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Publication Date
1982-08-01

LBL-14351 c.2

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ENERGY & ENVIRONMENT DIVISION

Presented at the 7th National Passive Solar Conference,
Knoxville, TN, August 29-September 1, 1982

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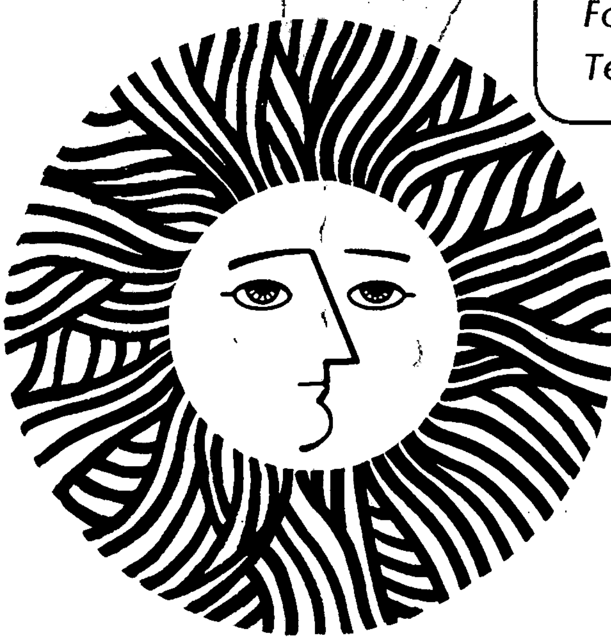

Prepared for the U.S. Department of Energy under Contract DE-AC03-76SF00098

DISCLAIMER

AGGREGATION OF U. S. POPULATION CENTERS INTO CLIMATE REGIONS*

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ABSTRACT

A technique is described for aggregating U.S. population centers into regional groups which have similar climates. The technique involves:

(1) the use of weather data for Standard Metropolitan Statistical Areas (SMSAs) to represent the climates of U. S. population centers;

(2) the selection and quantification of weather parameters to represent the salient climate characteristics of each SMSA;

(3) the sequential application of a decision-making procedure (with specifiable decision criteria) to each SMSA in order to determine which SMSAs group together to form a region; and

(4) the use of population-weighted regional averages of each of the climate parameters to determine which single SMSA best represents the entire region.

The value of the technique lies in its objectivity and flexibility in providing rational regional groupings for a wide range of specialized applications which can be explicitly defined by the user. For ease of use, the entire technique has been automated as an interactive computer program. Four examples of regional breakdowns obtained by this technique using different grouping criteria are presented and discussed [1].

1. BACKGROUND AND PURPOSE

Subdividing the U.S. into regions based on climate characteristics is useful for two general reasons:

(1) For many computer studies of building energy performance, it is impractical and inefficient to perform simulations for all sites where weather data is available. It is thus desirable to identify a manageable subset of all climates, each of which will yield simulation results that are suitably representative of a larger region.

(2) It is often desirable to determine the geographical extent or the demographic significance of climate regions that exemplify or highlight some climatic effect of particular interest or importance.

The selection of representative climate data has typically been 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 or uniqueness of a climate, and the choice of a climate by previous researchers. Recent studies [2,3] have used climates from the 26 original Typical Meteorological Year (TMY) climate data tapes [4], which appeared at first glance to blanket the entire continental U.S. However, very large segments of the population are not well represented by any of the original 26 sites. Furthermore, results from many of these climates provide only a limited amount of useful information, because the regions they represent contain so few people or buildings.

With the recent release of TMY climate data for over 200 cities, a more sophisticated and flexible method for grouping cities into climate regions became highly desirable.

2. METHOD

2.1 SMSA Identification

The 125 SMSAs used in this aggregation method, marked as black dots in Figures 4-7, contain over 140,000,000 people (2/3 of the U. S. population) and include every metropolitan area of 250,000 or more. By including populations living near SMSAs but not within their boundaries, 80-90% of the U.S. population are climatically represented by these sites.

* This work was supported by the Assistant Secretary for Conservation and Renewable Energy, Office of Solar Heat Technologies, Passive and Hybrid Solar Energy Division, of the U. S. Department of Energy under contract No. DE-AC03-76SF00098.

2.2 Climate Characterization

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 are inadequate for two reasons: the climatic parameters which most strongly affect building energy use may not be the ones which form the most lasting impression on people; and an attempt to compare two subjective characterizations will very often result in error.

To make an objective grouping of the SMSAs' climates for building energy analysis, it is necessary to identify quantifiable characteristics which most closely relate climate to building energy use. The method described here selects and quantifies certain climate parameters which the author's expect will correlate strongly with building energy use. Each climate is characterized by four quantities representing three climatic influences (temperature, solar effects, and humidity):

(1) heating degree days (HDD), relative to a base of 65^{o}F;

(2) cooling degree days (CDD), relative to a base of 65^{o}F;

(3) $\overline{K}_T$, the ratio of the annually available sunshine to the sunshine available if no atmosphere existed (extraterrestrial radiation); and

(4) latent enthalpy hours (Btu hour/pound dry air), the latent energy necessary to lower the humidity ratio of outside air to .0116 [5].

These are all annual parameters, which do not explicitly measure seasonal or daily variation. However, similarity of several annual parameters strongly indicates general climatic similarity, especially as it affects energy issues.

Climate information for each SMSA is derived from SOLMET and TMY weather data [6]. For the 125 SMSAs used in this study, annual heating degree days (HDD) range from 0 (Honolulu) to 9800 (Duluth), with a population-weighted mean of 4400 (Louisville). Annual cooling degree days (CDD) range from 100 (San Francisco) to 4200 (Honolulu), with a population-weighted mean of 1200 (Sacramento or Lexington, KY). Annual latent enthalpy hours (LEH) range from 0 in several west coast locations to 27,800 in Miami, with a weighted mean at 4000 (Baltimore or Lexington). Annual average $\overline{K}_T$ fractions range from 0.41 (Binghamton, NY.) to 0.70 (Las Vegas) with a weighted mean of .50 (Atlanta or Chicago).

Figures 1 and 2 are examples of the distribution of population for climate parameters. Eleven key SMSAs are noted on the bar charts by letters identified in Table 2. The climate regions represented by these SMSAs are shown on the map in Fig. 5. For heating degree days, Fig. 1 shows 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 1700 HDD. A smaller peak occurs in the Southeast. For $\overline{K}_T$, Fig. 2 has its largest peak at .46-.47 for the Northeast, Eastern Lakes, and Northwest, a nearby peak at .49-.50 for the Western Lakes and Southeast, and another at .59, mostly California.

2.3 Relationships of Climate Parameters

Plotting one parameter against another allows visual identification of the magnitude and range of the parameters for each group of SMSAs and the relationships between the two climate parameters. An example is presented in Fig. 3, where $\overline{K}_T$ is plotted against heating degree days. The eleven regional groupings from Fig. 5 are identified as an illustration.

Overlap of regions on the plot is caused by consideration of other climate parameters or the imposition of "external" considerations, such as the need for geographical contiguity, which may require alterations to the quantitatively generated regions.

2.4 Climate Region Identification

The basic technique used to generate climate regions (aggregations of SMSAs with similar climates) requires a climate center, usually a SMSA. Large cities often make the best climate centers because they tend to dominate the population-weighted averages of the region's climate parameters. Population-weighted averages are an important tool for evaluation of the appropriateness of a given climate center. Each of the climate parameters is then given a range -- the maximum allowable difference between the climate center and a SMSA being considered for inclusion in the climate region. If the difference between each of a SMSA's climate parameters and the corresponding parameter of the climate center is less than the maximum range, it will be included in the climate region. If a study to be performed is expected to be very sensitive to a particular climate parameter, the permissible range for that parameter might be set relatively low, to assure that there would not be a large difference in that parameter between any two population centers in the same climate region.

In the case where a given SMSA has a climate which qualifies for inclusion in more than one climate region, it can be included in either region, or included in the region whose climate center is "closest," climatically, to the SMSA in question. ("Climatic distance" in this context is defined and discussed in [1].)

When a finer breakdown of climates than the initial aggregation provides is desired, there are different ways of approaching the creation of new climate regions. One approach is to find the SMSAs which are not assigned to a climate region or fit poorly in the one to which they are assigned and create new regions for them. This will ensure that every SMSA is represented by a climate center with a very similar climate, but it may result in many regions with one or two SMSAs each and small populations.

Another approach is to try to divide the climate regions with very large populations by finer definitions of the climates in those regions. If one is trying to evaluate energy or economic impacts, areas with large populations and greater impact should have the most precisely defined climates, where parameters vary as little as possible within a given climate region.

2.5 Climate Region Analysis

Population-weighted means of each of the climate parameters are calculated for each climate grouping. This "ideal" center can then be used to determine the appropriateness of the existing climate center or to identify a more representative SMSA as the center. For each climate parameter, the nearest and farthest SMSAs from the center are also identified.

Since there is much trial and error in any climate region aggregation, the ability to quickly generate different groupings from different specifications is extremely important. In order to perform the considerable calculation and bookkeeping necessary for aggregation and allow for fast evaluation of changes to climate regions, an interactive computer program, GLOM+, was written.

3. RESULTS

The following examples of climate region groupings illustrate application of the method described above to specific energy analysis tasks.

3.1 5 Regions: Wide Climate Ranges

To identify a small number of regions into which the U. S. could be divided while still providing representation of building energy use across the range of climates in which most people live, relatively large ranges of all four climate characteristics were chosen. (Climate parameter ranges for all four examples are found in Table 1.)

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It was found that if five climate centers -- New York, Los Angeles, Detroit, Atlanta, and Houston -- were chosen, and regions were aggregated around them (see Fig. 4), the great majority of the SMSAs fell within those regions, and most were far more similar to the centers than the ranges allowed. When each of the remaining SMSAs were assigned to the most appropriate region, the population-weighted averages of the climate parameters in each region remained quite close to those of the climate centers.

3.2 11 Regions: Passive Cooling Assessment

As an example of an application requiring regionalization, the Department of Energy's Passive Cooling Technology Assessment [7] required (1) a manageable number of climates representing the entire U. S., (2) definition of areas most appropriately included with each chosen climate site, and (3) representative energy performance information for the largest population possible. It was necessary to identify regions with a narrower range of climate characteristics, suitable for more precise analysis of parametric studies. Starting with the largest SMSA, and continuing with the largest remaining SMSA after each climate region definition, regions were aggregated based on the specified ranges of the climate characteristics. This process was continued until all of the SMSAs were assigned.

The result was 24 climate regions ranging from 36 million people in the New York region to .2-.4 million in single-SMSA regions such as Albuquerque or Duluth. A map of these regions was modified to combine the 24 regions into 11 larger regions in order to limit the number of sites to be analyzed. These are shown in Fig. 5. The same regions or their centers are also used for illustration in Figures 1-3. Table 2 shows the relationship between the population-weighted means of each climate region and the climate centers. In most cases, good correspondence indicates a center which represents its region well.

3.3 11 Regions: Latent Emphasis

For studies of dehumidification, it was important to identify climate regions with special emphasis on latent enthalpy hours. Wide ranges for degree days and sunshine were allowed, while the allowable range of latent enthalpy hours was more restrictive.

Proceeding in a manner similar to the previous aggregation, the 11 climate regions shown in Fig. 6 were identified. The climate centers are similar to the 11-region grouping in Fig. 5, but the wider range of HDD and 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 variation of LEH occurs.

3.4 24 Regions: Reduced Population Extremes

When an aggregation of SMSAs into a larger number of regions was necessary, several approaches were taken to create the 24 climate regions in Fig. 7: finer climate definition in high-population areas, separation of population centers which fit poorly in their regions, and replacement of climate centers and reaggregation of SMSAs for better climate representation.

In Fig. 5, more than three quarters of the total SMSA population was in the regions around New York, Detroit, and Los Angeles. By identifying several new climate centers -- Chicago, Philadelphia, San Francisco, Boston, St. Louis, Cincinnati, and Buffalo -- ten regions were created from those three. Each of the new regions has very small variation in climate. Populations range from five to 18 million, and all ten of the new climate regions still rank in the top thirteen, but their populations are much more consistent with the rest of the regions than the original three. New York, though effectively restricted to its own metropolitan area, still has the highest population of any climate region.

In the South, more regions which do not appear in Fig. 5 were created -- Miami, San Antonio, Mobile, Memphis, and Oklahoma City. These were chosen largely because they represented climates different in some distinctive way from their previous climate centers.

The Southwest and Mountain areas, with small populations, accounted for only one new region, and some considerable rearranging to achieve better groupings.

4. CONCLUSIONS

Experience with the method of climate characterization and aggregation described above has led to several conclusions.

(1) When climate regions are aggregated on the basis of quantified climate parameters and account is taken of population density:

- o certain climates which have been used extensively for building energy studies (e.g. Albuquerque) are found to be climatic extremes and representative of only a small fraction of the U. S. population; and
- o other climates (e.g. New York, Atlanta, Los Angeles) have been found to be highly representative of regions containing much greater populations.

(2) Future work in this area should focus on:

- o correlating building energy perfromance with the current climate parameters to determine the significance of the ranges and the weighting of those parameters;
- o determining the need for and the form of additional parameters; and
- o using correlations between building features, building energy performance, and climate parameters as a basis for design recommendations.

5. REFERENCES

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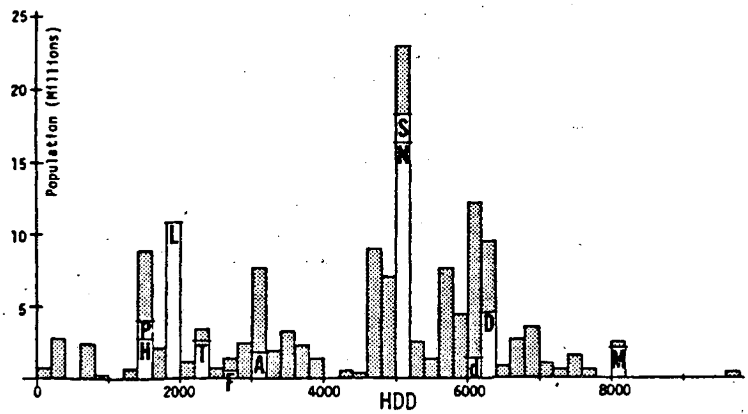

Fig. 1. Population Distribution by Heating Degree Days.

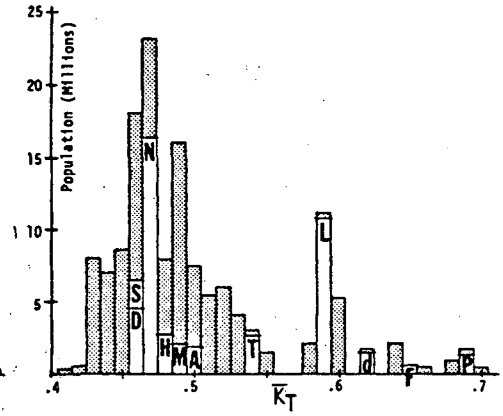

Fig. 2. Population Distribution by $\overline{K}_T$.

TABLE 1: CLIMATE PARAMETER RANGES* FOR GROUPS

Regions	HDD	CDD	LEH	$\overline{K}_T$
5	±1500	±1000	±5000	±0.05
11 (Standard)	±1000	±600	±3000	±0.04
11 (Latent)	±1500	±1000	±3500	±0.15
24	±1000	±600	±5000	±0.05

* Ranges used for initial selection only.

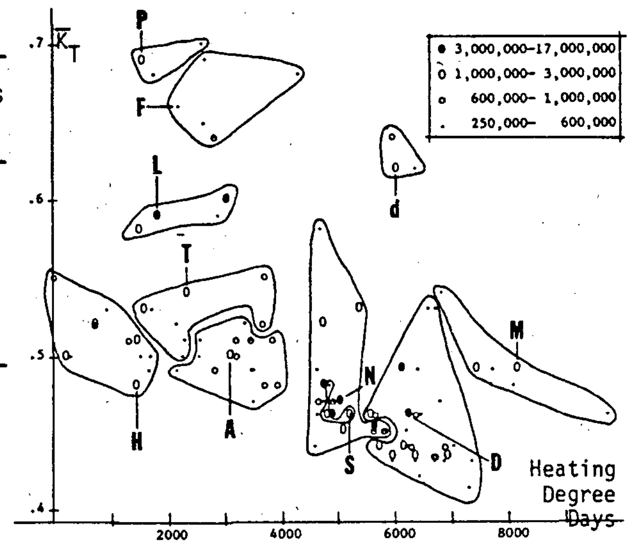

Fig. 3: Climate Parameter Relationships

TABLE 2: 11-REGION ANALYSIS

(Regional climate parameters are population-weighted means.)

Key	Climate Region/Center	Pop.(Millions)	HDD	CDD	LEH	KbT
	Northeast	58.8	5089	1018	2484	0.470
N	Center: New York	16.3	5033	1022	1534	0.470
	Great Lakes	50.6	6292	724	1858	0.458
D	Center: Detroit	4.6	6228	742	1600	0.460
	South	28.7	3290	1656	5866	0.497
A	Center: Atlanta	1.9	3094	1588	4931	0.500
	Gulf Coast	18.3	949	3248	20634	0.504
H	Center: Houston	2.8	1433	2889	18845	0.480
	California Coast	18.2	2162	469	96	0.592
L	Center: Los Angeles	10.8	1818	614	109	0.590
	Central Texas	14.3	2449	2534	9234	0.533
T	Center: Dallas/Ft.Worth	2.7	2335	2670	7951	0.540
	Northern Tier	12.6	7892	485	1368	0.491
M	Center: Minneapolis	2.1	8158	585	1770	0.490
	Fresno / El Paso	7.0	2905	1529	54	0.657
F	Center: Fresno	0.5	2650	1670	43	0.650
	Central Mountains	6.8	6044	703	3	0.626
d	Center: Denver	1.5	6016	625	5	0.620
	Pacific Northwest	5.4	5023	195	13	0.462
S	Center: Seattle	1.9	5184	128	0	0.460
	Desert Southwest	4.6	1781	3257	842	0.690
P	Center: Phoenix	1.3	1552	3506	968	0.690

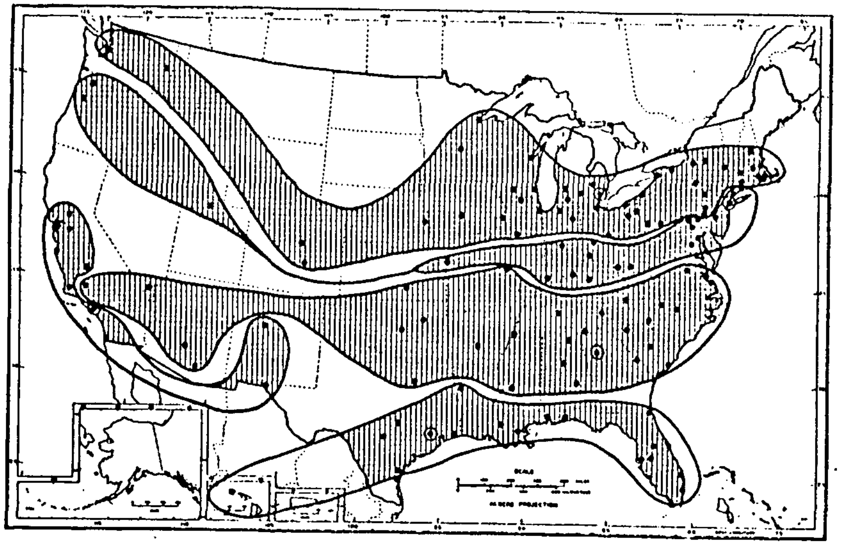

Fig. 4: Five Regions

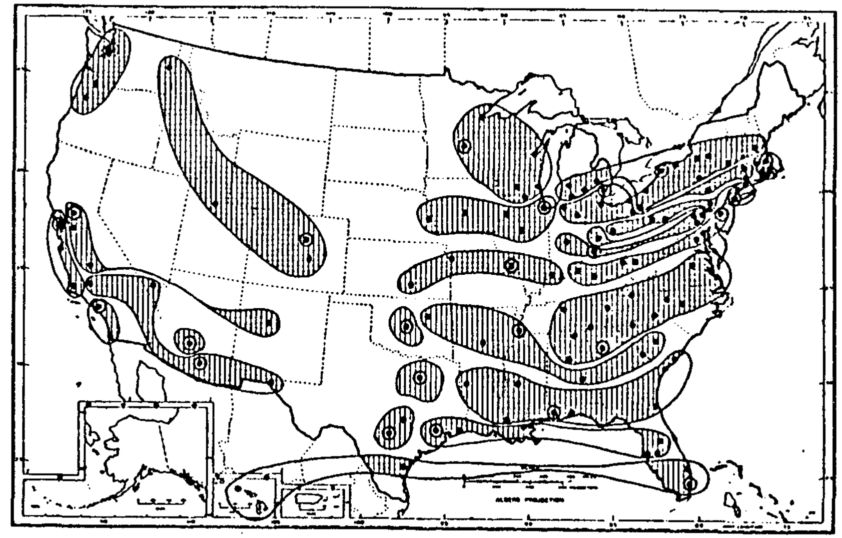

Fig. 7: Twenty-four Regions

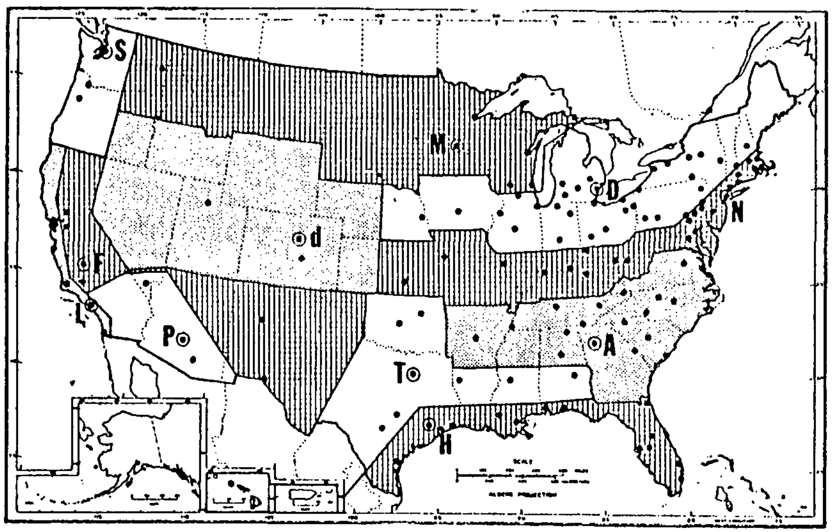

Fig. 5: Eleven Regions

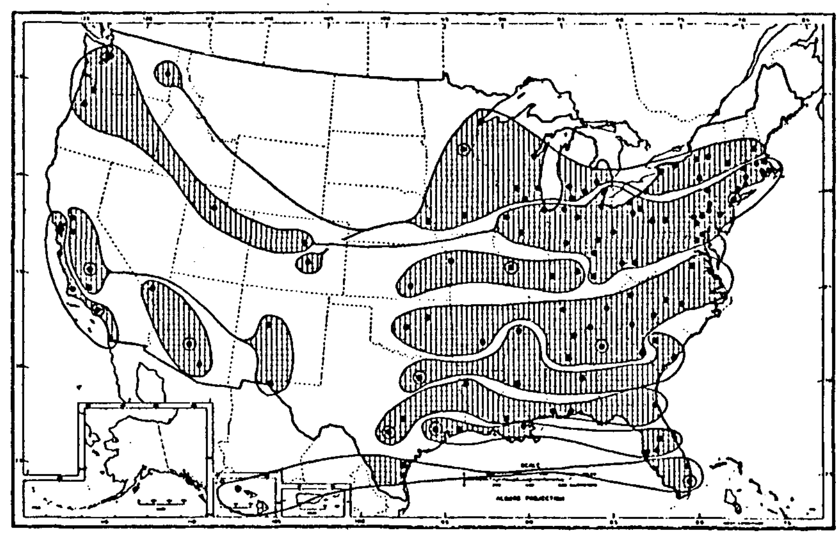

Fig. 6: Eleven Regions - Latent Emphasis

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