Climate Change and its Effect on Weather Data

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ABSTRACT

This paper analyzes how using weather data from various time periods (several decades' old, present day, and future projections) can impact the estimated energy savings for a variety of energy efficiency measures across the country.

The year 2015 marked the warmest year on Earth since recordkeeping began in 1880 and was the 39th consecutive year that the annual global temperature was above the historical average. Additionally, fifteen of the sixteen hottest years on record have occurred this century, the other occurring in 1998 (NOAA 2015). All of these indicators point to a climate that is changing so rapidly that weather "averages" relying on data several decades old or even several years old, may no longer represent an accurate method of predicting present-day or future weather scenarios. This paper considers:

- How a warming climate will potentially increase energy savings for cooling measures in the summer and decrease savings for heating measures in the winter. It also analyzes how some of these cooling and heating changes can offset each other depending on the location.
- How updating weather assumptions in engineering algorithms can significantly influence claimed savings. For certain areas of the country, we found that using more recent weather data for certain measures rather than data that are several decades old can impact claimed savings by more than 20%.

Introduction

Each year, we are reminded that climate change is happening before our eyes. No longer is climate change a prediction for the future, but it is rather a reality of the current state of our planet. The year 2015 not only marked the hottest year on record, but also the largest *margin* by which a temperature record was broken. Figure 1 depicts the global average temperature across land and ocean surface since 1970 compared with the 20th century average of 57°F (Rice 2016). These data clearly demonstrate a warming trend for the past several decades that shows no sign of reverting back to 20th century average temperatures.

Decisions on whether energy efficiency programs are ultimately deemed to be cost-effective, continued, or eliminated can be driven by the data used to estimate savings. Temperature data play an important role across the energy efficiency industry because program planners, implementers, and evaluators use it to predict and verify the amount of energy a particular project saves in a single year or over the course of its lifetime. Because weather varies by location, an efficient chiller installed in New York will save a different amount of energy than the same chiller installed in Arizona due to differences in cooling degree days (CDD). Regardless of the location, the projected energy savings for that same chiller relying on 20th century average CDD data, will produce different savings than relying on more recent CDD data. The following sections analyze these concepts in more detail.
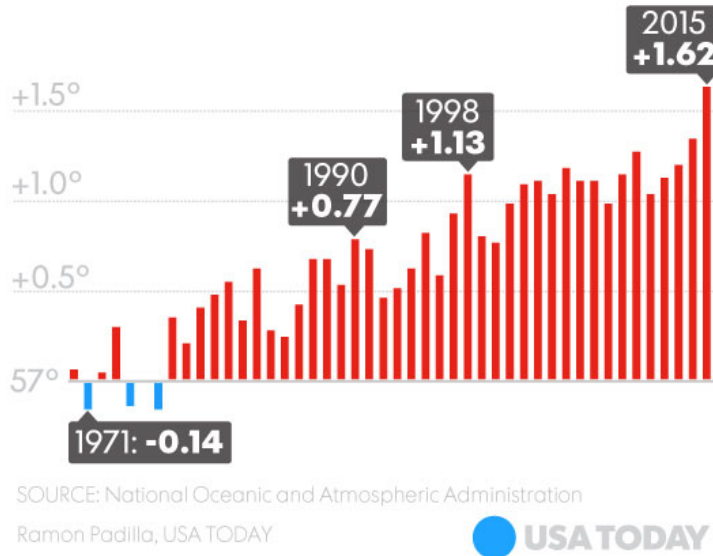
Figure 1. Average global temperature compared to 20th century average (1970-2015)

How We Use Weather Data

Weather data is used across many applications ranging from determining loads for heating and cooling system design to estimating energy savings from installing a new piece of equipment. We use weather data to predict energy use during specific seasons, years, or the lifetime of equipment.

A utility located in southern climates with large CDD requirements may be more inclined to incent cooling measures across their portfolio whereas programs located in colder northern climates with large heating degree day (HDD) requirements may be more inclined to incent measures that influence space heating. Incentive programs are designed such that the measures offered within the program achieve the optimal return on investment for their rate payers, and weather data plays a key role in determining those outcomes.

A program manager or implementer may rely on "average" weather data for a specific location to predict how much energy a given measure will save for their location. After a measure is installed, an evaluator will typically use actual weather data for that location to assess the actual energy savings achieved by the specific measure. If there are differences between the weather data assumed by a utility and the actual measured weather data for that year, a program may achieve different savings than expected. If the climate continues to warm as seen in Figure 1, cooling measures may achieve larger than anticipated savings. Conversely, heating measures may achieve lower than expected savings once actual weather is factored into savings estimates. Furthermore, trying to predict the amount of energy a specific measure will save 10, 15 or 20 years in the future is difficult with a rapidly changing climate, and results will vary depending on

the type of weather data used. In addition, the decisions on what weather data to use will influence the anticipated cost-effectiveness of entire programs and resulting investment decisions.

Types of Weather Data

Heating and Cooling Degree Days

As previously discussed, many energy industry professionals rely on cooling degree day and heating degree day assumptions when estimating the cooling or heating requirements of a piece of equipment, respectively. Most Technical Reference Manuals (TRM) reference assumed CDD and HDD values for locations within their territory. While CDD and HDD data are decent indicators of the typical cooling and heating requirements needed, it is important to ensure we use the most recent data available, or even use projected data to accurately predict and evaluate energy savings. Below we compare a range of outcomes using CDD and HDD data that are several decades old with more recent data and how these decisions influence claimed savings.

Typical Meteorological Year

In the absence of metering, many current methods for modeling energy and demand savings for large projects rely on average weather data over a specific time period for a given location. One example is the use of Typical Meteorological Year (TMY) data in energy models. TMY data are a collection of weather data from localized weather stations spanning multiple years. A TMY represents one year of data that pulls individual months of weather data from different years within the available range. The most recent TMY data available (TMY3) uses weather data collected from 1,020 locations between 1976 and 2005. The intent of a TMY is to present the range of possible weather data while still providing averages for a localized weather station. However, 7 out of the 10 hottest years on record have occurred since TMY3 data became available; therefore, it may no longer represent an accurate proxy for estimating present or future weather scenarios (NOAA 2015). In addition, some programs still use TMY2 data which is taken from the years 1961-1990 and results in less accurate savings estimates than applying TMY3 data.

U.S. Climate Normals

U.S. Climate Normals are the National Climatic Data Center's (NCDC) archive of three-decade averages of weather data including temperatures and precipitation (NOAA 1981-2010). Similar to TMY data, Climate Normals span several years to estimate averages for a single weather station. The latest Climate Normals data are from 1981-2010 and cover over 9,800 weather stations across the United States. While the data are updated every 10 years to reflect the most recent 30-year averages, it again may fall short of predicting actual weather patterns for more recent years. For example, three of the four hottest years on record (i.e., 2015, 2014, 2013) fall outside the 30-year average data and 2016 is already on track to break those records (LePage 2016). While 30-year average data has many uses, the climate is changing so rapidly that even data that are 10 years old are no longer an accurate representation of current or future weather scenarios.

Updating Weather Data Averages with More Recent Data

Energy professionals typically rely on weather data that are several years old or even several decades old for analyzing the impacts of proposed efficiency measures and for deciding which measures will achieve the greatest return on investment. However, a warming climate causes us to revisit the traditional method of using average weather data and consider using more recent data. One method that we can use to more accurately estimate energy savings is to use averages from more recent years or from the actual year that the change occurred.

Below, we analyzed CDD and HDD data for seven cities across the United States. We selected these cities based on their location in an attempt to capture variations across the country. We ran several comparisons of CDD and HDD data dating back to 1980 for these cities. We chose to start with 1980 because the data was available for all seven cities starting in 1980, it allows us to compare several decades of data, and several TRMs use weather data from similar time periods. The National Oceanic Atmospheric Administration (NOAA Climate) provides annual CDD and HDD (base 65°F) through 2014 with partial data for 2015 so our comparisons include data only through 2014. However, as noted above, 2015 was the hottest year on record so some of the trends below may be more pronounced had we included 2015 data.

Table 1 compares the average CDD and HDD for the seven selected cities from the time period 1980-2010, with the average CDD and HDD from 2011-2014 for the same locations. As seen in Table 1, all seven cities showed at least a 7% increase in average CDD from 2011-2014 compared with the average from 1980-2010. Conversely, five of the seven cities showed at least a 4% decrease in HDD over the same time period with two cities (Chicago and Indianapolis) showing a 2% and 0% decrease in HDD, respectively. As one would expect in a warming climate, these data show an increase in the required CDD and a decrease in the required HDD. We sorted the cities in Table 1 based on percent increase in CDD.

Table 1. Average CDD and HDD comparisons across different time periods

City	Cooling Degree Days			Heating Degree Days		
	1980-2010 Average	2011-2014 Average	% Increase	1980-2010 Average	2011-2014 Average	% Increase
San Francisco, CA	172	216	20%	2,616	2,440	-7%
Chicago, IL	865	1,023	15%	6,325	6,208	-2%
Indianapolis, IN	1,119	1,261	11%	5,321	5,304	0%
Boston, MA	802	900	11%	5,560	5,279	-5%
Las Vegas. NV	3,432	3,827	10%	2,049	1,723	-19%
Charleston, SC	2,417	2,598	7%	1,909	1,746	-9%
New York City, NY	1,277	1,370	7%	4,555	4,388	-4%

In addition to analyzing average CDD and HDD across certain time periods, we also identified the minimum and maximum CDD and HDD for these cities over the total analyzed time period (1980-2014). With a warming world, we would expect the maximum annual CDD and minimum HDD to be in the more recent years, with the minimum CDD and maximum HDD occurring further back in the datasets, before the most recent warming. This general trend was exactly what we found for these seven cities with the exception of a few outliers, as seen in Table 2.

Table 2. Maximum and Minimum CDD and HDD from 1980-2014

City	Max CDD		Min HDD		Min CDD		Max HDD	
	Value	Year	Value	Year	Value	Year	Value	Year
San Francisco, CA	497	2014	1,477	2014	42	1986	3,300	1982
Chicago, IL	1,324	2012	5,065	2012	457	1992	7,119	1985
Indianapolis, IN	1,619	2010	4,399	2012	726	1992	6,238	2014
Boston, MA	1,162	1983	4,754	2012	583	2000	6,057	1980
Las Vegas. NV	4,075	2007	1,306	2014	2,708	1982	2,554	1982
Charleston, SC	2,841	1990	1,184	1990	2,024	1997	2,475	1981
New York City, NY	1,721	2010	3,677	2006	877	1982	5,213	1980

ASHRAE published results of a similar study in the 2013 ASHRAE Fundamentals Handbook (ASHRAE 2013). According to the analysis described in ASHRAE (Thevenard 2009), the study analyzed 1,274 observing sites worldwide with complete data from 1977 to 2006 and compared the periods between 1977-1986 and 1997-2006. The results averaged across all locations in the study found:

- Cooling degree days increased by 245 °F days (base 50 °F)
- Heating degree days decreased by 427 °F days (base 65 °F)
- Annual dry-bulb temperature increased by 2.74 °F

The ASHRAE handbook suggests that some of the changes could be due to increased urbanization near weather-stations, but regardless of the reasons for these increases, the trends support a warming climate that we must account for in our savings estimates.

Impacts of Weather Choices

As shown in Table 1, San Francisco's average CDD from 1980-2010 was 172, while the average for 2011-2014 was 216 or 20% higher. The primary reason for that increase in CDD was due to 2014, which recorded 497 CDD, nearly three times the average from 1980-2014. HDD decreased in San Francisco by 7% when comparing the same time periods, with the minimum HDD value also occurring in 2014. If a program relied on average weather data for a measure installed in 2014 rather than actual 2014 weather data, they would have erroneously estimated energy savings.

In locations such as San Francisco, where there are relatively few CDD compared with HDD, a decrease in HDD may offset any increase in CDD and actually reduce the overall savings claimed for a specific measure or program. For example, estimating savings for a single-family home for an air sealing measure in San Francisco resulted in the savings shown in Figure 2. The figure presents cooling, heating, and total savings for residential air sealing based on three weather scenarios (1980-2010 average, 2011-2014 average, and 2014 actual)[1]. As seen in Figure 2, using more recent CDD and HDD data actually resulted in an overall decrease in claimed savings, even though the cooling savings increased significantly. This is due to the large

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[1] Assumes homes with central air conditioning. To estimate heating savings, we applied a weighted average of gas and electric heating types based on the Residential Energy Consumption Survey (RECs) 2009 data for California (EIA 2009).

influence of heating savings compared to the cooling savings. The decrease in HDD was more than enough to offset the increase in CDD in 2014 for this specific example.
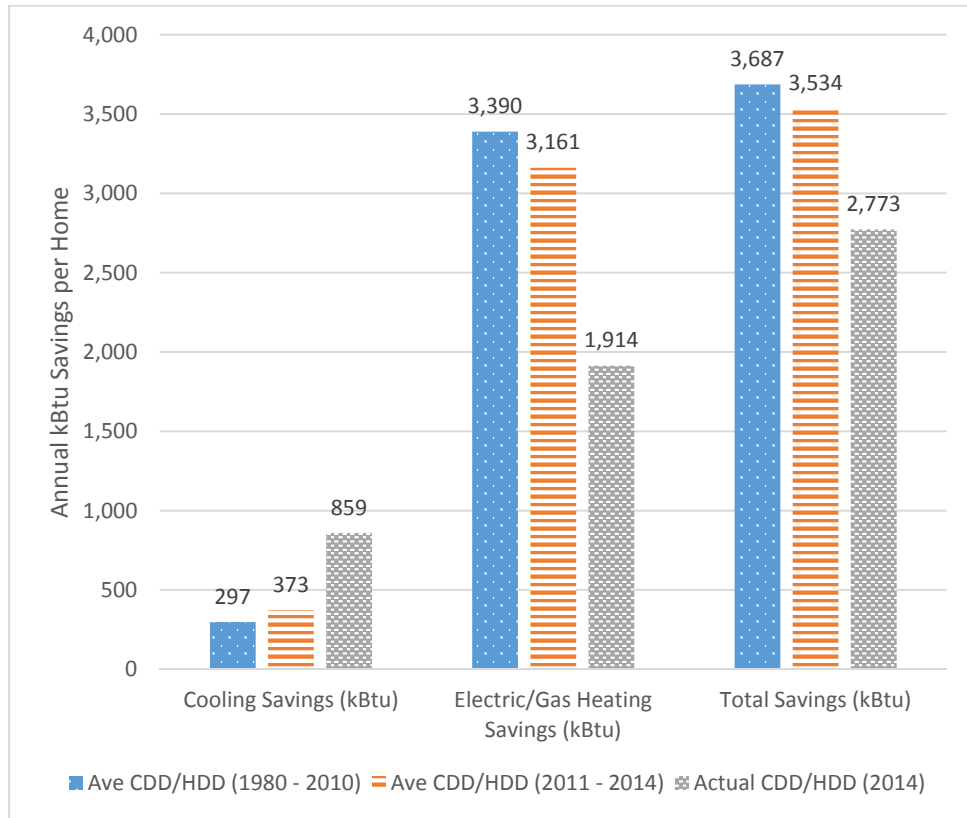

Figure 2. Example annual energy (kBtu) savings for a residential air sealing measure in San Francisco, CA

For a climate that is predominately cooled, rather than heated, any variation in heating savings due to a change in HDD may not be enough to offset a similar change in cooling savings. Figure 3 shows this trend for Charleston, SC, which is one such example. Similar to Figure 2, Figure 3 presents cooling, heating, and total electric savings for residential air sealing using three weather scenarios (1980-2010 average, 2011-2014 average, and 2014 only).[2]

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[2] Assumes homes with central air conditioning. To estimate heating savings, we applied a weighted average of gas and electric heating types based on the Residential Energy Consumption Survey (RECs) 2009 data for South Carolina (EIA 2009).

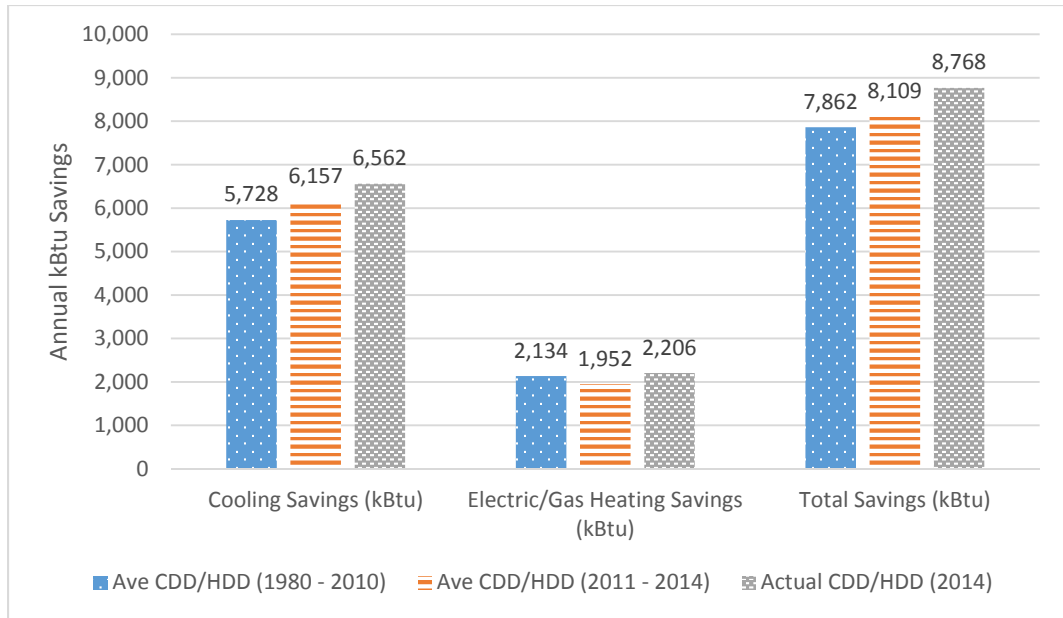**©2016 ACEEE Summer Study on Energy Efficiency in Buildings**

Figure 3. Example annual energy (kBtu) savings for a residential air sealing measure in Charleston, SC

The figures illustrate that it is no longer accurate to use average CDD and HDD that are several decades old due to the general trend of increasing numbers of CDD and decreasing numbers of HDD for cities across the country. As seen in the above figures, climate change and the use of more recent weather data will impact various regions of the country differently. Locations that have relatively high HDD requirements compared with CDD may see a decrease in overall energy savings for certain programs in a warming world. Locations with large CDD requirements may see increases to overall savings depending on the measures. In addition, the mix of heating fuels (e.g., gas vs. electric) across customer segments and the prevalence of air conditioning will directly affect the savings as CDD and HDD requirements shift. We need to analyze programs on a custom basis and take into account how climate change is impacting an individual mix of customers at a local level.

Future Projections

In addition to using more recent data to estimate energy savings, we can also create simple regression models or use software programs to attempt to predict future weather scenarios. While future projections or modeling introduce additional uncertainty to energy savings estimates, they represent a method we can use to try and estimate future energy savings and are likely more accurate than using weather data based on previous averages.

In Figure 4, we trended the CDD for Las Vegas, NV from 1980-2014. The data clearly show an upward trend, which can be graphed as a simple regression equation to predict potential future increases beyond the available data[3]. If a utility wanted to predict energy savings for a specific measure 5 or 10 years into the future, they could consider using a simple regression analysis similar to Figure 4 to predict future CDD or HDD requirements for their jurisdiction.

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[3] We show the R^2 value in Figure 4, but acknowledge that the R^2 value (0.6) is not a great fit for this particular trend line. However, this method may still produce more accurate results for future weather scenarios than relying on average data from previous decades.

Continuing to apply average values for a location such as Las Vegas would provide erroneous savings estimates as the CDD do not show averages, but rather an upward trend.
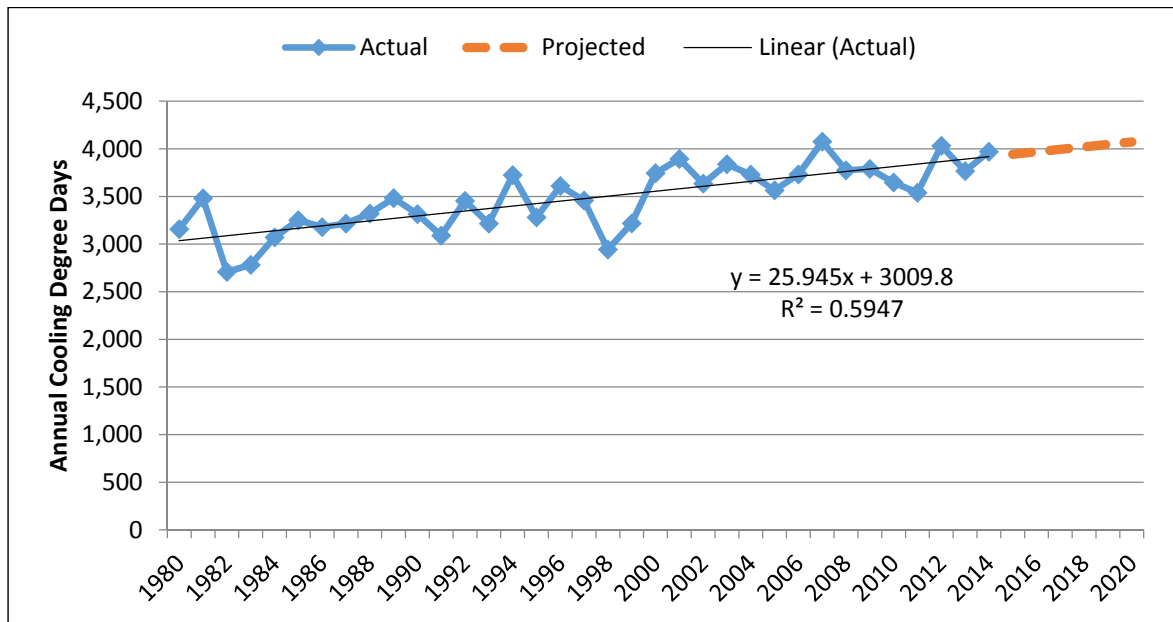

Figure 4. Actual and projected annual cooling degree days for Las Vegas, NV (1980-2020)

In addition to simple regression models, there are also several software programs available today that have the ability to transform average (e.g., TMY) weather data files into future weather scenarios. While some software programs are available for purchase, one free option is the Climate Change World Weather File Generator (CCWorldWeatherGen). This tool allows users to generate climate change files for locations around the world for use in building energy modeling software. The tool bases future weather scenarios from the Intergovernmental Panel on Climate Change (IPCC) Third Assessment Report summary data. It allows users to take any available TMY dataset for a given city and transform the data file into a 2020, 2050, or even 2080 prediction. While there are obvious limitations and various levels of uncertainty with any modeling software, the information leveraged from this type of analysis can provide building owners, developers, or program planners with additional information to better understand where the future climate for their area may be headed.

Impacts of Projected Data

Below we compare energy savings for a large chiller using traditional TMY data averages, present day weather, and future projections using the CCWorldWeatherGen tool.[4] Figure 5 compares the savings for installing a large chiller project in a commercial building in both Charleston, SC and Chicago, IL[5]. As seen in Figure 5, and the individual trend lines, the savings for these types of projects are projected to continue increasing in the future, mainly due

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[4] To project future weather data, this paper only analyzed this one software program as it is free for public use. We note however that it is just one of several that are available for performing future weather projections and other programs may provide slightly different results.

[5] We adjust only weather data in Figure 5. All chiller parameters including tonnage, efficiency, loading, and other operating conditions remain constant across the various projections.

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to a warmer climate which will result in increased CDD requirements at both locations. We include the TMY3 and 2015 actual values in the figure for a comparison to the projected data.

While we cannot accurately predict savings in 2020 or 2050 with certainty, it does give us an idea of how savings may be impacted in the future by climate change. By comparing the two actual data sets (TMY3 and 2015), we can see that simply using different datasets can have a large influence on the claimed savings as evidenced throughout this paper. If a program in Chicago used TMY3 data rather than actual data for 2015, they would have under claimed savings for this project by more than 30,000 kWh (12%). For Charleston, a similar project installed in 2015 that relied on TMY3 data could have achieved an additional 27,000 kWh (6%) simply by using actual 2015 data. Combining the energy savings based on actual weather data and projected data in the same figure allows us to more closely understand the sensitivity of energy savings measures that rely on weather data for energy savings estimates.
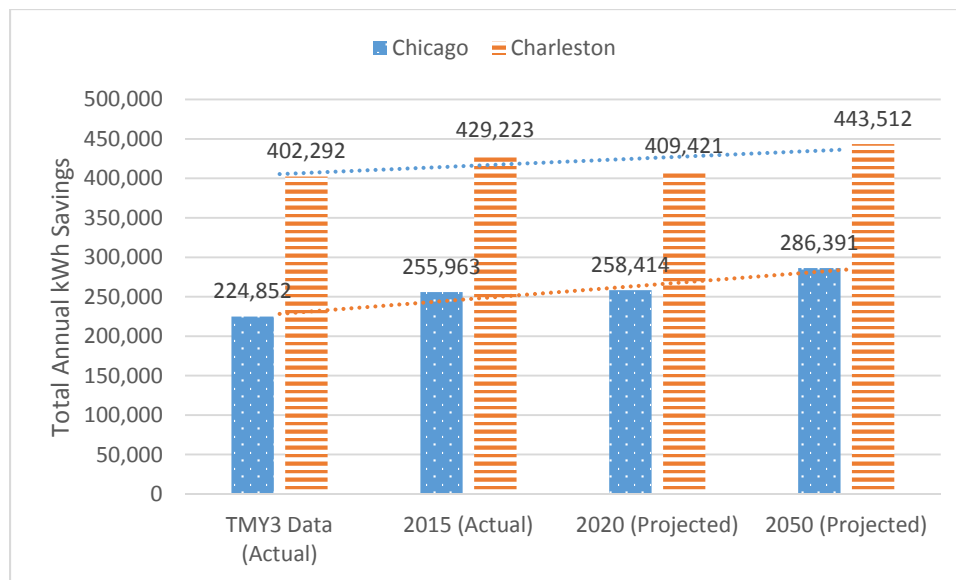

Figure 5. Energy savings comparison for a chiller in a commercial building using various weather data sets

Future Climate Outlook

There are no shortage of predictions for where our climate will go from here. Future predictions range from no increase in temperatures to an increase of several degrees Fahrenheit depending on the location. Figure 6 shows CO_2 concentrations in the atmosphere and global temperature for the past 800,000 years (Woodroof 2013). The most recent 2,000 years are just a small part of the graph, but the latest increase in CO_2 concentrations is clearly out of proportion with any other point during the previous 800,000 years of Earth's history. Assuming temperatures directly correlate to CO_2 as evident in Figure 6, we can expect continued, if not more dramatic warming in our immediate future.
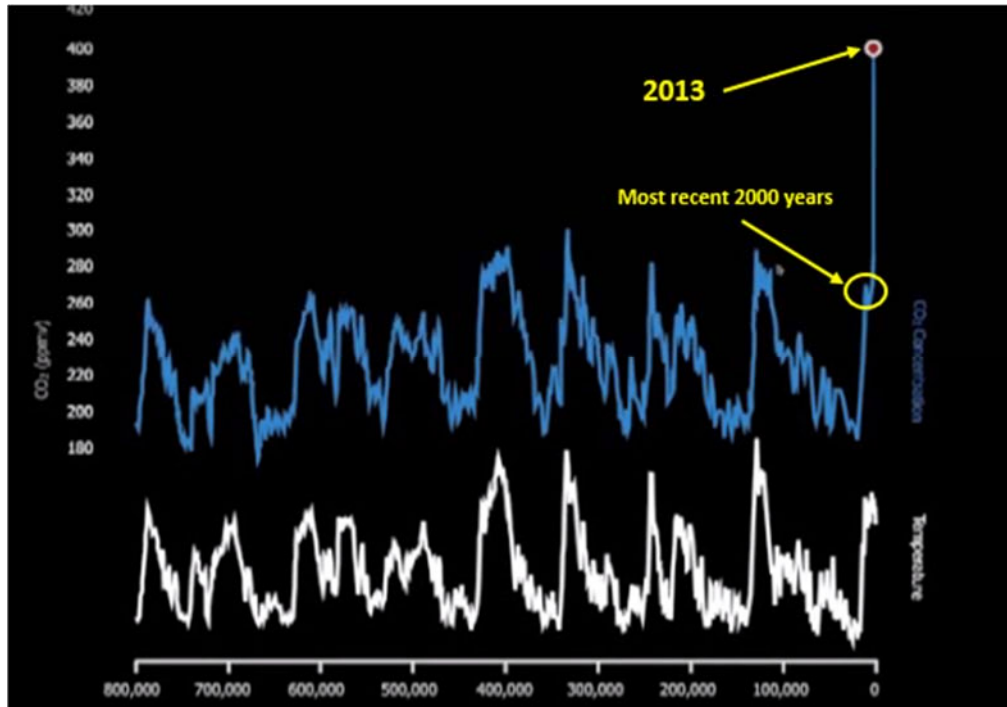
Figure 6. Global CO_2 and temperature data for past 800,000 years

Conclusion

As the climate continues to change, we need to ensure we use the most recent data and latest methods for estimating energy savings for energy conservation measures. Using the latest weather data allows for more accurate savings estimates, but also, it may push programs to incent a different menu of measures to achieve the greatest return on investment. As shown above, the decision around which weather data to use when estimating savings can influence savings significantly. If temperatures continue to rise, programs may place a greater emphasis on peak demand reduction or demand response programs to offset the increase in temperatures that may strain system capacity during peak periods. All of these considerations will need to be accounted for in a warming world.

While this paper only focused on a select number of cities, it is clear that a changing climate impacts each city or utility differently. A warming climate may offset increased cooling savings with decreased heating savings for a specific residential measure in San Francisco, but this likely would not be the case in warmer southern climates. Each program needs to analyze and address these types of questions on a measure-by-measure and location-specific basis. There is no one-size-fits-all approach that can be applied to all programs across the country. Moving forward, we need to use as close to real-time data as possible to ensure we are accounting for a changing climate as it continues to unfold before us.

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