



A global degree days database for energy-related applications

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ABSTRACT

Weather can have a profound effect on energy consumption particularly with respect to hot and cold temperatures, driving residential and commercial energy demand. The cooling and heating degree day methodology has been often regarded as a reliable means to account for this effect for purposes of normalization and econometric analysis. However, when applied within the context of international cross-country comparison, this methodology suffers from two major limitations: the lack of an appropriate international database that encompasses degree days at a functional spatial and temporal aggregation using various reference temperatures, and second, the existing methodologies only account for the effect of temperature and ignore the potential effect of other climatic factors such as humidity and solar radiation.

This paper addresses these issues by presenting a new database of population-weighted degree days for 147 countries for 1948–2013 at various reference temperatures based on multiple thermal comfort indices. The database was mainly developed to compare the influence of weather on energy use across countries. This is important for policy because it defines the playing field for potential intervention to improve energy efficiency and productivity. It also puts countries on equal footing when it comes to participating in international energy and environmental negotiations.

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1. Introduction

The cooling and heating degree days methodology is regarded as a reliable tool for appropriately accounting for the effect of weather on energy demand. Degree days methodologies are commonly used to calculate seasonally adjusted energy consumption in a variety of distinct geographies. These include, among others, Dombayci [1] for Turkey, Arguez et al. [27] for the United States, Badescu et al. [2] for Romania, You et al. [3] for China, Matzarakis [4] for Greece, Al-Hadrami [5] for Saudi Arabia, and Eurostat [6] for selected European countries.

The various databases available in literature are generated under a variety of definitions and methodologies and based on a range of reference temperatures. These are useful for planning energy systems and predicting seasonal load demands, for ironing out weather related variations in energy demand and are also equally used by traders and economist for analyzing competitive market

derived prices. Furthermore, quantifying the relationship between climatic conditions and energy consumption can raise awareness on the effect of climate change on future heating and cooling equipment investments [7]. Moreover, Daioglou et al. [8] use the same degree-days approach to project energy use in developing countries and Kavousian et al. [9] employs an applied approach for analyzing the effect of climate on energy demand with degree-days. In addition, Capeluto and Ochoa [10] implement a simulation-based methodology for assessing climatic energy strategies using degree-days while Trotter et al. [26] applies a degree days in a stochastic approach to forecast the effect of climate change on electricity demand in Brazil. Finally [11], and [12] extended his analysis to include implementation and comparison of several evapotranspiration models.

From a policymaking perspective, accounting for weather effect on energy demand is no longer restricted to domestic narrowly-focused analysis. There is also an emerging international context. Decision makers have increasingly noted the need for benchmarking the performance of their economies and the effect their policies have on other countries. However, the fragmented nature of degree days datasets, their lack of comprehensive coverage, and the variations in definition of weather adjustments make such comparison between countries difficult or even invalid.

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Furthermore, the majority of the calculated datasets only include the effects of temperature. They do not always address the potential effects of humidity and solar radiation, both of which may drive demand for air conditioning and heating.

There are some studies that take a global perspective using country-by-country data. The World Resource Institute (Baumert K. Selman M. [13], for example, used ground-based station temperature data to create a 30-year average of cooling (CDD) and heating degree-days (HDD) for around 90 countries. However, the dataset has not been updated and, for many countries, excludes large proportions of population and land area. Wheeler [14] developed a global population weighed CDD and HDD database using temperature records from 1980 to 2011, gathered from satellite re-analysis data. The dataset, however, is limited by the fixed reference temperature, the spatial and temporal aggregation associated with its analysis and the absence of other relevant climatic factors including humidity. Eurostat [6] provides a monthly HDD index for European Union countries for the period 1980 to 2009, while Benestad [15] generated CDD and HDD estimations and forecasts for 63 European locations from 1900 to 2100. Although these datasets include various countries, they are characterized by different spatial and temporal aggregation levels, and use calculation methodologies that hinder reliable comparisons between countries.

The CMCC¹-KAPSARC² database aims to overcome these limitations, and empower policymakers to make unbiased and comparable evaluations among countries. Its intention is to enable policy makers to account for differences in energy consumption that is simply due to diverging climatic conditions between their own country and another one taken as reference. This allows comparison of normalized data to determine whether residual differences are driven by other factors including structure of economy, efficiency or consumer behavior. Moreover, this dataset is freely available to the public.³

2. Description of the database

The database provides data on population-weighted degree days for 147 countries for the period ranging from 1948 to 2013. An important aspect of its development was to improve on existing degree days methodology, namely limited geographical availability, temporal and spatial aggregation, the lack of accounting for various climatic factors and the restrictive use of a singular reference temperature.

The dataset was created through combination of gridded atmospheric satellite datasets developed by the National Oceanographic Atmospheric Agency (NOAA). Degree days have been computed using datasets obtained from NOAA's National Centers for Environmental Prediction (NCEP/NCAR reanalysis first started by Ref. [16]. The data series employed were actual values and reanalysis of geo-located climate parameters: air temperature at 2 m altitude, relative humidity, solar radiation available at a four times intra-day frequency ranging from 1948 through 2013.

These parameters were used to calculate global thermal comfort indices within grids determined by latitude and longitude at a spatial resolution of $1.8^\circ \times 1.8^\circ$. The value of a decimal degree (1°) of longitude fluctuates between 40 km and 112 km depending on the location distance from the equator. One degree of latitude

remains 112 km regardless of location. Each of the resulting indices was represented on a Gaussian grid of 192 longitudes and 94 latitudes, for 96,428 time values at 6 h intervals.

Computed indices were population-weighted using Columbia University's Gridded Population of the World dataset (GPW v.3) from 1990 to 2013 and extrapolations from UNEP/GRID-Sioux Falls regional datasets for the years ranging from 1948 to 1990. The population-weighting procedure is important in order to avoid over-estimating energy consumption in areas with extreme weather conditions but without resident population. This can be the case of Siberia or the Sahara desert. The resulting indices were subsequently downscaled to an enhanced resolution of $1.6^\circ \times 1.6^\circ$ using statistical regressions and shaped into national boundaries using GIS geo-coding. All the local values of the sub-indices were summed to create annual national indices. Grids overlapping multiple boundaries were split proportionally to the respective surface of each country within the grid. Cooling and heating degree days for each index were calculated by taking the absolute difference between the sub-daily index value and thermal comfort index calculated using the reference climatic factors. These were set to be 60°F , 65°F or 70°F equivalent to 15.6°C , 18.3°C or 21.1°C , respectively.

Different policy-makers may have different preferences to which index to use depending on whether their predominant loads are heating or cooling and whether the demand is concentrated on the coast or inland. The CMCC-KAPSARC dataset can be used in a variety of flexible ways. It includes degree days based on pure temperature readings as well as others derived from thermal comfort indices that are calculated based on additional climatic parameters. The inclusion of these parameters helps convey the actual “feels-like” temperature that is sensed by human bodies and that triggers demand for air conditioning.

The dataset includes degree days based on five thermal indicators which are explained in detail in Appendix 1. These are:

- Temperature (T2m_C measured in $^\circ\text{C}$)
- Temperature (T2m_F measured in $^\circ\text{F}$)
- Heat index (HI, measured in $^\circ\text{F}$)
- Humidex (HUM, measured in $^\circ\text{C}$)
- Environmental Stress Index (ESI, measured in $^\circ\text{C}$)

The first two indices are both temperature-based but with different thermal units, Celsius and Fahrenheit. Celsius degree days cannot be derived from Fahrenheit ones (and vice versa) as the relationship between the two is not linear. Furthermore, having the temperature-based indices in the two units facilitates the ensuing comparison effort with the existing data in the literature and the degree days for thermal comfort indices.

The Heat Index was developed by the U.S. National Oceanographic and Atmospheric Administration (NOAA) in 1978 and later adopted by the USA National Weather Service. It aims at combining the effects of air temperature and relative humidity into a single parameter that provides a measure of the perceived temperature in degrees Fahrenheit. It was empirically derived by Steadman [17] for specific conditions of temperature and relative humidity and later expanded by NOAA's Climate Prediction Center to be defined at all values. Higher values of Heat Index correspond to hotter perceived environmental conditions.

The Humidex is an index developed and frequently used by the Meteorological Service of Canada, first defined by Richardson [18]. It is defined in Celsius and, similar to the Heat Index, aims at deriving a “feels-like” temperature based on the consideration of temperature and relative humidity. As with the Heat Index, higher values of the Humidex reflect hotter perceived conditions.

The last thermal comfort index that we enumerate is the Environmental Stress Index (ESI) which adds the effect of solar radiation

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³ Can be accessed on <http://www.kapsarc.org/en/Documents/KAPSARC-CMCC%20Enhanced%20Degree%20Days%20Database%20March%202015.xlsx>

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