Cooling Degree Days in Indiana

LAWRENCE A. SCHAAL,[1] Purdue University

Introduction

Abstract

Cooling degree days are used by the air-conditioning industry to estimate power requirements for cooling buildings as temperatures vary from day to day, seasonally and geographically. Normal cooling degree days are calculated for various climatic stations in Indiana and the appropriateness of the base temperature used will be related to daily data recorded from a typical Indiana home.

Cooling degree days is a meteorological statistic derived from accumulating the excess of the daily mean outdoor temperature above a chosen base temperature. They closely parallel the energy necessary to cool for human comfort the interior of buildings exposed to a hot exterior environment. The chosen base temperature has ranged from 60 to 75°F. This study will hopefully add to the apparent meager work done on this question for ordinary homes, or small buildings. Normal cooling degree days are calculated for some weather stations in Indiana from monthly mean temperatures and a chart for the state is constructed from the data.

One cooling degree day is a day when the mean temperature exceeds the base temperature one degree. Lower mean temperatures are given a value of zero. The resulting sum for a day, a week, or season enables comparisons from one area to another, within various time periods, and in a locale to assess cooling energy requirements of structures. Heating degree days which are calculated from mean temperatures below 65°F have a wide use in the heating industry, a fine example of profitable use of climatology.

Interest in this study started as the author considered the appropriateness of 65°F as the standard base temperature for cooling degree days. The *Glossary of Meteorology* (3) gives the common base of 75°F. In selected *Climatic Maps of the United States* (2) the base temperature used is 65°F. The *Climatological Handbook, Columbia Basin States* (4) suggests 60°F. In Indiana, a daily mean temperature of 65°F results from minimum temperature for the day of about 54°F and a maxium temperature of about 76°F. An air temperature of 76°F is still in the comfortable range for non-working humans under common humidity, wind and solar conditions. But as described in this paper, the solar radiation load on a small building seems to require a lower base temperature at least when the maximum interior temperature is set at 78°F.

The correlation of cooling requirements for several types of commercial buildings was reported by Thom (7). Correlations in a 15-day

---

[1] Agronomy Department and Environmental Science Services Administration, United States Department of Commerce.

study in Washington, D. C. ranged from 0.405 (office building) to 0.918 (hotel). The base temperature was 65°F.

Methods

In this low budget study the author compared the minutes the air conditioner ran in his own home to the measurements of air temperature and solar radiation at the Purdue University Agronomy Farm 6 miles west-northwest of the house. Readings, taken for 42 days at about 8 AM, consisted of the total minutes the home thermostat set at 78°F caused the coolant compressor to run and cool the house (Fig. 1).

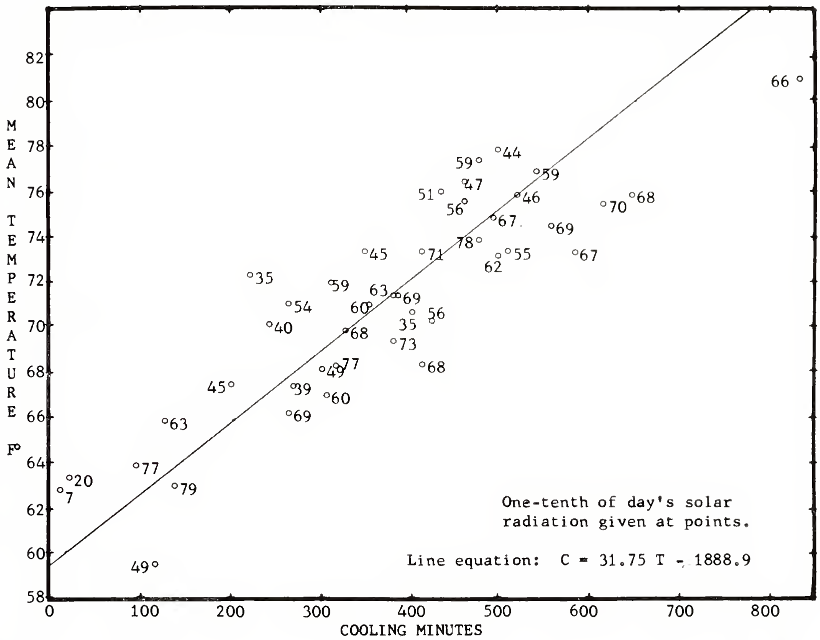

FIGURE 1. *Daily observations of outdoor mean temperature are related to minutes of cooling to maintain a temperature of 78°F or lower in a typical dwelling. The day's solar radiation in tens of calories per square centimeter is given at the point. Cooling minutes accumulated when the daily mean temperature exceeded 59°F generally.*

The circulating fan of the furnace ran continuously and the thermostat was set to turn on the coolant compressor when 78°F was exceeded during the 42 days. A simple electric clock was connected to the circuit on the furnace which actuated the coolant compressor and the coolant fan outside the house. The room thermostat closed the circuit for running the cooling equipment.

Cooling minutes used in this paper could be converted directly to electrical energy by using the electrical specifications of the electric motors.

Of some interest was the frequency and time periods when the cooling system ran. These were monitored by placing a hygrothermograph beside the outlet of the furnace. Thus the rise and fall of outlet air temperature and humidity were charted. These data made it quite obvious how the radiation load on the house had to be removed by the air conditioner. Cooling began on many days at about noon and continued until evening or midnight.

Results and Discussion

Linear regression was calculated for the 42 daily observations using $C = aT + k$ where: C was cooling minutes; T equalled the mean temperature for the 24-hour period (the average of the maximum and minimum temperature); a was the regression coefficient of T; and k was the constant. The equation of the regression line was:

$$C = 31.75\ T - 1888.9$$

when $C = 0$ then $$T = \frac{1888.9}{31.75} = 59.5$$

The intercept on T when cooling minutes were zero was 59.5°F. This data suggests a base temperature of about 60°F. The simple correlation coefficient was 0.880.

During the period of observation it was obvious that solar radiation had an effect on the minutes of cooling. For this reason solar radiation observed at the Agronomy Farm became the second factor in a multiple regression problem. The effect of showers was not studied. There were very few showers during the 42 days but during one evening a shower cooled the house and environs reducing the cooling minutes compared to other days at the same temperature. Showers favor shifting the base temperature higher since cooling minutes are less. A sunny day favors a lower base temperature because the interior temperature of the house increased by solar radiation greatly exceeds exterior air temperature. The multiple correlation equation using both temperature and solar radiation was $C = aT + bS + k$ where: $C =$ cooling minutes; $T =$ mean temperature of day; $S =$ solar radiation (daily total gram calories on a square centimeter of horizontal surface). The coefficients calculated were: $a = 30.15$; $b = 0.288$; resulting in $C = 30.15\ T + 0.288\ S - 1939.24$. If the first equation for C (obtained when the solar radiation term was not included) is placed equal to the above equation including the solar radiation term, we obtain: $31.75\ T - 1888.87 = 30.15\ T + 0.288\ S - 1939.24$; $1.6\ T = 0.288\ S - 50.37$; $T = 0.18\ S - 31.48$. This shows a relation of 1°F temperature change equal to 0.18 Langley where the two linear equations intersect. In the above equation the constant 1939.24 is a little greater than the 1888.9 of the first equation which did not have the solar radiation term. The intercept of T with zero minutes of cooling turns out to be 61.1°F.

The coefficient of T and S may also be normalized to show a relative relationship for one standard deviation of C by calculating Beta Coefficients (1). This is done by dividing the coefficients a and b by the standard deviation of C which was calculated to be 172.48. They were next multiplied by their respective standard deviations as follows: Calculated standard deviations: for C 172.48; for T 4.781; for S. 155.38.

$$\text{Beta for T} = \frac{30.15 \times 4.781}{172.48} = 0.8357;$$

$$\text{Beta for S} = \frac{0.2884 \times 155.38}{172.48} = 0.2598.$$

Therefore one standard deviation of C relates to 0.84 standard deviation of T and 0.26 standard deviation of S.

The significance of solar radiation to cooling minutes was calculated as follows ($N = 42$):

Source of Variation	*Degrees of Freedom*	*Sum of Squares*
C on T	40	275,116
C on T and S	39	195,118
Reduction due to adding S	1	79,928

For the well known F test, $\frac{79{,}928}{195{,}188/39} = \frac{79{,}928}{5005} = 15.97$

From F-table values (5), an F of 8.87 or greater indicates that the chance is less than 1 in 200 that this set of observations accidentally showed such a contribution from solar radiation increasing cooling minutes after the effect of temperature.

The correlation coefficients based on additional tests and computations are listed in Table 1.

TABLE 1. *Correlation coefficients.*

Daily mean temperature and cooling minutes	0.880
Daily highest temperature and cooling minutes	0.881
Daily mean temperature and solar radiation with cooling minutes	0.917
Daily highest temperature and solar radiation with cooling minutes	0.886

Linear correlation of the maximum temperature with cooling minutes was about the same as with the mean temperature and did not improve much with the addition of the solar radiation term. This seems to indicate that the maximum temperature reflected the effect of solar radiation with very little contribution by the minimum temperature or night temperature.

The importance of interaction between temperature and solar radiation (product of T and S) to cooling was computed. The addition of this third term to the equation became significant at the 5% level but not at the 1% level using the F test.

The one-story house of about 1200 square feet plus a full basement was insulated by 4-inch-thick bats of fiber glass insulation in ceilings and walls and is believed fairly typical of the contemporary 3-bedroom home. The roof was grey with a slope of 3 to 12. The window area was more than the average house, and storm windows were in place. Considerable attic ventilation came from openings under the eaves. It seems that the solar radiation load was proportionately larger than for a large apartment or office building having large interior areas away from exterior walls and roof. Afternoon relative humidity varied little during the experiment. Daily lows ranged from 39 to 86 at the Agronomy Farm and averaged 53% relative humidity.

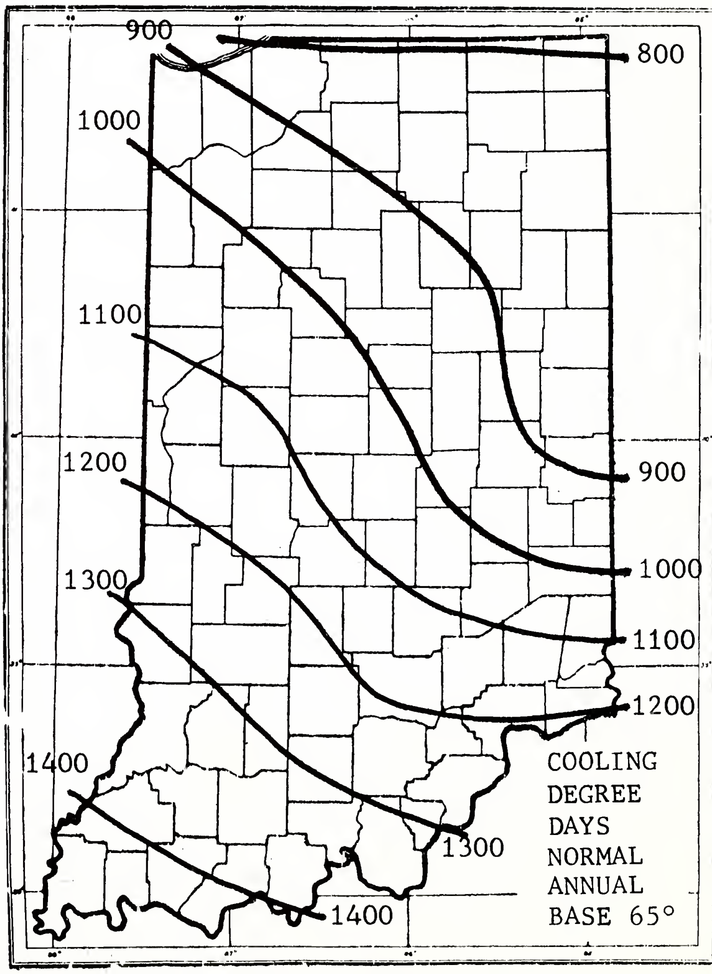

FIGURE 2. *Normal annual cooling degree days calculated from daily mean temperatures above 65°F.*

I conclude that in a sunny climate and for small houses the base temperature for cooling is closer to 60°F than 65°F, but perhaps for large multistoried buildings the base temperature may be more appropriately 65°F. Since 65°F is becoming the most frequently used base temperature, a normal cooling degree day map for Indiana has been drawn (Fig. 2). Monthly mean temperatures for the period of 1931-1960 were used since the World Meteorological Organization and Environmental Science Services Administration, Environmental Data Service use this average as the normal.

The monthly mean temperature of the mid-summer months readily convert to cooling degree days with practically no error by subtracting 65 from the mean and multiplying by the number of days in the month. However, for the peripheral months of the season when the mean is near 65 we used the standard deviation of the monthly mean temperature to estimate the additional degree days needed. Thom's unpublished nomogram (6) was used to estimate the increment.

For an example in the use of Figure 2, consider a location in Indiana where the normal of cooling degree days is 1200 for a season. A summer has just passed when the cost of cooling a new building was $300 and the cooling degree days totalled 1500 as calculated from daily temperatures nearby. What is the normal expected expense? Since 1500 cooling degree days is 300 more than the normal 1200 and 300 is 20% of 1500, then 20% of $300, or $60, is the above normal cost of cooling the building. A normal or average summer would result in cooling costs $60 less than $300, or $240. Supposing the next summer averaged near normal in cooling degree days and costs were appreciably different from $240. It would then be evident that changes in the efficiency of cooling had occurred.

The Indiana map relates to the standard exposure of official thermometers generally found in rural or village areas. These localities are generally cooler than the brick and concrete areas of the cities. Therefore city islands of heat are not shown unless included unknowingly in some substation data used.

Conclusions

In conclusion, this experiment favored a base temperature nearer 60 than 65°F for the computation of cooling degree days as they relate to home cooling. The test period, however, did cover a sunny period and a humidity much higher than found in the western plains, both of which should be inversely related to the base temperature.

Acknowledgments

The author is indebted to James E. Martin and Oscar Luetkemeier for Agronomy Farm observations, to Walter L. Stirm, Advisory Agricultural Meteorologist for instrumentation, and Robert May for computer work.

Literature Cited

1. ARKIN, HERBERT, and RAYMOND R. COLTON. 1946. An Outline of Statistical Methods, 4th Edition. Barnes and Noble Inc., N. Y. 224 p.

2. Data Information. 1968. Selected Climatic Maps of the United States. Environmental Science Services Administration, U. S. Department of Commerce. 32 p.

3. HUSCHKE, RALPH E. 1959. Glossary of Meterology. American Meteorological Society. 638 p.

4. Meteorology Committee, Pacific Northwest River Basins Commission. 1969. Climatological Handbook, Columbia Basin States, Temperature, Vol. 1, Part B. 540 p.

5. SNEDECOR, GEORGE W. 1965. Statistical Methods, Fifth Edition. Iowa State University Press, Ames, Ia. 534 p.

6. THOM, H. C. S. 1956. Monthly Degree Days derived from Monthly Mean Temperature, nomogram. Environmental Data Service, Environmental Science Services Administration, U. S. Department of Commerce.

7. THOM, H. C. S. 1966. Cooling Degree Days and Energy Consumption. Air Conditioning, Heating and Ventilation. **63**:53-54.