# Climate Classification for Building Energy Codes and Standards: Part 1—Development Process

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## ABSTRACT

*This paper describes the development of a new climate classification for use in characterizing the performance of energy efficiency measures for buildings. The classification is designed for use in energy codes and standards, design guidelines, and building energy analyses. This is the first paper in a two-paper set. This first paper contains background on climate classification and describes the development process for the new classification. The second paper presents the actual zone definitions, describes related climatic materials that have been developed, such as maps, and provides a comparison of the new classification with existing classifications. This paper includes a review of traditional climate classifications used by other disciplines and examines how climate is treated in current energy codes and standards. Details of the process used to develop the new classification system are presented along with a general description of the resulting classification.*

## INTRODUCTION

This is the first paper in a two-paper set. This paper contains background on climate classification and describes the development process for a new classification. The second paper presents—both descriptively and mathematically—the climatic zone definitions under the new climate classification, describes related climatic materials that have been developed to support use of the classification, such as maps, and provides a comparison of the new classification with existing classifications.

Climate has a major impact on the energy use of most commercial and residential buildings. Current energy codes and standards contain numerous requirements based on climate; for example, minimum R-values for roof insulation and maximum solar heat gain coefficients (SHGCs) for window glazing. Currently, ASHRAE's residential and nonresidential energy standards and the residential and commercial sections of the International Energy Conservation Code (IECC) use four different methods for specifying climate-dependent requirements. In many situations, the climate data needed to determine which requirements apply are not included in the standard or code documents. Only the IECC's commercial section is fully self-contained with respect to climatic data. It is also the only one of the four that provides clear and unambiguous specification of which requirements apply anywhere in the United States. To use the others, a user must locate referenced documents and then exercise judgment in selecting the most appropriate location for climatic data for the project. In addition to creating usability problems, the lack of a consistent and effective approach for handling climate impedes the incorporation of ASHRAE-developed criteria into the nation's model building codes.

A new climate classification has been developed to help improve the implementation of building energy codes and standards in the United States. This classification may also prove useful in design guidelines, analyses of current or future building populations, and other programs or research dealing with the relationship between climate and building energy use. This new classification builds on widely accepted classifications of world climates that have been applied in a variety of different disciplines. It was developed using SI units and climate indices believed to be widely available internationally to facilitate the development of information on building energy efficiency that can be applied anywhere in the world.

This paper reviews the evolution of general purpose climate classifications as well as approaches used with current

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building energy codes and standards. The process used to develop the new classification is explained, and a general description of the classification is presented.

## BACKGROUND

Because the new climate classification is partly based on approaches that have been used in developing climate classifications historically, we provide a brief overview of the evolution of general purpose climate classifications and classification methodologies. Classifications used with building energy codes and standards currently in force in the United States are discussed in the following section.

### General Purpose Climate Classifications

Scientists inevitably develop classifications for whatever it is they study. Classifications are needed to help generalize knowledge and understanding and for communication with peers. This section reviews climate classification schemes and approaches that have been used historically and then reviews more recent approaches based on statistical methods.

**Brief History of Climate Classification.** The earliest classifiers of climate were ancient astronomers, who postulated a spherical earth and from that understanding deduced five climate zones—one torrid, two temperate, and two frigid. Aristotle is credited with the first quantitative classification of a climate region in his definition of the tropics in the 4th Century B.C., a definition still used today. Ptolemy (2nd Century A.D.) is credited with a seven-zone classification of world climate based on the duration of the longest day, building on the ancients' recognition of the relationship between latitude and temperature (Oliver 1991). These early classifications are termed "genetic," meaning they are based on mechanisms that attempt to explain climatic variations.

The next major advance in climate classification did not come until after the invention of the thermometer and the accumulation of significant temperature data in the early 19th Century. In 1900, Wladimir Köppen, a Russian-born scholar, proposed a precipitation-based classification of world climate, a major departure from then-current classifications based on isotherms. Later work by Köppen (1918) established a classification system consisting of major climate groups, which were subdivided into climate types and subtypes. Köppen's classification includes quantitative definitions for these climate categories based on temperature and precipitation indices and uses two- and three-letter codes to designate climate types. The classification is termed "empirical" because it is designed to be descriptive rather than explanatory.

Numerous refinements of Köppen's original system and climate-type definitions have been proposed by Köppen, his students, and other researchers over the years. An American scientist, C.W. Thornwaite (1948), developed a well-known competitor to Köppen's classification, although his classification was more complex and somewhat cumbersome to use. Thornwaite is credited with important contributions related to "precipitation effectiveness," the concept that both precipitation and evaporation must be considered in classifications of dry versus humid climates. However, Köppen's system remains by far the most well-known classification of world climate. Even today, most textbooks on climatology and physical geography include a discussion of climate types based on his work. However, increasingly during the later third of the twentieth century, interest among climate scientists shifted toward the use of statistical methods for climate classification (Oliver 1991).

Another contribution for which Köppen is given credit is the idea that climate is driven by major patterns of atmospheric circulation (Oliver 1991). These patterns repeat themselves at similar latitudes on the various continents, resulting in distinct climate types that are repeated around the world. Figure 1 contains a world map showing climate types based on Köppen's work. Figure 2 is an enlargement of the lower 48 states in Figure 1, showing climate types based on Köppen's work in greater detail.

**Cluster-Based Classification.** Most early work on climate classification was limited by the availability of climatic data. By the 1980s, data availability ceased to pose a major limitation, at least for the United States. The availability of large quantities of reliable historic climatic data and powerful computational capabilities led to the development of a very different approach to climate classification based on the agglomeration of similar sites. The principal tool used in developing this type of classification is a statistical procedure called "hierarchical cluster analysis."

Hierarchical cluster analysis uses a distance metric that represents the degree of similarity or dissimilarity between observations (e.g., climate sites) in a data set. The distance metric can use any number of different climate indices (or clustering variables), such as heating and cooling degree-days, incident solar radiation, or average relative humidity. Clusters are formed by calculating the distances between all possible pairs of observations in the data set, joining the two closest observations into a cluster, calculating values representing the centroid of the resulting cluster, and repeating this process until only a single cluster remains. The end result of a cluster analysis is a hierarchical (tree-like) arrangement of the observations into progressively nested sets of subclusters. "Cutting" the nested cluster tree at a selected level results in a set of clusters that show the best way to group $n$ observations such that each cluster is relatively homogeneous in terms of the initial clustering variables.

Key decisions in using cluster analysis involve choosing the clustering variables and determining how to normalize and weight those variables. Other important decisions involve the detailed mechanics of the clustering procedure, such as the definition of the distance metric and the manner in which between-cluster distances are defined. Because judgment must be used in many areas, cluster analysis should be thought

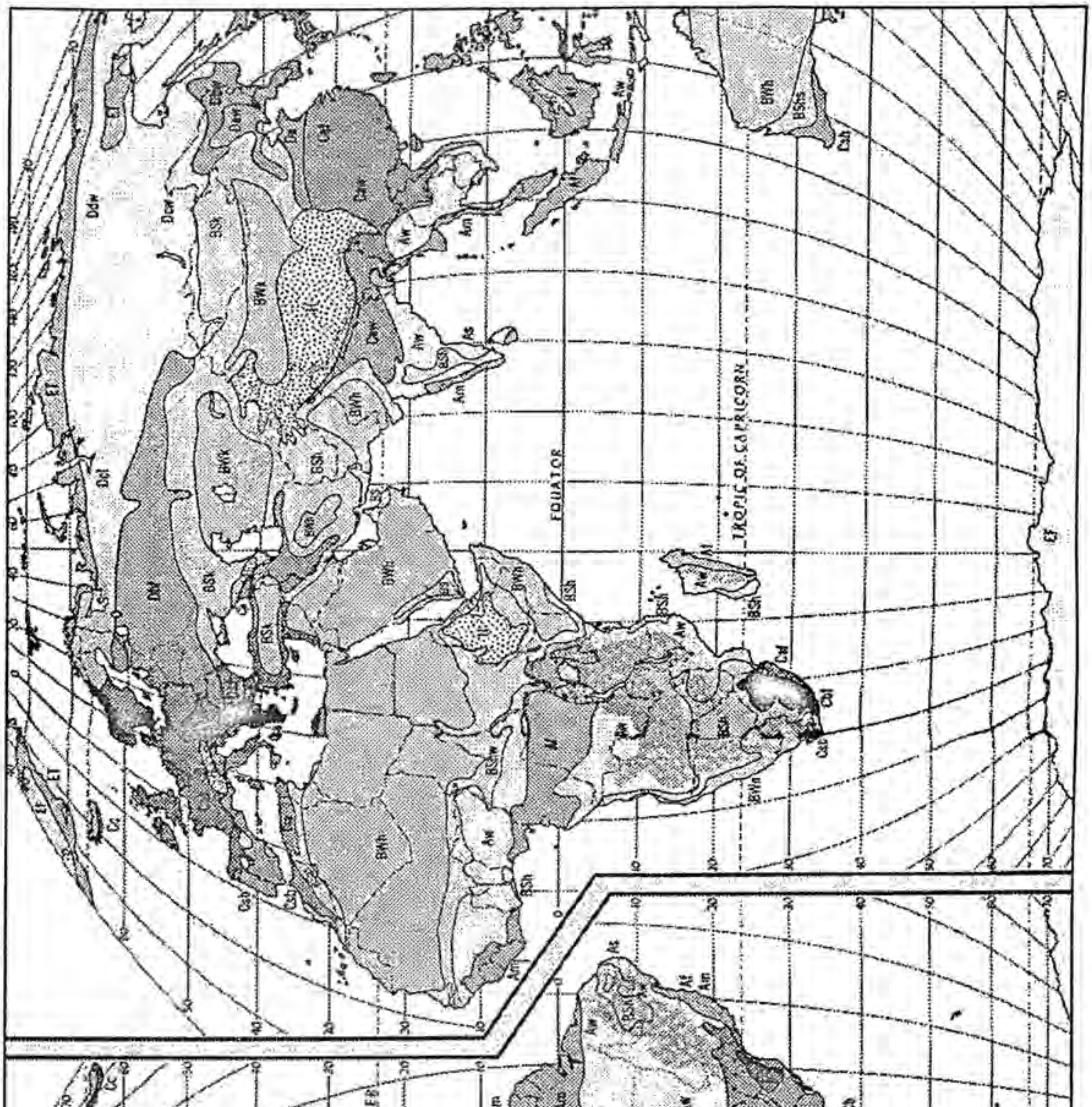


*Figure 1* *World climate classification based on Köppen's work.*

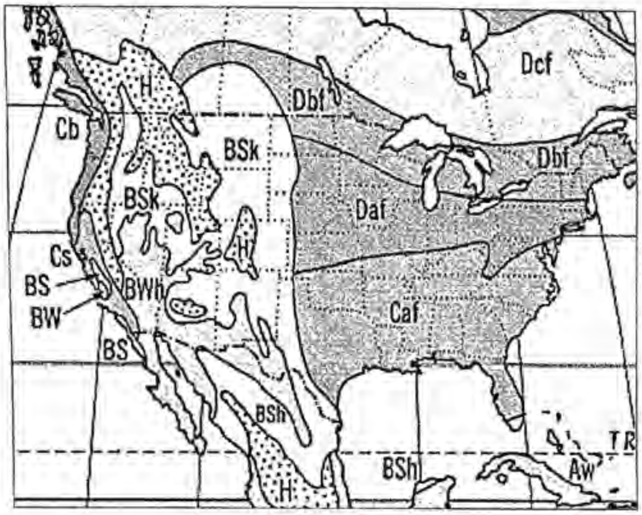


***Figure 2*** *Climate classification of U.S. based on Köppen's work.*

of as a tool for grouping like observations rather than as an automated process that leads to a single inevitable result.

Numerous technical papers that address the use of cluster analysis for climate classification can be found in the climatology and statistics literature (Oliver 1991), such as Fovell and Mei-Ying (1993). In addition, the ASHRAE literature contains several examples of the use of cluster analysis for climate classification (Andersson et al. 1985; ASHRAE 1989; Hadley and Jarnagin 1993). Andersson et al. (1985) used cluster analysis to select a set of cities for use in analyzing the nation's building stock. ASHRAE/IES Standard 90.1-1989 contains a table (Table 8A-0) that specifies climate groups for applying building envelope requirements, which was developed using cluster analysis (ASHRAE 1989). Hadley and Jarnagin (1993) used cluster analysis to define a set of 16 climate regions in the United States for use in developing requirements for Standard 90.1-1999 (ASHRAE 1999).

Anderssen et al. (1985), ASHRAE (1989), and Hadley and Jarnagin (1993) are instructive both as precedents in the use of cluster analysis and as illustrations of three different ways in which the results of cluster analysis can be presented. Anderssen et al. (1985) presented results as agglomerations of observations (several groupings of 5 to 24 clusters), but these clusters were not designed to provide full coverage of all U.S. locations. The clusters developed for Standard 90.1-1989 were translated into ranges of three to five different climatic parameters, and these parameter ranges defined 38 categories covering all U.S. locations. Hadley and Jarnagin (1993) include a map with climate region boundaries and representative cities for use in the analyses of 16 climate zones. This later method provides the most suitable presentation model for code purposes. It provides explicit boundaries and makes it unnecessary for the code user to obtain additional climatic data.

## Climate Classifications in Energy Codes and Standards

This section provides a review of how climate-dependent requirements are handled in energy codes and standards currently in use in the United States. This issue primarily involves how prescriptive requirements are defined and presented to the user; performance-based compliance alternatives are generally just derived from prescriptive requirements. Any new system for handling climate needs to show substantial improvement over the currently used systems. In addition, any new classification must be at least roughly compatible with current climate-dependent requirements to enable straight forward translation of current requirements that already enjoy consensus support.

**ASHRAE 90.1 Code and Standard 90.1-1989.** Although the ASHRAE 90.1 Code (90.1 Code) and the technically equivalent Standard 90.1-1989 have been superseded by ANSI/ASHRAE/IESNA Standard 90.1-2001 (90.1-2001), many state and local jurisdictions continue to have in force energy codes based on Standard 90.1-1989 (ASHRAE 1993a, 1989, 2001). Most climate-dependent requirements in the 90.1 Code are in Section 402 entitled, "Building Envelopes." Appendix C of Standard 90.1-1989 contains climatic data for approximately 240 cities in the United States and its possessions; and tables for these same locations were distributed as supplements to the 90.1 Code.

The 90.1 Code contains requirements for envelope conductance for floors (including slab-on-grade), basement walls, and lightweight opaque walls based on heating degree-days base 65°F (HDD65°F) [18°C (HDD18°C)]. For windows, a more flexible approach is used that involves packages of envelope features (called "Alternate Component Package" or "ACP Tables"). Some 38 different tables apply to an equal number of climate groups. These 38 climate groups were developed using cluster analysis. Each climate group represents an agglomeration of locations found to be similar, based on a combination of HDD50°F (HDD10°C), cooling degree-days base 65°F (CDD65°F) [18°C (CDD18°C)], incident solar on vertical east- and west-facing surfaces, cooling degree-hours base 80°F (27°C), and HDD65°F (HDD18°C).

The multicriteria approach to classification used for the 90.1 Code provided a technically improved basis for code requirements that addressed cooling; preceding codes had focused primarily on controlling envelope conductance. However, the main disadvantage of this approach is that it can be difficult to determine which requirements apply to locations not included in the list of 240 cities.

**Model Energy Code.** While the first edition of the Model Energy Code (MEC) dates from the late 1970s, most jurisdictions that have adopted the MEC use versions published in the 1990s. The 1992, 1993, and 1995 editions were developed by the Council of American Building Officials (CABO) (CABO 1992, 1993, 1995). Although CABO and its functions have been absorbed into the International Code Council (ICC), many state and local jurisdictions enforce codes based on some edition of the MEC.

HDD65°F (HDD18°C) is used in the MEC for requirements that limit building envelope conductance, and heating and cooling design conditions are required for HVAC equipment sizing. The MEC contains no climatic data, so unless values for HDD65°F (HDD18°C) and design temperatures have been prescribed by the adopting authority, users of the MEC must obtain the necessary climatic data from another source before using the code.

**International Energy Conservation Code.** The International Energy Conservation Code (IECC), the successor to the MEC, was first released in 1998 (ICC 1998). The 1998 IECC contains most of the materials from the 1995 MEC, as well as a new simplified chapter entitled, "Design by Acceptable Practice for Commercial Buildings," based on requirements in the 90.1 Code. Included with this chapter are a set of building envelope requirement tables and a set of 50 state climate maps (in Chapter 3) keyed to the new envelope tables. These climate maps were developed by PNNL, and their basis is documented in a technical support document.[1]

The climate maps identify 33 different climate zones whose boundaries follow state and county lines. The maps are primarily based on 500 degree-day bands of HDD65°F (HDD18°C) with zones numbered from 1 through 19; e.g., Zone 1 covers 0 to 500 HDD65°F, Zone 2 covers 500 to 1000, and so on. In addition, some of the zones were given "a," "b," and "c" designations that further subdivide the zones based on differences in cooling-related code requirements. The tables and climate maps were favorably received by users and code officials, at least in part, because they show unambiguously which requirements apply for each location in the country.

In the next edition of the IECC (2000 edition), the reference to the 90.1 Code was replaced with a reference to ASHRAE/IESNA Standard 90.1-1999 (90.1-1999), and the requirements (other than for envelope tables) in Chapter 8, "Commercial Design by Acceptable Practice," were updated for equivalence with 90.1-1999 (ICC 1999). This revision left the commercial envelope tables in IECC Chapter 8 inconsistent with the reference to 90.1-1999 in IECC Chapter 7—an inconsistency that clearly needs to be corrected. Fundamental incompatibilities between 90.1-1999 and the IECC in the way climate is addressed complicate making these revisions.

It is widely recognized that the residential sections of the IECC (and MEC) do not adequately address residential cooling. The residential cooling requirements they do contain are based on HDD65°F (HDD18°C). While the climate maps added to the IECC are highly suitable for use with the residential requirements, almost no reference is made to the maps in the residential sections of the code. Clearly, a coordinated effort is need to address shortcomings related to climate in the IECC.

**Standard 90.1-2001.** Standard 90.1-2001 (ASHRAE's current version containing minor revisions from 90.1-1999) uses a temperature bin-based approach for most climate-related envelope requirements. A different set of indices are used for mechanical requirements. For the envelope requirements, world climates are divided among 26 different bins based on combinations of HDD65°F (HDD18°C) and CDD50°F (CDD10°C). Figure 3 shows the bins used in 90.1-2001 and the distribution of a representative sample of U.S. locations within those bins. The standard contains a three-part appendix containing the needed U.S., Canadian, and international climatic data for roughly 800 cities.

One salient feature of the 90.1-2001 climate bins is their use of climate variable ranges that allow easy conversions between SI and I-P units. All bin boundaries occur at multiples of 900 degree-days Fahrenheit, which converts to 500 degree-days Celsius. In addition, the temperature bases of 65°F and 50°F correspond closely with 18°C, a degree-day base temperature used internationally, and exactly with 10°C, respectively.

**Standard 90.2-1993.** Standard 90.2-1993 (90.2) is ASHRAE's standard for energy-efficient design of new low-rise residential buildings (ASHRAE 1993b). While 90.2 has not been widely adopted for code use, it remains a significant potential beneficiary of an improved climate classification for buildings.

Standard 90.2 bases its climate-dependent requirements on a combination of HDD65°F (HDD18°C) and CDH74°F (CDH23°C). The standard includes a climate appendix defining those parameters for approximately 3300 U.S. and 1200 Canadian locations. As with all versions of Standard 90 to date, it is left up to the user (or code official) to determine the most appropriate degree-day values to use for any location not included in the appendix.

**Other Climate Classifications for Buildings.** Several other national-level climate classifications have been developed over the years to address building design issues related to

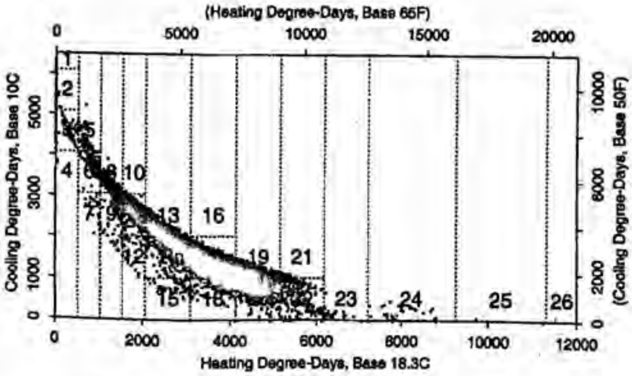


***Figure 3*** *Distribution of roughly 5000 U.S. locations within 90.1-2001 climate bins.*

1. R.S. Briggs, D.R. Conover, M.A. Halverson, J.A. Johnson, R.G. Lucas, E.J. Makela, E.E. Richman, and D.W. Winiarski. Technical Support Document for COM*check-EZ* Version 1.0, March 1997 (DOE 1997). Pacific Northwest National Laboratory, Richland, Wash. *(Letter report available from PNNL at 800-270-2633.)*

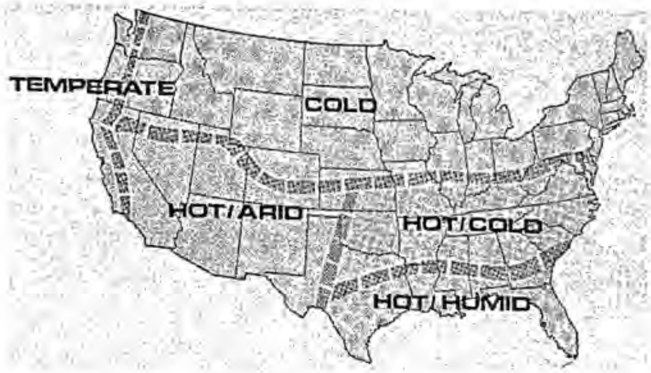


***Figure 4*** *Traditional characterization of U.S. climates for energy-efficient building design.*

energy. Those mentioned here were influential in the creation of the new climate classification.

Figure 4 shows a simple five-region map of the lower 48 states, which was developed in the early 1980s. This version of the map is from a handbook providing design guidance for energy-efficient small office buildings, although similar maps have appeared in other publications (BHKR 1985). Building America, an energy-efficient residential building program supported by the U.S. Department of Energy (DOE), also uses five climate zones featuring separate humid and dry zones (based on Köppen), although zone names and divisions differ somewhat from Figure 4 (DOE 2001). Two climate classifications that focus on thermal and moisture-related issues in building assemblies appear in the *ASHRAE Fundamentals Handbook* Chapter 24, "Thermal and Moisture Control in Insulated Assemblies—Applications"[2] and various other publications (ASHRAE 2001; Lstiburek 2000).

A prominent feature of all these "other" climate classifications is that they distinguish between the humid eastern and dry western regions of the United States. In addition, even with only three-to-five zones, most of these classifications recognize the relatively mild climates along the Pacific Coast as distinct from inland locations. Interestingly, the traditional divisions related to moisture that emerge prominently in earlier work can be found only subtly, if at all, in the five classifications for energy codes and standards discussed above.

## DEVELOPMENT PROCESS

Developing a climate classification is challenging because of the complexity of the phenomenon we understand as climate. Climate involves temperature, moisture, wind, and sun and includes both daily and seasonal patterns of variation of these parameters. Our goal for the effort was to develop a classification that could support simple, approximate ways of prescribing energy efficiency measures for buildings; it was not to develop an ideal categorization for all purposes.

This section describes the steps we used to develop the new climate classification. It includes: (1) a statement of objectives and criteria for success, (2) a description of climate parameters relevant to the performance of the various efficiency measures of interest, (3) a description of preliminary work using cluster analysis, and (4) a description of how the final zones were established.

Items 2 and 3 may not appear highly relevant, given that little of that work directly affected the final classification. The classification relied far less on statistical methods than was expected at the outset of the work. This we attribute more to a collective desire for climate maps that are simple and easy-to-explain than to any shortcoming or unsuitability of the statistical methods to climate classification for building energy use. We include the discussion of the climate parameters and statistical methods used in preliminary work because of their possible relevance to future extensions or enhancements to this or related work.

### Determining Criteria for Climatic Materials

To develop the climate classification, we first wrote a white paper to explain the purpose of the effort, proposed criteria for the classification, and the envisioned technical approach for the work. This white paper was circulated widely to interested parties within the ASHRAE and code development communities. The white paper, modified based on reviewer comments, provided the following list of criteria for the classification and climatic materials:

1. Offer consistent climatic materials for all compliance methods and code sections (including both commercial and residential).
2. Enable the code to be self-contained with respect to climatic data.
3. Be technically sound.
4. Map to political boundaries.
5. Provide a long-term climate classification solution.
6. Be generic and neutral (i.e., not overly tailored to current code requirements).
7. Be useful in beyond-code and future-code contexts.
8. Offer a more concise set of climate zones and presentation formats than in the current IECC.
9. Be acceptable to ASHRAE and usable in ASHRAE standards and guidelines.
10. Provide a basis for use outside of the United States.

The rationale for most of these criteria is fairly obvious, but a few of the criteria warrant additional explanation.

2. This classification divides the country into three climates—heating climates; mixed climates; and warm, humid climates—for applying thermal and moisture control measures. While the Handbook does not include a map showing these zones, the use of wet-bulb temperatures to define the warm, humid climates results in a mixed/humid dividing line not unlike that shown in Figure 4.

Item 4—mapping climate zones to easily recognizable political boundaries instead of to abstract climatic parameters—facilitates code implementation. Users and jurisdictions are able to easily tell what requirements apply, which is not the case in some locations when climate parameters are used.

Item 7, "Useful in future-code and beyond-code contexts," reflects the view that minimum-acceptable practice codes and standards can provide an effective platform on which to build other efficiency programs. Beyond-code programs are likely to encourage features and technologies not included in current codes, many of which are likely to be more climate sensitive than current requirements.

Item 9, "Usable in ASHRAE standards and guidelines," is important because effective coordination of both content and formats used in the IECC and ASHRAE standards offers the potential to facilitate rapid migration of ASHRAE standards into model codes. Previous efforts to translate ASHRAE criteria into the simpler and more prescriptive forms most desired by the code enforcement community has in some cases added years to the process of getting updated criteria adopted and into widespread use.

## Selecting Relevant Climate Parameters

We created a list of relevant climate parameters for possible use in developing the classification. These included parameters used in current codes as well as parameters needed for measures that may be addressed in future guidelines that go beyond current code minimums. Table 1 contains a list of energy efficiency strategies and corresponding climate parameters useful in predicting how these strategies are likely to perform. These climate parameters were considered possible candidates for use in the development of the classification. Most of these were not used directly in the statistical analyses, although they did influence the classification more subtly. Most of the parameters used directly in climate zone definitions show strong correlations with the variables in Table 1 and were selected in part because of those correlations.

## Compiling Source Climatic Data

We built a climatic data set from the latest 30-year record of weather observations available from the National Climatic Data Center (NCDC). The NCDC Solar and Meteorological Surface Observation Network (SAMSON) data set includes hourly observations from 237 U.S. weather stations covering the period from 1961 through 1990 (NCDC 1993). From these raw observations, we computed degree-days to various bases, various annual and monthly averages of incident solar radiation, annual and monthly aggregations of humidity parameters, and various relevant design-day conditions.

We also supplemented the data for each SAMSON station with its latitude, longitude, state, and current IECC climate zone—the later to establish a benchmark for performance comparisons for the various clustering scenarios.

## Generating Preliminary Zones Using Cluster Analysis

Our initial efforts involved cluster analyses of various subsets of the climatic variables, weighted in various ways. These analyses[3] included evaluations of individual climatic variables, separate clusters based on identifiable subsets of the variables (e.g., all heating-oriented variables, all cooling-oriented variables, and all solar-related variables), and comprehensive scenarios that included many or all relevant climate variables. We evaluated each cluster analysis at several possible numbers of clusters (e.g., dividing the United States into 5, 10, 15, or 20 zones) and cast the results onto a U.S. map for evaluation. It is important to be aware of several issues when evaluating the results of cluster analyses:

1. There must always be a subjective analysis of the results.
2. The appropriate weighting of various cluster variables is a subjective matter that depends on how the results are to be used. Some variables that are traditionally very important in classifying climate may not be as important in the context of energy code requirements.
3. A cluster analysis that focuses on a small number of related variables may result in clusters that span large physical distances. For example, clustering locations based on cooling-only variables will frequently group many Alaska locations with Hawaii. While this method may be reasonable from a technical standpoint, it may not fit with expectations for code materials.
4. A cluster analysis that includes too many climatic variables will require a large number of final clusters to achieve reasonable homogeneity within those clusters.
5. Mountainous regions defy clean geographic separation of clusters.

Several of these issues are illustrated in Figure 5, which is one example of a clustering result (out of dozens conducted). This analysis used four cooling-oriented climatic variables (cooling degree-hours base 80°F, average July horizontal solar, 2.5% cooling design temperature, and mean coincident wet-bulb temperature) and is shown for ten clusters. Note that cluster number three includes locations ranging from Maine to Washington to Hawaii. Cluster number one snakes from Kansas down through Texas and over to central California. Clusters two and four are so intertwined that a neat graphic representation is impossible. Although these results *do* provide valid information about the effect of these climatic variables on building cooling loads, they illustrate the inherent problems of using cluster analysis deterministically where simple coherent groupings are desired. When combined with other climatic variables in a more comprehensive clustering

[3] Our work used a standard Euclidean distance as the primary distance metric and a "compact" clustering approach wherein the distance between two clusters is defined as the maximum distance between a point in one cluster and a point in the other cluster. We scaled and centered all cluster variables to have a mean of zero and standard deviation of one prior to any weighting.

**TABLE 1**
**Climate Parameters Considered for Use in Classification Development**

| Issue/Strategy | Relevant Climate Variables |
|---|---|
| **Conduction/Insulation** | |
| Conductive heat loss to ambient | HDD65°F (HDD18°C), HDD50°F (HDD10°C) |
| Conductive heat loss to ground | Annual average dry-bulb temperature |
| Conductive heat gain from ambient | CDH80°F (CDH27°C), CDH74°F (CDH23°C), CDD65°F (CDD18°C), CDD50°F (CDD10°C) |
| **Solar/Control** | |
| Building orientation and form | Incident solar north, east-west, south |
| Window SHGC | CDH74°F (CDH23°C), CDD65°F (CDD18°C), incident solar north, east-west, south |
| Fixed shading | Latitude, CDD65°F (CDD18°C) |
| **Solar/Utilization** | |
| Passive solar heating | Incident solar south (five coldest months) |
| Building-integrated solar collectors | Incident solar (south tilt = latitude) |
| Daylighting | Annual average clearness index |
| **Misc./Design** | |
| Infiltration/exfiltration control in assemblies | HDD50°F (HDD10°C), latent enthalpy hours |
| Moisture control in assemblies | ASHRAE climate zone (from ASHRAE Fundamentals Handbook [ASHRAE 2001]) |
| Natural ventilation | Hours 8 a.m. – 4 p.m. between 55°F - 69°F (13°C - 21°C), average wind speed five warmest months, hrs. 55°F - 75°F (1°C – 24°C), and coincident wind speed (for residential) |
| Vestibule requirements | HDD50°F (HDD10°C) |
| **Mechanical/Miscellaneous** | |
| Economizer cooling | Hours 8 a.m. to 4 p.m. between 55°F - 69°F (13°C - 21°C) |
| Night venting strategies | Hours 8 a.m. to 4 p.m. between 55°F - 69°F (13°F - 21°C) |
| Moisture control in duct insulation | Monthly mean dew-point temperature |
| Evaporative cooling | 0.4% mean coincident wet-bulb temperature |
| Ventilation heat/coolth recovery | HDD50°F (HDD10°C) |
| Heat pump vs. electric resistance heat | HDD65°F (HDD18°C) |
| Ground-source and groundwater-source heat pumps | Annual average dry-bulb temperature |
| Absence of need for mechanical cooling | Cooling design dry-bulb temperature, mean coincident wet-bulb temperature |
| Absence of need for mechanical heating | Heating design dry-bulb temperature |
| Service/domestic water heating | Annual average. dry-bulb temperature |
| Peak demand/load management | Cooling design dry-bulb temperature, mean coincident wet-bulb temperature, heating design dry-bulb temperature |

analysis, the influence of these cooling-oriented variables continues to work against a clean geographically based set of zones.

For these and other reasons, we chose to set aside the cluster analysis tools and resort to more subjective methods to define the final division for the classification.

## Defining the Final Zones

The process we used to define the final zones was informed by the preliminary analyses using cluster analysis but not based directly on those analyses. Instead, boundaries were found in the Köppen classification that served as good approximations for the divisions that emerged from the cluster analysis-based groups but avoided the problems evident in the preliminary work using cluster analysis. Final numeric definitions were based on the Köppen-Geiger system as represented by Strahler (1969) and interpretation of Köppen's original work (1918), as documented in footnotes to Table 2 of the companion paper (Briggs 2003).

Figure 6 shows the climate divisions that resulted when the new classification process was applied to the United States. The country was divided into three primary climate groups—humid, dry, and marine. This and other major features of the classification are discussed below, using the continental United States to illustrate the development process and resulting classification.

**Humid-Dry Division.** The performance of several energy-related measures is influenced by atmospheric moisture. Other measures are influenced by parameters that correlate strongly with atmospheric moisture (and precipitation), such as the average intensity of incident solar radiation and diurnal temperature ranges. More than half of the strategies of interest listed in Table 1 relate either directly or indirectly to moisture.

After evaluating the correlations among climatic parameters related to atmospheric moisture (e.g., rainfall, relative humidity, cooling design conditions, incident solar, and atmospheric clearness), we decided to use a definition for dry and humid climates based on the Köppen-Geiger system, which uses annual precipitation (Strahler 1969). See Table 2 in the companion paper (Briggs 2003) for the quantitative definitions used in the new classification. The humid-dry boundary is defined in such a way that less annual precipitation is required for a cold location to be classified as "humid" than for a warm location. The "precipitation effectiveness" concept that underlies the definition is not unrelated to the psychrometric issues relevant to buildings and human comfort.

Figure 6 shows the humid-dry dividing line as applied geographically to the United States. Based on Köppen's early work (shown in Figure 2), the humid-dry dividing line bisects Texas as well as a band of states to the north—Kansas, Nebraska, and the Dakotas. Based on the definition shown in Table 2 (from the later Köppen-Geiger system), this dividing line falls close to the western boundary of the northern tier of states (Kramer 1963), which we ultimately used as the geographic boundary for this major division. Locating the humid-dry boundary along the state lines led to a simpler classification for the affected states. The humid-dry division is important from a continental perspective, where variations are

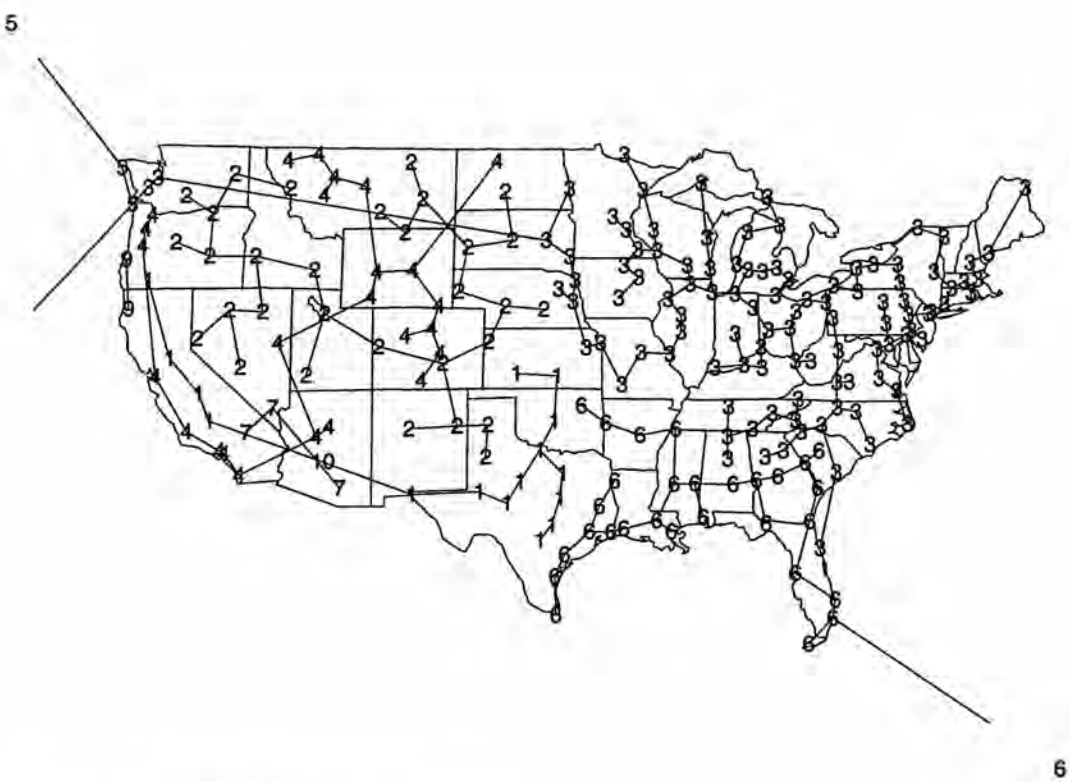

***Figure 5** Example clustering results for the U.S.*

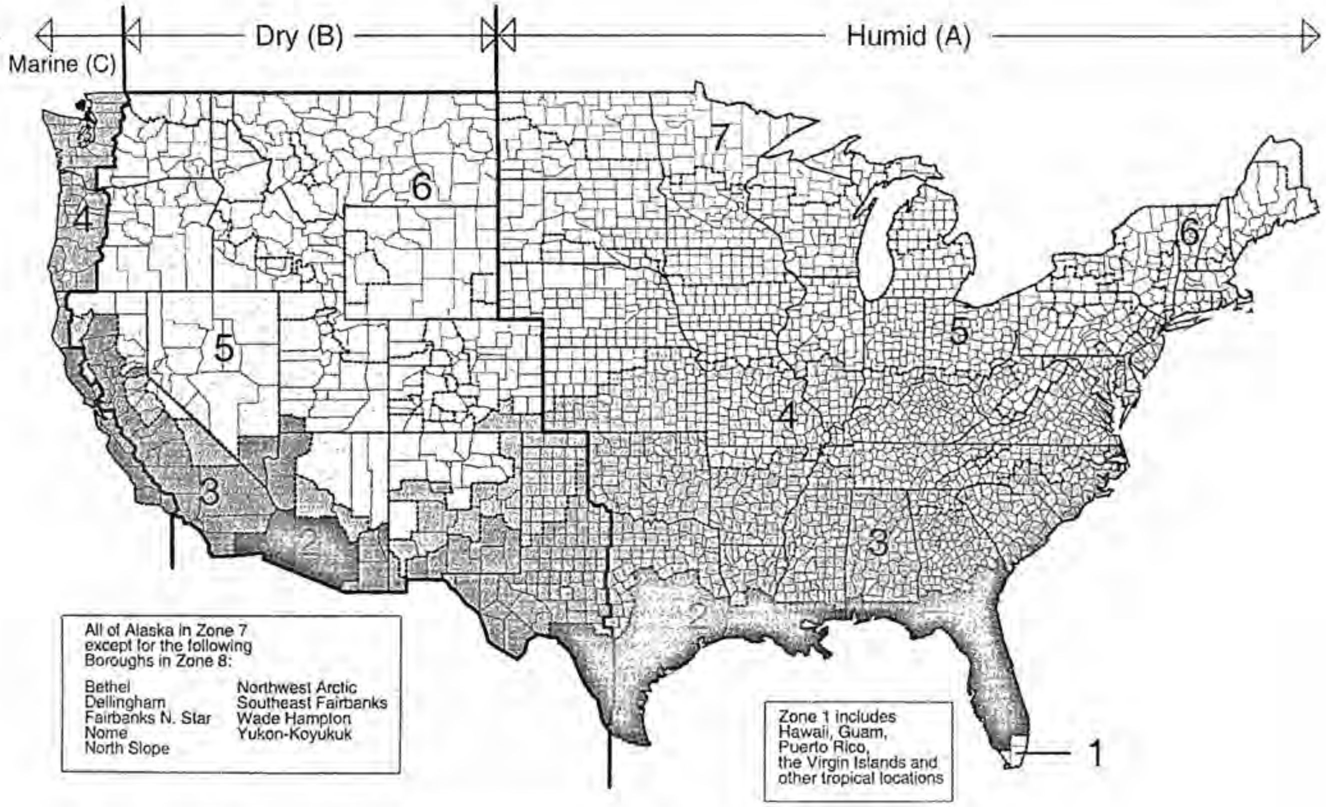


***Figure 6*** *Map of the U.S. showing climate zone assignments under the new classification.*

quite large, but it is not important enough within these states to warrant additional climate zones.

Similar humid-dry divisions can be found on most of the world's continents. Large areas having desert or steppe climates are found in central Australia, northern and southern Africa, central Asia, and parts of southern South America. In Europe, only limited areas in northern Spain meet the dry climate criteria.

**Marine Division.** In the United States, the equable climates of the Pacific Coast emerged as distinct groupings in many of the preliminary cluster analyses we performed. While the land area falling within this climate grouping is relatively small, it includes much of the most densely populated parts of three western states and includes the metropolitan areas of Seattle, Portland, and San Francisco. Both empirical and simulation-based studies of building energy use reveal that buildings in these locations tend to require significantly less energy for space conditioning than buildings in other parts of the country. Many residential buildings in these areas do not need mechanical air-conditioning.

We based the boundary for these marine climates primarily on definitions from the Köppen-Geiger system (Strahler 1969, Köppen 1931). For the United States, minor adjustments to the resulting climate maps were necessary to keep some sites east of the Cascade Mountains in Oregon and Washington and in the Sierra Nevada of Northern California out of the Marine zone. In Southern California, three coastal counties—Los Angeles, Orange, and San Diego—were excluded from the Marine zone because most of the remaining developable land area in these counties lies in warmer inland areas that do not meet the marine division criteria.

Climates meeting the criteria for marine zones occur in a number of locations around the world. Mediterranean climates are found in southern Europe and extreme north and south Africa, along the southern coast of Australia, and along the Pacific Coast in South America. Cooler areas that fall within the marine division occur in New Zealand, along the southeast coast of Australia, on the southern tips of Africa and South America, and along the Pacific coast of Canada. In the Americas, mountain ranges that parallel the Pacific coast limit the marine influences to narrow strips near the coast. In northern Europe where low lands extend far into the continent's interior, marine influences affect much larger areas. As a result, most of northern Europe (including all of the British Isles and much of Norway) falls into this division.

**Cooling-Dominated vs. Heating-Dominated Division.** The United States was used as a case study in establishing a cooling-dominated versus heating-dominated division. Throughout most of the eastern United States, isotherms run largely east-west, and a continuum of temperature conditions is present from the cooling-dominated climates in the South to the heating-dominated climates in the North. We chose to define climate zone divisions for the cooling-dominated climates using cooling criteria [CDD10°C (CDD50°F)] and for heating-dominated climates using heating criteria [HDD18°C (HDD65°F)]. A mixed cooling and heating zone defined by both criteria falls in between.

The placement of the boundary between Zones 3 and 4 (see Figure 6) was particularly significant because that boundary was situated to become the northerly limit for restrictions on glass SHGC for residential buildings in the IECC.[4] The existing boundary in the IECC is 3500 HDD65°F (1944 HDD18°C). Replacing that criterion with 2500 CDD10°C (4500 CDD50°F) created a line that generally coincides with the previous boundary through much of the South. However, the zone where SHGC is restricted was pushed significantly northward in parts of Oklahoma and was withdrawn from some areas of coastal California by the change. Both of these changes appear to be technically justified, as they extend the requirement where savings are high and withdraw them where savings are low in relation to other locations along the boundary.

We performed some analyses to assess the merits of using different cooling indices, e.g., CDD10°C, CDD18°C, CDH23°C, and CDH27°C (CDD50°F, CDD65°F, CDH74°F, and CDH80°F), respectively. CDD10°C was obviously a convenient index to use for translating 90.1-2001 criteria into the IECC, but 10°C (50°F) seemed too low for residential uses given generally assumed balance-point temperatures. These analyses revealed weaknesses in each of the candidate indices in that they tend to mask important climatic differences for some locations. For example, using CDD10°C causes some cool marine climates in the Pacific Northwest with no cooling needs to look just like (i.e., have similar CDD10°C indices as) humid locations on the East Coast with very significant cooling needs. However, using CDH27°C (CDH80°F) results in similar problems in that obviously dissimilar sites share very low values for CDH27°C.

We ultimately selected CDD10°C because it appeared to perform no worse that the other cooling indices overall and because it facilitated mapping of 90.1 requirements. In addition, once sites were separated according to the major climate groups—humid, dry, and marine—the shortcomings of any of these climatic parameters became far less problematic.

**Other Zone Boundaries.** An informal target number of 10 to 20 climate zones had been established early in the development process. Given that constraint, it was necessary to use much wider bands for the thermal parameters than the 500 HDD65°F (278 HDD18°C) bands currently used in the IECC. We selected bands of 1000 HDD18°C (1800 HDD65°F) because they resulted in boundaries that align with boundaries in the 90.1-2001 bins, facilitate the use of both SI and I-P units, and were able to effect a significant reduction in the number of zones. The 5000 CDD10°C (9000 CDD50°F) dividing line for the lower limit of the hottest zone (also a 90.1 bin boundary) was selected because it corresponds in the United States with the dividing line between tropical and subtropical climates in the Köppen-Geiger system (tropical requires that all mean monthly temperatures be over 18°C [64.4°F]). This put the tip of Florida in a zone with other locations that have essentially no heating loads, including many Caribbean Islands and vast areas in central South America, central Africa, and south Asia. The 3500 CDD10°C (6300 CDD50°F) dividing line was selected because it kept a set of humid Gulf Coast locations that had emerged as a group in many of the cluster analyses together with most of Florida and south Texas.

**Application Outside of the United States.** Given the interest of ASHRAE and the ICC in producing materials that are useful internationally, consideration was given in this work to its application outside of the United States. Linking the climate zones to Köppen's system of world climate classification, which is regarded as something of a standard, appears useful in encouraging international use. Any location in the world that has been mapped using the Köppen's system and for which some basic thermal data are available can be assigned a climate zone using these definitions.

However, some caveats are in order with respect to application of the classification outside of the United States. Numerous versions and variations on Köppen's original climate maps have been developed, and boundaries between zones can shift depending on which climate data were used in constructing the maps. Some reviewers of Köppen's work have suggested that his system is most useful when viewed as a pliable framework that can be adapted to specific needs rather than as a rigid and absolute classification system. The application of Köppen's climate criteria was made using examples from the United States, and time constraints prevented close examination of how these decision would apply on other continents. For example, Köppen's "dry season in summer" subtype was used in defining marine climates in the United States. In Northern Europe, this criterion does not appear to be necessary. There, equable climates (the chief attribute of the marine zone) occur further inland and in locations with more balanced precipitation throughout the year.

Two climate zones were defined in the classification but not thoroughly evaluated or actively applied because no sites in the United States or its possessions required their use. The two zones were 1B (dry and >5,000 CDD10°C [9,000 CDD50°F]), characterized as "tropical desert," and 5C (marine and 3000 < HDD18°C _ 4000 [5400 < HDD65°F _ 7200), characterized as "cool marine." The marine (C) designation was not used for zones colder than Zone 5 (or hotter than Zone 3), as marine climates are inherently neither very cold nor very hot. In addition, the humid (A) and dry (B) divisions were dropped for zones colder than Zone 6 because they did not appear to be warranted based on differences in appropriate building design requirements. Reevaluation of these decisions might be warranted before the approach is applied to locations outside of the United States.

4. The 1998 through 2002 editions of the IECC restrict window glass solar heat gain coefficient (SHGC) to a maximum of 0.4 in all locations with HDD65°F less than 3500 (HDD18°C < 1944). For locations HDD65°F greater than 3500, there is no restriction on SHGC.

## SUMMARY

This paper describes the process for development of a new climate classification for use in implementing building energy codes, standards, and beyond-code guidelines. We believe the new classification will prove simpler, more effective, and easier to use than those currently in use.

This paper documents the need for improved methods and materials for addressing climate in current energy codes and standards. It discusses various ways of categorizing climates that have been used in the past for various purposes and describes the process we used to develop a new classification for buildings and energy that is well rooted in scientific approaches to climate classification.

Complete definitions and descriptions of the new climate classification and comparisons to current classifications are presented in a companion paper, "Climate Classification for Building Energy Codes and Standards: Part 2 – Zone Definitions, Maps, and Comparisons" (Briggs et al. 2003).

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## REFERENCES

Andersson, B., W.L. Carroll, and M.R. Martin. 1985. Aggregation of U.S. population centers into climate regions. *ASHRAE Transactions* 91(2). Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

ASHRAE. 2001. *2001 ASHRAE Handbook—Fundamentals*, IP Edition. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

ASHRAE. 2001. *ASHRAE/IESNA Standard 90.1-2001, Energy Standard for Buildings Except Low-Rise Residential Buildings*. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

ASHRAE. 1999. *ASHRAE/IESNA Standard 90.1-1999, Energy Standard for Buildings Except Low-Rise Residential Buildings*. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

ASHRAE. 1993a. *Energy Code for Commercial and High-Rise Residential Buildings—Codification of ASHRAE/IES Standard 90.1-1989*. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

ASHRAE. 1993b. *ANSI/ASHRAE Standard 90.2-1993, Energy-Efficient Design of New Low-Rise Residential Buildings*. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

ASHRAE. 1989. *ASHRAE/IES Standard 90.1-1989, Energy Efficient Design of New Buildings Except Low-Rise Residential Buildings*. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

Briggs, R.S., R.G. Lucas, and Z.T. Taylor. 2003. Climate classification for building energy codes and standards: Part 2—Zone definitions, maps, and comparisons. *ASHRAE Transactions* 109(1). Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

BHKR (Burt Hill Kosar Rittelmann Associates). 1985. *Small Office Handbook: Design for Reducing First Costs and Utility Costs*. New York: Van Nostrand Reinhold Company.

CABO. 1995. *1995 Model Energy Code*. Falls Church, Va.: Council of American Building Officials.

CABO. 1993. *1993 Model Energy Code*. Falls Church, Va.: Council of American Building Officials.

CABO. 1992. *1992 Model Energy Code*. Falls Church, Va.: Council of American Building Officials.

Fovell, R.G., and C. Mei-Ying. 1993. Climate zones in the conterminous United States defined using cluster analysis. *Journal of Climate*, Vol. 6, pp. 2103–2135.

Hadley, D.L., and R.E. Jarnagin. 1993. Selecting representative climate stations for use in a building energy model. In *Proceedings of the CLIMA 2000 Conference*, Paper No. 277, CIBSE, London.

ICC. 1999. *International Energy Conservation Code*, 2000 Edition. Falls Church, Va.: International Code Council.

ICC. 1998. *International Energy Conservation Code*, 1998 Edition. Falls Church, Va.: International Code Council.

Köppen, W. 1918. Klassifikation der Klimate nach Temperatur, Niederschlag und Jahreslauf. *Petermanns Mitt.*, Vol. 64, pp. 193-203.

Köppen, W. 1931. *Grundriss Der Klimakunde*. Berlin: Walter De Gruyter & Co.

Kramer, F.L. 1963. The Köppen Dry/Humid Boundary: Preliminary Test of the Patton Formula. *Professional Geographer* 15(6):13-14.

Lstiburek, J. 2000. *Builder's Guide to Mixed Climates: Details for Design and Construction*. Newtown, Conn.: Taunton Press.

NCDC. 1993. Solar and Meteorological Surface Observational Network (SAMSON), 1961-1990, 3-volume CD-ROM set. Asheville, N.C.: National Climatic Data Center.

Oliver, J. 1991. The history, status and future of climatic classification. *Physical Geography* 12(3): 231-251.

Strahler, A. 1969. *Physical Geography*, 3d ed. New York: John Wiley and Sons, Inc.

Thornwaite, C.W. 1948. An approach toward a rational classification of climate. *Geographical Review*, Vol. 38, pp. 55-94.

DOE (U.S. Department of Energy). 2001. Building America Web Site, What are the climate zones? <http://www.eren.doe.gov/buildings/building_america/climate.shtml>.

DOE (U.S. Department of Energy). 1997. *COMcheck-EZ™ Compliance Guides—Commercial and High-Rise Residential Energy Code Compliance; Version 1.0.* DOE/EE/OBT-28432. Building Standards and Guidelines Program, Pacific Northwest National Laboratory, Richland, Wash.

## BIBLIOGRAPHY

Ackerman, E. A. 1941. The Köppen Classification of Climate in North America. *Geographical Review,* Vol. 31, pp. 105-111. New York: American Geographical Society.

Alkhalaf, A., and H. Kraus. 1993. Energy balance equivalents to the Geiger-Geiger climatic regions. *Bonner Meteorologische Abhandlungen*, No. 41, p. 69.

Knapp, C., T. Stoffel, and S. Whitaker. 1980. *Insolation Data Manual.* Solar Energy Research Institute, Rep. SERI/SP-755-789, Golden, Colo.

Connell, L.M., R.G. Lucas, Z.T. Taylor. 1996. *Methodology for Developing Version 2.0 of the MECcheck™ Materials for the 1992, 1993, and 1995 Model Energy Codes.* PNNL-11199/UC-1600, Pacific Northwest National Laboratory, Richland, Wash.

Owenby, J.R., D.S. Ezell, and R.R. Heim, Jr. 1992. *Annual Degree Days to Selected Bases Derived from the 1961 to 1990 Normals.* Climatography of the United States No. 81 - Supplement No. 2, U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Climatic Data Center, Asheville, N.C.

Spielvogel, L.G., and C.W. Griffin. 1980. *Air Conditioned Buildings in Humid Climates: Guidelines for Design, Operation, and Maintenance.* Southern Division, Naval Facilities Engineering Command, ARMM Consultants Inc., Gloucester, N.J.

Wilcock, A.A. 1968. Köppen After Fifty Years. *Annals of the Association of American Geographers*, Vol. 58, pp. 12-28.

Willmott, C.J., and Vernon, M.T. 1980. Solar climates of the coterminous United States: A preliminary examination. *Solar Energy,* Vol. 24, pp. 295-303.

Triantafyllou, G.N., and A.A. Tsonis. 1994. Assessing the ability of the Köppen system to delineate the general world pattern of climates. *Geophysical Research Letters 21*, No. 25, pp. 2809-2812.

DOE (U.S. Department of Energy). 1995. *1993 MECcheck™ Software User's Guide - 1993 Model Energy Code, Version 2.0.* Building Standards and Guidelines Program, Pacific Northwest National Laboratory, Richland, Wash.