Heating and Cooling Degree Days

Identification

1. Indicator Description

This indicator measures trends in heating degree days (HDD) and cooling degree days (CDD) in the United States between 1895 and 2023. Heating and cooling degree days are measures that reflect the amount of energy needed to heat or cool a building to a comfortable temperature, given how cold or hot it is outside. A "degree day" indicates that the daily average outdoor temperature was one degree higher or lower than some comfortable baseline temperature on a particular day. In this case, both heating and cooling degree days use a baseline of 65°F—a typical baseline used by the National Oceanic and Atmospheric Administration (NOAA). Heating degree days are summations of negative differences between the mean daily temperature and the 65°F base; cooling degree days are summations of positive differences from the 65°F base. The sum of the number of heating or cooling degree days over a year is roughly proportional to the annual amount of energy that would be needed to heat or cool a building in that location (Quayle & Diaz, 1980). Thus, HDD and CDD are rough surrogates for how climate change is likely to affect energy use for heating and cooling.

Components of this indicator include:

- Annual average HDD and CDD nationwide, compared with long-term averages (Figure 1).
- Change in annual HDD by state (Figure 2).
- Change in annual CDD by state (Figure 3).

2. Revision History

May 2014:	Indicator published.
June 2015:	Updated indicator with data through 2014.
August 2016:	Updated indicator with data through 2015.
April 2021:	Updated indicator with data through 2020.
June 2024:	Updated indicator with data through 2023.

Data Sources

3. Data Sources

Data for this indicator were provided by NOAA's National Centers for Environmental Information (NCEI). These data are based on temperature measurements from weather stations overseen by NOAA's National Weather Service (NWS). These underlying data are maintained by NCEI.

4. Data Availability

EPA obtained data for this indicator from NCEI at: www1.ncdc.noaa.gov/pub/data/cirs/climdiv. These data are a part of NOAA's Climate Divisional Database (*n*ClimDiv) and replace the previous Time Bias Corrected Divisional Temperature-Precipitation Drought Index.

The *n*ClimDiv product incorporates data from the daily version of NOAA's Global Historical Climatology Network (GHCN-Daily) and is updated once a month. For access to *n*ClimDiv data and documentation, see: www.ncdc.noaa.gov/monitoring-references/maps/us-climate-divisions.php.

Individual weather station data are maintained at NOAA's NCEI, and the data are distributed on various computer media (e.g., anonymous FTP sites), with no confidentiality issues limiting accessibility. Individual station measurements and metadata are available through NCEI's website (www.ncei.noaa.gov/products/land-based-station).

Methodology

5. Data Collection

This indicator measures annual average heating and cooling degree days nationwide and for each individual state. The HDD and CDD data are based on time-bias adjusted temperature data from weather stations throughout the contiguous 48 states. Some of these stations are automated stations operated by NOAA's National Weather Service. The remainder are Cooperative Observer Program (COOP) stations operated by other organizations using trained observers and equipment and procedures prescribed by NOAA.

Systematic collection of weather data in the United States began in the 1800s. Since then, observations have been recorded from 23,000 stations. At any given time, observations are recorded from approximately 8,000 stations. COOP stations generally measure temperature at least hourly, and they record the maximum and minimum temperature for each 24-hour time span. Cooperative observers include state universities, state and federal agencies, and private individuals whose stations are managed and maintained by the NWS. Observers are trained to collect data following NWS protocols, and the NWS provides and maintains standard equipment to gather these data. For an inventory of U.S. weather stations and information about data collection methods, see: www.ncei.noaa.gov/products/land-based-station, the technical reports and peer-reviewed papers cited therein, and the National Weather Service technical manuals at: www.weather.gov/coop.

This indicator is based on a specific quality-controlled set of long-term stations that NCEI has designated as its *n*ClimDiv dataset. Variables that are relevant to this indicator include observations of daily maximum and minimum temperatures.

6. Indicator Derivation

NCEI used several steps to calculate annual HDD and CDD data for each month of each year in each state (Arguez et al., 2011; Vose et al., 2014).

First, the raw station temperature data were adjusted to remove bias due to variation in the time of day at which temperature measurements were reported (Arguez et al., 2011; Karl et al., 1986; Vose et al., 2014). This bias arises from the fact that, historically, some COOP stations have reported temperatures over climatological days ending at different times of day (e.g., over the 24-hour period ending at midnight versus the 24-hour period ending at 7:00 pm). This variation leads to different reported daily minimum and maximum temperatures, as well as inconsistencies in mean temperature (which historically has often been calculated as [*minimum temperature* + *maximum temperature*]/2). To address this problem, NCEI used the statistical adjustment procedure from Karl et al. (1986) to remove bias due to differences in time-of-day definitions.

Second, daily bias-adjusted data were used to calculate mean temperatures in each month and year (Arguez et al., 2011; Vose et al., 2014). Additionally, the data were used to calculate the standard deviation of daily temperatures in each location for each month (pooling across all years) over the entire period for which temperature data were available.

Third, NCEI estimated the total monthly heating and cooling degree days at each location. A crude way to find monthly totals would be to simply add all the daily HDD and CDD values over the course of the month. For reasons related to data quality, however, NCEI used a modified version of the procedure presented by Thom (1954b, 1954a, 1966), which assumes that daily temperatures within a month are distributed normally. The expected number of HDD or CDD per month can then be expressed as a simple function of the actual monthly mean daily temperature and the long-term standard deviation of daily temperatures. The logic behind this approach is that HDD and CDD are measures that reflect both the mean (the “absolute value”) and standard deviation (the “spread”) of daily temperatures—and thus can be estimated from them. Although predictions based on this formula may be inaccurate for any particular day or week, on average across large time periods the predictions will be reasonably good. The rationale for using this approach is that daily COOP station data contain many “inhomogeneities” and missing data points that may add noise or bias to HDD and CDD estimates calculated directly from daily data. By estimating HDD and CDD following the Thom procedure, NCEI was able to generate estimates in a consistent way for all years of the data.

State and national averages for each year were calculated as follows:

1. NCEI calculated a monthly average HDD and CDD for each climate division (each state within the contiguous 48 has up to 10 climate divisions; see: www.ncdc.noaa.gov/monitoring-references/maps/us-climate-divisions.php) using climatologically aided interpolation to address topographic and network variability. This step is part of NCEI’s *n*ClimDiv analysis, in which NCEI uses station data and interpolation between stations to create a 5-kilometer grid across the contiguous 48 states for each variable in the dataset. Divisional averages are derived by averaging the grid cells within each climate division. This approach ensures that divisional SPI values are not biased towards areas that happen to have more stations clustered close together.

2. NCEI calculated monthly averages for each state by weighting the climate divisions by their population. With this approach, state HDD and CDD values more closely reflect the conditions that the average resident of the state would experience.

NCEI calculated monthly averages for the contiguous 48 states by weighting the divisions or states according to their population.

3. NCEI and EPA added each year's monthly averages together to arrive at annual totals for the contiguous 48 states and for each individual state.

All population-based weighting was performed using population data from the 2010 U.S. Census. Figure 1 shows the national HDD and CDD averages as described above. EPA developed the maps of state-level changes in HDD and CDD (Figures 2 and 3) by separating the historical record into two periods of roughly equal length (1895–1959 and 1960–2023), then calculating how average annual HDD and CDD in each state changed between the two periods.

7. Quality Assurance and Quality Control

NOAA follows extensive quality assurance and quality control (QA/QC) procedures for collecting and compiling weather station data. For documentation of COOP methods, including training manuals and maintenance of equipment, see: www.weather.gov/coop. These training materials also discuss QC of the underlying data set. Additionally, pre-1948 data in the COOP data set have recently been digitized from hard copy. Quality control procedures associated with digitization and other potential sources of error are discussed in Kunkel et al. (2005).

NOAA's *n*ClimDiv dataset follows strict QA/QC procedures to identify errors and biases in the data and then either remove these stations from the time series or apply correction factors. Procedures for *n*ClimDiv are summarized at: www.ncdc.noaa.gov/monitoring-references/maps/us-climate-divisions.php.

Analysis

8. Comparability Over Time and Space

HDD and CDD have been calculated using the same methods for all locations and throughout the period of record. Each climate division contributes to the state and national averages in proportion to its population. All population-based weighting was performed using population data from the 2010 U.S. Census, so as to avoid ending up with an HDD or CDD trend line that reflects the influence of shifting populations (e.g., more people moving to areas with warmer climates).

9. Data Limitations

Factors that may impact the confidence, application, or conclusions drawn from this indicator are as follows:

1. Biases may have occurred as a result of changes over time in instrumentation, measuring procedures, and the exposure and location of the instruments. Where possible, data have been adjusted to account for changes in these variables. For more information on these corrections, see Section 7.

2. Observer errors, such as errors in reading instruments or writing observations on the form, are present in the earlier part of this data set. Additionally, uncertainty may be introduced into this data set when hard copies of data are digitized. As a result of these and other reasons, uncertainties in the temperature data increase as one goes back in time, particularly given that

there are fewer stations early in the record. However, NOAA does not believe these uncertainties are sufficient to undermine the fundamental trends in the data. More information about limitations of early weather data can be found in Kunkel et al. (2005).

3. While heating and cooling degree days provide a good general sense of how temperature changes affect daily life, they are not an exact surrogate for energy use. Many other factors have influenced energy demand over time, such as more energy-efficient heating systems, the introduction and increasingly widespread use of cooling technologies, larger but better-insulated homes, and behavior change. In addition, an indicator of energy use would ideally account for changes in where people live (e.g., relative population growth in warm regions that require more cooling than heating), which this indicator does not.

10. Sources of Uncertainty

The main source of uncertainty in this indicator relates to the quality of the underlying weather station records. Uncertainty may be introduced into this data set when hard copies of historical data are digitized. As a result of these and other reasons, uncertainties in the temperature data increase as one goes back in time, particularly given that there are fewer stations early in the record. However, NOAA does not believe these uncertainties are sufficient to undermine the fundamental trends in the data. Vose and Menne (2004) suggest that the station density in the U.S. climate network is sufficient to produce robust spatial averages.

NCEI has taken a variety of steps to reduce uncertainties, including correcting the data for time-of-day reporting biases and using the Thom (1954b, 1954a, 1966) methodology to estimate degree days. The value of this approach is that it allows estimation of degree days based on monthly average temperatures, even when the daily data may include some inaccuracies. However, this methodology for estimating HDD and CDD from mean monthly temperatures and the long-term standard deviation of monthly temperatures also introduces some uncertainty. Although this peer-reviewed technique is considered reliable, it could produce inaccurate results if the standard deviation of temperatures has changed over time, for example due to an increasing trend of local variability in daily temperatures.

11. Sources of Variability

HDD and CDD are likely to display the same types of variability as the temperature record on which they are based. Temperatures naturally vary from year to year as a result of normal variation in weather patterns, multi-year climate cycles such as the El Niño–Southern Oscillation and Pacific Decadal Oscillation, and other factors. This indicator accounts for these factors by presenting a long-term record (1895–2023) of how HDD and CDD have changed over time.

12. Statistical/Trend Analysis

To test for the presence of long-term national-level changes in HDD and CDD, the annual average "contiguous 48 states" HDD and CDD data series in Figure 1 were analyzed by ordinary least squares linear regression for the full period of record (1895–2023). Both trends were statistically significant:

HDD: regression slope of -4.82 degree days per year ($p < 0.001$).
CDD: regression slope of +1.75 degree days per year ($p < 0.001$).

Based on ordinary least-squares linear regression of annual data points for each state, 46 states had statistically significant ($p < 0.05$) trends in HDD (all 46 decreasing), and 31 states had significant trends in CDD (all 31 increasing).

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