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EXEGESIS OF PROPOSED ASHRAE STANDARD 119: Air Leakage Performance for Detached Single-Family Residential Buildings

M. Sherman

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EXEGESIS OF PROPOSED ASHRAE STANDARD 119:

Air Leakage Performance for Detached Single-Family Residential Buildings

Max Sherman

Applied Science Division
Lawrence Berkeley Laboratory
University of California
Berkeley, California, 94720

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AUTHOR'S PREFACE

To develop ASHRAE Standard 119 required extensive deliberation over a significant length of time. As chairman of the Standards Project Committee (SPC), it became my responsibility to document the reasoning of the committee so that we would have a record of why we made certain decisions. Initially, we felt this record would be useful to the committee both during the initial development of the standard and during our response to public review comments. It soon became apparent, however, that this exegesis would be of value to a wider audience. Accordingly, I have prepared this document for broad distribution.

As the term "exegesis" implies, I have written this document in an attempt to demystify Standard 119. To those not intimately involved in the creation of a consensus standard, the final product often appears to be black magic; but, in general, the actual process used is well reasoned and solidly based. It is my hope that this document will communicate this rationality to you. Although the words contained herein are mine, the effort behind the standard belongs to the committee as a whole. In addition to writing Standard 119, the committee also gave this exegesis extensive review to assure that its views were properly represented.

During the development of the standard, the membership of SPC 119 changed somewhat, but I would like to acknowledge the committee members during the time of preparation of the documents: Norman Buckley, Donald Colliver, Don Carr, Earl Ferguson, Ross Gridley, David Harrje, Charles Hedlin, Peter Keyes, George Starsmeare, Jack Verschoor, Gren Yuill, Richard Weimar, and David Wilson. Several non-members regularly attended the SPC meetings and materially contributed to both the standard and its exegesis; included among these are Bill Jones and David Saum.

During the formation of Standard 119, over 300 weather datasets were investigated. Furthermore, several significant computer programs had to be written to reduce this data and prepare tables and plots for the committee. Every time the committee made some change to the standard, the data had to be rerun and replotted. To acknowledge the seemingly Sisyphean labor, I give my personal thanks to Bruce Dickinson and Brian Smith.

Max Howard Sherman

NOMENCLATURE

A	floor area (ft^2) [m^2]
ACH	air changes per hour [h^{-1}]
C	generalized shielding coefficient (see table 1)
C_p	heat capacity of air (0.245 BTU/lb-^{O}F) [1024 J/kg-K]
CDD	cooling degree-days (^{O}F-day) [^{O}C-day]
$CIDD$	cooling infiltration degree-days (^{O}F-day) [^{O}C-day]
E	seasonal energy (BTU) [Wh] [a]
F	load (BTU/h) [W] [b]
H	enthalpy (BTU/lb) [J/kg] [b c d]
H_b	(cooling) base enthalpy (28 BTU/lb) [65000 J/kg]
HDD	heating degree-days (^{O}F-day) [^{O}C-day]
$HIDD$	heating infiltration degree-days (^{O}F-day) [^{O}C-day]
IDD	infiltration degree-days (^{O}F-day) [^{O}C-day]
IDD_o	standard infiltration degree-days (3500^{O}F-day) [2000^{O}C-day]
IUA	infiltration-load coefficient (BTU/h/^{O}F) [W/K]
L_o	effective leakage area (ft^2) [m^2]
L_n	normalized leakage area [-]
Q	air flow (infiltration, ventilation) (ft^3/hr) [m^3/s]
Q_s	stack-induced infiltration (ft^3/hr) [m^3/s]
Q_w	wind-induced infiltration (ft^3/hr) [m^3/s]
R	fraction of total leakage area in the floor and ceiling [-]
T	absolute temperature [c d]

a) Subscripts "heat" and "cool" are used to indicate what season the load applied to.

b) Superscripts "sensible" and "latent" are used to distinguish the two parts of the (cooling) load.

c) Subscripts "out", "in", and "base" are used to indicate whether the quantity is for outdoors, indoor set-point, or indoor base use.

d) Superscripts "h" and "c" are used to indicate whether the set-point or base quantities are for heating or cooling climates, respectively.

ABSTRACT

The American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) has been actively developing consensus standards to govern and recommend energy use in buildings. One of these standards is Standard 119, *Air Leakage Performance for Detached Single-Family Residential Buildings*, which sets air-tightness requirements for single-family residential buildings and defines a classification method suitable for all buildings. Such standards do not generally include the reasoning behind them, although these deliberations can be of value to those making use of the final recommendations and requirements they contain. In this exegesis, we have provided the derivation of the standard and an interpretation of its potential effect.

Keywords: Air Leakage, Air Tightness, Infiltration, Standards, Ventilation.

INTRODUCTION

ASHRAE Technical Committee TC4.3, which is responsible for infiltration and ventilation requirements, realized that even though ASHRAE Standard 90 addresses the problem of energy conservation in residential buildings, it does not specifically set limits on air tightness, and that ASHRAE Standard 62 addresses ventilation requirements but does not specifically address infiltration. This committee therefore recommended that a Standards Project Committee (SPC) be formed to create a standard that addresses energy loads caused by infiltration and fills the gap between those two standards.

As will be discussed later, there are two parts to the standard: a classification scheme and a set of air-tightness limits. The standard was constructed this way to allow the classification methodology to be used for other purposes or in other standards, and to permit air-tightness limits to be changed in future revisions to 119 without affecting the classification mechanism.

Before discussing other choices and tradeoffs in the standard, readers may wish to acquaint themselves with the theoretical background that went into the standard. The appendix contains a summary of the models and equations used in the formation of the standard.

DEVELOPMENT OF THE STANDARD

One of the first major decisions approached by the committee was whether the standard should be a prescriptive standard or a performance standard. A prescriptive standard would specify the components and/or techniques and materials to be used in the building. Its advantage is that it is easy to design a structure that meets such a standard and, further, quality control is just a matter of checking to see whether particular components already exist in the building. The disadvantage of a prescriptive standard is that there is no assurance that the mere *presence* of a particular component will have an impact on the quantity of interest, in this case, air leakage.

Because the committee felt strongly that air tightness is highly dependent on the quality of the construction, we decided to require a performance-based standard. With a performance-based standard, actual measurement is necessary to determine whether existing air tightness meets the standard. The committee appreciated the implication in this decision that buildings in their design stages could not be guaranteed to meet the standard, but felt, as indicated in the Foreword to the standard, that the standard should be used for labeling-type functions and not occupancy-permit type functions.

characteristic of wind-induced flow. Additionally, a normalization factor was chosen for numerological convenience.

Typically, the normalized leakage turns out to be between 0.2 and 1.0, but factor-of-two differences could easily happen. The committee felt it would be easier for the user to classify the leakage with a *letter grade* and, therefore, constructed a classification table translating ranges of normalized leakage values from below 0.1 to above 1.6 into ten letter designations A to J. The span is sufficiently large that new classes should not have to be devised. At the present, only the most super-tight houses fall into the tightest classes (A-C); and only the leakiest houses typically seen in mild climates fall into the loosest classes (H-J). The spacing of the classes is geometric; the top of each class is 41% greater than the bottom (the actual ratio is the square root of two).

Designing the Standard

Although classifying leakage values is useful for comparing tightness across houses, it does not indicate what tightness level is appropriate for which climate. The committee spent a great deal of time debating the issue of what form the standard should take with respect to climate: constant infiltration across climates, constant infiltration load across climates, or the average between them.

If the constant infiltration form were to be chosen, then all houses would have to satisfy the same standard. Constant infiltration represents the simplest form because it does not require any climate calculations, but it unduly penalizes buildings in mild climates, who would be faced with a requirement far more stringent than normal and less cost-effective. If the constant infiltration load form were chosen, then the energy use attributable to infiltration would be the same for all climates. Here it was argued that those building in the more severe climates would have to invest substantially more in air tightness for the same payback. And so it appeared that a pseudo-economic optimum would be somewhere in between these two. In the end, however, the committee decided to go with the constant infiltration load option. The main reason for this decision was that it conforms to present practice in colder climates, where houses are made tight to provide comfort and to prevent structural damage due to condensation in wall cavities.

Once the form of the standard was settled, it was necessary to decide the level. The committee did not want to set a standard so stringent that no one could meet it, nor so loose that it accomplished nothing. The consensus was to set the level so that approximately 80-90% of new construction could and would meet it. In this case the standard had the effect of cutting off the tail of the distribution of bad buildings and moving current practice in the direction of tighter construction. The level of annual infiltration energy use was set at 150 MJ/m^2 to determine the relationship between IDDs and leakage class. (Infiltration degree-days (IDD) is a statistic developed along with this standard, to describe the severity of climate as it specifically relates to infiltration. The use and calculation of IDD is analogous to that of standard degree-days.) The calculations (described in the Appendix) were used to determine the range of IDDs that would be acceptable for each leakage class under the level of energy use chosen.

The biggest single effort involved in preparing the relationship, included in the standard, was in locating a sufficient number of sites having acceptable weather data. The problem of producing *typical* weather data is well known and was not in the purview of this committee. The committee elected to use weather data from the Weather Year for Energy Calculations (WYEC)[3,4] deemed by others to represent the best possible source of reliable data. Unfortunately, there are only about 50 sites for which this type of data has been generated, and this is far too sparse to cover the U.S. and Canada. There is, however, a large (over 200) source of weather data known as the Typical Meteorological Year (TMY) tapes. Although TMY data is not as carefully adjusted as is the WYEC data, a comparison using the same cities in both sets (of which there were approximately 30) showed a difference of less than 5% in IDD between the two. Therefore, we supplemented the WYEC sites with TMY sites. Because of the paucity of Canadian data in the WYEC and TMY sites, we compiled a set of actual weather files and constructed 10-year average values of IDDs assuming it would be representative of what is typical. In the standard, approximately 250 sites throughout the U.S. and Canada are included, and these cover almost all major population centers.

Demonstrating Compliance

In any standard there is a mechanism for demonstrating compliance; in the case of Standard 119, it is comparing the tightness of the building to the allowable tightness. You will recall that IDD data was used to generate the range of acceptable leakage classes for each of the 250 cities. This data was incorporated in a *Locations Table* in the Standard and it forms the primary mechanism for demonstrating compliance. That is, if the leakage class determined for a given building falls into the acceptable range indicated in the Locations Table, the building is deemed to have met the standard.

Because of the committee's concern that there may be locations of interest not in the Locations Table, we saw to it that two alternatives were included in the Standard.

Firstly, if the location of interest is not listed and it is determined that no location is *close enough,* then a calculation of infiltration-degree days must be made with user-supplied weather data. Infiltration degree-days are calculated using a technique based on the equations in the Appendix, and then the *Acceptable Leakage Class* table (Table 2 of the Standard) is used to determine which classes are acceptable.

If the Locations Table and calculation techniques cannot be used because of lack of data, the map, Figure 1 of the Standard, may be used. The map was developed by interpolating and extrapolating the data in the Locations Table to generate a grid covering the U.S. and Canada. Because of the potential of having local variations in climate, data far from the measured points is suspect. Furthermore, vagaries in the interpolation process imply that class boundaries are not necessarily unique; curves, loops, and wiggles in the class boundaries may occur as artifacts of the procedure. The user must take care in using the map for areas that are closer to class boundaries than to measured locations.

ADDITIONAL INFORMATION

The appendix to Standard 119 contains information that may be useful to the user but is not required by the Standard itself. Specifically, it lists the IDDs and related information about the sites in the Locations Table, and it gives recommendations concerning ventilation requirements. Over this latter issue, the committee vacillated.

As demonstrated in the appendix to this exegesis, methods are available for estimating seasonal air change rates from the information required by the standard. Estimates of air change rate could be useful to users of other standards, such as ASHRAE Standard 62. Because SPC 119 could not determine the methodology to be used for meeting other standards, however, it adopted a compromise position. That is, it adopted a compromise position whose intention was, without making explicit recommendations, to alert users to the possible ramifications on indoor air quality of applying the Standard. We achieved this goal by including a methodology using IDD and specific infiltration but not specifying exact procedures or explicit recommendations.

SUMMARY

This report, along with the mathematical derivations contained in the appendix, has presented the rationale of ASHRAE Standard 119P and has chronicled its development within the responsible committee. It is hoped that this exegesis proves useful to reviewers and users of the standard and to the developers of related efforts.

APPENDIX: THEORETICAL DERIVATIONS

Infiltration Modeling
Climate Modeling
Load Calculations
Standard-Specific Equations

The first part of this appendix deals with the general equations used in the Standard, specifically those dealing with infiltration models and the characterization of infiltration-related climate. The second part of this appendix is specific to the choices made in the Standard.

In the first section many of the auxiliary terms (e.g., f_s, H_b, etc.) are left open. In the second part of the appendix, as in the Standard, specific values for are chosen for these terms and are indicated in the NOMENCLATURE section.

GENERAL MODELS

If the goal of the standard is to limit infiltration-related energy consumption in different climates by limiting air leakage, it is necessary to be able to calculate this load from the measurable air-tightness parameters. We therefore need a model of infiltration that would allow us to separate the air tightness of the building from climate-dependent factors. The LBL infiltration model[5] was chosen as the basic calculational tool.

The LBL infiltration model assumes that infiltration flows caused by weather-induced pressures can be treated as flows through perfect orifices caused by weather-induced pressures. The only two weather factors that significantly influence infiltration are temperature difference (stack effect) and dynamic wind pressures (wind effect). This model leads to a simple superposition treatment that allows separation of the stack and wind terms:

Superposition:

$$Q = \sqrt{Q_w^2 + Q_s^2} \tag{1}$$

The stack and wind effects depend on the effective leakage area, L_o, and the induced pressures in the following way:

Stack-induced infiltration:

$$Q_s = L_o \, f_s \sqrt{|\Delta T|} \tag{2}$$

Wind-induced infiltration:

$$Q_w = L_o \, f_w \, v \tag{3}$$

Both terms contain constant factors which depend on building configuration but not on total leakage area or weather. These two factors need be calculated only once for each building (or class of buildings) and then used repeatedly:

Stack factor:

$$f_s = \frac{2}{3} \left(1 + R/2 \right) \frac{\sqrt{2\,\beta\,(1-\beta)}}{\sqrt{\beta} + \sqrt{1-\beta}} \sqrt{\frac{g h_s}{T_{ref}}} \tag{4.1}$$

$$f_s = \frac{\left(1 + R/2 \right)}{3} \left(1 - \frac{X^2}{(2-R)^2} \right)^{3/2} \sqrt{\frac{g h_s}{T_{ref}}} \tag{4.2}$$

Wind factor:

$$f_w = C \left(1 - R \right)^{1/3} \frac{\alpha_w \left(\frac{h_w}{h_{ref}} \right)^{\gamma_w}}{\alpha_t \left(\frac{h_t}{h_{ref}} \right)^{\gamma_t}} \tag{5}$$

The wind factor contains shielding and terrain parameters that depend on the environment surrounding the building. The two tables below contain the values of these parameters for different classes of terrain and shielding. (Terrain refers to the far-field geographic features while shielding refers to near-field features—i.e., a few building heights.) Each class has a qualitative description:

Table 1. Generalized shielding coefficients

Shielding Class	*C*	*Description*
I	0.324	No obstructions or local shielding whatsoever.
II	0.285	Light local shielding with few obstructions.
III	0.240	Moderate local shielding, some obstructions within two house heights.
IV	0.185	Heavy shielding, obstructions around most of perimeter.
V	0.102	Very heavy shielding, large obstructions surrounding perimeter within two house heights.

Table 2. Terrain parameters for standard terrain classes

Class	γ	α	*Description*
I	0.10	1.30	Ocean or other body of water with at least 5 km of unrestricted expanse.
II	0.15	1.00	Flat terrain with some isolated obstacles.
III	0.20	0.85	Rural areas with low buildings, trees, or other scattered obstacles.
IV	0.25	0.67	Urban, industrial, or forest areas or other built-up area.
V	0.35	0.47	Center of large city or other heavily built-up area.

To summarize the model, we can express the infiltration as a product of the effective leakage area and a specific infiltration:

$$Q = L_o s \tag{6}$$

where the specific infiltration is defined as follows:

$$s \equiv \sqrt{f_s^2 \left|\Delta T\right| + f_w^2 v^2} \tag{7}$$

Infiltration Load—Infiltration Degree-Days (IDD)

The previous expressions provide the hourly infiltration; the load associated with infiltration can be calculated from the infiltration and the enthalpy difference between inside and outside. The infiltration-related load can be treated in a manner analogous to that used for conduction loads; specifically, equivalent infiltration conductances and degree-days can be calculated. This approach, presented in detail in a technical paper,[6] is summarized below.

Using our definition of infiltration, the infiltration-related heat loss can be expressed as follows:

$$F_{infiltration} = \rho{*}C_p{*}L_o{*}s{*}(\ T_{in}^h - T_{out}\ ) \tag{8}$$

and the total heat load is

$$F_{heat} = UA{*}(\ T_{in}^h - T_{out}\ ) + \rho{*}C_p{*}L_o{*}s{*}(\ T_{in}^h - T_{out}\ ) - F_{free} \tag{9}$$

$$\text{for } F_{heat} > 0$$

The instantaneous cooling load contains parts that are both sensible (from conduction and infiltration) and latent (from infiltration only):

$$F_{cool} = F_{free} + UA*(T_{out} - T_{in}^{c}) + \rho*Q*(H_{out} - H_{in}^{c}) \qquad (15)$$
$$\text{for } F_{cool} > 0$$

Note that because the dominant moisture transport mechanism is bulk air movement (i.e. infiltration of moist air) latent-heat loads due to moisture diffusion through materials are ignored.

We can go through the same procedure used to derive HDD and HIDD with the exception that for the standard degree-days we use temperature differences, and for infiltration degree-days we use enthalpy differences:

$$CDD = \frac{1}{24} \sum_{hours} (T_{out} - T_{base}^{c}) \qquad \text{for } T_{base}^{c} < T_{out} \qquad (16)$$

$$CIDD = \frac{1}{24 C_p} \sum_{hours} \frac{s}{s_o} (H_{out} - H_{base}^{c}) \qquad \text{for } H_{base}^{c} < H_{out} \qquad (17)$$

where

$$T_{base}^{c} = T_{in}^{c} - \frac{F_{cool}^{sensible}}{UA + IUA} \qquad (18.1)$$

$$H_{base}^{latent} = H_{in}^{latent} - \frac{C_p \, F_{cool}^{latent}}{IUA} \qquad (18.2)$$

and the sensible base enthalpy is calculated from T_{base}^{c}.

The total seasonal load becomes the following:

$$E_{cool} = 24*\left(UA*CDD + IUA*CIDD \right) \qquad (19)$$

Summarizing both heating and cooling gives the following result for the infiltration load:

$$E_{infiltration} = 24*IUA*IDD \qquad (20)$$

where:

$$IDD = HIDD + CIDD \qquad (21)$$

STANDARD-SPECIFIC MODELS

In this part of the appendix the simplifications and calculations used in the Standard will be derived from the general arguments above. The Standard does not use all of the quantities in quite the same way as the previous part of the appendix might indicate. For example, the IDD expressions above require the prior calculation of free-heat to determine the base temperatures and enthalpy.

Because this calculation is both building- and climate-dependent, it is impractical to expect a user of the standard to make such a calculation. Therefore, all of the IDDs quoted in the standard use fixed base temperatures and enthalpies, which—along with f_s and f_w—are indicated in the NOMENCLATURE. These values were chosen to be consistent with other ASHRAE base values, which are assumed typical of the housing stock.

Normalized Leakage

The Standard uses for its leakage variable a quantity called the *normalized leakage,* L_n, which is a combination of the effective leakage area, the height of the building and the floor area:

$$L_n = 1000 \frac{L}{A} \left(\frac{h}{h_o} \right)^{0.3} \tag{22}$$

By including the height and floor area in the definition of normalized leakage, it is hoped that all of the important building characteristics are considered. Specifically, the height dependence is removed from the definition of specific infiltration and included in the definition of L_n. All of the calculations regarding the Standard will use the normalized leakage.

This expression is somewhat simplified from the exact one. We have assumed that the stack height, h_s, and the wind height, h_w, are the same and are replaced by a single quantity. We have also assumed that the height dependence of the two terms f_s and f_w is the same and can be factored out. (The exponent of 0.3 was chosen as intermediate between the lower limit of wind exponents, 0.1, and the upper limit of the stack effect, 0.5.) Thus when using the normalized leakage, one deals only with the specific infiltration terms for single-story structures.

Relating Leakage to Load

As indicated in the body of the text, the committee decided to set the standard in such a way that the infiltration-related load (calculated from IDDs) would be a constant, independent of climate. If we have a target of annual infiltration load per unit of floor area, we can rewrite the equation of load as follows:

$$\frac{24 * IUA * IDD}{A} = E / A \tag{23}$$

where E/A represents the target value (13 kBTU/ft^2), [42 kWh/m^2].

We assume that for a particular site the IDD is fixed. We then substitute in the definition of IUA and solve for the normalized leakage:

$$L_n = \frac{IDD_o}{IDD} \tag{24}$$

where:

$$24 * IDD_o = \frac{1000\ E\ /A}{\rho\ C_p\ s_o} \tag{25}$$

For the values in this standard, the value of IDD_o is approximately 3500°F-day and 2000°C-day.

CALCULATION OF AIR CHANGE RATE

It is often of interest to estimate the average air change rate for a building as a function of climate and leakage. For any detailed analysis the more rigorous methods summarized in the first part of the appendix are appropriate, but often it is desired to have simple *rule-of-thumb* estimates.

The basic equation comes from the LBL infiltration model, but requires substitutions to put it into the framework of the standard:

$$\frac{Q}{A\ h_o} = \frac{L_n}{1000}\ \frac{s}{h_o} \tag{26}$$

The term on the left (when in proper units) can be recognized as the air change rate. The factor of 1000 comes from the definition of the normalized leakage. The following expression results from the numerical values of h_o and s_o, and the substitution for ACH :*

$$ACH = L_n\ \frac{s}{s_o} \tag{27}$$

This expression obtains its simple form from our choice of normalization used in the normalized leakage. Thus, this expression is numerological in origin, but useful nevertheless.

* NOTE: This relation is an artifact of the system of units chosen and values of specific variables; it is not a general result.

If a crude estimate of the seasonal air change rate is desired and no knowledge of the climate is available, the specific infiltration can be approximated by using its average value, s_0 to get a simplistic relationship between leakage and average annual air change rate:*

$$ACH \approx L_n \tag{28}$$

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