Data Note:
Heating and Cooling Degree Days

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Summary

This Data Note summarizes the methodologies used by the World Resources Institute for calculating annual heating degree days (HDD) and cooling degree days (CDD) for 171 countries. Table 2 summarizes the results of the calculations. The heating and cooling degree day data shown in Table 2 is included in the Climate Analysis Indicators Tool (CAIT), as a Natural Factor Indicator.[1] In CAIT, two HDD and two CDD figures are provided for each country. The first is a population weighed national average (i.e., per capita) and the second is a "total" for the country, which is the per capita average multiplied by the total population. These two figures serve as proxies for the *per capita* and *total* heating cooling needs of a country, respectively.

1. Concept of Heating and Cooling Degree Days

A "degree day" is a measure of the average temperature's departure from a human comfort level of 18 °C (65 °F). The concept of degree days is used primarily to evaluate energy demand for heating and cooling services. In the United States, for example, degree day indicators are widely used in weather derivatives, energy trading, and weather risk management.

Using a base temperature of 18 °C, heating degree days (HDDs) are defined as 18 – T, where T is the average temperature of a given day. Thus, a day with an average temperature of 10 °C will have 8 degree heating days. Cooling degree days (CDDs) are calculated in a similar fashion: cooling degree days are defined as T – 18, where T is the average temperature. Accordingly, a day with an average temperature of 25 °C will have 7 degree cooling days. For both heating and cooling degree days, average temperature of a particular day is calculated by adding the daily high and low temperatures and dividing by two. Thus, if the daily high temperature is 20° and the daily low temperature is 10°, then the average temperature is 15 (resulting in 3 heating degree days).

Heating and cooling degree days are calculated in a cumulative fashion. For example, heating degree days for a weather station with daily average temperatures during a five-day period of 14, 13, 15, 10, and 9 are 1, 2, 0, 5, and 6. This sums to a total of 14 heating degree days over the period. To calculate the degree heating days of an entire year, the degree day calculations of all 365 days are simply summed. Naturally, heating degree days accumulate primarily during the winter, whereas cooling degree days tend to accrue during the warmer summer months.

Degree day calculations can also be made for regions. The National Climatic Data Center in the United States, for example, calculates heating degree days for each state and geographic region (e.g., Northeastern U.S.) as well as a U.S. national average. This is done by applying population

[1] See http://cait.wri.org

weightings to the degree day calculation generated from weather stations around the country. Thus, the degree day calculations from large metropolitan areas will be accorded more weight than calculations from sparsely populated areas.

2. Methodology

WRI has made HDD and CDD estimates for 171 countries. The methodology for calculating degree days for each country involves two steps: (1) calculation of heating and cooling degree days for all possible locations and (2) weighing degree day data by population, within each country, to obtain a national average. Population data—appropriately matched with the degree day data—enables population-weighted national averages to be constructed. These figures represent the HDD and CDD faced by an "average" person in the particular country.

2.1. Calculating Degree Days

Due to limitations in the available data, degree days were calculated using two different methods. The first method uses *daily* temperature averages to calculate degree days for a given location while the second method used the Erbs et al. (1983) method for calculating degree day data from *monthly* average temperatures. Table 2 notes whether Method 1 or 2 was used for each country. Each method is described in detail below.

i. Method 1

Method 1, used to calculate heating and cooling degree days for 115 countries, used degree day and degree hour data compiled by Crawley (1994) from the Global Daily Summary (GDS) version 1.0 and the International Station Meteorological Climate Summary (ISMCS) version 4.0 data. GDS contains daily summaries of temperature and precipitation for the period October, 1977 to December, 1991 for 10,277 locations while ISMCS contains detailed tables of many weather variables for the period of record (months in some locations and up to 70 years in the U.S.) for more than 1,000 locations. The compiled degree day data contains data for nearly 4500 international locations calculated from climate normals.

ii. Method 2

Method 2 was used for 56 countries that were not included in the dataset compiled by Crawley. This method calculated degree days based on *monthly average temperatures*. Monthly average temperatures were obtained from the World Climate website[2] which contains monthly average temperatures drawn from the Global Historical Climatology Network (GHCN) versions 1.0 and 2.0 (beta) (See References). GHCN is a comprehensive global surface baseline climate dataset comprised of surface station observations of temperature, precipitation, and pressure. GHCN contains data from over 6,000 weather stations. All GHCN data are on a monthly basis and represent climate normals for the period of record. The earliest station data is from 1697 while the most recent are from 1990. A typical period of record for a given weather station is between 50 and 20 years.

[2] http://www.worldclimate.com

To calculate degree days from monthly average temperatures, WRI followed the method developed by Erbs et al. (1983), described in Al-Homoud (1998). The Erbs method attempts to correct for under and/or over-representation of heating and cooling degree days when using a monthly average temperature. Typically when using monthly average temperatures, degree days are calculated as $D_m(18-T_a)$ for heating degree days and $D_m(T_a-18)$ for cooling degree days, where D_m is the number of days in the month and T_a is the average monthly temperature. Because this method does not account for temperature variability within the month, it is likely to over or under estimate heating and cooling needs. In order to compensate for this, the Erbs method calculates the standard deviation of the monthly average temperature around the yearly average (σ_y) and the daily average around the monthly average (σ_m). In turn, the standard deviation of the daily average temperatures around the monthly average is used to estimate daily average temperature variability within the month. Degree days for the month can then be calculated as:

$$DD_m = \sigma_m(D_m)^{1.5}[h/2 + \ln(e^{-ah} + e^{ah})/2a]$$

where:

$h = (T_{base}-T_a)/[\sigma_m (D_m)^{1/2}]$ (for heating degree days calculations),

$h = (T_a-T_{base})/[\sigma_m (D_m)^{1/2}]$ (for cooling degree days calculations),

$a= 1.698(D_m)^{1/2}$,

$\sigma_m= 1.45 - 0.29T_a + 0.664\sigma_y.$

Finally, the degree days for each month were summed to obtain a yearly total.

Both Method 1 and Method 2 yielded annual degree day data for several thousand international locations. In order to aggregate these data by country we used the weighting method described below.

2.2. Weighting the Degree Day Data

The average heating and cooling needs of an entire country can be determined by applying population weightings to the degree day calculations generated for locations within a country. Using population to weight the degree day data ensures that large metropolitan areas will be accorded more weight than calculations from sparsely populated areas so that the national average reflects the heating and cooling needs faced by the “average” citizen of that country (with some facing more, and others facing less).

Population figures used to construct the weightings were obtained from a population dataset compiled by Helders (2003). The population data were compiled from several national statistical agencies and international organizations and represent 2003 population estimates for cities, towns, administrative units, and countries. Estimates are based on the best available data.

In most cases, we chose domestic states or provincial units as the basis upon which to construct the weightings. In some cases, where no state or provincial population data was available, we used major metropolitan areas to construct the weightings.

First, HDD and CDD data (determined via either Method 1 or 2) for each location were matched to the corresponding city/town population figures where possible. The HDD and CDD data with no correlating population data were disregarded. This data often corresponded to weather stations in sparsely populated areas.

Next, the degree day data and associated city/town populations were grouped according to "administrative unit" (i.e., state, province or territory).[3] The HDD and CDD data were then weighed according to the administrative unit population and summed in order to obtain the average HDD and CDD for the country. Where degree day data are available for only one location within the administrative unit, that location served as a proxy for the entire administrative unit. Where degree day data for multiple locations are available within a single administrative unit, the degree day data for the multiple locations are weighed according to their share of the administrative unit population.

For example, the Indian state of Madhya Pradesh has degree day data for four locations, the cities of Gwalior, Jabalpur, Bhopal and Indore. The average state heating and cooling degree days were determined by weighting the degree day data of each location according to its share of the represented state population and then summing the weighted degree days to obtain the state total. Alternately, the small Indian state of Tripura has degree day data from only one location, the capital city of Agartala. Accordingly, the degree day data for Agartala is used as a proxy for the average degree days for the entire state. Once degree day calculations were made for each Indian state, the state degree day data were then weighted according to their share of the country population that was covered. The share of country population covered was calculated by summing the populations of the administrative units with at least one data point and dividing by the total country population. Table 2 shows how many locations were used to obtain the average heating and cooling degree days for the country as well as the share of the country population that was included in the weighting.

3. Results

Table 1 shows the top 10 countries for heating and cooling degree days. When interpreting the results, it is important to keep in mind the affect of the population weightings. While other countries not listed in Table 1 may have similar (or more extreme) climates, it may be that major population centers in those countries are located in more temperate areas, thus resulting in fewer HDD or CDD. Table 2 shows the comprehensive results, listing the heating and cooling degree days for each country as well as the number of locations used in the calculation, the percent of the country population covered by the weighting, and the method used to calculate the degree days. "NA" means that no data was available for that particular country.

Table 1. Top 10 HDDs and CDDs by Country

Country	HDD	Country	CDD
1. Mongolia	6681	1. Mali	4064
2. Russian Federation	5235	2. Niger	4033
3. Finland	5212	3. Burkina Faso	3903
4. Iceland	5031	4. Yemen	3868
5. Estonia	4605	5. Kiribati	3798
6. Kazakhstan	4575	6. Oman	3657
7. Norway	4535	7. Panama	3638
8. Canada	4493	8. Gambia	3603
9. Sweden	4375	9. Nauru	3599
10. Belarus	4299	10. Thailand	3567

[3] Examples of "administrative units" include Ontario (Canada), California (U.S.), Uttar Pradesh (India), Nizhnij Novgorod (Russia), Henan (China), and Wales (United Kingdom), Bali (Indonesia).

Table 2. Heating and Cooling Degree Day National Weighted Average

Country	Heating DDs	Cooling DDs	Number of Locations	Percent of Country Covered	Method 1 or Method 2
Afghanistan	2209	1049	3	23.7	2
Albania	1724	683	4	32.4	1
Algeria	1177	1154	23	48.6	1
Angola	42	1510	4	42.0	2
Antigua & Barbuda	NA	NA	NA	NA	NA
Argentina	1059	889	36	99.7	1
Armenia	3282	532	3	49.5	1
Australia	828	839	34	100	1
Austria	3446	173	18	100	1
Azerbaijan	2056	720	2	13.2	1
Bahamas	22	2521	7	93.1	1
Bahrain	NA	NA	NA	NA	NA
Bangladesh	3	2820	14	35.4	2
Barbados	0	3270	1	37.4	1
Belarus	4299	88	17	100	1
Belgium	3009	102	12	77.4	1
Belize	0	2916	2	38.6	2
Benin	1	3532	6	52.5	1
Bhutan	NA	NA	NA	NA	NA
Bolivia	2399	400	3	50.4	1
Bosnia & Herzegovina	2949	261	5	100	1
Botswana	360	1637	4	25.5	1
Brazil	118	2015	43	89.8	1
Brunei	0	3516	1	66.2	1
Bulgaria	2624	430	11	56.2	1
Burkina Faso	1	3903	7	29.6	1
Burundi	0	1953	1	11.7	2
Cambodia	0	3323	5	34.2	2
Cameroon	0	2682	10	67.5	2
Canada	4493	171	121	100	1
Cape Verde	0	2299	3	73.4	2
Central African Republic	0	2560	11	65.6	2
Chad	0	3566	12	82.9	2
Chile	1613	225	12	84.0	1
China	2158	1046	258	97.5	1
Colombia	677	2119	14	59.5	2
Comoros	0	2715	2	95.1	2
Congo	0	2462	9	60.4	2
Congo, Dem. Republic	6	1842	20	93.3	2
Cook Islands	0	2566	6	84	1
Costa Rica	1	1487	4	72.4	2
Côte d'Ivoire	0	2937	16	79.0	2
Croatia	2289	418	8	49.9	1
Cuba	8	2760	4	35.2	1

Table 2. Heating and Cooling Degree Day National Weighted Average

Country	Heating DDs	Cooling DDs	Number of Locations	Percent of Country Covered	Method 1 or Method 2
Cyprus	710	1091	3	76	1
Czech Republic	3569	108	9	67.4	1
Denmark	3621	40	10	70	1
Djibouti	NA	NA	NA	NA	NA
Dominica	NA	NA	NA	NA	NA
Dominican Republic	0	3053	1	31.3	1
Ecuador	751	1343	17	78.9	2
Egypt	400	1836	6	19.9	1
El Salvador	0	2215	2	39.0	2
Equatorial Guinea	NA	NA	NA	NA	NA
Eritrea	557	1230	2	25.6	2
Estonia	4605	38	4	61.4	1
Ethiopia	190	536	9	73.4	2
Fiji	0	2595	4	82	1
Finland	5212	48	21	85.1	1
France	2478	241	69	68.5	1
Gabon	0	2669	10	100	2
Gambia	0	3603	2	34.1	2
Georgia	2216	589	3	38.9	1
Germany	3252	122	85	100	1
Ghana	0	2949	5	63.1	2
Greece	1269	923	13	58.3	1
Grenada	NA	NA	NA	NA	NA
Guatemala	174	839	4	37.5	2
Guinea	0	2674	8	42.4	2
Guinea-Bissau	0	3098	2	24.4	2
Guyana	0	3363	3	63.2	1
Haiti	0	3093	1	35.4	1
Honduras	2	2289	8	56.6	2
Hungary	3057	256	20	80.9	1
Iceland	5031	40	7	94.3	1
India	80	3120	51	93.8	1
Indonesia	0	3545	19	65.8	1
Iran	1813	1037	10	58.2	2
Iraq	744	2444	10	69.3	2
Ireland	2977	19	8	52.5	1
Israel	756	1244	4	44.4	1
Italy	1838	600	38	99.9	1
Jamaica	0	3525	2	28.5	1
Japan	1901	896	84	100	1
Jordan	1173	1122	4	59.4	1
Kazakhstan	4575	481	36	98.1	1
Kenya	91	1265	13	75.3	1
Kiribati	0	3798	1	38.2	1
Korea (North)	3389	493	10	82.6	1

Table 2. Heating and Cooling Degree Day National Weighted Average

Country	Heating DDs	Cooling DDs	Number of Locations	Percent of Country Covered	Method 1 or Method 2
Korea (South)	2480	744	21	96.0	1
Kuwait	322	3166	5	59.9	2
Kyrgyzstan	3161	682	3	45.4	1
Laos	0	2833	4	42.5	2
Latvia	4237	58	4	41.3	1
Lebanon	1117	812	3	23.5	2
Lesotho	NA	NA	NA	NA	NA
Liberia	0	2851	1	3.6	2
Libya	606	1670	9	46.9	1
Lithuania	4218	68	4	66.2	1
Luxembourg	3467	99	1	28.4	1
Macedonia, FYR	2647	430	3	34.9	1
Madagascar	200	1607	8	100	1
Malawi	135	992	5	16.1	2
Malaysia	0	3411	12	54.7	1
Maldives	NA	NA	NA	NA	NA
Mali	2	4064	5	49.5	1
Malta	725	1043	1	29.8	1
Mauritania	4	3525	4	39.2	1
Mauritius	8	2148	1	9.1	1
Mexico	364	1560	45	86.5	1
Moldova	3317	325	3	33.9	1
Mongolia	6681	82	16	80.9	1
Morocco	772	910	16	81.2	1
Mozambique	21	2085	1	6.1	1
Myanmar	0	3180	9	60.1	2
Namibia	450	1242	7	44.8	1
Nauru	0	3599	1	9.4	2
Nepal	762	970	1	11.1	2
Netherlands	3035	68	11	72.4	1
New Zealand	1609	165	12	74.1	1
Nicaragua	0	3250	6	50.4	2
Niger	3	4033	11	100	1
Nigeria	0	3111	12	40.4	2
Niue	0	2463	1	100	2
Norway	4535	43	8	38.7	1
Oman	0	3657	4	58.4	2
Pakistan	831	2810	2	27.1	1
Palau	0	3498	2	68.1	2
Panama	0	3638	1	48.8	1
Papua New Guinea	1	3286	1	7.0	1
Paraguay	239	2197	4	17.0	1
Peru	285	1174	13	67.0	1
Philippines	2	3508	14	87.0	1
Poland	3719	100	26	97.2	1

Table 2. Heating and Cooling Degree Day National Weighted Average

Country	Heating DDs	Cooling DDs	Number of Locations	Percent of Country Covered	Method 1 or Method 2
Portugal	1367	345	11	97.2	1
Qatar	29	3374	1	50.6	2
Romania	3157	290	51	89.9	1
Russian Federation	5235	197	265	84.4	1
Rwanda	NA	NA	NA	NA	NA
Saint Kitts & Nevis	1	3541	1	5.7	1
Saint Lucia	NA	NA	NA	NA	NA
Saint Vincent & Grenadines	NA	NA	NA	NA	NA
Samoa	0	3280	1	39.5	1
Sao Tome & Principe	0	2675	2	42.8	2
Saudi Arabia	311	3136	10	56.9	1
Senegal	1	3379	9	71.6	1
Serbia & Montenegro	2813	334	18	100	1
Seychelles	3	3460	1	3.9	1
Sierra Leone	0	3093	6	100	2
Singapore	0	3261	1	100	2
Slovakia	3498	158	7	78.5	1
Slovenia	3290	189	2	40.7	1
Solomon Islands	0	3093	1	24.8	2
South Africa	630	824	40	100	1
Spain	1431	702	51	91.1	1
Sri Lanka	87	2943	10	43.7	2
Sudan	0	3486	20	73.9	2
Suriname	0	3252	5	68.1	2
Swaziland	NA	NA	NA	NA	NA
Sweden	4375	45	24	87.9	1
Switzerland	3419	137	11	44.9	1
Syria	1388	1187	6	55.3	1
Taiwan	231	2132	18	82.1	1
Tajikistan	2054	1203	8	78.2	1
Tanzania	2	2922	1	7.7	1
Thailand	1	3567	42	63.2	1
Togo	1	3318	2	64.7	1
Tonga	0	2190	5	94.9	2
Trinidad & Tobago	0	3316	2	8.2	1
Tunisia	892	1184	15	62.9	1
Turkey	2048	641	32	64.6	1
Turkmenistan	2218	1235	8	64.3	1
Uganda	0	1458	3	48.6	2
Ukraine	3752	224	38	86.6	1
United Arab Emirates	4	3294	4	90.3	2
United Kingdom	2810	66	21	92.2	1
United States of America	2159	882	384	99.7	1
Uruguay	1019	732	13	70.6	1
Uzbekistan	2251	1144	13	78.1	1

Table 2. Heating and Cooling Degree Day National Weighted Average

Country	Heating DDs	Cooling DDs	Number of Locations	Percent of Country Covered	Method 1 or Method 2
Vanuatu	1	2545	3	38.2	1
Venezuela	1	2381	12	7.3	2
Vietnam	81	3016	4	56.4	1
Yemen	0	3868	1	3.5	2
Zambia	105	1087	11	100	2
Zimbabwe	349	1010	9	64.7	1

Note: This table contains a complete listing of countries included in CAIT.

4. Limitations and Discussion

There are several limitations of the methods and results described above. First, there are inherent limits to the usefulness of heating and cooling degree day indicators. It is not the case that a degree day calculation will capture each and every need for heating or cooling services, in part due to the possibility of extreme high and low temperatures (which can be obscured by daily averages). In addition, other climatic factors, such as humidity and wind, will also influence the demand for heating and cooling services. Overall, degree days should be understood as a reasonable approximation—not an exact measure—of the heating and cooling needs (all other factors held equal) of a particular city, region, or country.

Second, there are limitations with respect to the data coverage. Overall, data coverage was very good for most industrialized countries and many other large countries, such as India, China, Brazil, and Russia. However, in some cases degree day data could not be found for significant population centers. In other cases, the match between population data and temperature data was less than optimal. The extent to which data coverage problems influence the results will depend on the particular characteristics of the country.

For example, the island nation of Nauru arrives at its national degree day average using data from only one location. The percentage of the country covered by this weighting is only 9.4 percent. However, because the total area of the country is only 21.2 sq km, it is likely that climactic conditions across the country show very little variation and thus the national degree day estimates are an accurate representation of Nauru's conditions. However, the national degree day average for Burundi, where climatic conditions might vary with altitude, may not give an entirely accurate picture. The degree day average of Burundi was determined using data from only one location and covers only 11 percent of the total country population. If there are population centers in Burundi that face significantly different climatic conditions than the 11 percent covered, this will influence the results significantly. Table 2 shows the number of degree day-location pairings used to obtain the results for each country. Together with the percentage of the country covered, as well as a general understanding of how climate varies within the country, it is possible to qualitatively assess the relative completeness of the data.

A third limitation of our results is the use of two, rather than a single method, which could adversely affect comparability. To determine the extent of this limitation, we used both methods—one using daily average temperatures and the other using monthly average temperatures—for a few countries (where data permitted). The two methods yield slightly different results. Table 3 shows heating and cooling degree estimates for selected countries using both Method 1 and Method 2 in order to offer a side-by-side comparison of the how results vary based on the method used. The table shows the differences in results in both percentage terms and in degree days. To the extent possible the same locations were used to obtain degree days for each country.

Table 3. Comparison of Heating and Cooling Degree Days for Selected Countries Using Method 1 and Method 2.						
	Heating Degree Days			**Cooling Degree Days**		
	Method 1	Method 2	Difference (%)*	Method 1	Method 2	Difference (%)*
Albania	1724	1780	56 (3.5%)	683	515	-168 (-24.6%)
Armenia	3282	3474	192 (5.9%)	532	432	-100 (-18.8%)
Azerbaijan	2056	2153	97 (4.7%)	720	674	-46 (-6.4%)
Chile	1613	1759	146 (9.1%)	225	86	-139 (-61.8%)
Kenya	91	105	14 (15.4%)	1265	1142	-123 (-9.7%)
Vietnam	81	34	-47 (-58%)	3016	2683	-333 (-11%)
Zimbabwe	349	371	22 (6.3%)	1010	744	-266 (-26.3%)
*Difference is determined by subtracting Method 2 results from Method 1 results. The difference is then divided by Method 1 results to obtain the percent difference.						

Heating degree day estimates using Method 2—with one exception (Vietnam)—are higher than estimates performed using Method 1. Cooling degree day estimates using Method 2 are consistently lower than Method 1. The margins of difference, in most cases, seem to be relatively small, though not insignificant. (Obviously, percentage differences become less meaningless as HDDs and CDDs approach zero.[4]) The differences for Chile (CDD), Zimbabwe (CDD), and Vietnam (HDD) seem particularly significant.

In addition to differences in the methodologies, the differing results might also be partially explained by the different underlying data sources used in each method, which may not have used the same period of record to depict "normal" climatic conditions (e.g., one source may have used 1970 to 1990 for a given location, while another source may have used 1900 to 1990 for that location). In this sense, actual *climate change* may influence the results.

Finally, caution should be exercised when analyzing degree day results in relation to energy use or greenhouse gas emissions. An understanding of other structural factors, energy intensities, and fuels is needed to adequately assess the energy or greenhouse gas implications of heating and cooling degree day indicators presented here. For example, average home sizes, the quality and prevalence of insulation, building design, and other structural factors vary widely from country to country. Energy intensities also differ widely with respect to providing heating and cooling services. Finally, the fuel used—ranging from coal, oil, diesel, gas, wood, hydro and other renewables—will significantly influence the greenhouse gas emission consequences for a given heating or cooling degree day value.

[4] For example, if Method 1 registered "1" HDD and Method 2 registered "2" HDDs. The results would be remarkably close, but Method 2 would be "100 percent" higher.

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