LBL-19237
EEB-EPB-86-09

To be presented at the ASHRAE semi-annual meeting, June 22-25, 1986, Portland, OR, and to be submitted for publication in ASHRAE Transactions, V. 92, Pt. 2.

INFILTRATION DEGREE-DAYS: A STATISTIC FOR QUANTIFYING INFILTRATION-RELATED CLIMATE

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April 1986

This work was funded by the Assistant Secretary for Conservation and Community Systems, Buildings Division Office of Buildings and Community Systems, of the U.S. Department of Energy under contract No. DE-AC03-76SF00098.

ABSTRACT

A new statistic, Infiltration Degree-Days (IDD), is introduced for quantifying the climatic conditions that influence infiltration. The well-known energy statistic, Degree Days (DD), is used to indicate the severity of climate relative to the conduction load through the building envelope (usually during the heating season). Infiltration Degree-Days (IDD) serves the same function for calculating infiltration and infiltration-related processes that standard degree-days has served for calculating conduction and conduction-related processes. Although standard degree-days is often used to estimate the entire load (i.e. conduction, radiation, and infiltration), it is calculated assuming a linear energy-flow relationship. IDD is designed to overcome the inaccuracies inherent in using standard degree-days for processes like infiltration that are nonlinear (in temperature and other climatic variables); they also potentially solve the problems associated with the use of degree-day formalisms for calculating cooling loads or any situations where the determination of latent heat is a problem. This report presents parallel derivations for standard and infiltration degree-days and includes formulas for determining the base temperature (and enthalpy) methods similar to the many variable-based degree-day methods currently in use for envelope-dominated structures. Also included are tables of heating and cooling IDD for various cases and selected cities in North America.

Keywords: Infiltration, Degree-days, Load Calculations, Ventilation, Weather, Climate, Building Envelope

NOMENCLATURE

C_p	Heat Capacity of Air (0.245 BTU/lb-dF) [0.284 Wh/kg-K]
CDD	Cooling Degree-Days (F-day) [^{o}C-day]
$CIDD$	Cooling Infiltration Degree-Days (F-day) [^{o}C-day]
E	Seasonal Energy (BTU) [Wh] [a]
ELA	Effective Leakage Area (in^2) [cm^2]
f_s	(Infiltration) Stack Parameter (ft^3/hr-in.^{2}-F^{½}) [m^3/hr-cm^2-K^{½}]
f_w	(Infiltration) Wind Parameter (ft^2-s/in.^{2}-hr)[m^2-s/cm^2-hr]
$F_{conduction}$	Conductive Heat Loss (BTU/h) [W]
F	Load (BTU/h) [W] [b]
F_{free}	Free Heat (Internal Gains) (BTU/h) [W]
$F_{infiltration}$	Infiltration Heat Loss (BTU/h) [W]
H	Enthalpy (BTU/lb) [Wh/kg] [b c d]
HDD	Heating Degree-Days (F-day) [^{o}C-day]
$HIDD$	Heating Infiltration Degree-Days (F-day) [^{o}C-day]
IUA	Infiltration Conductivity (BTU/h/F) [W/K]
Q	Total Infiltration (ft^3/hr) [m^3/hr]
s	Specific Infiltration (ft^3/hr-in.^{2}) [m^3/hr-cm^2]
s_o	Average Specific Infiltration (6.15 ft^3/hr-in.^{2}) [0.27 m^3/hr-cm^2]
T	Temperature (F) [^{o}C] [c d]
UA	Envelope Conductivity (BTU/h/F) [W/K]
v	Wind Speed (ft/s) [m/s]
ρ	Density of Air (0.018 lb/ft^3) [1.2 kg/m^3]

a) Subscripts "heat" and "cool" are used to indicate the season to which the load applies.

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

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

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

INTRODUCTION

Even though in residential buildings the heat loss due to infiltration in the winter is at least half as large as losses due to conduction and may be larger than conduction losses in the summer, until now no specific statistic analogous to degree-days has been developed to calculate infiltration loads. The most common practice that researchers use, at least in simplified analyses, is to combine the (weather-dependent) infiltration with the (weather-independent) conductance of the envelope and talk about an equivalent UA-value. This report describes a new quantity developed in our laboratory, Infiltration Degree-Days (IDD), which serves the same function for infiltration that degree-days serves for conduction.

Although the degree-days concept can be used for calculating both heating losses and cooling losses, by far the greatest amount of work has gone into the derivation of degree-days for heating. Therefore, our primary emphasis here is on heat-loss calculations; how infiltration degree-days can be used in warm climates requiring air-conditioning (i.e. cooling climates) follows that discussion.

Degree-day methods have been used for simplified energy calculations in buildings for over 20 years (Harris et al. 1965) and some of the earliest work goes back to the 1930s. The basic concept is that seasonal climate can be quantified by summing the average temperature difference each day over the number of days in the season. It should be noted that the original conceivers of the degree-day concept were attempting to use empirical methods (e.g. a 65 ^{O}F base temperature) to evaluate how much heat would be required to to maintain the range of 68 ^{O}F to 72 ^{O}F in the buildings of that time. At that time they did not attempt to interpret the meaning of their results in physical terms. This standard type of degree-days is also known as Heating Degree-Days (HDD).

Recent interest in energy conservation has recalled the use of degree-days and related concepts as a means of developing simple but accurate methods for predicting energy use in buildings (Dupagne et al., undated; Alereza et al. 1977; Uglow 1981). In many of the recent methods using the degree-days concept, physical interpretations are assigned to the various factors (e.g. the base temperature).

BACKGROUND, DEGREE-DAYS

As a simple method for quantifying the severity of climate in relation to the heating requirements of buildings, no statistic has been more successful than degree-days. Degree-days are often used as the only indicator of climate and, when combined with an effective conductance value for the building envelope, serve to estimate space-conditioning loads. The use of degree-days also allows the separation of weather-independent (i.e. building-specific) terms such as the shell conductance from weather-dependent driving forces such as the inside-outside temperature difference).

As an aid to understanding the advantage of our new statistic, Infiltration Degree-Days, we will present a brief derivation of the modern approach to degree-days. (A conventional definition of Heating Degree-Days assumes that the energy loss associated with the envelope of the building is linear in the inside-outside temperature difference and that a summation over the heating season of *some* temperature difference will yield adequate predictions of the energy consumed by space heating.) As originally derived, degree-days used the average of the daily minimum and maximum temperature difference from 65 ^{O}F, but for purposes of comparison we shall use the more modern ***variable-base degree-day*** method which uses degree-hours divided by 24 at bases that may be different from 65 °F (ASHRAE 1985).

Standard Derivation

We begin the standard derivation by limiting our consideration to conduction losses alone. The instantaneous load can then be expressed as follows:

$$F_{conduction} = UA \; (T_{in}^{h} - T_{out}) \tag{1}$$

With conduction as the only loss mechanism, the total energy (heat) that must be supplied is the difference between this loss and the free heat supplied by people, appliances, solar gain, etc.

$$F_{heat} = F_{conduction} - F_{free} \qquad \text{for } F_{heat} > 0 \tag{2}$$

Conventionally, the base temperature is defined to take into account the internal set-point and the effect of free heat:

$$T_{base} = T_{in} - \frac{F_{free}}{UA} \tag{3}$$

As reported in ASHRAE's *Handbook of Fundamentals* (ASHRAE 1981) the early work on degree-days estimated the base temperature to be 65 °F (American Gas Association; National District Heating Association 1932) by using internal loads and insulation levels typical of the time period; since that time, numerous modifications have been suggested (Reeves 1981; Kelnhofer 1979). As households increase their use of electrical appliances and increase the glazing area, free-heat values increase above those previously assumed. Furthermore, as energy conservation has become an important issue in the last decade, insulation values have gone up (and UA values have decreased). Because during this time the free heat has increased *and* the UA value has decreased, the base temperature tends to decrease, making the standard base is inappropriate. Accordingly, many researchers now use variable base temperatures (which are generally lower than the standard) and make other adaptations for calculating degree-days (Kusuda 1981; Sonderegger et al. 1985; Dupagne et al. 1982). In this report, we will treat the base temperature as a parameter that should be determined independently by using equation 3.[‡] Implicit, then, in every calculation of degree-days is a specific base temperature, and the heating load then becomes:

$$F_{heat} = UA * (T_{base} - T_{out}) \qquad \text{for } T_{base} > T_{out} \tag{4}$$

The annual heating load is defined as the sum over the heating season of the instantaneous loads:

$$E_{heat} = \sum_{hours} F_{heat} \qquad \text{for } F_{heat} > 0 \tag{5}$$

or, equivalently,

$$E_{heat} = UA * \sum_{hours} (T_{base} - T_{out}) \qquad \text{for } T_{base} > T_{out} \tag{6}$$

The above summation depends only on the temperature difference between the base and outside and can be calculated separately for each climate, once the base temperature is known. This

[‡] Note that the ASHRAE *Handbook of Fundamentals* uses long-term average temperatures (calculated from daily max-min temperatures) to yield degree-days. This technique will not be discussed here.

summation yields the number of Heating Degree-Days:

$$HDD = \frac{1}{24} \sum_{hours} (T_{base} - T_{out}) \qquad \text{for } T_{base} > T_{out} \tag{7}$$

and the heating load becomes simply the product of the HDD and the UA-value:

$$E_{heat} = 24 * UA * HDD \tag{8}$$

Treatment of Infiltration in the Standard Degree-Day Model

The other major mechanism of heat loss in small buildings is infiltration (i.e. convection). The exact[‡] instantaneous expression for combined losses is

$$F_{heat} = F_{conduction} + F_{infiltration} - F_{free} \qquad \text{for } F_{heat} > 0 \tag{9.1}$$

$$= (UA + \rho * C_p * Q) * (T_{in}^{h} - T_{out}) - F_{free} \qquad \text{for } F_{heat} > 0 \tag{9.2}$$

The simple adaptation, then, uses an effective UA that includes the infiltration term. If the infiltration were constant (as might be the case for a mechanically ventilated building) this approach would be used directly to find the annual heating load. Unfortunately, infiltration is strongly dependent on wind speed and outside temperature and cannot be treated as weather-independent; that is,

$$E_{heat} \neq 24 * (UA + \rho * C_p * Q) * HDD \tag{10}$$

Provided care is taken in choosing the correct balance point, this expression can be used for mechanically ventilated buildings that have very well-defined ventilation rates (e.g. large commercial buildings). Any time infiltration is coupled to outside temperature or season, however, this expression fails and cannot be simply modified. Before we can derive an expression that correctly includes infiltration, we must investigate the physical dependence of infiltration on weather.

BACKGROUND, INFILTRATION

During the last ten years, research on infiltration in buildings has become quite intense (Liddament 1983; ASTM 1984a; Sherman 1981). Many ASHRAE symposia have been devoted to the topic. In 1984 the American Society for Testing and Materials (ASTM) developed a standard test procedure for measuring infiltration using tracer dilution (ASTM 1984b) and an annex of the International Energy Agency (IEA) was created to manage the Air Infiltration Centre (AIC), which has been active in the promotion and exchange of infiltration research internationally. By 1984 the AIC had held five conferences and published their proceedings: "Air Infiltration Instrumentation and Measuring Techniques" (AIC 1980) "Building Design for Minimum Air Infiltration" (AIC 1981) "Energy Efficient Domestic Ventilation Systems for Achieving Acceptable Indoor Air Quality" (AIC 1982) "Air Infiltration Reduction in Existing Buildings" (AIC 1983) and "Implementation and Effectiveness of Air Infiltration Standards in Buildings" (AIC 1984) The AIC also produces technical notes on research issues which include wind pressure coefficients (Allen 1984) a comparison and validation of infiltration models (Liddament 1983) and a glossary

‡Because the purpose of this report is to examine the contribution of infiltration to the total energy load, losses due to radiation are not explicitly treated here, either for the standard case or for IDD.

of commonly used terms and their translations into other languages (Allen 1981). Additionally, the AIC keeps an up-to-date bibliography of all infiltration-related publications and will conduct abstract searches for researchers in member countries.

As a result of this research effort, there is now a greater understanding of the physical processes that drive infiltration. Like conduction, infiltration can be separated into an essentially weather-independent part (the air tightness of the envelope) driven by a weather-dependent term (wind and temperature difference). Unlike conduction loads, infiltration loads are nonlinear (i.e. the load is not simply proportional to the inside-outside temperature difference) and depend on wind speed in addition to the inside-outside temperature difference.

Model Description

Although the concept of Infiltration Degree-Days does not require the use of a *specific* model, the numerical calculation does. For purposes of this report, and because it is one of the simplest and most widely known of the physical models of infiltration, we will use the LBL infiltration model (Sherman and Modera 1984). The results, however, are not critically dependent on the details of the model and, therefore, our conclusion would not be significantly altered if a different model were used. The full derivation and validation of the model is presented in the AIC Technical Note 11 (Liddament 1983). Described briefly, the LBL model calculates infiltration through the envelope of the building by assuming that leaks in the envelope can be treated as simple orifices whose leakage characteristics can be quantified. Because the driving pressures on these leaks are caused by wind, indoor-outdoor temperature differences, and mechanical ventilation systems, the flow for each type of driving force is calculated separately and then combined using quadratic superposition.

The air tightness of the building envelope, which is independent of weather, is quantified by the Effective Leakage Area (ELA), the equivalent amount of orifice area of unit discharge coefficient that would allow airflow at a reference pressure of 4 Pascals (0.016 in. H_2O). In other words, the ELA of a particular crack is equal to the area of a perfect nozzle which, at 4 Pascals, would pass the same amount of air as the crack. ASTM standard E779 (ASTM 1984c) describes the fan pressurization technique commonly used to measure the ELA. Infiltration is is calculated by multiplying the ELA by the specific infiltration, **s**, as obtained by using the LBL model:

$$Q = ELA * s \tag{11}$$

The specific infiltration is a function of both the wind speed and temperature difference, as well as some building-dependent parameters:

$$s = \sqrt{f_w^2 v^2 + f_s^2 \mid T_{in} - T_{out} \mid} \tag{12}$$

Although the values of the wind and stack parameters (f_w, f_s) (Grimsrud et al. 1981) depend somewhat on the leakage distribution and siting of the particular structure being modeled, for our purposes, values for typical single-family houses are sufficient:

$$f_w = 0.047 \ m^2\text{-}s / cm^2\text{-}hr \qquad = 3.4 \ ft^2\text{-}s / in.^2\text{-}hr \tag{13.1}$$

$$f_s = 0.043 \ m^3/hr\text{-}cm^2\text{-}K^{1/2} \qquad = 7.3 \ ft^3/hr\text{-}in.^2\text{-}F^{1/2} \tag{13.2}$$

These values *can* vary as much as 50% for individual houses, but generally do not.

Values for the specific infiltration have been tabulated for major weather sites across North America (Sherman 1984) and the seasonal averages have been found to lie between 0.16-0.38 $m^3/hr\text{-}cm^2$ with an average of 0.27.

INFILTRATION DEGREE-DAYS

Now that we have a physical expression for infiltration we can derive a more accurate expression for degree-days. (As stated earlier, this derivation assumes that the ventilation is dominated by infiltration and natural ventilation; for mechanically-dominated situations the standard treatment described in the introduction is appropriate.) Using our definition of infiltration, the infiltration-related heat loss can be expressed as:

$$F_{infiltration} = \rho * C_p * ELA * s * (T_{in}^h - T_{out}) \tag{14}$$

and the total heat load as

$$F_{heat} = UA * (T_{in}^h - T_{out}) + \rho * C_p * ELA * s * (T_{in}^h - T_{out}) - F_{free} \quad \text{for } F_{heat} > 0 \tag{15}$$

Using the following assignments,

$$IUA = \rho * C_p * s_o * ELA \tag{16.1}$$

and

$$T_{base}^h = T_{in}^h - \frac{F_{free}}{UA + IUA} \tag{16.2}$$

the instantaneous load becomes

$$F_{heat} = UA * (T_{base}^h - T_{out}) + IUA * \frac{s}{s_o} * (T_{base}^h - T_{out}) \quad \text{for } T_{base} > T_{out.} \tag{17}$$

The annual consumption is calculated by summing this quantity over the heating season:

$$E_{heat} = UA * \sum_{hours} (T_{base}^h - T_{out}) + IUA * \sum_{hours} \frac{s}{s_o} * (T_{base}^h - T_{out}) \tag{18}$$

The first sum is recognizable as standard HDD; the second sum, however, is a degree-day-type sum with a weighting factor included (calculated from the relative infiltration) and is defined as Heating Infiltration Degree-Days (HIDD):

$$HIDD = \frac{1}{24} \sum_{hours} \frac{s}{s_o} (T_{base}^h - T_{out}) \qquad \text{for } T_{base}^h > T_{out} \tag{19}$$

Combining our definitions, we now have a simple but accurate expression for the total annual load caused by both conduction and infiltration:

$$E_{heat} = 24 * \left(UA * HDD + IUA * HIDD \right) \tag{20}$$

The presence of the specific-infiltration weighting factor in the definition of infiltration degree-days is the fundamental difference between HDD and HIDD. In calculating infiltration degree-days, periods of high infiltration (i.e. when **"s"** is relatively large) are weighted more heavily than periods of low infiltration. If infiltration were constant, or even randomly varying, there would be no significant difference between infiltration degree-days and standard degree-days but, as we see in Table 1, differences can be significant.

Table 1[‡] contains a dataset of both heating degree-days and heating infiltration degree-days for a set of cities represented by WYEC tapes (Crow 1980; Crow 1983; Degelman 1984) and for a spread of base temperatures calculated using the equations indicated herein. The data was calculated by using hourly weather information and summing the hourly calculations over the year. These tables compare HIDD and HDD with each other and also indicate how each one varies with base temperature for different cities. Although all IDD are calculated from degree-hours divided by 24, Table 1B includes a column of entries for *conventional* degree-days (i.e. the daily sum of the average temperature—half the maximum+minimum temperature—at a base temperature of 65 ^{o}F) as well as standard degree-days (i.e. 1/24th of the hourly difference from each base temperature).

It should be noted that the synthetic data represented by the WYEC tapes has been adjusted to represent long period mean values for the temperature and humidity needed by the IDD calculation. However, no such explicit adjustment has been made (or yet exists) for wind data. For purposes of illustrating the IDD technique, this lack of adjustment represents no problem, although the potential users of the data in the tables should be aware that it is not known how much (or if) the data would be changed if such an adjustment were made.

COOLING DEGREE-DAYS

The previous descriptions of degree-days have been strictly true only for those conditions where heating, not cooling, is required to keep the building comfortable. Because of the problems described below, it is impossible to use the same formalism for estimating cooling loads. Therefore, researchers have worked on defining cooling degree-days (CDD) to serve the same function for warm climates as that of heating degree-days serves in cold climates.

The concept of cooling degree-days (CDD) has never enjoyed as wide approval as that of heating degree-days for several reasons: 1) the mean temperature differences are smaller for cooling climates than for heating climates and uncertainties in free heat have a larger relative effect on CDD than on HDD; 2) latent loads have virtually no impact in heating climates but can have a profound impact in cooling climates; and 3) while comfort criteria and associated equipment set-points are relatively straightforward for heating climates, they can vary widely in the cooling climates. Finally, HVAC system operation and equipment performance are critical determinants of cooling loads. System operation is important because the decision, for example, of when and how to use natural ventilation will strongly affect the hours at which it is necessary to use cooling equipment. The specifications of the cooling equipment (in combination with weather and house parameters) can strongly affect loads through the dry-bulb and wet-bulb balance temperatures—the lower the internal balance-point humidity, the more cooling power required to maintain it. (This statement is true even if the humidity floats; estimation of the correct internal humidity, however, could be quite complex.)

[‡]Table 1A is in SI units; Table 1B is in IP units. Because of the convenient choice of bases in each system of units, the information in the "A" and "B" tables is complementary but not identical.

Some of these problems, such as choices of equipment and comfort level, may require a set of cooling degree-days for each operating scheme. For example, if no excess ventilation is used to provide cooling, refrigeration air conditioning may be needed throughout most of the season to keep the building comfortable; but if natural ventilation and/or evaporative cooling strategies are applied, very little refrigeration air conditioning should be required. It may become necessary to recalculate base temperatures and IDD for separate periods if different strategies are used (e.g. differentiate between day and night CIDD if natural ventilation is used at night but not during the day). Some of the other problems, particularly those relating to low temperature differences and variable internal gains, are endemic to cooling climates; in these cases, the associated inaccuracies must be suffered if the technique is to be used.

Recent research has suggested that an improvement to CDD can be effected by using enthalpy-based (as opposed to temperature-based) degree-days. Such a generic approach uses standard CDD to represent the sensible part of the cooling load plus a latent enthalpy term (referenced to a defined balanced humidity ratio). This approach neglects the fact that conduction is a purely sensible phenomenon whereas infiltration load (which is temperature-driven) depends on enthalpy differences.

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

$$F_{cool} = F_{free} + UA*(T_{out} - T_{in}^{c}) + \rho*Q*(H_{out} - H_{in}^{c}) \quad \text{for } F_{cool} > 0 \tag{21}$$

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.

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

$$CDD = \frac{1}{24} \sum_{hours} (T_{out} - T_{base}^{c}) \qquad \text{for } T_{base}^{c} < T_{out} \tag{22}$$

$$CIDD = \frac{1}{24 C_p} \sum_{hours} \frac{s}{s_o} (H_{out} - H_{base}^{c}) \qquad \text{for } H_{base}^{c} < H_{out} \tag{23}$$

The total seasonal load becomes the following:

$$E_{cool} = 24*\Big(UA*CDD + IUA*CIDD \Big) \tag{24}$$

Calculation of the Cooling Base Temperature

In the case of heating degree-days, a base temperature was established by balancing the losses through the envelope with the total internal gains. In the case of cooling degree-days, a similar procedure is followed with the additional complication that a cooling base temperature *and* a cooling base enthalpy must be found. Because there are two separate conditions, there is no way to guarantee that a set of base conditions can be found to simultaneously reduce to zero both the latent load and the sensible load. Thus, it may be (and is) possible to have either an infiltration load and no conduction load or a conduction load and no infiltration load depending on the ratio of latent load to sensible load.

To find the base temperature and enthalpy we assume that at base conditions both the sensible *and* latent loads will be zero:

$$F_{cool}^{sensible} = F_{cool}^{latent} = 0 \qquad at\ base\ conditions \tag{25}$$

Furthermore, if we now assume that the base enthalpy (for infiltration) is made up of a sensible part that uses the same base temperature as the conduction component, we can separate these two expressions:

$$F_{cool}^{sensible} = UA*(\ T_{in}^{c} - T_{base}^{c}\ ) + \frac{IUA}{C_p}*(\ H_{in}^{sensible} - H_{base}^{sensible}\ ) \tag{26.1}$$

$$= (\ UA + IUA\ )*(\ T_{in}^{c} - T_{base}^{c}\ ) \tag{26.2}$$

$$F_{cool}^{latent} = \frac{IUA}{C_p}(\ H_{in}^{latent} - H_{base}^{latent}\ ) \tag{27}$$

Solving these two equations for the base conditions yields the following:

$$T_{base}^{c} = T_{in}^{c} - \frac{F_{cool}^{sensible}}{UA + IUA} \tag{28.1}$$

$$H_{base}^{latent} = H_{in}^{latent} - \frac{C_p\ F_{cool}^{latent}}{IUA} \tag{28.2}$$

These two expressions allow the calculation of the base temperature and enthalpy from the interior comfort conditions and the sensible and latent internal gains. Comfort conditions can be estimated from various references on the subject of human comfort (Fanger 1972; Nevens 1975; Sherman 1985) or from an ASHRAE standard (ASHRAE 1981). The internal latent gains can be estimated from typical internal moisture generation (CIRA 1982) (e.g., 12 lb/day) and typical leakage areas (Sherman et al. 1984) (e.g., 300-900 cm^2). While this process is more cumbersome than that for HIDD, it is not surprising that extra care is required for conditions where internal gains and humidity play such an important role.

Results

Tables 2, 3, and 4 list the CDD and CIDD for the same cities as listed in Table 1. The difference among the three tables is that a different latent base enthalpy was chosen for each one: Table 2 contains a low latent base enthalpy (6 BTU/lb), which corresponds to dry interior conditions; Table 3 contains an intermediate latent base enthalpy (9 BTU/lb), which corresponds to the most comfortable interior conditions; and Table 4 contains a high latent base enthalpy (12 BTU/lb), which corresponds to humid interior conditions. The correct choice for a given circumstance will depend primarily on the system and associated control capability and secondarily on the internal moisture generation. For example, most refrigeration air conditioning systems in residential environments keep the indoor humidity quite low during operation and, for those with large on-times, Table 2 would be most appropriate; the new high efficiency models have less latent heat extraction and tend to keep indoor humidity high in more humid climates — indicating the use of Table 3 or 4.

For reasons discussed earlier, the choice of base and operating conditions is critical for any cooling degree-day calculation. Cooling degree-days should be accumulated for those periods in which (energy-consuming) air conditioning is operating and should not be accumulated for those periods in which alternative strategies (e.g. natural ventilation) are used. The base conditions used in calculating cooling degree-days are a combination of the interior temperature and humidity conditions and the internal heat and moisture generated. If there were separate temperature and humidity controls, the base conditions could be quickly calculated from these set-points. Unfortunately, most residential buildings control dry-bulb temperature only; to calculate the base latent enthalpy requires knowledge of the type of HVAC equipment and its operation in that climate. Otherwise internal humidity during operation cannot be estimated.

DISCUSSION AND CONCLUSIONS

The derivation presented above separates the linear (and sensible) conduction load from the more complex infiltration load. With the increase in accuracy, however, is the added complexity of a second genus of degree-days to keep track of, namely infiltration degree-days. Infiltration degree-days is to be used principally for quantifying climate with respect to infiltration and, as such, may be useful for those involved in setting standards[‡] relating directly to infiltration (Sherman 1984), and in simplified energy-estimating methods such as the one used by ASHRAE (ASHRAE 1985).

As can be seen from the data tables, IDD tends to amplify the differences from the mean. Because of their nonlinear dependence on both temperature and wind, severe climates tend to have relatively more infiltration degree-days than standard degree-days and mild climates less. Additionally, certain cities that may have unusually high or low average wind speeds or unusually high or low humidities may have quite different IDD from those of cities having the same IDD. This variability is especially pronounced in cooling climates and generally makes it impractical to try to relate infiltration degree-days to standard degree-days.

In the infiltration degree-days methodology for heating climates, we ignored effects due to latent loads; this procedure is common because indoor humidities in winter are allowed to float and no energy impact is associated with latent heat. If, however, winter humidities are to be controlled, either by humidifying a dry (leaky) house or dehumidifying a damp (tight) one, it would be more accurate to use heating (infiltration) degree-days that take into account latent loads and enthalpy differences. The procedure in this case would be exactly like the one used for cooling (infiltration) degree-days.

One of the least straightforward aspects of any degree-days methodology is its determination of the base temperature. Uncertainties in the base temperature caused by uncertainties in the internal gain and UA values can cause uncertainties in the calculation of degree-days. Because most heating climates are associated with relatively large inside-outside temperature differences, the uncertainties in the base temperature have a relatively small impact on the accuracy of the heating load calculation. For cooling (and mild heating) climates, however, uncertainties in base

[‡] At the time of this writing, ASHRAE Standard Project Committee 119P, in determining the maximum allowable leakage for single-family, detached, residential buildings, is planning to use infiltration degree-days as the measure of the severity of climate.

temperature can have a major effect. Adding further to these uncertainties is that the free heat from solar gain is variable in such climates. We would suggest, therefore, that future research efforts focus attention on the seasonal dependence of internal gains.

ACKNOWLEDGMENT

This work was funded by the Assistant Secretary for Conservation and Community Systems, Buildings Division Office of Buildings and Community Systems, of the U.S. Department of Energy under contract No. DE-AC03-76SF00098.

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TABLE 1A: STANDARD AND INFILTRATION HEATING DEGREE-DAYS (^{o}C-day/yr) TO DIFFERENT BASE TEMPERATURES

	Standard DD			Infiltration DD		
City, State	*5 ^{o}C*	*10 ^{o}C*	*15 ^{o}C*	*5 ^{o}C*	*10 ^{o}C*	*15 ^{o}C*
Albuquerque, NM	458	1034	1863	453	994	1754
Amarillo, TX	532	1105	1901	671	1387	2366
Atlanta, GA	239	588	1200	291	673	1284
Birmingham, AL	183	498	1093	180	468	989
Bismarck, ND	2071	3053	4243	2657	3840	5231
Boise, ID	695	1469	2563	715	1502	2593
Boston, MA	662	1419	2417	934	1908	3141
Brownsville, TX	5	46	199	5	46	185
Charleston, SC	103	371	861	107	368	819
Cheyene, WY	1137	2064	3269	1512	2736	4280
Chicago, IL	915	1707	2717	1172	2130	3305
Cleveland, OH	858	1633	2665	1122	2053	3238
Dayton, OH	807	1509	2457	992	1813	2868
Denver, CO	888	1657	2708	913	1677	2705
Des Moines, IA	1162	1946	2945	1391	2288	3399
Detroit, MI	1029	1858	2902	1301	2262	3417
Dodge City, KS	724	1405	2313	948	1827	2969
El Paso, TX	173	492	1058	163	459	980
Fort Worth, TX	123	413	938	131	426	943
Great Falls, MT	1443	2301	3486	1839	2954	4479
Indianapolis, IN	821	1534	2478	1005	1813	2843
Kansas City, MO	662	1276	2102	736	1372	2195
Lake Charles, LA	40	209	570	39	209	552
Las Vegas, NV	126	427	1008	125	416	963
Little Rock, AR	279	698	1339	293	709	1326
Los Angeles, CA	1	38	417	1	29	329
Madison, WI	1436	2346	3467	1705	2716	3917
Medford, OR	370	1080	2173	304	855	1685
Miami, FL	1	14	66	1	13	57
Minneapolis, MN	1626	2554	3664	1959	3049	4324
Nashville, TN	323	795	1519	346	823	1532
New York, NY	496	1151	2051	669	1507	2616
Oklahoma City, OK	378	882	1620	448	1032	1871
Omaha, NE	1007	1761	2724	1209	2073	3142
Phoenix, AZ	18	156	528	16	123	401
Pittsburgh, PA	826	1585	2603	963	1792	2853
Portland, ME	1162	2076	3243	1286	2248	3432
Portland, OR	206	752	1773	214	740	1674
Raleigh, NC	314	767	1468	328	777	1444
St Louis, MO	601	1251	2123	679	1377	2277
Salt Lake City, UT	750	1547	2591	762	1564	2599
San Antonio, TX	41	205	602	41	196	552
Seattle, WA	199	849	2036	200	862	2036
Tallahassee, FL	57	219	580	47	177	455
Tampa, FL	12	62	232	12	58	209
Washington, DC	382	954	1775	439	1066	1932
Edmonton, ALB	2581	3733	5148	3024	4278	5752
Montreal, QUE	1643	2549	3683	2056	3123	4396
Toronto, ONT	1228	2127	3279	1464	2478	3714
Vancouver, BC	277	947	2130	247	866	1924
Winnipeg, MAN	2799	3837	5089	3726	5013	6512

TABLE 1B: STANDARD AND INFILTRATION HEATING DEGREE-DAYS (F-day/yr) TO DIFFERENT BASE TEMPERATURES

	Standard DD				Infiltration DD		
City, State	*45 ^oF*	*55 ^oF*	*65 ^oF*	*65 $^oF^*$*	*45 ^oF*	*55 ^oF*	*65 ^oF*
Albuquerque, NM	1226	2636	4618	4221	1196	2503	4295
Amarillo, TX	1370	2727	4648	4191	1724	3412	5721
Atlanta, GA	659	1604	3215	2980	783	1768	3305
Birmingham, AL	532	1422	2983	2786	510	1309	2635
Bismarck, ND	4467	6638	9283	8985	5682	8258	11286
Boise, ID	1788	3677	6185	5882	1833	3741	6186
Boston, MA	1741	3486	5874	5653	2396	4598	7449
Brownsville, TX	27	202	729	533	27	193	655
Charleston, SC	353	1103	2414	2168	359	1069	2245
Cheyene, WY	2726	4855	7613	7262	3625	6398	9846
Chicago, IL	2228	4029	6331	6137	2821	4959	7558
Cleveland, OH	2109	3907	6312	6182	2705	4822	7497
Dayton, OH	1959	3613	5803	5596	2385	4272	6629
Denver, CO	2157	3968	6411	5915	2201	3988	6336
Des Moines, IA	2671	4455	6724	6533	3170	5188	7641
Detroit, MI	2467	4334	6730	6556	3065	5181	7745
Dodge City, KS	1797	3385	5484	5075	2348	4371	6966
El Paso, TX	520	1389	2866	2670	488	1291	2647
Fort Worth, TX	402	1211	2604	2344	421	1229	2581
Great Falls, MT	3209	5258	7989	7684	4100	6765	10206
Indianapolis, IN	1998	3657	5831	5613	2405	4251	6554
Kansas City, MO	1634	3073	5007	4828	1789	3251	5131
Lake Charles, LA	172	686	1718	1523	171	675	1628
Las Vegas, NV	411	1282	2795	2548	404	1233	2649
Little Rock, AR	786	1852	3420	3187	812	1854	3311
Los Angeles, CA	9	301	1969	1698	7	233	1562
Madison, WI	3263	5295	7825	7659	3831	6048	8689
Medford, OR	1145	2961	5523	4885	923	2317	4225
Miami, FL	7	65	283	218	6	58	235
Minneapolis, MN	3623	5667	8134	8034	4349	6725	9499
Nashville, TN	899	2100	3858	3697	948	2141	3820
New York, NY	1354	2914	5029	4910	1804	3762	6282
Oklahoma City, OK	1033	2271	4036	3762	1218	2637	4621
Omaha, NE	2371	4087	6274	6030	2821	4756	7128
Phoenix, AZ	97	596	1672	1347	80	459	1239
Pittsburgh, PA	2033	3818	6174	5943	2337	4241	6626
Portland, ME	2767	4838	7540	7400	3030	5178	7829
Portland, OR	703	2269	4879	4603	711	2182	4484
Raleigh, NC	879	2021	3778	3541	905	2015	3629
St Louis, MO	1557	3075	5089	4908	1737	3336	5364
Salt Lake City, UT	1929	3776	6137	5820	1955	3800	6119
San Antonio, TX	159	711	1806	1542	155	663	1623
Seattle, WA	750	2597	5528	5208	755	2625	5439
Tallahassee, FL	197	706	1760	1548	162	562	1345
Tampa, FL	47	238	883	597	45	219	760
Washington, DC	1082	2487	4410	4208	1230	2738	4714
Edmonton, ALB	5512	8073	11207	11214	6399	9124	12311
Montreal, QUE	3636	5659	8269	8202	4510	6840	9658
Toronto, ONT	2873	4913	7557	7506	3391	5643	8366
Vancouver, BC	912	2769	5735	5709	824	2526	5083
Winnipeg, MAN	5824	8108	10906	10832	7692	10472	13758

* This column was calculated by summing daily (min+max)/2.

TABLE 2A: COOLING DEGREE-DAYS (^oC-day/yr) TO DIFFERENT BASE TEMPERATURES USING LATENT BASE ENTHALPY OF 4 Wh/kg

	Standard DD			Infiltration DD		
City, State	*10 ^oC*	*15 ^oC*	*20 ^oC*	*10 ^oC*	*15 ^oC*	*20 ^oC*
Albuquerque, NM	2369	1373	653	2158	1502	1011
Amarillo, TX	2459	1430	681	4505	3506	2663
Atlanta, GA	2733	1520	633	4582	3679	2927
Birmingham, AL	2966	1736	813	4377	3532	2836
Bismarck, ND	1354	721	306	2184	1591	1126
Boise, ID	1634	904	430	1543	1008	624
Boston, MA	1627	799	294	3147	2326	1647
Brownsville, TX	4732	3060	1593	11767	10181	8736
Charleston, SC	3224	1889	847	6218	5152	4229
Cheyene, WY	1195	575	227	1719	1115	652
Chicago, IL	1844	1030	444	2986	2286	1723
Cleveland, OH	1624	831	317	3016	2264	1663
Dayton, OH	1923	1046	419	2958	2258	1699
Denver, CO	1676	903	404	1712	1127	683
Des Moines, IA	1851	1025	432	3168	2497	1952
Detroit, MI	1573	792	276	2475	1838	1322
Dodge City, KS	2297	1381	697	4978	3933	3060
El Paso, TX	3291	2031	1059	3259	2419	1788
Fort Worth, TX	3481	2181	1167	7031	5826	4794
Great Falls, MT	1226	586	227	1288	733	371
Indianapolis, IN	1966	1085	448	3269	2559	1978
Kansas City, MO	2521	1523	761	4241	3447	2784
Lake Charles, LA	3789	2324	1134	7610	6430	5378
Las Vegas, NV	3689	2445	1481	3111	2164	1458
Little Rock, AR	3043	1859	929	4904	4057	3335
Los Angeles, CA	2269	823	153	3716	2507	1572
Madison, WI	1416	713	253	2668	2068	1582
Medford, OR	1563	832	389	1542	1019	649
Miami, FL	5128	3354	1702	9866	8507	7236
Minneapolis, MN	1568	854	350	2982	2317	1767
Nashville, TN	2654	1553	712	4180	3376	2702
New York, NY	1996	1071	419	3326	2544	1909
Oklahoma City, OK	2803	1716	866	6188	5100	4181
Omaha, NE	2046	1183	545	3542	2829	2238
Phoenix, AZ	4516	3063	1892	4107	3222	2501
Pittsburgh, PA	1632	824	296	2509	1851	1332
Portland, ME	1189	531	171	1984	1423	984
Portland, OR	1334	530	169	1788	1081	597
Raleigh, NC	2547	1423	604	3916	3136	2478
St Louis, MO	2322	1370	646	4389	3588	2924
Salt Lake City, UT	1898	1117	559	1841	1225	767
San Antonio, TX	3862	2433	1259	7003	5838	4838
Seattle, WA	954	316	83	1520	848	416
Tallahassee, FL	3675	2211	1041	5358	4456	3672
Tampa, FL	4360	2705	1326	7903	6641	5495
Washington, DC	2375	1371	603	3867	3108	2465
Edmonton, ALB	637	228	50	802	462	247
Montreal, QUE	1269	578	167	1867	1347	949
Toronto, ONT	1295	623	215	1929	1404	1009
Vancouver, BC	861	218	24	1403	798	393
Winnipeg, MAN	1061	487	159	1852	1268	829

TABLE 2B: COOLING DEGREE-DAYS (F-day/yr) TO DIFFERENT BASE TEMPERATURES USING LATENT BASE ENTHALPY OF 6 BTU/lb

	Standard DD			Infiltration DD		
City, State	*55 °F*	*65 °F*	*75 °F*	*55 °F*	*65 °F*	*75 °F*
Albuquerque, NM	3214	1545	541	3206	2091	1252
Amarillo, TX	3339	1611	572	7103	5276	3716
Atlanta, GA	3640	1602	406	7333	5699	4307
Birmingham, AL	4039	1949	617	7021	5504	4194
Bismarck, ND	1757	751	235	3326	2285	1468
Boise, ID	2151	1009	376	2216	1331	717
Boston, MA	2035	772	186	4835	3347	2161
Brownsville, TX	6811	3687	1304	19608	16578	13707
Charleston, SC	4414	2075	588	10123	8150	6373
Cheyene, WY	1466	574	153	2471	1428	667
Chicago, IL	2452	1104	314	4656	3422	2391
Cleveland, OH	2066	822	198	4660	3332	2258
Dayton, OH	2532	1073	267	4608	3373	2365
Denver, CO	2178	972	330	2476	1474	722
Des Moines, IA	2460	1078	304	5021	3824	2823
Detroit, MI	1998	743	151	3805	2672	1754
Dodge City, KS	3167	1616	633	7902	6009	4367
El Paso, TX	4601	2429	952	4994	3571	2449
Fort Worth, TX	4907	2649	1045	11444	9227	7279
Great Falls, MT	1497	578	151	1729	853	329
Indianapolis, IN	2609	1133	297	5159	3892	2821
Kansas City, MO	3490	1775	633	6829	5393	4148
Lake Charles, LA	5305	2686	850	12523	10296	8243
Las Vegas, NV	5329	3192	1624	4625	3006	1840
Little Rock, AR	4247	2165	786	7973	6422	5043
Los Angeles, CA	2492	510	55	5461	3341	1794
Madison, WI	1796	677	135	4192	3121	2238
Medford, OR	2006	918	336	2225	1369	779
Miami, FL	7444	4012	1194	16420	13783	11211
Minneapolis, MN	2068	885	239	4693	3495	2482
Nashville, TN	3621	1729	534	6708	5252	3988
New York, NY	2611	1076	257	5191	3795	2648
Oklahoma City, OK	3904	2019	739	10044	8052	6340
Omaha, NE	2773	1310	425	5652	4366	3278
Phoenix, AZ	6619	4044	2145	6489	4912	3598
Pittsburgh, PA	2077	782	176	3843	2690	1763
Portland, ME	1416	468	90	3002	2014	1264
Portland, OR	1492	452	109	2477	1329	598
Raleigh, NC	3400	1507	413	6259	4840	3599
St Louis, MO	3179	1544	520	7083	5647	4387
Salt Lake City, UT	2582	1293	513	2675	1631	858
San Antonio, TX	5468	2913	1077	11432	9288	7380
Seattle, WA	961	242	39	2022	969	363
Tallahassee, FL	5102	2506	743	8737	7069	5549
Tampa, FL	6149	3145	978	12972	10566	8325
Washington, DC	3221	1494	403	6192	4808	3607
Edmonton, ALB	677	160	16	1081	556	247
Montreal, QUE	1530	490	64	2824	1930	1240
Toronto, ONT	1591	584	110	2934	2035	1361
Vancouver, BC	787	104	1	1882	918	341
Winnipeg, MAN	1285	433	86	2733	1732	1003

TABLE 3A: COOLING DEGREE-DAYS (^oC-day/yr) TO DIFFERENT BASE TEMPERATURES USING LATENT BASE ENTHALPY OF 6 Wh/kg

	Standard DD			**Infiltration DD**		
City, State	*10 °C*	*15 °C*	*20 °C*	*10 °C*	*15 °C*	*20 °C*
Albuquerque, NM	2369	1373	653	1301	834	503
Amarillo, TX	2459	1430	681	3171	2337	1655
Atlanta, GA	2733	1520	633	3379	2637	2028
Birmingham, AL	2966	1736	813	3256	2562	1976
Bismarck, ND	1354	721	306	1402	955	613
Boise, ID	1634	904	430	848	496	269
Boston, MA	1627	799	294	2053	1398	926
Brownsville, TX	4732	3060	1593	9622	8138	6786
Charleston, SC	3224	1889	847	4791	3858	3048
Cheyene, WY	1195	575	227	924	493	213
Chicago, IL	1844	1030	444	2061	1508	1060
Cleveland, OH	1624	831	317	2022	1440	985
Dayton, OH	1923	1046	419	2033	1489	1051
Denver, CO	1676	903	404	946	526	236
Des Moines, IA	1851	1025	432	2279	1742	1308
Detroit, MI	1573	792	276	1631	1129	754
Dodge City, KS	2297	1381	697	3587	2717	1988
El Paso, TX	3291	2031	1059	2164	1553	1076
Fort Worth, TX	3481	2181	1167	5419	4388	3517
Great Falls, MT	1226	586	227	577	259	97
Indianapolis, IN	1966	1085	448	2328	1754	1292
Kansas City, MO	2521	1523	761	3185	2525	1965
Lake Charles, LA	3789	2324	1134	6020	4950	4000
Las Vegas, NV	3689	2445	1481	1871	1214	765
Little Rock, AR	3043	1859	929	3774	3047	2423
Los Angeles, CA	2269	823	153	2123	1246	653
Madison, WI	1416	713	253	1872	1397	1013
Medford, OR	1563	832	389	865	527	307
Miami, FL	5128	3354	1702	8020	6699	5479
Minneapolis, MN	1568	854	350	2098	1556	1118
Nashville, TN	2654	1553	712	3109	2438	1878
New York, NY	1996	1071	419	2289	1668	1181
Oklahoma City, OK	2803	1716	866	4735	3823	3058
Omaha, NE	2046	1183	545	2594	2011	1531
Phoenix, AZ	4516	3063	1892	2934	2227	1660
Pittsburgh, PA	1632	824	296	1642	1139	747
Portland, ME	1189	531	171	1244	826	526
Portland, OR	1334	530	169	876	443	197
Raleigh, NC	2547	1423	604	2877	2218	1669
St Louis, MO	2322	1370	646	3327	2661	2098
Salt Lake City, UT	1898	1117	559	1036	605	302
San Antonio, TX	3862	2433	1259	5445	4441	3571
Seattle, WA	954	316	83	661	287	109
Tallahassee, FL	3675	2211	1041	4151	3355	2663
Tampa, FL	4360	2705	1326	6197	5027	4003
Washington, DC	2375	1371	603	2854	2214	1683
Edmonton, ALB	637	228	50	369	181	85
Montreal, QUE	1269	578	167	1186	804	526
Toronto, ONT	1295	623	215	1243	868	597
Vancouver, BC	861	218	24	625	271	98
Winnipeg, MAN	1061	487	159	1086	678	391

TABLE 3B: COOLING DEGREE-DAYS (F-day/yr) TO DIFFERENT BASE TEMPERATURES USING LATENT BASE ENTHALPY OF 9 BTU/lb

	Standard DD			Infiltration DD		
City, State	*55 °F*	*65 °F*	*75 °F*	*55 °F*	*65 °F*	*75 °F*
Albuquerque, NM	3214	1545	541	1856	1084	548
Amarillo, TX	3339	1611	572	4860	3365	2139
Atlanta, GA	3640	1602	406	5329	3996	2879
Birmingham, AL	4039	1949	617	5160	3894	2793
Bismarck, ND	1757	751	235	2063	1293	724
Boise, ID	2151	1009	376	1153	603	262
Boston, MA	2035	772	186	3019	1920	1155
Brownsville, TX	6811	3687	1304	15847	13013	10335
Charleston, SC	4414	2075	588	7688	5957	4408
Cheyene, WY	1466	574	153	1208	526	144
Chicago, IL	2452	1104	314	3146	2160	1371
Cleveland, OH	2066	822	198	3041	2027	1240
Dayton, OH	2532	1073	267	3102	2140	1355
Denver, CO	2178	972	330	1262	572	178
Des Moines, IA	2460	1078	304	3556	2602	1812
Detroit, MI	1998	743	151	2420	1562	941
Dodge City, KS	3167	1616	633	5578	3993	2664
El Paso, TX	4601	2429	952	3266	2205	1345
Fort Worth, TX	4907	2649	1045	8713	6832	5194
Great Falls, MT	1497	578	151	691	247	69
Indianapolis, IN	2609	1133	297	3607	2584	1773
Kansas City, MO	3490	1775	633	5065	3860	2810
Lake Charles, LA	5305	2686	850	9768	7754	5928
Las Vegas, NV	5329	3192	1624	2676	1613	905
Little Rock, AR	4247	2165	786	6062	4722	3542
Los Angeles, CA	2492	510	55	2899	1493	565
Madison, WI	1796	677	135	2885	2041	1350
Medford, OR	2006	918	336	1197	667	329
Miami, FL	7444	4012	1194	13133	10584	8166
Minneapolis, MN	2068	885	239	3225	2259	1474
Nashville, TN	3621	1729	534	4917	3702	2655
New York, NY	2611	1076	257	3487	2398	1544
Oklahoma City, OK	3904	2019	739	7599	5948	4475
Omaha, NE	2773	1310	425	4075	3032	2134
Phoenix, AZ	6619	4044	2145	4559	3308	2292
Pittsburgh, PA	2077	782	176	2439	1563	894
Portland, ME	1416	468	90	1805	1110	618
Portland, OR	1492	452	109	1109	473	172
Raleigh, NC	3400	1507	413	4513	3318	2323
St Louis, MO	3179	1544	520	5317	4098	3060
Salt Lake City, UT	2582	1293	513	1415	704	250
San Antonio, TX	5468	2913	1077	8790	6934	5252
Seattle, WA	961	242	39	777	275	79
Tallahassee, FL	5102	2506	743	6675	5194	3878
Tampa, FL	6149	3145	978	9987	7800	5843
Washington, DC	3221	1494	403	4489	3334	2339
Edmonton, ALB	677	160	16	459	199	76
Montreal, QUE	1530	490	64	1739	1098	634
Toronto, ONT	1591	584	110	1847	1223	762
Vancouver, BC	787	104	1	735	255	59
Winnipeg, MAN	1285	433	86	1525	857	398

TABLE 4A: COOLING DEGREE-DAYS (^oC-day/yr) TO DIFFERENT BASE TEMPERATURES USING LATENT BASE ENTHALPY OF 8 Wh/kg

	Standard DD			**Infiltration DD**		
City, State	*10 ^oC*	*15 ^oC*	*20 ^oC*	*10 ^oC*	*15 ^oC*	*20 ^oC*
Albuquerque, NM	2369	1373	653	696	392	187
Amarillo, TX	2459	1430	681	2064	1398	886
Atlanta, GA	2733	1520	633	2393	1794	1304
Birmingham, AL	2966	1736	813	2330	1747	1258
Bismarck, ND	1354	721	306	816	494	277
Boise, ID	1634	904	430	398	198	81
Boston, MA	1627	799	294	1201	766	464
Brownsville, TX	4732	3060	1593	7615	6227	4976
Charleston, SC	3224	1889	847	3541	2724	2033
Cheyene, WY	1195	575	227	371	134	27
Chicago, IL	1844	1030	444	1328	895	572
Cleveland, OH	1624	831	317	1254	821	503
Dayton, OH	1923	1046	419	1314	887	561
Denver, CO	1676	903	404	401	153	42
Des Moines, IA	1851	1025	432	1568	1143	807
Detroit, MI	1573	792	276	974	625	378
Dodge City, KS	2297	1381	697	2426	1710	1140
El Paso, TX	3291	2031	1059	1361	897	523
Fort Worth, TX	3481	2181	1167	4044	3175	2443
Great Falls, MT	1226	586	227	183	61	15
Indianapolis, IN	1966	1085	448	1567	1123	783
Kansas City, MO	2521	1523	761	2304	1746	1283
Lake Charles, LA	3789	2324	1134	4579	3618	2795
Las Vegas, NV	3689	2445	1481	1022	618	352
Little Rock, AR	3043	1859	929	2802	2177	1655
Los Angeles, CA	2269	823	153	997	456	153
Madison, WI	1416	713	253	1243	868	580
Medford, OR	1563	832	389	433	235	116
Miami, FL	5128	3354	1702	6228	4973	3849
Minneapolis, MN	1568	854	350	1379	955	619
Nashville, TN	2654	1553	712	2216	1659	1197
New York, NY	1996	1071	419	1471	1000	658
Oklahoma City, OK	2803	1716	866	3522	2751	2071
Omaha, NE	2046	1183	545	1821	1343	948
Phoenix, AZ	4516	3063	1892	1999	1448	1016
Pittsburgh, PA	1632	824	296	979	606	349
Portland, ME	1189	531	171	702	421	244
Portland, OR	1334	530	169	332	135	52
Raleigh, NC	2547	1423	604	1999	1461	1038
St Louis, MO	2322	1370	646	2437	1882	1422
Salt Lake City, UT	1898	1117	559	477	206	62
San Antonio, TX	3862	2433	1259	4100	3220	2447
Seattle, WA	954	316	83	202	69	19
Tallahassee, FL	3675	2211	1041	3083	2388	1801
Tampa, FL	4360	2705	1326	4625	3594	2711
Washington, DC	2375	1371	603	2004	1474	1044
Edmonton, ALB	637	228	50	137	59	23
Montreal, QUE	1269	578	167	689	428	249
Toronto, ONT	1295	623	215	756	501	314
Vancouver, BC	861	218	24	189	58	11
Winnipeg, MAN	1061	487	159	557	294	132

TABLE 4B: COOLING DEGREE-DAYS (F-day) TO DIFFERENT BASE TEMPERATURES USING LATENT BASE ENTHALPY OF 12 BTU/lb						
	Standard DD			Infiltration DD		
City, State	*55 °F*	*65 °F*	*75 °F*	*55 °F*	*65 °F*	*75 °F*
Albuquerque, NM	3214	1545	541	930	443	156
Amarillo, TX	3339	1611	572	3033	1878	997
Atlanta, GA	3640	1602	406	3698	2628	1730
Birmingham, AL	4039	1949	617	3605	2542	1654
Bismarck, ND	1757	751	235	1130	614	287
Boise, ID	2151	1009	376	501	204	56
Boston, MA	2035	772	186	1701	1002	503
Brownsville, TX	6811	3687	1304	12327	9693	7252
Charleston, SC	4414	2075	588	5552	4054	2790
Cheyene, WY	1466	574	153	403	91	8
Chicago, IL	2452	1104	314	1942	1206	667
Cleveland, OH	2066	822	198	1809	1078	572
Dayton, OH	2532	1073	267	1926	1188	636
Denver, CO	2178	972	330	444	123	17
Des Moines, IA	2460	1078	304	2390	1640	1044
Detroit, MI	1998	743	151	1386	815	419
Dodge City, KS	3167	1616	633	3637	2372	1362
El Paso, TX	4601	2429	952	1974	1153	501
Fort Worth, TX	4907	2649	1045	6400	4820	3435
Great Falls, MT	1497	578	151	183	46	8
Indianapolis, IN	2609	1133	297	2362	1599	999
Kansas City, MO	3490	1775	633	3583	2574	1726
Lake Charles, LA	5305	2686	850	7278	5507	3957
Las Vegas, NV	5329	3192	1624	1409	770	368
Little Rock, AR	4247	2165	786	4412	3275	2330
Los Angeles, CA	2492	510	55	1217	414	81
Madison, WI	1796	677	135	1854	1203	719
Medford, OR	2006	918	336	567	269	101
Miami, FL	7444	4012	1194	9965	7588	5404
Minneapolis, MN	2068	885	239	2047	1302	723
Nashville, TN	3621	1729	534	3425	2419	1574
New York, NY	2611	1076	257	2162	1371	812
Oklahoma City, OK	3904	2019	739	5568	4125	2822
Omaha, NE	2773	1310	425	2795	1930	1239
Phoenix, AZ	6619	4044	2145	3033	2072	1298
Pittsburgh, PA	2077	782	176	1375	764	371
Portland, ME	1416	468	90	968	530	269
Portland, OR	1492	452	109	370	132	35
Raleigh, NC	3400	1507	413	3048	2107	1360
St Louis, MO	3179	1544	520	3821	2824	1972
Salt Lake City, UT	2582	1293	513	566	178	26
San Antonio, TX	5468	2913	1077	6499	4855	3374
Seattle, WA	961	242	39	207	56	9
Tallahassee, FL	5102	2506	743	4849	3577	2484
Tampa, FL	6149	3145	978	7289	5389	3729
Washington, DC	3221	1494	403	3071	2119	1364
Edmonton, ALB	677	160	16	159	58	16
Montreal, QUE	1530	490	64	967	544	268
Toronto, ONT	1591	584	110	1094	666	370
Vancouver, BC	787	104	1	186	36	3
Winnipeg, MAN	1285	433	86	725	316	110