Title

AGGREGATION OF U.S. POPULATION CENTERS USING CLIMATE PARAMETERS RELATED TO BUILDING ENERGY USE

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DISCLAIMER

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SOLAR BUILDINGS RESEARCH AND DEVELOPMENT PROGRAM CONTEXT STATEMENT

November 21, 1985

In keeping with the national energy policy goal of fostering an adequate supply of energy at a reasonable cost, the United States Department of Energy (DOE) supports a variety of programs to promote a balanced and mixed energy resource system. The mission of the DOE Solar Buildings Research and Development Program is to support this goal, by providing for the development of solar technology alternatives for the buildings sector. It is the goal of the program to establish a proven technology base to allow industry to develop solar products and designs for buildings which are economically competitive and can contribute significantly to building energy supplies nationally. Toward this end, the program sponsors research activities related to increasing the efficiency, reducing the cost, and improving the long-term durability of passive and active solar systems for building water and space heating, cooling, and daylighting applications. These activities are conducted in four major areas: Advanced Passive Solar Materials Research, Collector Technology Research, Cooling Systems Research, and Systems Analysis and Applications Research.

Advanced Passive Solar Materials Research. This activity area includes work on new aperture materials for controlling solar heat gains, and for enhancing the use of daylight for building interior lighting purposes. It also encompasses work on low-cost thermal storage materials that have high thermal storage capacity and can be integrated with conventional building elements, and work on materials and methods to transport thermal energy efficiently between any building exterior surface and the building interior by nonmechanical means.

Collector Technology Research. This activity area encompasses work on advanced low-to-medium temperature (up to 180°F useful operating temperature) flat plate collectors for water and space heating applications, and medium-to-high temperature (up to 400°F useful operating temperature) evacuated tube/concentrating collectors for space heating and cooling applications. The focus is on design innovations using new materials and fabrication techniques.

Cooling Systems Research. This activity area involves research on high performance dehumidifiers and chillers that can operate efficiently with the variable thermal outputs and delivery temperatures associated with solar collectors. It also includes work on advanced passive cooling techniques.

Systems Analysis and Applications Research. This activity area encompasses experimental testing, analysis, and evaluation of solar heating, cooling, and daylighting systems for residential and nonresidential buildings. This involves system integration studies, the development of design and analysis tools, and the establishment of overall cost, performance, and durability targets for various technology or system options.

This report is an account of research conducted in systems analysis and applications research concerning passive solar technology assessment.

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ABSTRACT

A technique for aggregating population centers into groups based on selected climate parameters is presented. Climate information on the 125 largest Standard Metropolitan Statistical Areas (SMSAs) in the United States (U.S. Bureau of the Census 1980) is used to assign each SMSA to a particular group. The technique selects one SMSA in each region as a "climate center," whose climate is used to represent the entire region.

The 125 SMSAs contain over 140 million population and include every metropolitan area of 250 thousand or more. The climate variables used to group SMSAs of similar climate are heating and cooling degree days; $\overline{K}_T$, a measure of solar radiation; and latent enthalpy hours, a measure of moisture that must be removed from outside air to bring it to a standard comfort condition. Climate information is derived from SOLMET and TMY weather data. Characterization of U.S. climates in terms of these variables and relationships between pairs of variables is discussed.

An interactive agglomeration computer program, GLOM, aggregates the SMSAs into climate regions. The user provides aggregation rules based on specified ranges of the climate variables and a selection of initial climate centers. Considerable latitude is given to the user to manipulate and/or modify the computer-based groupings. The result is a series of SMSA groupings suitable for a wide variety of analyses in which climates with large populations can be evaluated using a minimum of representative centers for direct analysis. Statistical analysis is performed on each group to determine the population-weighted averages and ranges of climate parameters for SMSAs in the group and the relationship of each SMSA to group average climate characteristics and to the climate center of the group.

This information is useful in choosing climate centers for research that will have the greatest relevance for the greatest number of people. The technique has been used to determine climate regions and centers for the DOE Passive Cooling Technology Assessment. Because of the objective basis of the method, personal biases and misinformation about particular climates and climate "reputations" are largely overcome. In addition, the unrepresentativeness and relatively small populations of some popular sites for energy analysis, such as Albuquerque and Phoenix, are highlighted, and the similarity, by our criteria, of geographically distant sites (Boston-Seattle or New York-Cincinnati) are discovered.

INTRODUCTION

Research dealing with the effect of climate on buildings often takes the form of parametric computer analysis of typical buildings in one or more climates. The choice of climates is usually based on a variety of considerations, among which are proximity to the researcher, the researcher's familiarity with the climate, the availability of the data, the extremity of a climate, the uniqueness of a climate, and the choice of a climate by previous researchers.

As an example of such choices, four past residential parametric studies of the Passive Research and Development Group have used Albuquerque, Lake Charles (La.), Madison, and New York (Curtis 1979); Albuquerque and Madison (Kammerud 1979); Albuquerque and Washington (Place 1980); and Albuquerque, Madison, and Washington (Kammerud 1983). The choice of Albuquerque was dictated by its unusual climate ideally suitable to passive solar construction and its historical stature as a source of solar literature. Historical reasons also prompted the choice of Madison. Lake Charles was chosen to represent an additional climate *type* (hot, humid), and Washington was picked because of its familiarity to a large number of people. Only New York was included in part because of the number of people and/or buildings affected by its climate, and that decision was made only on a very subjective level.

As the state of the art advances, it is more common to make analyses for a much larger number of climates. Two recent studies (Place 1984; Andersson 1983) have used climates from the 26 original Typical Meteorological Year (TMY) climate data tapes*. Those sites were obviously chosen because weather data of the same quality as TMY was available at that time only for those sites, and they appeared at one glance to blanket the entire continental U.S. Since the purpose of such studies is to provide information to as many people as possible with regard to the given topic, the distribution of the sites is very important. If one looks more closely at the 26 sites, two shortcomings become quite clear.

First, climates representing very large segments of the population have been left out completely. For example, the large populations of the industrial Great Lakes region and southern California are not represented.

Second, and perhaps more important, are the sites that provide only a limited amount of useful information. This may occur because the climates of different sites (e.g. New York/Boston/Washington or Lake Charles/Apalachicola) are so close that analysis of several provides no significant increase in information over analysis of one. It may also occur because the sites used represent so few people or buildings (e.g. Great Falls, Bismarck, Dodge City, Ely, and even Albuquerque) that the implications of research findings are likely to be relatively insignificant.

In order to get the most out of building analyses having national implications, it is necessary to choose the sites to be analyzed by considering the impact the particular research is likely to have on the region climatically represented by a given site. Such consideration assures that no important areas are left out, and that valuable research time is not spent creating, compiling, and analyzing information of relatively limited value. One important correlation that has not been adequately quantified is the relationship between climate and population.

Numerous attempts have been made to define climate regions in the U. S. However, Kenneth Labs points out the limitations in popular regionalizations by House Beautiful (Siple 1949-52), Victor Olgyay (1963), Paul Grogger (1979), the American Institute of Architects (Loftness 1977;

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* "Typical Meteorological Year User's Manual: Hourly Solar Radiation - Surface Meteorological Observations," TD-9734, National Climatic Center, April 1981.

AIA/RC 1978), and Werner Terjung (1967): "...it is clear that overall agreement is not good. No consensus exists as to the necessary number, the delineation, or even the appropriateness of describing geographic zones for building design" (Labs 1982). The project described here differs from those above in that it attempts to present a *method* by which regions appropriate to a specific application can be generated, and incorporates consideration of population in the method.

In this report, we present a method of aggregating population centers based on the use of Standard Metropolitan Statistical Areas (SMSAs) according to similarity of climate. We also present a series of SMSA groupings based on a variety of climate definitions and assumptions about initial choices of sites. An important aspect of the method presented is the initial aggregation of climate regions based on *objective* categorization of the climates under consideration. In the process of refining those regions according to the users' specific needs, the process allows considerable flexibility, but the tendency to depend on personal impressions and interpretations of climate characteristics is largely eliminated. Discussions in this paper of the flexibility of the method should not be mistaken for the reintroduction of individual biases the method is intended to limit.

With the method provided here, researchers can begin to choose sites for climate analysis that will have the greatest impact, based on both the population represented by different sites and the researcher's evaluation of the importance of the particular topic in a given climate region.

METHODOLOGY

SMSA Data Base

For the purposes of this study, all the SMSAs with a total population greater than 250 thousand (July 1978 estimates) were identified. Thirteen groupings of SMSAs (Standard Consolidated Statistical Areas - SCSAs) replaced their constituent SMSAs, resulting in a total of 125 entities. All are referred to as SMSAs in our study (U.S. Bureau of the Census 1980).

The number of SMSAs was determined primarily by the population represented. The 25 largest SMSAs contain 91 million people, while the 25 largest SMSAs outside our group of 125 contain less than 5 million. Our 125 contain 143 million people, or about two-thirds of the country. Though we have made no attempt to allocate the populations of areas outside the SMSAs, our estimations indicate that the vast majority of the remaining population live in areas not significantly different, climatically, from the nearest SMSA. The only large areas not represented are Alaska and a stretch of the sparsely populated northern plains from western Minnesota to Idaho and northern Nevada. A smaller area without significant population centers is found in northwest Texas and eastern New Mexico.

Figure 1 is a map showing the distribution of the SMSAs used in this study. A list of the SMSAs can be found in Appendix 1. In the text and figures below, letters are used to identify eleven reference SMSAs. They are intended only to assist understanding of the concepts presented. The reference SMSAs and the regions they roughly represent are listed in Table 1. (The discussion of Figure 15 indicates possible reasons for aggregating climate regions around such SMSAs.)

Climate Characterizations

There are many ways of characterizing climates. The most common are subjective: rainy, sunny, hot, cloudy, humid, cold, windy, and many variations and combinations of these and other attributes. When dealing with building energy analysis, these subjective characterizations

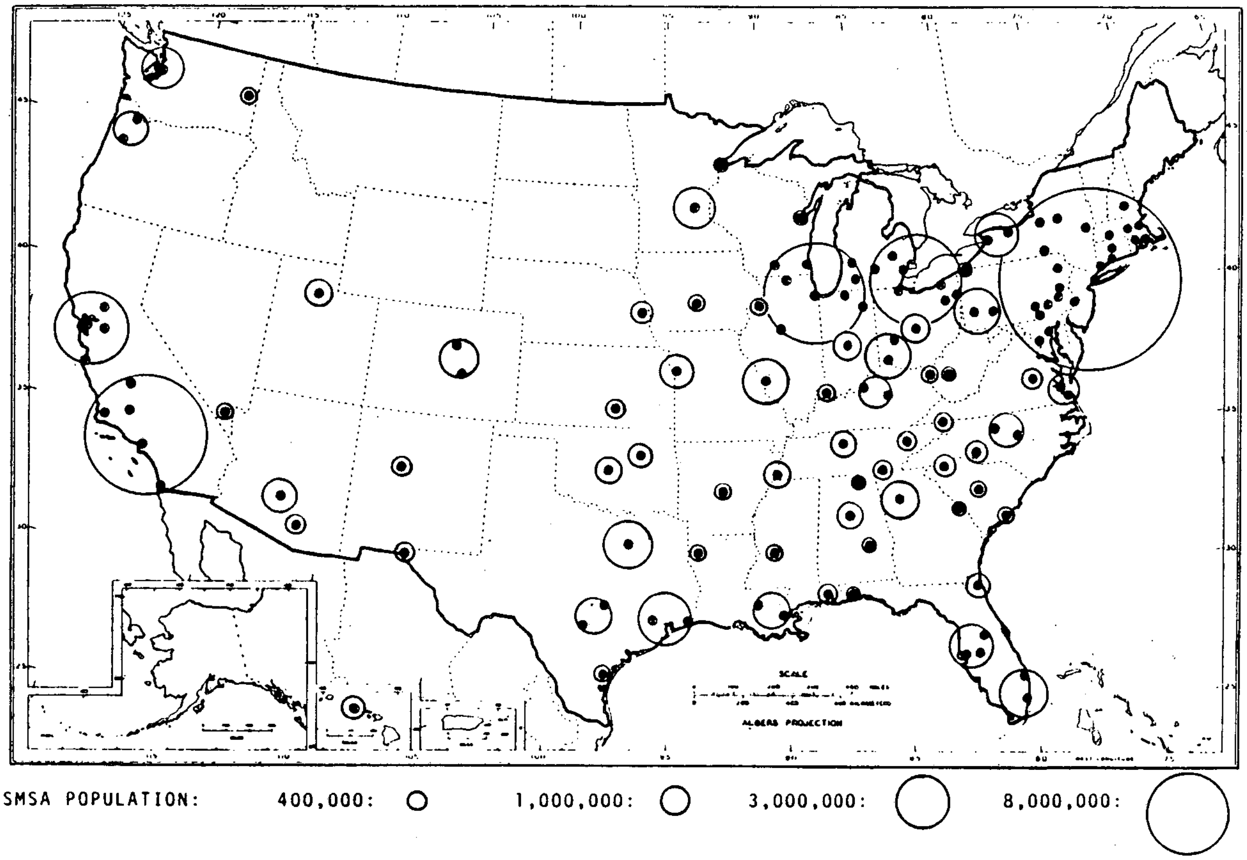

FIGURE 1: 125 LARGEST STANDARD METROPOLITAN STATISTICAL AREAS (SMSAs)

TABLE 1:
REFERENCE SMSAs & CLIMATE REGIONS

Climate Region	Reference SMSA	Key
Northeast	New York	N
Great Lakes	Detroit	D
South	Atlanta	A
Gulf Coast	Houston	H
California Coast	Los Angeles	L
Central Texas	Dallas	T
Northern Tier	Minneapolis	M
Fresno / El Paso	Fresno	F
Mountains	Denver	d
Pacific Northwest	Seattle	S
Desert Southwest	Phoenix	P

are inadequate for two reasons: the climate variables most distinctly affecting building energy use may not be the ones that form the most lasting impression on people; and the capability to compare two subjective characterizations is extremely likely to result in error. For example, the following statement is generally accepted: "It rains more in Seattle than in Boston." One should ask two questions when trying to decide if the statement has bearing on climate regions. First, is rainfall alone going to significantly affect the energy use of a building? Second, is the statement even true? The answer to each is no. The statement is merely a reflection of biases built on the climatic reputation of Seattle.

The Seattle-Boston example displays a bias built on Seattle's national reputation. Discussions of climate characteristics with a variety of people, including many researchers who use climate information regularly, have led to the conclusion that local biases are even more pronounced. There is a strong tendency for people to perceive variation of climate between nearby places familiar to them as much greater than variation of places farther away. The authors include themselves among those subject to this tendency and have been proved quite mistaken when objective climate measures have been used to test their judgment about climates they thought they understood.

If an objective grouping of climates for building energy analysis is to be made, it is necessary to identify those quantifiable characteristics that most closely relate climate to building energy use. It is then necessary to find a method of aggregating the locations for which data are available into regions of similar climate, based on those climate characteristics. The "House Beautiful" characterizations (Siple 1949-52) make an admirable early attempt to clearly quantify climates of specific locations and local climatic variation. An AIA/NOAA effort (AIA/RC 1978) illustrates the possibility of using building related climate characteristics to produce *one* regionalization of the U. S. A general methodology is required to develop regions appropriate to specific tasks.

For the purposes of this study, each climate is characterized by four quantities representing three climatic influences: heating and cooling degree days (temperature), $\bar{K}_T$ (solar), and latent enthalpy hours (humidity). $\bar{K}_T$ is the ratio of the available sunshine at the earth's surface to the sunshine available on a parallel plane above the atmosphere. Latent enthalpy hours are a measure of the amount of moisture that must be removed from outdoor air to bring it to 77°F and 60% relative humidity.

"Climate Region" and "Climate Center"

Our basic definition of a climate region is a group of SMSAs, each of whose climate characteristics fall within a defined range of variation of a climate center (a SMSA). Thus, a climate region is defined by the climate center around which it is aggregated and the ranges of variation allowed in each of the four climate parameters. This definition is in keeping with the intentions of this study, to use one climate description (that of the climate center) to characterize an entire climate region.

For purposes of analysis, a second climate center is introduced, an "ideal" population-weighted mean climate center. It is a climate defined only by the mean climate parameters of a SMSA grouping, weighted by the population of each SMSA, not an actual, physical place. This center can replace the "physical" climate center for analysis if the latter is removed from the region, or if the region is defined by absolute parameter ranges without reference to a physical center.

Data Base of Selected Climate Parameters

Heating degree days (HDD), cooling degree days (CDD), and $\bar{K}_T$ are all taken from long-term SOLMET averages (Knapp 1980) based on 24-25 years of measured information. Both degree day calculations are made from a base of 65°F (18.3°C). For a description of $\bar{K}_T$, see page vii of Knapp (1980). Briefly, it is the ratio of the average global horizontal radiation to the average extraterrestrial horizontal radiation.

Latent enthalpy hours (LEH) were calculated from a base of 61°F (16.1°C) dew point temperature and 75°F (23.9°C) dry bulb temperature, approximately in the center of the comfort zone, near the maximum allowable humidity in the zone. The excess moisture contained in air with higher enthalpy provides the basis for the enthalpy hour calculation in units of Btuh/lb of dry air (Wh^2/kg).

With respect to the 125 SMSAs used in this study, annual heating degree days range from 0 (Honolulu) to 9800 (Duluth), with a population-weighted mean of 4400 (Albuquerque or Louisville). Annual cooling degree days range from 100 (San Francisco and Santa Barbara) to 4200 (Honolulu), with a population-weighted mean of 1200 (Sacramento or Lexington, KY). Latent enthalpy hours range from 0 in several West Coast locations to 27,800 in Miami, with a population-weighted mean at 4000 (Baltimore or Lexington). Values over 8000 in this category are restricted to coastal areas of the Southeast and the Mississippi Valley. $\overline{K}_T$ fractions range from 0.41 (Binghamton, NY) to 0.70 (Las Vegas) with a weighted mean of .50 (Atlanta or Chicago). These values generally increase, moving from the Northeast to the Southwest.

Figures 2-5 show the distribution of population and SMSAs for each of the four climate characteristics. The location of several key cities is noted on the bar charts as well as the number of SMSAs represented in each bar.

Heating degree days, in Figure 2, show three major population peaks: the Northeast and Northwest at about 5100 HDD; the Great Lakes and Denver around 6200 HDD; and the southwest between Los Angeles and Houston at around 1700 HDD. A smaller peak occurs in the Southeast.

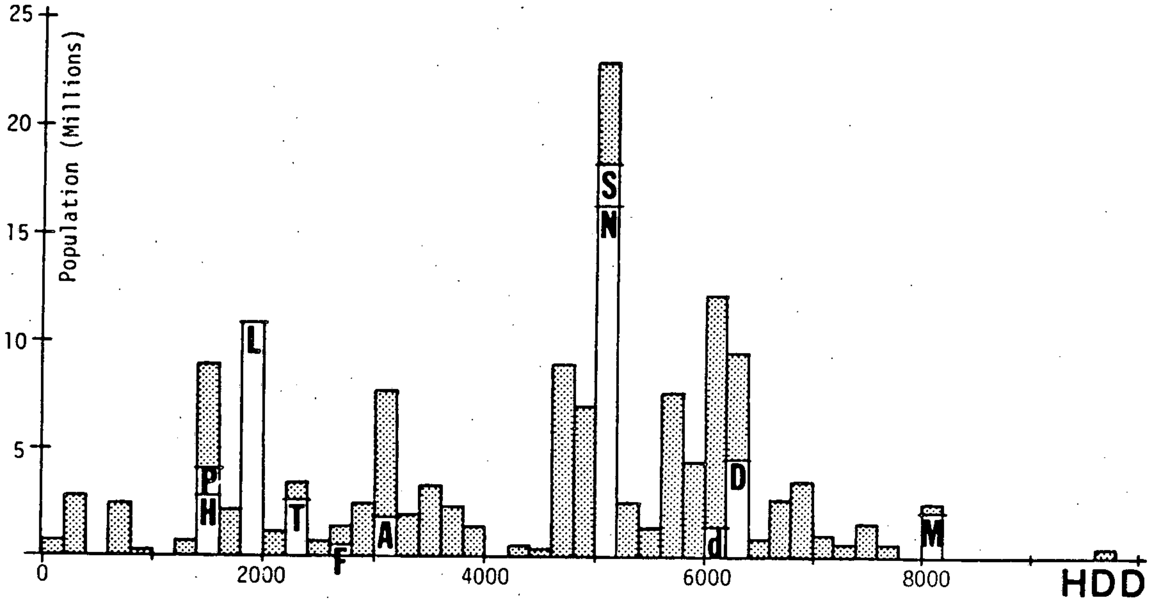

FIGURE 2: POPULATION DISTRIBUTION -- HEATING DEGREE DAYS (HDD)

Cooling degree days, in Figure 3, have much less variation, the dominant peak occurring between 400 and 1200 CDD, including the Northeast, Great Lakes, Mountain, and southern California regions, all with mild and/or short summers. The rest of the Pacific Coast is near zero. Smaller peaks occur for the Southeast (1600 CDD) and Texas (2800 CDD).

Latent enthalpy hours, in Figure 4, show an even more pronounced dominant peak, including virtually all of the country except for the Southeast and Texas. Half of the SMSA population lives in climates with less than 2000 LEH, three-quarters in climates with less than 4000. These are areas with cool (Northeast, Great Lakes) and/or dry (entire West) summers. Compare Atlanta (5000 LEH), Dallas (8000), Houston (19000), or Miami (28000).

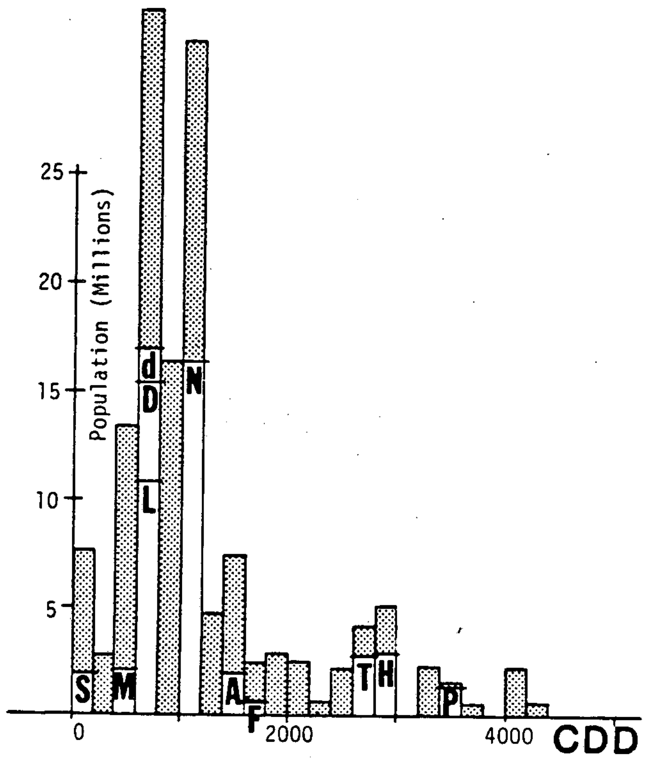

FIGURE 3: POPULATION DISTRIBUTION -- COOLING DEGREE DAYS (CDD)

$\bar{K}_T$ values, in Figure 5, have the largest peak at .46-.47 for the Northeast, eastern Great Lakes, and Northwest, a nearby peak at .49-.50, the western Great Lakes and Southeast, and another at .59-.60, mostly California.

More informative in many ways are displays of the relationships of two of the variables, such as those shown in Figures 6-12. These graphs plot one variable against another, so allowing visual identification of the magnitude and range of the variables for each group of SMSAs and the relationships between the two climate variables. For the purposes of discussion, the groupings marked on these graphs are the 11 shown in Table 1.

Figure 6 shows the relationship between heating and cooling degree days. The relationship is extremely consistent for most of the points, with very little scatter. The exception is a group of SMSAs from the West Coast, which actually form their own HDD/CDD relationship with a similar form but with considerably lower cooling requirements. It is also notable that, with regard to only HDD and CDD, the Detroit and Denver groupings seem to overlap completely, as do Fresno and Atlanta. This overlap does not extend to the graphs in which $\bar{K}_T$ is one of the variables, Figures 7 and 8. In both of these graphs, Detroit and Denver are seen as very different climates because of the difference in the available sunshine. Fresno and Atlanta are likewise distinct. The overlap of the New York grouping and that around Seattle in Figure 7 demonstrates the striking similarities of those two regions. However, perusal of graphs that include cooling degree days show the distinction of the Pacific Northwest, very cool summers resulting in minimal CDD.

Figures 9-11 show the relationship of latent enthalpy hours to the other variables. Figure 9 indicates that high LEH implies high CDD. The reverse, however, is not necessarily true. While most of the SMSAs show a very direct relationship between the two variables, about 10 SMSAs in the desert Southwest and California central valley, with a wide variation in CDD, show

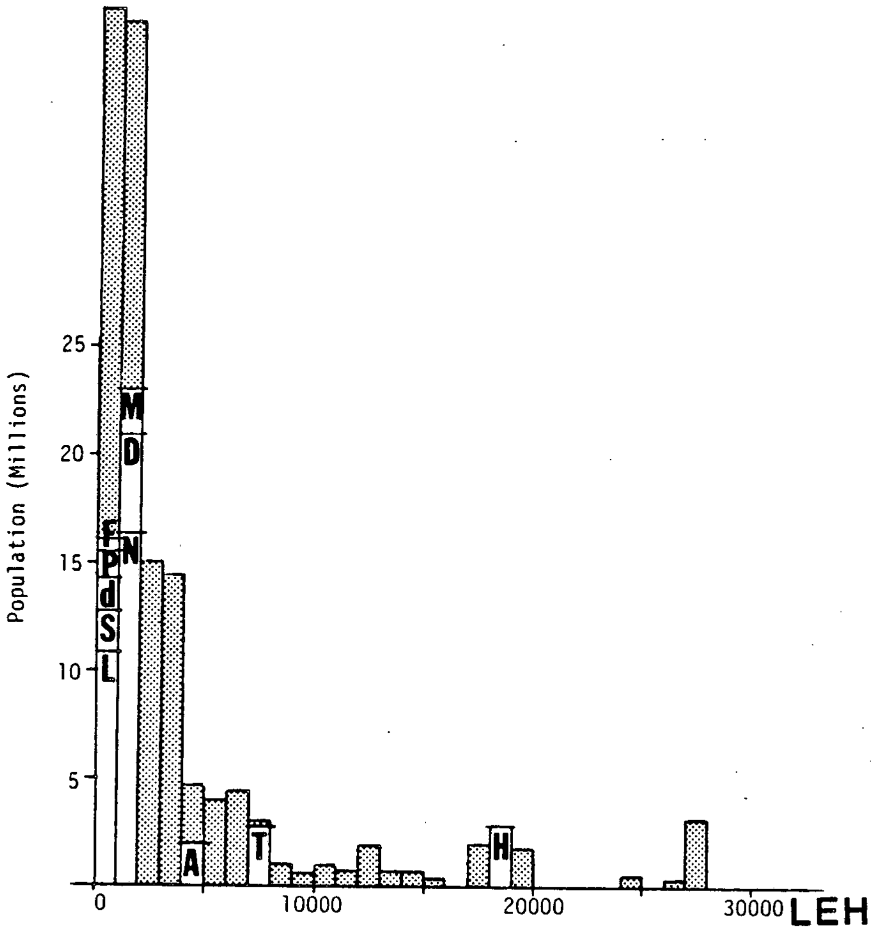

FIGURE 4: POPULATION DISTRIBUTION -- LATENT ENTHALPY HOURS (LEH)

almost no latent enthalpy hours. It is clear from Figure 10 that there is no important U.S. climate in which both heating degree days and latent enthalpy hours are high. Figure 11 shows that high LEH are restricted to climates with a relatively narrow range of $\bar{K}_T$, .48-.55.

Figure 12 demonstrates a rather unusual correlation between $\bar{K}_T$ and longitude. While there is some scatter, the correlation is surprisingly consistent except for the West Coast, especially the Northwest. The unusual "hole" in this scatterplot is apparently a difference in sunshine caused by the Appalachians.

Automation of the Aggregation Process

Because of the substantial amount of data involved, it was essential that the greater part of the climate region identification and analysis be automated. The result is GLOM, an interactive climate region agglomeration program. In GLOM, the concepts of "climatic distance" and "climate center" are quantified with respect to the four climate parameters discussed above. The operation of the program is interactive so that climate groupings, centers, and parameter ranges can be manipulated by both the program and the operator interactively to achieve the most appropriate climate region aggregations. The program can also be used to provide statistical information on the climate regions and their component SMSAs and populations.

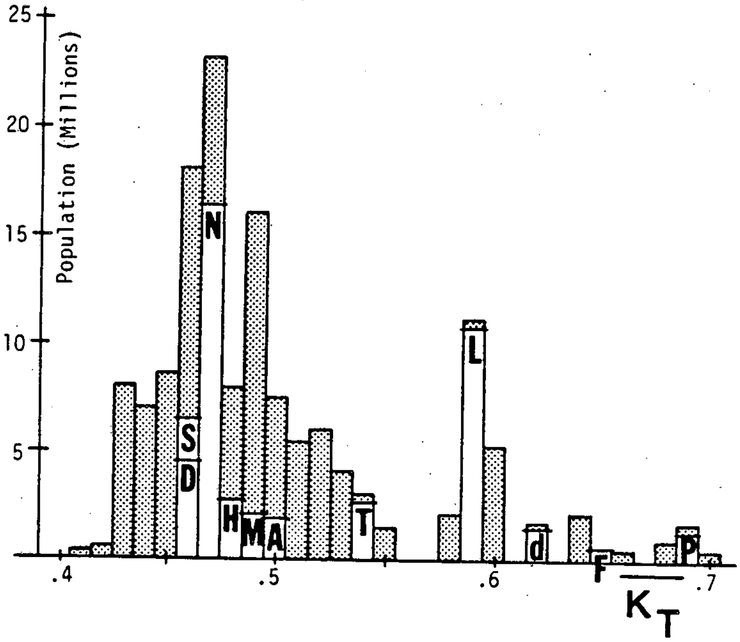

FIGURE 5: POPULATION DISTRIBUTION -- $\bar{K}_T$

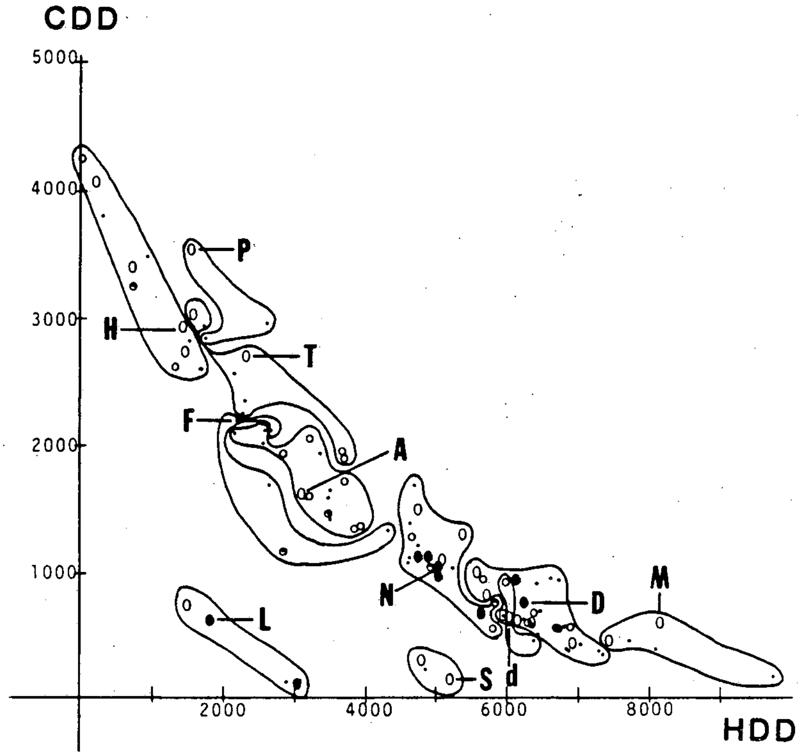

FIGURE 6: CLIMATE PARAMETER RELATIONSHIPS -- HDD / CDD

Use of an automated method of calculation makes substitution or addition of new climate parameters relatively simple. Different weights can also be given to the climate parameters used. Thus, the operation and results of a given climate region aggregation can be tailored to suit the specific climate sensitivities being investigated. Detailed information on the features and operation of GLOM is given elsewhere (Carroll 1985).

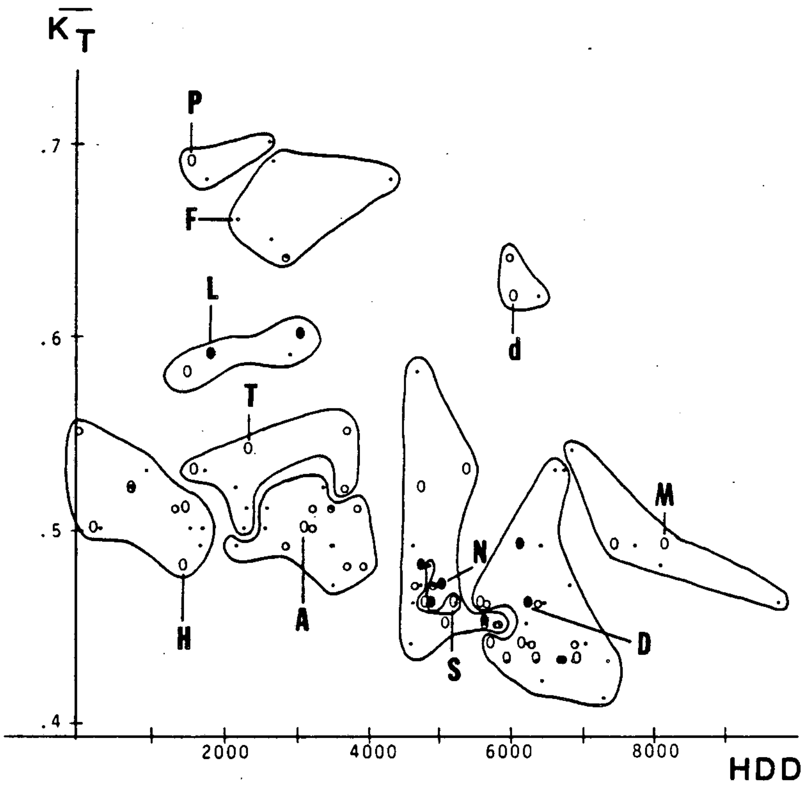

FIGURE 7: CLIMATE PARAMETER RELATIONSHIPS -- HDD / $\bar{K}_T$

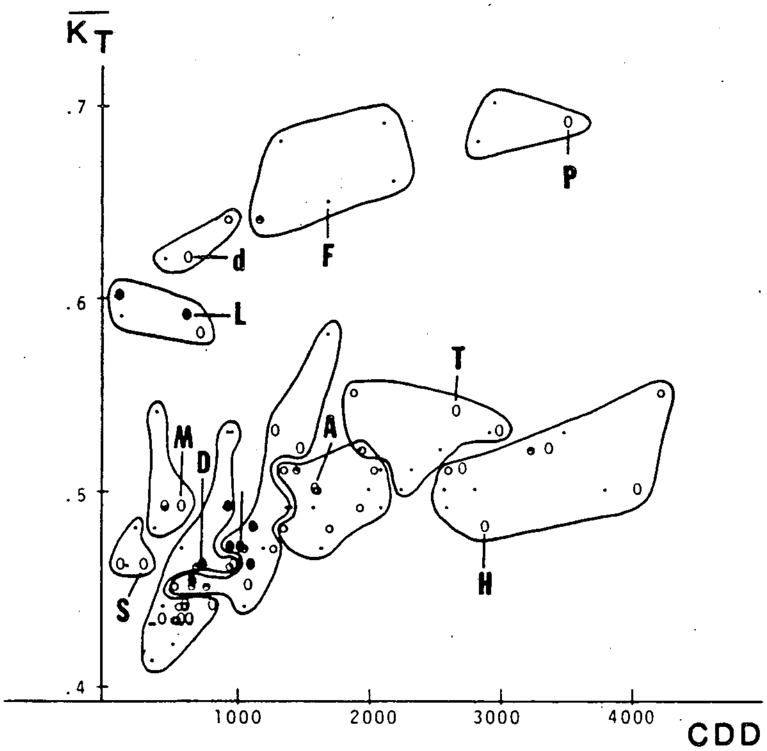

FIGURE 8: CLIMATE PARAMETER RELATIONSHIPS -- CDD / $\bar{K}_T$

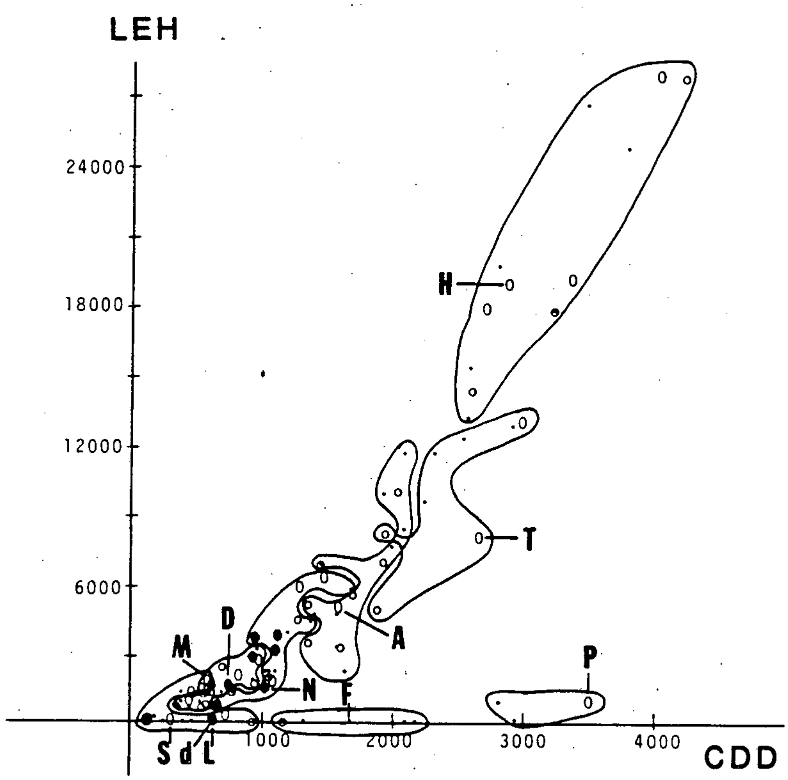

FIGURE 9: CLIMATE PARAMETER RELATIONSHIPS -- CDD / LEH

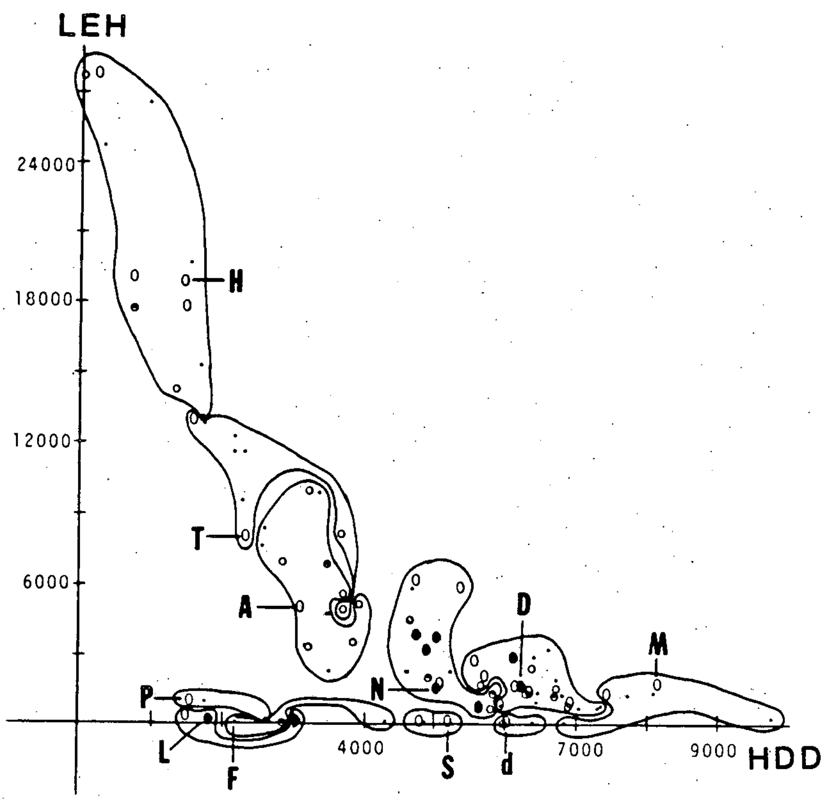

FIGURE 10: CLIMATE PARAMETER RELATIONSHIPS -- HDD / LEH

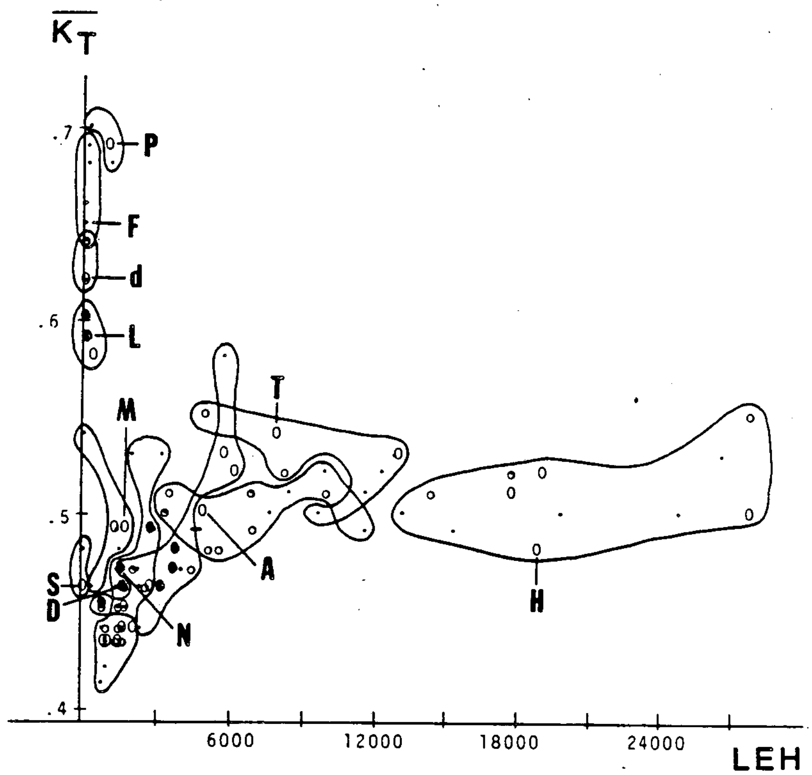

FIGURE 11: CLIMATE PARAMETER RELATIONSHIPS -- LEH / $\bar{K}_T$

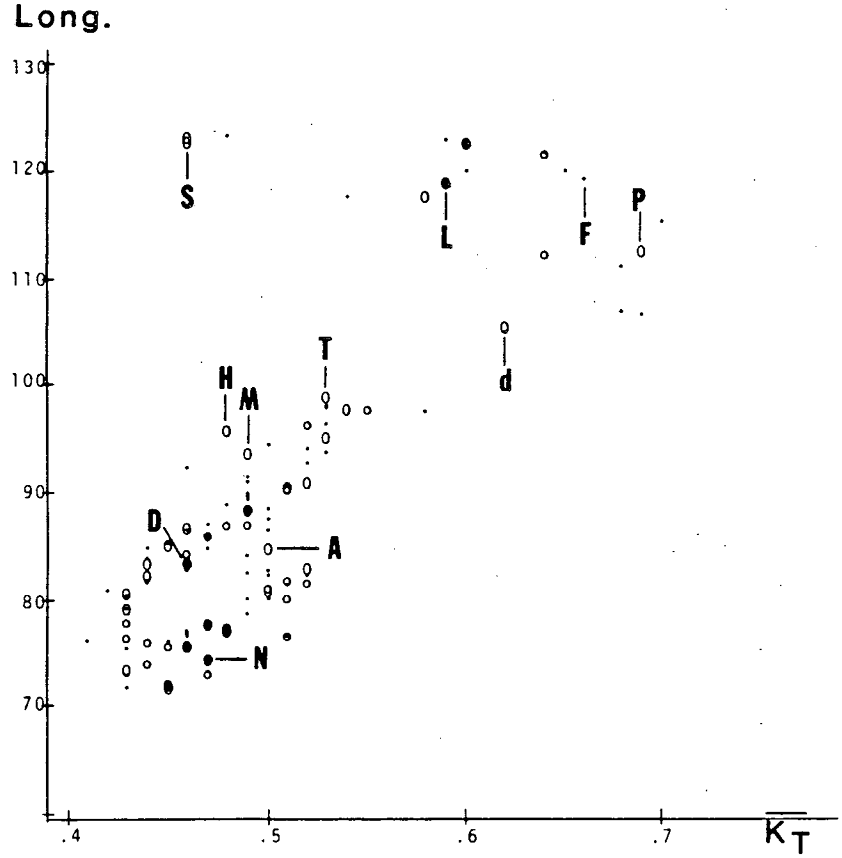

FIGURE 12: CLIMATE PARAMETER RELATIONSHIPS -- $\bar{K}_T$ / LONGITUDE

Climate Centers / Population-Weighted Centers

As described above, climate regions usually have two centers, a physical climate center (a particular SMSA) and an "ideal" population-weighted center, although the first is optional. The climate characteristics of these two centers are useful in climate region analysis. Such analysis helps to assure that modifications of the climate region and centers are effective in achieving the most useful climate aggregations.

By looking at the climate characteristics of the ideal center, one gets a very good idea of the overall climate characteristics of a given region. They give a simple quantification of the region as a whole so that different regions can be compared and the possibilities of combining or splitting regions can be more easily evaluated.

The physical center is presumed to be appropriate for energy analysis representative of the entire group. Comparison of its characteristics with those of the ideal center can provide an understanding of the biases of the center with respect to the entire region. It may be close to the population-weighted mean of several characteristics and widely different from another. If the energy analysis to be performed is very sensitive to the divergent characteristic, that should be understood and the appropriateness of the center or the region for the analysis should be reconsidered.

If the physical and ideal centers of a group are more different than desired (as measured by climatic "distance," discussed below), generally or with respect to a particular characteristic, the ideal center can be used to compare to other SMSAs in the climate region in order to find a more compatible physical climate center. Because the population is included in the calculation of the ideal climate center characteristics, even a small SMSA can be chosen as the center with a knowledge of how well its climate approximates the weather experienced by all the people in the climate region. By such comparisons, the best, most representative center of the region can be chosen.

Climatic "Distances"

The concept of climatic "distance" between a given SMSA and a climate center (possibly a SMSA) or between two SMSAs is calculated by GLOM. It is useful in understanding the climate region and choosing how to modify climate regions. The most appropriate definition of climatic distance will vary a great deal depending on the purpose to which the aggregation of climates will be put. The weighting and normalization of the different variables might well be different when residential evaporative cooling is the interest than they would be when studying potentials for solar controls in office buildings. GLOM is set up to make it easy to change weightings.

The definition chosen for the purposes of this report is simple and necessarily somewhat arbitrary. The climatic distance, D, between a SMSA and a climate center is:

$$D = [a^2(HDD_1-HDD_2)^2 + b^2(CDD_1-CDD_2)^2 + c^2(LEH_1-LEH_2)^2 + d^2(\bar{K}_{T1}-\bar{K}_{T2})^2]^{1/2}$$

where:

a,b,c,d are variable normalization factors, and

1,2 are Climate 1 and Climate 2, which can be SMSAs, climate centers, or any entity for which a full set of climate characterization parameters exist.

The normalization factors are taken to be the reciprocal of the range of the variable throughout the 125 SMSAs. Thus a=1/10,000 degree days, b=1/4000 degree days, c=1/30,000 enthalpy hours, and d=1/.30 (i.e. essentially equal weighting of the four parameters). Although strong relationships between pairs of variables exist, as demonstrated in Figures 6-12, for the purposes of the climatic distance calculation, each climate variable is treated as independent of the others.

A climate region in which the climatic distance between each SMSA and the center is small is known to be a region of consistently similar climate. A climate region with many large distances is known to be a region with a wide range of climate variation, requiring more care in the choice of a climate center and in evaluation of energy analysis results using a single weather data set to represent that region. The divergence of the climates must be kept in mind when determining to what extent results for the center apply to specific SMSAs that are climatically distant. Climate regions having SMSAs clustered at different distances from the center may be most effectively analyzed by splitting more distant SMSAs from the region to add to another region or to form their own.

Closest / Farthest

The analysis of each region includes a list of which SMSA within the region is closest to the ideal and farthest from the ideal and from the physical center, with respect to each climate characteristic and the climatic distance.

The list of closest SMSAs is useful in confirming that the physical center is indeed the closest SMSA to some or all of the population-weighted means. If that is not the case, it is useful in identifying those SMSAs that might make a better fit to the ideal.

The list of farthest SMSAs provides a quick look at those SMSAs lying farthest from centers. They become the most likely candidates for expulsion, reassignment, or formation of new regions. The lists are especially helpful for identification of wide divergence in a single characteristic. There may be some SMSAs that are quite close to the center for most characteristics but so different with respect to one that they are inappropriate for inclusion in the region.

CLIMATE REGION IDENTIFICATION: SELECTED EXAMPLES

The following examples of climate region identification illustrate some of the ways population-climate correlations, the GLOM program, and subjective manipulation of the climate regions resulted in climate regions for specific energy analysis tasks. Each of the groupings discussed grew out of a different need for information on the climate sensitivity of a particular aspect of building energy use. The adaptation of the method to the varying requirements of real projects demonstrates the flexibility of the method. In each case, the use of the climate regions and centers generated by the aggregation method gave the users a better understanding of the meaning and limitations of the results of their studies.

Five Regions - Wide Ranges and Population Emphasis

One project required a small number of regions into which the U. S. could be divided while still providing some representation of building energy use across the range of climates in which most people live. To accomplish this, relatively large ranges of all four climate characteristics were chosen. (When discussing parameter ranges in this section, the full interval will be stated; thus, 2000 HDD means a range of $\pm$1000 HDD from the climate center.) In this case, the intervals were 3000 HDD, 2000 CDD, 10000 LEH, and .10 $\bar{K}_T$.

It was found that if five climate centers -- Detroit, New York, Atlanta, Los Angeles, and Houston -- were chosen and regions were agglomerated around them, the vast majority of the SMSAs fell within those regions, and most were far closer to the centers than the ranges allowed.

Further, the population-weighted characteristics of the regions are all very close to those of the climate centers, although Houston is somewhat cloudier than its region as a whole.

The only areas outside the ranges of these initial regions were the Southwest and Mountain areas, which contain only a handful of metropolitan areas. In order to assign each of the SMSAs to a climate region, the range restrictions were removed and each of the 125 SMSAs assigned to the climate center to which it was closest (had the smallest climatic distance). The resulting five climate regions are shown in Figure 13* and detailed in Table 2.

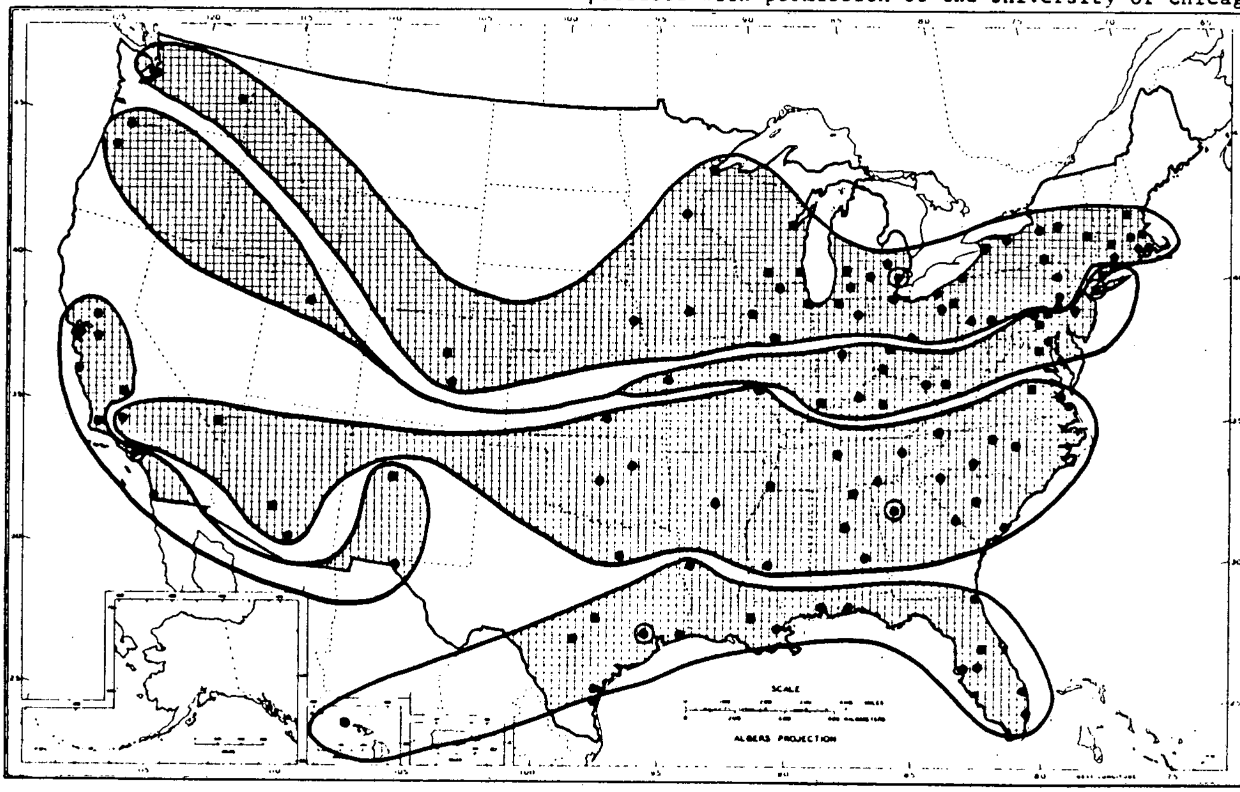

FIGURE 13: FIVE CLIMATE REGIONS

It is worth explaining some of the more surprising assignments in this figure. Denver and Colorado Springs are assigned to a region whose climate center is significantly to the north of them. Because of their altitude, they tend to be much colder than lower areas at a similar latitude. Despite the fact that they are much sunnier than their eastern climate centers, the climatic distance to those centers is less than the distance to the more southerly centers.

Bakersfield, in the California central valley, is assigned to the Atlanta climate region rather than Los Angeles, only 100 miles away. The California coast has very cool summers, while the

* The lines surrounding each of the regions in Figures 13, 14, and 16-19 are intended to group the population centers which belong to that region. They should not be taken to indicate that all of the territory within the lines should be considered part of the region. Figure 15 is an exception, discussed in the text. Although areas between two SMSAs of a single region will usually have a climate similar to the two SMSAs, this may not be true, especially where climates are affected by coastlines, altitude changes, or long distances.

TABLE 2: FIVE REGION SUMMARY *

Climate Region /Center	Pop. (Mil)	HDD	CDD	LEH	$\bar{K}_T$
North	47.2	6347	649	1497	.466
/Detroit	4.6	6228	742	1600	.457
Middle Latitudes	39.6	5018	1025	2373	.473
/New York	16.3	5033	1022	1534	.465
South	21.5	3189	1965	5732	.531
/Atlanta	1.9	3094	1588	4931	.495
California	20.7	2268	590	91	.600
/Los Angeles	10.8	1818	614	109	.588
Gulf Coast	14.2	1051	3200	19597	.507
/Houston	2.8	1433	2889	18845	.480

* Regional climate parameters are population-weighted means.

Populations are for SMSAs only. Total SMSA population (1978) is about 140 million.

southern central valley (across the coastal mountains) gets very hot. The similarity between Atlanta and Bakersfield in heating and cooling degree days overcomes the differences in latent effects and sunshine. Thus, in most cases, the climate of Atlanta is more representative of Bakersfield than that of Los Angeles.

The Pacific Northwest is included in the regions based in the Northeast, not only because the other regions are highly inappropriate, but also because there is a definite similarity between the two regions. The climatic distance between Detroit and Seattle is about the same as between Detroit and Madison, Wisconsin. New York City is climatically closer to Portland, Oregon, than to Albany. Phoenix is assigned to Atlanta, while nearby El Paso and Albuquerque are part of the Los Angeles region. Excessive heat in Phoenix makes its climate closer to Atlanta's, but the others are considerably higher and therefore cooler than Phoenix, so they are more similar to cooler Los Angeles.

The California coastal region seems small, and contains only 11 SMSAs, but it deserves its status as a major climate region because its SMSAs contains 21 million people, as compared to 22 million for the SMSAs in the Atlanta region and 14 million for Houston. The Detroit region contains 47 million and New York 40 million people.

Flexibility in the selection of these groupings occurs in several places. The original choices of the ranges of the climate characteristics were based on a judgment of acceptable differences. The decision of which climate centers to try was based on our experience with climate analysis and with GLOM. The determination of whether three or five or ten regions was a reasonable minimum was based on an understanding of building energy analysis and the sensitivity of past studies to climate variables as well as the results of interaction with GLOM. Although it was not done in this case, SMSAs, which for geographical, traditional, or other reasons would be more acceptable in a region different from that to which they were assigned by GLOM, could be reassigned within GLOM. Bakersfield, for example, might be reassigned just to obtain more geographically compact regions.

Seven Regions - Wide Ranges and Reduced Population Emphasis

The major drawback of the five region grouping is the relative incompatibility of the Mountain and Southwest climates with the climate regions to which they were assigned. In order to improve groupings for situations where those climates are important, two more climate centers, Denver and Phoenix, were added. The same criterion, climatic distance, was used to determine which SMSAs were assigned to the new regions. The result is shown in Figure 14 and Table 3.

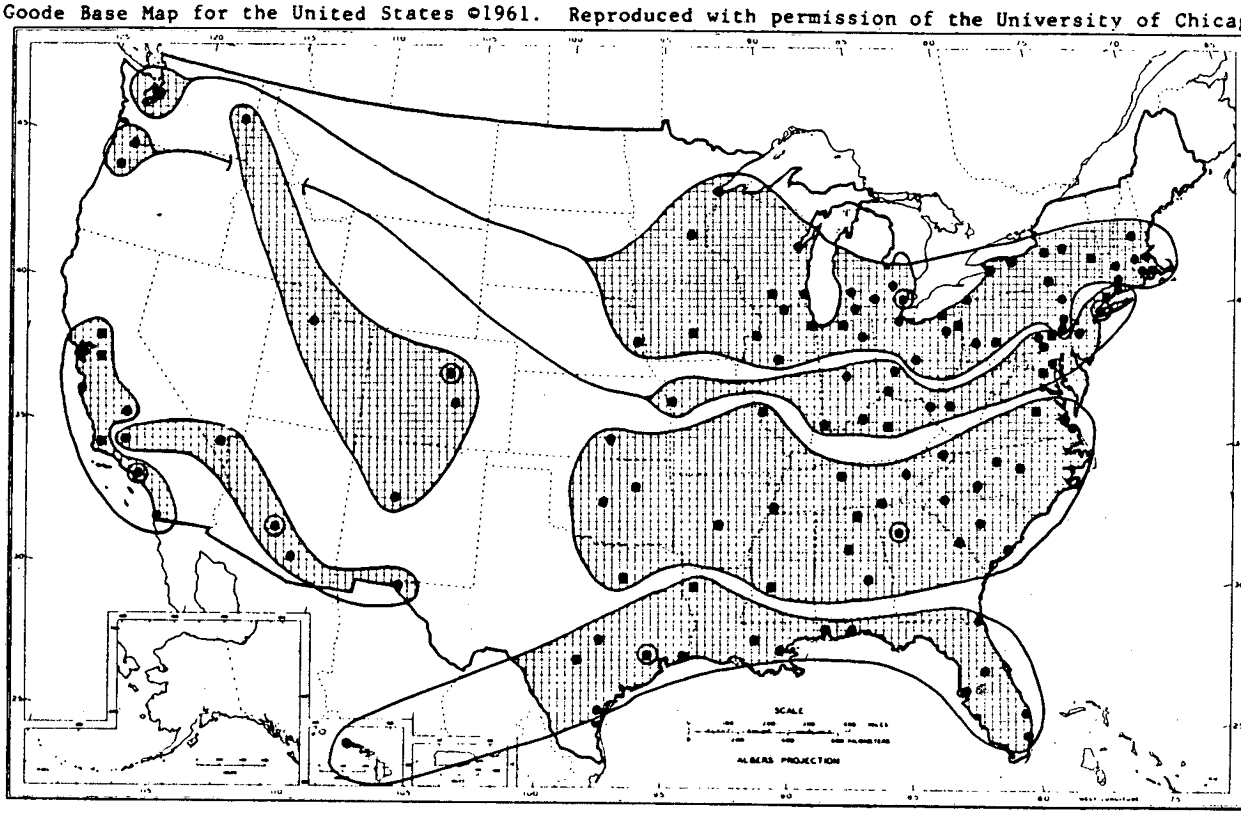

FIGURE 14: SEVEN CLIMATE REGIONS

These two new regions would be very difficult to justify on the basis of population, since they have only 6 million inhabitants between them. However, the inappropriateness of including their rather unusual climates in one of the five climate regions of the first grouping makes the seven region grouping a reasonable alternative.

Eleven Regions - Flexibility for Special Requirements

In order to define climate regions for a technology assessment with a national scope (Carroll 1982), several requirements had to be fulfilled. Ten or twelve climate regions could be analyzed; all major centers of population and construction had to be well represented; and "types" of climate perceived to be significant had to be included.

An initial attempt was made to group climates based on parameter intervals of 2000 HDD, 1200 CDD, 6000 LEH, and .08 $\bar{K}_T$. An attempt was made to include the largest SMSAs (New York, Los Angeles, Chicago, etc.) and smaller SMSAs with identifiable climate types (Seattle, Albuquerque, Phoenix, and others). Large cities often make the best climate centers because they tend

TABLE 3: SEVEN REGION SUMMARY *

Climate Region /Center	Pop. (Mil)	HDD	CDD	LEH	$\bar{K}_T$
North	45.1	6354	653	1567	.460
/Detroit	4.6	6228	742	1600	.457
Middle Latitudes	38.7	4997	1027	2424	.469
/New York	16.3	5033	1022	1534	.465
California	19.8	2217	542	91	.596
/Los Angeles	10.8	1818	614	109	.588
South	19.0	3366	1816	6390	.511
/Atlanta	1.9	3094	1588	4931	.495
Gulf Coast	14.2	1051	3200	19597	.507
/Houston	2.8	1433	2889	18845	.480
Mountain	3.4	5907	748	17	.625
/Denver	1.5	6016	625	5	.618
Desert Southwest	2.9	1966	2948	623	.686
/Phoenix	1.3	1552	3506	968	.686

* Regional climate parameters are population-weighted means.
Populations are for SMSAs only. Total SMSA population (1978) is about 140 million.

to dominate the population-weighted averages of the region.

The result was a grouping of 24 climate regions. Using GLOM, regions with limited usefulness and those that could not be justified on the basis of the population they represented were incorporated into other regions. For example, the SMSAs represented by Chicago were found to be nearly as well represented by Minneapolis or Detroit, so the region aggregated around Chicago was divided between those two centers. On the other hand, single-SMSA "regions" such as Albuquerque or Duluth did not have the population to justify separate study, despite their unusual and extreme climates. The result of such refinement was the eleven regions shown in Figure 15 and Table 4.

In this case, non-SMSA population was also to be included in the study. More sparsely populated areas were assigned to the various climate regions. The assignments were made based on the users' knowledge of climate characteristics and a desire to use state or county borders where possible to divide regions.

This 11-region grouping has proved to be very useful for several studies. In a particular study, the eleven regions may produce only three or four distinctive trends. However, by observing which regions show similar trends and accounting for similarities and differences in climate characteristics, the causes of the trends can often be discovered. In another study, different regions may show common trends. A simple parametric study may use fewer regions, and a comprehensive study may use twice as many, but the eleven regions have been a useful starting point to determine what approach to take to identify the most productive set of climate regions for a given purpose.

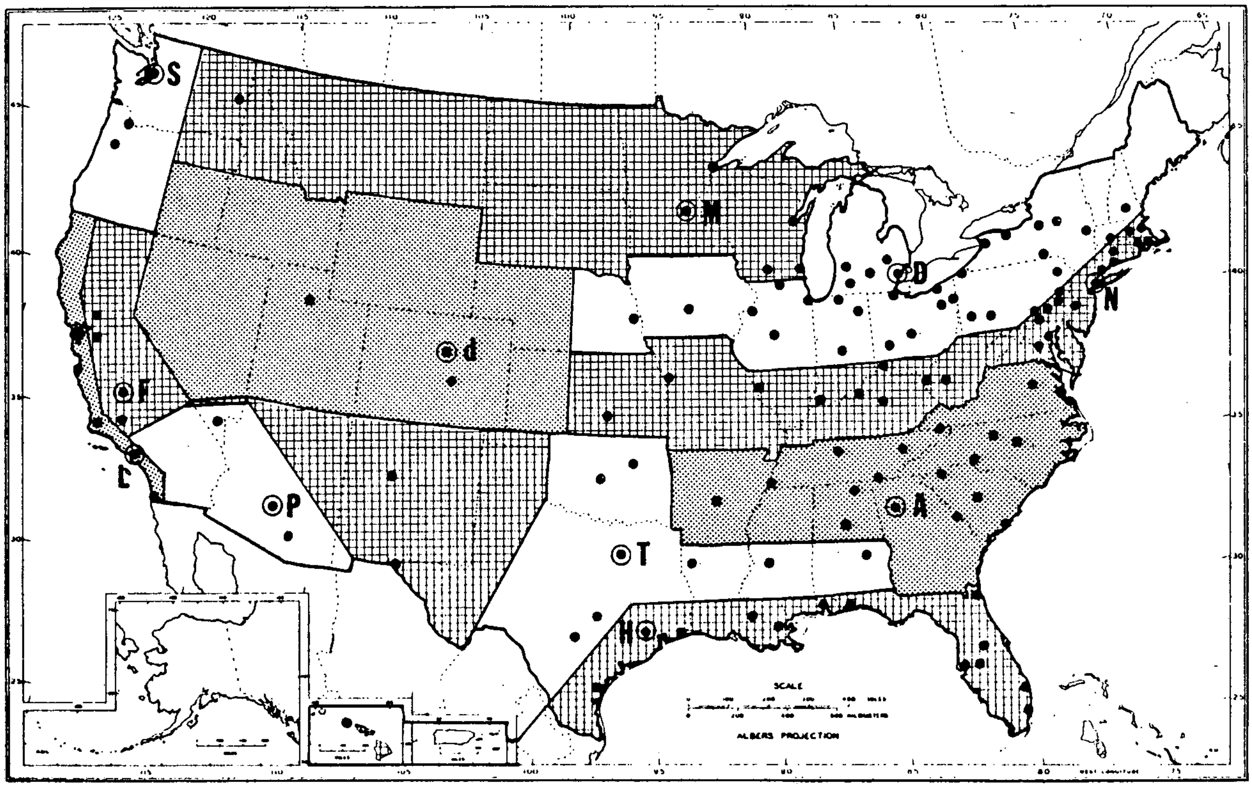

FIGURE 15: ELEVEN CLIMATE REGIONS

Fourteen Regions - Division of "Two-Climate" Regions

The fourteen region grouping shown in Figure 16 and Table 5 is a variation of the eleven regions discussed above. Three of the eleven regions had two areas of large population within the region with similar but clearly distinguishable climates. The San Francisco area contains six million people and has a distinctly cooler climate than Los Angeles; south Florida, south Texas, and Hawaii have four million people and a much hotter and more humid climate than Houston; and the area around St. Louis is somewhat sunnier and more humid than New York. Therefore, three new regions were added to the original 11.

It can be seen, especially in the cases of Los Angeles and Houston, that the centers are more representative of their new, more compact regions, based on comparison of climate parameters. Most of the fourteen regions have a great deal of geographic contiguity as well as climatic similarity. There is also a greater similarity between regions in terms of population, the only major exceptions being the New York and Detroit regions, where there is minimal climate difference across areas of substantial population.

It is generally advantageous to avoid dramatic differences in the populations of regions, because there is always a tendency to attribute equal value to each region. It might be found, for example, that a building modification reduces energy use in eight regions, and increases it in two. But if twice as many people live in the two regions than in the eight, the wrong impression may be received. It is always necessary to consider the need for population representation against the importance of climate differences in general or with respect to particular climate parameters. The next three climate groupings demonstrate possibilities for dealing with special requirements.

TABLE 4: ELEVEN REGION SUMMARY *

Climate Region /Center	Pop. (Mil)	HDD	CDD	LEH	$\bar{K}_T$
Northeast	45.8	5089	1018	2484	.470
/New York	16.3	5033	1022	1534	.465
Great Lakes	33.0	6292	724	1858	.458
/Detroit	4.6	6228	742	1600	.457
California Coast	18.1	2162	469	96	.592
/Los Angeles	10.8	1818	614	109	.588
Gulf Coast	12.3	949	3248	20634	.504
/Houston	2.8	1433	2889	18845	.480
South	11.5	3290	1656	5866	.497
/Atlanta	1.9	3094	1588	4931	.495
Central Texas	6.6	2449	2534	9234	.533
/Dallas	2.7	2335	2670	7951	.536
Northern Tier	4.9	7892	485	1368	.491
/Minneapolis	2.1	8158	585	1770	.494
Pacific Northwest	3.3	5023	195	13	.462
/Seattle	1.9	5184	128	0	.462
Fresno/El Paso	3.0	2905	1529	54	.657
/Fresno	0.5	2650	1670	43	.651
Mountains	2.6	6044	703	3	.626
/Denver	1.5	6016	625	5	.618
Desert Southwest	2.1	1781	3257	842	.690
/Phoenix	1.3	1552	3506	968	.686

* Regional climate parameters are population-weighted means (SMSA population only).
Regional populations (1978) are for entire areas shown in Figure 15.

Twenty-Four Regions - Similar Regional Populations

In constructing a larger set of climate regions, it was decided to set tight limits on climate parameter variation in those cases where large populations and/or numerous SMSAs fell into the same general climate characterization. The rationale is that where large populations live in similar climates, it is more important to identify even small differences in climate effects. By adopting such a strategy, with the interactive mode of GLOM, large regions tend break into smaller ones with relatively even population. Much of the search for the right combination of regions takes the form of trial and error, which can be done with relative ease using GLOM. The twenty-four regions in Figure 17 and Table 6 were determined through such a technique. In this case, care was also taken to make sure that if no existing region represented a particular SMSA well, a new region would be created to serve that purpose.

In the fourteen region grouping, more than half of the population was in the regions around Detroit and New York. By identifying several new climate centers -- Chicago, Buffalo, Boston, Philadelphia, and Cincinnati -- seven regions were created from those two. Each of the new regions has very small variation in climate and populations ranging from five to 18 million. The seven new climate regions still rank in the top eleven in population, but their populations are much more consistent with the rest of the regions than the original two. New York, though

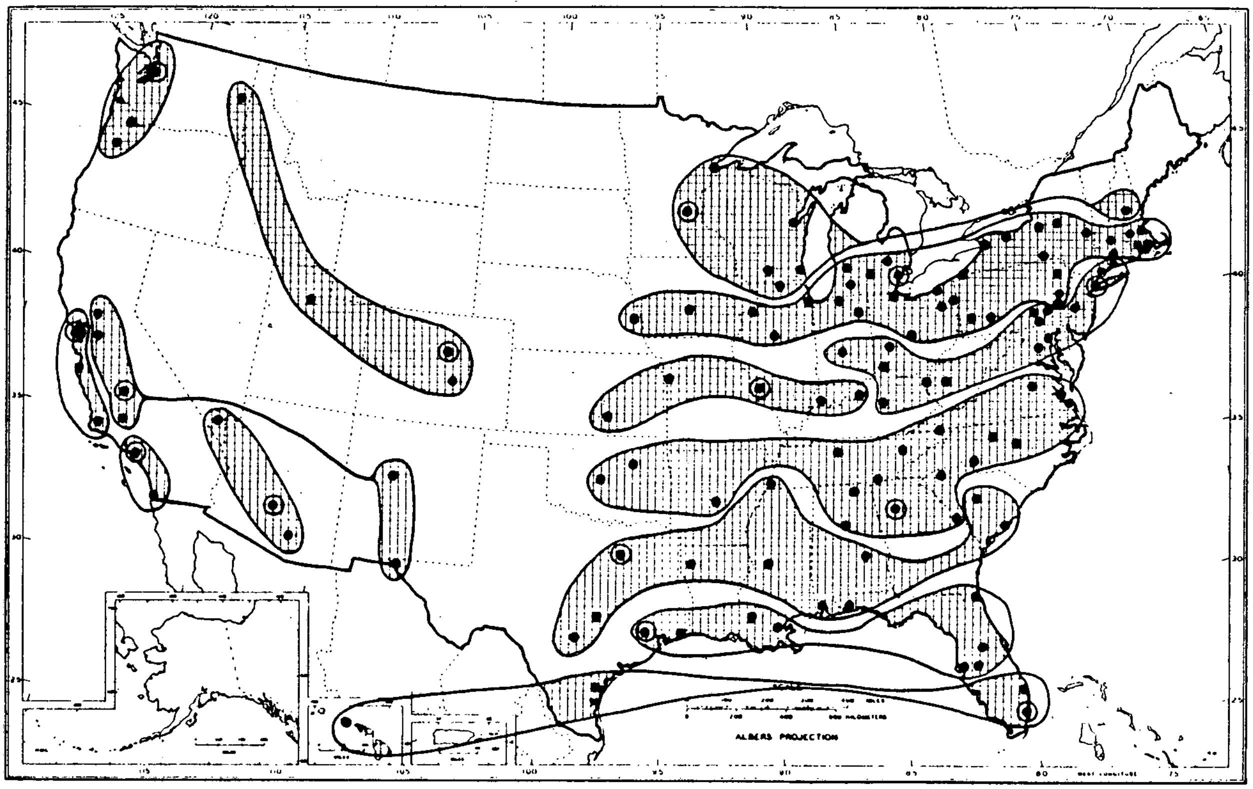

FIGURE 16: FOURTEEN CLIMATE REGIONS

effectively restricted to its own metropolitan area, still has the highest population of any climate region.

Several regional centers not used in previous groupings appeared in the South as well -- San Antonio, Mobile, Memphis, and Oklahoma City. These were chosen largely because they represented climates distinguishably different from their previous climate centers.

The Southwest and Mountain areas presented a special problem. In the fourteen region grouping, the three climate regions is this area were characterized by small populations *and* wide variation in climate. The interactivity of GLOM was especially useful in this case, because a large number of combinations had to be tried before the solution arose. First, Spokane was found to fit better with Buffalo than with Denver. Then it was discovered that by replacing Fresno with Sacramento and Tucson, Las Vegas could be assigned to Tucson, Albuquerque could be assigned to Sacramento, and Tucson and Sacramento could be separated. This reduced the climate variation in each region.

The map in Figure 17 shows a set of climate regions that is still incomplete. The choice of Mobile was so clever that it effectively removed the entire climate region from Dallas. Oklahoma City was such a poor choice that it sits alone in its climate region. New York's climate region includes only its own metropolitan area and Dayton, Ohio. Some readjustment of these regions using GLOM is probably advisable.

TABLE 5: FOURTEEN REGION SUMMARY *

Climate Region /Center	Pop. (Mil)	HDD	CDD	LEH	$\bar{K}_T$
Great Lakes	38.2	6205	701	1663	.456
/Detroit	4.6	6228	742	1600	.457
Northeast	34.8	5003	1038	2321	.467
/New York	16.3	5033	1022	1534	.465
S. California	12.5	1775	629	138	.589
/Los Angeles	10.8	1818	614	109	.588
Upper South	11.3	3408	1629	5328	.501
/Atlanta	1.9	3094	1588	4931	.495
Gulf Coast	7.7	1235	2938	18018	.500
/Houston	2.8	1433	2889	18845	.480
Lower South	7.5	2227	2550	10306	.523
/Dallas	2.7	2335	2670	7951	.536
N. California	5.6	3036	108	0	.600
/San Francisco	4.7	3042	108	0	.597
Kansas-Kentucky	5.3	4872	1400	5697	.517
/St.Louis	2.4	4748	1474	6211	.517
Northern Tier	5.1	7923	483	1430	.485
/Minneapolis	2.1	8158	585	1770	.494
Tropics	3.8	235	3995	27280	.512
/Miami	2.3	205	4037	27754	.506
Pacific Northwest	3.3	5023	195	13	.462
/Seattle	1.9	5184	128	0	.462
Fresno/El Paso	3.0	2905	1529	54	.657
/Fresno	0.5	2650	1670	43	.651
Mountains	3.0	6130	669	3	.617
/Denver	1.5	6016	625	5	.618
Desert Southwest	2.1	1781	3257	842	.690
/Phoenix	1.3	1552	3506	968	.686

* Regional climate parameters are population-weighted means.
Populations are for SMSAs only. Total SMSA population (1978) is about 140 million.

TABLE 6: TWENTY-FOUR REGION SUMMARY *

Climate Region /Center	Pop. (Mil)	HDD	CDD	LEH	$\bar{K}_T$
New York	18.3	5053	1020	1575	.470
/New York	16.3	5033	1022	1534	.465
Phila.-Wash.	13.5	4837	1079	3505	.467
/Philadelphia	5.6	4864	1103	3168	.461
S. California	12.5	1775	629	138	.589
/Los Angeles	10.8	1818	614	109	.588
Lake Erie	11.6	6244	672	1650	.449

/Detroit	4.6	6228	742	1600	.457
Boston-Pitts.	10.2	5739	672	1010	.444
/Boston	3.7	5620	661	779	.450
Chicago-Iowa	9.3	6197	922	2793	.494
/Chicago	7.7	6125	923	2782	.492
Upper South	9.2	3394	1563	4895	.494
/Atlanta	1.9	3094	1588	4931	.495
Buffalo-Mich.	7.3	6851	493	1126	.436
/Buffalo	1.3	6926	436	1021	.425
Gulf Coast	6.6	1196	2999	18594	.500
/Houston	2.8	1433	2889	18845	.480
N. California	5.6	3036	108	0	.600
/San Francisco	4.7	3042	108	0	.597
Northern Tier	4.8	7953	490	1458	.488
/Minneapolis	2.1	8158	585	1770	.494
Missouri-Kansas	4.4	4917	1427	5936	.526
/St.Louis	2.4	4748	1474	6211	.517
Cincinnati	3.9	5263	1033	2211	.456
/Cincinnati	1.6	5069	1080	1762	.453
Tropics	3.8	235	3995	27280	.512
/Miami	2.3	205	4037	27754	.506
Pacific Northwest	3.3	5023	195	13	.462
/Seattle	1.9	5184	128	0	.462
Mountains	3.0	6130	669	3	.617
/Denver	1.5	6016	625	5	.618
Lower South	2.9	1779	2484	13307	.503
/Mobile	.4	1683	2576	13155	.495
Memphis-Tulsa	2.8	3102	2020	9107	.512
/Memphis	.9	3226	2029	10005	.510
Dallas	2.7	2335	2670	7951	.536
/Dallas	2.7	2335	2670	7951	.536
California Valley	2.2	3075	1301	58	.650
/Sacramento	1.0	2842	1157	43	.638
High Desert	1.6	2290	2510	352	.683
/Tucson	.5	1751	2813	1012	.679
San Antonio	1.5	1623	2966	12897	.529
/San Antonio	1.0	1570	2993	12953	.531
Phoenix	1.3	1552	3506	968	.686
/Phoenix	1.3	1552	3506	968	.686
Oklahoma City	.8	3694	1876	5001	.548
/Oklahoma City	.8	3694	1876	5001	.548

* Regional climate parameters are population-weighted means.

Populations are for SMSAs only. Total SMSA population (1978) is about 140 million.

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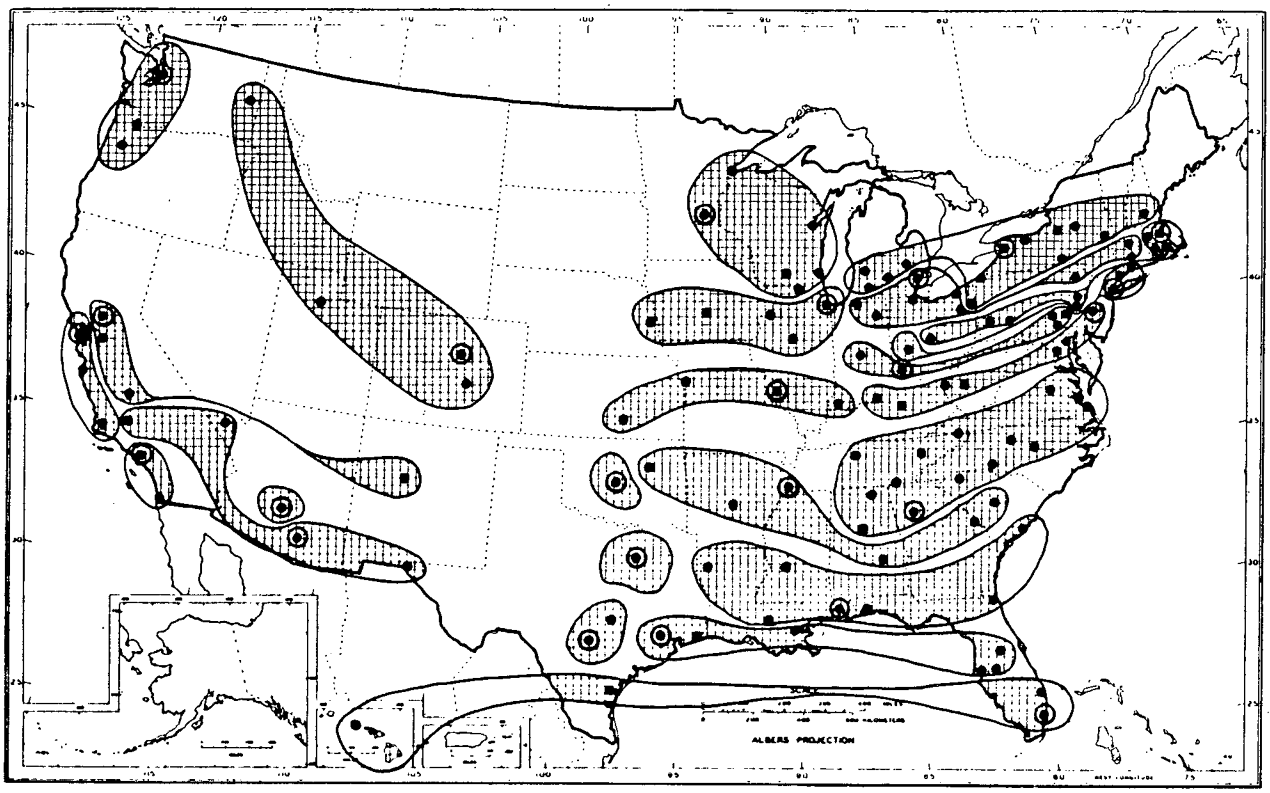

FIGURE 17: TWENTY-FOUR CLIMATE REGIONS

Eleven Regions - Latent Emphasis

As part of a study of dehumidification it was important to identify climate regions with special emphasis on latent enthalpy hours. Ranges for degree days and sunshine were set very high (HDD=3000, CDD=2000, and $\bar{K}_T$=.30), while latent enthalpy hours were set relatively low (LEH=7000). Starting with the largest SMSA, and continuing with the largest remaining SMSA after each climate region definition, regions were agglomerated around the SMSAs based on the specified ranges of the climate characteristics. The result was the eleven climate regions shown in Figure 18 and Table 7.

The climate centers are similar to the eleven region grouping in Figure 15, but the wider range of HDD and $\bar{K}_T$ resulted in the expansion of the New York and Minneapolis regions, eliminating Detroit, Denver, and Seattle. Conversely, the tighter limitations on the variation in LEH resulted in the formation of additional climate regions in the Southeast and the Mississippi Valley, where the largest values of LEH occur.

Three Regions - Daylighting Emphasis

In the assessment of daylighting effects, only a few regions were desired, because the assessment of each site was very time-consuming. Since the effectiveness of the daylighting aperture assessed is dependent in the first estimation primarily on the availability of beam sunlight, it was decided to base the choices entirely on $\bar{K}_T$. Looking at Figure 5, it was clear that one region should cover the peak around .60 $\bar{K}_T$ and the other two should split the bulk of the country between .43 and .55. Using GLOM to find the best centers, New York (.47), Atlanta (.50), and

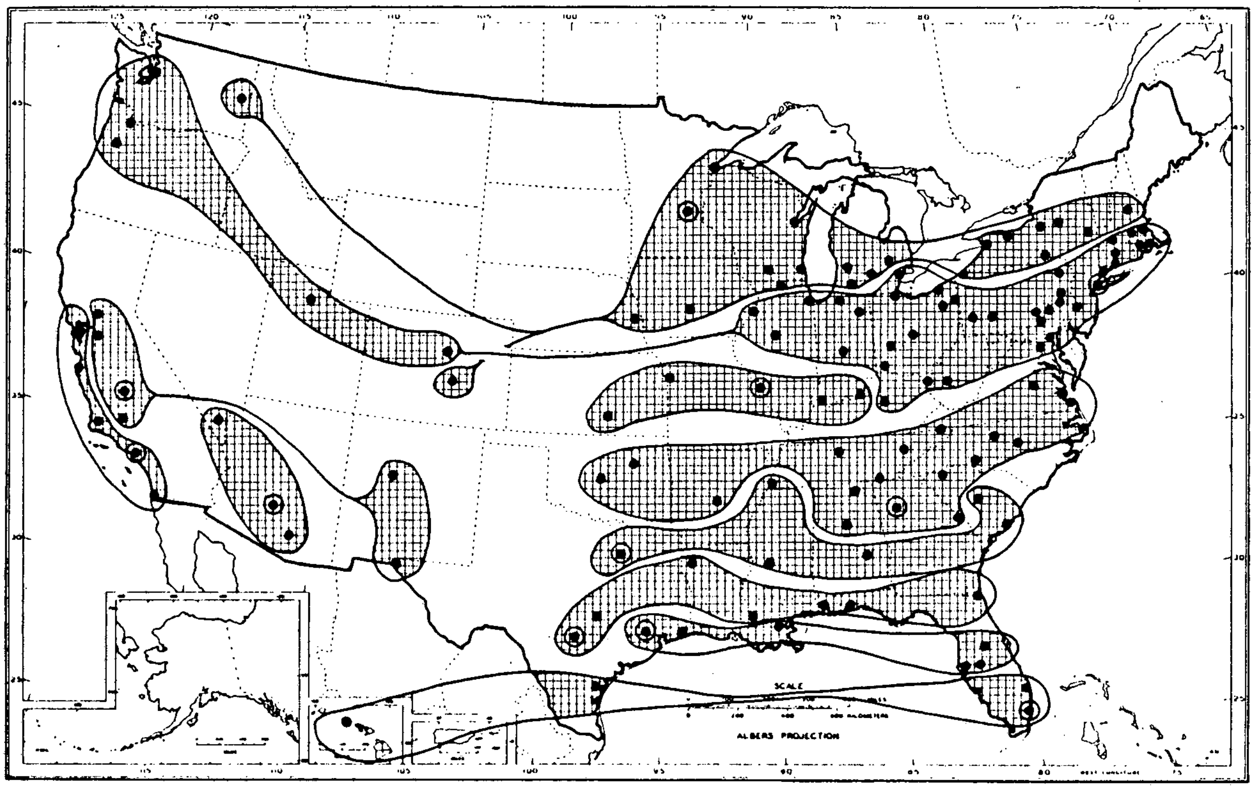

FIGURE 18: ELEVEN CLIMATE REGIONS -- LATENT EMPHASIS

Los Angeles (.59) were chosen. The rest of the SMSAs were assigned based *only* on the comparison of their $\overline{K}_T$ values with those of the three climate centers. The result is the climate regions in Figure 19 and Table 8.

The small number of regions and the dependence on $\overline{K}_T$ results in more significant differences between regional climate parameters and those of the centers than has been seen in the other examples. This is especially true of HDD, because $\overline{K}_T$ is strongly correlated to longitude (see Figure 12), while HDD is strongly correlated to latitude, so it is expected that a grouping based only on the former will show great variety in the latter within each region. Nevertheless, the centers represent the regions well in terms of solar availability, which was of overriding importance in this case.

CONCLUSIONS

Use of an objective method of definition of climate regions for building energy analysis can overcome common biases as to the representativeness of certain climates and the usual subjective characterization of climates based on a variety of parameters, many of which have little or no bearing on the energy consumption of buildings.

Use of an interactive climate agglomerator such as GLOM can:

- make more objective definition of climate regions and analysis of climate regions practical;

TABLE 7: ELEVEN REGION SUMMARY -- LATENT EMPHASIS *

Climate Region /Center	Pop. (Mil)	HDD	CDD	LEH	$\bar{K}_T$
Northeast	71.3	5491	859	1886	.468
/New York	16.3	5033	1022	1534	.465
California Coast	18.1	2162	469	96	.592
/Los Angeles	10.8	1818	614	109	.588
Northern Tier	13.0	7249	519	1316	.469
/Minneapolis	2.1	8158	585	1770	.494
Upper South	11.3	3408	1629	5328	.501
/Atlanta	1.9	3094	1588	4931	.495
Gulf Coast	6.6	1196	2999	18594	.500
/Houston	2.8	1433	2889	18845	.480
Kansas-Kentucky	5.3	4872	1400	5697	.517
/St.Louis	2.4	4748	1474	6211	.517
Middle South	4.9	2495	2419	8956	.524
/Dallas	2.7	2335	2670	7951	.536
Tropics	3.8	235	3995	27280	.512
/Miami	2.3	205	4037	27754	.506
Lower South	3.7	1636	2736	13448	.515
/San Antonio	1.0	1570	2993	12953	.531
Fresno/El Paso	3.0	2905	1529	54	.657
/Fresno	.5	2650	1670	43	.651
Desert Southwest	2.1	1781	3257	842	.690
/Phoenix	1.3	1552	3506	968	.686

* Regional climate parameters are population-weighted means.
Populations are for SMSAs only. Total SMSA population (1978) is about 140 million.

- allow variation of climate definitions through parameter weighting based on the particular goals of the intended application; and
- provide statistical analysis of each region as it is defined.

The aggregation of definable regions of locations with climates similar to one for which a study is done provides the possibility to extend the findings from one analysis across a much broader area, with much greater confidence, than was possible before. The examples described indicate a considerable range of climate definition and a variety of uses to which the results can be put.

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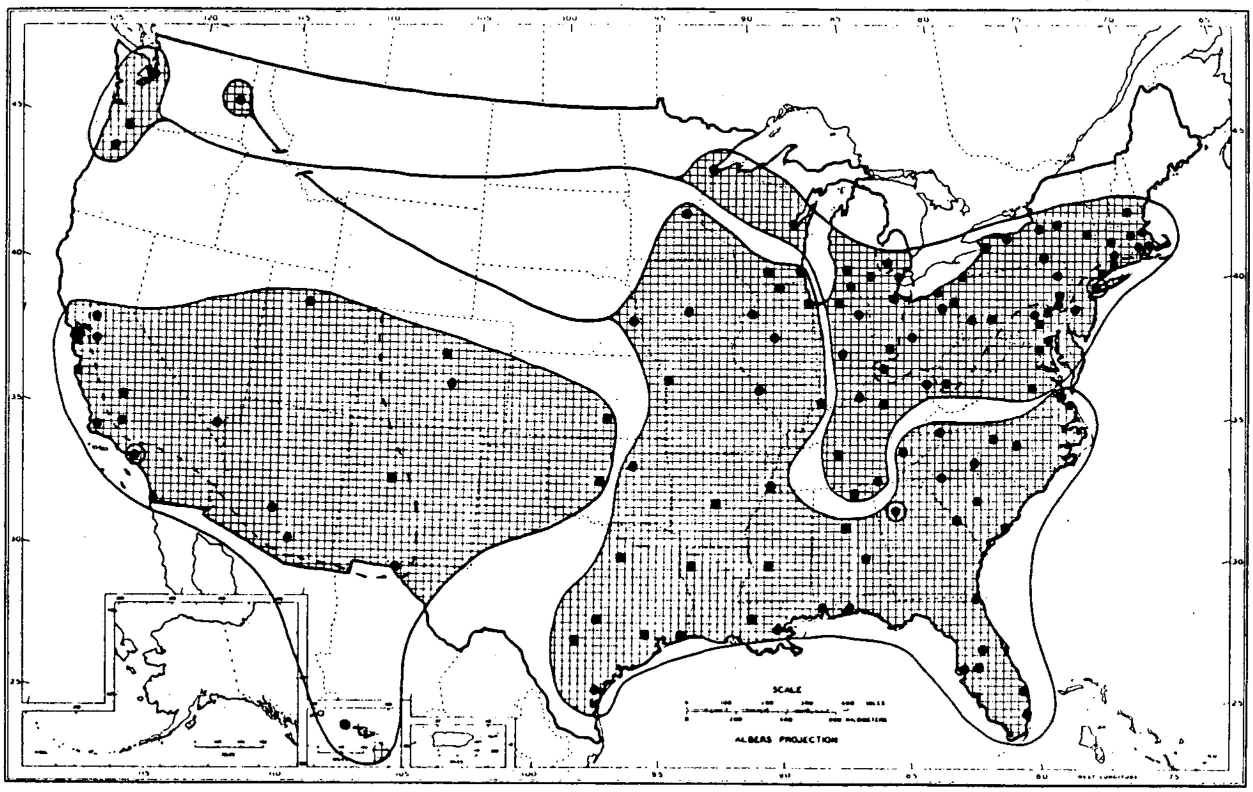

FIGURE 19: THREE REGIONS -- DAYLIGHTING EMPHASIS

TABLE 8: THREE REGION SUMMARY -- DAYLIGHTING EMPHASIS *

Climate Region /Center	Pop. (Mil)	HDD	CDD	LEH	$\bar{K}_T$
North	70.8	5491	843	1868	.458
/New York	16.3	5033	1022	1534	.465
South	44.7	3806	1793	8014	.505
/Atlanta	1.9	3094	1588	4931	.495
West	27.7	2675	887	368	.609
/Los Angeles	10.8	1818	614	109	.588

* Regional climate parameters are population-weighted means.

Populations are for SMSAs only. Total SMSA population (1978) is about 140 million.

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APPENDIX A: SMSA Population, Climate and Location Data

SMSA	Pop. (1000)	TMY	HDD	CDD	LEH	$\bar{K}_T$	WND	LAT	LNG
Albany-Schenectady NY	792	Albany	6887	572	916	.437	8.8	42.6	73.8
Albuquerque NM	409	Albuquerque	4291	1316	119	.682	9.0	35.0	106.6
Allentown-Bethlehem PA-NJ	626	Allentown	5827	770	1466	.454	10.0	40.6	75.5
Appleton-Oshkosh WI	291	Greeenbay	8096	385	1464	.480	11.0	44.1	88.5
Atlanta GA	1852	Atlanta	3094	1588	4931	.495	9.1	33.7	84.4
Augusta GA-SC	291	Augusta	2547	1994	7675	.500	6.0	33.5	82.0
Austin TX	478	Austin	1737	2907	12775	.526	10.0	30.3	97.7
Bakersfield CA	365	Bakersfield	2183	2178	15	.656	6.0	35.4	119.0
Baltimore MD	3145	Baltimore	4729	1107	3764	.476	9.5	39.3	76.6
Baton Rouge LA	445	BatonRouge	1669	2585	15308	.492	8.0	30.4	91.2
Beaumont-Port Arthur TX	364	PortArthur	1517	2797	19746	.499	11.0	30.1	94.1
Binghamton NY-PA	303	Binghampton	7285	369	810	.405	11.0	42.2	70.0
Birmingham AL	818	Birmingham	2844	1928	6968	.494	7.4	33.5	86.8
Boston-Brockton MA-NH	3688	Boston	5620	661	779	.450	12.6	42.3	71.1
Bridgeport CT	394	LaGuardia	4909	1048	2036	.468	9.0	41.2	73.2
Bristol-Johnson TN-VA	411	Knoxville	3478	1568	4767	.479	7.3	36.5	82.2
Buffalo NY	1303	Buffalo	6926	436	1021	.425	12.3	42.9	78.7
Canton OH	404	Akron/Canton	6223	634	1636	.444	10.8	40.8	81.4
Charleston SC	389	Charleston	2146	2077	11632	.491	8.8	32.9	80.0
Charleston WV	261	Charleston	4590	1055	2313	.435	6.5	38.4	81.6
Charlotte-Gastonia NC	606	Charlotte	3217	1595	3352	.503	8.0	35.2	80.8
Chattanooga TN-GA	401	Chattanooga	3505	1634	2283	.465	6.0	35.0	85.3
Chicago-Gary IL-IN	7678	Chicago	6125	923	2781	.492	10.3	41.8	87.8
Cincinnati-Ham. OH-KY-IN	1646	Cincinnati	5069	1080	1761	.453	7.1	39.1	84.7
Cleveland-Akron OH	2876	Cleveland	6152	612	1636	.439	10.8	41.5	81.7
Colorado Springs CO	291	ColoSprings	6374	461	1	.621	10.4	38.8	104.8
Columbia SC	380	Columbia	2597	2086	8392	.510	7.0	34.0	81.0
Columbus OH	1089	Columbus	5701	808	2096	.444	8.7	40.0	83.0
Corpus Christi TX	302	CorpusChr.	929	3474	26565	.530	12.0	27.8	97.4
Dallas-Fort Worth TX	2720	Dallas	2290	2754	7951	.536	11.1	32.8	96.8
Davenport-Rock Is. IA-IL	374	Moline	6394	893	2944	.493	10.0	41.5	90.6
Dayton OH	834	Dayton	5639	936	1752	.458	11.0	39.8	84.2
Denver-Boulder CO	1505	Denver	6016	625	4	.618	9.0	39.7	104.9
Des Moines IA	334	DesMoines	6709	927	1952	.529	11.1	41.6	93.6
Detroit-Ann Arbor MI	4641	Detroit	6228	742	1600	.457	10.2	42.4	83.0
Duluth-Superior MN-WI	266	Duluth	9765	175	362	.463	11.5	46.8	92.2
El Paso TX	443	ElPaso	2677	2097	70	.687	9.6	31.8	106.5
Erie PA	269	Erie	6851	373	964	.430	12.0	42.1	80.1
Eugene-Springfield OR	258	Salem	4851	230	5	.476	8.0	44.0	123.1
Evansville IN-KY	295	Evansville	4628	1363	4466	.487	9.0	38.0	87.6
Flint MI	521	Flint	7040	437	757	.442	11.0	43.0	83.7
Fort Wayne IN	376	FortWayne	6208	747	1760	.450	10.0	41.1	85.1
Fresno CA	479	Fresno	2650	1670	43	.651	6.3	36.8	119.7
Grand Rapids MI	585	GrandRapids	6800	574	1350	.466	10.0	43.0	85.7
Greensboro-Win-Salem NC	779	Greensboro	3845	1341	3559	.507	9.0	36.1	79.8

SMSA	Pop. (1000)	TMY	HDD	CDD	LEH	$\bar{K}_T$	WND	LAT	LNG
Greenville-Spartan. SC	541	Greenville	3163	1571	3352	.502	8.0	36.8	82.4
Harrisburg PA	430	Harrisburg	5224	1024	2319	.456	7.7	40.2	76.9
Hartford-New Britian CT	1045	Hartford	6349	583	1476	.429	9.0	41.8	72.7
Honolulu HI	720	Honolulu	0	4221	27753	.546	11.8	21.3	157.8
Houston-Galveston TX	2793	Houston	1433	2889	18845	.480	7.6	30.0	95.4
Huntington-Ash. WV-KY-OH	300	Huntington	4622	1098	2313	.456	6.5	38.4	82.4
Huntsville AL	293	Chattanooga	3505	1634	2283	.465	6.0	34.7	86.6
Indianapolis IN	1156	Indianapolis	5576	974	2745	.459	11.0	39.8	86.2
Jackson MS	299	Jackson	2299	2320	11652	.512	7.7	32.3	90.2
Jacksonville FL	702	Jacksonville	1327	2596	14328	.514	9.0	30.3	81.6
Johnstown PA	265	Pittsburgh	5929	646	890	.425	10.0	40.3	78.9
Kalamazoo MI	270	GrandRapids	6800	574	1350	.466	10.0	42.3	85.6
Kansas City MO-KS	1325	KansasCity	5357	1283	5807	.525	10.2	39.1	94.6
Knoxville TN	456	Knoxville	3478	1568	4767	.479	7.3	36.0	83.9
Lakeland-Winter Haven FL	278	Orlando	733	3226	17714	.522	8.7	28.0	81.9
Lancaster PA	351	Harrisburg	5224	1024	2319	.456	7.7	40.0	76.3
Lansing MI	458	Flint	7040	437	757	.442	8.0	42.7	84.6
Las Vegas NV	377	LasVegas	2601	2945	199	.704	8.9	36.2	115.1
Lexington KY	300	Lexington	4729	1197	4021	.471	9.7	38.0	84.5
Little Rock AR	376	LittleRock	3353	1924	9933	.523	8.2	34.7	92.3
Los Angeles CA	10784	LosAngeles	1818	614	109	.588	6.2	33.9	118.4
Louisville KY-IN	887	Louisville	4644	1267	4511	.470	8.4	38.2	85.8
Madison WI	319	Madison	7729	459	1343	.491	9.9	43.1	89.3
Manchester-Nashua NH	260	Concord	7358	347	922	.434	6.7	43.0	71.4
Memphis TN-AR-MS	889	Memphis	3226	2029	10005	.510	9.2	35.1	90.0
Miami-Fort Lauderdale FL	2333	Miami	205	4037	27753	.506	9.1	25.8	80.3
Milwaukee-Racine WI	1594	Milwaukee	7443	450	1277	.489	11.8	43.0	87.9
Minneapolis-St.P. MN-WI	2063	Minneapolis	8158	585	1769	.494	10.6	44.9	93.2
Mobile AL	435	Mobile	1683	2576	13155	.495	9.3	30.7	88.2
Montgomery AL	258	Montgomery	2268	2237	9609	.504	7.0	32.4	86.3
Nashville TN	786	Nashville	3695	1694	5584	.480	7.9	36.1	86.7
New Bedford-Fall R. MA	472	Providence	5791	531	779	.450	10.8	41.6	70.9
New Haven-Waterbury CT	755	LaGuardia	4909	1048	2036	.468	8.0	41.3	72.9
New Orleans LA	1141	NewOrleans	1463	2705	17754	.511	8.4	29.9	90.1
New York NY-NJ-CT	16285	Newark	5033	1022	1533	.465	9.4	40.8	74.0
Newport News-Hampton VA	361	Norfolk	3487	1440	6902	.505	10.6	37.0	76.5
Norfolk-Va.Beach VA-NC	800	Norfolk	3487	1440	6902	.505	10.6	36.8	76.3
Oklahoma City OK	789	OklahomaCity	3694	1876	5001	.548	12.9	35.5	97.5
Omaha NE-IA	582	Omaha	6601	949	3224	.531	10.9	41.4	96.0
Orlando FL	610	Orlando	733	3226	17714	.522	8.7	28.5	81.4
Pensacola FL	276	Mobile	1683	2576	13155	.495	8.0	30.4	87.2
Peoria IL	361	Moline	6394	893	2944	.493	10.3	40.7	89.6
Philadelphia PA-DE-NJ-MD	5603	Philadelphia	4864	1103	3168	.461	9.6	39.9	75.3
Phoenix AZ	1293	Phoenix	1552	3506	967	.686	6.1	33.4	112.0
Pittsburgh PA	2277	Pittsburgh	5929	646	890	.425	10.0	40.5	80.2

SMSA	Pop. (1000)	TMY	HDD	CDD	LEH	$\bar{K}_T$	WND	LAT	LNG
Portland OR-WA	1140	Portland	4792	299	35	.455	7.8	45.5	122.7
Providence RI	853	Providence	5791	531	779	.450	10.8	41.8	71.4
Raleigh-Durham NC	494	Raleigh	3514	1393	4790	.488	8.0	35.8	78.6
Reading PA	306	Allentown	5827	770	1466	.454	9.0	40.3	75.9
Richmond VA	612	Richmond	3938	1353	5144	.479	7.6	37.5	77.4
Rochester NY	970	Rochester	6718	531	1658	.430	9.7	43.2	77.6
Rockford IL	269	Madison	7729	459	1343	.491	10.0	42.3	89.1
Sacramento CA	951	Sacramento	2842	1157	43	.638	8.3	38.5	121.5
St. Louis MO-IL	2386	St.Louis	4748	1474	6210	.517	9.5	38.8	90.4
Salinas-Monterey CA	276	SanFrancisco	3042	108	0	.597	8.7	36.6	121.9
Salt Lake City-Ogden UT	843	SaltLakeCity	5981	927	0	.640	8.7	40.8	111.9
San Antonio TX	1036	SanAntonio	1570	2993	12953	.531	9.3	29.5	98.5
San Diego CA	1744	SanDiego	1507	722	318	.583	6.7	32.7	117.2
San Fran.-Oak.-S.Jose CA	4717	SanFrancisco	3042	108	0	.597	8.7	37.6	122.1
Santa Barbara-S.Maria CA	292	SantaMaria	3053	83	0	.599	7.0	34.4	119.7
Santa Rosa CA	274	Oakland	2909	128	0	.591	8.7	38.4	122.6
Scranton-Wilkes-Barre PA	629	Scranton	6277	607	1466	.437	8.4	41.4	75.6
Seattle-Tacoma WA	1905	Seattle	5184	128	0	.462	9.3	47.5	122.3
Shreveport LA	356	Shreveport	2165	2538	12312	.519	8.9	32.5	93.7
South Bend IN	281	SouthBend	6462	695	1426	.460	11.0	41.7	86.2
Spokane WA	320	Spokane	6835	387	0	.538	8.7	47.6	117.5
Springfield MA	587	Hartford	6349	583	1476	.429	9.0	42.1	72.6
Stockton CA	313	Sacramento	2842	1157	43	.638	8.3	38.0	121.3
Syracuse NY	650	Syracuse	6678	551	1354	.426	9.8	43.0	76.2
Tampa-St. Petersburg FL	1396	Tampa	716	3366	19037	.521	8.8	27.9	82.4
Toledo OH-MI	776	Toledo	6381	684	2546	.457	9.5	41.6	83.5
Tucson AZ	462	Tucson	1751	2813	1011	.679	8.2	32.1	110.9
Tulsa OK	629	Tulsa	3679	1948	8231	.519	10.6	36.2	96.0
Utica-Rome NY	326	Syracuse	6678	551	1354	.426	9.8	43.1	75.2
Washington DC-MD-VA	3017	Washington	5008	940	3734	.472	9.2	39.0	77.4
W.Palm Bch-Boca Raton FL	487	W.PalmBeach	299	3785	24755	.497	9.0	26.7	80.0
Wichita KS	398	Wichita	4685	1672	5807	.577	12.6	37.7	97.3
Worcester-Fitchburg MA	645	Boston	5620	661	779	.450	10.5	42.2	71.8
York PA	356	Harrisburg	5224	1024	2319	.456	7.7	40.0	76.7
Youngstown-Warren OH	546	Youngstown	6426	517	993	.420	10.0	41.1	80.6

SMSA Standard Metropolitan Statistical Area

TMY Typical Meteorological Year (Climate Data)

HDD Heating Degree Days (^{o}F.day, base 65^{o}F)

CDD Cooling Degree Days (^{o}F.day, base 65^{o}F)

LEH Latent Enthalpy Hours (btu.hr/lb of dry air)

WND Annual Average Wind Speed (miles/hour)

$\bar{K}_T$ Solar Radiation (fraction)

LAT Latitude (^{o}N)

LNG Longitude (^{o}W)

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