FINAL REPORT

Massachusetts Typical Weather – Research and Dataset Development

MA22C04-B-TMY

Date: August 17, 2023

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List of acronyms used in this report

C&I	Commercial and industrial
CZ	Climate zone
EEAC	Massachusetts Energy Efficiency Advisory Council
eTRM	Massachusetts electronically published technical resource manual for the period evaluated
EUL	Effective useful life
FCM	Forward capacity market
GRR	Gross realization rate
HVAC	Heating, ventilating, and air-conditioning
ISP	Industry standard practice
MATW	Massachusetts typical weather
NOAA	National Oceanic and Atmospheric Administration
PA	Program administrator
PY	Program year
RESI	Residential
RR	Realization rate
TMY	Typical meteorological year
TRM	Technical resource manual
WG	Working group

EXECUTIVE SUMMARY

DNV, the MA Commercial and Industrial evaluation contractor, and Guidehouse, the MA Residential evaluation contractor, (collectively, "the team") carried out the Massachusetts Typical Weather (MATW) – Research and Dataset Development study for the Massachusetts Program Administrators (PAs) and Energy Efficiency Advisory Council (EEAC) Consultants from March 2022 to February 2023.

The program sponsor PAs were Berkshire Gas Company (Berkshire), Cape Light Compact, Eversource, Liberty Utilities (Liberty), National Grid, and Unitil.

Background

The MA Commercial and Industrial evaluators require weather data to accurately calculate energy usage and savings for energy savings projects which are weather-dependent. These projects are often weather-dependent, so building energy simulation software such as EnergyPlus is used to account for various complex energy savings measures and their interactions. Building simulation software requires hourly weather data for each hour of the year. While it is possible to use historical data for this purpose, a typical meteorological year (TMY) is preferred for consistency and comparison purposes. TMY data is a weather dataset constructed by the National Renewable Energy Laboratory (NREL) to provide solar irradiance and weather data for building and solar simulation software.

The NREL first published TMY datasets in 1978 based on historical weather data from 1952 to 1975.[1] However, recognizing that weather and climate change over time, the NREL updated the TMY dataset by publishing TMY2 in 1994 based on historical weather data from 1961-1990 and TMY3 in 2007 based on historical weather data from 1976-2005.

A TMY is a constructed dataset that comprises weather conditions for each hour of the year, where each month corresponds to actual weather data from that month in the year when the weather is considered most typical. That is, each month of data in the TMY is based on real data but the year chosen as most representative varies by month. For example, the TMY3 dataset for Worcester, MA uses January data from 1976, February data from 1977, and March data from 1989. In this way, TMY data preserves the vagaries which occur in real data while providing a standardized dataset which corresponds to a typical or "average" year.

While TMY data is necessary for building simulation software, evaluators have developed a habit of using TMY data for other analyses as well, such as to construct 5F bin data (number of hours per year which occur in each 5F bin, e.g., hours per year in which the temperature is between 51-55F, 56–60F, etc) for use in bin analyses. For more than a decade, TMY3 data has been used in this way. Thus, for weather-dependent measures, evaluators have calculated energy and demand savings that would be expected based on the weather data that is now 18 to 47 years old (as of 2023).

Therefore, recognizing that weather patterns are changing over time, and particularly since these changes are accelerating due to climate change, this project was undertaken to determine how best to update the weather data used for energy and demand savings calculations. The project aims to ensure that the weather data used for these analyses is up-to-date and reflects current weather patterns.

Study purpose and objectives

The study's overall purpose was to research methods for generating a weather dataset representative for Massachusetts that will be suitable for use in programs and are in a similar format as the current TMY3 weather dataset. This is a crucial step towards improving the accuracy and effectiveness of energy efficiency programs in Massachusetts. Accurate weather

[1] Users Manual for TMY3 Data Sets, Revised May 2008 https://www.nrel.gov/docs/fy08osti/43156.pdf#page=8

data is essential to identify the most effective energy-saving measures, measure progress, and evaluate the success of these programs. By generating a representative weather dataset for Massachusetts, we can set more accurate and achievable energy efficiency goals and evaluate the impact of these programs more effectively. The use of more current weather data will help ensure that the generated weather dataset is reliable and can be updated regularly to reflect changes in the climate. The results of this study will not only benefit energy efficiency programs but also have broader implications for planning and climate adaptation strategies.

The objectives of the study were as follows:

1. **Review the Massachusetts residential weather normalization approach.** Review the approach taken on recent MA residential evaluation studies to determine whether the MA Commercial and Industrial evaluators should adopt the same method.
2. **Research and identify the optimal method for generating the Massachusetts typical weather (MATW) dataset.** A typical meteorological year for Massachusetts is a compendium of actual historical months that includes a distribution of high and low temperatures observed. Within a weather dataset, for each month of the year, the historical month with conditions nearest to the weighted mean and median value over the whole period (of typically 15–30 years) is determined and selected as the "typical" month. This selection process is then repeated for each month in the year and these months are combined to produce a full year of hourly samples that make up the typical meteorological year dataset. The objective of this task is to research current literature to identify methods for generating an updated TMY weather dataset and present options to stakeholders and decide the method applicable to MA.
3. **Generate the new MATW dataset.** Generate TMY-like weather datasets for 15 stations in MA to be used by both commercial and industrial (C&I) and residential (RESI) programs. The dataset format will be similar to the current TMY3 format.
4. **Recommend process for updating MATW dataset.** Provide guidelines for updating the MATW dataset.

Approach

The research and analysis of this study was conducted under the review and engagement of a Working Group comprising representatives from the EEAC, the Massachusetts PAs, and the team of evaluation consultants. The responsibilities of the Working Group were to review and approve the approaches, findings, and draft recommendations that arose from this study. The Working Group met three times.

Findings

During the course of this work, the team found that the NREL is no longer updating TMY datasets. However, Climate.OneBuilding.org, a resource for building energy simulation and weather data comprising the efforts of two dedicated volunteers, has developed "TMYx" files using data from the United States National Oceanic and Atmospheric Administration's (NOAA) Integrated Surface Database. These TMYx files are constructed in the same manner as the TMY datasets described in the Background section. The most recent TMYx files are based on weather data from the 15-year period from 2007 to 2021.

Recommendations

The Working Group recommendations are as follows:

Recommendation 1: Use TMYx 2007–2021 weather dataset representative of the location of the project being evaluated. The participants of the Working Group reached a consensus that TMYx weather will be used to define typical year weather for energy savings in Massachusetts' energy efficiency program evaluations. TMYx datasets for 15 locations across Massachusetts will be made available on the MA eTRM website for public access.

The advantages of using TMYx to model energy consumption are:

- TMYx utilizes weather data that is more current than TMY3.
- TMYx follows the same format and same methodology as TMY3.
- TMYx can be applied with same building simulation software as TMY3.
- TMYx is planned to be updated periodically (every 2–3 years).

Recommendation 2: Maintain current method but use TMYx for calculating energy savings and on-peak demand. The Working Group participants agreed to maintain the current methods of calculating energy savings and on-peak demand (ISO-NE definition), but using the TMYx weather dataset instead.

Recommendation 3: TMYx adoption strategy. In order to accurately calculate savings resulted from installation of weather-dependent projects, implementers and evaluators normalize impacts for both the baseline and installed projects to typical weather. To accurately capture the climate change impacts on energy consumption, stakeholders expect the weather dataset to be updated every 3 to 5 years. Weather updates pose challenges due to the files' availability and the education of program implementers and contractors. The PAs and EEAC determined that a staged approached for adoption of updated weather files will best meet these challenges. Our team recommends the following adoption calendar:

1) C&I Custom and new construction projects initiated[2] prior to 7/15/2023:

   - To calculate ex-post impacts, evaluators will continue to use TMY3 weather files
   - The program evaluated gross realization rate will be calculated using the following formula:

$$GRR = \frac{Ex - post\_Savings_{TMY3\ weather}}{Ex - ante\_Savings_{Program\ Weather}}$$

   Where:

GRR	= program gross realization rate
$Ex - post\_Savings_{TMY3\ weather}$	= evaluated savings using TMY3 dataset
$Ex - post\_Savings_{Program\ weather}$	= tracking savings reported by the program

   - Starting with the next evaluation the Custom Electric program, when possible, evaluation recalculate the ex-post (program reported) savings using TMYx weather and provide in the site reports the following results: difference in impacts by comparing the program reported savings and the ex-ante savings evaluators calculate using TMYx. The results will present differences between impacts calculate using both TMY3 and TMYx weather files.

2) C&I Custom and new construction projects initiated on or after 7/15/2023:

   - To calculate ex-post impacts, evaluators **will use TMYx** weather files regardless of what weather data the program used to calculate ex-ante impacts (tracking impacts).
   - The program evaluated gross realization rate will be calculated using the following formula:

$$GRR = \frac{Ex - post\_Savings_{TMYx}}{Ex - ante\_Savings_{Program\ Weather}}$$

   Where:

[2] C&I Custom projects and new construction projects initiated prior to 7/15/2023 should use the TMY3 weather dataset for evaluation. Project initiation is defined as the earliest of the following milestones that could occur, depending on the project and PA: 1) Memorandum of Understanding date; 2) Engineering Service Agreement date; 3) Signing of any application; 4) Signing of a registration form.

GRR	= program gross realization rate
$Ex - post\_Savings_{TMYx}$	= evaluated savings using TMYx weather dataset
$Ex - post\_Savings_{Program\,weather}$	= tracking savings reported by the program

3) Ongoing studies and evaluations that produce savings values for the Massachusetts TRM will begin using TMYx data immediately to inform an overall TRM update in October 2024 for the 2025-2027 program cycle.

Table ES-1**Error! Reference source not found.** summarizes the adoption calendar.

Table ES-1. TMYx adoption calendar

Track	Timeline for Evaluation to Update to TMYx Weather Data*
C&I – Custom	Begin with projects that are initiated by 7/15/2023**
C&I - Prescriptive	Update any ongoing EM&V studies immediately
New Construction -- All	Begin with projects that are initiated by 7/15/2023**
Residential (excluding New Construction)	Update any ongoing EM&V studies immediately

*TMYx dataset resulted from this study
**C&I Custom projects and new construction projects initiated prior to 7/15/2023 should use the TMY3 weather dataset for evaluation. Project initiation is defined as the earliest of the following milestones that could occur, depending on the project and PA: 1) Memorandum of Understanding date; 2) Engineering Service Agreement date; 3) Signing of any application; 4) Signing of a registration form

1 INTRODUCTION

DNV, the MA Commercial and Industrial evaluation contractor, and Guidehouse, the MA Residential evaluation contractor, (collectively, "the team") carried out the Massachusetts Typical Weather (MATW) – Research and Dataset Development study for the Massachusetts Program Administrators (PAs) and Energy Efficiency Advisory Council (EEAC) Consultants from March 2022 to February 2023.

The program sponsor PAs were Berkshire Gas Company (Berkshire), Cape Light Compact, Eversource, Liberty Utilities (Liberty), National Grid, and Unitil.

1.1 Study purpose and objectives

The study's overall purpose was to research methods for generating a weather dataset representative of Massachusetts that will be suitable for use in programs and are in a similar format as the current TMY3 weather dataset. The objectives of the study were as follows:

1. **Review the Massachusetts residential weather normalization approach.** Review the approach taken on recent MA residential evaluation studies to determine if the MA C&I evaluators should adopt the Residential methodology.
2. **Research and identify the optimal method for generating the MATW dataset.** Research current literature to identify methods for generating an updated TMY weather dataset. Present options to stakeholders and decide the method applicable to MA.
3. **Generate the new MATW dataset.** Generate TMY-like weather datasets for 15 stations in MA. This weather data will be available and used by both commercial and industrial (C&I) and residential (RESI) programs. The dataset format will be similar to the current TMY3 format.
4. **Recommend process for updating MATW dataset.** Provide guidelines for updating the MATW dataset.

1.2 Study background

Weather data provides important variables for calculating impacts resulting from installing weather-sensitive measures through programs offered by Program Administrators (PA) in MA. Accurate, up-to-date weather data is an essential component of energy efficiency programs because it allows for an objective assessment of energy and peak demand savings and provides a firm technical basis for setting energy efficiency goals and for evaluating programs' performance.

PAs have been using the Typical Meteorological Year, version 3 (TMY3) weather dataset for reporting and evaluating results of energy efficiency programs for decades in Massachusetts and other states. The TMY datasets, which were provided for 15 weather stations in MA (see Table 2-4) were generated by the National Renewable Energy Laboratory (NREL) to provide a synthetic "typical year" for standardized comparison of heating, cooling, and solar collection systems. The TMY3 sets were constructed using weather observations selected as "typical" from the years 1991 to 2005. It is important to note that a TMY is not an average of weather conditions, but a compendium of actual historical months that includes a distribution of high and low temperatures observed. For each month of the year, the historical month with meteorological conditions and solar radiance nearest to the weighted mean and median value over the whole period (of 15–30 years) is determined and selected as the "typical" month. This process is then repeated for each month in the year. These months are combined to give a full year of hourly samples.

The TMY3 weather dataset does not reflect changes in temperature, humidity, and other weather variables due to changes in climate since 2005, nor does it address future climate predictions. The objective of this study is to generate a MATW dataset that more accurately reflects the current weather conditions in Massachusetts.

2 METHODOLOGY AND APPROACH

The team's approach used the steps detailed in the following sections to achieve the research objectives and ensure that the evaluators met the study goals of the PAs and EEAC Consultants.

2.1 Literature reviews

2.1.1 Review of weather normalization methods

The team reviewed the approach used to generate the weather data included in the Energy Optimization Fuel Displacement Impact and Process Study (MA20R24-B-EOEVAL) and Massachusetts Residential Building Use and Equipment Characterization Study. The team discussed the methods and the relevant details to be presented in WG #1, and prepared a slide deck summarizing the findings.

2.1.2 Literature and methodology research

The team researched what approaches are being used elsewhere in the industry in the USA and Canada, and gathered available papers and reports that present methods for generating datasets for typical weather from a forecasting perspective (e.g., both load forecasting and EE measure impacts forecasting). Approaches that the team reviewed and synthesized for stakeholders include:

- Custom approaches in other states using recent weather data, similar to what the Residential team did in MA. The team researched how other programs use weather data to estimate electric energy and peak demand reduction impacts.
- The use of TMYx files developed by Climate.OneBuilding.Org, which generally use 15 years of recent data by weather station from approximately 2004 through 2018 and which were first published in 2019. In a recent update, the makers of this site also published TMYx files with data from 2007 to 2021.
- The use of future climate models and projections based on the emissions scenarios (known as Representative Concentration Pathways or RCPs) that have been presented by scientists from the Intergovernmental Panel on Climate Change (www.IPPC.com) in their published Assessment Reports (AR).

These approaches all have strengths, limitations, and implications for expected impacts. The team discussed these, and showed the respective temperature, humidity, heat and cold indices, etc.—which serve as a proxy for measure impact adjustments—across these methods. The comparison also included current TMY3 values for each variable and provided an estimate of percentage changes in energy and peak savings across the various methods.

The team presented the findings and recommended a method to be used in MA together with options that were reviewed but not considered. The team also developed a slide deck that presented researched papers/documents and the methods with advantages and disadvantages, which was discussed in WG #2.

2.2 Working Group sessions

The Working Groups, as an overall body, were tasked with reviewing and approving the methods for generating the MATW dataset. Members were expected to prepare for and attend the Working Group session(s), comment on materials in a timely fashion, and weigh in on deliberations. The Working Group comprised representatives from the EEAC, the Massachusetts PAs, and the evaluation consultants (the team). The Working Group reviewed and approved the approaches, findings, and draft recommendations that arose from this study. Working Group members are noted in Table 2-1.

Table 2-1. Working Group members

Organization	Designated Member
PA Representation	Margaret Song, Cape Light Compact Matt Siska, Berkshire Gas / Liberty Utilities Jillian Winterkorn, Berkshire Gas Jaclyn Rambarran, Eversource Sharon Jones, Lexicon Energy Consulting, on behalf of Eversource Megan Errichetti, Eversource Aakanksha Dubey, National Grid Dave Jacobson, National Grid Adam Wirtshafter, National Grid Mary Downes, Unitil
EEAC	Ralph Prahl Jennifer Chiodo Robert Wirtshafter
Evaluation Consultants	Mimi Goldberg, DNV Ken Agnew, DNV Chad Telarico, DNV Naveed Khan, DNV George Sorin Ioan, DNV David Basak, Guidehouse Ken Seiden, Guidehouse Anna Brannon, Guidehouse

The Working Group met three times for durations of 60 minutes over a period of approximately seven months. The topics discussed during each meeting are presented in Table 2-2. After each Working Group session, the team circulated key takeaways to the members for review, revision, or identification of further issues associated with the topics that were discussed.

Table 2-2. Working Group meetings topics

Session	Date	Topics
1 – 60′	5/13/2022	• Massachusetts Residential Weather Normalization Approaches • More Recent Approach for a Southwestern Utility • Climate Change, Benefit-Cost and Policy Considerations
2.1 – 60′	10/07/2022	• Review methods used by various states, TMYx dataset and implications, future climate models • Recommend method for generating a TMY weather dataset for Massachusetts
2.2 – 60′	12/2/2022	• Review current definitions of peak periods • Review TMYx and peak periods • Recommendations

2.2.1 Working Group #1

The Working Group participants met on May 13, 2022, and discussed the study objectives to ensure the results of the study would enhance the accuracy of weather used by commercial and industrial (C&I) programs in Massachusetts. Then, the Working Group discussed the approach used on two recent RESI studies in MA to determine if that approach can be used for C&I programs.

The Residential Evaluation Team (Guidehouse) summarized the approach as follows:

- For each study, Guidehouse used the previous 15 years of weather data, and then selected unique month/year combinations based on the combinations that produced average consumption across prototypical energy simulation models.
- Each study has a unique population and end use of interest (e.g., statewide electric usage, statewide gas usage, heat pump participant electric usage), and each study had a unique analysis approach (e.g., metering, building simulation, or billing analysis). Because of the different population mix and modeled consumption, the months/year combination was different for the two studies. For example, for the month of July, a baseline study selected 2008 and an energy optimization study for heat pump participants selected 2016 as sources for weather.
- To build an updated typical year weather file, the team “stitched” together the actual weather data for Worcester, MA from the representative month/year combinations to build one 8760 hourly weather file. Weather data for other stations was not generated for the two recent studies.
- Because the approach is based on matching building simulation consumption, each unique study may select different month/year combinations, as the median months may be different for different studies.

The Working Group discussed the approach. While there is a logic to building weather data to meet the specific needs of a study, that data cannot serve as a benchmark across multiple programs, nor can it be used by the implementation community for planning and reporting savings. The Working Group concluded that the MATW dataset should be applicable to all energy efficiency programs offered in MA—both Resi and C&I—and available to both implementers and evaluators.

The Working Group discussed options for accounting for rapidly changing weather. A point was made that cooling and heating equipment installed today will be operating for the next 20 years. Therefore, the MATW dataset should reflect the average weather conditions experienced during the lifetime of the equipment, where due to climate change, future weather is likely to be warmer on average than current weather. The Working Group indicated we should research established procedures for incorporating forecasts into the MATW dataset and determine if they could be applied in MA. The key takeaways from Working Group #1 can be found in APPENDIX A.

2.2.2 Working Group #2.1

The Working Group participants met on October 7, 2022, and discussed the advantages and disadvantages of the methods and approaches for generating a weather dataset used by various states and jurisdictions (Table 2-3) to choose the weather dataset going forward in both commercial and industrial (C&I) and residential (RESI) programs in Massachusetts.

Table 2-3. Methods used by various states

Dataset	States	Variable Used for Selection	Range (Years)	Selection Criteria	Resolution	Includes Forecasting
TMYx	Arizona, others	Same as TMY3	2007-2021	Same as TMY3	Hourly	No
CZ2022	California	Dry bulb and dewpoint temperature, windspeed and two solar values	1998-2017	Max, min, avg (dry bulb and dewpoint), 50% weighted, 10% for windspeed and 50% for 2 solar values	Hourly	No
NOAA 30-year normals	Illinois	Dry bulb and dewpoint temperature, windspeed	1991-2020	Average dry bulb and dewpoint temperature, windspeed	Hourly	No

The discussion then focused on the TMYx weather dataset, HDD and CDD comparisons between TMYx and TMY3, their implications, and future climate projection models. Finally, the Working Group decided on TMYx as the most appropriate weather dataset.

The key takeaways from Working Group #2.1 can be found in **Error! Reference source not found.**.

2.2.3 Working Group #2.2

The Working Group participants met on December 2, 2022, and discussed the definitions of peak periods used by both commercial and industrial (C&I) and residential (RESI) programs in Massachusetts and the Massachusetts Technical Reference Manual (TRM) peak definitions to identify similarities and differences.

<u>C&I Peak Energy and Demand definitions:</u>

- Electric energy (kWh) savings definitions (used by PAs):
    - Winter
        - Peak: 7:00 AM – 11:00 PM, weekdays except holidays, October to May
        - Off-Peak: 11:00 PM – 7:00 AM weekdays, all day weekends and holidays, October to May
    - Summer
        - Peak: 7:00 AM – 11:00 PM, weekdays except holidays, June to September
        - Off-Peak: 11:00 PM – 7:00 AM weekdays, all day weekends and holidays, June to September

- Electric peak demand (kW) savings definitions (applied by evaluation, in TRM, and used for FCM filings):
  - Summer: 1:00 PM – 5:00 PM, weekdays except holidays, June to August
  - Winter: 5:00 PM – 7:00 PM, weekdays except holidays, December and January
- Peak gas savings are not currently calculated
- Evaluation uses TMY weather dataset for both energy and demand calculations

Residential Peak Energy and Demand definitions:

- Electric energy (kWh) savings definitions are the same as C&I
- Electric peak demand (kW) savings definitions:
  - System Peak: The 2-hour period with the highest average ISO-NE system load
  - Seasonal Peak (same definition as ISO-NE): All hours for which the ISO-NE system load is >90% of the forecasted max system load for the season
  - On Peak (same definition as C&I): 1-5 PM in Jun/Jul/Aug (Summer) / 5-7 PM in Dec/Jan (Winter)
  - Residential Peak: 5-7 PM (Summer) / 7-9 PM (Winter) on the day of the system peak
  - All peak periods are limited to non-holiday weekdays

The Working Group participants then discussed the current approach to peak savings, additional peak period definitions (on-peak, seasonal, system peak, residential peak) and the relationship between the weather data and the definition of peak. The Working Group concluded that it was outside of the scope of the study to redefine peak periods, and that programs should continue using the on-peak definition. TMYx should be used similarly to TMY3 to calculate energy and demand during peak periods.

The key takeaways from Working Group #2.2 can be found in **Error! Reference source not found.**.

2.3 Processing the TMYx datasets

After WG #2.1, the stakeholders decided the TMYx dataset from weather recorded between 2007 and 2021 using the International Standards Organization (ISO) 15927-4:2005 methodology (similar to the methodology used by NREL to develop the TMY3 dataset) will be adopted in MA. The team gathered the weather files (provided in *.EPW format from https://www.climate.onebuilding.org/) for 15 weather stations (same 15 stations in MA for which TMY3 weather is available, listed in Table 2-4) and converted the files to *.xlsx and *.BIN formats. The *.EPW files are used in EnergyPlus / OpenStudio, *.xlsx are used in Excel, and *.BIN files are used in eQUEST. Finally, the team QC'd the final weather files to ensure the simulations ran successfully and natively within their appropriate application environments. The weather data fields for TMYx can be found in Table C-1Table within APPENDIX C.

Table 2-4. Massachusetts Typical Weather (MATW) stations

USAF*	Station Name	Latitude	Longitude
725067	BARNSTABLE MUNI BOA	41.667	-70.283
725088	BEVERLY MUNI	42.583	-70.917
725090	BOSTON LOGAN INT'L ARPT	42.367	-71.017
744910	CHICOPEE FALLS WESTO	42.200	-72.533
744904	LAWRENCE MUNI	42.717	-71.117
725066	MARTHAS VINEYARD	41.400	-70.617
725063	NANTUCKET MEMORIAL AP	41.250	-70.067
725065	NEW BEDFORD RGNL	41.667	-70.950
725075	NORTH ADAMS	42.700	-73.167
725098	NORWOOD MEMORIAL	42.183	-71.183
725060	OTIS ANGB	41.650	-70.517
725064	PLYMOUTH MUNICIPAL	41.917	-70.733
725073	PROVINCETOWN (AWOS)	42.067	-70.217
744915	WESTFIELD BARNES MUNI AP	42.150	-72.717
725095	WORCESTER REGIONAL	42.267	42.267

*US Air Force station number

3 COMPARING TMY3 WITH TMYX HEATING AND COOLING REQUIREMENTS

The team downloaded the TMY3 weather dataset and TMYx weather datasets for both the 2004–2018 and 2007–2021 periods for Boston (Boston Logan International Airport) and Worcester (Worcester Regional Airport). The team then calculated the annual cooling degree days (CDD) and heating degree days (HDD) associated with each weather data file for both weather stations. The CDD and HDD are calculated using the average daily dry bulb temperature and a base temperature of 65°F.

A comparison of the CDD and HDD for the different weather datasets for Boston is shown in Table 3-1, and the corresponding comparison for Worcester is shown in Table 3-2.

Table 3-1. CDD and HDD comparison for Boston

Dataset	Range	CDD	HDD	CDD %	HDD %
TMY3	1976-2005	694	5,742	100%	100%
TMYx 2004-2018	2004-2018	859	5,410	124%	94%
TMYx 2007-2021	2007-2021	884	5,342	127%	93%

Table 3-2. CDD and HDD comparison for Worcester

Dataset	Range	CDD	HDD	CDD %	HDD %
TMY3	1976-2005	336	7,079	100%	100%
TMYx 2004-2018	2004-2018	523	6,416	156%	91%
TMYx 2007-2021	2007-2021	570	6,319	170%	89%

The team found that the CDD increased, and the HDD decreased with the use of more recent weather data for both Boston and Worcester. The same trend continues even between the two TMYx files as we move from a slightly older 15-year period to a more recent 15-year period.

4 RECOMMENDATIONS

This section presents recommendations the Working Group made based on the research findings.

4.1 Recommendation 1: Use TMYx 2007–2021 dataset representative of Massachusetts

During the WG #2 meeting, the stakeholders reviewed the available weather datasets and determined TMYx 2007–2021 characterizes the weather in MA more accurately than the other available datasets.

The advantages of using TMYx to model energy consumption are:

- TMYx utilizes weather data that is more current than TMY3.
- TMYx follows the same format and same methodology as TMY3.
- TMYx can be applied with same building simulation software as TMY3.
- TMYx is planned to be updated periodically (every 2–3 years).

4.2 Recommendation 2: Use TMYx 2007–2021 to model weather-dependent peak demand and energy savings

During the WG #2 meeting, the stakeholders discussed the methods used for calculating peak demand and determined TMYx should be used to model weather-dependent peak demand.

The Working Group recommends that both Residential and Commercial and Industrial programs use TMYx to model peak demand and energy consumption of energy systems that are weather-dependent. The TMYx dataset will be provided by DNV to stakeholders for distribution to all interested parties.

4.3 Recommendation #3: TMYx adoption strategy

To accurately capture the climate change impacts on energy consumption, stakeholders expect the weather dataset to be updated every 3 to 5 years. The weather updates pose challenges due to the files' availability and the education of program implementers and contractors. The PAs and EEAC determined that a staged approached for adoption of updated weather files will best meet these challenges. Our team recommends the following adoption calendar:

1) C&I Custom and new construction projects initiated[3] prior to 7/15/2023:

   - To calculate ex-post impacts, evaluators will continue to use TMY3 weather files
   - The program evaluated gross realization rate will be calculated using the following formula:

$$GRR = \frac{Ex - post\_Savings_{TMY3\ weather}}{Ex - ante\_Savings_{Program\ Weather}}$$

   Where:

GRR	= program gross realization rate
$Ex - post\_Savings_{TMY3\ weather}$	= evaluated savings using TMY3 dataset
$Ex - post\_Savings_{Program\ weather}$	= tracking savings reported by the program

   - Starting with the next evaluation the Custom Electric program, when possible, evaluation recalculate the ex-post (program reported) savings using TMYx weather and provide in the site reports the following results: difference

[3] C&I Custom projects and new construction projects initiated prior to 7/15/2023 should use the TMY3 weather dataset for evaluation. Project initiation is defined as the earliest of the following milestones that could occur, depending on the project and PA: 1) Memorandum of Understanding date; 2) Engineering Service Agreement date; 3) Signing of any application; 4) Signing of a registration form

in impacts by comparing the program reported savings and the ex-ante savings evaluators calculate using TMx. The results will present differences between impacts calculate using both TMY3 and TMYx weather files.

2) C&I Custom and new construction projects initiated on or after 7/15/2023:

- To calculate ex-post impacts, evaluators **will use TMYx** weather files regardless of what weather data the program used to calculate ex-ante impacts (tracking impacts).
- The program evaluated gross realization rate will be calculated using the following formula:

$$GRR = \frac{Ex - post\_Savings_{TMYx}}{Ex - ante\_Savings_{Program\,Weather}}$$

Where:

GRR	= program gross realization rate
$Ex - post\_Savings_{TMYx}$	= evaluated savings using TMYx weather dataset
$Ex - post\_Savings_{Program\,weather}$	= tracking savings reported by the program

3) Ongoing studies and evaluations that produce savings values for the Massachusetts TRM will begin using TMYx data immediately to inform an overall TRM update in October 2024 for the 2025-2027 program cycle.

Table 4-1 summarizes the adoption calendar.

Table 4-1. TMYx adoption calendar

Track	Timeline for Evaluation to Update to TMYx Weather Data
C&I – Custom	Begin with projects that are initiated by 7/15/2023*
C&I - Prescriptive	Update any ongoing EM&V studies immediately
New Construction -- All	Begin with projects that are initiated by 7/15/2023*
Residential (excluding New Construction)	Update any ongoing EM&V studies immediately**

*C&I Custom projects and new construction projects initiated prior to 7/15/2023 should use the TMY3 weather dataset for evaluation. Project initiation is defined as the earliest of the following milestones that could occur, depending on the project and PA: 1) Memorandum of Understanding date; 2) Engineering Service Agreement date; 3) Signing of any application; 4) Signing of a registration form
**The team updated the HDD and CDH values used by the Residential programs. More details are provided in APPENDIX D.

APPENDIX A. WORKING GROUP SESSION #1 TAKEAWAYS

During the first Working Group (WG) session on 05/13/2022, stakeholders discussed the following topics:

1. Study objectives
2. Approach used on two recent residential studies
3. Agreeing on the next research tasks

This document summarizes the discussions to date with input from the WG #1 session put in a draft of the final WG recommendations.

WG #1 objectives

WG participants discussed the study objectives to ensure the results of the study will enhance the accuracy of weather used by both commercial and industrial (C&I) and residential (RESI) programs in Massachusetts. Then, the WG discussed the approach used on two recent RESI studies in MA to determine if that approach can be used for C&I programs. Finally, the WG decided on the next task to be completed by the DNV team.

Study objectives

The study work plan identified the following objectives:

1. Generate a MATW weather dataset to be used by both C&I and RESI programs in MA
2. Compare the newly developed MATW dataset with TMY3 to provide details on impacts MATW dataset would have on programs' reported savings
3. Provide recommendations for future updates to the MATW weather dataset

Key takeaway: WG participants agree with the objectives and that the methods used to generate the MATW should be based on best practice. The methods will have the be discussed and agreed by the WG.

Approach used on two recent RESI studies

The Residential Evaluation Team (Guidehouse), summarized the approach as follows:

- For each study, Guidehouse used the previous 15 years of weather data, and then selected unique month/year combinations based on the combinations that produced average consumption across prototypical energy simulation models.
- Each study has unique population and end use of interest (e.g., statewide electric usage, statewide gas usage, heat pump participant electric usage) and each study had a unique analysis approach (e.g., metering, building simulation, or billing analysis). Because of the different population mix and modeled consumption, the months/year combination was different for the two studies. As an example, for the month of July, a baseline study selected 2008 and an energy optimization study for heat pump participants selected 2016 as sources for weather.
- To build an updated typical year weather file, the team "stitched" together the actual weather data for Worcester, MA from the representative month/year combinations to build one 8760 hourly weather file. Weather data for other stations was not generated for the two recent studies.
- Because the approach is based on matching building simulation consumption, each unique study may select different month/year combinations, as the median months may be different for different studies.

The WG discussed the approach. While there is a logic to building weather data to meet specific needs of a study, that data no longer can serve as a benchmark across multiple programs, nor can it be used by the implementation community for planning and reporting savings. The WG concluded that the MATW dataset should be applicable to all energy efficiency programs offered in MA and available to both implementers and evaluators.

The WG discussed options for accounting for rapidly changing weather. A point was made that cooling and heating equipment installed today will be operating for the next 20 years, so the MATW should reflect the average weather conditions experienced in the lifetime of the equipment. The WG indicated we should research on established procedures for incorporating forecasts into the MATW dataset and determine if they could be applied in MA.

Key takeaway: WG participants agree the MATW dataset should be applicable to all energy efficiency programs in MA and a reference for both implementers and evaluators. C&I and RESI teams should collaborate to develop and present a method to generate the MATW dataset.

Next research tasks

The study work plan included a task to research how weather datasets have been developed in other jurisdictions. WG members agreed the C&I and RESI teams should conduct further research and present a method to be discussed on a following WG (WG#2).

Key takeaway: WG participants agree that C&I and RESI teams should research available literature and present a method to generate the MATW dataset in WG #2.

APPENDIX B. WORKING GROUP SESSION #2 TAKEAWAYS

The study has three main objectives, as follows:

1. Generate a Massachusetts typical weather (MATW) weather dataset to be used by both commercial and industrial (C&I) and residential (RESI) programs in MA.
2. Compare the newly developed MATW dataset with typical meteorological year (TMY3) to provide details on impacts MATW dataset would have on programs' reported savings.
3. Provide recommendations for future updates to the MATW weather dataset.

The objectives presented above will be achieved using methods decided by a working group that includes stakeholders' representatives. The working group met first to discuss the objectives and initiate the research and met again to decide on the methods and tasks required to meet the study objectives. This document summarizes the discussions and decisions made during working group (WG) 2. This WG consisted of two sessions, #2.1 and #2.2.

During the WG #2.1 session on October 7, 2022, stakeholders discussed the following topics:

1. Study objectives
2. Research findings
3. Recommendations
4. Next steps

WG #2.1 objectives

WG participants discussed advantages and disadvantages of methods and approaches for generating a weather dataset used by various states and jurisdictions to choose the weather dataset going forward in both commercial and industrial (C&I) and residential (RESI) programs in Massachusetts. Then, the discussion focused on the TMYx weather dataset, comparisons between TMYx and TMY3, their implications, and future climate projection models. Finally, the WG decided on the appropriate weather dataset.

Research findings

The C&I evaluation team, DNV, summarized the methods and approaches used by various states, including TMYx, CZ2022, (National Oceanic and Atmospheric Administration) NOAA, the variables used for selections, selection criteria, and the resolution of each dataset.

The RESI evaluation team, Guidehouse, introduced TMYx weather file history, then illustrated a comparative analysis of TMYx and TMY3 CDD, HDD, average monthly dry bulb temperature of the various weather file history (TMY3, TMYx 2004–2018, TMYx 2007–2021) across different cities in MA. The WG then discussed future climate projection available tools and Guidehouse illustrated models a comparative analysis of TMYx and TMY3 CDD, HDD, average monthly dry bulb temperature of the various weather file history (TMY3, TMYx 2004–2018, TMYx 2007–2021, 2011–2030 (RCP4.5 – 50%), 2021–2040 (RCP4.5 – 50%) in MA.

WG #2.1 recommendations

The advantages of using TMYx to model energy consumption are presented below:

- TMYx is based on more recent weather data than TMY3.
- TMYx the same format and same methodology as TMY3.
- TMYx can be used with building simulation software as TMY3.
- TMYx is updated regularly (every 2–3 years).

Based on the details provided above, DNV and Guidehouse proposed that both C&I and RESI programs use TMYx weather data to define a typical year weather for MA.

Key takeaway: C&I and RESI teams collaborated to develop and present a common method to generate the MATW dataset. WG participants decided that programs will use TMYx weather to define typical year weather for energy savings.

Next steps

The study work plan included a task to research how weather datasets have been developed in other jurisdictions for peak periods savings. WG members agreed the C&I and RESI teams should review peak periods definitions and discuss the value of using different weather datasets for peak and energy and present a method to be discussed during WG #2.2.

During the WG #2.2 session on December 2, 2022, stakeholders discussed the following topics:

1. Current definitions of peak periods
2. TMYx and peak periods
3. Recommendations
4. Suggested next stage activities
5. Next steps

WG #2.2 objectives

WG participants discussed the definitions of peak periods used by both commercial and industrial (C&I) and residential (RESI) programs in Massachusetts and the Massachusetts Technical Reference Manual (TRM) peak definitions to identify similarities and differences. Then, the WG discussed additional peak period definitions (on peak, seasonal, system peak, residential peak) and how to approximate them using the TMYx weather. Finally, the WG discussed the recommendations and decided on the next steps.

Current definitions of peak periods

DNV presented C&I peak periods definitions that are currently used by PAs. Then, DNV presented electric peak demand (kW) calculations methods used by evaluators. Evaluators use TMY3 weather dataset for both energy and demand calculations.

DNV then presented the peak definitions provided by the MA TRM, which included seasonal peak, not currently utilized by C&I PAs. Guidehouse then presented residential peak period definitions, including system peak, seasonal peak, on-peak (same definition as C&I), and residential peak.

Research findings

Guidehouse presented a table that explained how each of the new peak periods could be derived using the TMYx dataset:

- On-peak: This can be directly translated to TMYx.
- Seasonal peak: Derive a simple model from historical weather data and seasonal peak hours to predict seasonal peak hours in the TMYx data.
- System-peak: Derive a simple model from historical weather data and system peaks to predict system peak in the TMYx data.
- Residential peak: Use the same specified hours, on the modeled system peak day.

Key takeaway: WG concluded it is outside of the scope of the study to redefine peak periods. TMYx can be used similarly to TMY3 to calculate energy and demand during peak periods.

Ad-hoc discussion

The WG discussed the timing of switching from using the current weather files and the new MATW files. The WG decided the evaluators will use the new dataset as it will become available.

Key takeaway: The WG discussed the current approach to peak savings and concluded programs should remain using on-peak definition only. Evaluators will use the MATW dataset as soon as it will be approved and filed by stakeholders.

Recommendations

WG concluded evaluation working group would not define periods and agreed to maintain the current methods of calculating energy savings and on-peak demand (ISO NE definition) but using TMYx weather dataset instead.

Next steps

- T006 Add on in the draft work plan will be updated as follows:
    - T006 – Analyze impact of using TMYx dataset instead of TMY3 on energy consumption and peak demand
- PAs to confirm they're not using other definitions (system, seasonal, etc.) for peak besides on-peak definition in the MA TRM. Using other definitions would lead to additional analysis to calculate energy and demand.

APPENDIX C. TMYx WEATHER DATASET FORMAT

Table C-1 in this Appendix presents the description of fields provided in the TMYx weather dataset.

Table C-1. TMYx weather dataset fields

Field	Element	Unit or Range	Resolution	Description
1	Year	YYYY		Year at the time indicated
2	Month	MM		Month at the time indicated
3	Day	dd		Day at the time indicated
4	Hour	hh		Hour at the time indicated
5	Minute	mm		Minute at the time indicated
6	Data Source and Uncertainty Flags			The source flag indicates whether the data were measured, modeled, or missing, and the uncertainty flag provides an estimate of the uncertainty of the data. See EnergyPlus reference for additional information.
7	Dry Bulb Temperature (C)	Degrees Celsius	0.1º C	Dry-bulb temperature at the time indicated
8	Dew Point Temperature	Degrees Celsius	0.1º C	Dew-point temperature at the time indicated
9	Relative Humidity	%	1%	Relative humidity at the time indicated
10	Atmospheric Station Pressure	Pascal	1 Pa	Station pressure at the time indicated
11	Extraterres trial Horizontal Radiation	Watt-hour per square meter	1 Wh/m2	Amount of solar radiation received on a horizontal surface at the top of the atmosphere during the 60-minute period ending at the timestamp
12	Extraterrestrial Direct Normal Radiation	Watt-hour per square meter	1 Wh/m2	Amount of solar radiation received on a surface normal to the sun at the top of the atmosphere during the 60-minute period ending at the timestamp
13	Horizontal Infrared Radiation Intensity	Watt-hour per square meter	1 Wh/m2	rate of infrared radiation emitted from the sky falling on a horizontal upward-facing surface
14	Global Horizontal Radiation	Watt-hour per square meter	1 Wh/m2	Total amount of direct and diffuse solar radiation received on a horizontal surface during the 60-minute period ending at the timestamp
15	Direct Normal Radiation	Watt-hour per square meter	1 Wh/m2	Amount of solar radiation (modeled) received in a collimated beam on a surface normal to the sun during the 60- minute period ending at the timestamp
16	Diffuse Horizontal Radiation	Watt-hour per square meter	1 Wh/m2	Amount of solar radiation received from the sky (excluding the solar disk) on a horizontal surface during the 60-minute period ending at the timestamp
17	Global Horizontal Illuminance	Lux	100 lx	Average total amount of direct and diffuse illuminance received on a horizontal surface during the 60-minute period ending at the timestamp

Field	Element	Unit or Range	Resolution	Description
18	Direct Normal Illuminance	Lux	100 lx	Average amount of direct normal illuminance received within a 5.7° field of view centered on the sun during 60-minute period ending at the timestamp
19	Diffuse Horizontal Illuminance	Lux	100 lx	Average amount of illuminance received from the sky (excluding the solar disk) on a horizontal surface during the 60-minute period ending at the timestamp
20	Zenith Luminance	Candela per square meter	10 cd/m2	Average amount of luminance at the sky's zenith during the 60- minute period ending at the timestamp
21	Wind Direction	Degrees from north (360° =north; 0° = undefined, calm)	10°	Wind direction at the time indicated
22	Wind Speed	Meters per second	0.1 m/s	Wind speed at the time indicated, in tenths of meters/second
23	Total Sky Cover	Tenths of sky	1 tenth	Amount of sky dome covered by clouds or obscuring phenomena at the time indicated
24	Opaque Sky Cover	Tenths of sky	1 tenth	Amount of sky dome covered by clouds or obscuring phenomena that prevent observing the sky or higher cloud layers at the time indicated
25	Visibility	kilometer	1 km	Distance to discernable remote objects at the time indicated (7777 = unlimited)
26	Ceiling Height	Meter	1 m	Height of the cloud base above local terrain (77777 = unlimited)
27	Present Weather Observation			Please refer to EnergyPlus manual
28	Present Weather Codes			Please refer to EnergyPlus manual
29	Precipitable Water	millimeter	1 mm	Total precipitable water contained in a column of unit cross section from Earth to top of atmosphere
30	Aerosol Optical Depth	unitless	0.001	The broadband aerosol optical depth per unit of air mass due to extinction by the aerosol component of the atmosphere
31	Snow Depth	Centimeter	1 cm	Snow depth in centimeters on the day indicated, (999 = missing data)
32	Days Since Last Snowfall	Days	1 day	Number of days since last snowfall (maximum value of 88, where 88 = 88 or greater days; 99 = missing data)
33	Albedo	[unitless]	0.01	The ratio of reflected solar irradiance to global horizontal irradiance
34	Liquid Precipitation Depth	Millimeter	1 mm	The amount of liquid precipitation observed at the indicated time for the period indicated in the liquid precipitation quantity field
35	Liquid Precipitation Quantity	Hour	1 hr	The period of accumulation for the liquid precipitation depth field

*Value of -9900 indicates the measurement is missing.

APPENDIX D. TMYx DEGREE DAY VALUES BY WEATHER STATION

The Team updated the HDD and CDH values using TMYx weather and the following formulas:

$$HDD = \sum_{i=1}^{365}\left[Maximum\left(0{,}60°\text{F} - \frac{dailyMaximum + dailyMinimum}{2}\right)\right]$$

$$CDH = \sum_{i=1}^{8760}[Maximum(0, hourlyTemperature - 75°\text{F})]$$

Where,

HDD	= heating degree days
$dailyMaximum$	= maximum dry-bulb temperature in a given day as provided by TMYx
$dailyMinimum$	= minimum dry-bulb temperature in a given day as provided by TMYx
CDH	= cooling degree hours
$hourlyTemperature$	= dry-bulb temperature in a given hour as provided by TMYx

The two formulas discussed above are derived from Section 8 of the Massachusetts Multifamily Program Impact Analysis study report, which was finalized in July 2012. Table D-1 presents the HDD and CDH values that replace the values currently used by the Residential Programs.

Table D-1. HDD and CDH for residential program

Station Name	HDD	CDH
BARNSTABLE MUNI BOA	4,241	2,159
BEVERLY MUNI	4,736	3,799
BOSTON LOGAN INT'L ARPT	4,156	5,937
CHICOPEE FALLS WESTO	5,078	6,642
LAWRENCE MUNI	4,607	5,009
MARTHAS VINEYARD	4,335	2,234
NANTUCKET MEMORIAL AP	3,900	448
NEW BEDFORD RGNL	4,319	5,082
NORTH ADAMS	5,420	3,507
NORWOOD MEMORIAL	4,509	7,230
OTIS ANGB	4,440	2,420
PLYMOUTH MUNICIPAL	4,589	4,189
PROVINCETOWN (AWOS)	4,103	1,785
WESTFIELD BARNES MUNI AP	4,916	4,796
WORCESTER REGIONAL	5,082	3,207

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