	15.36	15.43	1.54	13.87	0.00654		
0.34	85	15.98	16.05	16.05	1.59	14.44	0.00681		
0.36	90	16.59	16.55	16.55	1.63	14.93	0.00705	C= 3.2E-04	C1= 8.142E-04
0.38	95	17.20	17.16	17.13	1.68	15.49	0.00731		
0.40	100	17.73	17.74	17.66	1.72	15.99	0.00755		C2= 2.37
0.42	105	18.23	18.27	18.20	1.76	16.47	0.00777	n= 0.6950	
0.44	110	18.96	18.93	18.90	1.80	17.13	0.00808		C3= 1.26
0.46	115	19.49	19.43	19.43	1.84	17.61	0.00831		
0.48	120	20.15	20.04	20.03	1.88	18.19	0.00859	C.V.= 1.4703 (%)	C.V.= 0.7696 (%)
0.5	125	20.67	20.57	20.54	1.92	18.67	0.00881		

Series Crack Leakage Calculation : (F1~E)

Pressure Difference Across Crack (in.Wg)	(Pa)	Flow Rate Rep.1 (cfm)	Rep.2 (cfm)	Rep.3 (cfm)	System Leak (cfm)	Corrected Mean (cfm)	Corrected Mean (m^3/sec.)	Power Model Predicted Q (m^3/sec.)	New Model Predicted Q (m^3/sec.)
0.02	5	10.96	11.30	10.85	0.40	10.64	0.00502	0.00529	0.00530
0.04	10	17.15	17.40	17.64	0.56	16.84	0.00795	0.00774	0.00786
0.06	15	21.74	21.76	21.78	0.68	21.08	0.00995	0.00968	0.00984
0.08	20	25.34	25.35	25.20	0.78	24.52	0.01157	0.01134	0.01151
0.10	25	28.42	28.74	28.61	0.87	27.72	0.01308	0.01282	0.01298
0.12	30	31.13	31.44	31.31	0.95	30.34	0.01432	0.01417	0.01431
0.14	35	34.07	34.23	33.98	1.03	33.07	0.01561	0.01543	0.01553
0.16	40	36.47	36.49	36.38	1.10	35.35	0.01668	0.01660	0.01667
0.18	45	38.75	38.90	38.80	1.16	37.65	0.01777	0.01772	0.01774
0.20	50	40.94	41.08	40.88	1.22	39.74	0.01876	0.01877	0.01875
0.22	55	42.93	43.19	43.11	1.28	41.80	0.01973	0.01979	0.01972
0.24	60	44.97	45.44	45.37	1.34	43.92	0.02073	0.02076	0.02064
0.26	65	46.95	46.98	46.90	1.39	45.55	0.02150	0.02169	0.02152
0.28	70	48.87	48.79	48.62	1.44	47.32	0.02233	0.02259	0.02237
0.30	75	50.43	50.56	50.40	1.49	48.97	0.02311	0.02347	0.02319
0.32	80	52.26	52.39	52.13	1.54	50.72	0.02394		
0.34	85	53.96	54.09	53.94	1.59	52.41	0.02474		
0.36	90	55.52	55.65	55.50	1.63	53.92	0.02545	C= 0.00218	C1= 1.750E-03
0.38	95	57.33	57.07	57.03	1.68	55.47	0.02618		
0.40	100	58.73	58.76	58.63	1.72	56.99	0.02690		C2= 0.59
0.42	105	60.20	60.42	60.29	1.76	58.54	0.02763	n= 0.5504	
0.44	110	61.57	61.88	61.66	1.80	59.90	0.02827		C3= 2.55
0.46	115	63.09	63.48	63.45	1.84	61.50	0.02902		
0.48	120	64.67	64.79	64.58	1.88	62.80	0.02964	C.V.= 1.3651 (%)	C.V.= 0.6415 (%)
0.5	125	65.89	65.92	65.72	1.92	63.92	0.03017		

Component Leakage Test: Exterior Frame / Gypsum Board: CO-1

Pressure Difference Across Crack (in.Wg)	Pressure Difference Across Crack (Pa)	Flow Rate: Rep.1 (cfm)	Rep.2 (cfm)	Rep.3 (cfm)	Chamber Leak (cfm)	Corrected Mean (cfm)	Corrected Mean (m^3/sec.)	Power Model Predicted Q (m^3/sec.)	New Model Predicted Q (m^3/sec.)
0.02	5	0.37	0.37	0.35	0.29	0.08	0.00004	0.00005	0.00007
0.04	10	0.70	0.70	0.57	0.41	0.24	0.00011	0.00010	0.00013
0.06	15	0.94	0.94	0.84	0.51	0.39	0.00019	0.00016	0.00019
0.08	20	1.17	1.17	1.09	0.60	0.55	0.00026	0.00021	0.00024
0.10	25	1.31	1.39	1.15	0.67	0.62	0.00029	0.00026	0.00029
0.12	30	1.52	1.51	1.37	0.74	0.73	0.00034	0.00032	0.00034
0.14	35	1.64	1.71	1.49	0.80	0.81	0.00038	0.00037	0.00039
0.16	40	1.83	1.83	1.75	0.86	0.95	0.00045	0.00043	0.00044
0.18	45	1.95	2.01	1.88	0.91	1.03	0.00049	0.00048	0.00048
0.20	50	2.13	2.13	1.99	0.97	1.12	0.00053	0.00053	0.00052
0.22	55	2.23	2.24	2.16	1.01	1.20	0.00056	0.00059	0.00056
0.24	60	2.40	2.40	2.27	1.06	1.30	0.00061	0.00064	0.00060
0.26	65	2.51	2.51	2.38	1.11	1.36	0.00064	0.00070	0.00064
0.28	70	2.62	2.62	2.49	1.15	1.43	0.00067	0.00075	0.00068
0.30	75	2.73	2.79	2.59	1.19	1.51	0.00071	0.00081	0.00072
0.32	80	2.83	2.89	2.75	1.24	1.59	0.00075		
0.34	85	2.92	2.98	2.86	1.28	1.64	0.00078		
0.36	90	3.03	3.08	2.90	1.31	1.69	0.00080		
0.38	95	3.13	3.18	3.01	1.35	1.75	0.00083		
0.40	100	3.23	3.28	3.16	1.39	1.83	0.00087		
0.42	105	3.38	3.38	3.25	1.43	1.91	0.00090		
0.44	110	3.47	3.52	3.40	1.46	2.00	0.00095		
0.46	115	3.56	3.62	3.50	1.49	2.07	0.00098		
0.48	120	3.66	3.71	3.60	1.53	2.13	0.00100		
0.5	125	3.81	3.86	3.69	1.56	2.23	0.00105		

Power Model	New Model
C = 1.01E-05	C1 = 1.260E-04
n = 1.0145	C2 = 6.04
	C3 = 1.35
C.V. = 10.5207 (%)	C.V. = 2.9093 (%)

Component Leakage Test: Exterior Frame / Insulating Board: CO-2

Pressure Difference Across Crack (in.Wg)	Pressure Difference Across Crack (Pa)	Flow Rate: Rep.1 (cfm)	Rep.2 (cfm)	Rep.3 (cfm)	Chamber Leak (cfm)	Corrected Mean (cfm)	Corrected Mean (m^3/sec.)	Power Model Predicted Q (m^3/sec.)	New Model Predicted Q (m^3/sec.)
0.02	5	3.72	4.42	4.73	0.29	4.00	0.00189	0.00200	0.00209
0.04	10	5.95	6.97	6.88	0.41	6.19	0.00292	0.00294	0.00305
0.06	15	7.45	8.91	8.78	0.51	7.86	0.00371	0.00369	0.00380
0.08	20	8.97	10.80	10.47	0.60	9.48	0.00447	0.00432	0.00443
0.10	25	10.12	12.19	12.06	0.67	10.79	0.00509	0.00489	0.00498
0.12	30	11.23	13.34	13.42	0.74	11.93	0.00563	0.00542	0.00548
0.14	35	12.51	14.49	14.09	0.80	12.90	0.00609	0.00590	0.00594
0.16	40	13.41	15.45	15.20	0.86	13.83	0.00653	0.00635	0.00637
0.18	45	14.39	16.27	15.95	0.91	14.63	0.00090	0.00678	0.00677
0.20	50	15.26	17.06	16.67	0.97	15.37	0.00725	0.00719	0.00715
0.22	55	16.16	17.79	17.31	1.01	16.07	0.00759	0.00758	0.00752
0.24	60	16.71	18.47	17.88	1.06	16.62	0.00785	0.00796	0.00786
0.26	65	17.45	18.99	18.44	1.11	17.19	0.00811	0.00832	0.00819
0.28	70	17.96	19.58	18.76	1.15	17.61	0.00831	0.00867	0.00851
0.30	75	18.61	20.13	19.37	1.19	18.17	0.00858	0.00901	0.00882
0.32	80	19.21	20.55	19.81	1.24	18.62	0.00879		
0.34	85	19.87	20.85	20.34	1.28	19.08	0.00900		
0.36	90	20.26	21.25	20.78	1.31	19.45	0.00918		
0.38	95	20.54	21.53	21.06	1.35	19.69	0.00929		
0.40	100	21.02	21.81	21.65	1.39	20.10	0.00949		
0.42	105	21.25	22.28	22.15	1.43	20.47	0.00966		
0.44	110	21.39	22.76	22.57	1.46	20.78	0.00981		
0.46	115	21.61	22.97	23.01	1.49	21.03	0.00993		
0.48	120	21.93	23.63	23.46	1.53	21.48	0.01014		
0.5	125	22.34	23.87	23.84	1.56	21.79	0.01028		

Power Model	New Model
C = 8.19E-04	C1 = 3.940E-04
n = 0.5554	C2 = 0.71
	C3 = 7.11
C.V. = 3.4685 (%)	C.V. = 2.4459 (%)

APPENDIX J

Data Tables for Component Leakage Tests

Component Leakage Test: Wall Penetrations / Outlets: CO-3

Pressure Difference Across Crack (In.Wg)	(Pa)	Flow Rate Rep.1 (cfm)	Rep.2 (cfm)	Rep.3 (cfm)	Chamber Leak (cfm)	Corrected Mean (cfm)	Corrected Mean (m^3/sec.)	Power Model Predicted Q (m^3/sec.)	New Model Predicted Q (m^3/sec.)
0.02	5	2.16	2.23	2.23	0.29	1.92	0.00090	0.00092	0.00082
0.04	10	3.46	3.58	3.52	0.41	3.11	0.00147	0.00147	0.00143
0.06	15	4.69	4.64	4.69	0.51	4.16	0.00196	0.00193	0.00193
0.08	20	5.48	5.60	5.48	0.60	4.92	0.00232	0.00234	0.00237
0.10	25	6.38	6.57	6.33	0.67	5.76	0.00272	0.00271	0.00276
0.12	30	7.24	7.29	7.16	0.74	6.49	0.00306	0.00307	0.00312
0.14	35	7.99	8.12	8.08	0.80	7.27	0.00343	0.00340	0.00346
0.16	40	8.69	8.81	8.72	0.86	7.88	0.00372	0.00372	0.00377
0.18	45	9.36	9.57	9.49	0.91	8.56	0.00404	0.00403	0.00407
0.20	50	10.19	10.23	10.11	0.97	9.21	0.00435	0.00432	0.00435
0.22	55	10.79	10.79	10.71	1.01	9.75	0.00460	0.00461	0.00462
0.24	60	11.43	11.39	11.43	1.06	10.35	0.00489	0.00489	0.00488
0.26	65	11.99	11.99	11.99	1.11	10.88	0.00514	0.00516	0.00512
0.28	70	12.31	12.75	12.30	1.15	11.31	0.00534	0.00542	0.00536
0.30	75	13.08	13.26	12.96	1.19	11.91	0.00562	0.00568	0.00559
0.32	80	13.66	13.80	13.72	1.24	12.49	[illegible]		
0.34	85	14.26	14.36	14.29	1.28	13.03	0.00615		
0.36	90	14.89	14.86	14.93	1.31	13.58	0.00641		
0.38	95	15.44	15.41	15.45	1.35	14.08	0.00665		
0.40	100	15.88	15.75	15.86	1.39	14.44	0.00682		
0.42	105	16.47	16.48	16.48	1.43	15.05	0.00710		
0.44	110	17.06	16.88	16.99	1.46	15.52	0.00732		
0.46	115	17.56	17.53	17.53	1.49	16.05	0.00757		
0.48	120	18.09	17.95	18.03	1.53	16.49	0.00778		
0.5	125	18.72	18.42	18.63	1.56	17.02	0.00803		

Power Model: C = 3.12E-04; n = 0.6720; C.V. = 0.9346 (%)

New Model: C1 = 7.80E-04; C2 = 2.01; C3 = 1.07; C.V. = 1.1585 (%)

Component Leakage Test: Wall Penetrations / Outlets with Gaskets: CO-4

Pressure Difference Across Crack (In.Wg)	(Pa)	Flow Rate Rep.1 (cfm)	Rep.2 (cfm)	Rep.3 (cfm)	Chamber Leak (cfm)	Corrected Mean (cfm)	Corrected Mean (m^3/sec.)	Power Model Predicted Q (m^3/sec.)	New Model Predicted Q (m^3/sec.)
0.02	5	2.02	1.95	1.81	0.29	1.64	0.00078	0.00080	0.00074
0.04	10	3.20	3.14	3.26	0.41	2.79	0.00131	0.00128	0.00127
0.06	15	4.24	3.81	3.59	0.51	3.37	0.00159	0.00167	0.00170
0.08	20	5.11	4.95	5.01	0.60	4.43	0.00209	0.00203	0.00207
0.10	25	5.80	5.03	6.76	0.67	5.15	0.00243	0.00235	0.00240
0.12	30	6.60	6.46	6.36	0.74	5.73	0.00271	0.00266	0.00271
0.14	35	7.27	7.23	7.05	0.80	6.38	0.00301	0.00294	0.00299
0.16	40	7.86	7.73	7.69	0.86	6.90	0.00326	0.00322	0.00326
0.18	45	8.47	8.39	8.22	0.91	7.45	0.00352	0.00348	0.00351
0.20	50	8.91	8.61	8.86	0.97	7.83	0.00369	0.00374	0.00375
0.22	55	9.66	8.92	9.34	1.01	8.29	0.00391	0.00398	0.00397
0.24	60	10.12	9.92	10.04	1.06	8.96	0.00423	0.00422	0.00419
0.26	65	10.65	9.77	10.42	1.11	9.17	0.00433	0.00445	0.00440
0.28	70	11.22	10.27	11.03	1.15	9.69	0.00457	0.00468	0.00460
0.30	75	11.75	11.47	11.48	1.19	10.37	0.00490	0.00490	0.00479
0.32	80	12.23	11.33	11.96	1.24	10.60	0.00500		
0.34	85	12.73	12.43	12.43	1.28	11.26	0.00531		
0.36	90	13.28	13.01	12.91	1.31	11.75	0.00555		
0.38	95	13.70	13.39	13.34	1.35	12.13	0.00572		
0.40	100	14.04	13.89	13.53	1.39	12.43	0.00587		
0.42	105	14.54	14.32	13.96	1.43	12.85	0.00606		
0.44	110	15.10	14.81	14.08	1.46	13.20	0.00623		
0.46	115	15.44	15.19	15.05	1.49	13.73	0.00648		
0.48	120	15.78	15.63	15.81	1.53	14.15	0.00668		
0.5	125	16.43	16.23	15.99	1.56	14.65	0.00692		

Power Model: C = 2.74E-04; n = 0.6679; C.V. = 2.2372 (%)

New Model: C1 = 5.81E-04; C2 = 2.01; C3 = 1.35; C.V. = 1.8031 (%)

Component Leakage Test: Wall Penetrations / Outlets, Top Wire Holes: C0-5

Pressure Difference Across Crack (In.Wg)	(Pa)	Flow Rate Rep.1 (cfm)	Rep.2 (cfm)	Rep.3 (cfm)	Chamber Leak (cfm)	Corrected Mean (cfm)	Corrected Mean (m^3/sec.)	Power Model Predicted Q (m^3/sec.)	New Model Predicted Q (m^3/sec.)
0.02	5	2.09	2.33	2.68	0.29	2.08	0.00098	0.00099	0.00087
0.04	10	3.80	3.66	3.71	0.41	3.31	0.00156	0.00154	0.00148
0.06	15	4.79	4.81	4.81	0.51	4.29	0.00203	0.00201	0.00199
0.08	20	5.77	5.82	5.65	0.60	5.15	0.00243	0.00242	0.00242
0.10	25	6.71	6.45	6.56	0.67	5.90	0.00278	0.00279	0.00282
0.12	30	7.49	7.19	7.28	0.74	6.58	0.00311	0.00314	0.00318
0.14	35	8.27	8.03	7.98	0.80	7.29	0.00344	0.00347	0.00351
0.16	40	9.09	8.71	8.80	0.86	8.01	0.00378	0.00378	0.00382
0.18	45	9.74	9.31	9.48	0.91	8.60	0.00406	0.00408	0.00411
0.20	50	10.53	9.97	10.10	0.97	9.23	0.00436	0.00437	0.00439
0.22	55	11.37	10.38	10.68	1.01	9.79	0.00462	0.00464	0.00466
0.24	60	12.03	11.30	11.27	1.06	10.47	0.00494	0.00491	0.00491
0.26	65	12.52	11.86	11.86	1.11	10.98	0.00518	0.00517	0.00516
0.28	70	13.15	12.60	12.46	1.15	11.58	0.00547	0.00543	0.00539
0.30	75	13.87	13.00	13.03	1.19	12.10	0.00571	0.00567	0.00562
0.32	80	14.72	13.65	13.58	1.24	12.75	0.00602		
0.34	85	15.18	14.44	14.18	1.28	13.32	0.00629		
0.36	90	15.76	14.99	14.74	1.31	13.85	0.00654		
0.38	95	16.41	15.47	15.04	1.35	14.29	0.00674		
0.40	100	17.02	15.98	15.99	1.39	14.94	0.00705		
0.42	105	17.67	16.67	16.44	1.43	15.50	0.00732		
0.44	110	18.24	17.21	17.01	1.46	16.03	0.00756		
0.46	115	19.01	17.97	17.79	1.49	16.76	0.00791		
0.48	120	19.78	18.59	18.19	1.53	17.32	0.00818		
0.5	125	20.45	19.27	18.78	1.56	17.94	0.00847		

Power Model	New Model
C = 3.49E-04	C1 = 7.73E-04
n = 0.6459	C2 = 1.78
	C3 = 1.05
C.V. = 0.6784 (%)	C.V. = 1.7696 (%)

Component Leakage Test: Wall Penetrations / Outlets, Top Wire Holes Sealed: CO-6

Pressure Difference Across Crack (In.Wg)	(Pa)	Flow Rate Rep.1 (cfm)	Rep.2 (cfm)	Rep.3 (cfm)	Chamber Leak (cfm)	Corrected Mean (cfm)	Corrected Mean (m^3/sec.)	Power Model Predicted Q (m^3/sec.)	New Model Predicted Q (m^3/sec.)
0.02	5	1.66	1.74	1.69	0.29	1.41	0.00066	0.00067	0.00058
0.04	10	2.81	2.75	2.74	0.41	2.35	0.00111	0.00110	0.00105
0.06	15	3.72	3.60	3.55	0.51	3.11	0.00147	0.00148	0.00145
0.08	20	4.61	4.53	4.27	0.60	3.87	0.00183	0.00181	0.00181
0.10	25	5.33	5.28	5.00	0.67	4.53	0.00214	0.00213	0.00215
0.12	30	6.09	5.95	5.63	0.74	5.16	0.00243	0.00243	0.00245
0.14	35	6.76	6.71	6.22	0.80	5.76	0.00272	0.00271	0.00274
0.16	40	7.39	7.30	6.79	0.86	6.30	0.00297	0.00298	0.00301
0.18	45	8.15	7.84	7.43	0.91	6.89	0.00325	0.00324	0.00326
0.20	50	8.66	8.53	7.83	0.97	7.37	0.00348	0.00350	0.00351
0.22	55	9.31	9.01	8.40	1.01	7.89	0.00372	0.00375	0.00374
0.24	60	9.80	9.53	8.97	1.06	8.37	0.00395	0.00399	0.00397
0.26	65	10.43	10.20	9.53	1.11	8.94	0.00422	0.00422	0.00418
0.28	70	10.91	10.76	10.03	1.15	9.42	0.00444	0.00445	0.00439
0.30	75	11.60	11.22	10.48	1.19	9.90	0.00467	0.00468	0.00459
0.32	80	12.15	11.85	10.94	1.24	10.41	0.00491		
0.34	85	12.70	12.40	11.41	1.28	10.90	0.00514		
0.36	90	13.35	12.92	11.94	1.31	11.42	0.00539		
0.38	95	13.66	13.35	12.38	1.35	11.78	0.00556		
0.40	100	14.39	13.88	12.81	1.39	12.30	0.00581		
0.42	105	14.98	14.38	13.29	1.43	12.79	0.00604		
0.44	110	15.47	14.86	13.85	1.46	13.27	0.00626		
0.46	115	15.94	15.35	14.24	1.49	13.68	0.00646		
0.48	120	16.46	15.95	14.63	1.53	14.15	0.00668		
0.5	125	17.09	16.42	15.26	1.56	14.70	0.00694		

Power Model	New Model
C = 2.12E-04	C1 = 7.59E-04
n = 0.7167	C2 = 2.61
	C3 = 0.91
C.V. = 0.5342 (%)	C.V. = 1.5568 (%)

Component Leakage Test: Wall Penetrations / Outlets with gaskets, Top Wire Holes: CO-7

Pressure Difference Across Crack (in.Wg)	(Pa)	Flow Rate Rep.1 (cfm)	Rep.2 (cfm)	Rep.3 (cfm)	Chamber Leak (cfm)	Corrected Mean (cfm)	Corrected Mean (m^3/sec.)	Power Model Predicted Q (m^3/sec.)	New Model Predicted Q (m^3/sec.)
0.02	5	1.81	1.66	1.81	0.29	1.47	0.00070	0.00071	0.00062
0.04	10	2.87	2.87	3.00	0.41	2.50	0.00118	0.00116	0.00112
0.06	15	3.72	3.77	3.91	0.51	3.29	0.00155	0.00155	0.00154
0.08	20	4.61	4.56	4.87	0.60	4.08	0.00193	0.00190	0.00191
0.10	25	5.28	5.33	5.56	0.67	4.72	0.00223	0.00222	0.00225
0.12	30	5.97	6.09	6.19	0.74	5.35	0.00252	0.00253	0.00256
0.14	35	6.62	6.83	6.92	0.80	5.99	0.00283	0.00282	0.00285
0.16	40	7.25	7.48	7.65	0.86	6.60	0.00312	0.00310	0.00313
0.18	45	7.81	7.97	8.31	0.91	7.12	0.00336	0.00337	0.00339
0.20	50	8.42	8.40	8.90	0.97	7.61	0.00359	0.00363	0.00363
0.22	55	8.94	9.31	9.33	1.01	8.18	0.00386	0.00388	0.00387
0.24	60	9.49	9.78	9.93	1.06	8.67	0.00409	0.00412	0.00410
0.26	65	10.08	10.31	10.63	1.11	9.23	0.00436	0.00436	0.00432
0.28	70	10.50	10.87	11.03	1.15	9.65	0.00455	0.00460	0.00453
0.30	75	[illegible]	11.45	11.70	1.19	10.20	0.00481	0.00483	0.00473
0.32	80	11.47	11.85	12.03	1.24	10.55	0.00498		
0.34	85	11.99	12.58	12.70	1.28	11.15	0.00526		
0.36	90	12.39	13.06	13.35	1.31	11.62	0.00548		
0.38	95	12.97	13.60	13.67	1.35	12.06	0.00569		
0.40	100	13.40	14.05	14.24	1.39	12.51	0.00590		
0.42	105	13.75	14.51	14.66	1.43	12.88	0.00608		
0.44	110	14.14	15.00	14.93	1.46	13.23	0.00624		
0.46	115	14.81	15.56	15.74	1.49	13.87	0.00655		
0.48	120	15.19	15.79	16.10	1.53	14.17	0.00669		
0.5	125	15.64	16.27	16.41	1.56	14.55	0.00686		

Power Model	New Model
C = ERR	C1 = 7.21E-04
	C2 = 2.49
n = 0.7061	C3 = 1.01
C.V.= 0.7768 (%)	C.V.= 1.4510 (%)

Component Leakage Test: Wall Penetrations / Outlets with Gaskets, Top Wire Holes Sealed: CO-8

Pressure Difference Across Crack (in.Wg)	(Pa)	Flow Rate Rep.1 (cfm)	Rep.2 (cfm)	Rep.3 (cfm)	Chamber Leak (cfm)	Corrected Mean (cfm)	Corrected Mean (m^3/sec.)	Power Model Predicted Q (m^3/sec.)	New Model Predicted Q (m^3/sec.)
0.02	5	1.35	1.31	1.39	0.29	1.06	0.00050	0.00053	0.00048
0.04	10	2.33	2.23	2.36	0.41	1.89	0.00089	0.00086	0.00085
0.06	15	2.93	2.93	3.05	0.51	2.46	0.00116	0.00115	0.00116
0.08	20	3.64	3.58	3.69	0.60	3.04	0.00143	0.00140	0.00143
0.10	25	4.19	4.14	4.25	0.67	3.52	0.00166	0.00164	0.00168
0.12	30	4.73	4.68	4.88	0.74	4.02	0.00190	0.00187	0.00191
0.14	35	5.24	5.19	5.39	0.80	4.47	0.00211	0.00208	0.00212
0.16	40	5.79	5.65	5.79	0.86	4.88	0.00231	0.00229	0.00232
0.18	45	6.18	6.14	6.23	0.91	5.27	0.00249	0.00249	0.00251
0.20	50	6.57	6.62	6.71	0.97	5.67	0.00267	0.00268	0.00269
0.22	55	7.04	7.00	7.18	1.01	6.06	0.00286	0.00286	0.00286
0.24	60	7.41	7.37	7.63	1.06	6.41	0.00303	0.00304	0.00303
0.26	65	7.83	7.80	8.00	1.11	6.77	0.00319	0.00322	0.00319
0.28	70	8.25	8.07	8.45	1.15	7.10	0.00335	0.00339	0.00334
0.30	75	8.60	8.56	8.76	1.19	7.45	0.00351	0.00356	0.00349
0.32	80	8.92	8.87	9.15	1.24	7.75	0.00366		
0.34	85	9.31	9.15	9.54	1.28	8.06	0.00380		
0.36	90	9.74	9.59	9.89	1.31	8.42	0.00397		
0.38	95	10.00	10.01	10.20	1.35	8.72	0.00411		
0.40	100	10.35	10.27	10.66	1.39	9.04	0.00427		
0.42	105	10.77	10.65	10.91	1.43	9.35	0.00441		
0.44	110	11.14	10.98	11.29	1.46	9.68	0.00457		
0.46	115	11.41	11.17	11.63	1.49	9.91	0.00468		
0.48	120	11.84	11.70	11.96	1.53	10.30	0.00486		
0.5	125	12.13	12.01	12.35	1.56	10.60	0.00500		

Power Model	New Model
C = 1.70E-04	C1 = 5.00E-04
	C2 = 2.37
n = 0.7047	C3 = 1.09
C.V.= 1.2873 (%)	C.V.= 0.9263 (%)

Component Leakage Test: Wall Penetrations / Copper Water Line: CO-9

Pressure Difference Across Crack (in.Wg)	(Pa)	Flow Rate Rep.1 (cfm)	Rep.2 (cfm)	Rep.3 (cfm)	Chamber Leak (cfm)	Corrected Mean (cfm)	Corrected Mean (m^3/sec.)	Power Model Predicted Q (m^3/sec.)	New Model Predicted Q (m^3/sec.)
0.02	5	0.40	0.40	0.40	0.29	0.12	0.00005	0.00007	0.00007
0.04	10	0.72	0.72	0.62	0.41	0.27	0.00013	0.00012	0.00013
0.06	15	0.89	0.89	0.89	0.51	0.38	0.00018	0.00017	0.00018
0.08	20	1.13	1.05	1.05	0.60	0.48	0.00023	0.00021	0.00023
0.10	25	1.27	1.27	1.27	0.67	0.60	0.00028	0.00026	0.00027
0.12	30	1.48	1.41	1.41	0.74	0.70	0.00033	0.00030	0.00032
0.14	35	1.61	1.54	1.54	0.80	0.76	0.00036	0.00035	0.00036
0.16	40	1.74	1.67	1.60	0.86	0.81	0.00038	0.00039	0.00040
0.18	45	1.86	1.79	1.72	0.91	0.88	0.00041	0.00043	0.00043
0.20	50	1.98	1.98	1.91	0.97	0.99	0.00047	0.00047	0.00047
0.22	55	2.14	2.09	1.98	1.01	1.05	0.00050	0.00051	0.00050
0.24	60	2.26	2.21	2.08	1.06	1.12	0.00053	0.00055	0.00054
0.26	65	2.37	2.37	2.19	1.11	1.20	0.00057	0.00058	0.00057
0.28	70	2.48	2.42	2.29	1.15	1.24	0.00059	0.00062	0.00060
0.30	75	2.65	2.52	2.46	1.19	1.35	0.00064	0.00066	0.00063
0.32	80	2.69	2.63	2.57	1.24	1.40	0.00066		
0.34	85	2.85	2.74	2.68	1.28	1.48	0.00070		
0.36	90	2.96	2.84	2.73	1.31	1.53	0.00072	C = 1.67E-05	C1 = 1.08E-04
0.38	95	3.06	2.95	2.83	1.35	1.59	0.00075		
0.40	100	3.16	3.05	2.93	1.39	1.66	0.00078		C2 = 4.15
0.42	105	3.20	3.20	3.04	1.43	1.72	0.00081	n = 0.8518	
0.44	110	3.35	3.25	3.08	1.46	1.76	0.00083		C3 = 1.10
0.46	115	3.45	3.35	3.18	1.49	1.83	0.00086		
0.48	120	3.49	3.43	3.28	1.53	1.87	0.00088	C.V.= 5.1187 (%)	C.V.= 2.7706 (%)
0.5	125	3.58	3.53	3.38	1.56	1.94	0.00091		

Component Leakage Test: Wall Penetrations / Switches, Top Wire Holes: CO-10

Pressure Difference Across Crack (in.Wg)	(Pa)	Flow Rate Rep.1 (cfm)	Rep.2 (cfm)	Rep.3 (cfm)	Chamber Leak (cfm)	Corrected Mean (cfm)	Corrected Mean (m^3/sec.)	Power Model Predicted Q (m^3/sec.)	New Model Predicted Q (m^3/sec.)
0.02	5	1.67	1.74	1.74	0.29	1.43	0.00068	0.00073	0.00066
0.04	10	3.08	3.20	3.08	0.41	2.71	0.00128	0.00122	0.00119
0.06	15	4.08	4.19	4.03	0.51	3.58	0.00169	0.00164	0.00165
0.08	20	5.10	5.10	4.95	0.60	4.46	0.00210	0.00203	0.00207
0.10	25	5.83	5.88	5.75	0.67	5.15	0.00243	0.00240	0.00244
0.12	30	6.71	6.69	6.36	0.74	5.85	0.00276	0.00274	0.00279
0.14	35	7.48	7.57	7.06	0.80	6.57	0.00310	0.00308	0.00312
0.16	40	8.10	8.19	7.86	0.86	7.19	0.00340	0.00339	0.00343
0.18	45	8.83	8.87	8.66	0.91	7.88	0.00372	0.00370	0.00372
0.20	50	9.50	9.50	9.14	0.97	8.42	0.00397	0.00400	0.00400
0.22	55	10.17	10.20	9.78	1.01	9.03	0.00426	0.00430	0.00427
0.24	60	10.74	10.86	10.39	1.06	9.60	0.00453	0.00458	0.00452
0.26	65	11.41	11.37	11.04	1.11	10.17	0.00480	0.00486	0.00477
0.28	70	12.01	12.05	11.44	1.15	10.68	0.00504	0.00513	0.00501
0.30	75	12.67	12.66	12.12	1.19	11.29	0.00533	0.00540	0.00524
0.32	80	13.21	13.13	12.58	1.24	11.74	0.00554		
0.34	85	13.71	13.71	13.23	1.28	12.28	0.00579		
0.36	90	14.29	14.35	13.70	1.31	12.80	0.00604	C = 2.22E-04	C1 = 8.04E-04
0.38	95	14.92	14.81	14.20	1.35	13.29	0.00627		
0.40	100	15.54	15.47	14.83	1.39	13.89	0.00656		C2 = 2.84
0.42	105	15.95	16.12	15.35	1.43	14.38	0.00679	n = 0.7393	
0.44	110	16.66	16.56	15.91	1.46	14.91	0.00704		C3 = 1.06
0.46	115	17.10	17.00	16.41	1.49	15.34	0.00724		
0.48	120	17.71	17.65	17.02	1.53	15.93	0.00752	C.V.= 1.6489 (%)	C.V.= 1.3151 (%)
0.5	125	18.25	18.25	17.73	1.56	16.51	0.00779		

Component Leakage Test: Wall Penetrations / Switches, Top Wire Holes Sealed: CO-11

Pressure Difference Across Crack (in.Wg)	(Pa)	Flow Rate Rep.1 (cfm)	Rep.2 (cfm)	Rep.3 (cfm)	Chamber Leak (cfm)	Corrected Mean (cfm)	Corrected Mean (m^3/sec.)	Power Model Predicted Q (m^3/sec.)	New Model Predicted Q (m^3/sec.)
0.02	5	0.95	1.39	1.39	0.29	0.96	0.00045	0.00048	0.00043
0.04	10	1.89	2.26	2.26	0.41	1.72	0.00081	0.00080	0.00078
0.06	15	2.63	2.96	2.93	0.51	2.33	0.00110	0.00107	0.00108
0.08	20	3.24	3.69	3.49	0.60	2.88	0.00136	0.00133	0.00135
0.10	25	3.87	4.24	4.08	0.67	3.40	0.00160	0.00156	0.00159
0.12	30	4.42	4.78	4.62	0.74	3.87	0.00182	0.00178	0.00181
0.14	35	4.81	5.29	5.06	0.80	4.25	0.00201	0.00200	0.00202
0.16	40	5.26	5.79	5.45	0.86	4.64	0.00219	0.00220	0.00222
0.18	45	5.82	6.23	5.91	0.91	5.07	0.00239	0.00240	0.00241
0.20	50	6.26	6.61	6.35	0.97	5.44	0.00257	0.00259	0.00259
0.22	55	6.81	6.86	6.83	1.01	5.82	0.00275	0.00278	0.00276
0.24	60	7.10	7.54	7.16	1.06	6.21	0.00293	0.00296	0.00292
0.26	65	7.53	7.66	7.57	1.11	6.48	0.00306	0.00314	0.00308
0.28	70	7.90	8.32	8.03	1.15	6.93	0.00327	0.00332	0.00324
0.30	75	[illegible]	[illegible]	[illegible]	1.19	7.31	0.00345	0.00349	0.00338
0.32	80	8.70	9.07	8.67	1.24	7.58	0.00358		
0.34	85	9.01	9.51	9.18	1.28	7.96	0.00376		
0.36	90	9.33	10.09	9.53	1.31	8.34	0.00393		
0.38	95	9.78	10.40	9.84	1.35	8.65	0.00408		
0.40	100	10.06	10.66	10.23	1.39	8.93	0.00421		
0.42	105	10.49	11.11	10.57	1.43	9.30	0.00439		
0.44	110	10.95	11.52	10.94	1.46	9.68	0.00457		
0.46	115	11.09	11.81	11.23	1.49	9.88	0.00466		
0.48	120	11.50	12.17	11.69	1.53	10.26	0.00484		
0.5	125	11.83	12.65	11.95	1.56	10.58	0.00499		

Power Model: C = 1.48E-04; n = 0.7318; C.V. = 1.8114 (%)

New Model: C1 = 5.13E-04; C2 = 2.73; C3 = 1.06; C.V. = 1.3370 (%)

Component Leakage Test: Wall Penetrations / Switches with Gaskets, Top Wire Holes Sealed: CO-12

Pressure Difference Across Crack (in.Wg)	(Pa)	Flow Rate Rep.1 (cfm)	Rep.2 (cfm)	Rep.3 (cfm)	Chamber Leak (cfm)	Corrected Mean (cfm)	Corrected Mean (m^3/sec.)	Power Model Predicted Q (m^3/sec.)	New Model Predicted Q (m^3/sec.)
0.02	5	0.95	0.86	0.86	0.29	0.60	0.00028	0.00028	0.00024
0.04	10	1.43	1.27	1.32	0.41	0.92	0.00044	0.00044	0.00042
0.06	15	1.75	1.75	1.67	0.51	1.21	0.00057	0.00058	0.00057
0.08	20	2.20	1.93	2.07	0.00	1.47	0.00069	0.00071	0.00071
0.10	25	2.48	2.42	2.38	0.67	1.75	0.00083	0.00082	0.00083
0.12	30	2.77	2.77	2.65	0.74	1.99	0.00094	0.00093	0.00094
0.14	35	3.03	2.99	2.87	0.80	2.16	0.00102	0.00103	0.00105
0.16	40	3.35	3.30	3.19	0.86	2.42	0.00114	0.00113	0.00114
0.18	45	3.54	3.51	3.40	0.91	2.57	0.00121	0.00122	0.00124
0.20	50	3.80	3.86	3.60	0.97	2.79	0.00132	0.00131	0.00132
0.22	55	4.05	4.00	3.79	1.01	2.93	0.00138	0.00140	0.00141
0.24	60	4.34	4.25	4.13	1.06	3.18	0.00150	0.00148	0.00149
0.26	65	4.58	4.48	4.27	1.11	3.34	0.00157	0.00157	0.00156
0.28	70	4.82	4.72	4.47	1.15	3.51	0.00166	0.00165	0.00164
0.30	75	4.99	4.90	4.65	1.19	3.65	0.00172	0.00173	0.00171
0.32	80	5.17	5.17	4.83	1.24	3.82	0.00180		
0.34	85	5.40	5.35	5.06	1.28	4.00	0.00189		
0.36	90	5.57	5.48	5.24	1.31	4.12	0.00194		
0.38	95	5.70	5.65	5.41	1.35	4.23	0.00200		
0.40	100	5.92	5.83	5.59	1.39	4.39	0.00207		
0.42	105	6.08	6.00	5.63	1.43	4.48	0.00211		
0.44	110	6.25	6.21	5.85	1.46	4.65	0.00219		
0.46	115	6.47	6.34	6.20	1.49	4.84	0.00228		
0.48	120	6.55	6.51	6.33	1.53	4.93	0.00233		
0.5	125	6.71	6.71	6.54	1.56	5.09	0.00240		

Power Model: C = 9.33E-05; n = 0.6758; C.V. = 1.0035 (%)

New Model: C1 = 2.62E-04; C2 = 2.13; C3 = 0.94; C.V. = 1.7952 (%)

Component Leakage Test: Wall Penetrations / Switches with Gaskets, Top Wire Holes: CO-13

Pressure Difference Across Crack (in.Wg)	(Pa)	Flow Rate Rep.1 (cfm)	Rep.2 (cfm)	Rep.3 (cfm)	Chamber Leak (cfm)	Corrected Mean (cfm)	Corrected Mean (m^3/sec.)	Power Model Predicted Q (m^3/sec.)	New Model Predicted Q (m^3/sec.)
0.02	5	0.69	0.79	0.79	0.29	0.47	0.00022	0.00028	0.00030
0.04	10	1.72	1.50	1.65	0.41	1.21	0.00057	0.00052	0.00057
0.06	15	2.35	2.29	2.35	0.51	1.82	0.00086	0.00075	0.00082
0.08	20	2.87	2.69	2.87	0.60	2.21	0.00104	0.00097	0.00105
0.10	25	3.29	3.20	3.52	0.67	2.67	0.00126	0.00118	0.00126
0.12	30	3.78	3.72	4.03	0.74	3.10	0.00146	0.00140	0.00147
0.14	35	4.33	4.10	4.57	0.80	3.53	0.00167	0.00160	0.00166
0.16	40	4.65	4.55	4.99	0.86	3.87	0.00183	0.00181	0.00185
0.18	45	5.17	4.93	5.55	0.91	4.30	0.00203	0.00201	0.00202
0.20	50	5.53	5.34	5.89	0.97	4.62	0.00218	0.00221	0.00219
0.22	55	5.93	5.74	6.34	1.01	4.99	0.00235	0.00240	0.00236
0.24	60	6.28	6.19	6.81	1.06	5.36	0.00253	0.00260	0.00252
0.26	65	6.63	6.44	7.15	1.11	5.63	0.00266	0.00279	0.00267
0.28	70	6.92	6.82	7.56	1.15	5.95	0.00281	0.00298	0.00282
0.30	75	7.25	7.21	7.93	1.19	6.27	0.00296	0.00317	0.00297
0.32	80	7.71	7.54	8.38	1.24	6.64	0.00313		
0.34	85	7.96	7.90	8.85	1.28	6.96	0.00329		
0.36	90	8.32	8.24	9.17	1.31	7.26	0.00343		
0.38	95	8.55	8.51	9.48	1.35	7.49	0.00354		
0.40	100	8.95	8.82	9.90	1.39	7.84	0.00370		
0.42	105	9.26	9.14	10.29	1.43	8.13	0.00384		
0.44	110	9.52	9.40	10.58	1.46	8.38	0.00395		
0.46	115	9.75	9.75	11.00	1.49	8.67	0.00409		
0.48	120	10.14	10.13	11.33	1.53	9.01	0.00425		
0.5	125	10.36	10.35	11.56	1.56	9.20	0.00434		

Power Model: C = ERR; n = 0.8962; C.V.= 5.8579 (%)

New Model: C1 = 5.150E-04; C2 = 4.74; C3 = 1.17; C.V.= 1.4660 (%)

Component Leakage Test: Premium Awning on the Wall: CO-14

Pressure Difference Across Crack (in.Wg)	(Pa)	Flow Rate Rep.1 (cfm)	Rep.2 (cfm)	Rep.3 (cfm)	Chamber Leak (cfm)	Corrected Mean (cfm)	Corrected Mean (m^3/sec.)	Power Model Predicted Q (m^3/sec.)	New Model Predicted Q (m^3/sec.)
0.02	5	3.41	2.68	3.12	0.29	2.78	0.00131	0.00131	0.00107
0.04	10	5.41	4.89	5.25	0.41	4.77	0.00225	0.00224	0.00203
0.06	15	7.30	6.86	7.05	0.51	6.56	0.00310	0.00305	0.00291
0.08	20	9.05	8.37	8.59	0.60	8.07	0.00381	0.00381	0.00373
0.10	25	10.58	9.98	10.00	0.67	9.52	0.00449	0.00452	0.00449
0.12	30	12.14	11.25	11.64	0.74	10.94	0.00516	0.00520	0.00521
0.14	35	13.56	12.79	13.14	0.80	12.36	0.00583	0.00586	0.00589
0.16	40	15.10	14.01	14.20	0.86	13.58	0.00641	0.00649	0.00654
0.18	45	16.24	15.43	15.72	0.91	14.88	0.00702	0.00711	0.00716
0.20	50	17.61	16.74	17.07	0.97	16.17	0.00763	0.00771	0.00776
0.22	55	18.98	18.07	18.10	1.01	17.37	0.00820	0.00829	0.00834
0.24	60	20.40	19.45	19.81	1.06	18.82	0.00888	0.00887	0.00890
0.26	65	21.60	20.75	21.05	1.11	20.02	0.00945	0.00943	0.00944
0.28	70	25.01	21.91	22.16	1.15	21.87	0.01032	0.00998	0.00996
0.30	75	24.41	23.23	23.29	1.19	22.45	0.01060	0.01053	0.01047
0.32	80	25.74	24.31	24.55	1.24	23.63	0.01115		
0.34	85	27.16	25.55	26.09	1.28	24.99	0.01179		
0.36	90	28.29	26.94	27.19	1.31	26.16	0.01235		
0.38	95	29.56	28.22	28.34	1.35	27.36	0.01291		
0.40	100	30.91	29.33	29.68	1.39	28.58	0.01349		
0.42	105	32.23	30.56	30.92	1.43	29.81	0.01407		
0.44	110	33.41	32.00	32.17	1.46	31.06	0.01466		
0.46	115	34.71	33.02	33.53	1.49	32.26	0.01522		
0.48	120	36.08	34.30	34.71	1.53	33.50	0.01581		
0.5	125	37.02	35.57	35.78	1.56	34.56	0.01631		

Power Model: C = 3.81E-04; n = 0.7687; C.V.= 1.7409 (%)

New Model: C1 = 2.567E-03; C2 = 3.2; C3 = 0.57; C.V.= 2.6847 (%)

Component Leakage Test: Premium Double Hung on the Wall: CO-15

Pressure Difference Across Crack (In.Wg)	(Pa)	Flow Rate Rep.1 (cfm)	Rep.2 (cfm)	Rep.3 (cfm)	Chamber Leak (cfm)	Corrected Mean (cfm)	Corrected Mean (m^3/sec.)	Power Model Predicted Q (m^3/sec.)	New Model Predicted Q (m^3/sec.)
0.02	5	4.71	4.87	4.67	0.29	4.46	0.00211	0.00203	0.00164
0.04	10	7.72	7.47	7.60	0.41	7.18	0.00339	0.00343	0.00310
0.06	15	10.17	10.06	10.19	0.51	9.63	0.00454	0.00467	0.00443
0.08	20	14.77	12.43	12.63	0.60	12.68	0.00598	0.00581	0.00567
0.10	25	15.34	14.73	14.61	0.67	14.22	0.00671	0.00688	0.00683
0.12	30	17.61	17.08	16.85	0.74	16.44	0.00776	0.00790	0.00792
0.14	35	19.87	19.25	18.59	0.80	18.44	0.00870	0.00887	0.00895
0.16	40	21.99	21.58	21.06	0.86	20.69	0.00976	0.00982	0.00994
0.18	45	24.12	23.51	22.89	0.91	22.59	0.01066	0.01073	0.01088
0.20	50	26.15	25.53	24.72	0.97	24.50	0.01156	0.01163	0.01179
0.22	55	28.24	27.64	26.69	1.01	26.51	0.01251	0.01250	0.01266
0.24	60	30.45	29.51	28.57	1.06	28.45	0.01343	0.01335	0.01351
0.26	65	32.37	31.65	30.45	1.11	30.38	0.01434	0.01418	0.01432
[illegible]	[illegible]	34.46	33.66	32.38	1.15	32.35	0.01527	0.01500	0.01512
0.30	75	36.44	35.86	34.16	1.19	34.30	0.01619	0.01581	0.01590
0.32	80	38.33	37.64	36.13	1.24	36.13	0.01705		
0.34	85	40.62	39.68	38.13	1.28	38.20	0.01803		
0.36	90	42.58	41.56	39.69	1.31	39.96	0.01886		
0.38	95	44.48	43.59	41.57	1.35	41.86	0.01976		
0.40	100	46.41	45.57	43.36	1.39	43.72	0.02064		
0.42	105	48.55	47.75	45.20	1.43	45.74	0.02159		
0.44	110	50.87	49.81	47.05	1.46	47.78	0.02255		
0.46	115	52.89	51.36	48.92	1.49	49.56	0.02339		
0.48	120	54.88	53.87	50.91	1.53	51.69	0.02440		
0.5	125	56.77	55.75	53.37	1.56	53.74	0.02536		

Power Model			New Model		
C =	ERR		C1 =	3.982E-03	
n =	0.7577		C2 =	3.06	
			C3 =	0.54	
C.V.=	1.8069	(%)	C.V.=	2.5806	(%)

Component Leakage Test: Economy Double Hung on the Wall: CO-16

Pressure Difference Across Crack (In.Wg)	(Pa)	Flow Rate Rep.1 (cfm)	Rep.2 (cfm)	Rep.3 (cfm)	Chamber Leak (cfm)	Corrected Mean (cfm)	Corrected Mean (m^3/sec.)	Power Model Predicted Q (m^3/sec.)	New Model Predicted Q (m^3/sec.)
0.02	5	28.60	27.20	29.87	0.29	28.27	0.01334	0.01375	0.01282
0.04	10	45.56	45.49	46.35	0.41	45.38	0.02142	0.02116	0.02100
0.06	15	61.42	57.90	58.59	0.51	58.79	0.02775	0.02723	0.02751
0.08	20	71.92	69.47	68.86	0.60	69.49	0.03279	0.03257	0.03310
0.10	25	83.22	80.00	79.46	0.67	80.23	0.03786	0.03742	0.03806
0.12	30	92.36	88.93	88.91	0.74	89.33	0.04216	0.04191	0.04258
0.14	35	101.17	98.43	97.53	0.80	98.24	0.04637	0.04613	0.04675
0.16	40	109.33	107.15	105.93	0.86	106.61	0.05031	0.05013	0.05064
0.18	45	118.09	114.92	113.76	0.91	114.68	0.05412	0.05394	0.05431
0.20	50	125.26	121.88	121.49	0.97	121.91	0.05754	0.05760	0.05778
0.22	55	133.09	129.17	128.13	1.01	129.11	0.06094	0.06111	0.06109
0.24	60	140.19	136.77	135.13	1.06	136.30	0.06433	0.06451	0.06425
0.26	65	146.39	141.85	141.80	1.11	142.24	0.06713	0.06781	0.06729
0.28	70	153.85	149.46	148.23	1.15	149.36	0.07049	0.07101	0.07022
0.30	75	160.13	155.61	155.58	1.19	155.91	0.07358	0.07412	0.07304
0.32	80	166.49	162.09	160.94	1.24	161.94	0.07643		
0.34	85	172.89	167.82	166.43	1.28	167.77	0.07918		
0.36	90	178.85	173.13	172.83	1.31	173.62	0.08194		
0.38	95	184.14	179.30	178.00	1.35	179.13	0.08454		
0.40	100	190.27	185.06	183.53	1.39	184.90	0.08726		
0.42	105	196.45	190.41	188.68	1.43	190.42	0.08987		
0.44	110	201.80	196.12	194.66	1.46	196.07	0.09253		
0.46	115	206.56	201.46	199.56	1.49	201.03	0.09488		
0.48	120	212.56	207.13	205.26	1.53	206.79	0.09759		
0.5	125	217.98	213.07	210.16	1.56	212.17	0.10013		

Power Model			New Model		
C =	5.05E-03		C1 =	8.463E-03	
			C2 =	1.42	
n =	0.6222		C3 =	1.32	
C.V.=	0.8210	(%)	C.V.=	0.7252	(%)

Component Leakage Test: Premium Casement on the Wall: CO-17

Pressure Difference Across Crack (in.Wg)	(Pa)	Flow Rate Rep.1 (cfm)	Rep.2 (cfm)	Rep.3 (cfm)	Chamber Leak (cfm)	Corrected Mean (cfm)	Corrected Mean (m^3/sec.)	Power Model Predicted Q (m^3/sec.)	New Model Predicted Q (m^3/sec.)
0.02	5	6.88	6.64	6.33	0.29	6.33	0.00299	0.00269	0.00214
0.04	10	8.46	10.30	10.25	0.41	9.26	0.00437	0.00460	0.00411
0.06	15	10.69	13.75	13.76	0.51	12.22	0.00577	0.00629	0.00593
0.08	20	17.03	17.15	16.98	0.60	16.46	0.00777	0.00785	0.00764
0.10	25	20.16	20.21	20.25	0.67	19.54	0.00922	0.00933	0.00926
0.12	30	23.26	23.23	23.44	0.74	22.57	0.01065	0.01074	0.01079
0.14	35	26.06	26.19	26.29	0.80	25.38	0.01198	0.01209	0.01226
0.16	40	28.86	29.18	29.13	0.86	28.20	0.01331	0.01341	0.01366
0.18	45	31.78	31.97	32.01	0.91	31.01	0.01463	0.01468	0.01501
0.20	50	34.58	34.75	35.00	0.97	33.81	0.01596	0.01593	0.01631
0.22	55	37.38	37.56	37.67	1.01	36.52	0.01724	0.01715	0.01757
0.24	60	40.25	40.50	40.37	1.06	39.31	0.01855	0.01834	0.01879
0.26	65	42.86	43.15	42.83	1.11	41.84	0.01975	0.01951	0.01997
0.28	70	45.69	46.06	46.12	1.15	44.80	0.02115	0.02065	0.02112
0.30	75	48.46	48.65	48.99	1.19	47.51	0.02242	0.02178	0.02224
0.32	80	51.26	51.73	51.56	1.24	50.28	0.02373		
0.34	85	54.10	54.39	54.33	1.28	53.00	0.02501		
0.36	90	56.75	57.16	57.39	1.31	55.79	0.02633	C = 7.77E-04	C1 = 6.7010E-03
0.38	95	59.66	59.87	60.09	1.35	58.52	0.02762		
0.40	100	62.32	62.86	62.98	1.39	61.33	0.02895		C2 = 3.2
0.42	105	65.07	65.70	65.01	1.43	63.84	0.03013	n = 0.7721	
0.44	110	68.43	68.38	68.53	1.46	66.99	0.03161		C3 = 0.43
0.46	115	70.84	71.52	71.23	1.49	69.70	0.03290		
0.48	120	73.85	74.02	73.93	1.53	72.41	0.03417	C.V. = 2.3491 (%)	C.V. = 2.6476 (%)
0.5	125	76.77	76.83	76.93	1.56	75.28	0.03553		

Component Leakage Test: Economy Casement on the Wall: CO-18

Pressure Difference Across Crack (in.Wg)	(Pa)	Flow Rate Rep.1 (cfm)	Rep.2 (cfm)	Rep.3 (cfm)	Chamber Leak (cfm)	Corrected Mean (cfm)	Corrected Mean (m^3/sec.)	Power Model Predicted Q (m^3/sec.)	New Model Predicted Q (m^3/sec.)
0.02	5	9.15	9.09	9.03	0.29	8.81	0.00416	0.00383	0.00279
0.04	10	14.28	14.53	14.45	0.41	14.01	0.00661	0.00654	0.00543
0.06	15	18.62	18.97	19.36	0.51	18.47	0.00872	0.00896	0.00793
0.08	20	22.93	23.35	23.42	0.60	22.64	0.01068	0.01120	0.01033
0.10	25	27.21	27.59	27.54	0.67	26.77	0.01264	0.01331	0.01262
0.12	30	31.33	31.44	31.77	0.74	30.77	0.01452	0.01533	0.01483
0.14	35	35.49	35.73	36.07	0.80	34.97	0.01650	0.01727	0.01696
0.16	40	39.51	40.04	40.41	0.86	39.13	0.01847	0.01915	0.01901
0.18	45	44.03	44.48	44.96	0.91	43.58	0.02057	0.02098	0.02101
0.20	50	48.33	49.03	49.42	0.97	47.96	0.02264	0.02276	0.02295
0.22	55	52.93	53.12	53.46	1.01	52.15	0.02461	0.02451	0.02483
0.24	60	57.50	57.50	57.87	1.06	56.56	0.02670	0.02622	0.02666
0.26	65	61.75	62.27	62.39	1.11	61.03	0.02880	0.02789	0.02845
0.28	70	66.24	67.61	66.77	1.15	65.72	0.03102	0.02954	0.03020
0.30	75	71.16	71.65	71.61	1.19	70.28	0.03317	0.03116	0.03190
0.32	80	75.84	76.74	76.22	1.24	75.03	0.03541		
0.34	85	80.44	81.35	81.05	1.28	79.67	0.03760		
0.36	90	84.23	86.38	85.92	1.31	84.19	0.03974	C = 1.10E-03	C1 = 1.4157E-02
0.38	95	87.24	90.76	90.45	1.35	88.13	0.04159		
0.40	100	90.67	95.81	95.42	1.39	92.58	0.04369		C2 = 3.2
0.42	105	93.94	99.83	99.45	1.43	96.31	0.04546	n = 0.7745	
\44	110	97.16	103.37	103.51	1.46	99.89	0.04714		C3 = 0.26
46	115	101.41	106.40	106.63	1.49	103.32	0.04876		
8	120	105.39	109.80	109.69	1.53	106.76	0.05039	C.V. = 4.7133 (%)	C.V. = 4.0332 (%)
[illegible]	125	111.74	113.70	113.71	1.56	111.49	0.05262		