Survey of Tightness Limits for Residential Buildings
July 2001

For the
Chicago Regional Diagnostics Working Group

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This document is available at www.karg.com/btlsurvey.htm

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Table of Contents

Acknowledgements

Funding and support for this project was provided primarily by the US Department of Energy and the Chicago Region low-income weatherization programs of Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, Ohio, and Wisconsin.

Introduction and Objectives

A number of low-income weatherization organizations in the DOE Chicago Region calculate one or more building tightness limit values before weatherization work – specifically air sealing – is done. Building tightness limit values determine a low limit for air sealing and give guidance regarding the need for continuously operating ventilation and combustion venting safety in tight buildings.

There are currently two types of tightness limits: Building Tightness Limits for acceptable indoor air quality (the BTL and BTLa methods are discussed in this paper) and Depressurization Tightness Limits for ensuring safe combustion appliance venting (the DTL method is discussed in this paper).

The generalized tightness limit procedure followed by many weatherization programs is noted in Table 1.

Table 1. Current Use of Tightness Limit Procedures by Some Wx Programs

Pre-Weatherization	**Example Values and Actions**
1. Blower door test, CFM_{50}	2200 CFM_{50}
2. Building tightness limit (BTL or BTLa), CFM_{50}	1300 CFM_{50} *The higher of these two values is*
3. Depressurization tightness limit (DTL), CFM_{50}	1100 CFM_{50} *used for the overall tightening limit*
4. The higher of values 2 and 3 is used as the house overall tightness limit (OTL)	1300 CFM_{50}
Post-Weatherization	
5. Blower door test, expressed as CFM_{50}	1050 CFM_{50}
6. If whole house CFM_{50} is below building tightness limit, add continuously operating exhaust ventilation	Add continuously operating ventilation
7. If whole house CFM_{50} is below depressurization tightness limit, mitigate possible draft problem.	Mitigate possible draft problem
8. Perform worst-case draft test using DTL value as guide. Check for venting code violations.	Perform worst-case draft test, using DTL as guide for mitigation of possible draft problems. Check for venting code violations.

Building Tightness Limits for Acceptable Indoor Air Quality

During the last decade, two building tightness calculation procedures have been developed for ensuring acceptable indoor air quality (IAQ). One of these methods is based on the American Society of Heating, Refrigerating and Air-Conditioning Engineers Standard 62-1999, *Ventilation for Acceptable Indoor Air Quality*. This method – referred to as the BTL method in this paper – is clearly explained in an article in *Home Energy* magazine (Tsongas 1993). For acceptable IAQ, this standard requires 15 CFM per person (assuming a minimum of five people) or 0.35 air changes per hour (ACH), whichever is greater, must be supplied by natural air leakage and/or continuously operating ventilation.

Tsongas' *Home Energy* article and the ZipTest Pro™ software for the Texas Instruments TI-86 calculator express the BTL as a CFM_{50} value so that it is easy to use as a limit for blower door guided air sealing.[1] Please refer to Appendix A for a flow chart of this calculation method.

[1] The author and seller of the ZipTest Pro™ building diagnostics software is the author of this paper. The ZipTest Pro™ software is the only available software for the calculation of the BTL procedure.

The second and more complex method – BTLa – is based on ASHRAE Standard 62, Standard 119 (*Air Leakage Performance for Detached Single-Family Residential Buildings*), and Standard136 (*A Method of Determining Air Change Rates in Detached Dwellings*). The BTLa procedure is part of The Energy Conservatory TECTITE™ software and is a part of the ZipTest Pro™ software for the Texas Instruments TI-86 calculator.[2] Unlike the TECTITE™ software, the ZipTest Pro™ software calculates the tightness limit as a CFM_{50} value for use as a tightening guide and calculates the required CFM for continuously operating exhaust ventilation when a house is tighter than the BTLa limit. Please refer to Appendix B for a flow chart of this calculation method.

The BTLa method, like the BTL method, is based on the parameters set in ASHRAE 62-1999: For acceptable IAQ, 15 CFM per person or 0.35 air changes per hour (ACH), whichever is greater, must be supplied by natural air leakage and/or continuously operating ventilation. However, the BTLa method uses different calculation methods – based on ASHRAE 119 and 136 – than the BTL method to arrive at the final tightness limits.

Tightness Limits for Safe Combustion Venting
This paper also addresses the Depressurization Tightness Limit (DTL), a pre-weatherization calculation performed by some of the state weatherization programs. If the house is tightened to a level lower than this limit, naturally vented combustion appliances might backdraft when exhaust fans are operating (bathroom exhaust, kitchen exhaust, vented dryers, etc.). This limit, expressed as a CFM_{50} value, sets a low limit for air sealing that may or may not be lower than the building tightness limit for the same house. Please refer to Appendix C for a flow chart of the DTL method.

Tightness Limit Practices in Chicago Wx Region, 1998
In 1998 on behalf of the Chicago Regional Diagnostics Working Group, the State of Michigan conducted "a survey to determine acceptable building tightness levels for homes weatherized using blower door technology."[3] A table summarizing the results of this survey is included as Appendix D. All of the methods reported in 1998, with the exception of Illinois,[4] use the method recommended by ASHRAE Standard 62 (ASHRAE 1999) or a number that approximates this Standard.

The survey results show a lack of uniformity among the Chicago Region weatherization programs. For example:

- A few states increase the CFM_{50} value of the building tightness limit if wood burning devices are used in the house. This is a questionable technique because building tightness limit methods based on ASHRAE Standard 62 are not intended to provide for adequate combustion supply air, but only for acceptable indoor air quality for the occupants.
- A number of states in the Region reported the use of one building tightness limit, regardless of the house configuration, location, or number of occupants. This is a questionable technique because the calculated tightness limit for a given service region can vary by more than a factor of two, depending on the house configuration, location, and number of occupants.

The 1998 survey not only shows a lack of uniformity among the programs of the region, it also demonstrates some misunderstanding of the purpose of the calculation of the building tightness limit.

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[2] The ZipTest Pro™ software (WxWare Diagnostics) and the TECTITE™ software (The Energy Conservatory) are the only software programs available for the calculation of the BTLa procedure.
[3] Mike Kessler of the Office of Energy, Housing, and Emergency Programs conducted this survey. The quote is from the cover page of the fax sent to state weatherization programs requesting information about building tightness limit procedures used in each of the DOE Chicago Region states.
[4] At the time this survey information was collected, Illinois was not performing blower door test, therefore, the energy auditors in Illinois were not using a building tightness limit method of any kind.

Objectives
This paper was written with the objectives of:

- Clarifying the use and background of the tightness limit calculation procedures;
- Recommending which of the two building tightness limit procedures – BTL or BTLa – should be used;
- Recommending the most accurate method of sizing a continuously operating exhaust fan when a house is tighter than the building tightness limit; and
- Recommending methods to improve the use of depressurization tightness limits.

Glossary

Part of the difficulty of house tightening limits and depressurization is the terminology; it is sometimes confusing. Some new terms are used in this paper in an attempt to clarify concepts. Conventional and new terms are defined below.

Terms Related to Acceptable Indoor Air Quality

BTL: Building Tightness Limit calculation procedure, expressed in units of CFM_{50}, based on the American Society of Heating, Refrigerating and Air-Conditioning Engineers Standard 62-1999, *Ventilation for Acceptable Indoor Air Quality*. This method was clearly explained in an article in *Home Energy* magazine (Tsongas 1993). The method closely follows the parameters set in ASHRAE 62-1999: For acceptable indoor air quality, 15 CFM per person (set minimum of five people) or 0.35 air changes per hour (ACH), whichever is greater, must be supplied by natural air leakage and/or continuously operating ventilation. Refer to Appendix A for a flow chart of this calculation method.

BTLa: Building Tightness Limit calculation procedure, expressed in units of CFM_{50}, that is more complex than the BTL method and is based on ASHRAE Standard 62, Standard 119 (*Air Leakage Performance for Detached Single-Family Residential Buildings*), and Standard136 (*A Method of Determining Air Change Rates in Detached Dwellings*). This method closely follows the parameters set in ASHRAE 62-1999: For acceptable indoor air quality, 15 CFM per person or 0.35 air changes per hour (ACH), whichever is greater, must be supplied by natural air leakage and/or continuously operating ventilation. However, the BTLa method uses different calculation methods – based on ASHRAE 119 and 136 – than the BTL method to arrive at the final tightness limits. Refer to Appendix B for a flow chart of this procedure.

Building Tightness Limit: A general term for a house-tightening limit, expressed in units of CFM_{50}, used for ensuring adequate indoor air quality for the house occupants. Two building tightness limit procedures discussed in this paper are ***BTL*** and ***BTLa***.

Terms Related to Combustion Venting Safety

BDL: The Building Depressurization Limit is a selected indoor negative pressure; expressed in Pascals, immediately around vented combustion appliances that use indoor air for combustion supply air. If a combustion appliance experiences a negative pressure of a greater magnitude than the ***BDL***, it has the potential to backdraft, causing a hazardous condition for the occupants. The ***BDL*** for furnaces and boilers is often –5 Pascals and for stand-alone natural draft water heaters, –2 Pascals. Field studies have been done to determine the negative pressure at which these appliances will begin to backdraft.

CAZ: Combustion Appliance Zone. A basement or utility room where *vented* combustion appliances are located (although a kitchen might have a gas range, unless the range oven is vented to the outdoors, the kitchen is not considered a combustion appliance zone). A room with a functioning fireplace or woodstove is also considered a combustion appliance zone.

DTL: Depressurization Tightness Limit calculation procedure, expressed in units of CFM_{50}, performed to estimate the building tightness level at which combustion appliances might backdraft when the house is under conditions of ***worst-case depressurization***. A ***BDL*** must be selected for the calculation of the

DTL. The ***DTL*** sets a low limit for air sealing that may or may not be lower than the ***building tightness limit*** for the same house. Refer to Appendix C for a flow chart of this procedure.

Worst-Case Depressurization: A condition created when 1) all exhaust appliances (bathroom exhaust, kitchen exhaust, vented dryers, etc.) are operating, 2) the interior doors of a house are in a position that causes the greatest negative pressure in the ***CAZ***, 3) the furnace air handler is operating if such operation causes increased negative pressure in the ***CAZ***, and 4) the weather is such that the greatest negative pressure is created in the ***CAZ***.

Terms Related to Acceptable Indoor Air Quality and Combustion Venting Safety

OTL: The Overall Tightness Limit is expressed in units of CFM_{50}. The ***OTL*** considers both the ***building tightness limit*** and the ***DTL***. For example, if the ***building tightness limit*** is 1300 CFM_{50} and the ***DTL*** is 1400 CFM_{50}, the ***OTL*** for the house is 1400 CFM_{50}, satisfying both the ***building tightness limit*** and the ***DTL***.

Discussions with Experts

Interviews were conducted with the eight people listed below to learn their opinions regarding building tightness limit and depressurization tightness limit methods. These people were selected because of their in-depth knowledge of tightness limits, ventilation guidelines, indoor air quality, and combustion safety.

- Tom Andrews, Indiana CAP Director's Association (3/23/2001)
- Jim Fitzgerald, Center for Energy and Environment (3/21/2001)
- Paul Francisco, Ecotope, Inc. (various dates in March 2001)
- John Hockman, J.L. Hockman Consulting (5/4/2001)
- Gary Nelson, The Energy Conservatory (3/9/2001)
- Collin Olson, The Energy Conservatory (3/16/2001, 5/24/2001)
- Larry Palmiter, Ecotope, Inc. (3/28/2001)
- Max Sherman, Lawrence Berkeley Laboratory (3/9/2001)

The generalized results of these interviews are:

- Blower door tests are a very accurate and repeatable measurement of the tightness of a building. However, using blower door readings to estimate an average seasonal or annual air leakage rate can be off by a factor of two or more. This means that BTL and BTLa values can be off by a similar error factor, even though they are expressed in CFM_{50}. This low level of accuracy makes both the BTL and BTLa methods suspect. As a result, it is probably a good idea to install a 50 CFM fan in any house that has natural leakage less than 30 CFM/person or 0.7 ACH; in other words, quiet and efficient fans should be put in most houses. The reason for this broad approach is to ensure consistent IAQ in the rather inconsistent interior environment of a dwelling. This inconsistency results from:
    - Variability of occupant activities,
    - Variability of the source strength of pollutants, and
    - Variability of natural air leakage in most homes.
- The BTLa method uses the calculation of the effective leakage area as a basis for other calculations. The effective leakage area is based on a house pressure difference of 4 Pascals; at this slight pressure difference there is a potential for a high degree of inaccuracy.
- Although the BTL and the BTLa calculations are subject to error, they are still good numbers to calculate.
- Low-income energy auditors should use building tightness limits as guidelines.
- It is worthwhile to provide building tightness numbers, but seasonal variation of air leakage cannot be predicted accurately by blower door testing. The methods can give a false sense of security to field analysts. Better to promote wider use of mechanical ventilation in low-income houses.
- BTLa method is better than BTL method because it is more “standards based” (based on three ASHRAE standards rather than only one). However, it is not a good idea to calculate ACH_{nat} because

of seasonal variability. In addition, it might be misleading to calculate "target CFM_{50}" because it is based on a potentially inaccurate calculation. On the other hand, the calculation of ventilation CFM needed in tight houses is a good value to provide energy auditors.

- The ventilation calculation of the BTLa method should not be based on the quadrature rule, but rather on the 0.5 rule (Palmiter and Bond 1991, ASHRAE 1997) because of increased accuracy.
- Install inline kitchen fan of 30 CFM to operate continuously.
- ASHRAE 62.2P has a new home bias (ASHRAE 2000), so it might not be appropriate for the homes of the weatherization program.[5]
- The ASHRAE standards upon which these methods are based are derived from average houses. These averages are not necessarily the best basis for ventilation calculations. More research should be done.
- Intermittent ventilation does not work very well. Energy efficient, quiet fans should be installed and operated continuously. They should be hard wired without switches

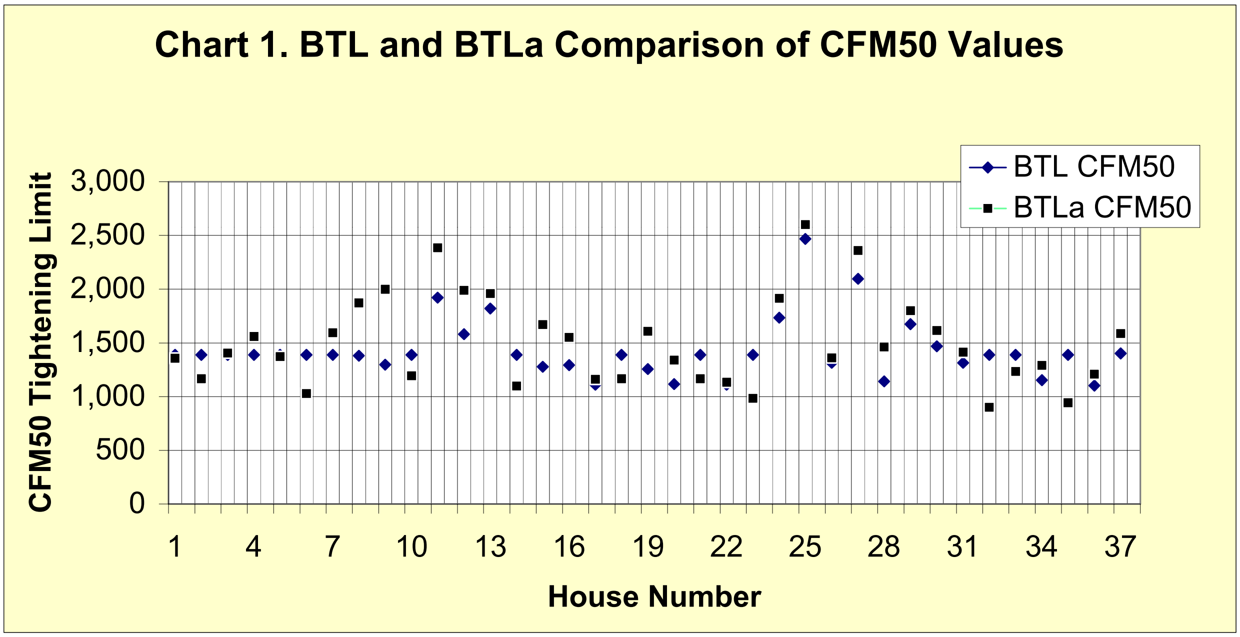
Comments related to depressurization tightness limits for safe combustion venting included:

- Good idea to use different building depressurization limit (BDL) values, e.g., -2 to –5 Pascals, depending on combustion appliance configuration (Fitzgerald 2001). However, a menu of BDL values might be confusing for the complexities of the low-income weatherization program.
- If one house depressurization limit must be selected, it should be –3 Pascals.
- If vent system is installed according to NFPA codes, venting problems are unusual.
- To assume that chimney is always in good condition is risky.
- Chimneys on exterior walls – cold chimneys – are more likely to suffer from draft problems.
- Increased cold-weather stack effect in house tends to be offset by increased draft in the chimney.
- The worst-case depressurization test used by many weatherization energy auditors can lead to a false sense of security because of variations in weather conditions. For example, an appliance demonstrating an acceptable draft during cold weather may not do so during warm weather.

[5] Because ASHRAE 62.2P, *Ventilation and Acceptable Indoor Air Quality in Low-Rise Residential Buildings,* is proposed and under review, and one of its primary authors thinks it might not be appropriate for the existing homes of the weatherization program, its tentative guidelines were not considered for this paper.

Comparison of BTL and BTLa Methods

Filed data was collected from twenty-three houses in Ohio and fourteen houses in Wisconsin. This data was used to compare the results of the BTL and BTLa procedures and corresponding exhaust fan sizing. The information was entered on a spreadsheet that calculated BTL, BTLa, DTL, ventilation fan CFM, and other values. Refer to Appendix E for a sample of three Field Comparison of BTL and BTLa Procedure Results: House Data Sheets and to Appendix F for a Composite of Field Data for BTL and BTLa Results.



The thirty-seven houses for which these methods were calculated show different results in most cases. Compare lines 11 and 33 in Appendix F.[6] Chart 1 shows the comparison of the CFM_{50} values for each of the thirty-seven houses. For twenty-five of the thirty-seven sample houses, the BTLa CFM_{50} values are higher than the BTL CFM_{50} values.

The BTLa method requires more data entry than the BTL procedure, but it also yields more information, most of which can be very useful to a weatherization energy auditor. Refer to Tables 2 and 3 for a lists of BTL and BTLa input data and output values.

Table 2. BTL Procedure Inputs/Outputs	
Input Data	***Output Values***
Climate zone	BTL CFM_{50}
Building square feet	Lawrence Berkeley number
Occupants (min. of 5)	
Ceiling height	
Building stories	
Building exposure	
Based on ZipTest Pro™ software	

[6] The Energy Conservatory TECTITE™ software is the basis for the BTLa software, so TECTITE™ calculates the same values and the BTLa procedure, except for the CFM_{50} limit and required ventilation of the house is tighter than the CFM_{50} limit. The designers of the TECTITE™ software were against including a CFM_{50} limit as an output value for the software because: 1) this limit changes as the house is tightened because it is based, in part, on the flow exponent. As the house is tightened the character of the leaks change, altering the flow exponent. This changing flow exponent makes the CFM_{50} limit a "moving target." 2) They did not want to encourage the use of building tightness limit targets for they give the impression that this is a precise calculation that is valid for all weather conditions. 3) They wanted to encourage the use of ventilation in houses and felt a building tightness limit target might lead energy auditors to think ventilation was not needed when it actually was.

In the opinion of experts, the BTLa procedure is likely to be more accurate than the BTL procedure; they recommended its use over that of the simpler BTL method. More field research is needed to test the accuracy of the BTL and the BTLa procedures.

Table 3. BTLa Procedure Inputs/Outputs	
Input Data	***Output Values***
House CFM_{50}	Effective leakage area (ELA), in^2
Flow exponent (0.65 default)	Equivalent leakage area, in^2
Weather factor	Estimated natural CFM
House square footage	Estimated natural ACH
House volume	Natural CFM/occupant
Building height	Target ELA minimum
Story height	Target CFM minimum
Occupant count (bedrooms + 1)	Target CFM_{50} limit
	Exhaust ventilation CFM
Based on ZipTest Pro™ software	

Improving Methods

A number changes can be made to improve the tightness limit methods that are now being used in the Chicago Region.

1. Combining Methods
Building tightness limit procedures should not include allowances for combustion appliances – combining methods could give misleading results. These methods are based on standards for acceptable indoor air quality and were never intended to include provisions for combustion supply air. Combustion supply air requirements should be guided by codes such as NFPA 54, 31, and 211 and by the depressurization tightness limit procedure.

2. Use of Pre-Selected, Fixed Limits
Building tightness limits should be calculated for each house, they should not be set by a state program or local agency as a single value to use on all houses in a state or agency service area. Calculated building tightness limits can vary by more than a factor of two for a single site, depending on house configuration, location, and number of occupants.

3. BTLa Over BTL
Although no field research has been done to demonstrate that the BTLa procedure is more accurate than the BTL procedure, the experts who had an opinion favored the BTLa method. This method does give the energy auditor more information than the BTL procedure, but at the expense of requiring more input data.

The use of the BTLa procedure (as with many other pressure related methods) requires a caution: As a house is tightened, the character of the leaks in the envelope changes. This changes the flow exponent, represented by n in the flow equation[7]

$$Q = FC \; x \; \Delta P^n$$

Where:
Q = the leakage flow rate
FC = the flow coefficient, CFM flow at 1 ΔP
ΔP = the pressure difference between the inside and outside of the building
n = the flow exponent, or the slope of the house leakage curve

This change in the flow exponent means that any calculated value that is a function of n will also change when a house is tightened.[8] Examples of values dependent on n include estimated natural ACH and target CFM_{50} in the BTLa procedure and the DTL value related to combustion venting. This adds a

[7] The flow exponent ranges from 0.5 (large openings and fully turbulent airflow) to 1.0 (porous openings or small cracks and fully laminar airflow). A multi-point blower door test (determining airflow at four or more different house pressures) is the most common method of determining the flow exponent. For a single-point blower door test, most commonly performed at 50 Pascals pressure difference, the flow exponent is assumed to be 0.65, a good average value.
[8] There is a possibility that the flow exponent will not change when a house is tightened, in other words, that the average character of the leaks will not change. However, this is probably unlikely.

degree of uncertainty to these calculated values. However, this uncertainty does not undermine the usefulness of the BTLa procedure; it is a valid method that will benefit from future field research.

4. Exhaust Fan Sizing Methods

The BTLa procedure that is part of the ZipTest Pro™ software calculates the CFM of continuously operating exhaust ventilation when the house is actually tighter than the building tightness limit. This ventilation calculation is based on the quadrature rule. With this method of predicting the effect of unbalanced exhaust fan systems, the total flow is given by

$$Q_{tot} = \sqrt{\left(Q_{nat}^2 + Q_{fan}^2\right)}$$

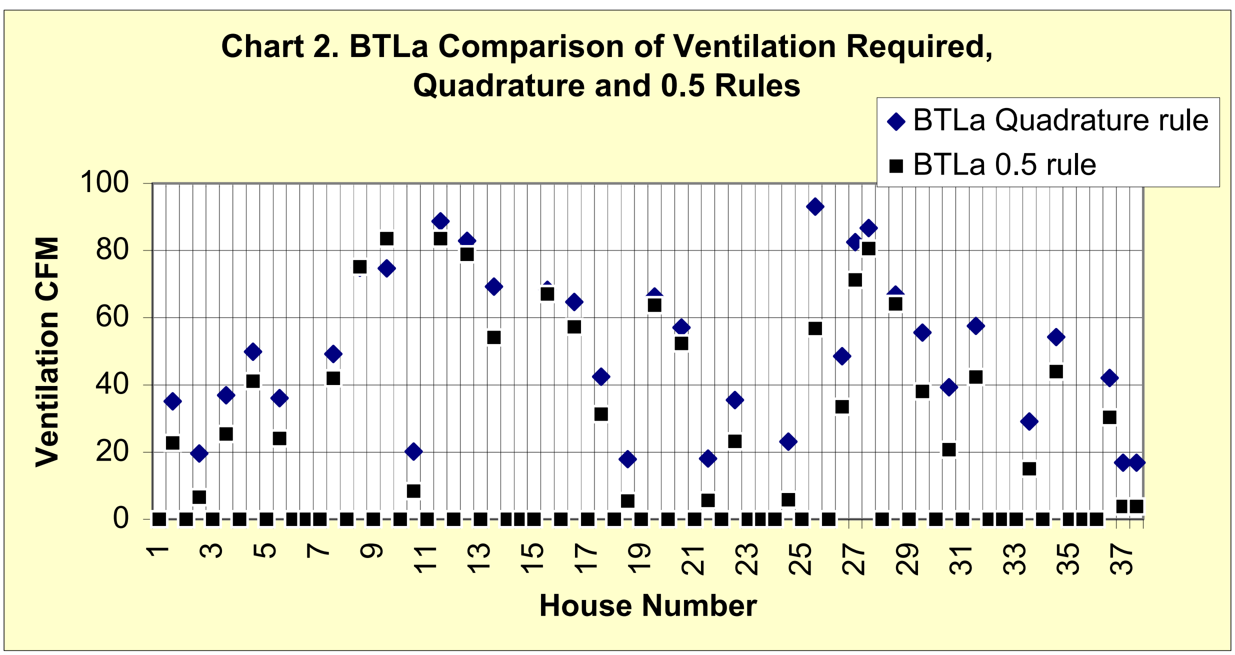
However, Palmiter and Bond (1991) demonstrated a more accurate method for predicting the interaction between mechanical ventilation and natural air leakage. They refer to this method as the 0.5 rule, represented by

$$Q_{total} = 0.5Q_{fan} + Q_{natural} \quad \text{for} \quad Q_{fan} \leq 2Q_{natural}$$

$$Q_{total} = Q_{fan} \quad \text{for} \quad Q_{fan} \geq 2Q_{natural}$$

“For a single fan, this model states that if the fan flow is less than twice the natural infiltration rate, then the added flow through the zone with the fan on is half the fan flow. If the fan flow is twice the natural infiltration rate or greater, then the added flow through the zone when the fan operates is the difference between the fan flow and the natural infiltration rate.” (Francisco and Palmiter 1996).

Chart 2 shows a comparison of the quadrature and the 0.5 rules for the thirty-seven sample houses used for this survey. For each of the thirty-seven sample houses, the house was hypothetically tightened to 80



percent of the BTL value.[9] The objective of this tightening was to “force” ventilation in each of the sample houses under the parameters of the BTL method. However, because the BTL and BTLa methods are different, this hypothetical forcing of ventilation did not result in required ventilation for all thirty-seven houses when calculated with the BTLa method. In all but two of thirty-two cases where ventilation was called for using the BTLa procedure, the quadrature rule resulted in higher CFM ventilation than the 0.5 rule.

The equation used to calculate the quadrature rule for this comparison was:

$$\sqrt{\left((Target\ CFM)^2-(Estimated\ Natural\ CFM)^2\right)}$$

for

$$Estimated\ Natural\ CFM \le Target\ CFM$$

For the 0.5 rule the equations used were:

$$Fan\ CFM = Target\ CFM$$

for

$$Target\ CFM \ge 2\ Estimated\ Natural\ CFM$$

and

$$Fan\ CFM = 2\left(Target\ CFM - Estimated\ Natural\ CFM\right)$$

for

$$Target\ CFM \langle\ 2\ Estimated\ Natural\ CFM$$

Because Palmiter and Bond (1991) demonstrated that the 0.5 rule is more accurate than the quadrature rule, the ventilation calculation in the BTLa routine of the ZipTest Pro™ software should be altered to the 0.5 rule equation.

5. Worst-Case Draft Variability

Weatherization energy auditors often determine a pre-weatherization depressurization tightness limit (DTL) and then perform a related post-weatherization worst-case draft test. Unlike the building tightness limits procedures, the DTL and worst-case draft test relate to combustion safety. The calculated DTL is used as a house-tightening limit. The worst-case draft test is a “real-time” procedure that measures negative pressure in a CAZ and confirms a proper draft in the vent.

For the worst-case draft test, the auditor sets the house up by turning on all exhaust appliances, putting all the interior doors in worst-case position, and running the air handler (creating the greatest negative pressure in the CAZ). Because of the variability of weather and the precarious nature of the operation of vent systems, it is important that the auditor understand that the worst-case draft test might not actually be worst-case.

The uncertainty of worst-case testing cannot be eliminated unless worst-case weather conditions can be simulated at the site; this is an unlikely possibility. However, making certain that the venting system meets

[9] See individual data sheets for each of the thirty-seven sample homes in Appendix E and in Appendix F, see lines 8 through 12 and 31 and 32.

all national code requirements can reduce the risk of venting problems.[10] Making certain the house is not tightened to a level lower than the DTL can further reduce this risk.[11] However, if it is, efforts should be made to mitigate possible venting problems. More field research is needed here.

Recommendations for Use of Tightness Limits

1. Use Methods as Guides, Not as Absolutes
No building tightness limit is foolproof. The calculated tightness limits should be used as guides rather than hard and fast dictates. The numbers are worth calculating, but auditors should also use their related experience before making final decisions for the weatherization work plan.

Blower door tests are a very accurate and repeatable measurement of the tightness of a building. However, using blower door readings to estimate an average seasonal or annual air leakage rate can be off by a factor of two or more. This means that BTL and BTLa values can be off by a similar factor under some conditions.

Additionally, as a house is tightened, the character of the leaks in the envelope changes. This changes the flow exponent and adds a degree of uncertainty to these calculated tightness limit values.

Because of these uncertainties, the auditor should temper her interpretation of the calculated tightness limits by what she sees in the house or hears from the client. For example, if there is a build up of moisture in the house or the occupants are experiencing respiratory health problems, exhaust ventilation should be installed if the source of the problems cannot be mitigated.

Similarly, for safe combustion venting, the DTL should be calculated and the worst-case draft test should be performed, but good common sense must also be used. The appraising auditor should remember that weather conditions vary greatly and that an adequate draft today might become a backdraft tomorrow.

2. Use the BTLa Procedure Rather than the BTL Procedure
The resource people questioned for this study prefer the BTLa procedure to the BTL procedure. The BTLa (or TECTITE™) procedure should be used because it 1) is probably more accurate, 2) is more "standards" based, and 3) supplies the energy auditor with more useful data than the BTL procedure.

If the BTLa procedure includes the calculation of the required ventilation CFM for tight houses, the 0.5 rule should be used rather and the quadrature rule.

The BTLa value should be calculated for every house, rather than using a generalized building tightness limit for an entire weatherization service area or house type.

If post-weatherization flow exponent can be easily determined, use it for the BTLa calculation rather than using the default value of 0.65. The flow exponent for a house is determined by performing a multi-point blower door test. This requires calculating the house CFM at from four to eight different house pressures to determine the house leakage curve. The flow exponent is the slope of this leakage curve. The APT apparatus available from The Energy Conservatory simplifies the determination of the flow exponent.

For houses with basements, use these rules when calculating the BTLa and house compliance with this method:

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[10] Those involved with testing thousands of vent systems for the Minneapolis Airport Sound Insulation Project over the over the last few years have found that vent systems installed according to code (NFPA 31, 54, and 211) are unlikely to cause hazardous conditions (Telephone conversation with Jim Fitzgerald, March 21, 2001).

[11] If it is convenient, for example if the auditor has the use of The Energy Conservatory APT to easily perform multi-point blower door tests, the flow exponent should be determined and used to calculate the post-weatherization DTL. Because the DTL value is dependent on the flow exponent and the flow exponent usually changes as a house is tightened, the DTL pre- and post-weatherization can change. Of course, the most important DTL value is the one calculated post-weatherization.

- If a basement is occupied, the basement door should be left open during the whole house blower door test. The basement floor area should also be included in the square footage of the house and the basement volume should be added to the above grade house volume.
- If the basement is not occupied, or occasionally occupied, the basement door should be left closed during the whole house blower door test. The basement floor area should not be included in the square footage of the house and the basement volume should not be added to the above grade house volume.

3. Ensuring Effective Ventilation

Most houses experience real air leakage rates as low as zero during times when stack-effect induced pressures are low, even houses that have a moderate to high CFM_{50} value. Because low-income clients are not as likely to have air conditioning, they are probably more likely to open windows then those living in dwellings with central air or window air conditioners. The passive ventilation provided by open windows improves indoor air quality and can be an adequate and inexpensive substitute for mechanical ventilation. During the delivery of client education, auditors should encourage clients to open windows to supply fresh air indoors.

When exhaust fans are installed, they should always be high quality, efficient, and quiet. Sone values – noise levels – should be 1.5 or less, electrical consumption should be 30 Watts or less, and fans should be rated for continuous use.

Fans can be installed in bathrooms, kitchens, laundry areas, or central halls. Some experts think bathrooms are ideal because bathrooms are the source of odors and moisture. Others think central halls are a better location because they offer better coverage of the other spaces in the house. More research is needed here. In the mean time, the auditor should use her best judgment.

Experts also have various opinions regarding exhaust fan control. Some think it is important to give the client easy control with a conveniently located switch, others think the fan should be hard-wired with no switch. More research is needed here, also.

Passive air inlets, e.g., Fresh 80s, are probably rarely needed in low-income weatherization houses; after all, they just make the house leakier. For the unlikely case of a house that is very tight and an occupant is bed-ridden, it will probably help to install passive air inlets in the bedroom of the bed-ridden occupant.

4. Use the DTL with Care

Unlike the building tightness limits procedures, the DTL and worst-case draft test relate to combustion safety. The calculated DTL is used as a house-tightening limit. On the other hand, the worst-case draft test is a “real-time” procedure that measures negative pressure in a CAZ and confirms a proper draft at the appliance.

Because of varying weather conditions, the auditor might not actually be measuring CAZ pressure and draft under true *worst-case* conditions. The auditor can set the house up in what she thinks is the worst-case condition by turning on all exhaust appliances, putting all the interior doors in worst-case position, and turning on the air handler (creating the greatest negative pressure in the CAZ), but the auditor has no control over the weather.

Because of this uncertainty, the DTL value and the worst-case draft test should be used with care; the auditor should always notice weather conditions and use common sense. The DTL should be calculated using the appropriate BDL.[12] The DTL should not be violated by house tightening; if it is, the situation must be properly mitigated.

If post-weatherization flow exponent can be easily determined, use it for DTL calculation rather than using the default value of 0.65. The flow exponent for a house is determined by performing a multi-point blower

[12] Refer to Worst-Case Draft procedure based on the fieldwork of Tom Andrews of the Indiana CAP Director’s Association, presented at the Weatherization Today Conference, French Link, Indiana, July 10 – 12, 2001.

door test. This requires calculating the house CFM at from four to eight different house pressures to determine the house leakage curve. The flow exponent is the slope of this leakage curve. The APT apparatus available from The Energy Conservatory simplifies the determination of the flow exponent.

5. Check the Vent System and Code Compliance

For combustion venting safety, the auditor should not assume that the chimney is in good condition. The chimney and other parts of the vent systems should be checked for proper construction, strict compliance with the appropriate codes (NFPA 31, 54, and 211), and proper maintenance. Any problems or code violations should be corrected.

Chimneys on cold exterior walls can present difficult problems because they cool faster and take longer to warm. Make sure they are used in compliance with the appropriate code and maintained properly.

6. Further Research

Many of the experts consulted for this survey think that more field research is needed to confirm or fine-tune the procedures, not only for building tightness limits to ensure adequate indoor air quality, but also for depressurization tightness limits to ensure safe combustion venting. We are not aware of any field-testing currently underway that appraises the accuracy of these procedures.

One of the objectives of any related field research should be the simplification of procedures and calculations without the sacrifice of accuracy.

The Minneapolis Airports Commission Sound Insulation Program conducted by the Center for Energy and Environment is using these procedures or variations in thousands of houses. Although the objective of this project is not to test the accuracy of these procedures, it is a rich testing ground for the application of tightness limits and combustion safety to low-income programs. The lessons learned from this project are expected to lead to procedure improvements.

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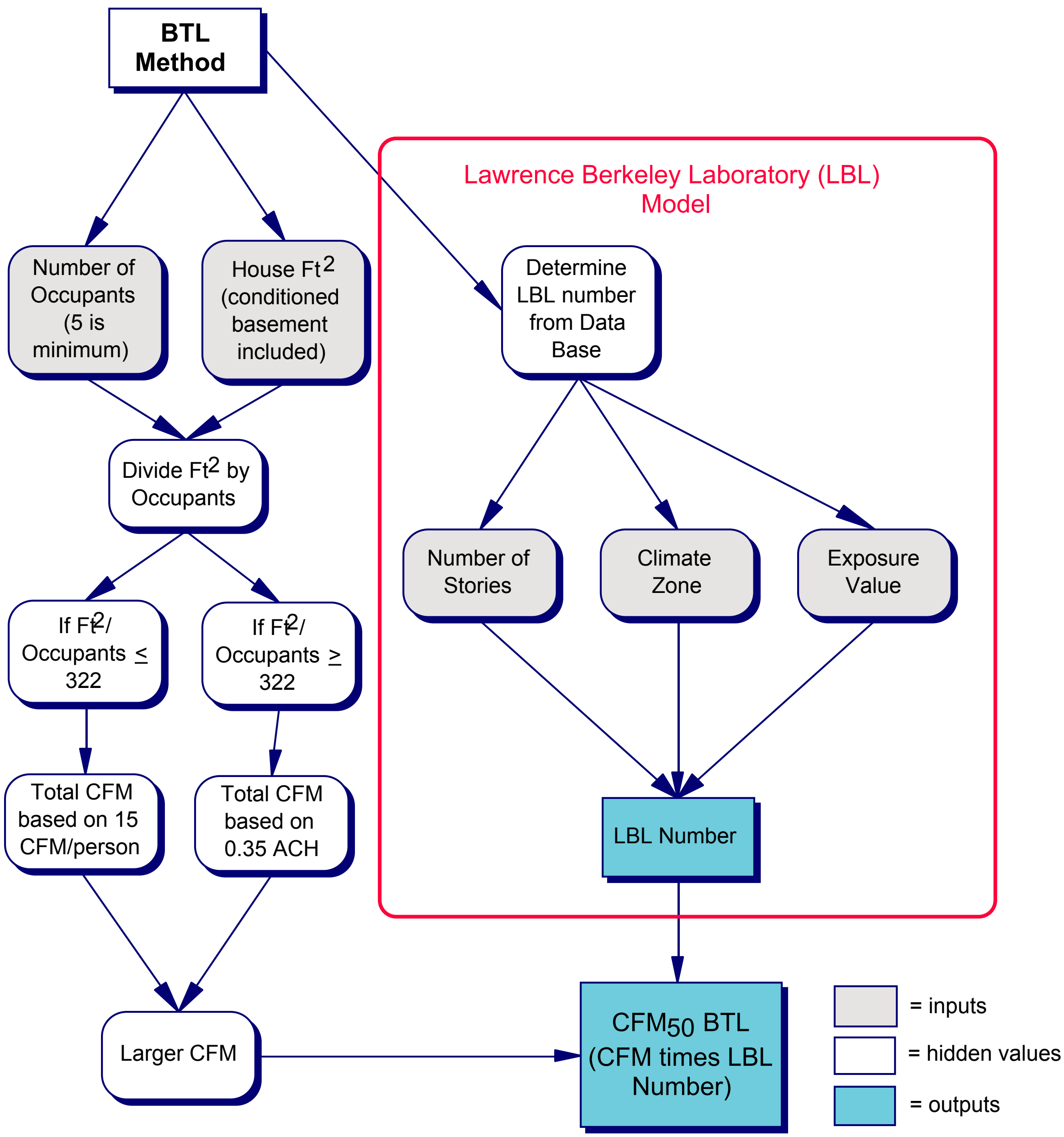
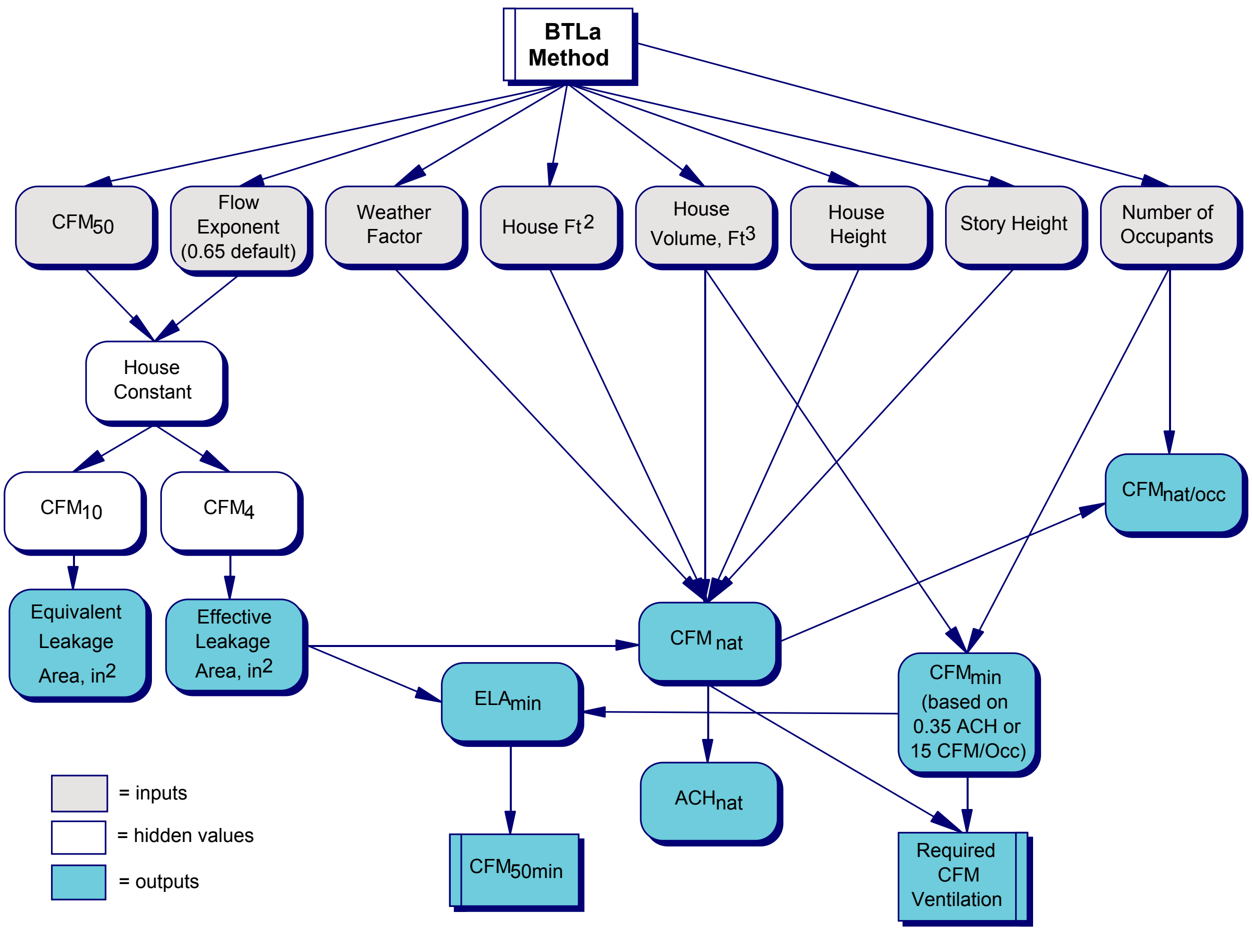
Appendices

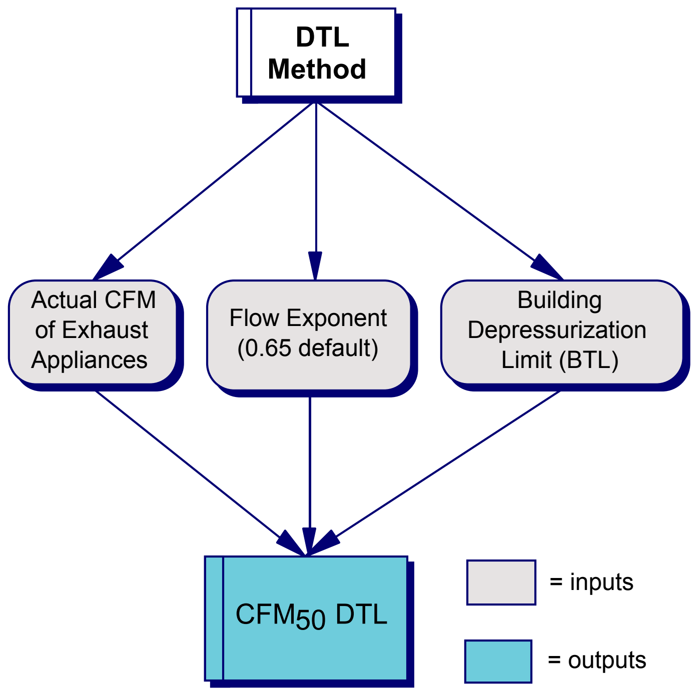
Appendix A – BTL Model Flowchart



Appendix B – BTLa Model Flowchart



Appendix C – DTL Model Flowchart



Appendix D – Survey of Tightness Limits used by Chicago Region Weatherization Programs

Building Tightness Limits for Chicago Region Weatherization Programs			
State	***Base Limit, CFM_{50}***	***Add to Base Limit***	***Comments***
Illinois	Do not use method, do not do blower door test	--	--
Indiana	The greater of: 1) 15 CFM x 17 x 5 people = 1275 CFM_{50}, 2) 0.35 x house volume x 17/60	+ account for additional people if necessary	- IAQ may dictate higher limit.
Iowa	The greater of: 1) 15 CFM x 17 x 5 people = 1275 CFM_{50}, 2) 0.35 x house volume x 17/60	+ account for additional people if necessary	--
Michigan	1200 CFM_{50}	+ 300 CFM_{50} for each person above 5 persons	- IAQ or smokers may dictate higher limit.
Minnesota	1500 CFM_{50}	+ 500 CFM_{50} for wood burning device + 225 CFM_{50} for each person above 5 persons	- If draft test fails, make-up air is added - IAQ may dictate higher limit
Missouri	1) 1500 CFM_{50}, or 2) 250 CFM_{50} x occupants + smokers	--	--
Ohio	Building Tightness Limit (BTL) based on ASHRAE 62 (use a constant LBLn = 18.5)	+ count each smoker as two people. + count pets over 60 lbs. as one person.	- Also calculate estimated depressurization for combustion safety. Use a -5 Pascal limit.
Wisconsin	1500 CFM_{50}	+ 225 CFM_{50} per smoker + 225 CFM_{50} per person over 5 persons + 175 CFM_{50} per ft^3 of woodstove firebox	--
- Information for this study was obtained in 1998; programs may use different standards today.			

Appendix E – Field Comparison of BTL and BTLa Procedure Results: House Data Sheets

House 1

Field Data

Building Tightness Limit (BTL) Calculations (Based on ASHRAE Standard 62)

Pre-Weatherization

Job: 1-L99-050B

Notes:

05/23/2001 16:22	INPUTS		ANSWERS
Climate Zone:	2	CFM 50 BTL:	1,388
Bldg. Square Ft:	938	CFM 50 Blower Dr.:	1745
Bedrooms + 1, 5 min:	5	LBL Number:	18.5
Ceiling Height:	8.00	◄Entry has no effect	
Stories Above Gd:	1 Story	Ventilation CFM (Quad):	None
Building. Exposure:	Normal	Ventilation CFM (0.5 Rule):	None

Quadrature Rule/0.5 Rule #VALUE!

Building Tightness Limit (BTLa) Calculations (Based on ASHRAE Standards 62, 119, and 136)

Pre-Weatherization

Job:

Notes:

05/23/2001 16:22			ANSWERS
CFM50 of Bldg:	1745	ELA in^2:	96
Flow Exponent:	0.65	EqLA in^2:	180
Weather Factor:	0.84	Estim. Nat CFM:	77
Bldg. Square Ft:	938	Estim. Nat ACH:	0.617
Building Volume:	7504	Nat CFM/Occup't:	19
Building Height:	9.0	Target ELA$_{min}$:	74
Story Height:	8.0	Target CFM$_{min}$:	60
Bedrooms + 1:	4	Ventilation CFM (Quad):	None
		Ventilation CFM (0.5 Rule):	None
		Target CFM50$_{min}$:	1356
		Leakage Ratio:	0.86

Quadrature Rule/0.5 Rule #VALUE!

Depressurization Tightness Limit (DTL) Calculations for Safe Combustion Venting

Pre-Weatherization

Job:

Notes:

05/23/2001 16:22	INPUTS		ANSWERS
CFM Exhst Fans:	265	Fan CFM Limit:	391
Flow Exponent:	0.65	CFM50 Limit:	1,184
Building CFM50:	1745	Neg. Press., Pa:	-2.8
Limit in Pascals:	-5.0		

Field Data CFM50 x 63 % (to force ventilation)

Building Tightness Limit (BTL) Calculations (Based on ASHRAE Standard 62)

Post-Weatherization

CFM50 BTL x 80% = 1110

CFM50 BTL/CFM50 = 79

05/23/2001 16:22	INPUTS		ANSWERS
Climate Zone:	2	CFM 50 BTL:	1,388
Bldg. Square Ft:	938	CFM 50 Blower Dr, x %:	1099
Bedrooms + 1:	5	LBL Number:	18.5
Ceiling Height:	8.00	◄Entry has no effect	
Stories Above Gd:	1 Story	Ventilation CFM (Quad):	46
Building. Exposure:	Normal	Ventilation CFM (0.5 Rule):	31

Quadrature Rule/0.5 Rule 146.9%

Building Tightness Limit (BTLa) Calculations (Based on ASHRAE Standards 62, 119, and 136)

Post-Weatherization

Target CFM50$_{min}$ x 80% = 1085

05/23/2001 16:22			ANSWERS
CFM50 of Bldg:	1099	ELA in^2:	60
Flow Exponent:	0.65	EqLA in^2:	114
Weather Factor:	0.84	Estim. Nat CFM:	49
Bldg. Square Ft:	938	Estim. Nat ACH:	0.389
Building Volume:	7504	Nat CFM/Occup't:	12
Building Height:	9.0	Target ELA$_{min}$:	74
Story Height:	8.0	Target CFM$_{min}$:	60
Bedrooms + 1:	4	Ventilation CFM (Quad):	35
		Ventilation CFM (0.5 Rule):	23
		Target CFM50$_{min}$:	1356
		Leakage Ratio:	0.54

Quadrature Rule/0.5 Rule 154.5%

Depressurization Tightness Limit (DTL) Calculations for Safe Combustion Venting

Post-Weatherization

Job:

Notes:

05/23/2001 16:22	INPUTS	ALERT	ANSWERS
CFM Exhst Fans:	265	Fan CFM Limit:	246
Flow Exponent:	0.65	CFM50 Limit:	1,184
Building CFM50:	1099	Neg. Press., Pa:	-5.6
Limit in Pascals:	-5.0		

House 2

Field Data

Building Tightness Limit (BTL) Calculations (Based on ASHRAE Standard 62)

Pre-Weatherization

Job: 2-21871-00

Notes:

05/23/2001 16:30	INPUTS		ANSWERS
Climate Zone:	2	CFM 50 BTL:	1,388
Bldg. Square Ft:	591	CFM 50 Blower Dr.:	4081
Bedrooms + 1, 5 min:	5	LBL Number:	18.5
Ceiling Height:	9.00	◄Entry has no effect	
Stories Above Gd:	1 Story	Ventilation CFM (Quad):	None
Building. Exposure:	Normal	Ventilation CFM (0.5 Rule):	None

Quadrature Rule/0.5 Rule #VALUE!

Building Tightness Limit (BTLa) Calculations (Based on ASHRAE Standards 62, 119, and 136)

Pre-Weatherization

Job:

Notes:

05/23/2001 16:30			ANSWERS
CFM50 of Bldg:	4081	ELA in^2:	224
Flow Exponent:	0.65	EqLA in^2:	421
Weather Factor:	0.90	Estim. Nat CFM:	210
Bldg. Square Ft:	591	Estim. Nat ACH:	2.369
Building Volume:	5319	Nat CFM/Occup't:	53
Building Height:	9.0	Target ELA_{min}:	64
Story Height:	9.0	Target CFM_{min}:	60
Bedrooms + 1:	4	Ventilation CFM (Quad):	None
		Ventilation CFM (0.5 Rule):	None
		Target $CFM50_{min}$:	1166
		Leakage Ratio:	2.78

Quadrature Rule/0.5 Rule #VALUE!

Depressurization Tightness Limit (DTL) Calculations for Safe Combustion Venting

Pre-Weatherization

Job:

Notes:

05/23/2001 16:30	INPUTS		ANSWERS
CFM Exhst Fans:	83	Fan CFM Limit:	914
Flow Exponent:	0.65	CFM50 Limit:	371
Building CFM50:	4081	Neg. Press., Pa:	-0.1
Limit in Pascals:	-5.0		

Field Data CFM50 x 27 % (to force ventilation)

Building Tightness Limit (BTL) Calculations (Based on ASHRAE Standard 62)

Post-Weatherization

CFM50 BTL x 80% = 1110

CFM50 BTL/CFM50 = 34

05/23/2001 16:30	INPUTS		ANSWERS
Climate Zone:	2	CFM 50 BTL:	1,388
Bldg. Square Ft:	591	CFM 50 Blower Dr, x %:	1102
Bedrooms + 1:	5	LBL Number:	18.5
Ceiling Height:	9.00	◄Entry has no effect	
Stories Above Gd:	1 Story	Ventilation CFM (Quad):	46
Building. Exposure:	Normal	Ventilation CFM (0.5 Rule):	31

Quadrature Rule/0.5 Rule 147.6%

Building Tightness Limit (BTLa) Calculations (Based on ASHRAE Standards 62, 119, and 136)

Post-Weatherization

Target $CFM50_{min}$ x 80% = 933

05/23/2001 16:30			ANSWERS
CFM50 of Bldg:	1102	ELA in^2:	60
Flow Exponent:	0.65	EqLA in^2:	114
Weather Factor:	0.90	Estim. Nat CFM:	57
Bldg. Square Ft:	591	Estim. Nat ACH:	0.640
Building Volume:	5319	Nat CFM/Occup't:	14
Building Height:	9.0	Target ELA_{min}:	64
Story Height:	9.0	Target CFM_{min}:	60
Bedrooms + 1:	4	Ventilation CFM (Quad):	20
		Ventilation CFM (0.5 Rule):	7
		Target $CFM50_{min}$:	1166
		Leakage Ratio:	0.75

Quadrature Rule/0.5 Rule 297.8%

Depressurization Tightness Limit (DTL) Calculations for Safe Combustion Venting

Post-Weatherization

Job:

Notes:

05/23/2001 16:30	INPUTS		ANSWERS
CFM Exhst Fans:	83	Fan CFM Limit:	247
Flow Exponent:	0.65	CFM50 Limit:	371
Building CFM50:	1102	Neg. Press., Pa:	-0.9
Limit in Pascals:	-5.0		

House 3

Field Data

Building Tightness Limit (BTL) Calculations (Based on ASHRAE Standard 62)			
Pre-Weatherization			
Job:	3-00-005B		
Notes:			
05/23/2001 16:30	INPUTS		ANSWERS
Climate Zone:	2	CFM 50 BTL:	1,388
Bldg. Square Ft:	1100	CFM 50 Blower Dr.:	2172
Bedrooms + 1, 5 min:	5	LBL Number:	18.5
Ceiling Height:	8.00	◄Entry has no effect	
Stories Above Gd:	1 Story	Ventilation CFM (Quad):	None
Building. Exposure:	Normal	Ventilation CFM (0.5 Rule):	None

Quadrature Rule/0.5 Rule #VALUE!

Building Tightness Limit (BTLa) Calculations (Based on ASHRAE Standards 62, 119, and 136)			
Pre-Weatherization			
Job:			
Notes:			
05/23/2001 16:30			ANSWERS
CFM50 of Bldg:	2172	ELA in^2:	119
Flow Exponent:	0.65	EqLA in^2:	224
Weather Factor:	0.84	Estim. Nat CFM:	93
Bldg. Square Ft:	1100	Estim. Nat ACH:	0.632
Building Volume:	8800	Nat CFM/Occup't:	23
Building Height:	8.0	Target ELA_{min}:	77
Story Height:	8.0	Target CFM_{min}:	60
Bedrooms + 1:	4	Ventilation CFM (Quad):	None
		Ventilation CFM (0.5 Rule):	None
		Target $CFM50_{min}$:	1405
		Leakage Ratio:	1.00

Quadrature Rule/0.5 Rule #VALUE!

Depressurization Tightness Limit (DTL) Calculations for Safe Combustion Venting			
Pre-Weatherization			
Job:			
Notes:			
05/23/2001 16:30	INPUTS		ANSWERS
CFM Exhst Fans:	459	Fan CFM Limit:	486
Flow Exponent:	0.65	CFM50 Limit:	2,050
Building CFM50:	2172	Neg. Press., Pa:	-4.6
Limit in Pascals:	-5.0		

Field Data CFM50 x 51 % (to force ventilation)

Building Tightness Limit (BTL) Calculations (Based on ASHRAE Standard 62)			
Post-Weatherization			
		CFM50 BTL x 80% =	1110
		CFM50 BTL/CFM50 =	64
05/23/2001 16:30	INPUTS		ANSWERS
Climate Zone:	2	CFM 50 BTL:	1,388
Bldg. Square Ft:	1100	CFM 50 Blower Dr, x %:	1108
Bedrooms + 1:	5	LBL Number:	18.5
Ceiling Height:	8.00	◄Entry has no effect	
Stories Above Gd:	1 Story	Ventilation CFM (Quad):	45
Building. Exposure:	Normal	Ventilation CFM (0.5 Rule):	30

Quadrature Rule/0.5 Rule 149.3%

Building Tightness Limit (BTLa) Calculations (Based on ASHRAE Standards 62, 119, and 136)			
Post-Weatherization			
		Target $CFM50_{min}$ x 80% =	1124
05/23/2001 16:30			ANSWERS
CFM50 of Bldg:	1108	ELA in^2:	61
Flow Exponent:	0.65	EqLA in^2:	114
Weather Factor:	0.84	Estim. Nat CFM:	47
Bldg. Square Ft:	1100	Estim. Nat ACH:	0.322
Building Volume:	8800	Nat CFM/Occup't:	12
Building Height:	8.0	Target ELA_{min}:	77
Story Height:	8.0	Target CFM_{min}:	60
Bedrooms + 1:	4	Ventilation CFM (Quad):	37
		Ventilation CFM (0.5 Rule):	25
		Target $CFM50_{min}$:	1405
		Leakage Ratio:	0.51

Quadrature Rule/0.5 Rule 145.3%

Depressurization Tightness Limit (DTL) Calculations for Safe Combustion Venting			
Post-Weatherization			
Job:			
Notes:			
05/23/2001 16:30	INPUTS	ALERT	ANSWERS
CFM Exhst Fans:	459	Fan CFM Limit:	248
Flow Exponent:	0.65	CFM50 Limit:	2,050
Building CFM50:	1108	Neg. Press., Pa:	-12.9
Limit in Pascals:	-5.0		

Appendix F – Composite of Field Data for BTL and BTLa Results

	1		2		3		4		5		6		7		8		9	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
BTL Method																		
1. CFM 50 Blower Dr.:	1745	1099	4081	1102	2172	1108	1580	1106	1828	1097	2726	1090	2003	1102	4658	1118	2824	1045
2. Climate Zone:	2		2		2		2		2		2		2		2		2	
3. Bldg. Square Ft:	938		591		1100		1514		1150		800		1458		2322		1989	
4. Bedrooms + 1:	5		5		5		5		5		5		5		5		5	
5. Ceiling Height:	8.00		9.00		8.00		8.00		8.00		8.00		8.00		6.89		7.55	
6. Stories Above Gd:	1 Story		1 Story		1 Story		1 Story		1 Story		1 Story		1 Story		2 Stories		2 Stories	
7. Building. Exposure:	Normal		Normal		Normal		Normal		Normal		Normal		Normal		Normal		Normal	
8. Field Data CFM50 x %		**63**		**27**		**51**		**70**		**60**		**40**		**55**		**24**		**37**
9. CFM50 BTL x 80% =		**1110**		**1110**		**1110**		**1110**		**1110**		**1110**		**1110**		**1105**		**1037**
10. CFM50 BTL/CFM50 =		**79**		**34**		**64**		**88**		**75**		**50**		**69**		**30**		**46**
11. CFM 50 BTL:	**1,388**		**1,388**		**1,388**		**1,388**		**1,388**		**1,388**		**1,388**		**1,381**		**1,296**	
12. CFM 50 Blower Dr, x %:		**1,099**		**1,102**		**1,108**		**1,106**		**1,097**		**1,090**		**1,102**		**1,118**		**1,045**
13. LBL Number:	**18.5**		**18.5**		**18.5**		**18.5**		**18.5**		**18.5**		**18.5**		**14.8**		**14.8**	
14. Ventilation CFM (Quad):	**None**	**46**	**None**	**46**	**None**	**45**	**None**	**45**	**None**	**46**	**None**	**46**	**None**	**46**	**None**	**55**	**None**	**52**
15. Ventilation CFM (0.5 Rule):	**None**	**31**	**None**	**31**	**None**	**30**	**None**	**30**	**None**	**31**	**None**	**32**	**None**	**31**	**None**	**36**	**None**	**34**
16. Quadrature Rule/0.5 Rule		**1.47**		**1.48**		**1.49**		**1.49**		**1.46**		**1.44**		**1.48**		**1.54**		**1.53**
BTLa Method																		
17. Flow Exponent:	0.65		0.65		0.65		0.65		0.65		0.65		0.65		0.65		0.65	
18. Weather Factor:	0.84		0.90		0.84		0.86		0.86		0.86		0.84		0.84		0.84	
19. Bldg. Square Ft:	938		591		1100		1514		1150		800		1458		2322		1989	
20. Building Volume:	7504		5319		8800		12112		9200		6400		11664		15999		15017	
21. Building Height:	9.00		9.00		8.00		9.00		8.00		8.00		8.00		19.00		10.00	
22. Story Height:	8.00		9.00		8.00		8.00		8.00		8.00		8.00		6.89		7.55	
23. Bedrooms + 1:	4		4		4		4		4		3		4		4		5	
24. ELA in^2:	**96**	**60**	**224**	**60**	**119**	**61**	**87**	**61**	**100**	**60**	**150**	**60**	**110**	**60**	**256**	**61**	**155**	**57**
25. EqLA in^2:	**180**	**114**	**421**	**114**	**224**	**114**	**163**	**114**	**189**	**113**	**281**	**113**	**207**	**114**	**481**	**115**	**292**	**108**
26. Estim. Nat CFM:	**77**	**49**	**210**	**57**	**93**	**47**	**72**	**50**	**80**	**48**	**119**	**48**	**86**	**47**	**232**	**56**	**124**	**46**
27. Estim. Nat ACH:	**0.62**	**0.39**	**2.37**	**0.64**	**0.63**	**0.32**	**0.35**	**0.25**	**0.52**	**0.31**	**1.12**	**0.45**	**0.44**	**0.24**	**0.87**	**0.21**	**0.49**	**0.18**
28. Nat CFM/Occup't:	**19**	**12**	**53**	**14**	**23**	**12**	**18**	**13**	**20**	**12**	**40**	**16**	**21**	**12**	**58**	**14**	**25**	**9**
29. Target ELA_{min}:	**74**		**64**		**77**		**86**		**75**		**57**		**87**		**103**		**110**	
30. Target CFM_{min}:	**60**		**60**		**60**		**71**		**60**		**45**		**68**		**93**		**88**	
31. Ventilation CFM (Quad):	**None**	**35**	**None**	**20**	**None**	**37**	**None**	**50**	**None**	**36**	**None**	**None**	**None**	**49**	**None**	**75**	**None**	**75**
32. Ventilation CFM (0.5 Rule):	**None**	**23**	**None**	**7**	**None**	**25**	**None**	**41**	**None**	**24**	**None**	**None**	**None**	**42**	**None**	**75**	**None**	**84**
33. Target $CFM50_{min}$:	**1356**		**1166**		**1405**		**1560**		**1372**		**1029**		**1593**		**1872**		**1998**	
34. Target $CFM50_{min}$ x 80% =		**1085**		**933**		**1124**		**1248**		**1098**		**823**		**1275**		**1498**		**1598**
35. Leakage Ratio:	**0.86**	**0.54**	**2.78**	**0.75**	**1.00**	**0.51**	**0.54**	**0.38**	**0.82**	**0.49**	**1.60**	**0.64**	**0.75**	**0.41**	**1.24**	**0.30**	**0.75**	**0.28**
36. Quadrature Rule/0.5 Rule		**1.55**		**2.98**		**1.45**		**1.21**		**1.50**		**######**		**1.17**		**1.00**		**0.89**
DTL Method																		
37. CFM Exhst Fans:	265		83		459		238		165		199		215		225		225	
38. Flow Exponent:	0.65		0.65		0.65		0.65		0.65		0.65		0.65		0.65		0.65	
39. Limit in Pascals:	-5.0		-5.0		-5.0		-5.0		-5.0		-5.0		-5.0		-5.0		-5.0	
40. Fan CFM Limit:	**391**	**246**	**914**	**247**	**486**	**248**	**354**	**248**	**409**	**246**	**610**	**244**	**448**	**247**	**1,043**	**250**	**632**	**234**
41. CFM50 Limit:	**1,184**		**371**		**2,050**		**1,063**		**737**		**889**		**960**		**1,005**		**1,005**	
42. Neg. Press., Pa:	**-2.8**	**-5.6**	**-0.1**	**-0.9**	**-4.6**	**-12.9**	**-2.7**	**-4.7**	**-1.2**	**-2.7**	**-0.9**	**-3.7**	**-1.6**	**-4.0**	**-0.5**	**-4.2**	**-1.0**	**-4.7**

	10		11		12		13		14		15		16		17		18	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
BTL Method																		
1. CFM 50 Blower Dr.:	2107	1096	4345	1521	4183	1255	4118	1441	1415	1118	2219	1021	6948	1042	1838	882	2419	1113
2. Climate Zone:	2		2		2		2		2		2		2		2		2	
3. Bldg. Square Ft:	1092		2466		2391		2352		552		1850		1872		1400		580	
4. Bedrooms + 1:	5		5		5		5		5		5		5		5		5	
5. Ceiling Height:	8.00		8.00		7.66		7.45		7.50		8.00		8.00		8.00		9.00	
6. Stories Above Gd:	1 Story		1.5 Stories		2 Stories		2 Stories		1 Story		2 Stories		2 Stories		2 Stories		1 Story	
7. Building. Exposure:	Normal		Normal		Normal		Shielded		Normal		Normal		Normal		Normal		Normal	
8. Field Data CFM50 x %		**52**		**35**		**30**		**35**		**79**		**46**		**15**		**48**		**46**
9. CFM50 BTL x 80% =		**1110**		**1537**		**1265**		**1456**		**1110**		**1022**		**1034**		**888**		**1110**
10. CFM50 BTL/CFM50 =		**65**		**44**		**38**		**44**		**99**		**58**		**19**		**60**		**58**
11. CFM 50 BTL:	**1,388**		**1,922**		**1,581**		**1,819**		**1,388**		**1,278**		**1,293**		**1,110**		**1,388**	
12. CFM 50 Blower Dr, x %:		**1,096**		**1,521**		**1,255**		**1,441**		**1,118**		**1,021**		**1,042**		**882**		**1,113**
13. LBL Number:	**18.5**		**16.7**		**14.8**		**17.8**		**18.5**		**14.8**		**14.8**		**14.8**		**18.5**	
14. Ventilation CFM (Quad):	**None**	**46**	**None**	**70**	**None**	**65**	**None**	**62**	**None**	**44**	**None**	**52**	**None**	**52**	**None**	**46**	**None**	**45**
15. Ventilation CFM (0.5 Rule):	**None**	**32**	**None**	**48**	**None**	**44**	**None**	**42**	**None**	**29**	**None**	**35**	**None**	**34**	**None**	**31**	**None**	**30**
16. Quadrature Rule/0.5 Rule		**1.46**		**1.46**		**1.47**		**1.47**		**1.52**		**1.50**		**1.53**		**1.48**		**1.51**
BTLa Method																		
17. Flow Exponent:	0.65		0.65		0.65		0.65		0.65		0.65		0.65		0.65		0.65	
18. Weather Factor:	0.84		0.84		0.84		0.86		0.86		0.86		0.90		0.90		0.90	
19. Bldg. Square Ft:	1092		2466		2391		2352		552		1850		1872		1400		580	
20. Building Volume:	8736		19728		18315		17522		4140		14800		14976		11200		5220	
21. Building Height:	8.00		12.00		19.00		17.00		7.50		14.00		16.00		16.00		9.00	
22. Story Height:	8.00		8.00		7.66		7.45		7.50		8.00		8.00		8.00		9.00	
23. Bedrooms + 1:	3		4		4		4		3		4		4		4		4	
24. ELA in^2:	**116**	**60**	**239**	**83**	**230**	**69**	**226**	**79**	**78**	**61**	**122**	**56**	**381**	**57**	**101**	**48**	**133**	**61**
25. EqLA in^2:	**218**	**113**	**449**	**157**	**432**	**130**	**425**	**149**	**146**	**115**	**229**	**105**	**717**	**108**	**190**	**91**	**250**	**115**
26. Estim. Nat CFM:	**90**	**47**	**210**	**73**	**225**	**67**	**215**	**75**	**58**	**46**	**115**	**53**	**391**	**59**	**104**	**50**	**124**	**57**
27. Estim. Nat ACH:	**0.62**	**0.32**	**0.64**	**0.22**	**0.74**	**0.22**	**0.74**	**0.26**	**0.84**	**0.66**	**0.47**	**0.21**	**1.57**	**0.24**	**0.55**	**0.27**	**1.43**	**0.66**
28. Nat CFM/Occup't:	**30**	**16**	**52**	**18**	**56**	**17**	**54**	**19**	**19**	**15**	**29**	**13**	**98**	**15**	**26**	**12**	**31**	**14**
29. Target ELA_{min}:	**66**		**131**		**109**		**108**		**60**		**92**		**85**		**64**		**64**	
30. Target CFM_{min}:	**51**		**115**		**107**		**102**		**45**		**86**		**87**		**65**		**60**	
31. Ventilation CFM (Quad):	**None**	**20**	**None**	**89**	**None**	**83**	**None**	**69**	**None**	**None**	**None**	**68**	**None**	**65**	**None**	**42**	**None**	**18**
32. Ventilation CFM (0.5 Rule):	**None**	**8**	**None**	**83**	**None**	**79**	**None**	**54**	**None**	**None**	**None**	**67**	**None**	**57**	**None**	**31**	**None**	**5**
33. Target $CFM50_{min}$:	**1193**		**2386**		**1990**		**1960**		**1098**		**1670**		**1551**		**1160**		**1166**	
34. Target $CFM50_{min}$ x 80% =		**955**		**1909**		**1592**		**1568**		**878**		**1336**		**1241**		**928**		**933**
35. Leakage Ratio:	**0.98**	**0.51**	**1.49**	**0.52**	**1.09**	**0.33**	**1.17**	**0.41**	**1.13**	**0.89**	**0.84**	**0.39**	**2.40**	**0.36**	**0.77**	**0.37**	**1.67**	**0.77**
36. Quadrature Rule/0.5 Rule		**2.42**		**1.06**		**1.05**		**1.28**		**######**		**1.02**		**1.13**		**1.36**		**3.28**
DTL Method																		
37. CFM Exhst Fans:	180		225		225		765		106		747		103		174		174	
38. Flow Exponent:	0.65		0.65		0.65		0.65		0.65		0.65		0.65		0.65		0.65	
39. Limit in Pascals:	-5.0		-5.0		-5.0		-5.0		-5.0		-5.0		-5.0		-5.0		-5.0	
40. Fan CFM Limit:	**472**	**245**	**973**	**340**	**936**	**281**	**922**	**323**	**317**	**250**	**497**	**229**	**1,555**	**233**	**411**	**198**	**542**	**249**
41. CFM50 Limit:	**804**		**1,005**		**1,005**		**3,417**		**473**		**3,337**		**460**		**777**		**777**	
42. Neg. Press., Pa:	**-1.1**	**-3.1**	**-0.5**	**-2.6**	**-0.6**	**-3.6**	**-3.8**	**-18.9**	**-0.9**	**-1.3**	**-9.4**	**-30.9**	**-0.1**	**-1.4**	**-1.3**	**-4.1**	**-0.9**	**-2.9**

April 9, 2001 R. Karg

Composite of Field Data for BTL and BTLa Results (continued)

	19		20		21		22		23		24		25		26		27	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
BTL Method																		
1. CFM 50 Blower Dr.:	4181	1003	3498	875	3088	1112	7030	914	2680	1099	1880	1391	5119	1996	2282	1050	1785	1678
2. Climate Zone:	2		2		2		2		2		2		2		2		2	
3. Bldg. Square Ft:	1940		1616		700		1100		682		2088		3600		1812		2536	
4. Bedrooms + 1:	5		5		5		5		5		5		5		5		5	
5. Ceiling Height:	7.50		8.00		9.00		7.53		8.00		7.70		7.94		7.45		7.66	
6. Stories Above Gd:	2 Stories		2 Stories		1 Story		2 Stories		1 Story		1 Story		2 Stories		1.5 Stories		1 Story	
7. Building. Exposure:	Normal		Normal		Normal		Normal		Normal		Normal		Normal		Normal		Normal	
8. Field Data CFM50 x %		**24**		**25**		**36**		**13**		**41**		**74**		**39**		**46**		**94**
9. CFM50 BTL x 80% =		**1005**		**893**		**1110**		**888**		**1110**		**1388**		**1974**		**1052**		**1677**
10. CFM50 BTL/CFM50 =		**30**		**31**		**45**		**16**		**51**		**93**		**49**		**58**		**118**
11. CFM 50 BTL:	**1,256**		**1,116**		**1,388**		**1,110**		**1,388**		**1,735**		**2,468**		**1,315**		**2,096**	
12. CFM 50 Blower Dr, x %:		**1,003**		**875**		**1,112**		**914**		**1,099**		**1,391**		**1,996**		**1,050**		**1,678**
13. LBL Number:	**14.8**		**14.8**		**18.5**		**14.8**		**18.5**		**18.5**		**14.8**		**16.7**		**18.5**	
14. Ventilation CFM (Quad):	**None**	**51**	**None**	**47**	**None**	**45**	**None**	**43**	**None**	**46**	**None**	**56**	**None**	**98**	**None**	**47**	**59**	**68**
15. Ventilation CFM (0.5 Rule):	**None**	**34**	**None**	**33**	**None**	**30**	**None**	**27**	**None**	**31**	**None**	**37**	**None**	**64**	**None**	**32**	**34**	**45**
16. Quadrature Rule/0.5 Rule		**1.50**		**1.44**		**1.51**		**1.61**		**1.47**		**1.51**		**1.54**		**1.49**		**1.50**
BTLa Method																		
17. Flow Exponent:	0.65		0.65		0.65		0.65		0.65		0.54		0.62		0.64		0.69	
18. Weather Factor:	0.90		0.90		0.90		0.90		0.90		0.94		0.94		0.94		0.94	
19. Bldg. Square Ft:	1940		1616		700		1100		682		2088		3600		1812		2536	
20. Building Volume:	14550		12928		6300		8283		5456		16078		28584		13499		19426	
21. Building Height:	15.00		16.00		9.00		15.00		8.00		9.50		21.00		18.50		9.00	
22. Story Height:	7.50		8.00		9.00		7.53		8.00		7.70		7.70		7.70		7.66	
23. Bedrooms + 1:	5		5		4		4		3		4		6		4		4	
24. ELA in^2:	**230**	**55**	**192**	**48**	**170**	**61**	**386**	**50**	**147**	**60**	**138**	**102**	**304**	**119**	**128**	**59**	**89**	**83**
25. EqLA in^2:	**432**	**104**	**361**	**90**	**319**	**115**	**726**	**94**	**277**	**113**	**233**	**173**	**556**	**217**	**239**	**110**	**173**	**163**
26. Estim. Nat CFM:	**221**	**53**	**197**	**49**	**159**	**57**	**372**	**48**	**123**	**50**	**123**	**91**	**355**	**138**	**135**	**62**	**78**	**73**
27. Estim. Nat ACH:	**0.91**	**0.22**	**0.91**	**0.23**	**1.51**	**0.54**	**2.70**	**0.35**	**1.35**	**0.55**	**0.46**	**0.34**	**0.74**	**0.29**	**0.60**	**0.28**	**0.24**	**0.23**
28. Nat CFM/Occup't:	**44**	**11**	**39**	**10**	**40**	**14**	**93**	**12**	**41**	**17**	**31**	**23**	**59**	**23**	**34**	**15**	**19**	**18**
29. Target ELA_{min}:	**88**		**74**		**64**		**62**		**54**		**105**		**143**		**75**		**130**	
30. Target CFM_{min}:	**85**		**75**		**60**		**60**		**45**		**94**		**167**		**79**		**113**	
31. Ventilation CFM (Quad):	**None**	**66**	**None**	**57**	**None**	**18**	**None**	**35**	**None**	**None**	**None**	**23**	**None**	**93**	**None**	**49**	**83**	**87**
32. Ventilation CFM (0.5 Rule):	**None**	**64**	**None**	**52**	**None**	**6**	**None**	**23**	**None**	**None**	**None**	**6**	**None**	**57**	**None**	**33**	**71**	**81**
33. Target $CFM50_{min}$:	**1607**		**1339**		**1166**		**1133**		**984**		**1915**		**2602**		**1360**		**2360**	
34. Target $CFM50_{min}$ x 80% =		**1286**		**1071**		**933**		**906**		**787**		**1532**		**2082**		**1088**		**1888**
35. Leakage Ratio:	**1.47**	**0.35**	**1.33**	**0.33**	**1.87**	**0.67**	**3.59**	**0.47**	**1.77**	**0.72**	**0.49**	**0.36**	**0.95**	**0.37**	**0.73**	**0.34**	**0.41**	**0.39**
36. Quadrature Rule/0.5 Rule		**1.04**		**1.09**		**3.24**		**1.53**		**######**		**3.99**		**1.64**		**1.45**		**1.08**
DTL Method																		
37. CFM Exhst Fans:	106		100		238		106		88		180		150		230		150	
38. Flow Exponent:	0.65		0.65		0.65		0.65		0.65		0.54		0.62		0.64		0.69	
39. Limit in Pascals:	-5.0		-5.0		-5.0		-5.0		-5.0		-5.0		-5.0		-5.0		-5.0	
40. Fan CFM Limit:	**936**	**225**	**783**	**196**	**691**	**249**	**1,574**	**205**	**600**	**246**	**547**	**405**	**1,231**	**480**	**520**	**239**	**365**	**343**
41. CFM50 Limit:	**473**		**447**		**1,063**		**473**		**393**		**618**		**624**		**1,009**		**733**	
42. Neg. Press., Pa:	**-0.2**	**-1.6**	**-0.2**	**-1.8**	**-1.0**	**-4.7**	**-0.1**	**-1.8**	**-0.3**	**-1.0**	**-0.6**	**-1.1**	**-0.2**	**-0.8**	**-1.4**	**-4.7**	**-1.4**	**-1.5**

	28		29		30		31		32		33		34		35		36		37	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
BTL Method																				
1. CFM 50 Blower Dr.:	3348	904	1783	1337	1905	1162	2815	1042	868	868	2232	1116	1971	926	1439	1108	1620	891	1059	1059
2. Climate Zone:	2		2		2		2		2		2		2		2		2		2	
3. Bldg. Square Ft:	1987		1940		1720		1820		870		1376		1733		1056		1617		1709	
4. Bedrooms + 1:	5		5		5		5		5		5		5		5		5		5	
5. Ceiling Height:	7.40		8.00		7.91		8.37		8.37		7.50		7.70		7.80		7.00		7.60	
6. Stories Above Gd:	2 Stories		1 Story		1 Story		2 Stories		1 Story		1 Story		2 Stories		1 Story		1.5 Stories		1 Story	
7. Building. Exposure:	Exposed		Normal		Normal		Normal		Normal		Normal		Normal		Normal		Normal		Normal	
8. Field Data CFM50 x %		**27**		**75**		**61**		**37**		**100**		**50**		**47**		**77**		**55**		**100**
9. CFM50 BTL x 80% =		**913**		**1340**		**1175**		**1052**		**1110**		**1110**		**922**		**1110**		**882**		**1121**
10. CFM50 BTL/CFM50 =		**34**		**94**		**76**		**46**		**125**		**63**		**59**		**96**		**69**		**125**
11. CFM 50 BTL:	**1,141**		**1,675**		**1,468**		**1,315**		**1,388**		**1,388**		**1,152**		**1,388**		**1,103**		**1,402**	
12. CFM 50 Blower Dr, x %:		**904**		**1,337**		**1,162**		**1,042**		**868**		**1,116**		**926**		**1,108**		**891**		**1,059**
13. LBL Number:	**13.3**		**18.5**		**18.5**		**14.8**		**18.5**		**18.5**		**14.8**		**18.5**		**16.7**		**18.5**	
14. Ventilation CFM (Quad):	**None**	**52**	**None**	**55**	**None**	**49**	**None**	**54**	**59**	**59**	**None**	**45**	**None**	**46**	**None**	**45**	**None**	**39**	**50**	**50**
15. Ventilation CFM (0.5 Rule):	**None**	**36**	**None**	**36**	**None**	**33**	**None**	**37**	**56**	**56**	**None**	**29**	**None**	**30**	**None**	**30**	**None**	**25**	**37**	**37**
16. Quadrature Rule/0.5 Rule		**1.47**		**1.49**		**1.47**		**1.47**		**1.04**		**1.52**		**1.52**		**1.49**		**1.53**		**1.34**
BTLa Method																				
17. Flow Exponent:	0.65		0.63		0.58		0.64		0.63		0.66		0.65		0.55		0.63		0.50	
18. Weather Factor:	0.94		0.94		0.94		0.94		0.94		0.94		0.94		0.94		0.94		0.94	
19. Bldg. Square Ft:	1987		1940		1720		1820		870		1376		1733		1056		1617		1709	
20. Building Volume:	14704		15520		13605		15233		7282		10320		13344		8237		11319		12988	
21. Building Height:	19.00		9.50		9.00		18.00		8.00		10.00		19.00		10.50		17.00		9.00	
22. Story Height:	7.40		8.00		7.91		8.37		8.00		7.53		7.70		7.80		7.00		7.60	
23. Bedrooms + 1:	4		3		3		4		3		2		4		3		3		3	
24. ELA in^2:	**186**	**50**	**104**	**78**	**126**	**77**	**160**	**59**	**50**	**50**	**119**	**59**	**108**	**51**	**103**	**79**	**93**	**51**	**85**	**85**
25. EqLA in^2:	**348**	**94**	**191**	**144**	**222**	**135**	**297**	**110**	**92**	**92**	**226**	**113**	**203**	**96**	**176**	**135**	**172**	**95**	**139**	**139**
26. Estim. Nat CFM:	**199**	**54**	**95**	**71**	**113**	**69**	**183**	**68**	**46**	**46**	**105**	**53**	**119**	**56**	**96**	**74**	**92**	**51**	**74**	**74**
27. Estim. Nat ACH:	**0.81**	**0.22**	**0.37**	**0.28**	**0.50**	**0.30**	**0.72**	**0.27**	**0.38**	**0.38**	**0.61**	**0.31**	**0.53**	**0.25**	**0.70**	**0.54**	**0.49**	**0.27**	**0.34**	**0.34**
28. Nat CFM/Occup't:	**50**	**13**	**32**	**24**	**38**	**23**	**46**	**17**	**15**	**15**	**53**	**26**	**30**	**14**	**32**	**25**	**31**	**17**	**25**	**25**
29. Target ELA_{min}:	**80**		**99**		**89**		**78**		**49**		**68**		**71**		**52**		**66**		**87**	
30. Target CFM_{min}:	**86**		**91**		**79**		**89**		**45**		**60**		**78**		**48**		**66**		**76**	
31. Ventilation CFM (Quad):	**None**	**67**	**None**	**56**	**None**	**39**	**None**	**58**	**None**	**None**	**None**	**29**	**None**	**54**	**None**	**None**	**None**	**42**	**17**	**17**
32. Ventilation CFM (0.5 Rule):	**None**	**64**	**None**	**38**	**None**	**21**	**None**	**42**	**None**	**None**	**None**	**15**	**None**	**44**	**None**	**None**	**None**	**30**	**4**	**4**
33. Target $CFM50_{min}$:	**1462**		**1799**		**1616**		**1413**		**900**		**1234**		**1291**		**943**		**1210**		**1587**	
34. Target $CFM50_{min}$ x 80% =		**1170**		**1440**		**1293**		**1130**		**720**		**987**		**1033**		**755**		**968**		**1269**
35. Leakage Ratio:	**0.99**	**0.27**	**0.49**	**0.37**	**0.59**	**0.36**	**0.91**	**0.34**	**0.48**	**0.48**	**0.78**	**0.39**	**0.64**	**0.30**	**0.96**	**0.74**	**0.59**	**0.32**	**0.33**	**0.33**
36. Quadrature Rule/0.5 Rule		**1.04**		**1.46**		**1.89**		**1.36**		**######**		**1.94**		**1.23**		**######**		**1.39**		**4.44**
DTL Method																				
37. CFM Exhst Fans:	180		230		0		150		150		230		0		180		150		150	
38. Flow Exponent:	0.65		0.63		0.58		0.64		0.63		0.66		0.65		0.55		0.63		0.50	
39. Limit in Pascals:	-5.0		-5.0		-5.0		-5.0		-5.0		-5.0		-5.0		-5.0		-5.0		-5.0	
40. Fan CFM Limit:	**758**	**205**	**422**	**316**	**507**	**309**	**649**	**240**	**203**	**203**	**485**	**242**	**441**	**207**	**410**	**316**	**378**	**208**	**335**	**335**
41. CFM50 Limit:	**795**		**972**		**0**		**650**		**641**		**1,059**		**0**		**631**		**643**		**474**	
42. Neg. Press., Pa:	**-0.5**	**-4.1**	**-1.9**	**-3.0**	**0.0**	**0.0**	**-0.5**	**-2.4**	**-3.1**	**-3.1**	**-1.6**	**-4.6**	**0.0**	**0.0**	**-1.1**	**-1.8**	**-1.2**	**-3.0**	**-1.0**	**-1.0**