

Bridging the Gap: How Updated Weather Datasets Improve Energy Efficiency Modeling

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ABSTRACT

So-called “typical” weather datasets play an important role in modeling energy impacts of efficiency projects installed at commercial facilities. Traditional datasets such as the third version of the Typical Meteorological Year (TMY3) are widely used. However, due to their reliance on dated weather data, they no longer accurately reflect current weather conditions today. This discrepancy leads to meaningful underestimations of cooling loads and overestimations of heating loads in energy models, which poses an issue as program goals shift towards electrification via heat pumps. Using outdated weather references that over-estimate increases in electric energy consumption and decreases in fossil fuel consumption distorts the impacts of replacing fossil fuel heating systems with heat pumps.

In this paper, we report on an evaluation study, conducted to review current weather normalization methods used in both residential and commercial programs, which swiftly pivoted to identify existing weather datasets that provide a more up-to-date representation of typical weather conditions in the face of anthropogenic climate change. The study ultimately focused on comparing the TMY3 dataset, which uses weather data recorded between 1976-2005, to other potential datasets - notably the TMYx dataset, which uses weather data recorded between 2007-2021. Our research methodology included a comprehensive analysis of existing weather normalization practices, comparing the accuracy and reliability of different typical weather datasets, and calculating the differences in energy model outputs when using TMY3 versus TMYx. The subject study identified a more accurate weather dataset and proposed the steps necessary for its adoption across commercial programs. The study group’s efforts revealed that most North American jurisdictions predominantly use four typical weather datasets, with TMY3 being the most utilized. However, TMYx emerged as a superior alternative due to its use of more recent weather data.

The study demonstrated that TMYx, generated using the same methodology as TMY3, but with updated data, provides a more accurate characterization of current climate conditions. A key outcome of the study was the recommendation to adopt the TMYx dataset. Approximately one year after its introduction, program sponsors mandated the use of TMYx.

Introduction

The predictive power of a model is often limited by simplified assumptions and how well they map to (a typically uncertain) reality. Models for estimating the impacts of energy efficiency improvements are built atop assumptions about future weather, a *famously* difficult phenomenon to accurately predict. But predict we must; The highest efficiency air conditioning (AC) system offers no meaningful benefit if the world is suddenly plunged into a new ice age – its utility and marginal benefit critically depend on how often it is called into service over the course of its life. To assess its value proposition, we must be able to form accurate estimates of the need it will satisfy.

Weather data is available in copious supply – but only for *past* weather. If one has reason to believe that weather systems' behavior is changing over time, the value of past data declines. The United States "Typical Meteorological Year," or TMY for short, was first developed by Sandia Labs in 1978 and drew upon 23 years of weather data from 248 locations, as well as solar radiation data from the SOLMET/ERSATZ database. NREL undertook a redux of the effort – TMY2 - in 1994, with a subsequent 15-year update in 2007.

As of 2021, the volume of generated weather data has picked up considerably. The advent of open source data systems, data collected by low Earth orbit satellites, a proliferation of weather reporting stations (ASOS/AWOS), and development of an ISO standard around TMY methodologies haven given rise to TMYx – a series of TMY datasets with global coverage (249 countries, 17,300+ reporting stations as of 2024), updated on an approximately 2-year cadence with a 15-year retrospective span (Lawrie and Crawley 2022).

Beginning in 2021, Massachusetts' electric and natural gas utilities and energy efficiency service providers including Berkshire Gas, Cape Light Compact, Eversource, Liberty, National Grid, and Unitil (collectively, the Mass Save® Sponsors) investigated alternatives to TMY3 that would be more representative of a world as impacted by climate change, but in the same format as existing TMY datasets to keep adoption costs as low as possible. TMYx emerged as the dominant choice to succeed TMY3.

Background

TMY data consists of hourly datapoints for the whole of a theoretical year. It is valued as a consistently agreed upon benchmark. TMY3, the present industry standard version of this tool, was developed to make best use of all available data in an age of exponential growth in information density. With numerous datasets to draw from, the developers of TMY3 selected its sources with the goal of maximizing the number of stations whose reports were drawn upon (1,020 – just over four times the count of its predecessors) and the number of years for which these data were recorded (30, as with TMY2). Wilcox and Marion (2008, p.2) explain the objective behind those decisions as being focused on less spread between the dataset and the long-run character of observed weather; in other words, TMY3 is optimized for statistical precision.

What's "Typical" About The TMY?

TMY describes the methodology that gave rise to these datasets. The 'Typical' year this method produces is a thought experiment – the year does not exist in the data (as a year, anyway) and likely has never actually happened. Instead, each month of the TMY is selected from the available historical data, based upon several criteria. Thus, the 'Typical' January *did* happen, as did the 'Typical' February – but they did not necessarily happen sequentially in real life as they do in the final dataset. The following judging criteria are used: horizontal radiation, direct normal radiation, dry bulb temperature, dew point temperature, and wind speed. These factors were important to two use cases that prompted development of the TMY: solar energy and building performance (Ibid).

The final product is not median, nor mean, nor mode – but attempts to achieve a similar effect: an estimate of central tendency. Specifically, the month used in any TMY model is chosen to minimize

As such, TMY3 performs admirably in describing temperature, precipitation, and other key variables that inform building performance models as the past thirty years have delivered these variables. Weather is a surprisingly stable system on a year-by-year basis – or at least it had been.

The New Normal: Enter The “Hockey Stick.”

Between 1850 and 1925, global temperature tracked closely to its historical trajectory. When exactly the true discontinuity begins is a subjective matter – but shortly after 1950 observed temperatures depart sharply to the upside of historic trends– never to return (IPCC 2023, 2021). The fact of climate change means historical weather data is a *trailing indicator* (D’Agostino et al. 2021; Crawley & Lawrie 2021; 2015).

So long as the trend continues to curve upwards, history becomes an increasingly poor source of predictive data. The further back one reaches, the worse those data are for one’s current needs. This creates a tension between a key aspect of TMY3’s strategy: the use of large datasets, especially “as many years as possible,” to reduce statistical noise, and its intended purpose (to inform prospective estimates of benchmark weather). This tension places precision at odds with accuracy, and TMYx has the potential to address this tension.

The Data Needs of Mass Save.

Mass Save is the brand name for a comprehensive set of programs, administered by Eversource and the other Sponsors within each of their own service territories. The energy efficiency experts responsible for administering both commercial and industrial (C&I) and residential offerings require weather data to accurately estimate energy usage and weather dependent savings for efficiency projects they support. TMY is a meaningful proxy for true, site-specific, historical data that ensures consistent and equal treatment of similarly situated customers. Simulation software such as EnergyPlus or eQUEST use TMY3 data as input assumptions for weather states that impact a structure’s energy use.

As of 2023, TMY3 data reflect a weather reality that is now 18 to 47 years in the past. Recognizing that weather patterns change over time – particularly in response to anthropogenic climate change – Massachusetts stakeholders concluded that a need existed for an up-to-date TMY.

To serve as a suitable replacement for TMY3, the alternative dataset would need to meet several key criteria that TMY3 satisfied: (1) it had to provide at least hourly data to ensure compatibility with existing modeling tools; (2) it needed to offer sufficient spatial resolution to support geographically differentiated estimates; (3) the data had to be reliable; (4) it needed to come from a credible source; and (5) it had to be cost-effective, given the Sponsor’s fiduciary responsibility to ratepayers.

Methodology

At the inception of the subject study (MA22C04), its working group was tasked with: (1) Reviewing existing weather normalization approaches; (2) identifying best practices for generating a typical weather dataset; (3) generating a new dataset conforming to the needs outlined above and those best practices; and (4) recommending a process for updating that dataset going forward. Very early in this process, the study working group elected to change course and proceeded to explore TMYx as a drop-in replacement for TMY3 – rather than develop a new process.

To understand the needs of the Sponsors’ personnel, a working group was created consisting of personnel, the evaluation consulting team, and members of the Energy Efficiency Advisory Committee (the quasi-regulatory body tasked with oversight of the Mass Save programs). The working group’s efforts were supported by a broad literature search to establish a background.

The working group met three times to discuss the identified candidate approaches, each session lasting roughly one hour. Discussion topics for each session are presented in Table 1, below.

Table 1. MA22C04 Working Group meeting schedule

Session	Topics
5/13/2022	<ul style="list-style-type: none"> • MA residential weather normalization approaches • Recent approach by a comparable out-of-state utility • Climate change as a factor • Benefit-Cost and policy considerations
10/7/2022	<ul style="list-style-type: none"> • Review of methods used in various states • TMYx dataset and implications of use • Future climate models and implications of use • Preliminary recommendation for updated TMY dataset for Massachusetts • DECISION: Advance TMYx as recommended approach.
12/2/2022	<ul style="list-style-type: none"> • Review of current definitions of peak periods • Review TMYx impact on peak periods • Final recommendations

Weather-driven energy demand is dominated by the need for heating and cooling services. The ‘Degree Day’ is the standard unit of measure – reflective of a period of 24 hours where the outdoor air temperature deviated from a reference temperature – and thus can be assumed to have required correction by the building’s HVAC, to maintain comfort. Typically, the reference temperature is 65°F (18.33°C).

More extreme variances in temperature require more power to correct – so models build estimates of the demand for heating and cooling load based on provided inputs of assumed envelope efficiency, ventilation rates, and other relatively knowable values.

To assess the potential consequences of the working group’s decision to select TMYx as the replacement for TMY3, we take the additional step in this paper of comparing the TMYx dataset, along with the other candidate datasets explored by the working group, against the actual recorded weather data for the three-year period of 2022, 2023, and 2024. We make these comparisons for two weather stations: Boston Logan International Airport (KBOS) and Worcester Regional Airport (KORH).

Findings

The TMYx forecast generally outperforms among the group of replacement candidates for the observed three-year period of actual weather data from 2022-2024 (see Table 2 below). While its outperformance of TMY3 is considerable, it does not substantially best the current Massachusetts residential methodology in terms of predictive accuracy – though it certainly does so in terms of costs.

Candidate TMY3 Successor Datasets and/or Methodologies Considered by the Working Group

The working group considered three alternatives to the TMY3: localized approaches, TMYx, and IPCC Representative Concentration of Pathway.

Massachusetts' residential energy optimization weather methodology (MARES).

As was the case in several state programs at the time, residential energy efficiency projects were relying upon a bespoke methodology in lieu of TMY3 (Guidehouse Inc. 2021, 11). The nearest weather station, by ZIPCODE, to a given site was identified as the source for data. That weather station's average *daily* data was then queried to arrive at the number of heating degree days (HDD) and cooling degree days (CDD). Several regression models were produced and the "highest R-squared that did not have negative coefficient estimates" model was selected and then applied to a "15-year normal weather year." This model year was constructed from the median estimated daily consumption for the site, among the months from the prior 15-year period.

The working group identified several benefits of this approach including the potential for flexibility based on geography, population of interest, and end use of interest. Each study producing a dataset by this method adapted the methodology to meet the specific needs for that study. Tellingly, this methodology (as ran in 2021 for Worcester, MA) selected only two months prior to 2010, and five of the twelve months selected occurred after March 2015 – thereby falling into the most recent third of the observed time frame – an indicator that recent data were more 'typical.'

As a bespoke solution, however, this approach produces analyses that cannot be compared to similar efforts that rely on TMY3 – or indeed even other instances of having used this approach because no two instances are the same. This approach is also computationally expensive, comparatively.

TMYx.

TMYx is produced by Climate.OneBuilding¹, a volunteer project of Linda Lawrie and Drury Crawley – significant contributors to the production of the NREL-maintained EnergyPlus software package. TMYx conforms to the 2021 ASHRAE Handbook and ISO standards for TMY.

TMYx benefits from the march of technology. For example, rather than calculate estimates of solar radiation based on ground measurements, satellite network density is sufficient to take those measures from low Earth orbit. The proliferation of automated weather stations (ASOS/AWOS) (especially those in service to airports of small size) allows collection of data from over 17,000 locations worldwide – fifteen within Massachusetts itself. These data can be gathered with comparative ease and the broader use case means computing resources are trivially affordable to produce TMYx datasets on a two-to-three year cadence. The result is still a trailing indicator – but one with a greatly reduced lag time.

TMYx has ease of use benefits over its competitors, particularly for those using TMY3 already – and especially those using EnergyPlus (such as the Mass Save Sponsors and evaluators) as TMYx was developed by EnergyPlus developers. It is an open-source product, available at no cost, and requires minimal effort to adapt. It conforms to industry standards, allowing comparability across jurisdictions and lending credibility. It is also updated on a cadence that roughly matches the three-year planning cycle used by the program administrators.

TMYx is not, however, without its limitations. As the product of two volunteers, TMYx introduces a form of Key Personnel risk. Should either contributor stop updating the dataset, TMYx would rapidly descend into obsolescence as have prior TMYs. There are also particulars of how evaluators of the Mass Save programs apply the TMY that still require some effort and regular re-calculation due to TMYx's more frequent update interval.

¹ <https://climate.onebuilding.org/>

IPCC representative concentration pathway (RCP) projections.

The working group considered forecasts produced by the Intergovernmental Panel on Climate Change (IPCC) as a means to escape the retrospective nature of weather data. On an approximately six-year cadence, the IPCC produces Assessment Reports (AR6 is the current edition) which develops projections of global temperature performance as far out as the year 2100 – known as Representative Concentration Pathways (RCPs). Several RCPs are available, based on various scenarios of greenhouse gas emission reduction levels. The working group, due to the uncertainty of forward-looking projections and lack of clarity for which future scenario should be selected, decided against selecting an RCP as a replacement for TMY3.

Comparative predictive accuracy of candidate alternatives.

Two candidates were meaningfully comparable as they result in hourly values for relevant weather criteria and thus advanced by the study working group: TMYx and the existing methodology used for residential projects.

Prima facie differences between datasets.

Figure 1 (Boston Logan International Airport) and Figure 2 (Worcester Regional Airport) show the mean temperature estimate for each month for a given dataset (MARES is the “Massachusetts Residential Energy Optimization Weather Methodology” discussed above). The right three clusters represent the averages for winter (Dec, Jan, Feb), summer (Jun, Jul, Aug), and the shoulder seasons (the remaining six months). TMY3 consistently estimates lower temperatures with the sole exception of the month of March. In Worcester, the differences between TMY3 and TMYx become even more pronounced, especially for the months of January and August.

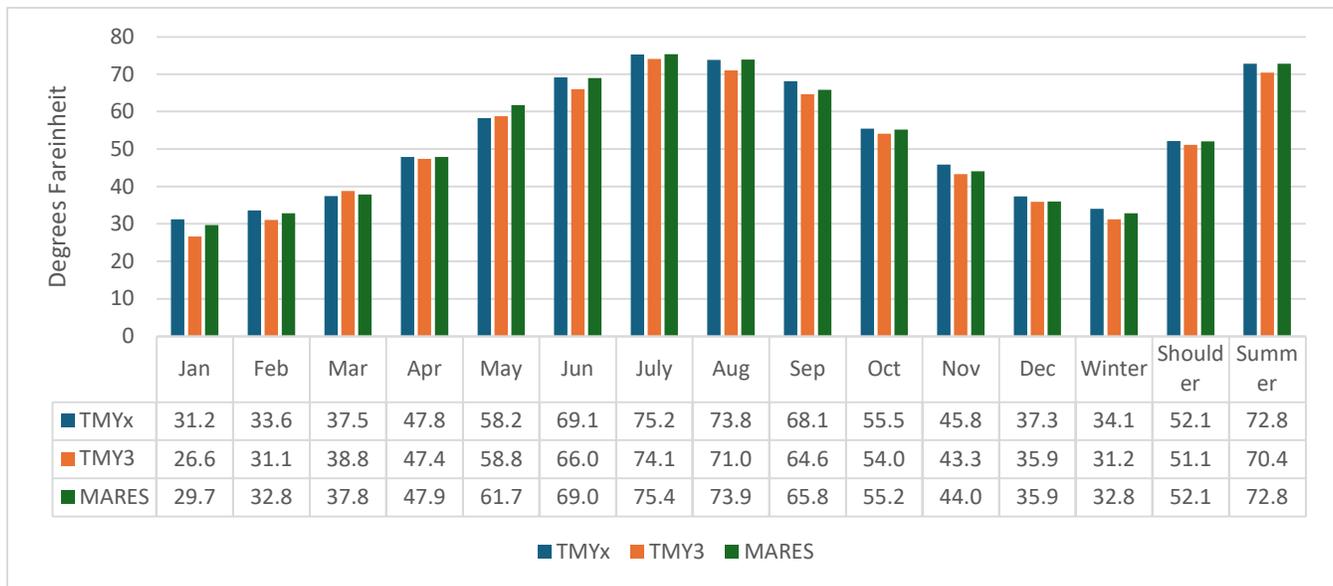


Figure 1. Boston Logan International Airport Mean Temperature by Month and Season

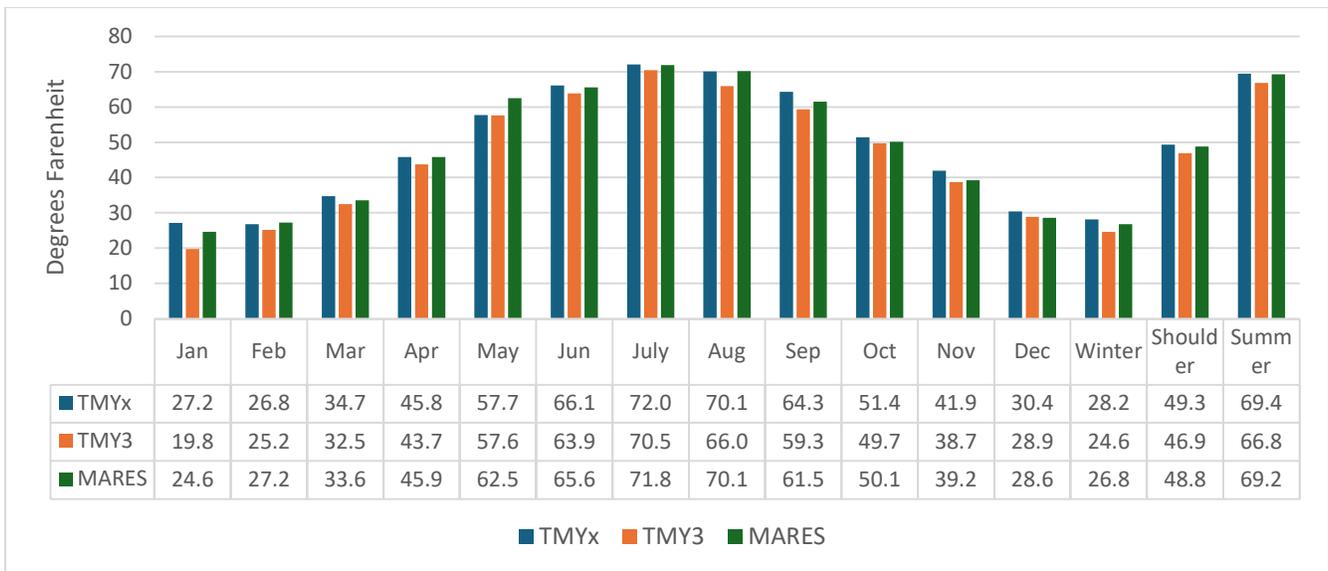
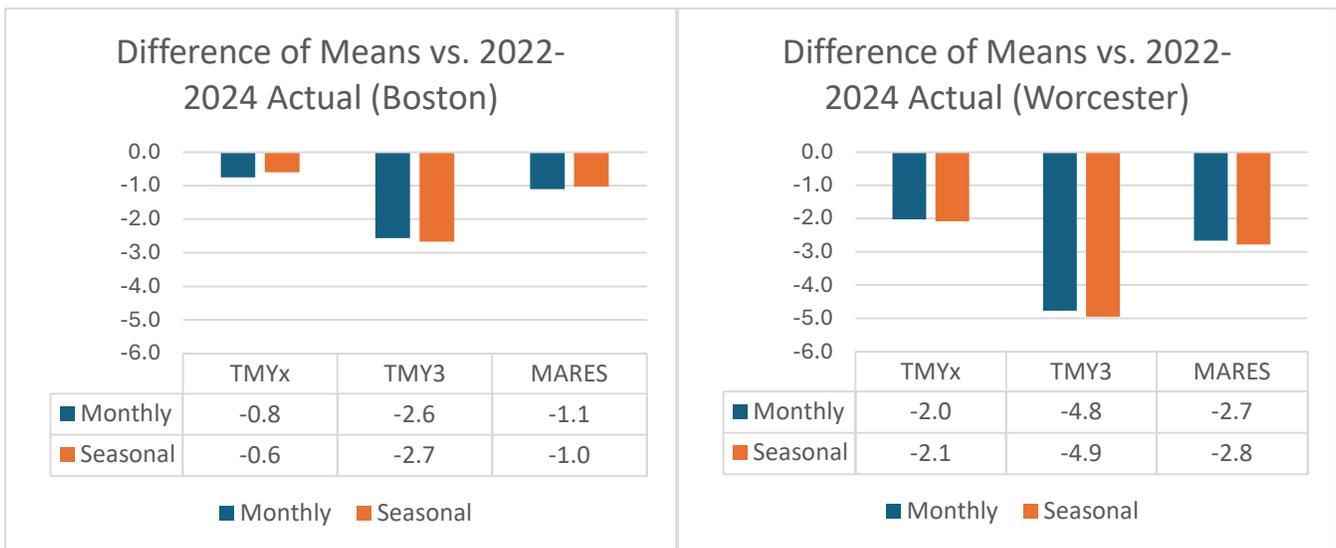


Figure 2. Worcester Regional Airport Mean Temperature by Month and Season

The impact of anthropogenic climate change on temperatures is highly visible in the relative differences between each TMY dataset and the mean monthly and seasonal actual temperatures for the years of 2022 through 2024. Figures 3 (Boston) and 4 (Worcester) show the mean difference of TMY3, TMYx, and MARES from the actual mean temperatures (NOAA 2025) for the three-year period.² For comparison, the largest difference between mean monthly temperatures for the three-year period for Boston is 10 degrees Fahrenheit (January 2022 was especially cold compared to 2023 or 2024), the second largest difference is 6 degrees (2023’s November was also considerably colder than either of its neighbors’). For Worcester the largest two actual differences were 11 and 7 degrees (January and November, as with Boston).



Figures 3 and 4. Mean Discrepancy Between TMY Data and 2022-2024 Actual Means. for Boston (left) and Worcester (right). Source: NOAA 2025

² Mean monthly temperature over three years was used to stabilize the differences.

Differences between datasets and actual observed values.

HDDs and CDD are the primary means by which weather datasets inform many models. HDDs represent the proxy for expected heating service need and are typically defined as the product of the distance below 65° Fahrenheit temperatures are, and the duration of time for which they remain there. CDDs represent the reverse – time the temperature spends above 65°F. Particulars may vary model to model, for example HDD may use a 55°F threshold to reflect definite heating need, or CDD may use 75°F. These assumptions are surely defensible in the proper context, but the industry standard definition – including those used by financial markets – are set against a 65°F switchover temperature.

Table 2. Actual, observed HDD for Boston Logan International Airport and Worcester Regional Airport

Location	2022	2023	2024	3 Yr Mean
Boston	5,227	4,895	5,130	5,084
Worcester	6,052	5,621	5,732	5,802

Source: NOAA 2025

Table 3. Actual, observed CDD for Boston Logan International Airport and Worcester Regional Airport

Location	2022	2023	2024	3 Yr Mean
Boston	1,021	852	910	927
Worcester	751	697	792	747

Source: NOAA 2025

Tables 2 and 3 provide calculated heating/cooling degree days for Boston and Worcester based on hourly ASOS/AWOS data obtained from NOAA (2025). Tables 4 and 5 provide the projected values for the same as offered by TMY3, MARES, and TMYx³. For each dataset’s estimate of degree days, the deviation from the observed mean is given in the following cell; the proportion of the estimate itself is expressed as a percentage of the observed mean in parenthetical.

Table 4. Candidate dataset projections for HDD vs. deviation from observed 3-year mean

Location	TMY3		MARES		TMYx	
	HDD	Deviation	HDD	Deviation	HDD	Deviation
Boston	5,885	+801 (116%)	5,559	+474 (109%)	5,409	+325 (106%)
Worcester	7,275	+1,473 (125%)	6,724	+922 (116%)	6,471	669 (112%)

Source: NOAA 2025

Table 5. Candidate dataset projects for CDD vs. deviation from observed 3-year mean

Location	TMY3		MARES		TMYx	
	CDD	Deviation	CDD	Deviation	CDD	Deviation
Boston	804	-123 (87%)	1,010	+82 (109%)	982	+55 (106%)
Worcester	492	-255 (66%)	709	-38 (95%)	689	-57 (92%)

³ These values differ from those reported in the MA22C04-B-TMY final report (DNV & Guidehouse 2023) due to methodological differences. DNV & Guidehouse estimate HDD/CDD using the daily mean temperature whereas we use actual hourly values since these were available from NOAA.

Source: NOAA 2025

As part of the work to make the case for TMYx adoption, the evaluation team compared the differences between TMY3 and two different TMYx versions (the most, and second most recent) to highlight the consequences (DNV & Guidehouse 2025, p8). The evaluation team's analysis revealed the trailing nature of TMY based on historical data and observed trends consistent with a warming climate. We find the same when comparing against actual observations.

All three analyzed models over-predict heating days, despite the three-year period (2022-2024) featuring a pair of cold snaps. TMY3 is decidedly the worst offender. TMY3 over-predicts HDDs by 16% for Boston, and 25% for Worcester. MARES overpredicts by 9% for Boston and 16% for Worcester. TMYx's overprediction is 6%, and 12% respectively.

TMY3 also dramatically under-predicts cooling days for both cities. MARES and TMYx over-correct for rising temperatures in terms of Boston's cooling demand, but their error is less than that of TMY3. For Worcester, however, the same pattern is observed as for heating days: both MARES and TMYx are off in the same direction as TMY3, but by an order of magnitude fewer degree days.

A second trend observed by the evaluation team is the powerful impact of the ocean as a thermal regulator. All discrepancies for Worcester – inland and whose AWOS is relatively exposed on a large hill – are more severe than for Boston – parked directly on the shore of the Atlantic Ocean. We observe the same.

Discussion

Accuracy is both critically important, and highly elusive, in predictive modeling. Weather systems exacerbate both by being spectacularly chaotic. HVAC demand is powerfully driven by relatively small differences in temperature. Consumer energy needs driven by temperature can make or break the cost effectiveness of many energy efficiency improvements.

All stakeholders desire highly accurate information in this space. Consumers want to know if the cost to them is worth it, and how much future energy demand to plan for. Regulators want to know that ratepayer dollars are going towards projects that provide meaningful relief to strained energy systems. Utilities want to be able to bid claimed savings into forward capacity markets – and grid operators want those claims to be reliable. Grid operators also need to know how large the future electrical system must be to meet demand. All of these depend on the accuracy of predictions made by models – which in turn depend on meaningfully accurate predictions of future weather.

Small temperature differences may not inspire strong reactions in consumer audiences. Users of HVAC systems do not think in terms of, "two degrees Fahrenheit, on average, over a year." Instead, they experience the financial impacts of, "\$450/month during the heating season," or, "replacing a heat pump after eighteen months because it was not large enough to meet the needs under increasingly hotter summers." Inaccuracies in theoretical TMY data eventually become real financial pain, felt by real people.

Building response to outdoor temperature is never one-size fits all. Region, culture, fuel mix, economics, and countless other factors all play a role. Nonetheless, two basic rules appear axiomatic: Overestimation of HDD will lead to models that over-emphasize the importance of efficient heating schemes. Underestimation of CDD will lead to models that fail to capture the growing importance of efficient cooling schemes. Insulation matters in both heating and cooling cases but is more potent when either is needed more dramatically or for longer periods.

At the national level, the U.S. EIA (2014, p4) estimated gas consumption in the United States to increase marginally by 1.581 Billion cubic feet (Bcf) (16.46M therms) – per HDD. This HDD-driven consumption is not

uniform – e.g. the Great Lakes region drives 0.33Bcf of that, while New England (which uses more electricity and oil), drives 0.07Bcf of natural gas demand – so one’s mileage will literally vary.

EPA (2021) provides per capita estimates of electricity use as a function of CDDs using data from 1973-2020. The slope of recent data is more dramatic, as HVAC equipment becomes more commonplace, but roughly matches the best fit line (p. 10) of 0.92kWh per degree day per person – roughly 305,348MWh per summer CDD at the same national scale.

We also note that not all weather-dependent energy savings are purely driven by heating or cooling loads, either. Kang and Reiner (2022) captured differential electricity loads from cold temperatures in gas-fired homes and found significant (albeit small) changes in occupant behavior likely to have been in reaction to the weather:⁴ approximately 211 kWh per year more electricity use per degree C below heating threshold, which amounts to \$185 per year at Massachusetts’ residential rates. Heating and cooling, however, *are* the dominant energy end uses that respond to temperature.

Conclusion

Unmoved by the importance that historical data holds in our current system, anthropogenic climate change inflicts a departure from historical trends – and one that is currently accelerating (Nerem et al. 2018). Continued reliance on increasingly stale datasets is not advisable under such conditions.

Best practices often must evolve in the face of changing dynamics, and the adaptations for deteriorating usefulness of data as a function of time must include efforts to incorporate more recent data as a continuous process. TMYx is a meaningful, compatible alternative for TMY3. It delivers superior performance to TMY3 and as a drop-in substitute it does so at vanishingly small marginal cost. By shortening the time frame its data is pulled from, and allowing that time frame to roll along with the passage of time itself, it offers a form of adaptation to climate change. It is a sacrifice of some of the precision and stability of larger datasets in exchange for improvements – in some ways dramatic – in accuracy. Program planners and evaluators, including statisticians and engineers, have traditionally sought to achieve a certain level of precision in their study results as a stated, primary objective. However, the ultimate aim of any energy efficiency program must be accurate predictions of marginal cost – and so precision must yield to getting those predictions on-target.

TMYx is not perfect; no model ever will be. But where the objective is to get as close as possible to understanding the real results of today’s energy efficiency projects, the Mass Save Sponsors are presently (as of mid-to-late 2023) testing the hypothesis that TMYx will deliver. Insofar as three years – 2022, 2023, and 2024 – can show us, it is looking to be a good bet.

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⁴ A microwave oven may not seem like a weather dependent load, until a very cold day calls for a bowl of hot soup.

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