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ABSTRACT

Because the load due to air infiltration typically accounts for one-third of space conditioning loads, ASHRAE (American Society of Heating, Refrigerating and Air-conditioning Engineers) is in the process of writing a standard which addresses the maximum leakage associated with good construction. This standard, SPC 119P, is a link between ASHRAE Standard 90, which addresses energy conservation in new residential construction, and Standard 62, which specifies the minimum acceptable ventilation to achieve adequate indoor air quality. Within Standard 119 there is currently a classification scheme that groups building tightness into categories depending on envelope leakage, floor area and building height. In addition to being used for this residential leakage standard, this classification scheme is intended to be used to label the tightness of any building residential or commercial, new or existing. This report will present the background around SPC 119P, indicate a proposed form that the standard may take, and present some of the rationale behind it.

Keywords: Air Leakage, Standards, Air Infiltration, Leakage Area.

SYMBOL TABLE

A	Floor Area m^2
ACH	Air Exchange Rate hr^{-1}
C_p	Volumetric Heat Capacity of Air 1234 $J/K\text{-}m^3$
E	Infiltration Load J/hr
ELA	Effective Leakage Area cm^2
h	Building Height m
h_1	Height of a Single Story 2.5m
H	Enthalpy J/m^3
H_{base}	Base value of enthalpy 82,000 J/m^3
H_{in}	Inside Enthalpy J/m^3
H_{out}	Outside Enthalpy J/m^3
HDD	Heating Degree-Days (as calculated by ASHRAE) ^oC-days
k_n	nthe constant (arbitrary)
IDD	Infiltration Degree-Days K-days
IDD_o	A specified number of IDD 450^oC-days
NL	Normalized Leakage
Q	Infiltration m^3/hr
s	Specific Infiltration $m^3/hr\text{-}cm^2$
s_{ave}	Average specific infiltration for North America
T	Air Temperature ^oC
T_{ave}	Average Annual Temperature ^oC
T_{base}	Base value of air temperature 18.3^oC
T_{in}	Average Indoor Temperature 22^oC
T_{max}	Maximum no cool temperature 25.5^oC
T_{min}	Minimum no heat temperature 15.5^oC
v	Meteorological (10 m.) wind speed m/s
¼x½	Annual sum of the hourly values of x

INTRODUCTION

In this report will be discussed the details of a generic leakage standard for residential buildings. While based on the same objectives, principles, and methods that are being used in the proposed ASHRAE standard (119), the standard discussed herein need not be the same as the proposed ASHRAE standard.

BACKGROUND

Prior to the 1973/74 oil embargo, the primary infiltration concern in the heating and ventilating profession was the estimation of peak loads for the sizing of HVAC equipment. In the intervening decade, however, it has become clear that the energy loss due to infiltration represents a significant energy loss that can no longer go unchecked. To put this in perspective, buildings use over one-third of the total resource energy consumed in the U.S. with residential building accounting for about two-thirds of that share. Space conditioning (i.e. heating and cooling) account for over half of the energy used in buildings and infiltration accounts for at least a third of that. Putting this all together infiltration energy losses account for approximately one-fifteenth of the resource energy used in this country -- over 5 Quads (120 million ton oil equivalent).

The enormous expense (on the order of $50 billion) of heating and cooling air that has leaked into a building has caused the professional societies involved, primarily ASHRAE, and government agencies, primarily DOE, to re-examine their priorities regarding infiltration. The technical committee responsible for infiltration and ventilation in ASHRAE (TC4.3) has been an extremely active one; they are responsible for the revamping of the infiltration and ventilation chapter in the Handbook of Fundamentals and for administering several research proposals. Government sponsored research in the area of infiltration and ventilation has increased during the last decade and reflects the importance of the topic.

As technical research efforts mature and a consensus forms among the research and professional community regarding what can and what should be done, the time is ripe for the adoption of standards. The purpose of such consensus standards is to guide the practitioner in proper methods and to assure the ultimate consumer that he is purchasing something that meets some generally accepted criteria. In the field of energy conservation it is ASHRAE standard 90, "Energy Conservation in New Building Design", that is most widely used. This standard deals with both loads and systems, but refers little to air infiltration. Although it does not address the issue of overall infiltration performance directly, standard 90 does state that doors, windows, and curtain walls must meet certain performance specifications and that all joints must be sealed.

As the realization spread that plugging leaks was a cost effective method of saving energy, a concern arose that the indoor air quality of tightened buildings was being threatened as houses grew tighter. Many research programs have been and are being done on the sources and sinks of pollutants and on the interaction between ventilation and indoor air quality. One outcome of this research is ASHRAE standard 62, "Ventilation for Acceptable Indoor Air Quality"; this standard has both a performance part, which specifies maximum acceptable levels of certain pollutants, and a prescriptive part, which specifies minimum ventilation rates.

Currently there is an area that is not covered by either standard 90 (which is an energy conservation standard) and standard 62 (which is a health and safety standard) -- namely that of overall envelope tightness. Standard 90 deals with the thermal resistance of the envelope and standard 62 deals with minimum ventilation requirements, but not where is the acceptable tightness of the envelope for energy conservation addressed. It is for this reason that ASHRAE has convened a new standard committee, SPC 119P, to determine the minimum tightness levels that should be required.

OVERVIEW

This standard is limited in scope to those structures that can reasonably be expected to economically benefit from the application of the standard and to those types of structures in which there is a significant body of knowledge. Specifically, the standard applies only to detached single-family residential structures and does not apply to those structures that are conditioned for only a small fraction of the year.

This standard has two purposes: classification and limitation. The standard introduces a classification scheme that allows each structure to be ranked and categorized by its air tightness from class

A (the tightest class) to class J (the leakiest class). These classes span the range from the very tightest measured houses to some of the leakiest measured houses. This classification scheme can stand alone as a method for comparing or labeling houses as to their air tightness. Even though the scope excludes buildings other than single-family residential ones, it is reasonable to expect that this classification method could be used on some of these excluded structures as soon as the measurement procedures warrant it.

The limitation section of the standard uses a new measure of the severity of climate, Infiltration Degree-Days (IDD), to set a maximum leakage class, as defined in the classification section. Infiltration degree-days are discussed in detail in a following section, but, simply, they are a measure of the severity of the climate in relation to infiltration in the same way that common degree-days are a measure of the severity of the climate in relation to thermal conduction through the envelope. Thus, for each site the number of IDD can be calculated from typical weather data and from that the acceptable leakage classes can be determined. In addition to the calculation methods the standard has a list of over one hundred cities for which IDD and acceptable leakage classes have been determined.

The standard contains two informational sections which, while not part of the standard proper, contain information that may be useful to the intended user. The first one concerns the estimation of typical annual air change rates for houses in each of the leakage classes. Although the purpose of the standard is to limit infiltration, nowhere in the standard proper is infiltration discussed. This is due to the fact that the details of the house, its environment and the microclimate around may have a substantial effect on the infiltration, but the air tightness can still be unambiguously measured. An attempt, however, is made to give an estimate of the lower limit of the average infiltration. It is expected that the users of standard 62 might wish to have some sort of method for estimating the contribution infiltration may make to the total ventilation.

The second informational section contains a map of the U.S. and southern Canada and on it are marked the cities that are contained in the standard. From the IDD values of each city an interpolation is made to cover the map with the different acceptable leakage zones. Because the values far away from measured cities and near the zone borders are sensitive to the details of the interpolation, this map cannot be used as part of the standard. It is, however, very informative in that it gives one an idea of the severity of climate over the entire area.

THEORETICAL CONSIDERATIONS

In order to come up with a standard, one must use a model of the physical processes involved and manipulate the results to come up with expressions for quantity of interest in terms of measurable quantities. For example, an energy conservation standard may set limits on R-values because the standards committee understood how R-values affected energy loss. In our case, we want to control infiltration and infiltration energy loss by setting standards for air tightness.

In deriving the expressions for this standard many specific details of individual buildings are averaged out. Therefore, the model that we use to connect air tightness to infiltration can, in general, be a generic one, rather than a specific one. For those few times when it is necessary to use a specific model to calculate a number we have used the LBL infiltration model.

Generally speaking the infiltration can be thought of as a product of the leakage of the envelope and a driving term. We can write the expression for the infiltration for a single-story house as follows:

$$Q = ELA * s \qquad (1)$$

The calculation of the driving term, s, need not concern us yet as long as we realize that it is some combination of the wind and stack pressures and may contain other details about the structure. The expression above is for a single-story house; we may generalize this to any height with the addition of a term to account for the fact that both the wind and the stack effects increase with increasing height:

$$Q = (h/h_1)^{0.3} * ELA * s \qquad (2)$$

The exponent of 0.3 is chosen to approximate the height dependence of the stack effect (0.5) and wind effect (0.1 - 0.25).

This expression gives the instantaneous infiltration as a function of the driving forces, leakage, and building height; but, if we wish to compare houses, we must have a way of normalizing the infiltration to account for house sizes. We have elected to use the floor area as the normalization; we do so for two reasons: 1) the leakage is measured by an area and so some other area is an appropriate normalization, and 2) floor area is usually easily obtainable for almost any house. The normalized expression then becomes the following:

$$Q/A = (h/h_1)^{0.3} * (ELA/A) * s \tag{3}$$

We now define a dimensionless quantity called the normalized leakage, NL, that is a quantification of the air tightness of the envelope:

$$NL = 0.1 * (h/h_1)^{0.3} * (ELA/A) \tag{4}$$

If we substitute this definition into equation 3 we get the following:

$$Q/A = 10 * NL * s \tag{5}$$

In addition to the infiltration we are also interested in the infiltration-induced load. The load can be calculated from the infiltration by multiplying the air infiltration by the amount of energy required to bring the infiltrating to indoor conditions (i.e. the enthalpy difference between indoor and outdoor air):

$$E = Q * (H_{in}-H_{out}) \tag{6}$$

We can find the infiltration load normalized by floor area by combining the two previous equations:

$$E/A = 10 * NL * s * (H_{in}-H_{out}) \tag{7}$$

Selection Criteria: In constructing an air tightness standard two prospective criteria come to mind: 1) setting the maximum infiltration to be a constant, and 2) setting the maximum infiltration load to be a constant. The former concept would set the annual infiltration to be less than a specific number:

$$\tfrac{1}{4}Q/A\tfrac{1}{2} \ \tfrac{1}{4} \ k_1 \qquad (8)$$

where k_1 is a constant

Inserting equation 5 into this limit yeilds the following:

$$10 * NL * \tfrac{1}{4}s\tfrac{1}{2} \ \tfrac{1}{4} \ k_1 \qquad (9)$$

If we use the LBL model to find the annual average of the specific infiltration, $\tfrac{1}{4}s\tfrac{1}{2}$, we discover that it only varies about 20% throughout North America. Thus for our purposes we can treat it as a constant. We then find that the normalized leakage is constrained to be below a constant value:

$$NL \ \tfrac{1}{4} \ k_2 \qquad (10)$$

where $k_2 = k_1/(10*\tfrac{1}{4}s\tfrac{1}{2})$

An alternative to constant infiltration is constant infiltration load. This can be represented as follows:

$$\tfrac{1}{4}E/A\tfrac{1}{2} \ \tfrac{1}{4} \ k_3 \qquad (11)$$

where k_3 is a specified constant.

Substituting the definition for the infiltration load, equation 7, yeilds the following results:

$$10 * NL * \tfrac{1}{4}s*(H_{in}-H_{out})\tfrac{1}{2} \ \tfrac{1}{4} \ k_3 \qquad (12)$$

The average quantity (in brackets) is a measure of the severity of the climate. Because the concept of degree-days is relatively well understood in the buildings community, we wish to make our climate severity term in a similar form. We, therefore, define infiltration degree days to be proportional to the bracketed term:

$$IDD = \tfrac{1}{4}s*(H_{in}-H_{out})\tfrac{1}{2}/(24*C_p*s_{ave}) \qquad (13)$$

Combining the definition of infiltration degree-days (eq. 13) with the limitation on the infiltration load (eq. 12) we get the following limit for the normalized leakage:

$$NL = k_4/IDD \qquad (14)$$

where $k_4 = k_3/(240*C_p*s_{ave})$ is a constant.

Choosing a Form

We have derived two possible functional forms for the basis of our standard: 1) constant normalized leakage (i.e. constant infiltration), and 2) normalized leakage inversely proportional to infiltration degree-days (i.e. constant infiltration load). Unfortunately, both these functional forms have serious draw-backs. If we choose constant infiltration, then the houses in the mild climates must meet the same tightness criterion as the severe climates. Since it would cost about the same for them to tighten their houses to this level, it would put an unfair burden on the mild climates.

Conversely, if we choose constant infiltration load, then both climates are paying about the same for their energy, but the severe climates had to tighten their houses more and thus it cost them significantly more. The law of decreasing marginal returns implies that the severe climates are then at a disadvantage relative to the mild ones.

Although both suggestions have disadvantages, we have delineated the two extremes; the optimum must lie in between. The exact optimum depends on many details of both the model and the structure -- ones we do not wish to deal with. Therefore, we choose a functional form which is approximately half way between the two positions and assume that there is no need to improve it further. Specifically, we assume that the normalized leakage decreases as the square-root of IDD:

$$NL = (IDD/IDD_o)^{-0.5} \quad (15)$$

Like the previous two criteria, this form contains a single adjustable parameter (IDD_o) to specify the standard, but it must lie closer to the true economic optimum than do they.

Classification

The previous section completely defines a standard once the value of IDD_o has been chosen. It would be possible to measure the normalized leakage and determine the IDD for each site and verify if the standard is met. It was felt, however, that this method of using the standard could lead to ambiguity and abuse. Small changes in local weather would change the appropriate value of NL; changes in the way in which NL is measured could have a significant effect. Finally, application of this standard would require repeated calculations to be made, and might not be appropriate for many users.

In order to solve most of these problems a system of classifications was developed, based on the equations above. For each measured NL there is a unique leakage class (A-J) and certain classes are acceptable for certain IDD zones. Because of the square-root in the previous equation, the top of each leakage class is root two times the bottom of the class and the top of each IDD zone is twice the bottom of that zone. Thus, an easy-to-apply set of leakage classes and IDD zones replace all the equations as a means for meeting the standard.

OPERATIONAL DEFINITIONS

The sections above give an overview of the standard and the theoretical background behind it. A standard, however, is a set of operational definitions and instructions that must be followed. In this section we summarize these instructions as they currently exist within the standard.

Measurement Procedures

There are two types of data required by the standard: weather data and building data. Unless the site of interest is one in the table contained within the standard, hourly weather data is necessary to calculate the infiltration degree-days. Weather tapes from the National Oceanographic and Atmospheric Administration (NOAA) may be used for this purpose; either TMY or TRY type tapes are adequate but they must contain hourly temperature, humidity and wind speed. For those few sites that neither are close enough to a listed site nor have hourly weather data, the standard provides a alternate method. To use this standard it is always necessary to make a measurement of the air tightness of the envelope, as well as related quantities. This standard uses the concept of effective leakage area (ELA) to quantify the leakage of the envelope.

The ELA is defined as the equivalent amount of open area (of unity discharge coefficient) that would pass the same amount of air under a specified reference pressure. The ELA can be calculated from fan pressurization measurements by extrapolating the measured flows to the reference pressure which is taken to be four pascals. The other quantities that are required for the standard are floor area and building height. All these quantities as well as the fan pressurization test method are as specified in ASTM standard E779-84 and, accordingly, E779 is required as part of this standard.

There are two quantities that are used in the standard and calculated from the measured data: normalized leakage and infiltration degree-days. Normalized leakage is calculated from the measured structure data and infiltration degree-days are calculated from the weather.

Leakage Classification

Leakage classification is quantified by the leakage class, which in turn is calculated from the normalized leakage. Normalized leakage is a quantity that depends only on the structure and not on the surrounding environment; as such it can be used to compare the air tightness of houses in different environments. It is a dimensionless quantity that uses the ELA normalized by floor area and contains a height correction term. All measured quantities can be found in the report section of ASTM E779-84. The numerical form of the normalized leakage (as presented in a previous section) is as follows:

$$NL=0.1*(ELA/A)*(h/h_1)^{0.3} \qquad (16)$$

The normalized leakage is used to determine the leakage class of the building from table 1:

TABLE 1: CLASSIFICATION OF LEAKAGE

Normalized Leakage	**Leakage Class**	**Leakage Category**
¼0.10	A	I
0.10-0.14	B	
0.14-0.20	C	
0.20-0.28	D	II
0.28-0.40	E	
0.40-0.57	F	
0.57-0.80	G	III
0.80-1.13	H	
1.13-1.60	I	
½1.60	J	

(The category labels are included for convenience only, and correspond to the qualitative descriptions tight, medium, and loose.)

Leakage Limitations

The standard limits the amount of leakage that a building envelope may have depending on the severity of the climate of the building site. Infiltration degree-days are a measure of the severity of the climate as it affects infiltration loads in much the same way that heating degree-days are a measure of the severity of the heating season as it affects conduction through the building envelope. In the standard infiltration degree-days must be calculated by one of the two methods below or taken from a Locations Table.

The primary calculation method requires the following hourly data for a typical year: outdoor dry-bulb temperature, humidity and wind speed. For every hour in which the dry-bulb temperature is below

T_{min} or is above T_{max} infiltration degree-days are accumulated as follows:

$$\begin{gathered} IDD = 1/(24*s_{ave}) * \\ \tfrac{1}{4}s*(T_{base}-T)\tfrac{1}{2} \quad + \quad \tfrac{1}{4}s*(H-H_{base})\tfrac{1}{2}/C_p \\ \text{for } T\tfrac{1}{4}T_{min} \qquad\qquad \text{for } T\tfrac{1}{2}T_{max} \end{gathered} \tag{17}$$

We use the following definitions for the specific infiltration:

$$s = 0.044 * (v^2 + \quad T-T_{in} \quad)^{0.5} \tag{18}$$

$$s_{ave} = 0.27 \tag{19}$$

The <u>secondary calculation method</u>, which may <u>only</u> be used if it can be demonstrated that hourly data are not available and that no pre-calculated site is close enough, requires only two values: the "base 65" degree-days as calculated in the ASHRAE Handbook of Fundamentals, and the average annual temperature. Using the same definitions as above the total infiltration degree-days can be expressed as follows:

$$IDD = 2*HDD + 365*(T_{ave} - T_{base}) \tag{20}$$

Having defined the severity of climate through IDD, we may now go on to define the limitations imposed by the standard. For each range of IDD there are a set of acceptable leakage classes. The following table displays those classes:

Table 2: ACCEPTABLE LEAKAGE CLASS

Infiltration Degree-Days **°C-days**	**Acceptable Classes**
¼625	A-H
625- 1250	A-G
1250- 2500	A-F
2500- 5000	A-E
5000-10000	A-D
½10000	A-C

Compliance is demonstrated if the measured leakage class is acceptable for the calculated number of infiltration degree-days. (This table was generated assuming IDD_o=450°C-days.)

ESTIMATION TECHNIQUES

Because this standard govern air tightness for infiltration reduction, estimation of actual infiltration rates do appear within the body of the standard. As we show below, in order to estimate infiltration from leakage and climate it is necessary to make more detailed assumptions about the house (i.e. use a specific model) than was necessary for the tightness standard itself. Furthermore, if an estimation of air change rate were part of the standard, liability questions could arise if a problem occurred because of actual infiltration rates below the estimated ones in the standard.

This section gives a technique for the estimation of air exchange rates from normalized leakage values and climate. These air change rates are seasonal average ones based on the average climate; instantaneous values of air exchange may differ quite radically from the averages calculated herein. The results in this section assume a typical structure that is typically shielded from a typical wind; these factors can easily vary by a factor of two.

In order to estimate the air change rate we can begin with equation 5, dividing through by the height of a single story:

$$Q/(A*h_1) = 10 * NL * s / h_1 \qquad (21)$$

We recognize that the left hand side of this equation is the air change rate. Averaging over the year we get that

$$ACH = 10 * NL * \frac{1}{4}s\frac{1}{2} / h_1 \tag{22}$$

One should take care when applying a formula like this because of the in-built assumptions. This air change rate is the annual average assuming that there is no mechanical ventilation, natural ventilation (e.g. open windows) and no occupant effects (e.g. door openings).

If we choose a particular model, we may evaluate the specific infiltration and thus find a numerical result for the air change rate. We therefore use the LBL model to evaluate $\frac{1}{4}s\frac{1}{2}$ for the average conditions in North America. To within the 20% spread in specific infiltration values we can use the following expression as a "rule-of-thumb":

$$ACH = NL \tag{23}$$

The most important assumption that has gone into this evaluation is that the structure is typically (moderately) shielded. Variations in the shielding can cause errors of up to 50% in the air change rate.

Table 3 gives the range of seasonal infiltration rates for houses of different leakage class. The minimum value is calculated assuming a reasonable lower bound of $\frac{1}{4}s\frac{1}{2}=0.18m^3/hr\text{-}cm^2$ and a reasonable upper bound of $\frac{1}{4}s\frac{1}{2}=0.36m^3/hr\text{-}cm^2$. The standard value is calculated assuming that the structure exactly meets the air tightness standard.

Table 3: TYPICAL SEASONAL INFILTRATION RATES

	Leakage Class	**ACH RANGE hr^{-1}**		
		Min	**Standard**	**Max**
	A*	0.00	0.14	0.14
Category I	B*	0.07	0.20	0.20
	C	0.10	0.28	0.29
	D	0.14	0.36	0.40
Category II	E	0.20	0.48	0.58
	F	0.29	0.62	0.80
	G	0.40	0.77	1.15
Category III	H	0.58	0.99	1.60
	I*	0.80	--	2.30
	J*	1.15	--	--

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* Leakage classes above H, do not meet the requirements for any climate and, therefore, do not have a standard value; class J has no maximum value because it has no upper limit on leakage. Leakage classes A and B are more than sufficient to meet any climate and therefore their standard entries and equal to their maximums.

Estimation of Average Loads

In the same way that we derived the average air change rate from equation 5, we may derived the average load per unit floor area from equation 7. If we combine equation 7 with the definition of IDD and using the LBL model to evaluate it, we get the following:

$$\tfrac{1}{4}\mathbf{E/A}\tfrac{1}{2} = 240 * C_p * NL * s_{ave}{}^{*} * IDD \qquad (24)$$

which, upon substituting for s_{ave} and evaluating numerically, leads to the following numerical expression:

$$\tfrac{1}{4}\mathbf{E/A}\tfrac{1}{2} = 80{,}000 * NL * IDD \qquad (25)$$

TABLE 4: LOCATIONS TABLE

CITY	Infiltration Degree-Days			[s]	Acceptable
	Heating	Cooling	Total		Classes
BIRMINGHAM,AL	1424	606	2031	.22	A-F
MOBILE,AL	875	1124	1999	.24	A-F
PHOENIX,AZ	709	682	1390	.18	A-F
PRESCOTT,AZ	2690	52	2742	.26	A-E
TUCSON,AZ	946	371	1316	.24	A-F
WINSLOW,AZ	2678	64	2742	.26	A-E
YUMA,AZ	472	1244	1717	.24	A-F
ARCATA,CA	2028	0	2028	.20	A-F
CHINA LAKE,CA	1138	79	1217	.22	A-G
DAGGETT,CA	1329	208	1537	.29	A-F
FRESNO,CA	1306	182	1488	.20	A-F
LONG BEACH,CA	687	58	745	.20	A-G
LOS ANGELES,CA	650	7	657	.20	A-G
MOUNT SHASTA,CA	2952	25	2977	.24	A-E
OAKLAND,CA	1417	0	1417	.23	A-F
POINT MUGU,CA	843	3	846	.19	A-G
RED BLUFF,CA	1698	131	1829	.26	A-F
SACRAMENTO,CA	1503	107	1610	.23	A-F
SAN DIEGO,CA	417	11	428	.18	A-H
SAN FRANCISCO,CA	1850	4	1854	.26	A-F
SANTA MARIA,CA	1426	1	1426	.20	A-F
COLORADO SPRINGS,CO	3992	18	4010	.30	A-E
DENVER,CO	3550	5	3555	.28	A-E
EAGLE,CO	4624	2	4627	.24	A-E
GRAND JUNCTION,CO	3124	12	3136	.25	A-E
PUEBLO,CO	3049	31	3079	.25	A-E
WASHINGTON,DC	2180	444	2624	.24	A-E

TABLE 4: LOCATIONS TABLE(Cont.)

CITY	**Infiltration Degree-Days**			**[s]**	**Acceptable**
	Heating	**Cooling**	**Total**		**Classes**
APALACHICOLA,FL	643	1392	2036	.19	A-F
JACKSONVILLE,FL	652	1212	1864	.25	A-F
MIAMI,FL	72	2446	2517	.23	A-E
TAMPA,FL	249	1407	1657	.23	A-F
ATLANTA,GA	1741	461	2202	.25	A-F
BOISE,ID	3226	13	3238	.26	A-E
IDAHO FALLS,ID	6329	29	6358	.33	A-D
LEWISTON,ID	2929	11	2941	.24	A-E
POCATELLO,ID	4747	6	4752	.31	A-E
CHICAGO,IL	3709	204	3914	.28	A-E
INDIANAPOLIS,IN	3744	333	4077	.28	A-E
DES MOINES,IA	4144	267	4411	.28	A-E
DODGE CITY,KS	3920	459	4379	.34	A-E
LOUISVILLE,KY	2713	409	3122	.27	A-E
LAKE CHARLES,LA	949	1280	2229	.23	A-F
NEW ORLEANS,LA	1022	1222	2244	.24	A-F
BOSTON,MA	4358	267	4624	.36	A-E
CARIBOU,ME	6481	20	6501	.31	A-D
PORTLAND,ME	4302	86	4387	.26	A-E

TABLE 4: LOCATIONS TABLE(Cont.)

CITY	InfiltrationDegree-Days			[s]	Acceptable
	Heating	Cooling	Total		Classes
DETROIT,MI	4193	320	4513	.29	A-E
SAULT STE MARIE,MI	5967	34	6001	.29	A-D
DULUTH,MN	6873	55	6927	.32	A-D
INTERNATIONAL FALLS,MN	6867	29	6896	.30	A-D
MINNEAPOLIS,MN	5573	353	5926	.31	A-D
JACKSON,MS	1328	1062	2390	.24	A-F
COLUMBIA,MO	3146	458	3604	.27	A-E
KANSAS CITY,MO	3093	843	3937	.28	A-E
ST LOUIS,MO	3276	609	3884	.28	A-E
CUTBANK,MT	6520	1	6521	.34	A-D
GREAT FALLS,MT	5744	1	5745	.36	A-D
MISSOULA,MT	3928	4	3932	.23	A-E
OMAHA,NE	4029	589	4618	.29	A-E
SCOTTSBLUFF,NE	4780	90	4870	.31	A-E
ELKO,NV	3723	3	3727	.23	A-E
ELY,NV	4914	0	4914	.29	A-E
LAS VEGAS,NV	1295	189	1484	.25	A-F
LOVELOCK,NV	3214	4	3218	.25	A-E
RENO,NV	3087	8	3094	.23	A-E
TONOPAH,NV	3661	9	3670	.29	A-E
WINNEMUCCA,NV	3650	1	3650	.26	A-E
YUCCA FLATS,NV	2607	17	2624	.25	A-E
ALBUQUERQUE,NM	2353	35	2388	.24	A-F

TABLE 4: LOCATIONS TABLE(Cont.)

CITY	InfiltrationDegree-Days			[s]	Acceptable
	Heating	Cooling	Total		Classes
ALBANY,NY	4487	161	4648	.28	A-E
BINGHAMPTON,NY	4904	92	4996	.30	A-E
BUFFALO,NY	4740	65	4805	.32	A-E
NEW YORK,NY	3128	201	3329	.31	A-E
CAPE HATTERAS,NC	1714	901	2616	.29	A-E
GREENSBORO,NC	2074	381	2454	.24	A-F
RALEIGH,NC	2028	418	2446	.25	A-F
BISMARCK,ND	6552	167	6719	.31	A-D
AKRON,OH	3978	193	4171	.29	A-E
CINCINNATI,OH	2781	280	3061	.26	A-E
CLEVELAND,OH	4187	238	4426	.29	A-E
DAYTON,OH	4067	469	4537	.30	A-E
OKLAHOMA CITY,OK	3049	1162	4211	.33	A-E
TULSA,OK	2201	1088	3289	.28	A-E
ASTORIA,OR	2629	6	2636	.25	A-E
MEDFORD,OR	2153	20	2172	.20	A-F
NORTH BEND,OR	2492	0	2492	.26	A-F
PORTLAND,OR	2843	14	2857	.26	A-E
REDMOND,OR	3441	3	3443	.24	A-E
PHILADELPHIA,PA	3383	377	3760	.29	A-E
PITTSBURGH,PA	3619	184	3804	.29	A-E
CHARLESTON,SC	1178	883	2061	.25	A-F

TABLE 4: LOCATIONS TABLE(Cont.)

CITY	Infiltration Degree-Days			[s]	Acceptable
	Heating	Cooling	Total		Classes
RAPID CITY,SD	5199	117	5315	.32	A-D
SIOUX FALLS,SD	5544	375	5919	.33	A-D
CHATTANOOGA,TN	2048	313	2362	.23	A-F
MEMPHIS,TN	1752	1001	2754	.24	A-E
NASHVILLE,TN	2013	543	2556	.25	A-E
AMARILLO,TX	3209	462	3672	.34	A-E
AUSTIN,TX	1072	1434	2506	.25	A-E
BROWNSVILLE,TX	321	3077	3397	.29	A-E
EL PASO,TX	1394	261	1655	.24	A-F
FORT WORTH,TX	1436	1291	2726	.26	A-E
HOUSTON,TX	986	1581	2567	.26	A-E
LUBBOCK,TX	2497	469	2966	.31	A-E
SAN ANTONIO,TX	1066	1299	2365	.25	A-F
CEDAR CITY,UT	3334	5	3339	.26	A-E
SALT LAKE CITY,UT	3446	12	3458	.26	A-E
BURLINGTON,VT	4885	106	4992	.28	A-E
NORFOLK,VA	2111	521	2632	.29	A-E
RICHMOND,VA	2464	453	2918	.24	A-E
OLYMPIA,WA	2850	7	2857	.24	A-E
SEATTLE,WA	3146	11	3157	.27	A-E
SPOKANE,WA	4047	2	4049	.27	A-E
CHARLESTON,WV	2385	231	2616	.22	A-E
MADISON,WI	4487	161	4647	.28	A-E

TABLE 4: LOCATIONS TABLE(Cont.)

CITY	**InfiltrationDegree-Days**			[s]	**Acceptable**
	Heating	**Cooling**	**Total**		**Classes**
CHEYENE,WY	5076	1	5077	.32	A-D
CASPER,WY	6068	3	6071	.37	A-D
ROCK SPRINGS,WY	6039	0	6039	.32	A-D
SHERIDAN,WY	4449	12	4461	.27	A-E
CALGARY,ALTA	5708	0	5708	.27	A-D
EDMONTON,ALTA	5672	5	5677	.25	A-D
VANCOUVER,BC	2455	17	2472	.21	A-F
CHURCHILL,MAN	12375	7	12382	.33	A-C
WINNEPEG,MAN	7233	96	7329	.30	A-D
SAINT JOHNS,NF	6768	43	6811	.36	A-D
FORT SMITH,NWT	8531	5	8536	.26	A-D
FROBISHER BAY,NWT	12277	0	12277	.31	A-C
HALIFAX,NS	4542	55	4597	.27	A-E
OTTAWA,ONT	5247	86	5333	.27	A-D
TORONTO,ONT	4671	246	4917	.27	A-E
MONTREAL,QUE	4542	193	4735	.25	A-E
PRINCE ALBERT,SASK	7111	46	7157	.27	A-D
REGINA,SASK	7815	23	7838	.33	A-D
SASKATOON,SASK	7062	15	7077	.29	A-D
WHITEHORSE,YT	7369	0	7369	.27	A-D

While the locations table is the best way to determine what the standard requirements are at a particular site, it does not give one a very good overview of what the standard requires for North America in general. In figure 1 we present a map of North America that contains values from the locations table, interpolated to cover the entire map. The crosses indicate the position of a city from the locations table; the contour lines are of infiltration degree-days; and the shaded areas represent different areas of acceptable leakage classes. The dashed lines indicate the mid-point of each class. Note that occasionally a site in the middle of a shaded region may be of a different range than the shading indicates; this is done to avoid the map looking spotty -- the locations table contains the correct values.

As indicated in figure 1, the majority of the southern plain of Canada and the northern plains of the U.S. are in acceptable classes A-D. Although not on the map, but reflected in the locations table, the north of Canada (including Alaska) has some extreme climates in the A-C range. The majority of the U.S. (contained in a broad band from the northwest to the southern plain to the east and northeast) is in the A-E range. This band extends northward on the coasts into to Canada, but in the case of eastern British Columbia may be an artificial result caused by the paucity of weather sites. The southwest and southeast of the U.S. are in the relatively mild A-F class; southern California is the only section of North America to be in the A-G class.

We may use the equations developed in the previous section to make an estimate of annual infiltration rate for houses that exactly meet the standard. Combining eqs. 18 and 22, with the data from the locations table, we calculate an average infiltration rate. Care must be taken in interpreting this number, however, as this value represents the <u>annual</u> contribution <u>neglecting</u> <u>occupant</u> <u>and</u> <u>mechanical</u> <u>effects</u> and only for the <u>period</u> <u>in</u> <u>which</u> <u>the</u> <u>building</u> <u>is</u> <u>conditioned</u>. The total ventilation rate will, in general, be higher than this estimate and monthly values could easily vary by a factor of two from these estimates, hourly values by a factor of five or more.

With the above caveats in mind figure 2 gives an estimate of the infiltration rate for a house that exactly meets the standard. Most of Canada would have seasonal infiltration rates of approximately 0.3 air changes per hour -- the temperate parts slightly higher and the far north (including Alaska) slightly lower. The northern half of the U.S. would have air change rates between 0.3 and 0.4 ach with the Pacific northwest and eastern seaboard at or above 0.4 ach. The southern third of the U.S. would virtually all have infiltration rates above 0.4 with the populated regions of California lying between 0.5 and 0.7 ach.

In a similar manner to the air change plot of figure 2, we may combine eqs. 19 and 24 to estimate the average seasonal infiltration load (per unit floor area). While this procedure may give a reasonable estimate of the annual energy cost (in units of resource energy) associated with air infiltration, it is only a crude predictor of instantaneous infiltration load. Like the air change estimate, the load estimate is subject to large hourly variations, in addition it is subject to systematic monthly variation -- in the same way that conduction losses vary with the seasons.

Figure 3 is a plot of the average infiltration load for North America for a house that exactly meets the standard. Because the standard requires tighter houses for more extreme climates, the range of values is not large; the load goes from just under 50 MJ/m^2-yr for southern California to almost 150 MJ/m^2-yr for the Canadian plains. With the exception of the mild southwest and cold northern plains, the U.S. appears to lie in the range of 75-125 MJ/m^2 for annual infiltration resource energy.

Summary

In this report we have presented the derivation of and thoughts behind a generic standard on air leakage which should be very similar to the proposed ASHRAE standard SPC 119 on the air tightness of residential buildings. As this standard progresses through the consensus process it will undoubtly change, but the physical underpinnings presented here will most likely remain. This physical basis on which the model was developed allows an estimation of the impacts that such a standard will have on average infiltration rates and building loads. The classification scheme inherent in the model gives the standard flexibility so that should it become necessary to quantitatively change the standard, the requirements could be tightened (loosened) by simply adjusting the value of the constant within the standard, IDD_o, and hence the IDD ranges for each leakage class.

DISCUSSION

The concepts presented in this report allow us to define a standard for air tightness that is based on the economic goal of minimizing the life cycle cost of infiltration. We may now use these concepts to predict some of the effects that the standard will have on North American housing.

We begin by compiling a Locations Table. This table will have a set of representative cities for which good weather data was available. We then use the hourly weather data to calculate the specific infiltration, the number of infiltration degree-days, and the acceptable leakage classes according to the standard. This table, combined with a measurement of leakage, becomes the entire standard for the sites that can be represented by the included cities.

ACKNOWLEDGEMENT

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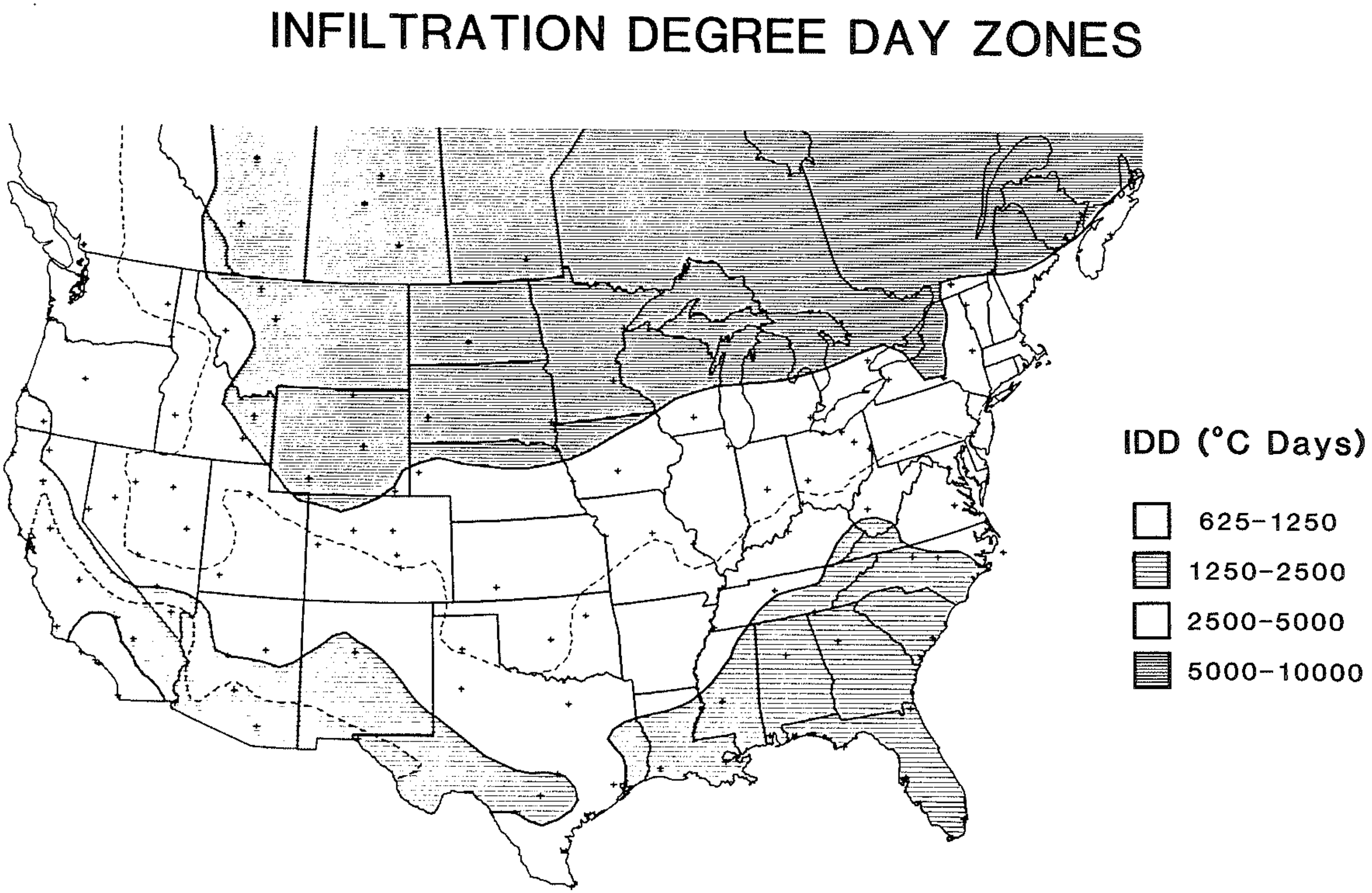

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Figure 1: Zones of Infiltration Degree Days that Correspond to Unique Acceptable Leakage Classes for North America.

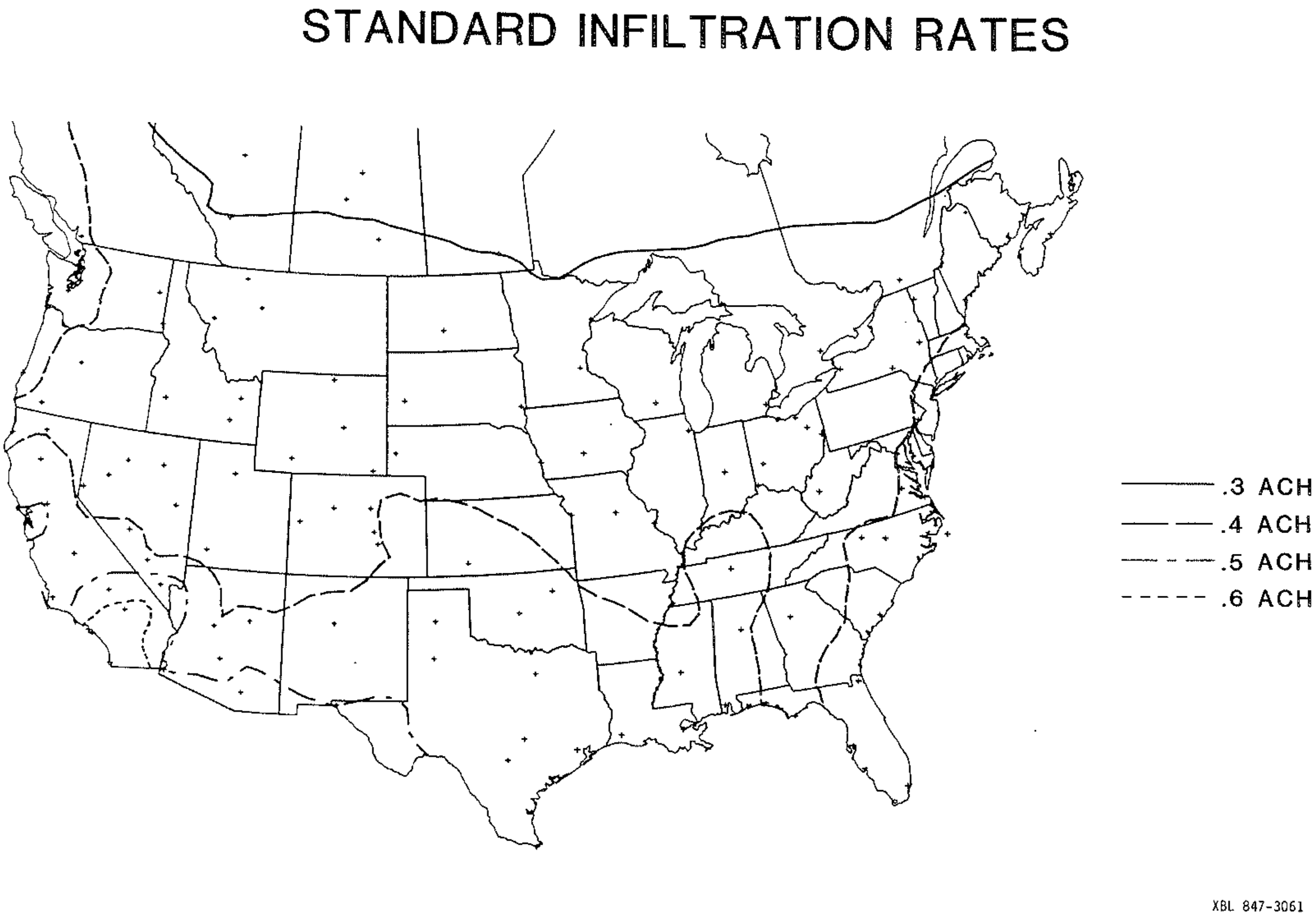

Figure 2: Lines of Constant Infiltration Rate Estimated Assuming Leakage Standard is Exactly Met.

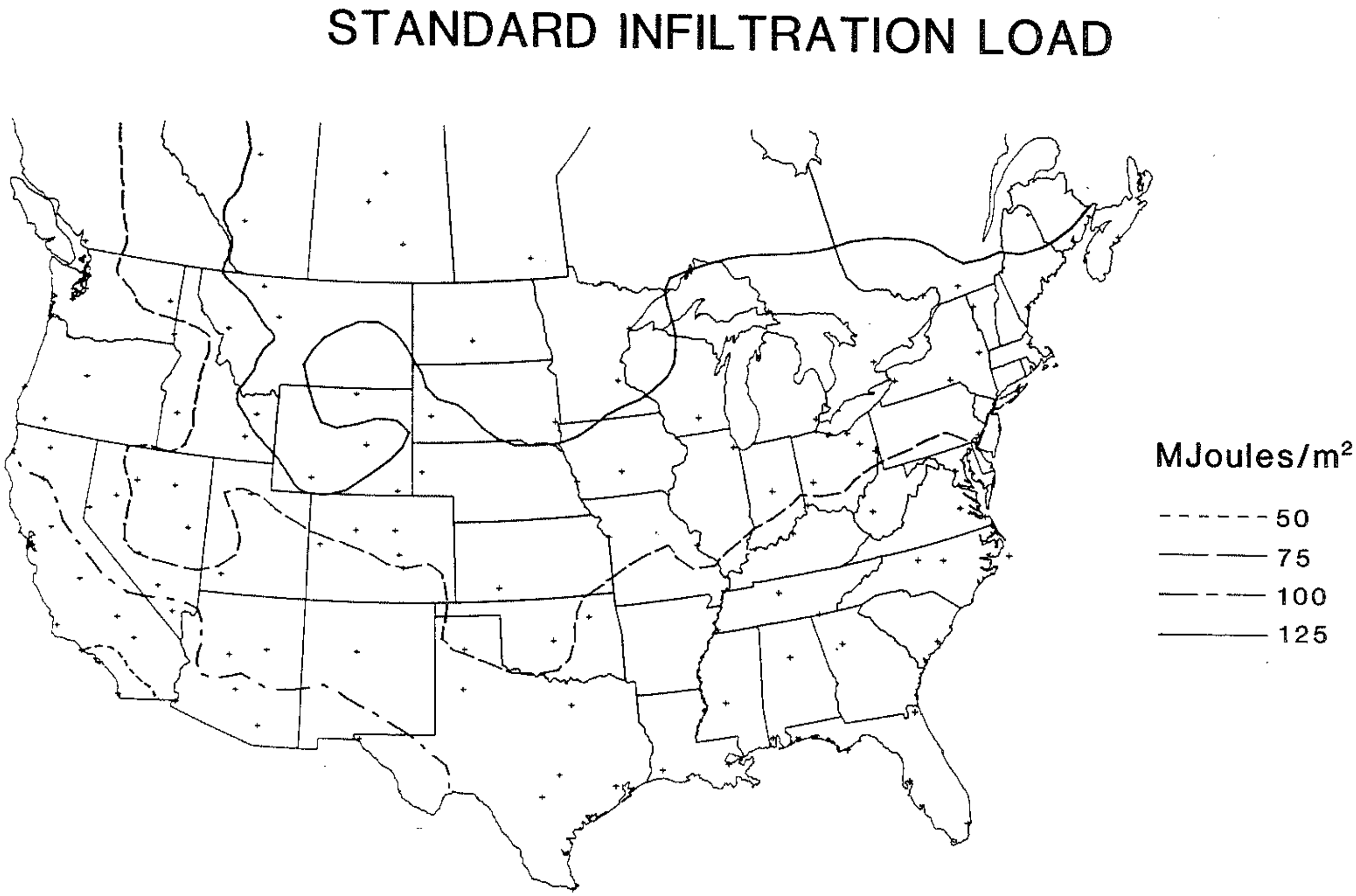

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Figure 3: Lines of Constant Annual Infiltration-Induced Load (Per Unit Floor Area) Assuming Leakage Standard is Exactly Met.