Climate Classification for Building Energy Codes and Standards

Authors

Robert S. Briggs*, Member
Robert G. Lucas*
Z. Todd Taylor*, Member

Abstract

This paper describes a new climate classification for use in characterizing the performance of energy efficiency measures for buildings. This classification is designed for use in energy codes and standards, design guidelines, and building energy analyses. The paper includes a review of traditional climate classifications used by other disciplines and examines how climate is treated in current energy codes and standards. The new classification system is presented along with other materials that have been developed to facilitate its use in implementing energy codes and standards. Methods used to develop the classification are explained, and the classification is compared with others in current use. Significant advantages of the new classification are highlighted.

Keywords: building code, classification, code, energy, energy conservation, standard, weather data

* Robert S. Briggs is Senior Research Scientist with Pacific Northwest National Laboratory (PNNL), Robert G. Lucas is Science/Engineering Associate with PNNL, and Z. Todd Taylor is Senior Research Scientist with PNNL.

Climate Classification for Building Energy Codes and Standards

1 Introduction

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 climate 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 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 building energy codes and standards. The process used to develop the new classification is explained, and the climate zone definitions that make up the classification are presented and illustrated graphically. The new classification is also compared with those currently in use in a model energy code and an ASHRAE standard.

2 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 in Section 2.1. Classifications used with building energy codes and standards currently in force in the United States are discussed in Section 2.2.

2.1 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.

2.1.1 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 text books 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 scientist 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.

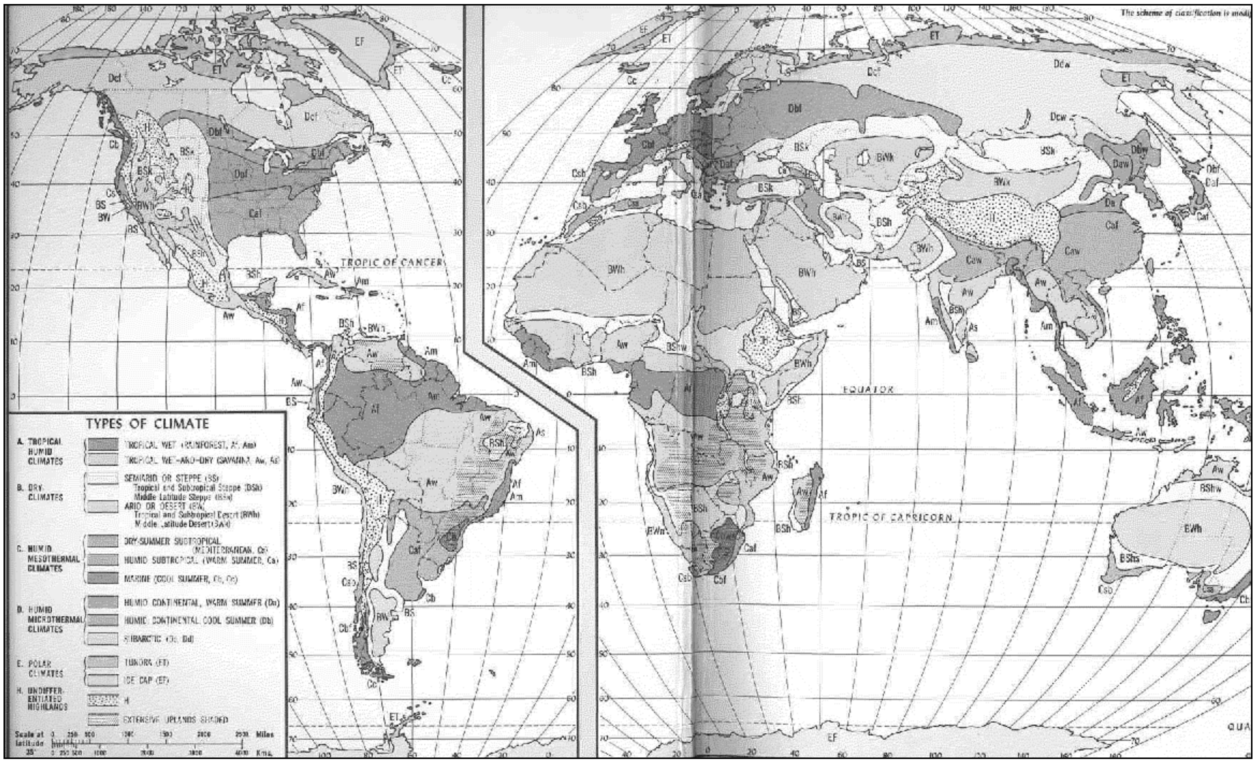

Figure 1 – World Climate Classification Based on Köppen's Work

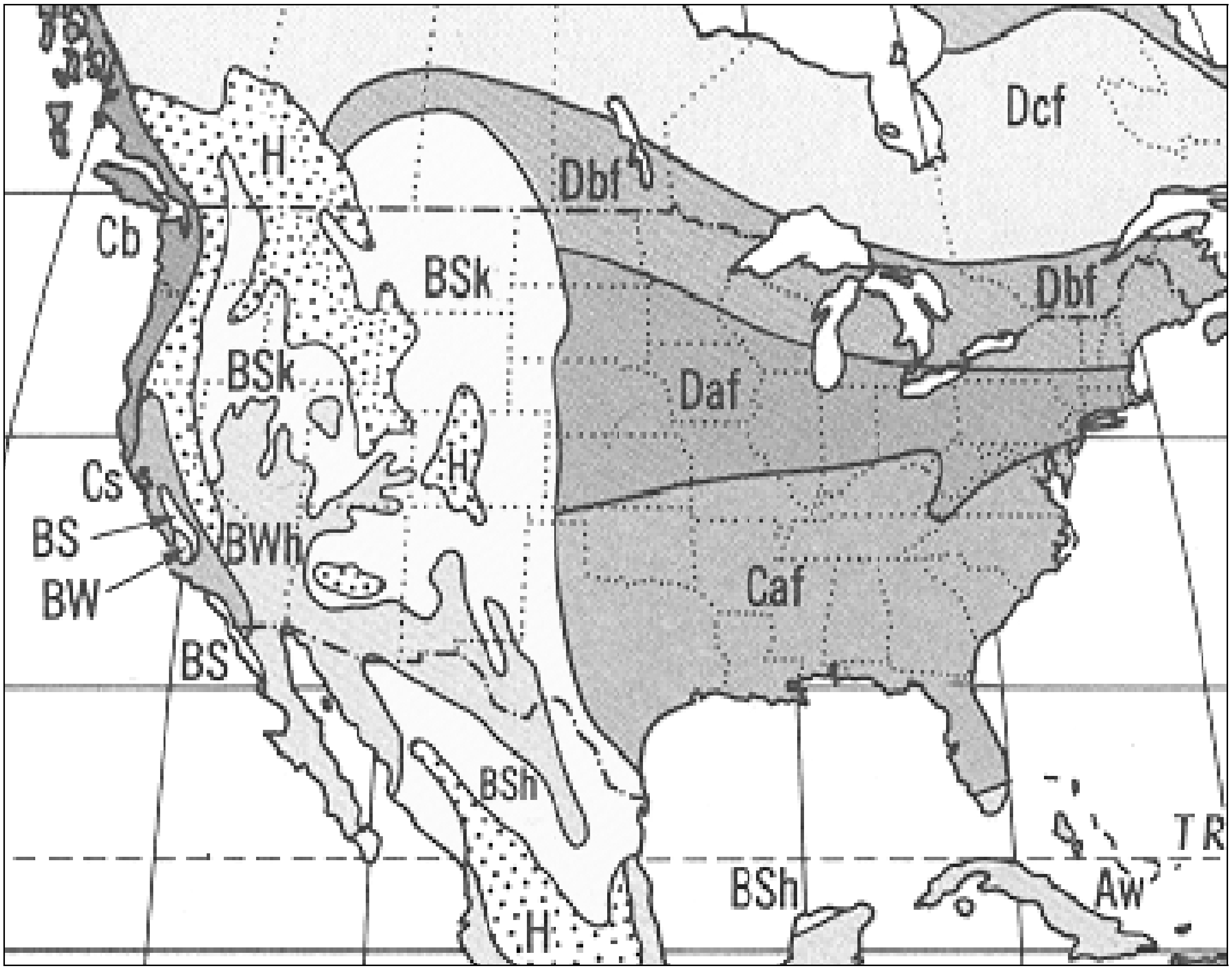

Figure 2 – Climate Classification of United States Based on Köppen's Work

2.1.2 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 climate 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 dataset. 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 dataset, 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 homogenous 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 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 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 the results of a cluster analysis in Table 8A-0, which specifies climate groups for use in applying building envelope requirements (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.

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 climate 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 climate data.

2.2 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.

2.2.1 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 supplanted 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, 1999). Most climate-dependent requirements in the 90.1 Code are in Section 402 entitled, "Building Envelopes." Appendix C of Standard 90.1-1989 contains climate 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 light-weight opaque walls based on heating degree-days base 65ºF (HDD65ºF) [18ºC (HDD18ºC)]. 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 HDD50ºF (HDD10ºC), cooling degree-days base 65ºF (CDD65ºF) [18ºC (CDD18ºC)], incident solar on vertical east- and west-facing surfaces, cooling degree-hours base 80ºF (27ºC), and HDD65ºF (HDD18ºC).

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.

2.2.2 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.

HDD65ºF (HDD18ºC) 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 climate data, so unless values for HDD65ºF (HDD18ºC) and design temperatures have been prescribed by the adopting authority, users of the MEC must obtain the necessary climate data from another source before using the code.

2.2.3 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]

[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. Pacific Northwest National Laboratory, Richland, Washington. *(Letter report available from PNNL at 800-270-2633)*

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 HDD65ºF (HDD18ºC) with zones numbered from 1 through 19; e.g., Zone 1 covers 0 to 500 HDD65ºF, Zone 2 covers 500 to 1000, and so on. In addition, some of the zones are 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 HDD65ºF (HDD18ºC). 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.

2.2.4 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 HDD65ºF (HDD18ºC) and CDD50ºF (CDD10ºC). 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 climate 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 65ºF and 50ºF correspond closely with 18ºC, a degree-day base temperature used internationally, and exactly with 10ºC, respectively.

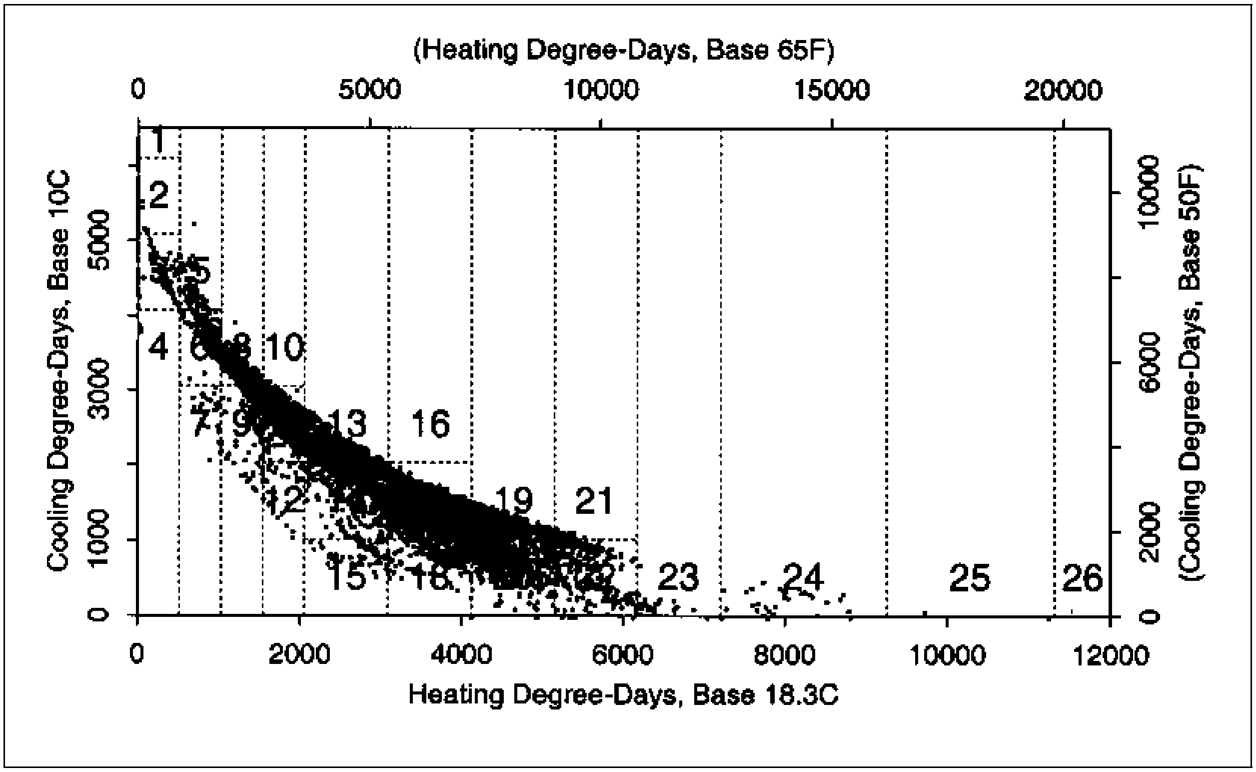

Figure 3 – Distribution of Roughly 5000 U.S. Locations Within 90.1-2001 Climate Bins

2.2.5 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 HDD65ºF (HDD18ºC) and CDH74ºF (CDH23ºC). 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.

2.2.6 Other Climate Classifications for Buildings

Several other national-level climate classifications have been developed over the years to address building design issues related to 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 U.S. Department of Energy (DOE) 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 DOE, also uses five climate zones featuring separate humid and dry zones (based on

Köppen), although zone names and dividing lines differ somewhat from Figure 4. 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 publications by Building Science Corporation (ASHRAE 2001; Lstiburek 2000).

A prominent feature of all of 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.

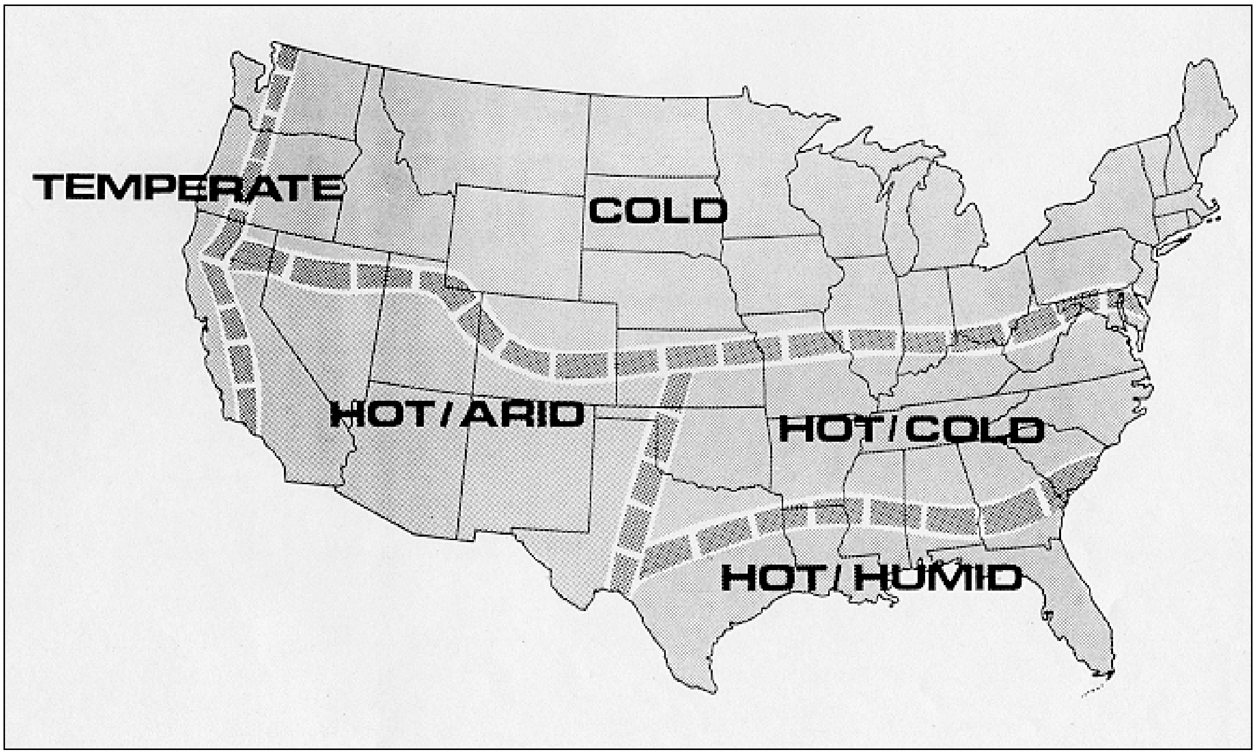

Figure 4 – Traditional Characterization of U.S. Climates for Energy-Efficient Building Design

3 Development Process

Developing a climate classification is challenging because of the complexity of the phenomena we understand as climate. Climate involves temperature, moisture, wind, and sun, and includes both daily

[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.

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 short-coming 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.

3.1 Determining Criteria for Climate 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 climate materials:

1. Offer consistent climate materials for all compliance methods and code sections (including both commercial and residential)
2. Enable the code to be self-contained with respect to climate 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.

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.

3.2 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.

Table 1 – Climate Parameters Considered for Use in Classification Development

Issue/Strategy	Relevant Climate Variables
Conduction/Insulation	
Conductive heat loss to ambient	HDD65ºF (HDD18ºC), HDD50ºF (HDD10ºC)
Conductive heat loss to ground	Annual average drybulb temperature
Conductive heat gain from ambient	CDH80ºF (CDH27ºC), CDH74ºF (CDH23ºC), CDD65ºF (CDD18ºC), CDD50ºF (CDD10ºC)
Solar/Control	
Building orientation and form	Incident solar north, east-west, south
Window SHGC	CDH74ºF (CDH23ºC), CDD65ºF (CDD18ºC), incident solar north, east-west, south
Fixed shading	Latitude, CDD65ºF (CDD18ºC)
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	HDD50ºF (HDD10ºC), latent enthalpy hours
Moisture control in assemblies	ASHRAE climate zone (from ASHRAE Fundamentals Handbook [ASHRAE 2001])
Natural ventilation	Hours 8 AM – 4 PM between 55 - 69ºF (13 - 21ºC), average wind speed five warmest months, hrs. 55 - 75ºF (13 – 24ºC) and coincident wind speed (for residential)
Vestibule requirements	HDD50ºF (HDD10ºC)
Mechanical/Miscellaneous	
Economizer cooling	Hours 8 a.m. to 4 p.m. between 55 - 69ºF (13 - 21ºC)
Night venting strategies	Hours 8 a.m. to 4 p.m. between 55 - 69ºF (13 - 21ºC)
Moisture control in duct insulation	Monthly mean dewpoint temperature
Evaporative cooling	0.4% mean coincident wetbulb temperature
Ventilation heat/coolth recovery	HDD50ºF (HDD10ºC)
Heat pump vs. electric resistance heat	HDD65ºF (HDD18ºC)
Ground-source and groundwater-source heat pumps	Annual average drybulb temperature
Absence of need for mechanical cooling	Cooling design drybulb temperature, mean coincident wetbulb temperature
Absence of need for mechanical heating	Heating design drybulb temperature
Service/domestic water heating	Annual average. drybulb temperature
Peak Demand/Load Management	Cooling design drybulb temperature, mean coincident wetbulb temperature, heating design drybulb temperature

3.3 Compiling Source Climate Data

- *We built a climate 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) dataset 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.

3.4 Generating Preliminary Zones Using Cluster Analysis

Our initial efforts involved cluster analyses of various subsets of the climate variables, weighted in various ways. These analyses[3] included evaluations of individual climate 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. Several issues are important to be aware of 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 climate 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 climate variables (cooling degree-hours base 80ºF, 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 climate 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 climate variables in a more comprehensive clustering 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.

[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.

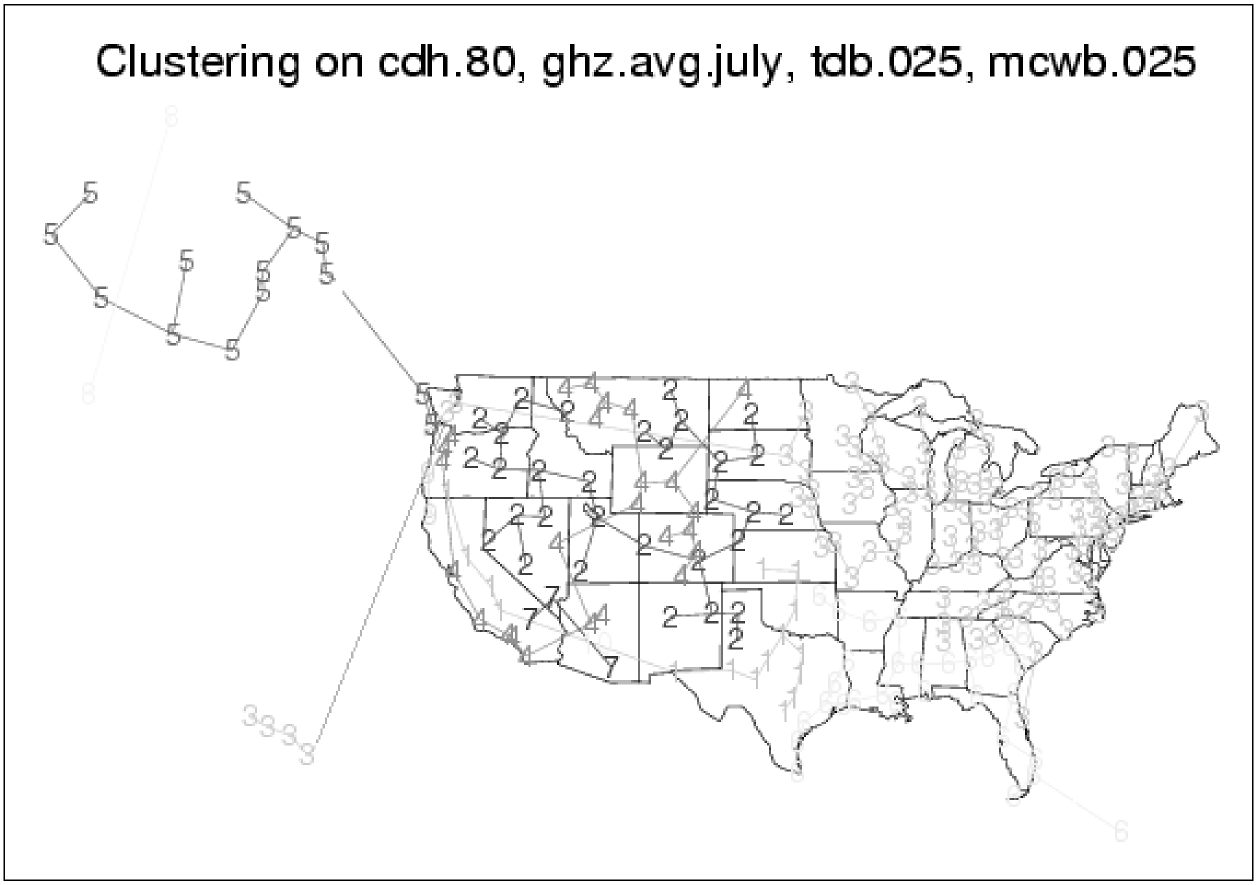

Figure 5 – Example Clustering Results for the United States

3.5 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 pre-existing classifications 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.

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 in Sections 3.5.1 through 3.5.4 using the continental United States to illustrate the development process and resulting classification.

3.5.1 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 climate 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 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, which we ultimately used as the geographic boundary for this major division (Kramer 1963). 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 quite large, but 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.

3.5.2 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); see Table 2. 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 lie 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 a 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.

3.5.3 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 are 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 [CDD10ºC (CDD50ºF)] and for heating-dominated climates using heating criteria [HDD18ºC (HDD65ºF)]. 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 HDD65ºF (1944 HDD18ºC). Replacing that criterion with 2500 CDD10ºC (4500 CDD50ºF) 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., CDD10ºC, CDD18ºC, CDH23ºC, and CDH27ºC (CDD50ºF, CDD65ºF, CDH74ºF, and CDH80ºF), respectively. CDD10ºC was obviously a convenient index to use for translating 90.1-2001 criteria into the IECC, but 10ºC (50ºF) 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 CDD10ºC, causes some cool marine climates in the Pacific Northwest with no cooling needs to look just like (i.e., have similar CDD10ºC indices as) humid locations on the East Coast with very significant cooling needs. However, using CDH27ºC (CDH80ºF) results in similar problems in that obviously dissimilar sites share very low values for CDH27ºC.

We ultimately selected CDD10ºC 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 climate parameters became far less problematic.

[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 HDD65ºF less than 3500 (HDD18ºC < 1944). For locations HDD65ºF greater than 3500, there is no restriction on SHGC.

3.5.4 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 HDD65ºF (278 HDD18ºC) bands currently used in the IECC. We selected bands of 1000 HDD18ºC (1800 HDD65ºF) 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 CDD10ºC (9000 CDD50ºF) 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 18ºC [64.4ºF]). 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 CDD10ºC (6300 CDD50ºF) 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.

3.5.5 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, appear 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 the definitions in Table 2.

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 suggest 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 were 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 CDD10ºC [9,000 CDD50ºF]), characterized as "tropical desert," and 5C (marine and 3000 < HDD18ºC ≤ 4000 [5400 < HDD65ºF ≤ 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. Re-evaluation of these decisions might be warranted before applying the approach is applied to locations outside of the United States.

4 Climate Materials

The climate classification is the centerpiece of a set of climate materials developed for implementing energy codes and standards. The classification has taken several different forms in the climate materials—state and national maps, tables that list the climate zones for each state/county, and a table that defines the underlying climate criteria on which the zones are based. Maps have proven useful over the years as an effective way to enable code users to determine climate dependant requirements. Zone numbers found on the maps serve as the index to a table of code requirements. The table of climate criteria, on the other hand, provides an explanation of the underlying basis for the maps and enables the classification to be applied outside of the United States. Climate zones defined rigidly from climate criteria inevitably contain discontinuities and awkwardly-placed zone boundaries that align poorly with administrative jurisdictions, therefore it was necessary to smooth some of the map boundaries. For code purposes in the United States, the maps and equivalent county-based lists must take precedence. The maps are clear and explicit and were developed to overcome ambiguities associated with classifications based directly on climate criteria.

4.1 Climate Zone Definitions

Tables 2A and 2B contain definitions and explanatory information for each of the 17 climate zones in the new classification.

Table 2A – Climate Zone Definitions for New Classification (Part A)

<table>
<tr><td colspan="2">A. Major Climate Type Definitions[1]</td></tr>
<tr><td colspan="2">I. Marine Type Definition - Locations meeting the following criteria:
• mean temperature of coldest month between –3ºC (27ºF) and 18ºC (65ºF)[2] AND
• warmest month mean < 22ºC (72ºF)[3] AND
• at least four months with mean temperatures over 10ºC (50ºF)[4] AND
• dry season in summer[5]. The dry season in summer criterion is met when the month with the heaviest rainfall in the colder season has at least three times as much precipitation as the month in the warmer season with the least precipitation. The colder season is October, November, December, January, February, and March in the Northern Hemisphere and April, May, June, July, August, and September in the Southern Hemisphere. All other months are considered the warmer season, in their respective hemispheres.</td></tr>
<tr><td>II. Dry Type Definition (SI) - Locations meeting the following criteria:
Not Marine AND
$P_{cm} < 2.0 \times (T_C + 7)$
where:
P_{cm} = annual precipitation in cm
T_C = annual mean temperature in degrees Celsius</td><td>II. Dry Type Definition (I-P) - Locations meeting the following criteria:
Not Marine AND
$P_{in} < 0.44 \text{ x } (T_F – 19.5)$
where:
P_{in} = annual precipitation in inches
T_F = annual mean temperature in degrees Fahrenheit</td></tr>
<tr><td>III. Humid Type Definition (SI) - Locations meeting the following criteria:
Not Marine AND
$P_{cm} \geq 2.0 \times (T_C + 7)$</td><td>III. Humid Type Definition (I-P) - Locations meeting the following criteria:
Not Marine AND
$P_{in} \geq 0.44 \times (T_F – 19.5)$</td></tr>
</table>

Notes:
1. Humid, dry, and marine zone definitions are based on Strahler 1963, Plate 2, except as noted.
2. These criteria are necessary to exclude Köppen's (D) "snow" climates and (A) "tropical" climates.
3. This criterion excludes the (a) "hot in summer" climates, such as the Southeastern and Midwestern United States.
4. This criterion excludes some marine climates in high latitude locations, such as Alaska, Iceland, and Northern Norway, from special treatment as marine climates.
5. This "dry season in summer" definition is from Köppen 1931 (German text), p.129. The authors were unable to find in this text quantitative definitions for "colder season" and "warmer season," only an acknowledgement of the inherent difficulty in defining these seasons in a way that is effective for all world climates. The month-based definitions were created by the authors to make the climate definitions complete and computable.
Under the variants of the Köppen system reviewed for this work, the dry in summer criterion was part of the Cs (Mediterranean) but not the Cb (Marine, Cool Summer) subdivision. We included it in the general Marine zone definition for use in the United States because dry summers are a characteristic attribute of the Pacific marine climates that we felt were necessary to recognize in the classification. It was also useful in excluding isolated locations in other parts of the country from meeting the Marine zone criteria. Specifically, sites at higher elevations in the Southern Appalachian Mountains (such as Asheville, NC) and medium elevations in the Southwestern United States (such as Albuquerque, NM) otherwise marginally met the marine criteria. Outside of the United States, such as in Northern Europe where marine influences extend far inland and summers are not as dry, this criterion may not be useful and could be dropped.

Table 2B – Climate Zone Definitions for New Classification (Part B)

B. Thermal Zone Definitions					
Zone No.	**Climate Zone Name and Type**	**Thermal Criteria(1,8)**	**Representative U.S. City***	**Köppen Class.**	**Köppen Classification Description**
1A	Very Hot – Humid	5000 < CDD10ºC	Miami, FL	Aw	Tropical Wet-and-Dry
1B(7)	Very Hot – Dry	5000 < CDD10ºC	---	BWh	Tropical Desert
2A	Hot – Humid	3500 < CDD10ºC ≤ 5000	Houston, TX	Caf	Humid Subtropical (Warm Summer)
2B	Hot – Dry	3500 < CDD10ºC ≤ 5000	Phoenix, AZ	BWh	Arid Subtropical
3A	Warm – Humid	2500 < CDD10ºC ≤ 3500	Memphis, TN	Caf	Humid Subtropical (Warm Summer)
3B	Warm – Dry	2500 < CDD10ºC ≤ 3500	El Paso, TX	BSk/BWh/H	Semiarid Middle Latitude/Arid Subtropical/Highlands
3C	Warm – Marine	HDD18ºC ≤ 2000	San Francisco, CA	Cs	Dry Summer Subtropical (Mediterranean)
4A	Mixed – Humid	CDD10ºC ≤ 2500 AND HDD18ºC ≤ 3000	Baltimore, MD	Caf/Daf	Humid Subtropical/Humid Continental (Warm Summer)
4B	Mixed – Dry	CDD10ºC ≤ 2500 AND HDD18ºC ≤ 3000	Albuquerque, NM	BSk/BWh/H	Semiarid Middle Latitude/Arid Subtropical/Highlands
4C	Mixed – Marine	2000 < HDD18ºC ≤ 3000	Salem, OR	Cb	Marine (Cool Summer)
5A	Cool – Humid	3000 < HDD18ºC ≤ 4000	Chicago, IL	Daf	Humid Continental (Warm Summer)
5B	Cool – Dry	3000 < HDD18ºC ≤ 4000	Boise, ID	BSk/H	Semiarid Middle Latitude/Highlands
5C(7)	Cool – Marine	3000 < HDD18ºC ≤ 4000	---	Cfb	Marine (Cool Summer)
6A	Cold – Humid	4000 < HDD18ºC ≤ 5000	Burlington, VT	Daf/Dbf	Humid Continental (Warm Summer/Cool Summer)
6B	Cold – Dry	4000 < HDD18ºC ≤ 5000	Helena, MT	BSk/H	Semiarid Middle Latitude/Highlands
7	Very Cold	5000 < HDD18ºC ≤ 7000	Duluth, MN	Dbf	Humid Continental (Cool Summer)
8	Subarctic	7000 < HDD18ºC	Fairbanks, AK	Dcf	Subarctic

<u>Notes</u>:

1. Column 1 contains alphanumeric designations for each zone. These designations are intended for use when the zones are referenced in the code. The numeric part of the designation relates to the thermal properties of the zone. The letter part indicates the major climatic group to which the zone belongs; A indicates humid, B indicates dry, and C indicates marine. The climatic group designation was dropped for Zones 7 and 8 because we did not anticipate any building design criteria sensitive to the humid/dry/marine distinction in very cold climates. Zones 1B and 5C have been defined but are not used for the United States. Zone 6C (Marine and HDD18ºC > 4000 (HDD65ºF > 7200) might appear to be necessary for consistency. However, very few locations in the world are both as mild as is required by the Marine zone definition and as cold as necessary to accumulate that many heating degree days. In addition, such sites do not appear climatically very different from sites in Zone 6A, which is where they are assigned in the absence of a Zone 6C..
2. Column 2 contains a descriptive name for each climate zone and the major climate type from Table 2A. The names can be used in place of the alphanumeric designations wherever a more descriptive designation is appropriate.
3. Column 3 contains definitions for the zone divisions based on degree-day cooling and/or heating criteria. The humid/dry/marine divisions must be determined first before these criteria are applied. The definitions in Table 2A and 2B contain logic capable of assigning a zone designation to any location with the necessary climate data anywhere in the world. However, the work to develop this classification focused on the 50 United States. Application of the classification to locations outside of the United States is untested.
4. Column 4 contains the name of a SAMSON station found to best represent the climate zone as a whole. See Section 4.3 for an explanation of how the representative cities were selected.
5. Column 5 lists the abbreviations for the climate groups based on a simplified version of the Köppen system (Finch et al. 1957). (see Figures 1 and 2). This information relates the climate zones to a widely-used world classification system, and may facilitate application outside of the United States.
6. Column 6 contains a verbal description derived from Köppen's work that serves to explain the two- and three-letter codes in the previous column.
7. Zones 1B and 5C do not occur in the United States, and no representative cities were selected for these zones due to data limitations. Climates meeting the listed criteria do exits in such locations as Saudi Arabia; British Columbia, Canada; and Northern Europe.
8. SI to I-P Conversions:

2500 CDD10ºC = 4500 CDD50ºF	3000 HDD18ºC = 5400 HDD65ºF
3500 CDD10ºC = 6300 CDD50ºF	4000 HDD18ºC = 7200 HDD65ºF
5000 CDD10ºC = 9000 CDD50ºF	5000 HDD18ºC = 9000 HDD65ºF
2000 HDD18ºC = 3600 HDD65ºF	7000 HDD18ºC = 12600 HDD65ºF

4.2 Climate Maps and Tables

Figure 6 presents the climate classification in the form of a map of the United States. The humid/dry/marine letter designations have been shown at the top of the map rather than with each zone number because some code requirements may use only the numeric (thermal) part of the zone designations. Larger scale maps showing only single states are being developed to facilitate code implementation in states containing more than one climate zone.

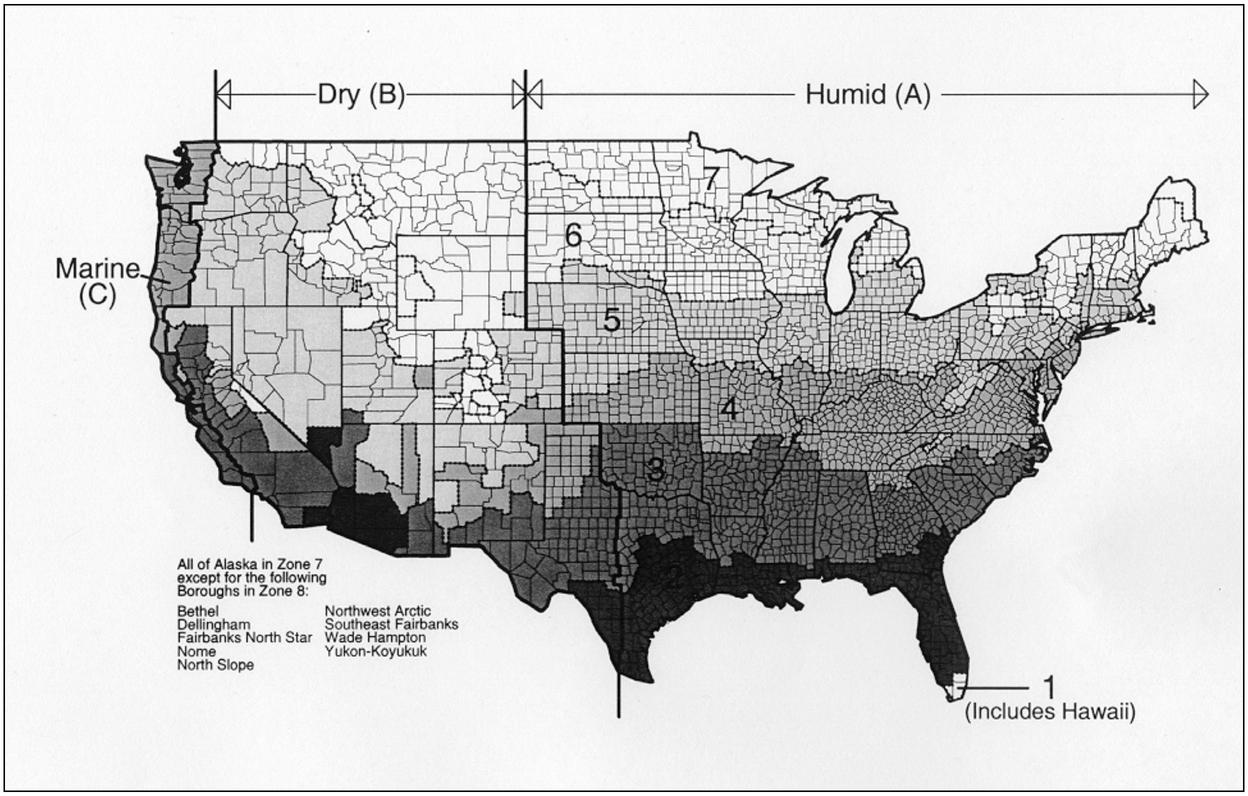

Figure 6 – Map of the United States Showing Climate Zone Assignments Under the New Classification

The materials include an alternate text-based presentation format. Several states, such as Texas and Georgia, contain a large number of relatively small counties. A table listing states and county zone assignments has been created to allow users to positively identify climate zone assignments in those few locations for which map interpretation may be difficult. The table was developed for inclusion in the code itself or as a normative appendix.

4.3 Representative Cities

Sections 4.3 and 4.4 discuss the development of two additional sets of data that complement the climate classification—representative cities and a mapping of counties to SAMSON weather stations. This information is pertinent to energy code development and to performance-based code compliance, respectively. Similar methods were used in developing each of these sets of supporting data.

We selected a representative city for each of the climate zones that occur in the United States (see Table 2B) to facilitate use of the classification in code development and other types of analyses. For example, code criteria could be developed for a given climate zone based on simulation performed using the designated representative city for that climate zone. Cities were selected from among the SAMSON stations for which TMY2 hourly weather files area available (Marion 1985). (We hereafter refer to these as SAMSON stations.) The representative city assignments are not intended for code users (i.e., those required to demonstrate compliance with the code) and are not intended for inclusion in the code document itself.

In choosing representative cities we sought to satisfy two criteria. First, it is desirable that the representative city be similar to the "average" weather conditions within a zone, not favoring either mild or harsh climates and preferably located somewhat centrally within the zone's geographic extent. Second, a representative city should, to the extent possible, favor weather conditions where buildings are predominantly located. These criteria are often in conflict since population centers tend to be in the milder climates. Because the potential uses of the representative cities are many and varied, there is no one "correct" set. The set we have chosen represents a compromise that facilitates a reasonable intuitive understanding of the climate zones and can be used to make reasonable assessments of energy performance of buildings within the climate zone. For situations that require better isolation of local climatic nuances, we have also mapped each individual county to a SAMSON station, as discussed briefly in Section 4.4.

Our approach for selecting representative cities was to examine the distribution of towns and cities within each climate zone and, using information about the cities' weather (heating and cooling degree-days) and population, identify a "best" SAMSON station to represent the cities in the zone. We made use of two supplementary databases of climate data and city information. First is a NOAA database of 4775 cities for which aggregate climate information is available (Owenby 1992). The NOAA database has been used for prior code-development work and is the basis for much of the climate information available in the MEC*check* and COM*check* code compliance software. (DOE 1995, 1997) Each NOAA location was mapped to a SAMSON station that best matches its climate, as discussed below in Section 4.3.1.

The second database was used to get better geographical coverage than is possible with the 4775 NOAA locations. The Populated Places database (PPL) is part of the Geographic Names Information System of the U.S. Geological Survey (USGS 2000). The PPL data include latitude, longitude, elevation, and population for over 164,000 identifiable locations (or "features" as they are called in the PPL documentation) in the U.S. and its territories. The PPL features are mostly cities and towns, but also include large housing subdivisions and other unincorporated places. While this level of geographical coverage is perhaps overkill for selecting zone-level representative weather stations, it is very helpful for county level mappings (see Section 4.4).. Also, because the PPL locations are tied directly to population, they better represent the geographic distribution of buildings than do the NOAA locations, many of which represent climates not typical of building construction, such as mountain tops, dams, forest lookout stations, etc.

The PPL data provides very good geographical coverage of the United States. However, since there is no climatic information included in PPL data, it was necessary to map each PPL location to one of the 4775

NOAA locations, as described below in Section 4.3.2. Each NOAA location was further mapped to a best representative SAMSON station, enabling each PPL location to be mapped to a representative SAMSON station. This allowed us to quantify the number, distribution, and population of cities and towns in each climate zone that are mapped to each SAMSON station. We used a combination of the total population referencing each SAMSON station and population-weighted climate means (e.g., HDD65ºF [HDD18ºC] and CDD65ºF [CDD18ºC]) to inform our selection of SAMSON stations to represent each zone. The final selections were based on subjective evaluations of these criteria, an effort to provide good representation for all US regions in the representative city set as a whole, and a deliberate bias towards the more populous and better know stations. The results are shown in Table 2B.

4.3.1 Mapping NOAA Locations to SAMSON Stations

In most cases, the best SAMSON station is the one closest to the subject NOAA location—the 4775 NOAA locations give fairly good coverage of much of the country. However, in many mountainous regions or sparsely populated regions the closest SAMSON station is not necessarily the best choice. We defined a new distance metric that incorporates not only the actual number of miles between NOAA/SAMSON pairs, but also the differences in heating and cooling degree-days and elevation.

We expressed the new distance metric in units of miles to facilitate reasoning about the differences. To transform degree-day and elevation differences into units of miles, we calculated an *equivalent latitude miles*. This quantity is based on the observation that as one moves northward (increasing latitude) or upward (increasing elevation), heating degree-days tend to increase and cooling degree-days tend to decrease. A regression analysis of the degree-day and elevation differences between various NOAA/SAMSON pairs allowed us to conveniently quantify those differences in units of miles. The equation resulting from that analysis is:

$$d_{equiv} = I + \alpha \times \Delta HDD + \beta \times \Delta CDD + \gamma \times \Delta Elev$$

where

d_{equiv} =	equivalent latitude distance between locations (miles),
ΔHDD =	difference in heating degree-days between locations (base-65F),
ΔCDD =	difference in cooling degree-days between locations (base-65F),
$\Delta Elev$ =	difference in elevation between locations (feet),
I =	-6.88315367
α =	0.10607746
β =	-0.01485033
γ =	-0.07184735

The best SAMSON station for each NOAA location was selected as the one with the minimum total distance:

$$d_{total} = d_{actual} + d_{equiv}$$

where

d_{actual} = actual distance between locations (miles),
d_{equiv} = equivalent latitude distance between locations (miles),

d_{total} = total distance describing geographical and climatic difference between locations (miles)

4.3.2 Mapping PPL Locations to NOAA Locations

Because of the vast number of PPL locations available (158,408 in the 50 states) it is almost always possible to select the nearest NOAA location as the best representation of the local climate. The exceptions are when the PPL location and the nearest NOAA location have very different elevations. Our process for assigning a representative NOAA location to each PPL location was quite simple:

1. For each PPL location, identify the 20 nearest NOAA locations based on geographic distance..
2. If the elevation of the nearest NOAA location is within 300 feet of that of the PPL location, use that NOAA location.
3. Otherwise, choose from among the 20 nearest NOAA locations the one that is nearest in elevation to that of the PPL location.

4.4 Mapping Counties to SAMSON Stations

Virtually every building energy code that has been developed for use in the United States has included a performance-based compliance path, which allows users to perform an energy analysis and demonstrate compliance based on equivalence with prescriptive requirements. In 90.1-2001, the method is called the, “Energy Cost Budget Method” (Chapter 11), and in the IECC it is called, “Systems Analysis” for residential buildings (in Chapter 4) and “Total Building Performance” for commercial buildings (in Section 806).

To perform these analyses, users must select appropriate weather data given their project’s location. Ordinarily these analyses require the use of 8,760 hours of weather data representing a typical weather year—data which are available for the SAMSON stations but not for any of the other data sets. The selection of appropriate weather data is entirely straightforward for any project located in or around one of the 237 SAMSON stations available for the United States and possessions. For other locations, selecting the most appropriate site can be problematic. The energy codes reviewed in Section 2 offer little help in these selections; they usually require the user to use climate data from a site that is “appropriate,” “representative,” “closest,” or “approved.” To simplify these decisions for users, we mapped every county in the United States to the most appropriate SAMSON station for each county as a whole. This mapping is not necessarily intended for inclusion in the code but could be included as an informative appendix to the code, included in a supporting document such as a users guide, or embedded in compliance software.

This mapping can be used in the absence of better information but should not necessarily be considered the only climate data permitted for a given county. Code officials and design practitioners may have access to data that better reflects regional or even microclimatic conditions than that available nationally for this work. Elevation has a large impact on climate, and elevation can vary dramatically within individual counties, particularly in the Western United States. Where elevation differences are significant, code officials may require use of sites that differ from these designations for performance-based compliance.

Appropriate treatment of elevation differences remains an unresolved issue in current energy codes. The new climate classification does not attempt to resolve this issue, leaving the problem in the hands of state and local code authorities. Where very high (or unusually low) elevation sites exist within a jurisdiction, code authorities may require use of SAMSON stations for performance-based compliance that different from the locations indicated in this mapping.

The method used to assign counties to SAMSON stations was very similar to the method used to assign representative cities to the climate zones (see Section 4.3). The main difference is that far less subjective evaluation was needed, and county assignments were based almost entirely on the total population of PPL locations mapped to each SAMSON station. That is, for each county, the representative SAMSON station is that station to which the greatest total PPL population "points."

5 Comparisons of New and Existing Climate Zones

An objective for any effective classification is to maximize between-group variation over the parameters of interest, while minimizing within-group variation. A large between-group variation will enable generalizations embodied in the code requirements to be better tailored to each climate zone. A small within-group variation will ensure that the generalizations will fit each zone. We contend that this new classification better represents climatic diversity while defining more coherent climate zones than the classifications it is designed to replace.

The following sections present brief comparisons between the new classification and the current IECC maps and the 90.1-2001 climate bins. However, given the many similarities between the new classification and the maps currently in the IECC, rigorous analysis of the differences hardly seemed warranted. Instead a brief discussion is provided that highlights major differences .

5.1 Comparison with Existing IECC Zones

The climate zones under the new classification represent a significant but evolutionary change from those in the 1998 through 2002 editions of the IECC. There are two chief differences between the classifications: 1) most dividing lines are based on 1800 degree-days Fahrenheit (1000 degree-days Celsius) divisions rather than 500 degree-day Fahrenheit (278 degree-day Celsius) increments and 2) the A, B, and C climate zone subdivisions used to reflect other climatic dimensions have been redefined to align with major, widely-recognized climatic types.

The increase in the size of degree-day bands has reduced the number of climate zones but also the coherence of the resulting zones, at least with respect to the degree-day parameters. Most interested parties seem willing to accept the reduced coherence in exchange for the significant (roughly 50%) reduction in the number of zones. However, offsetting the reduction in coherence due to larger degree-day bands is the fact that many of the new divisions simply make more sense climatically than those they are designed to replace. The new A, B, and C divisions have been used judiciously to better address climatic differences that have long been recognized as significant, which is not the case for the A, B, and C divisions in the current IECC maps. Other refinements, such as the use of cooling criteria as the basis for zone divisions in cooling-dominated climates, also serve to offset some of the "imprecision" introduced by using wider temperature bands.

5.2 Comparison with 90.1-2001 Climate Bins

Roughly 5,000 climate sites and their associated climates zone (or bin) assignments are shown overlaid on a map of the United States in Figures 7a and 7b. Figure 7a shows the bin assignments based on 90.1-

2001, and Figure 7b shows the bin assignments based on the proposed classification In Figure 7a, bins 1 through 9 are designated by their zone numbers, while bins 10 through 23 are designated by letters; i.e., Zone 10 by “a,” Zone 11 by “b,” and so on. In Figure 7b, the “A” (humid) zones and Zone 7 are designated using their numbers 1 through 7, “B” (dry) zones are designated using the letters a through f, and “C” (marine) zones are designated using the letters g and h. Both figures are based on strict bin or zone definitions; therefore, Figure 7b provides a picture of where divisions naturally fell prior to adjustments to better align them with state and county boundaries.

There are many similarities between the two figures. The zone assignments in Figure 7a appear a bit more variable partly because of the larger number of the categories displayed—23 vs. 14 in 7b. However, additional attributes of the distribution in 7a make coherent and effective geographic boundaries difficult to define. There is more overlap and interpenetration of the zone designations in Figure 7a than 7b. Further, where interpenetrations occur, there are often three or more bins interspersed. Any map developed to represent these categories must either be very complex or require extensive manual intervention to simplify. Figure 7b also shows some overlap of zone numbers, but these overlaps usually involve only two adjacent zones, affecting only the appearance of the dividing line between them.

Other problematic attributes of the Figure 7a distribution are that quite dissimilar climate types share the same bin designations. For example, Bin 5 includes sites in both the arid Southwest and the humid Gulf Coast and Florida. This climatic variation results in very large within-group variations for all parameters related to moisture. Sites in Bin 14 can be found in a band from Puget Sound in the Pacific Northwest to Northern California, and also in the Philadelphia and New York metropolitan areas. Bin 14 sites can also be found in Southern California, Arizona, Tennessee, and North Carolina. Several other bins, such as Bin 17, map to an even broader geographic area. Bin 17 can be found in no less than 30 different states. In contrast, under the new classification with 32% fewer zones, no climate zone can be found in more than 17 states.

Obviously, Figures 7a and 7b do not provide a definitive view of the effectiveness of these classifications. A rigorous statistical analysis probably could establish useful metrics for measuring the relative performance of the two classifications, although performing such analyses was not within the scope of this effort. However, the comparison they do offer is at least suggestive of some of the advantages offered by this new climate classification.

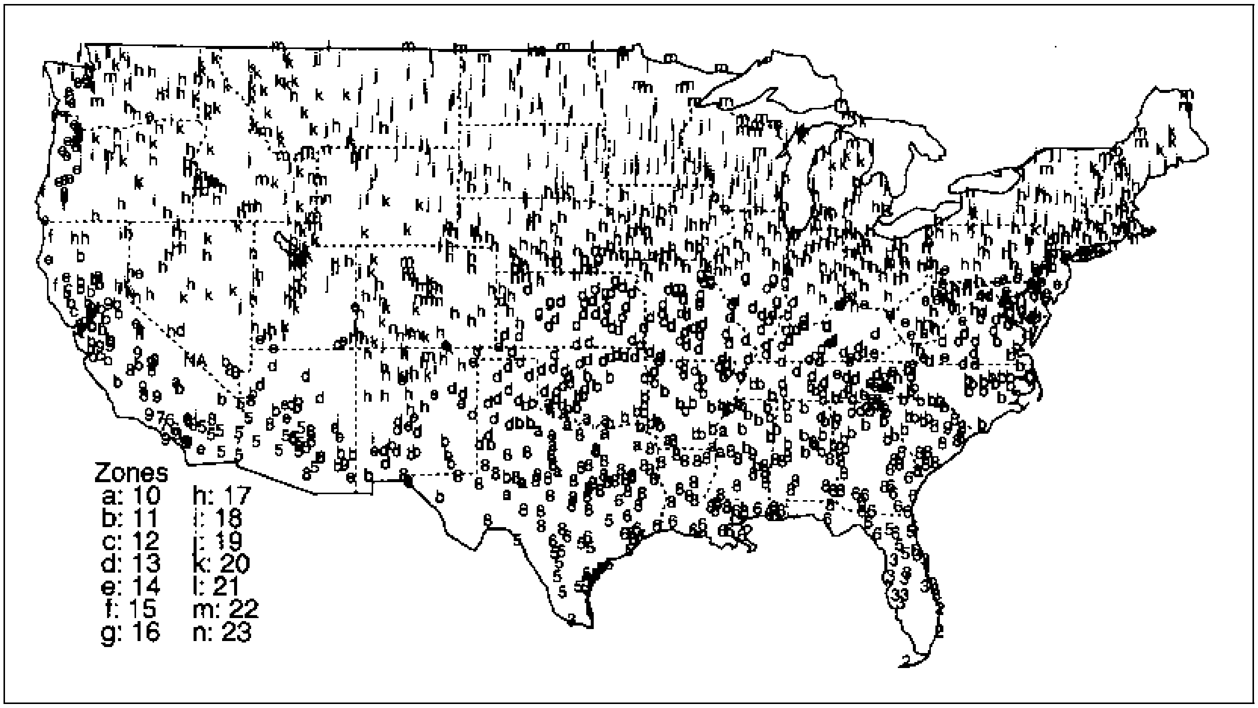

Figure 7a – Distribution of Locations Belonging to 90.1-2001 Bins

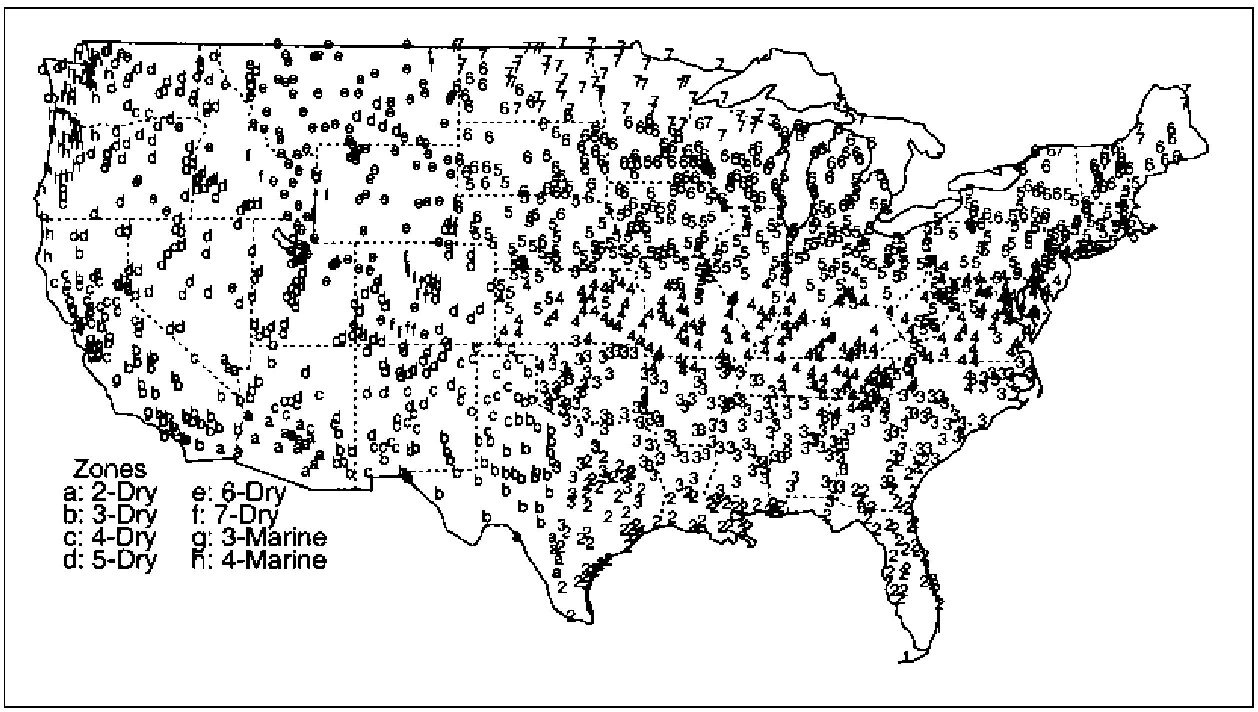

Figure 7b – Distribution of Locations Belonging to Climate Zones Under New Classification

6 Conclusion

This paper has presented 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. Evidence presented in this paper support the following assertions:

- A need exists for improved methods and materials for addressing climate in current energy codes and standards.
- The classification presented here is substantially simpler and more concise than current materials. The package of materials (maps, tables, zone definitions, and data files) developed to support the classification offer the potential to make codes and standards that use the materials less complex and easier to use.
- The new classification is well rooted in scientific approaches to climate classification. Its use of SI units and basis on a classification system that enjoys global acceptance may encourage acceptance of codes and standards that utilize the new classification outside of the United States.
- While this paper does not attempt to provide analytical proof, the comparisons with current approaches presented in this paper suggest the new classification offers an improved treatment of climate—offering climate zones that are both more homogeneous and better represent the range of climates found in the United States.

It is not possible to develop a classification for something as complex and multidimensional as climate that will be ideal for all applications and all situations. The new classification is intended to strike an appropriate balance between simplicity and usability on the one hand, and accuracy and analytical power on the other. If both the ASHRAE standards development community and the building codes community find that an effective balance has been achieved, this work could help expedite the incorporation of improved technical materials into the Nation's building codes.

7 Acknowledgement

The work reported on in this paper was funded by the Office of Building Research and Standards (BRS) of the U.S. Department of Energy (DOE-EE/RE). The DOE Program Manager for this effort was Mr. Ronald Majette.

The authors wish to gratefully acknowledge the generous contributions of John Hogan in providing technical guidance and review for this work.

8 References

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

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, Georgia.

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

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

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, Georgia.

Andersson, B., W. L. Carroll, and M. R. Martin. "Aggregation of U.S. Population Centers into Climate Regions." *ASHRAE Transactions*, 1985. V. 91 Pt. 2.

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

Council of American Building Officials (CABO). 1995. *1995 Model Energy Code*. Falls Church, Virginia.

Council of American Building Officials (CABO). 1993. *1993 Model Energy Code*. Falls Church, Virginia.

Council of American Building Officials (CABO). 1992. *1992 Model Energy Code*. Falls Church, Virginia.

Finch, V. C., G. T. Trewartha, A. H. Robinson, and E. H. Hammond. 1957. *Physical Elements of Geography*, Fourth Edition. McGraw-Hill Book Company, Inc., New York.

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, November 1993, CIBSE, London.

International Code Council (ICC). 1999. *International Energy Conservation Code*, 2000 Edition. Falls Church, Virginia.

International Code Council (ICC). 1998. *International Energy Conservation Code*, 1998 Edition. Falls Church, Virginia.

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

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

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

Lstiburek, J. February 2000. *Builder's Guide to Mixed Climates: Details for Design and Construction*. ISBN: 1561583758, Taunton Press, Newtown, Connecticut.

Marion, William and Ken Urban. 1985. "User's Manual for TMY2s – Typical Meteorological Years," National Renewable Energy Laboratory, Golden Colorado, June.

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

Oliver, J. 1991. "The History, Status and Future of Climatic Classification." *Physical Geography*, 12(3):231-251.

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, North Carolina.

Strahler, A. 1969. *Physical Geography*, Third Edition. John Wiley and Sons, Inc., New York.
Thornwaite, C. W. 1948. "An Approach Toward a Rational Classification of Climate." *Geographical Review*, Vol. 38, pp. 55-94.

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

U.S. Department of Energy (DOE). 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, Washington.

U.S. Geological Survey, National Mapping Division. 2000. The Geographic Names Information System. http://geonames.usgs.gov/gnisftp.html Reston, VA. March.

9 Bibliography

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

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, Colorado.

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, Washington.

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

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. ; Tsonis, A. A. . 1994. "Assessing the Ability of the Köppen System to Delineate the General World Pattern of Climates." *Geophysical Research Letters 21*, No.25, p.p. 2809-2812.