NBS BUILDING SCIENCE SERIES 116

Geographical Variation in the Heating and Cooling Requirements of a Typical Single-Family House, and Correlation of These Requirements to Degree Days

U.S. DEPARTMENT OF COMMERCE • NATIONAL BUREAU OF STANDARDS

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William L. Carroll

Center for Building Technology
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Washington, D.C. 20234

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FOREWORD

This is one of a series of reports planned to document NBS research efforts in developing energy and cost data needed to formulate energy budgets for Building Energy Performance Standards (BEPS). The work described in this report was jointly supported by ERDA/NBS Modification No. 2 of Contract E(49-1)3800 and Task Order No. A008-BCS to Interagency Agreement No. EA-77-A-01-6010, and by HUD/NBS Contract No. RT193-12.

Edward A. Arens and William L. Carroll

SI CONVERSION UNITS

In view of the present accepted practice in this country for building technology, common U.S. units of measurement have been used throughout this document. In recognition of the position of the United States as a signatory to the General Conference of Weights and Measures, which gave official status to the metric SI system of units in 1960, assistance is given to the reader interested in making use of the coherent system of SI units by giving conversion factors applicable to U.S. units used in this document.

Length

1 in = 0.0254 meter (exactly)
1 ft = 0.3048 meter (exactly)

Area

1 in^2 = 6.45×10^{-4} $meter^2$
1 ft^2 = 0.09290 $meter^2$

Volume

1 in^3 = 1.639×10^{-5} $meter^3$
1 gal (U.S. liquid) = 3.785×10^{-3} $meter^3$

Mass

1 ounce-mass (avoirdupois) = 2.834×10^{-2} kilogram
1 pound-mass (avoirdupois) = 0.4536 kilogram

Pressure or Stress (Force/Area)

1 inch of mercury (60°F) = 3.377×10^3 Pascal
1 pound-force/$inch^2$ (psi) = 6.895×10^3 Pascal

Energy

1 foot-pound-force (ft•lb•f) = 1.356 joule
1 Btu (International Table) = 1.055×10^3 joule
1 kilowatt-hour (kWh) = 3.600×10^6 joule = 3.412×10^3 Btu

Power

1 watt = 1 joule/sec
1 Btu/hr = 0.2929 watt

Temperature

$t_{°F} = 1.8\ t_{°C} + 32$
$(\text{Degree days})_{°F} = 1.8\ (\text{Degree days})_{°C}$

Heat

1 (Btu•in)/(h•ft^2•F) = 1.442 x 10^{-1} W/(m•K) (thermal conductivity)
1 Btu/lbm•°F = 4.184 x 10^3 J/(kg•K) (specific heat)
1 langley = 4.184 x 10^4 J/m^2 = 1 cal/cm^2 = 3.69 Btu/ft^2

ABSTRACT

The report has three main purposes:

First, it assesses 'Test Reference Year' (TRY) hourly climate data tapes to determine how well they represent long-term average climate when used for estimating average annual heating and cooling requirements. The report presents a method to adjust heating and cooling requirements that are computed using TRY data, in order to make them represent long-term average heating and cooling requirements.

Second, the report quantifies the geographic variation of annual heating and cooling requirements across the U.S. by computing the heating and cooling requirements of a typical ranch-style residence for the 8760 hours of each of the 60 TRY tapes, and adjusting the results by the method described above.

Third, the effectiveness of 'degree-day' data for predicting these computed annual heating and cooling requirements is examined, and the variability of heating and cooling requirements within degree-day 'zones' of 1000 degree day width is presented.

Key words: Building energy conservation; climatic effects on building energy consumption; computer modeling of building energy consumption; energy conservation; geographical variation of building energy consumption; residential energy consumption.

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We thank Candace L. Roat, Daniel Nall, and Andre Tanner, Architectural Research Program, NBS, James Filliben, Statistical Engineering Section, NBS, Paul R. Achenbach, Building Environment Division, NBS, and Charles Robinson, Thermal Engineering Program, NBS, for their help in preparing and analyzing the data presented here.

INTRODUCTION

PURPOSE AND BACKGROUND

The rapidly rising cost of energy has made buildings' heating and cooling operating costs, taken over the expected life span of the building, often exceed the first costs of construction. Accordingly, building designers have been increasingly considering energy conservation during design, and are attempting to determine the optimum investment of construction funds into energy-conserving design options.

At the same time, the national energy shortage has highlighted the fact that heating and cooling buildings consumes almost one fifth of the entire national energy demand. This energy has, in consequence become the focus of regulatory agencies promulgating energy conservation standards, and of energy planners and suppliers.

This report addresses several topics that may be useful to building designers, and to planners and regulators concerned with larger-scale energy issues:

1. Building designers need to be able to compute accurately the average annual energy requirements of buildings in order to optimize energy conserving measures. The "Test Reference Year" (TRY) hourly climate data tapes provided by National Oceanic and Atmospheric Administration (NOAA) are being used by engineers for computing building energy requirements in a large number of U.S. locations. The tapes were not originally selected to represent average, or long-term, climate; the appropriateness of using TRY tapes for this purpose needs to be determined and possible errors quantified.

2. Both designers and regulators charged with developing building energy standards need to know the geographic variation of building heating and cooling requirements around the U.S. The heating and cooling variations should be attributable to climate and location alone, and not include the effects of existing regional differences in construction practices.

3. Designers, regulators, and energy planners need to investigate the usefulness of degree days for predicting building heating and cooling requirements in locations with widely varying sunlight, humidity, and wind. Since the degree day to the base 65°F is the basis of most traditional methods of energy calculation, and is also the basis of most energy standards, e.g., ASHRAE Standard 90-75, a detailed comparison of this parameter against energy requirements nationwide is useful. An investigation of degree days to other base base temperatures is also needed.

4. There is a need to investigate whether geographical zones can be identified within which building energy requirements could be considered constant with respect to climate. Regulators, energy planners, and designers are using such zones to formulate building energy standards, priority lists for energy conserving measures, and other such regulatory and design implements.

APPROACH

1. The report describes in detail the Test Reference Year data tapes for computerized building energy calculations. The TRY tapes' accuracy in representing the average long-term climate is tested by comparing the degree days and average temperatures calculated from the TRY tapes themselves to the National Weather Service's long-term records for these parameters. Degree days to a wide range of different base temperatures have also been investigated for each TRY tape.

2. The geographical variation of annual heating and cooling requirements across the U.S. is given, using one single-family ranch house as a basis for the computer simulation. The ranch house has been carefully designed to be representative of current typical house con-

struction, and the energy demands caused by the activities of a typical occupancy have been included in the simulation.

3. The correlation of heating and cooling requirements to heating and cooling degree days is determined for degree days to two bases: the traditional National Weather Service base of 65°F, and empirically determined bases specific to this residence. The correlation is obtained by comparing the annual values of heating and cooling requirements with TRY-calculated degree days for each of the 60 locations for which TRY tapes are available.

4. The heating and cooling requirements, as calculated from the TRY tapes, are then adjusted to more closely represent the long-term climate at each location. The percent difference between TRY-calculated degree days and long-term degree days is used to adjust the energy values.

5. The report describes the variation in heating and cooling requirements within 1000-degree-day bands defined by degree days to the base 65°F. Such bands have been incorporated in building energy standards, on the assumption that energy consumption is reasonably uniform within each band. It may be inequitable to require uniform insulation levels across a band with a wide variation in heating and cooling requirements, particularly if the adjacent zone with lower insulation requirements contains locations with higher heating and cooling requirements.

This report is the first of a series being prepared by the authors to describe the effects of climate on heating and cooling requirements on buildings. The companion reports will use the TRY data and the NBS Loads Determination Program (NBSLD) [7] program to define the functional relationships between heating and cooling requirements and the individual climatic elements of temperature, humidity, solar radiation, and wind. Additional building designs are included in the investigation. The reports will also include a method of abbreviating climatic data for reduced computation costs and ease of analysis, a means of increasing the representativeness of TRY data, and a method for providing more geographically specific computerized climate data to building sites.

1. THE TEST REFERENCE YEAR TAPES

1.1 DESCRIPTION OF TRY TAPES

A Test Reference Year (TRY) Computer tape consists of climate data in a standardized format for use by engineers in comparing energy requirements of various heating and cooling systems. The climate data are in hourly form for the full reference year, as needed for computer simulation of building heating and cooling performance. The TRY tapes are provided by NOAA, in accordance with criteria developed by ASHRAE Technical Committee 4.2 (Engineering Weather Data). TRY tapes are now available for 60 cities. The data are generally recorded at weather stations in nearby airports. The number of tapes is to be increased to 90 in the future with the addition of data from military bases.

Appendix A, part 1, lists available TRY tapes. The list includes the city, the year chosen to be the representative TRY, and the coordinates and elevation of the weather station.

The tapes contain the following climatic information for each of the 8,760 hours of the year (or 8784 hours for leap years):

- Dry-bulb temperature
- Wet-bulb temperature
- Dew-point temperature
- Wind direction
- Wind speed
- Barometric pressure at station
- Weather (consisting of precipitation, fog, haze, dust)
- Total sky cover
- Cloud amount of each of four cloud layers
- Type of cloud for each of four cloud layers
- Height of base of each of four cloud layers
- Solar radiation (not currently included in the tapes)

The various building energy computer programs draw from this list whichever climatic elements they require in their calculation procedure.

Each TRY tape consists of one year's climate records chosen from a population of 27 years of records on U.S. National Weather Service 1440 series data tapes. The year chosen as the TRY year varies with location. The TRY selection procedure is described in Appendix A, part 2.[1] The TRY data were not intended to be sufficiently typical of long-term climate to yield reliable estimates of average energy requirements. However, since they are currently the only publicly available hourly data tapes which are representative of the long-term temperature record,* they have come to be used for energy calculations by the engineering and research communities. It is therefore desirable to determine how representative each TRY tape is of the long-term average climate.

1.2 DETERMINING THE REPRESENTATIVENESS OF TRY DATA

It is possible to check the representativeness of each TRY tape by comparing the number of heating and cooling degree days in the TRY tape data with those established from long-term climatic records. This method was was chosen here after initial results showed a well defined correlation between annual degree days and calculated annual heating and cooling requirements.

The number of heating degree days for a particular day is calculated from the following:

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* Another nationwide data tape series is in preparation at time of writing. This is the Typical Meteorological Year (TMY), prepared by the Department of Energy in NOAA's SOLMET format. The years are primarily intended for use in designing solar systems. Each year is a composite of the most typical months from 23 years of record. The criteria for typicalness are weighted toward solar radiation, but also include temperature, humidity, and wind velocity.

$$N = [T_b - 1/2(T_{max} + T_{min})]$$

where: T_b is a specified "base temperature"
T_{max} is the daily maximum temperature**
T_{min} is the daily minimum temperature**
$1/2(T_{max} + T_{min})$ is the NOAA definition of daily average temperature.

N is set to zero if the calculated value is negative. The expression for cooling degree days is:

$$N = [1/2(T_{max} + T_{min}) - T_b].$$

The daily calculated degree-day values are then summed for monthly and annual periods to give a measure of accumulated temperature difference. The National Weather Service uses a method devised by H.C.S. Thom [2, 3, 4] to calculate monthly heating and cooling degree days from monthly average temperature and the standard deviation of daily average temperatures about the monthly average. Both heating and cooling degree days to the base 65°F are calculated by NOAA as described above from long-term temperature records for a large number of locations in the U.S. [5].

The base temperature should be a daily average temperature above which (in the case of heating degree days) there is, on the average, no heating load or below which (in the case of cooling degree days) there is, on the average, no air conditioning load. If the base temperatures do correspond to these thresholds, and if heating and cooling requirements are basically proportional to temperature, the degree-day total for a given period will then be basically proportional to the heating and cooling quired for that period. This proportionality relates climate to energy use.

The results presented in Chapter 3 show that annual heating and cooling requirements of the ranch-style test house used in this study are basically proportional to heating and cooling degree days, when the base temperature for heating degree days is 53°F, and for cooling degree days is 68°F. Thus the preferred test of each TRY tapes' representativeness of predicting the annual heating requirements of this test house would be a comparison of its number of heating degree days, base 53°F, with a long-term record of heating degree days, base 53°F. In order to test the TRY tapes' representativeness for predicting annual cooling of this test house, a similar comparison would be made with cooling degree days, base 68°F. This approach is taken in Chapter 4.

** There is a small difference between the procedure used here and that used by NOAA in calculating degree days. NOAA uses actual extreme temperatures, taken from continuous records, while the TRY tapes provide only the maximum and minimum hourly values for T_{max} and T_{min}, respectively, for each day. This should cause only insignificant differences in determining the daily average, and thus the calculated degree days.

The traditional base for both types of degree days, however, is 65°F. Since nearly all the published climatic data and building energy use data are expressed in terms of degree days to this base, the general comparison of TRY and long-term degree days presented in Table 1.1 uses degree days to this base. Table 1.1 contains:

a. The number of 65°F base heating and cooling degree days for each reported location computed from the tapes.

b. The NOAA National Weather Service's long-term degree-day totals calculated for the same locations.

c. A similar comparison of the annual mean temperatures in the TRY to those in the long-term record.

d. A similar comparison of the annual mean temperatures in the TRY to those in the long-term record.

The relationship between the number of 65°F base degree-days and the number with other bases may be determined by computing and plotting of the numbers of degree days to a wide range of degree-day bases. An example of such output is presented in Figure 1.3, a frequency distribution of degree days versus degree-day base temperature.

Figure 1.3 reveals that this relationship is nearly linear for inland stations, within the ranges of interest: 65°F to 53°F for heating degree degree days, and 65°F to 68°F for cooling degree days. Coastal locations, which have fewer cold days and a higher proportion of their total days in the range 53°F to 65°F than inland stations, exhibit a more significant curve in their heating degree-day frequency distributions in in this range. San Francisco has the most extreme curvature of all the TRY locations.

1.3 RESULTS

Figures 1.1 and 1.2 give an indication of the accuracy of the whole population of TRY tapes at predicting actual long-term heating and cooling degree-day data to base 65°F. The relevant statistics are:

TABLE 1.1

Station	TRY Heating Degree Days (Base 65°)	Long Term Heating Degree Days	% Deviation $\frac{TRY-LT}{LT} \times 100$	TRY Cooling Degree Days (Base 65°)	Long Term Cooling Degree Days	% Deviation $\frac{TRY-LT}{LT} \times 100$	TRY Annual Mean Temperature	Long Term Annual Mean Temperature
Albany, NY	7265	6888	+ 5.5	492	654	-24.8	46.8	47.6
Albuquerque, NM	4322	4292	+ 0.7	1345	1316	+ 2.2	56.5	56.8
Amarillo, TX	4219	4183	+ 0.9	1258	1433	-12.2	56.3	57.4
Atlanta, GA	2928	3095	- 5.4	1469	1589	- 7.6	60.6	60.8
Birmingham, AL	2824	2844	- 0.7	1654	1928	-14.2	61.7	62.4
Bismarck, ND	9538	9044	+ 5.5	528	487	+ 8.4	40.6	41.4
Boise, ID	5697	5833	- 2.3	749	714	+ 4.9	51.7	50.9
Boston, MA	5829	5621	+ 3.7	674	661	+ 2.0	51.0	51.3
Brownsville, TX	497	650	-23.5	3851	3874	- 0.6	73.9	73.8
Buffalo, NY	6866	6927	- 0.8	400	437	- 8.5	47.5	47.1
Burlington, VT	8093	7876	+ 2.8	368	395	- 6.8	44.4	44.4
Charleston, SC	2200	2146	+ 2.5	1976	2078	- 4.9	64.3	64.7
Cheyenne, WY	7131	7255	- 1.7	308	327	- 5.8	46.4	45.9
Chicago, IL	6191	6127	- 1.0	713	925	-22.9	50.3	50.6
Cincinnati, OH	4950	4844	+ 2.2	1147	1080	+ 6.2	54.7	54.0
Cleveland, OH	6569	6154	+ 6.7	670	613	+ 9.3	49.3	49.7
Columbia, MO	5202	5078	+ 2.4	1205	1269	- 5.0	54.1	54.4
Detroit, MI	6510	6419	+ 1.4	687	743	- 7.5	49.3	49.1
Dodge City, KS	5356	5046	+ 6.1	1326	1411	- 6.0	53.7	54.9
El Paso, TX	2683	2678	+ 0.2	1951	2098	- 7.0	63.7	63.4
Fort Worth, TX	2317	2832	-18.2	2500	2587	- 3.4	65.3	65.5
Fresno, CA	2653	2650	+ 0.1	1639	1671	- 1.9	61.8	62.3
Great Falls, MT	7566	7652	- 1.1	343	339	+ 1.2	45.6	44.9
Houston, TX	1599	1434	+ 1.5	2745	2889	- 5.0	67.7	68.9
Indianapolis, IN	5875	5577	+ 5.3	902	974	- 7.4	51.4	52.3
Jackson, MS	2365	2258	+ 4.7	2361	2321	+ 1.7	64.8	65.2
Jacksonville, FL	1231	1327	- 7.2	2722	2596	+ 4.9	68.6	68.4
Kansas City, MO	5065	5161	- 1.9	1475	1420	+ 3.9	55.2	54.5
Lake Charles, LA	1647	1498	+ 9.9	2633	2739	- 3.9	67.1	68.3
Los Angeles, CA	1577	1819	-13.3	354	615	-42.4	61.2	61.7
Louisville, KY	4599	4640	- 0.8	1207	1268	- 4.8	55.8	55.6
Lubbock, TX	3505	3545	+ 1.1	1557	1647	- 5.5	59.6	59.7
Madison, WI	7473	7730	- 3.3	424	460	- 7.8	46.2	44.9
Medford, OR	4568	4930	- 7.3	456	562	-18.9	53.4	53.0

TABLE 1.1 (CONTINUED)

Station	TRY Heating Degree Days (Base 65°)	Long Term Heating Degree Days	% Deviation $\frac{TRY-LT}{LT} \times 100$	TRY Cooling Degree Days (Base 65°)	Long Term Cooling Degree Days	% Deviation $\frac{TRY-LT}{LT} \times 100$	TRY Annual Mean Temperature	Long Term Annual Mean Temperature
Memphis, TN	3252	3227	+ 0.8	1858	2029	- 8.4	61.7	61.6
Miami, FL	152	206	-26.2	4189	4038	+ 3.7	76.1	75.5
Minneapolis, MN	8405	8310	+ 1.1	894	527	+69.6	44.7	43.5
Nashville, TN	3533	3696	- 4.4	1483	1694	-12.5	59.5	59.4
New Orleans, LA	1774	1465	+21.1	2653	2705	- 1.9	67.1	68.3
New York, NY	4579	4909	- 6.7	1027	1048	- 2.0	55.0	54.3
Norfolk, VA	3340	3488	- 4.2	1358	1441	- 5.8	59.5	59.3
Oklahoma City, OK	3921	3695	+ 6.1	1882	1876	+ 0.3	59.0	59.9
Omaha, NE	6231	6049	+ 3.0	1007	949	+ 6.1	50.8	51.5
Philadelphia, PA	5192	4865	+ 6.7	1081	1104	- 2.1	53.7	54.6
Phoenix, AZ	1516	1552	+ 2.3	3334	3508	- 5.0	70.1	70.3
Pittsburgh, PA	5712	5930	- 3.7	732	647	+13.1	51.5	50.4
Portland, ME	7682	7498	+ 2.5	292	252	+15.9	45.3	45.0
Portland, OR	4965	4792	+ 3.6	248	300	-17.3	52.0	52.6
Raleigh, NC	3640	3514	+ 3.6	1355	1394	- 2.8	58.4	59.1
Richmond, VA	4538	3939	+15.2	1236	1353	- 8.6	55.9	57.8
Sacramento, CA	2966	2843	+ 4.3	973	1159	-16.0	58.5	60.3
St. Louis, MO	5225	4750	+10.0	1390	1475	- 5.8	54.6	55.9
Salt Lake City, UT	6246	5983	+ 4.4	958	927	+ 3.3	50.8	51.0
San Antonio, TX	1883	1570	+19.9	2860	2994	- 4.5	67.3	68.8
San Diego, CA	1244	1507	-17.5	600	722	-16.9	63.3	62.9
San Francisco, CA	3394	3042	+11.6	98	108	- 9.3	55.4	56.9
Seattle-Tacoma, WA	5484	5185	+ 5.8	134	200	-33.0	50.2	51.1
Tampa, FL	473	718	-34.1	3152	3366	- 6.4	72.0	72.2
Tulsa, OK	3641	3680	- 1.1	1719	1949	-11.8	59.6	60.2
Washington, DC	4164	4211	-1.1	1491	1415	+ 5.4	57.7	57.3

° <u>Heating</u>:

Best-fit regression equation: $DD_{TRY} = 0.99\ DD_{LT} + 115$
Residual standard deviation: 298 degree days
Correlation coefficient*: 0.99

° <u>Cooling</u>:

Best-fit regression equation: $DD_{TRY} = 1.03\ DD_{LT} + 40$
Residual standard deviation: 137 degree days
Correlation coefficient: 0.99

These results do not determine the tape's representativeness on a monthly basis. The differences between the TRY and long-term monthly degree days tend to be considerably larger than for the annual values. The same observation holds for the differences between the TRY and long term monthly average temperatures, as compared to the differences in the annual values given in Table 1.1.

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* The correlation coefficient is a measure of dependence between two variables and is defined as

$$r = \frac{1}{N} \Sigma \left[\left(\frac{x-\overline{x}}{\sigma_x} \right) \left(\frac{y-\overline{y}}{\sigma_y} \right) \right]$$

where $\overline{x}$ and $\overline{y}$ are respectively the mean of all the x values and the mean of all the y values, σ_x and σ_y are respectively the standard deviations of all the x values and all the y values, and N is the number of x,y observations. 1.0 represents perfect dependence between the two variables.

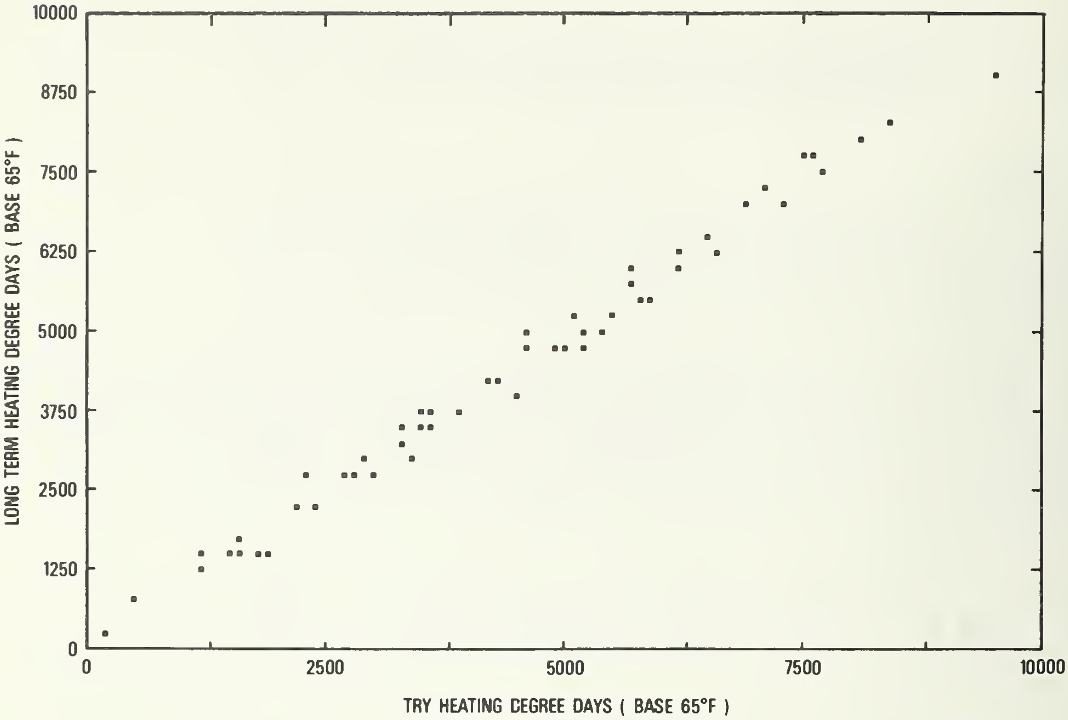


FIGURE 1.1

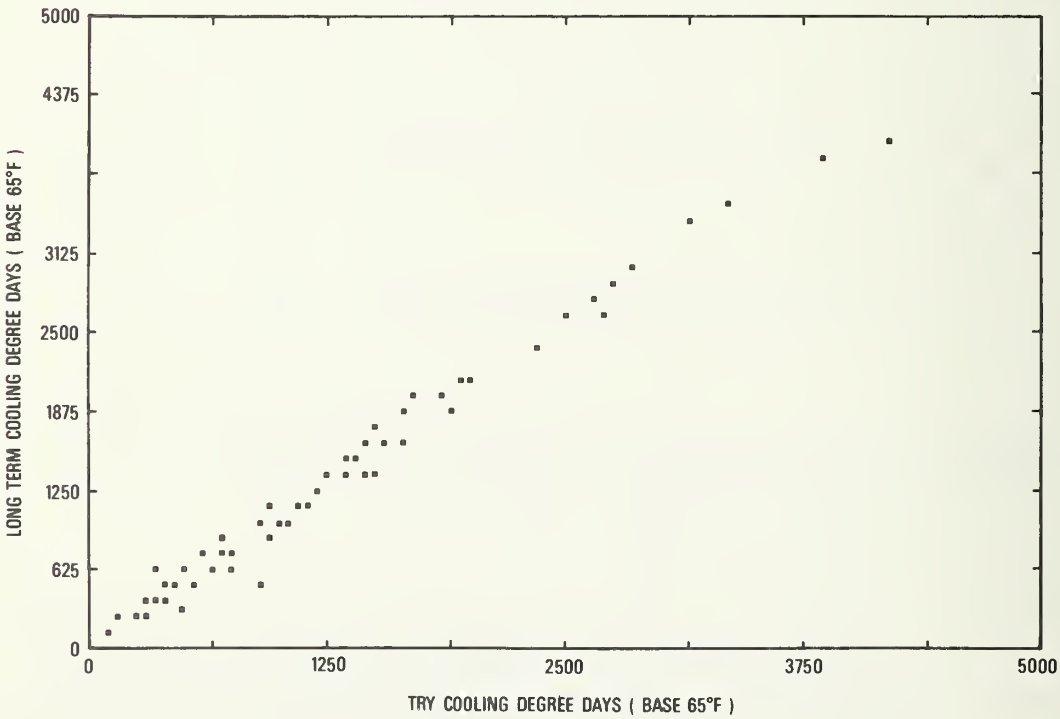
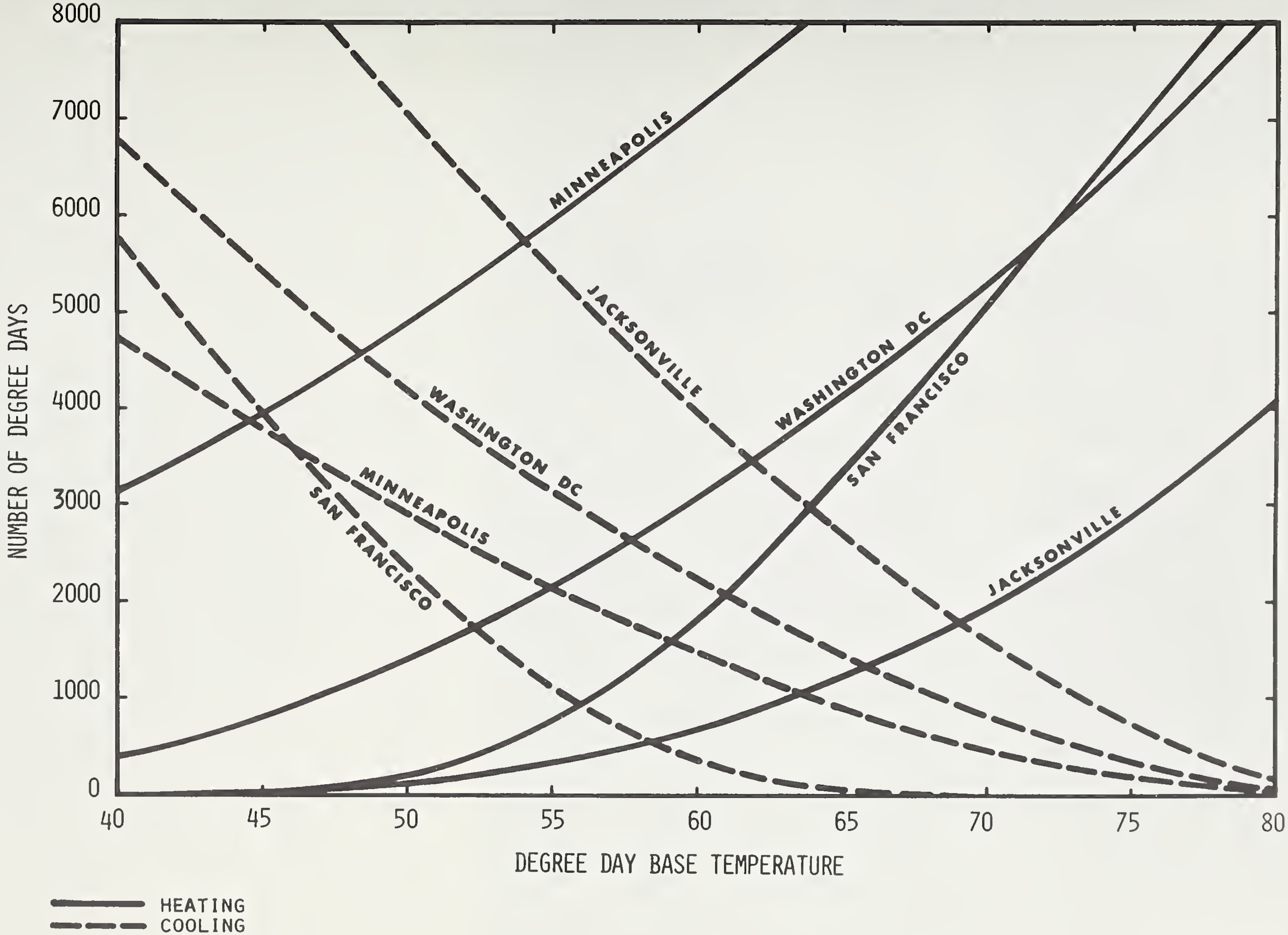


FIGURE 1.2


NUMBER OF DEGREE DAYS
8000
7000
6000
5000
4000
3000
2000
1000
0
40
45
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60
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70
75
80
DEGREE DAY BASE TEMPERATURE
MINNEAPOLIS
JACKSONVILLE
WASHINGTON DC
WASHINGTON DC
SAN FRANCISCO
MINNEAPOLIS
SAN FRANCISCO
JACKSONVILLE
HEATING
COOLING

FIGURE 1.3

2. GEOGRAPHICAL VARIATION OF HEATING AND COOLING REQUIREMENTS IN THE U.S.

2.1 REPRESENTATIVE HOUSE

A 1200 square-foot single-story ranch-style house with a slab-on-grade floor was selected as representative of new construction in the U.S. based on 1974 statistics collected by the NAHB Research Foundation.[6]

A ranch house based on these statistics was designed by S.R. Hastings of NBS, as representative of current house design. This design is being used for research on the energy effectiveness of various insulation levels and building design features at NBS. A detailed description of the design, with drawings, is given in Appendix B. The ranch-house envelope parameters and operational data were encoded to permit heating and cooling load calculations by the NBS Loads Determination (NBSLD) computer program[7]. A listing of the building description as input to NBSLD is attached in Appendix C.

2.2 ANNUAL HEATING AND COOLING REQUIREMENTS

The annual heating and cooling requirements of the representative ranch house, as calculated from the 60 TRY tapes, are presented in Table 2.1 and Figure 2.1. The range of the values is: heating requirements, 0.2 to 64.5 million Btu; cooling requirements, 0.9 to 33.7 million Btu; and total, 3.6 to 68.9 million Btu. The average heating requirement is 21.8 million Btu and the average cooling requirement, 10.4 million Btu.

2.3 HEATING AND COOLING REQUIREMENTS IN RELATION TO ENERGY CONSUMPTION

The heating and cooling requirements are accumulated loads, or heating and cooling energy deficits, that need to be met by the heating and cooling equipment. The energy conversion efficiencies of heating and cooling equipment are not included in the table and figure. In order to obtain the energy needed to meet these heating and cooling requirements, one must first make an assumption about the types of heating and cooling systems in the house. Second, one must divide the heating and cooling requirements given here by the seasonal coefficients of performance (COPs) of the heating and cooling equipment, respectively. This gives the energy required at the house ("metered load"). If one is interested in source energy, which is the generally accepted way to put different types of energy or fuel on a common energy denominator, one must multiply connected load by a resource utilization factor.[8]

The "total" heating plus cooling requirement given here is useful as an indicator of climate stresses only; since the COPs of heating and cooling equipment are rarely the same, the combined energy needed to meet the "total" requirement will vary with the proportions of heating and cooling requirements making up the total.

2.4 GEOGRAPHIC VARIATION

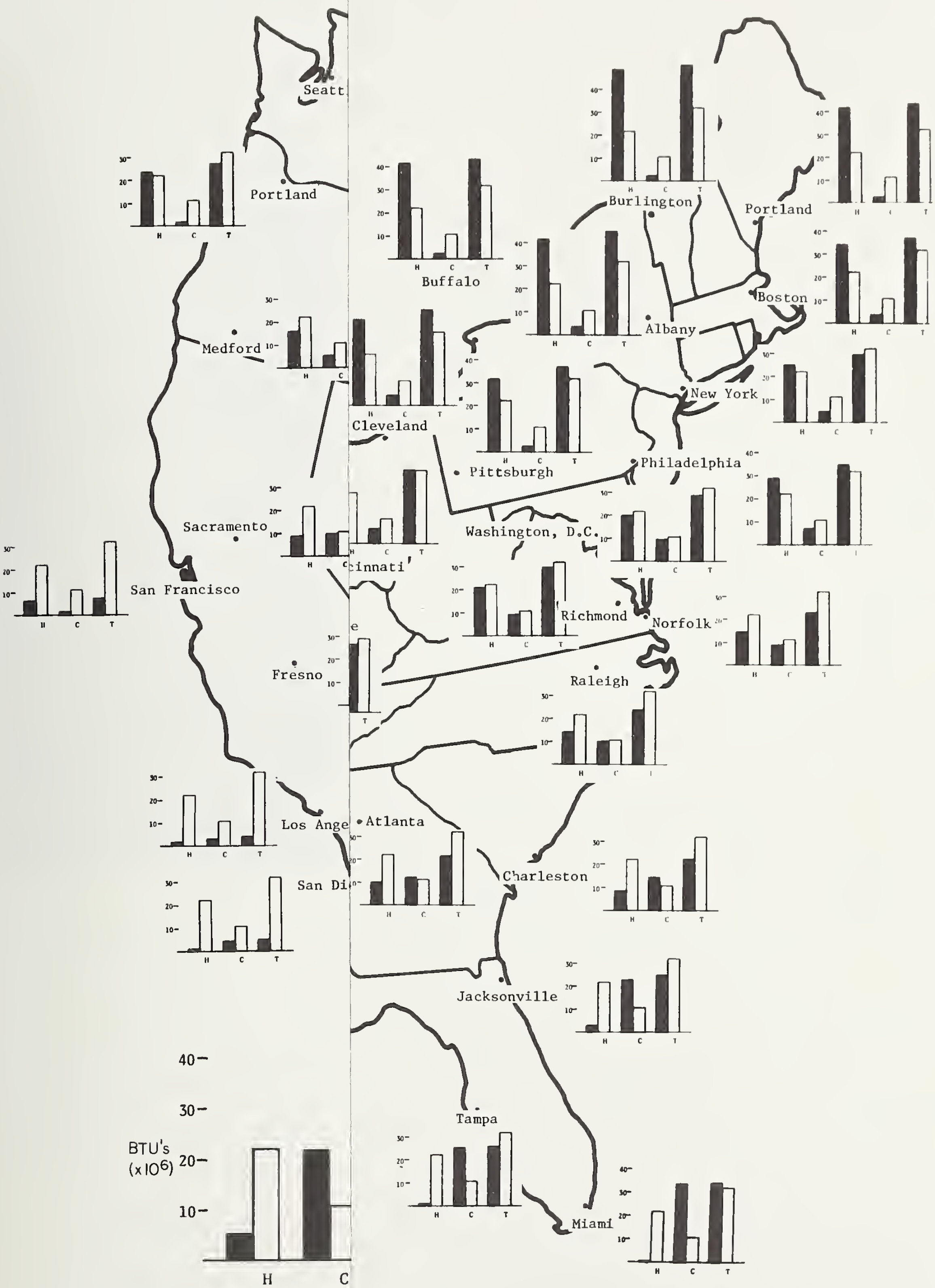
In comparison with the real population of housing, the heating and cooling requirements in Figure 2.1 are expected to be overestimated in the colder northern locations and underestimated in the hotter southern locations. This is because the ranch house used in the study is kept uniform across the country. It is relatively less insulated than many existing northern houses and more insulated than most southern houses. However, as noted in Appendix C, the insulation levels assumed in the ranch house are now commonly used in construction in all regions of the country.

Figure 2.1 would be most useful if the relative heating and cooling requirements it presents are valid proportionally for other types of buildings and other insulation levels. At present, several other single-family residences have been modeled at NBS, using a selected group of TRY stations. This research was not complete at time of writing, but the house types, insulation levels, and variations in assumed operating conditions that have been tested to date have shown geographic variations proportional to those given in Figure 2.1.

TABLE 2.1

ANNUAL HEATING AND COOLING REQUIREMENTS OF TEST HOUSE AT 60 TRY STATIONS, IN MILLIONS OF BTU

Station	Heating	Cooling	Total
Albany, NY	41.7	3.2	44.9
Albuquerque, NM	15.8	10.1	25.9
Amarillo, TX	19.8	10.1	29.9
Atlanta, GA	9.6	11.4	21.0
Birmingham, AL	9.3	12.5	21.8
Bismarck, ND	64.5	4.4	68.9
Boise, ID	29.7	5.5	35.2
Boston, MA	34.0	3.2	37.2
Brownsville, TX	1.1	32.4	33.5
Buffalo, NY	41.3	1.9	43.2
Burlington, VT	48.6	2.1	50.7
Charleston, SC	8.1	14.0	22.1
Cheyenne, WY	42.7	2.1	44.8
Chicago, IL	33.4	4.3	37.7
Cincinnati, OH	27.2	6.1	33.3
Cleveland, OH	37.6	4.1	41.7
Columbia, MO	28.4	8.7	37.1
Detroit, MI	38.4	4.5	42.9
Dodge City, KS	30.1	9.0	39.1
El Paso, TX	8.1	17.3	25.4
Fort Worth, TX	7.1	21.9	29.0
Fresno, CA	7.1	16.4	23.5
Great Falls, MT	53.5	2.0	55.5
Houston, TX	4.5	22.9	27.4
Indianapolis, IN	33.8	5.9	39.7
Jackson, MS	8.1	18.4	26.5
Jacksonville, FL	2.3	22.7	25.0
Kansas City, MO	27.0	10.1	37.1
Lake Charles, LA	4.9	21.8	26.7
Los Angeles, CA	1.2	2.4	3.6
Louisville, KY	22.0	8.4	30.4
Lubbock, TX	16.1	12.9	29.0
Madison, WI	43.3	2.9	46.2
Medford, OR	16.2	5.4	21.6
Memphis, TN	12.8	14.6	27.4
Miami, FL	.2	33.7	33.9
Minneapolis, MN	55.3	5.5	60.8
Nashville, TN	14.9	10.7	25.6
New Orleans, LA	4.9	21.0	25.9
New York, NY	24.8	4.7	29.5
Norfolk, VA	14.3	8.5	22.8
Oklahoma City, OK	21.1	14.3	35.4
Omaha, NE	35.5	7.6	43.1
Philadelphia, PA	28.3	6.4	34.7
Phoenix, AZ	3.0	29.9	32.9
Pittsburgh, PA	33.1	3.9	37.0
Portland, ME	41.7	1.8	43.5
Portland, OR	24.0	1.9	25.9
Raleigh, NC	13.9	9.8	23.7
Richmond, VA	20.6	8.8	29.4
Sacramento, CA	8.3	9.7	18.0
St. Louis, MO	27.7	10.0	37.7
Salt Lake City, UT	33.8	6.6	40.4
San Antonio, TX	6.0	22.1	28.1
San Diego, CA	.6	3.7	4.3
San Francisco, CA	5.7	.9	6.6
Seattle-Tacoma, WA	25.5	1.1	26.8
Tampa, FL	.7	24.9	25.6
Tulsa, OK	15.7	13.9	29.6
Washington, DC	19.7	9.0	28.7



Heating, cooling, and t

station against average le-family house using test reference year data

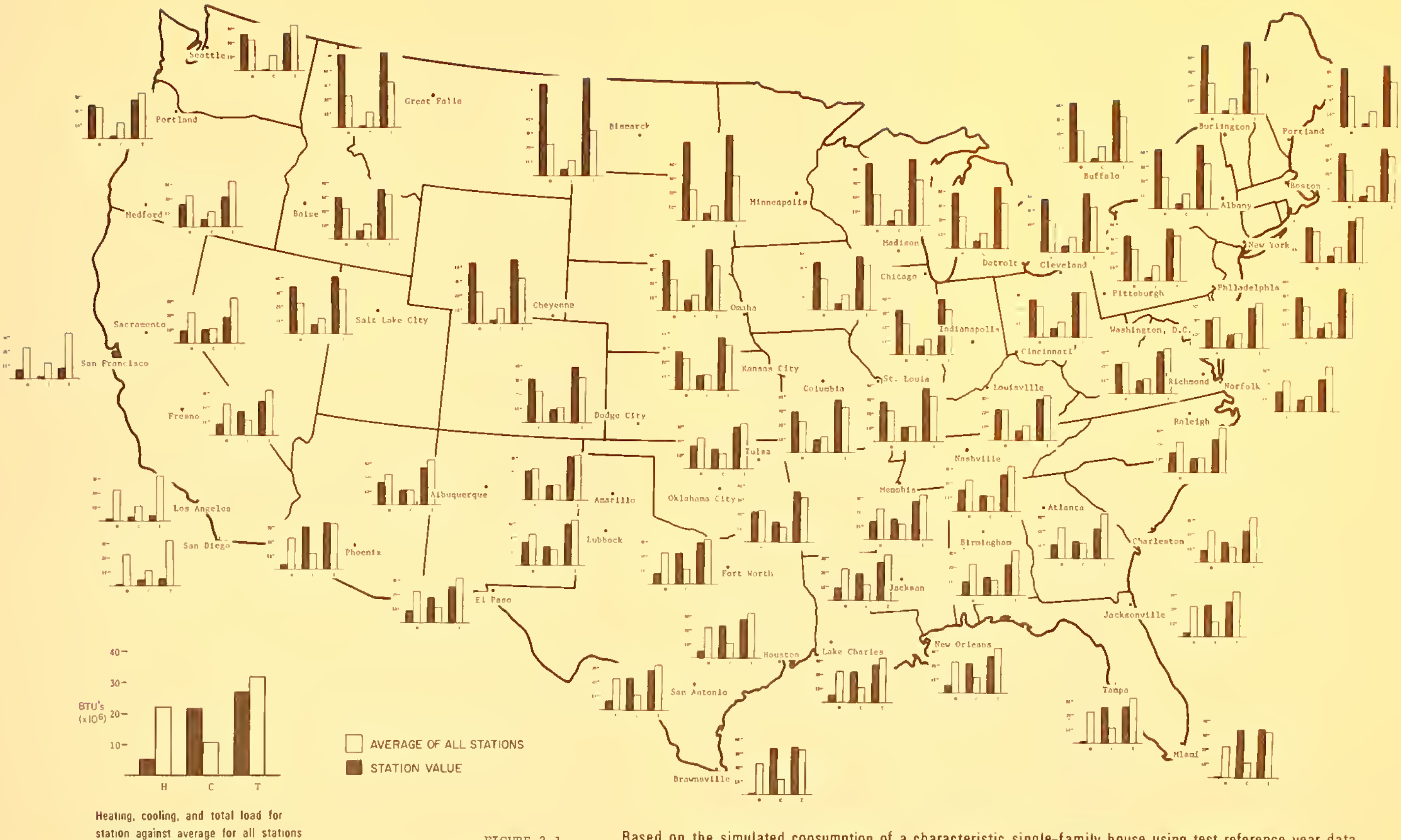


FIGURE 2.1 Based on the simulated consumption of a characteristic single-family house using test reference year data

3. CORRELATION OF HEATING AND COOLING REQUIREMENTS WITH DEGREE DAYS

3.1 INTRODUCTION

The heating and cooling requirements calculated for 60 U.S. locations provide a useful test of the predictive accuracy of the degree day. Both heating and cooling degree days are considered here. The traditional NOAA degree days to the base 65°F are considered first, and degree days to an empirically determined base appropriate for the representative ranch house are considered second, both for heating and for cooling.

3.2 DEGREE DAYS TO BASE 65°F

The 65°F base heating degree day has been in steady use for over 40 years by utilities and fuel suppliers as a measure to predict the demand of the average population of buildings. It is also used by the building design profession to estimate monthly and annual heating requirements. It has evidently been satisfactory for this purpose, although the base temperature is high for most buildings except those with no insulation and smaller internal loads than are common today.

The cooling degree day, also with base 65°F, is published by the NOAA for all stations, but has not gained as wide acceptance in the design professions as the heating degree day.

Figure 3.1 compares heating requirements with the number of heating degree days, base 65°F, for each of the 60 TRY stations calculated. The degree-day numbers are calculated from the TRY tapes themselves. The regression lines do not pass through the origin; the equation $Q_H = 0.007 \times DD_{H65} - 9.0$; Q_H is the annual heating requirement in millions of Btu, and DD_{H65} is the number of heating degree days, base 65°F. The residual standard deviation is 3.5×10^6 Btu, and the correlation coefficient, 0.97.[9]

Figure 3.2 compares cooling requirements with number of cooling degree days, base 65°F, for each station. As with the heating degree days, the cooling degree-day numbers are calculated from the TRY tapes themselves. The regression line does not pass through the origin, the equation being $Q_c = 0.009 \times DD_{C65} - 1.3$, where Q_c is the annual cooling requirement and DD_{C65} is the number of cooling degree days to the base 65°F. The residual standard deviation is 1.3×10^6 Btu, and the correlation coefficient, 0.98.

3.3 DEGREE DAYS TO A BASE MATCHED TO THE BALANCE POINT OF THE RANCH HOUSE

In theory the degree-day base temperature should equal the "balance point" of the building being predicted: the temperatures above which, or below which, the heating or cooling system is not needed, respectively. The balance points of the ranch house were found empirically from a detailed analysis of the hours in which there were heating and cooling loads in the house. They were also found by an iteration of plots such as Figures 3.3 and 3.4 at different base temperatures.

Figure 3.3 compares heating requirements with the number of heating degree days, base 53°F, for each of the 60 TRY stations calculated. The degree day numbers are calculated from the TRY tapes themselves. The regression line passes quite close to the origin, the equation being: $Q_H = 0.01 \times DD_{H53} - 0.4$. The residual standard deviation is 2.0×10^6 Btu, and the correlation coefficient is 0.99. The accuracy of fit is considerably improved over the equation using the 65°F base heating degree day.

Figure 3.4 compares cooling requirements with the number of cooling degree days, base 68°F, for each of the 60 TRY stations calculated. The regression equation is: $Q_c = .01 \text{ X } DD_{C68} + .08$. The residual standard deviation is 1.3×10^6 Btu and the correlation coefficient is 0.99. The accuracy of fit is improved over the equation using the 65° base cooling degree day.

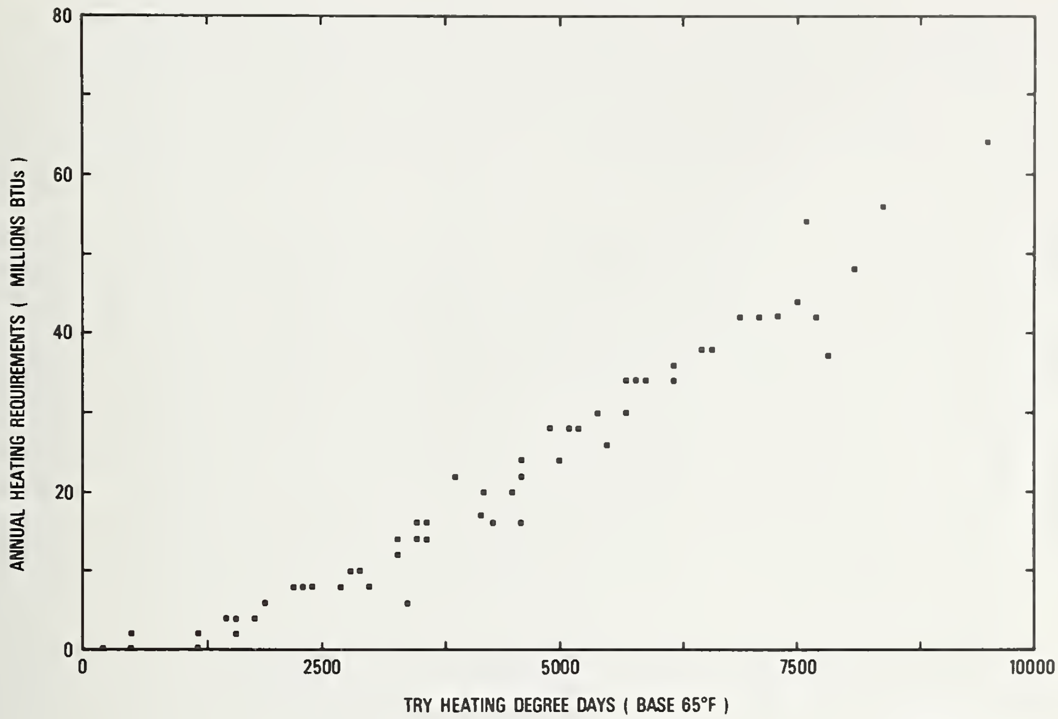


FIGURE 3.1

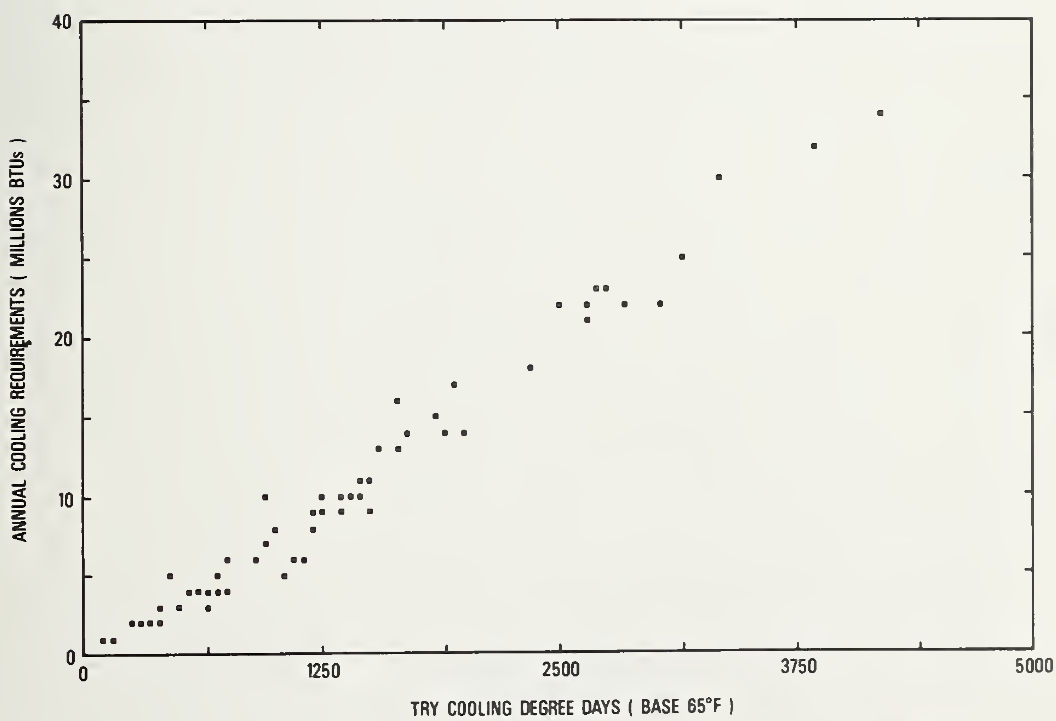


FIGURE 3.2

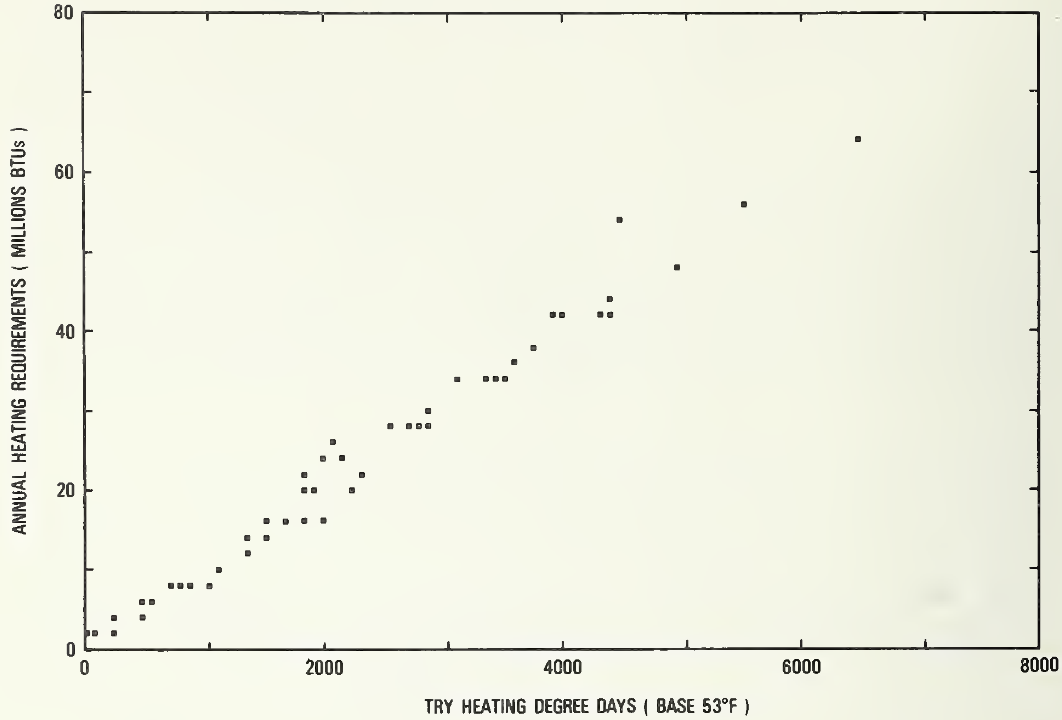


FIGURE 3.3

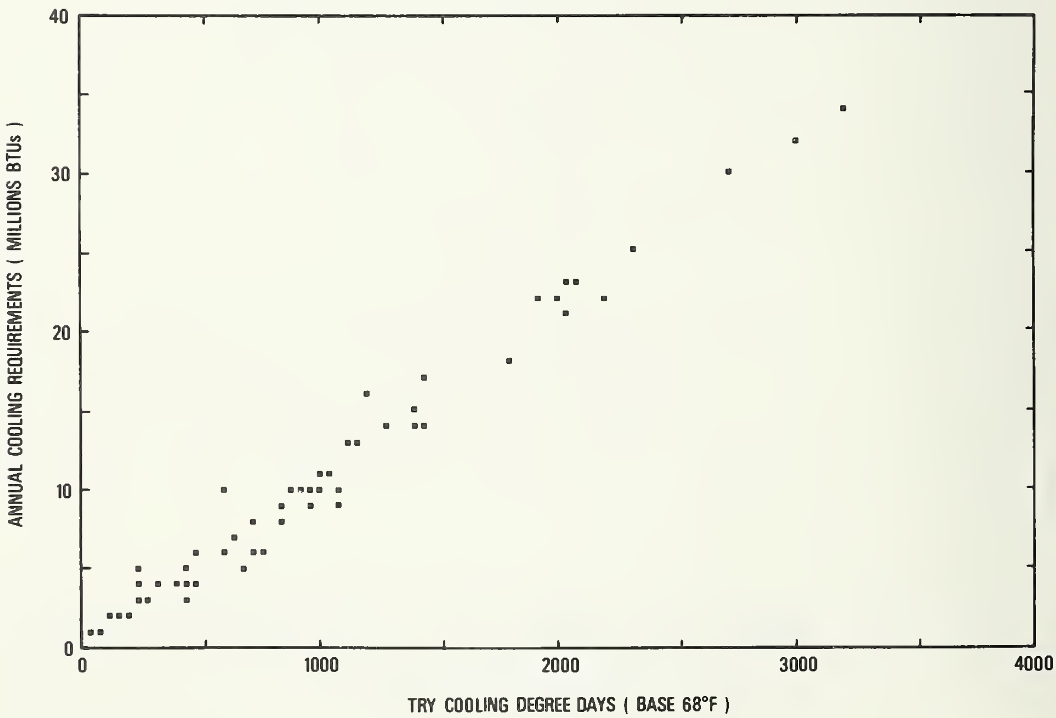


FIGURE 3.4

3.4 CONCLUSIONS

With the newer building stock better insulated, with greater appliance usage releasing more heat in the house than in the past, and with occupants using lower thermostat settings as their energy consciousness increases, the use of heating degree days calculated to a lower base temperature becomes desirable. The 53° base temperature given here applies only to the design and simulated operation of this ranch house.

Although the results show a good correlation between cooling degree days and annual cooling requirements, they do not prove the utility of cooling degree days for design purposes. This is because these results use the same house with the same internal heat release, and window orientation and size, in all cases. Since solar gain and internal heat release make up a large proportion of the total cooling requirements, any variation in these parameters makes the determination of cooling requirements based on cooling degree days less accurate than has been found here. In design practice, where there is a significant variation in solar gain or internal heat loads between design alternatives, cooling degree days are considered less useful than other methods such as cooling degree hours for estimating cooling requirements.

Cooling degree days have been shown to have value in comparing the energy requirements of a prototype across geographic regions. In this way, they may be useful for energy regulatory purposes.

4. ADJUSTMENT OF TRY-COMPUTED ANNUAL HEATING AND COOLING REQUIREMENTS TO REPRESENT THE LONG-TERM RECORD

4.1 PROCEDURE

It is possible to adjust or "correct" the heating and cooling requirements calculated from the TRY years and presented in Table 2.1 to make them approximate the long-term record. The procedure used here is specific to the test ranch house:

Using the calculated annual heating and cooling requirements, Q_{TRY} for each location (Table 2.1 and Figure 2.1) corrected requirements are calculated from:

$$Q_{LT} = \frac{DD_{LT}}{DD_{TRY}} \times Q_{TRY} ,$$

where Q_{LT} is the annual heating (cooling) requirement corrected to be representative of the long-term climate at the location.

Q_{TRY} is the annual heating (cooling) requirement calculated from the TRY tape.

DD_{LT} is the number of long-term heating (cooling) degree days calculated to a base temperature equal to the balance point of the ranch house, using the procedure developed by Thom[2].

DD_{TRY} is the number of heating (cooling) degree days to the appropriate base temperature, as obtained from the TRY data by the procedure discussed in Chapter 1.

Table 4.1 presents DD_{LT} and DD_{TRY} for the base temperatures 53° and 68°, equal to the balance points of the ranch house, for all 60 stations.

4.2 RESULTS

Table 4.2 presents the adjusted heating and cooling requirements for the representative house at the 60 TRY stations. These values differ from those in Table 2.1 and Figure 2.1 in that they represent long-term average climate rather than just the TRY year itself.

The mean adjusted annual heating requirement for the 60 locations is 21.56×10^6 Btu, and for cooling, 11.10×10^6 Btu. The adjusted heating value for each city is higher than the TRY value for that city in 28 cases, lower in 29 cases, and the same in 3 cases. The population of TRY tapes predicts slightly more heating requirements on the average than the long-term climate. The difference is 0.2×10^6 Btu. The TRY tapes have on the average 45 more heating degree days, base 53°F, than the long-term climate. This difference is on the order of 2 per cent of the average number of degree days.

The TRY tapes are warmer than the long-term climate in the cooling season as well. The adjusted cooling value is higher than the TRY value in 39 cases, lower in 17 cases, and the same in 4. The average cooling load is 0.7×10^6 Btu lower for the TRY tapes than for the long-term climate. The TRY tapes have on the average 36 less cooling degree days, base 68°F, than the long-term climate; the difference is on the order of 4 per cent of the average number of degree days.

The percentage heating or cooling error for individual stations is mostly a function of the size of the heating and cooling requirements. TRY stations with larger requirements tend to have lower error percentages.

4.3 CONCLUSIONS

A method is proposed here to adjust the annual heating and cooling requirements predicted by the TRY weather data. The method is based on the relationships found between heating and cooling requirements and the

TABLE 4.1

COMPARISON OF TRY AND LONG-TERM HEATING(BASE 53°F)
AND COOLING (BASE 68°F) DEGREE DAYS

Station	Heating Degree Days (Base 53°F)			Cooling Degree Days (Base 68°F)		
	TRY	Long-Term	% deviation $\frac{TRY-LT}{LT} \times 100$	TRY	Long-Term	% deviation $\frac{TRY-LT}{LT} \times 100$
Albany	4326	4034	7.2	285	348	-18.1
Albuquerque	2007	2003	0.2	950	923	2.9
Amarillo	1942	1964	-1.1	876	1047	-16.3
Atlanta	1110	1225	-9.4	988	1132	-12.7
Birmingham	1096	1118	-2.0	1142	1420	-19.6
Bismarck	6495	5967	8.9	328	307	6.8
Boise	2896	2994	-3.3	462	461	0.2
Boston	3108	2930	6.1	439	397	1.1
Brownsville	51	101	-5.0	2999	3042	46.9
Buffalo	3936	4002	-1.7	203	239	-15.1
Burlington	4940	4822	2.5	211	225	-6.2
Charleston	716	699	2.4	1407	1518	-7.3
Cheyenne	3965	4143	-4.3	135	176	-23.3
Chicago	3442	3536	-2.7	461	622	-25.9
Cincinnati	2562	2663	-3.8	757	731	3.6
Cleveland	3761	3422	10.0	415	361	15.0
Columbia	2857	2729	4.7	843	902	-6.5
Detroit	3731	3672	1.6	431	398	8.3
Dodge City	2905	2758	5.3	960	992	-3.2
El Paso	1001	934	7.2	1448	1576	-8.1
Fort Worth	795	805	-1.2	1938	2031	-4.6
Fresno	761	771	-1.3	1193	1221	-2.3
Great Falls	4474	4583	-2.4	190	187	1.6
Houston	459	357	28.6	2091	2235	-6.4
Indianapolis	3326	3075	8.2	591	590	0.2
Jackson	839	813	3.2	1787	1747	2.3
Jacksonville	225	321	-29.9	2042	1934	5.6
Kansas City	2782	2816	-1.2	1084	1043	3.9
Lake Charles	466	382	22.0	1996	2098	-4.9
Los Angeles	37	174	-78.7	117	309	-62.1
Louisville	2295	2353	-2.5	829	884	-6.2
Lubbock	1524	1534	-0.7	1106	1198	-7.7
Madison	4438	4759	-6.8	243	267	-9.0
Medford	1847	2103	-12.2	252	337	-25.2
Memphis	1373	1382	-0.7	1391	1534	-9.3
Miami	12	5	140.0	3190	3113	2.5
Minneapolis	5556	5264	5.6	601	366	64.2
Nashville	1539	1694	-9.2	1034	1250	-17.3
New Orleans	482	377	27.9	2028	2064	-1.7
New York	2135	2457	-13.1	670	698	-4.0
Norfolk	1322	1445	-8.5	943	1011	-6.7
Oklahoma City	1826	1691	9.0	1455	1421	2.4
Omaha	3600	3553	1.3	702	840	-16.4
Philadelphia	2758	2439	13.1	731	747	-2.1
Phoenix	253	321	-21.2	2735	2957	-7.5
Pittsburgh	3096	3245	-4.6	428	384	11.5
Portland, ME	4431	4305	2.9	146	125	16.8
Portland, OR	1972	1841	7.1	125	152	-17.8
Raleigh	1559	1474	5.8	934	974	-4.1
Richmond	2275	1771	28.5	849	944	-10.1
Sacramento	914	797	14.7	606	755	-19.7
St. Louis	2892	2476	16.8	1008	1085	-7.1
Salt Lake City	3530	3237	9.1	644	645	-0.2
San Antonio	583	395	47.6	2220	2358	-5.9
San Diego	21	116	-81.9	251	371	-32.4
San Francisco	507	537	-5.6	33	21	57.1
Seattle	2061	1517	35.9	72	85	-15.3
Tampa	36	97	-62.9	2318	2568	-9.7
Tulsa	1671	1676	-0.3	1265	1487	-14.9
Washington, DC	1857	1976	-6.0	1084	1006	7.8

TABLE 4.2

ANNUAL HEATING AND COOLING REQUIREMENTS OF TEST HOUSE AT 60 TRY STATIONS CORRECTED TO REPRESENT THE LONG-TERM CLIMATE IN MILLIONS OF Btu

Station	Heating	Cooling	Total
Albany, NY	38.8	3.9	42.7
Albuquerque, NM	15.8	9.8	25.6
Amarillo, TX	20.0	12.1	32.1
Atlanta, GA	10.6	13.1	23.7
Birmingham, AL	9.5	15.5	25.0
Bismarck, ND	59.3	4.1	63.5
Boise, ID	30.6	5.5	36.1
Boston, MA	32.0	2.9	34.8
Brownsville, TX	2.2	32.7	34.9
Buffalo, NY	42.1	2.2	44.4
Burlington, VT	47.6	2.3	49.9
Charleston, SC	7.9	15.1	23.1
Cheyenne, WY	44.4	2.7	47.1
Chicago, IL	34.4	5.8	40.2
Cincinnati, OH	28.3	6.2	34.5
Cleveland, OH	34.2	3.6	37.8
Columbia, MO	27.3	9.3	36.6
Detroit, MI	37.6	4.1	41.8
Dodge City, KS	28.6	9.3	37.9
El Paso, TX	7.5	18.9	26.4
Fort Worth, TX	7.2	23.0	30.2
Fresno, CA	7.2	16.7	23.9
Great Falls, MT	54.6	2.0	56.5
Houston, TX	3.5	24.5	28.0
Indianapolis, IN	31.1	5.9	37.0
Jackson, MS	7.9	18.0	25.9
Jacksonville, FL	3.3	21.5	24.8
Kansas City, MO	27.3	9.7	37.0
Lake Charles, LA	4.0	22.9	26.9
Los Angeles, CA	5.6	6.3	12.0
Louisville, KY	22.7	9.0	31.7
Lubbock, TX	16.3	13.9	30.2
Madison, WI	46.3	3.2	49.5
Medford, OR	18.5	7.2	25.7
Memphis, TN	12.9	16.1	29.0
Miami, FL	0.1	33.0	33.1
Minneapolis, MN	52.5	3.4	55.9
Nashville, TN	16.4	13.0	29.3
New Orleans, LA	3.8	21.4	25.2
New York, NY	28.5	4.9	33.4
Norfolk, VA	15.6	9.1	24.7
Oklahoma City, OK	19.6	14.0	33.6
Omaha, NE	35.2	9.1	44.3
Philadelphia, PA	24.9	6.5	31.4
Phoenix, AZ	3.8	32.3	36.1
Pittsburgh, PA	34.8	3.5	38.3
Portland, ME	40.5	1.6	42.0
Portland, OR	22.3	2.3	24.6
Raleigh, NC	13.2	10.2	23.4
Richmond, VA	16.1	9.8	25.8
Sacramento, CA	7.2	12.1	19.4
St. Louis, MO	23.8	10.8	34.6
Salt Lake City, UT	31.1	6.6	37.7
San Antonio, TX	4.1	23.4	27.5
San Diego, CA	3.3	5.5	8.8
San Francisco, CA	6.0	0.6	6.6
Seattle-Tacoma, WA	18.8	1.3	26.8
Tampa, FL	1.9	27.6	29.5
Tulsa, OK	15.7	16.4	32.1
Washington, DC	20.9	8.4	29.3

heating and cooling degree days to a base appropriate to the test ranch house.

On the whole, the 60 TRY tapes contain somewhat warmer temperatures than the long-term average climate record. This is reflected in the slightly lower heating requirements and higher cooling requirements predicted by the TRY tapes.

5. VARIATION OF HEATING AND COOLING REQUIREMENTS IN CLIMATE ZONES BASED ON DEGREE DAYS

5.1 INTRODUCTION

The initial purpose of this investigation was to develop climate zones for building energy standards. The zones, based on climatic parameters, would define areas of relatively uniform heating and cooling requirements. With such zones, various requirements of building energy standards might be applied equitably across the different climates of the country.

The research on the geographic distribution of loads described above yields some information on one common type of climate classification, in which the zones are defined as bands of annual degree days, base 65°F, one thousand degree days in width. The calculations done here allow the range of heating and cooling requirements to be determined for each of these zones.

The 60 stations were classified into nine heating degree-day bands and five cooling degree-day bands, based on their long-term annual degree-day totals. The heating and cooling requirements for each station, as adjusted to represent the long-term record (Table 4.2), were then collected into each band.

5.2 RESULTS

Tables 5.1 and 5.2 show the variability of heating and cooling requirements with each band. The range of the values within each band and the overlap between bands are seen to be substantial. The non-uniformity may have serious implications for the equitability of climate zones based on degree days to the base 65°F.

A large part of the observed heating variability within these zones is due to the difference between 65°F and the 53°F balance point of the house, which has the effect of causing coastal locations, particularly west coast locations, to have low heating requirements in relation to their degree days. The coastal locations have a larger proportion of daily average temperatures in the range between 65°F and 53°F than the inland locations. Consequently, the representative house in these locations will accumulate numerous degree days without any heating energy being required. This characteristic of coastal cities may be seen in Figure 1.3, where San Francisco displays considerable curvature in the cumulative degree day distribution between 53°F and 65°F.

The resulting poor fit of coastal cities in heating zones based on 65°F degree days may be seen in Table 5.1. Two cities in particular appear as low points in their heating zones, overlapping the adjacent lower degree-day zone. These are San Francisco (6.0 million Btu) and Seattle (18.8).

The positions of these coastal cities improve when arranged in zones based on 53°F based heating degree days. Table 5.3 presents such zones for comparison. The zone widths are reduced to 600 degree days, since the numbers of 53°F based degree days are inherently lower, and it is desirable to divide the country into ten zones to permit comparison with the ten 65°F-based degree-day zones.

The positions of the coastal cities are now more evenly distributed throughout the zones, and the overlapping has largely disappeared. San Francisco and Seattle have each dropped down three zones, reflecting their relatively small numbers of degree days to base 53°F.

A second part of the variability in both heating and cooling requirements is due to the different levels of sunlight in the various locations. The low heating requirements for Albuquerque (15.8 in Table 5.1) are a result of the high sunlight level there. Since a degree-day-based zone system does not take solar radiation into account, the solar variability will weaken the relationship between any heating or cooling degree days. Changing the degree-day base does not erase this variability. Albuquerque also has low heating requirements for its zone in Table 5.3. Solar

TABLE 5.1

ANNUAL HEATING REQUIREMENTS WITHIN ZONES DEFINED BY 1000 DEGREE DAY BANDS.*

In million of Btu

Degree Days (Heating) Base 65°F	0–999	1000–1999	2000–2999	3000–3999	4000–4999	5000–5999	6000–6999	7000–7999	8000–8999	9000–9999
	0.1	3.3	7.2	6.0	15.8	18.8	34.2	40.5	52.5	59.3
	1.9	3.3	7.2	10.6	18.5	27.3	34.4	44.4		
	2.2	3.5	7.2	12.9	20.0	27.3	35.2	46.3		
		3.8	7.5	13.2	20.9	28.6	37.6	47.6		
		3.8	7.9	15.6	22.3	30.6	38.8	54.6		
		4.0	7.9	15.7	22.7	31.1	42.1			
		4.1	9.5	16.1	23.8	31.1				
		5.6		16.3	24.9	32.0				
				16.4	28.3	34.8				
				19.6	28.5					

* Long-term heating degree days to base 65° (Table 1.1) and adjusted heating requirements (Table 4.2) used.

TABLE 5.2

ANNUAL COOLING REQUIREMENTS WITHIN ZONES DEFINED BY 1000 DEGREE DAY BANDS.*

In million of Btu

Degree Days (Cooling) Base 65°F	0–999	1000–1999	2000–2999	3000–3999	4000–4999
	0.6	4.9	15.1	27.6	33.0
	1.3	6.2	16.1	32.3	
	1.6	6.5	18.0	32.7	
	2.0	8.4	18.9		
	2.2	9.0	21.4		
	2.3	9.1	21.5		
	2.3	9.3	22.9		
	2.7	9.3	23.0		
	2.9	9.7	23.4		
	3.2	9.8	24.5		
	3.5	9.8			
	3.4	10.2			
	3.6	10.8			
	3.9	12.1			
	4.1	12.1			
	4.1	13.0			
	5.5	13.1			
	5.5	13.9			
	5.8	14.0			
	5.9	15.5			
	6.3	16.4			
	6.6	16.7			
	7.2				
	9.1				

* Long-term cooling degree days to base 65° (Table 1.1) and adjusted cooling requirements (Table 4.2) used.

TABLE 5.3

ANNUAL HEATING REQUIREMENTS DIVIDED INTO 10 ZONES OF 53°F - BASED HEATING DEGREE DAYS.*

In millions of Btu

Degree Days (Heating) Base 53°F	0-599	600-1199	1200-1799	1800-2399	2400-2999	3000-3599	3600-4199	4200-4799	4800-5399	5400-5999
	0.1	7.2	10.6	15.8	23.8	31.1	37.6	40.5	47.6	59.3
	1.9	7.2	12.9	18.5	24.9	31.1	38.8	46.3	52.5	
	2.2	7.2	13.2	20.0	27.3	34.2	42.1	54.6		
	3.3	7.5	15.6	20.9	27.3	34.4	44.4			
	3.3	7.9	15.7	22.3	28.3	34.8				
	3.5	7.9	16.1	22.7	28.5	35.2				
	3.8	9.5	16.3		28.6					
	3.8		16.4		30.6					
	4.0		18.8		32.0					
	4.1		19.6							
	5.6									
	6.0									

* Long-term heating degree days (Table 4.1) and adjusted heating requirements (Table 4.2) used.

TABLE 5.4

ANNUAL COOLING REQUIREMENTS DIVIDED INTO 6 ZONES OF 68°F - BASED COOLING DEGREE DAYS.*

In millions of Btu

Degree Days (Cooling) Base 68°F	0-600	600-1199	1200-1799	1800-2399	2400-2999	3000-3599
	0.6	4.9	13.0	21.4	27.6	32.7
	1.3	5.8	14.0	21.5	32.3	33.0
	1.6	6.2	15.1	22.9		
	2.0	6.5	15.5	23.0		
	2.2	6.6	16.1	23.4		
	2.3	8.4	16.4	24.5		
	2.3	9.0	16.7			
	2.7	9.1	18.0			
	2.9	9.1	18.9			
	3.2	9.3				
	3.4	9.3				
	3.5	9.7				
	3.6	9.8				
	3.9	9.8				
	4.1	10.2				
	4.1	10.8				
	5.5	12.1				
	5.5	12.1				
	5.9	13.1				
	6.3	13.9				
	7.2					

* Long-term cooling degree days (Table 4.1) and adjusted cooling requirements (Table 4.2) used.

variability causes a great deal of the spread in the cooling requirements in Tables 5.2 and 5.4. Cooling requirements are generally more sensitive to solar gains are than heating requirements.

A third part of the variability in the cooling zones can be traced to the effect of the daily range of temperature, a climatic characteristic which is suppressed by daily average temperature and degree-day data. A day with an average temperature of 65°F but with a large daily range might require heating by night and cooling by day, accumulating energy requirements without accumulating either type of degree day. Thus the house in this climate will seem to have high energy demands in relation to its degree-days zone.

To illustrate this, the two points in Figure 3.2 showing high cooling loads in relation to their degree day totals are Sacramento and Fresno, both in the central valley of California. During the summer, sea breeze penetration of the valley causes a sharp temperature drop at night, which accounts for an unusually large daily range at these locations. In Fresno, the daily average temperature in July and August is 80°F, meaning that cooling degree days accumulate at only 15 per day. The daytime temperature, however, will have reached an average daily maximum of 99°F, which will have required considerable cooling.

The daily range in these months averages 38°F, the highest of the 60 TRY locations[10]. Sacramento, with an average temperature in these months of 75°F and an average daily maximum of 93°F, has the second highest daily range.

A fourth source of variability in energy consumption within degree-day-based zones is atmospheric humidity. Humidity influences the latent heat requirements of maintaining acceptable indoor humidity. The variation of this influence geographically depends on the humidity limits being maintained in the building. The influence is more significant during cooling.

In this study, latent load was found to constitute between 0 and 13% of the cooling energy requirements in the 60 locations. The extreme variation in latent loads between locations with similar degree day numbers is between 1.5% in Phoenix (3334 TRY degree days) and 12% in Brownsville (3851 TRY degree days). Brownsville is adjacent to the humid Gulf of Mexico, while Phoenix is in the desert, isolated from maritime air.

Although the greater humidity in Brownsville causes an extra 10% in its annual cooling requirements over Phoenix, it can be seen that the loads for Phoenix are actually greater than Brownsville's in proportion to their degree days. Other factors, probably the daily range and sunlight which are greater in Phoenix than Brownsville, are offsetting the humidity effect. Their combined influence causes a difference of over 10% between Phoenix and Brownsville.

5.3 CONCLUSIONS

It has been shown that, although degree days represent heating and cooling requirements fairly well in the aggregate (Figures 3.1 and 3.2), there is still considerable variation between individual stations with similar numbers of degree days to the base 65°F. Part of this variation has been explained as due to the discrepancy between 65°F and the proper degree-day base temperature for a given building, but other causes of variation which the degree-day parameter cannot measure are solar radiation, the daily temperature range, and humidity.

6. CONCLUSION

The TRY climate data tapes for computer energy calculation have been climatologically analysed. The deviation of each TRY from the true average year (as represented by the long-term record) is quantified using annual degree days and annual average temperatures (Tables 1.1 and 4.1). The deviation between TRY and long-term degree days is found to exceed 10% at numerous locations. The more extreme percentage deviations occur at locations with insignificant numbers of degree days. The deviation in annual average temperature ranges from 0 to 2.6°F.

Annual heating and cooling requirements of a test ranch house were calculated using each of the 60 available TRY tapes to define the geographic and climatic diversity of heating and cooling requirements in the U.S. The ranch house was designed with care to assure its representativeness. The heating and cooling requirements calculated in this way were adjusted by the above-mentioned degree-day comparison to represent the long-term record rather than the TRY year itself (Table 4.2). The relationships between these values may be of general use if the heating and cooling requirements from other residential and small commercial building types prove to be proportional. It should be noted that the values of heating and cooling requirements presented in Tables 2.1 and 4.2 are annual accumulated energy loads on the house's HVAC system, and may be substantially lower than the fuel energy required to satisfy those loads through whatever system the house may have.

Combination of the TRY tape analysis and the energy calculations gives a new test of the effectiveness of degree days to different bases in predicting annual heating and cooling requirements. (Figures 3.1 and 3.2). In this house the optimal heating degree-day base is 53°F and the cooling degree-day base is 68°F. The effectiveness of climate classification based on traditional degree day zones to the base 65° could also be assessed (Figures 5.1 and 5.2). The variation of heating and cooling requirements within 1000 degree-day bands is large, exceeding 300% in several bands; but it is perhaps more signficant that the bands contain outliers that overlap adjacent bands. Zones based on the heating and cooling balance points of the house are free of the variation due to coastal versus inland location, but solar radiation and other climatic influences continue to cause variation. One may conclude that degree-day-based climate zones are imperfect for organizing annual building energy requirements, but when necessary, they should be designed so that the base temperature for the degree days matches as closely as possible the overall balance point of the building population for which the zones are intended.

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APPENDIX A

1. List of the TRY tapes available May 1977.

Station	Selected TRY	Latitude N __ ° __ '	Longitude W __ ° __ '	Elevation feet
Albany, NY	1969	4239	07345	19
Albuquerque, NM	1959	3503	10637	5311
Amarillo, TX	1968	3514	10142	3607
Atlanta, GA	1975	3339	08426	1010
Birmingham, AL	1965	3334	08645	620
Bismarck, ND	1970	4646	10045	1647
Boise, ID	1966	4334	11613	2838
Boston, MA	1969	4222	07102	15
Brownsville, TX	1955	2554	09726	19
Buffalo, NY	1974	4256	07844	705
Burlington, VT	1966	4428	07309	332
Charleston, SC	1955	3254	08002	41
Cheyenne, WY	1974	4109	10449	6126
Chicago, IL	1974	4159	08754	658
Cincinnati, OH	1957	3909	08431	761
Cleveland, OH	1969	4124	08151	777
Columbia, MO	1968*	3849	09213	887
Detroit, MI	1968*	4214	08320	633
Dodge City, KS	1971	3746	09958	2582
El Paso, TX	1967	3148	10624	3918
Fort Worth, TX	1975	3250	09703	537
Fresno, CA	1951	3646	11943	328
Great Falls, MT	1956*	4729	11122	3662
Houston, TX	1966	2959	09522	96
Indianapolis, IN	1972*	3944	08617	792
Jackson, MS	1964*	3219	09000	31
Jacksonville, FL	1965	3025	08139	24
Kansas City, MO	1968*	3918	09443	1014
Lake Charles, LA	1966	3007	09313	9
Los Angeles, CA	1973	3356	11824	105
Louisville, TY	1972*	3811	08544	477
Lubbock, TX	1955	3339	10149	3254
Madison, WI	1974	4308	08920	858
Medford, OR	1966	4222	12252	1312
Memphis, TN	1964*	3503	08959	563
Miami, FL	1964*	2548	08016	7
Minneapolis, MN	1970	4453	09313	834
Nashville, TN	1972*	3607	08641	590
New Orleans, LA	1958	2959	09015	4
New York, NY	1951	4047	07358	132
Norfolk, VA	1951	3654	07612	22
Oklahoma City, OK	1951	3524	09736	1285
Omaha, NE	1966	4122	09601	1323
Philadelphia, PA	1969	3953	07515	5
Phoenix, AZ	1951	3326	11201	1117
Pittsburgh, PA	1957	4027	08000	747
Portland, ME	1965	4339	07019	43
Portland, OR	1960*	4536	12236	21
Raleigh, NC	1965	3552	07847	434
Richmond, VA	1969	3730	07720	164
Sacramento, CA	1962	3831	12130	17
St. Louis, MO	1972*	3845	09023	535
Salt Lake City, UT	1948*	4046	11158	4222
San Antonio, TX	1960*	2932	09828	788
San Diego, CA	1974	3244	11710	13
San Francisco, CA	1974	3737	12223	8
Seattle-Tacoma, WA	1960*	4727	12218	400
Tampa, FL	1953	2758	08232	19
Tulsa, OK	1973	3611	09554	668
Washington, DC	1957	3851	07702	10

* Leap Year

2. Selection procedure for TRY years.

Source: "Tape Reference Manual, Test Reference Years," National Climatic Center, Asheville, N.C.*

The principle of selection is to eliminate years in the period of record containing months with extremely high or low mean temperatures until only one year remains. The period of record examined for 59 United States stations is 1948-1975. The 60th station, Portland, Oregon, has a period of record of 1949-1975.

Extreme months are arranged in order of importance for energy comparisons. Hot Julys and cold Januarys are assumed to be the most important. All months are ranked by alternating between the warm half (May to October) and the cold half (November to April) of the year, with the months closest to late July or late January given priority. The resulting order is given in the center column below. If, in addition, it is assumed that that hot summer months or cold winter months are more important than cool summer or mild winter months, then the order of extreme months will be down the first column below from "Hottest July" to Coolest April" and then down the last column from "Coolest July" to "Warmest April."

Hottest	July	Coolest
Coldest	January	Mildest
Hottest	August	Coolest
Coldest	February	Mildest
Hottest	June	Coolest
Coldest	December	Mildest
Hottest	September	Coolest
Coldest	March	Mildest
Warmest	May	Coolest
Coolest	November	Warmest
Warmest	October	Coolest
Coolest	April	Warmest

The first step in the selection process is to mark all 24 extreme months. Continue marking months starting with next-to-the-hottest July, then next-to-the-coldest January and so on down the first column and then down the second column above until only one year remains without any marked months. If two or more years remain without any marked months, the process is repeated with the third, fourth, etc., hottest or coldest extremes until only one year remains without any marked month. The remaining year is the Test Reference Year.

The weather in the test year is a standard for comparison of heating and cooling systems. It is not considered sufficiently typical to yield reliable estimates of average energy requirements over several years.

APPENDIX B

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Design of the Representative Ranch-Style House

The design of this house evolved from statistics compiled by the National Association of Homebuilders (NAHB) and from the designer's experience in residential construction practices. The source of the statistics is the "National Survey of Characteristics and Construction Practices for All Types of One-Family Homes" completed by NAHB in February of 1974. The survey covered a total of 84,000 homes built by 1,600 builders selected randomly from the 27,000 builder members of NAHB.

From this survey, three house designs have been developed to represent the total new housing stock:

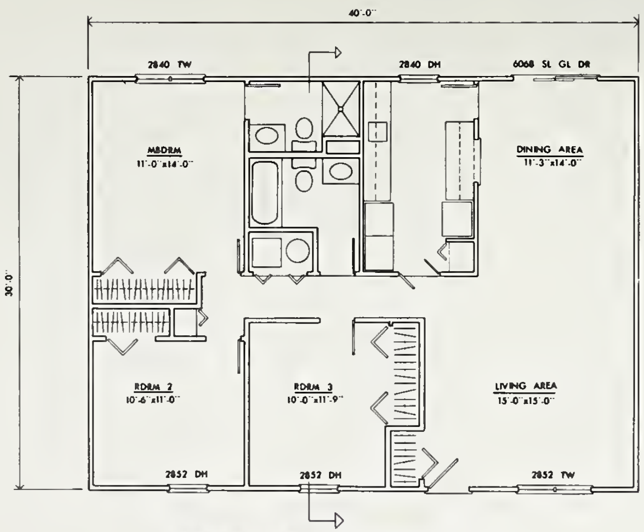
1. A 1200-square-foot ranch.
2. A 1300-square-foot town house.
3. A 2000-square-foot two-story traditional house.

The 1200 square foot ranch house was selected for the computer analysis because it was felt to be the most prevalent house design. The 1974 NAHB survey reports that single-family detached houses represent 73 percent of the housing stock (excluding mobile homes). The most common height is one story, representing 52 percent of the single-family detached houses. The predominant number of bedrooms is three, representing 67.7 percent of the single-family houses. The average floor area for the single-family-detached house was 1568 square feet. The three-bedroom ranch design used to represent one-story houses is reduced in floor area to 1200 square feet for two reasons: 1) it was felt that one-story houses would tend to have smaller floor areas than the overall average floor area of all single-family detached houses which include two-story houses, split-level houses, and houses with basements. 2) it was felt that since the publication of the survey in 1974 there has been a trend (which will continue into the future) toward more compact houses as the cost of land, materials, and labor continue to increase.

The house design includes interior partitioning for the sake of completeness although the computer analysis focuses on the exterior envelope. Windows have been excluded from the side walls, as is common practice due to probable closeness of houses to either side. Window proportions have been arbitrarily specified for the front and rear elevations. The window areas were selected as the minimum desirable for the room areas, independent of orientation since it is an unknown. Once the house is sited, it is desirable for the sake of energy conservation to increase the window area on the south exposure. It should be noted that this design is meant meant to be representative of construction practices and is not a house specifically designed for energy conservation. The house is represented in Figure B.1. More detailed documentation on the design of the ranch as well as the townhouse and two-story houses is available in NBSIR 77-1309: Three Proposed Typical House Designs for Energy Conservation Research. It should be noted that the ranch illustrated therein has a slightly smaller aspect ratio of 28 x 42 feet.

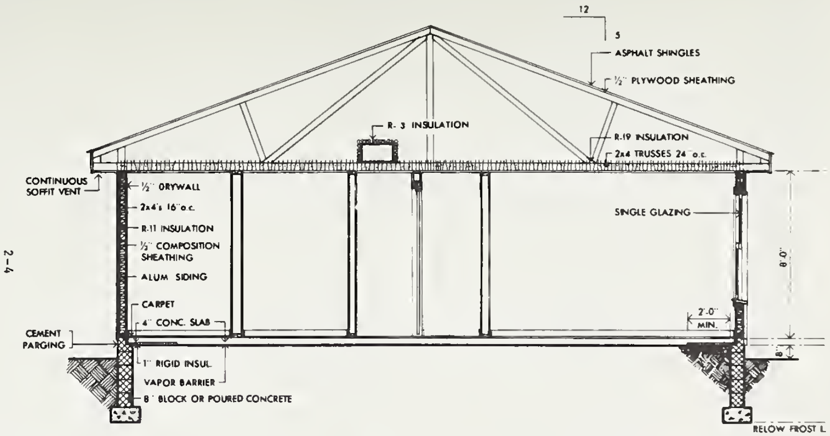
Following are the material specifications for the ranch house design combined with percentages of all single-family houses reported to have such materials.

Material Specification	NAHB Reported
Foundation/Floor	Percent of Total
Slab on grade	34.1
Basement (8" conc. walls)	62.7
1" perimeter insulation (R 5)	
(NAHB reported percentage of houses without)	23.9
Carpet	85.1
Exterior Walls	
Wood siding	(no percentage)
Composition sheathing (R 0.63)	(no percentage)
2" x 4" studs @ 16 inches on center	78.1
3 1/2" kraft paper batt insulation (R 11)	71.1
1/2" drywall	(no percentage)
Windows	
Doublehung	32.7
Single-glazed	69.8
Without storm sash	75.1
Doors	
Solid wood (front entry)	66.5
No storm door	75.1
Sliding glass door (dining area)	(no percentage)
Roof/Ceiling	
Single-gable form	74.7
Asphalt shingle	85.1
1/2" plywood sheathing	54.7
2" x 4" trusses 24" on center	62.6
Insulation, 6"± loose fill (R 19)	41.2
1/2" drywall ceiling	80.1
Plumbing/Mechanical	
Warm-air ducted	79.1
Natural gas furnace	48.9
Central A.C. (electric)	66.7
Domestic hot water (electric)	50.9



FLOOR PLAN OF A TYPICAL RANCH HOUSE

AUG.10.1977 0 2 4 8 NBS

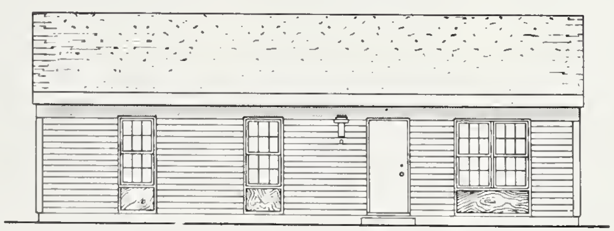


2-4

SECTION THRU TYPICAL RANCH

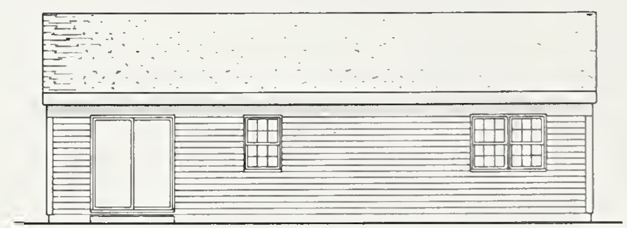
0 2 4 8

AUG 10.1977 NRS



FRONT ELEVATION OF A TYPICAL RANCH HOUSE

AUG 10,1977 0 2 4 R NBS



REAR ELEVATION OF A TYPICAL RANCH HOUSE

AUG 10.1977 0 2 4 R NRS

FIGURE B.1

APPENDIX C

Description of the Heating and Cooling Load Modeling Procedures Used for the Representative Ranch House

1. Approach

The ranch house design described in Appendix B was used as a basis for calculating annual heating and cooling requirements at each of the 60 TRY locations using the NBSLD loads calculation program[7]. This appendix describes in detail how that modeling effort was accomplished, including assumptions of how the building was used.

2. Insulation Levels

Since the purpose of the research described here is to define heating and cooling requirements as a function of the geographic variation in climate, a single insulation level is used in all computations. The level selected is that required to meet ASHRAE Standard 90-75[11] in a site with 5,000 heating degree days[1], the median for the continental U.S.

The maximum permissible ceiling and slab transmittance (U-value) are specified for this degree-day number in the ASHRAE Standard. The wall, window, and door U-values are combined and must not exceed an average U-value that is specified in the Standard. The average value for 5,000 degree days is U = 0.235 Btu/hr ft^2 °F, and may be met by various combinations of wall, window, and door U-values. The representative ranch house, equipped with storm windows, no storm door, and wall cavity insulation with a resistance of R = 0.8 hr ft^2 °F/Btu (equivalent to 1/4 inch of fiberglass batt insulation), will meet this value. The same house with no storm windows, no storm door, and cavity insulation with resistance R = 3.6 (equivalent to one inch of fiberglass batt insulation) will also meet the required value. Neither of these insulation thicknesses is available on the market, the usual minimum being 3-1/2" batts, with resistance R = 11.

Since conventional building materials and practices are to be simulated in the ranch house, the design with single glazing (no storm windows) and 3-1/2" of wall insulation was chosen. This design has sufficient insulation to meet the ASHRAE 90-75 Standard for locations with up to 7,800 degree days, or the equivalent of Madison, Wisconsin. Only three locations among the 60 climate stations tested here have degree-day numbers in excess of this.

The NAHBRF statistics suggest that the Standard is conservative and does not specify insulation levels as high as those being installed in current typical residential wood-frame construction. The insulation levels given

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[1] Heating and cooling degree days are assumed to be calculated from the traditional base temperature of 65°F unless otherwise stated.

in Appendix B are representative of a large proportion of housing being built in southern as well as northern regions of the U.S.

3. Operating Conditions

In the simulation of the space heating and cooling of the ranch house, the operating conditions of the house have to be assumed and inserted in the NBSLD program.

The primary operating condition is the control of interior temperature. In this simulation, the interior temperature is allowed to float between 68° and 78°F. Within this 'dead band', no loads are imposed on either the heating or cooling system. Below 68° the heater comes on to maintain 68°, and above 78° the air conditioner comes on to maintain 78°. These temperature settings are felt to be representative of prudent and quite conventional residential temperature control.

The operating conditions of a building also include the heat loads imposed by appliances, lights, and the occupants themselves throughout the day. These loads act to decrease the heating and increase the cooling requirements of the house. The loads are large enough to have a significant influence on the energy requirements of the building.

NBSLD calculates heating and cooling loads on an hourly basis throughout the day. Experiments on occupied buildings which yielded hourly profiles were found to be very sparse. After reviewing the experimental data obtained at Twin Rivers [12], the modeling assumptions used in two previous computer studies [13,14], and unpublished assumptions used by other researchers, it was decided to employ the profiles prepared by Hittman Associates in a study for HUD[14]. Assuming an occupancy for two adults and two children, the hourly loads caused by appliances, lights, and occupants are presented in Figure C.1.

4. Infiltration and Ventilation Rates

The displacement of internal air by external air also influences the heating and cooling requirements of the building. The extent of such air displacement in the computer simulation is largely determined by the assumptions made in setting up the program. This simulation incorporated some changes in the basic NBSLD calculation procedures.

The air displacement takes place as infiltration or ventilation. Infiltration may be defined as uncontrolled air leakage through the building envelope imposing heating or cooling loads on the building, while ventilation is controlled air displacement for removal of unwanted internal heat or odors. Natural ventilation occurs through windows and vents and is controlled by the occupants. Mechanical ventilation by window fans or whole-house fans is not included in this simulation.

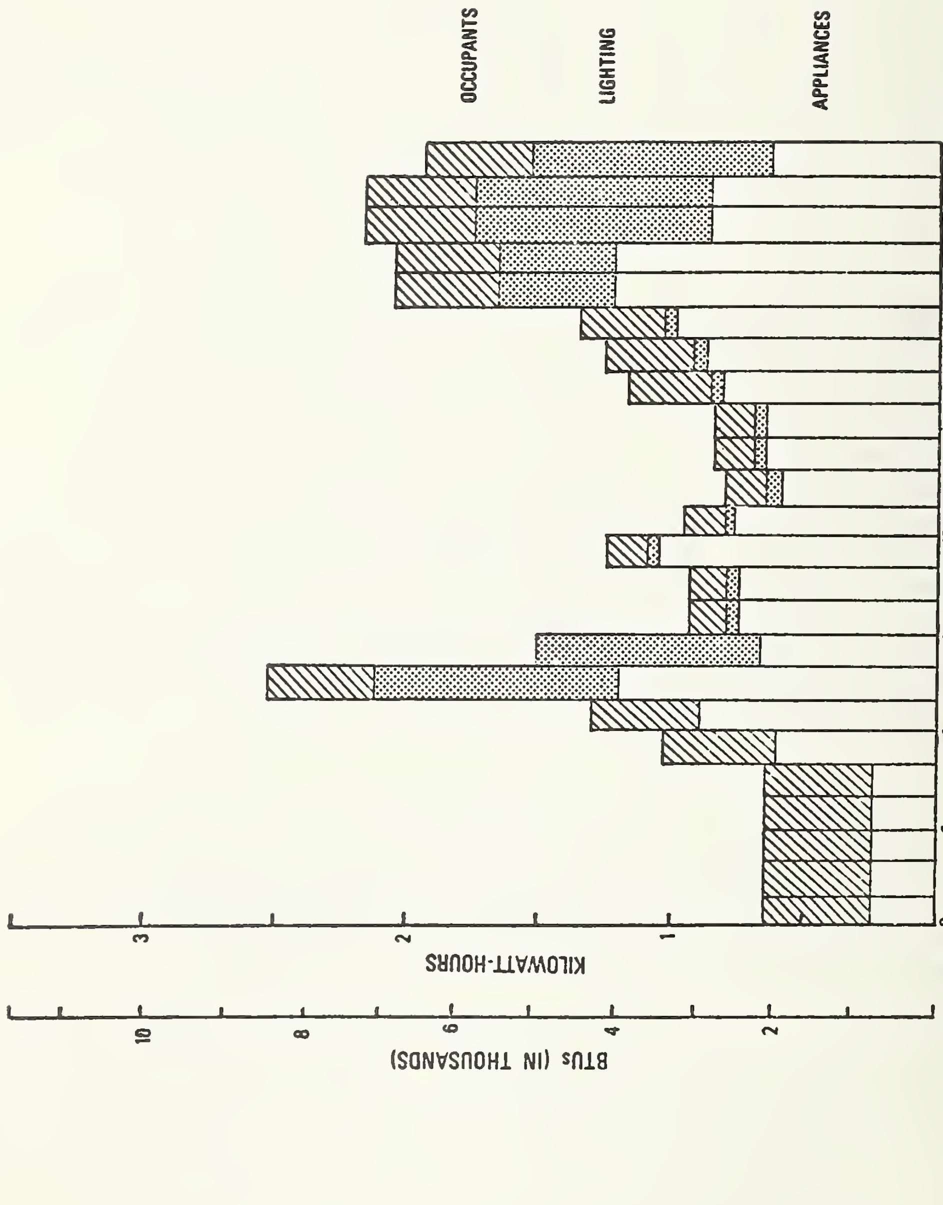
BTUs (IN THOUSANDS)
10
8
6
4
2
KILOWATT-HOURS
3
2
1
HOUR OF DAY
0
3
6
9
12
15
18
21
24
OCCUPANTS
LIGHTING
APPLIANCES

FIGURE C.1

The version of NBSLD used here calculates infiltration as a function of the wind speed and temperature difference between inside and outside of the house, using an empirical relationship developed by Coblentz and Achenbach[15]. The relationship is scaled in this study so that the air change rate under winter design conditions (15 mph wind, 70°F temperature difference between inside and outside) is 0.5, and the minimum air change rate is set at 0.1.

The maximum ventilation rate in a given hour is assumed to be 12 times the infiltration rate calculated as described above (Dr. Charles M. Hunt, NBS, private communication). However, the ventilation is assumed to be limited, so that internal heat gains are removed at a rate which maintains an interior temperature of 78°F.

If larger ventilation rates are climatically possible, they are assumed to go unused (as when the occupants control ventilation by lowering windows). This assumption is employed in this version of NBSLD to avoid the necessity of iteratively recomputing the heat gains or losses through the envelope at the reduced room temperatures.

If, at 78°F, the internal heat gains are greater than the maximum possible ventilative heat removal for that hour, natural ventilation becomes unable to maintain interior comfort conditions. At this point, all windows are assumed closed and air conditioning is employed to remove the heat and maintain the interior air temperature at 78°F.

Another modeling assumption is the rate of ventilation in the attic above the heated or cooled space in the house. The ventilation rate in the attic is fixed at two air changes per hour.

5. Floor Slab Model

The way in which the floor slab is modeled has a major influence on the heating and cooling performance of the house. The state of the art in building energy analysis programs cannot at present analytically describe the three-dimensional heat flow in the slab (through it and laterally along it). In addition, current algorithms do not adequately predict the hourly and seasonal thermal performance of a solid of great depth such as the earth below the slab.

The NBSLD algorithms approximate slab and earth behavior by modeling the heat flow through, and the thermal storage of, the slab and earth in one dimension (the vertical direction) only. The slab is underlaid by an arbitrary thickness of earth to a lower boundary with a fixed ground temperature. The insulation value of the slab, the earth thickness to constant ground temperature, and the ground temperature itself, are chosen to model fluxes realistically.

Three experimental studies of heat flow in slabs on grade were reviewed [16,17,18]. It was found that the steady-state heat flows determined in these experiments could be approximated by a hypothetical combination of slab construction, ground thickness, and ground temperature. Based on this review, the slab in the ranch house has been modeled as follows:

carpet and padding
4" concrete
1" polystyrene insulation (R = 5)
6" earth

The dynamic performance of the slab during temperature fluctuations could not be checked against experimental data, but it is probably realistic since the two upper layers of the slab are modeled exactly. The insulation below the slab would not be found in a typical slab of today except around the perimeter. It was found to be necessary, however, in order to approximate the actual steady-state heat flux of a typical slab built to ASHRAE 90-75 requirements.

Below the 6" earth layer, a constant ground temperature is assumed. Review of the ground temperature profiles in the above experiments provided an equation for estimating this temperature. It is based on the deep ground temperatures given in the NBSLD manual, dry soil tables.[7] One value is used for the summer months (June through September) and another for the winter (October through May). The equations for winter and summer ground temperature at 6" are:

$$T_G \text{ winter} = \left(\frac{T_G 1 \text{ winter} + T_G 1 \text{ spring}}{2} + 70° \right) /2$$

$$T_G \text{ summer} = \left(\frac{T_G 1 \text{ summer} + T_G 1 \text{ fall}}{2} + 73° \right) /2$$

where

T_G = the ground temperature at 6" below the surface used in modeling the slab

T_G^1 = the deep ground temperature derived from nearby locations presented in the dry soil tables[7].

Table C.1 presents the 6" ground temperatures used at each location in this study.

6. Orientation and Solar Transmission of Windows

The ranch house is oriented with the front door facing south. This places a larger area of glass on the north side (72 ft^2) than the south (55 ft^2), which is less effective solar design than if the house were rotated 180°. The orientation is felt to be acceptable in that the house is intended to represent typical, rather than optimal, siting practice. The small size of south-facing windows is somewhat compensated for by the lack of any external shading (by terrain, trees or other buildings) assumed in the model.

All glazed areas in the ranch house are modeled with a shading coefficient of 0.8 to account for the internal drapes and blinds (a shading coefficient of 1 represents no shading of a single-pane window). The overhangs in this version of the ranch house are sufficiently small that they are not modeled.

7. Listing of the Building Description Coding of the Ranch House

Reference: Kusuda, T. 1976. NBSLD, the Computer Program for Heating and Cooling Loads in Buildings (NBS Building Science Series 69).

The basic program has been modified by James Barnett of the Thermal Engineering Section, NBS, to simulate infiltration and ventilation as described in section 4 above.

Lines 28 and 29 are Barnett's additions required for an expanded output version that produces a detailed breakdown of loads through all building envelope components. The IRF's are demoted to the end of the listing.

The example shown in Figure C.2 is for the Washington, D.C. house.

TABLE C.1

Ground Temperatures Used in Heating and Cooling Loads Simulation

Location	October-May	June-September
Albany, NY	57	66
Albuquerque, NM	67	73
Amarillo, TX	67	75
Atlanta, GA	68	75
Birmingham, AL	63	70
Bismarck, ND	55	64
Boise, ID	56	63
Boston, MA	57	64
Brownsville, TX	67	75
Buffalo, NY	57	66
Burlington, VT	56	63
Charleston, SC	63	72
Cheyenne, WY	57	63
Chicago, IL	58	67
Cincinnati, OH	58	66
Cleveland, OH	58	66
Columbia, MO	60	68
Detroit, MI	57	65
Dodge City, KS	60	69
El Paso, TX	67	75
Fort Worth, TX	67	75
Fresno, CA	68	75
Great Falls, MT	54	61
Houston, TX	67	75
Indianapolis, IN	58	67
Jackson, MS	65	73
Jacksonville, FL	69	75
Kansas City, MO	60	67
Lake Charles, LA	65	73
Los Angeles, CA	68	75
Louisville, KY	61	69
Lubbock, TX	67	75
Madison, WI	56	65
Medford, OR	61	67
Memphis, TN	62	69
Miami, FL	68	75
Minneapolis, MN	55	65
Nashville, TN	62	69
New Orleans, LA	67	75
New York, NY	59	67
Norfolk, VA	60	68
Oklahoma City, OK	63	71
Omaha, NE	58	66
Philadelphia, PA	58	66
Phoenix, AZ	67	73
Pittsburgh, PA	58	66
Portland, ME	57	64
Portland, OR	59	65
Raleigh, NC	63	72
Richmond, VA	60	68
Sacramento, CA	67	72
St. Louis, MO	60	68
Salt Lake City, UT	57	64
San Antonio, TX	67	75
San Diego, CA	70	78
San Francisco, CA	67	72
Seattle-Tacoma, WA	60	64
Tampa, FL	68	75
Tulsa, OK	63	71
Washington,DC	60	68

FIGURE C.2

```
Q$Q$Q$*AFILE(1).H1WDC(0)
2,1,0,0,0,0, 3,2,77 (PIER50)  ASHRAE 90-75 H.R.5000 D.D.
 HASTINGS RANCH HOUSE 1
 0.,0.,0.,0.,0.,0.,1.,1.,.023,.023,.023,.023,.023,.023,.023
.023,.023,.023,.023,0.5,0.5,1.,1.,1.
.17,.17,.17,.17,.17,.48,.71,.95,.57,.61,.57,.88,.62,.48,.48
.51,.48,.65,.70,.81,1.00,.62,.70,.48
1.,1.,1.,1.,1.,1.,1.,1.,0.4,0.4,0.4,0.4,0.4,0.4,0.4
0.69,0.69,1.,1.,1.,1.,1.,1.,1.
 0.,0.,0.,0.,0.,0.,1.,1.,.023,.023,.023,.023,.023,.023,.023
.023,.023,.023,.023,0.5,0.5,1.,1.,1.
.17,.17,.17,.17,.17,.48,.71,.95,.57,.61,.57,.88,.62,.48,.48
.51,.48,.65,.70,.81,1.00,.62,.70,.48
1.,1.,1.,1.,1.,1.,1.,1.,0.4,0.4,0.4,0.4,0.4,0.4,0.4
0.69,0.69,1.,1.,1.,1.,1.,1.,1.
 0.,0.,0.,0.,0.,0.,1.,1.,.023,.023,.023,.023,.023,.023,.023
.023,.023,.023,.023,0.5,0.5,1.,1.,1.
.17,.17,.17,.17,.17,.48,.71,.95,.57,.61,.57,.88,.62,.48,.48
.51,.48,.65,.70,.81,1.00,.62,.70,.48
1.,1.,1.,1.,1.,1.,1.,1.,0.4,0.4,0.4,0.4,0.4,0.4,0.4
0.69,0.69,1.,1.,1.,1.,1.,1.,1.
78.,78.,78.,78.,78.,78.,78.,78.,78.,78.,78.,78.
78.,78.,78.,78.,78.,78.,78.,78.,78.,78.,78.,78.
78.,78.,78.,78.,78.,78.,78.,78.,78.,78.,78.,78.
78.,78.,78.,78.,78.,78.,78.,78.,78.,78.,78.,78.
68.,78.,20.,60.
365,0,9
8.,21.,232.,95.,20.,65.,18.,68.,60.,0.1,76.5,38.,5.,256.,20.
*************H.R. 90-75*********************
****************************CHANGES 3*30 TO MATCH TOM & ED'S VERSIONS
 HASTINGS RANCH HOUSE 1
0,0,0
1.,0.52,1.03,3.0,0.,0.5,75.,0.,0.5,0.6,0.1,1.
3,4,8,23
78.,68.,50000.,50000.,73.,60.
1,1
4,2,3,2
40.,30.,7.96
1,1,1200.,0.,0.,0.,0.9,0.,             ROOF
0.,0.,0.,0.,0.,0.,0.
0.,0.,0.,0.,0.,0.,0.,0.
4,10,20.,0.,0.5,0.,0.9,0.,             DOOR
0.,0.,0.,0.,0.,0.,0.
0.,0.,0.,0.,0.,0.,0.,0.
2,2,181.3,0.,0.,0.,0.9,0.,             R13.3 WALL
0.,0.,0.,0.,0.,0.,0.
0.,0.,0.,0.,0.,0.,0.,0.
2,3,63.6,0.,0.,0.,0.9,0.,              R6.7 STUDS
0.,0.,0.,0.,0.,0.,0.
0.,0.,0.,0.,0.,0.,0.,0.
3,10,55.1,0.,1.13,0.8,0.,0.,           SINGLE GLAZED
0.,0.,0.,0.,0.,0.,0.
0.,0.,0.,0.,0.,0.,0.,0.
2,2,209.06,90.,0.,0.,0.9,0.
0.,0.,0.,0.,0.,0.,0.
0.,0.,0.,0.,0.,0.,0.,0.
2,3,30.94,90.,0.,0.,0.9,0.
0.,0.,0.,0.,0.,0.,0.
```

```
0.,0.,0.,0.,0.,0.,0.,0.
2,2,189.4,180.,0.,0.,0.9,0.
0.,0.,0.,0.,0.,0.,0.
0.,0.,0.,0.,0.,0.,0.,0.
2,3,58.6,180.,0.,0.,0.9,0.
0.,0.,0.,0.,0.,0.,0.
0.,0.,0.,0.,0.,0.,0.,0.
3,10,72.0,180.,1.13,0.8,0.,0.
0.,0.,0.,0.,0.,0.,0.
0.,0.,0.,0.,0.,0.,0.,0.
2,2,209.06,-90.,0.,0.,0.9,0.
0.,0.,0.,0.,0.,0.,0.
0.,0.,0.,0.,0.,0.,0.,0.
2,3,30.94,-90.,0.,0.,0.9,0.
0.,0.,0.,0.,0.,0.,0.
0.,0.,0.,0.,0.,0.,0.,0.
5,4,1200.,0.,0.,0.,0.,0.,        R3.6 SLAB (=R8.6 WITH THE POLYSTYR LAYER)
0.,0.,0.,0.,0.,0.,0.
0.,0.,0.,0.,0.,0.,0.,0.
0.4,0.05,112.,1.875,2.0,1.,    R19 ATTIC
0,0,0,0,0
3,             IRF1
0.,0.,0.,0.,0.6
0.0417,0.07,34.,0.29,0.,0.63
0.,0.,0.,0.,0.5
INSIDE SURF. RES. (ROOF)
1/2 IN. PLYWOOD
 BUILD. PAP.+ASPH. SHIG.
4,             IRF2
0.0417,0.0938,50.,0.2,0.,0.45
0.292,0.0265,2.0,0.2,0.,11.
0.0417,0.0317,20.,.31,0.,1.32
0.03125,0.0497,37.,.29,0.,0.59
1/2 IN. GYPBOARD (R13.3)
3 1/2 IN. INSULATION R11
1/2 IN. SHEATHING
3/8 IN. WOOD SIDING
4,             IRF3
0.0417,0.0938,50.,0.2,0.,0.45
0.292,0.07,32.,.33,0.
0.0417,0.0317,20.,.31,0.,1.32
0.03125,0.0497,37.,.29,0.,0.59
1/2 IN. GYPBOARD (R6.7)
2X4 STUD
1/2 IN. SHEATHING
3/8 IN. WOOD SIDING
4,          IRF90-75
0.,0.,0.,0.,1.5
0.333,1.0,140.,0.2,0.
0.0833,0.01667,2.2,0.29,0.,5.
0.5,0.75,100.,0.2,0.
CARPET&PADDING (R3.6)
4 IN. CONCRETE SLAB
1 IN. POLYSTYRENE R5
6 IN.EARTH TO GRND TEMP
```

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The report has three main purposes:
First, it assesses 'Test Reference Year' (TRY) hourly climate data tapes to determine how well they represent long-term average climate when used for estimating average annual heating and cooling requirements. The report presents a method to adjust heating and cooling requirements that are computed using TRY data, in order to make them represent long-term average heating and cooling requirements.

Second, the report quantifies the geographic variation of annual heating and cooling requirements across the U.S. by computing the heating and cooling requirements of a typical ranch-style residence for the 8760 hours of each of the 60 TRY tapes, and adjusting the results by the method described above.

Third, the effectiveness of 'degree-day' data for predicting these computed annual heating and cooling requirements is examined, and the variability of heating and cooling requirements within degree-day 'zones' of 1000 degree day width is presented.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)* Building energy conservation; climatic effects on building energy consumption; computer modeling of building energy consumption; energy conservation; geographical variation of building consumption; residential energy consumption.

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