Assessment of Future Typical Meteorological Year Data Files

Final Report | Report Number 21-01 | November 2020

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Our Vision:

New York is a global climate leader building a healthier future with thriving communities; homes and businesses powered by clean energy; and economic opportunities accessible to all New Yorkers.

Our Mission:

Advance clean energy innovation and investments to combat climate change, improving the health, resiliency, and prosperity of New Yorkers and delivering benefits equitably to all.

Assessment of Future Typical Meteorological Year Data Files

Final Report

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NYSERDA Report 21-01 NYSERDA Contract 153938 November 2020

Notice

Abstract

Weather data has a wide range of applications in the built environment such as the analysis of energy efficiency measures, life cycle cost, emissions, embedded carbon, and urban heat islands. For the past 40 years, building simulation efforts have usually relied on typical meteorological year (TMY) data, but recently some modelers have switched to alternate weather files, such as future typical meteorological year (FTMY) and extreme meteorological year (XMY) data.

This report summarizes the findings of the "Assessment of Future Typical Meteorological Year Data Files" study that explored the impacts of switching from existing TMY datasets (which generally use weather from 2005 and earlier) to recent or future-looking datasets. The study started with a literature review and stakeholder interviews, which revealed an active field of emerging research into weather files. Next, a weather file analysis explored the data variation of all available weather file types for three New York State locations. This analysis compared heating and cooling degree days, hourly temperatures, and the potential for passive design strategies across weather file types for envelope dominated buildings. Finally, EnergyPlus modeling examined how building energy use may be affected by switching to a different weather file type. The report summarizes the current state of weather file availability and usage, data variation among available formats, and impacts on projected energy use and passive design. The discussion identifies challenges to switching to new formats, types of analyses that will be most impacted, and recommended next steps.

Keywords

climate change, dynamic downscaling, extreme meteorological year (XMY), future meteorological year (FTMY), morphing, or time series adjustment, passive design, statistical methods, stochastic models, typical meteorological year (TMY), weather files

Acknowledgments

This worked was completed by Carrie Brown, Anna LaRue, and Vrushali Mendon from Resource Refocus LLC and Elizabeth Gilman and Nicholas Rajkovich from the University of Buffalo Department of Architecture. The project team would like to thank NYSERDA staff that participated in stakeholder interviews including James E. Wilcox and Hillel Hammer from the Energy and Environmental Analysis team, Steve Finkle, Patrick Fitzgerald, and Matt Brown from the New Construction Team, and Robert Carver from Advanced Buildings. They would also like to thank our external stakeholder interviewees including: Dru Crawley from Bentley Systems, Joe Huang from White Box Technologies, Seth Holmes from the University of Hartford Department of Architecture, Danny Tam and Bill Pennington from the California Energy Commission, Dan Suyeyasu and Ben Brannon from WeatherShift. And finally, they would like to thank Joe Huang and Parag Rastogi for providing weather files to use for the study.

Table of Contents

List of Figures

List of Tables

Acronyms and Abbreviations

AMY	Actual Meteorological Year
ANSI/RESNET/ICC	American National Standards Institute/Residential Energy Services Network/International Code Council
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
AWE-GEN-2d	Advanced WEather GENerator
C&S	Codes and Standards
CCWorldWeatherGEN	Climate Change World Weather Generator
CDD	Cooling Degree Days
CEC	California Energy Commission
CIBSE	Chartered Institution of Building Services Engineers
CityBES	City Building Energy Saver
ddy	Design Day
DSY	Design Summer Year
EDSL	Environmental Design Solutions Limited
EEM	Energy Efficiency Measure
epw	EnergyPlus Weather Data
EUI	Energy Use Intensity
FTMY	Future Typical Meteorological Year
GCMs	Global Climate Models
GHG	Greenhouse Gas
HDD	Heating Degree Days
HGA	Hammel, Green and Abrahamson
HVAC	Heating, Ventilation, And Air Conditioning
IBPSA-USA	United States regional affiliate of the International Building Performance Simulation Association
idf	Intermediate Data Format
IECC	International Energy Conservation Code
IOUs	Investor-Owned Utilities
IPCC	Intergovernmental Panel on Climate Change
ISD	Integrated Solar Database
JFK	John Fitzgerald Kennedy Airport
kBtu/sf	One Thousand British Thermal Units per Square Foot
kBtuh	One Thousand British Thermal Units per Hour
NREL	National Renewable Energy Laboratory
NSRDB	National Solar Radiation Database

NYCCSC	New York Climate Change Science Clearinghouse
NYC	New York City
NY	New York
NYSERDA	New York State Energy Research and Development Authority
NYS	New York State
PG&E	Pacific Gas and Electric Company
PHI	Passive House Institute
PHiUS	Passive House Institute US
PMV	Predicted Mean Vote
PV	Photovoltaic
RCMs	Regional Climate Models
RCP	Representative Concentration Pathways
SHGC	Solar Heat Gain Coefficient
TMY	Typical Meteorological Year
TRY	Test Reference Year
UKCIP	United Kingdom Climate Impacts Programme
XMY	Extreme Meteorological Year

Executive Summary

Weather data has a wide range of applications in the built environment such as the analysis of energy efficiency measures, life cycle cost, emissions, embedded carbon, and urban heat islands. For the past 40 years, building simulation efforts have usually relied on typical meteorological year (TMY) data, but recently some modelers have switched to alternate weather files, such as future typical meteorological year (FTMY) and extreme meteorological year (XMY) data.

This report summarizes the findings of the "Assessment of Future Typical Meteorological Year Data Files" study that explored the impact of switching from existing TMY datasets (which generally use weather from 2005 and earlier) to recent or future-looking datasets. The study started with a literature review and stakeholder interviews, which revealed an active field of emerging research into weather files. Next, a weather file analysis explored the data variation of all available weather file types for three New York State locations. This analysis compared heating and cooling degree days, hourly temperatures, and the potential for passive design strategies across weather file types for envelope dominated buildings. Finally, EnergyPlus modeling examined how building energy use may be affected by switching to a different weather file type. The report summarizes the current state of weather file availability and usage, data variation among available formats, and impacts on projected energy use and passive design. The discussion identifies challenges to switching to new formats and the types of analyses that will be most impacted.

Key Findings:

Weather File Analysis: For the three locations explored, cooling degree days (CDD) increase and heating degree days (HDD) decrease over time or with increased warming percentile. This increase in CDD is outweighed by the decrease in HDD, resulting in a lower number of total HDD and CDD annually. In all three locations, the warmer weather files all result in a higher number of hours for which the passive strategies can achieve comfort (based on the psychrometric chart analysis). However, the distribution of the available strategies within these totals varies.

Modeling Exercise: For this limited analysis, the overall trend is for decreased heating and increased cooling, and this is more pronounced in Buffalo than in NYC. For the all-electric single family model, energy use intensity (EUI) and peak demand decrease over time or with increased climate projection percentiles for this single-family heat pump example. But, this occurs with a general shift from heating to cooling needs. If a mixed fuel case were explored -- when the peak demand is likely to be driven by air conditioning in the summer months -- one would expect to see an increase in peak demand over time.

Lessons Learned: Challenges to switching to newer formats include: collective action problems, lack of vetted data available in formats that can be used in building simulation tools, and a lack of standardization. Examples of the types of analyses that will be especially affected include: decarbonization and fuel switching, peak loads, resiliency, and Codes & Standards and Programs (especially at the measure level).

1 Objectives

On behalf of the New York State Energy Research and Development Authority (NYSERDA), Resource Refocus and the University at Buffalo Department of Architecture conducted a short, exploratory study, Assessment of Future Typical Meteorological Year Data Files, to gather information about current practice in weather file applications, with an emphasis on the use of typical meteorological year (TMY) type data. The overall goal was to understand how weather data choice may impact energy efficiency measure (EEM) savings in program and code development protocols, as well as other building system design applications.

By gaining a better understanding of the effects of switching from existing TMY data sets, which generally use weather from 2005 and earlier, to more recent or future-looking data sets, NYSERDA can gauge whether to prioritize incorporating new weather data into future protocols. The study included the following elements:

- Task 1: Literature Review and External Stakeholder Interviews
- Task 2: NYSERDA Use Cases
- Task 3: Weather File Analysis and Modeling Exercise

1.1 Background

Weather data has a wide range of applications in the built environment such as the analysis of EEMs, life-cycle cost, emissions, embedded carbon, and urban heat islands. For the past 40 years, building simulation efforts have typically relied on TMY or reference year data,[1] but recently some applications have been switching to alternate weather files, such as future typical meteorological year (FTMY) and extreme meteorological year (XMY) data.

[1] Crawley, D., et al., 2019. “Should We Be Using Just ‘Typical’ Weather Data in Building Performance Simulation?” Building Simulation 2019 Proceedings. https://www.researchgate.net/publication/334469318_Should_We_Be_Using_Just_'Typical'_Weather_Data_in_Building_Performance_Simulation

1.1.1 Weather File Types

As described in the "Weather and Climate in Building Performance Simulation" chapter from *Building Performance Simulation for Design and Operation* (Crawley and Barnaby 2019, 192)*:*

> Traditionally, weather data for simulation have been represented in files of values for the 8760 hours of a year (or 8784 hours for a leap year). This form evolved for two reasons. First, until the 1990s, most weather observations were made manually; a one-hour measurement/reporting cycle was practical and sufficient for most applications. Second, a one-hour time step was (and still is) used in many building simulation models as a natural interval—short enough to capture behaviors of interest but long enough to allow practical execution times…
>
> The most common building modeling application is full-year hourly simulation to calculate energy use. Extensive effort has been applied to finding representative or typical weather years that allow estimation of long-term (multiyear) performance from a single-year analysis.

Building simulation tools require clean data in specific formats to successfully complete simulation runs, hence the development of standardized files of representative years. Early work in this area developed test reference year (TRY) files with data from ~1948–1975, which selected for milder months and did not include solar data. This methodology was updated with the typical meteorological year (TMY) approach. TMY-type weather files include comma-separated hourly data on dry-bulb air temperature, humidity, solar illuminance, cloud cover/sky condition, wind, ground temperature, ground surface albedo, atmospheric pressure, and precipitation (Crawley and Barnaby 2019, 197):

> A TMY is a composite of typical months, not necessarily from the same year. A data record of N years contains N Januaries, N Februaries, and so forth. Various methods have been used to select the best representative for each of the 12. All rely on statistical measures of the similarity of the distributions of daily indices such as minimum, mean, and maximum dry-bulb temperature; minimum, mean, and maximum dew-point temperature; mean and maximum wind velocity; and daily total global and direct solar radiation. Weightings are used for the indices, influencing their importance.

Early work includes:

- Test reference year (TRY): ~1948–1975 for 60 U.S. locations
- Design summer year (DSY): single continuous year; used for overheating analysis
- Typical meteorological year (TMY), derived from various periods of record:
  - TMY: 1948–1980
  - TMY2: 1961–1990 (updated to include newly available weather station data)

Weather file data has continued to evolve. TMY-type files currently in use include:

- Typical meteorological year (TMY):
  - TMY3: 1991–2005
  - TMYx or TMY4: compiled data from 2001 and forward (emerging research)
- Actual meteorological year (AMY) weather files include historical data for location for a single year (as opposed to the composite data found in TMY files).
- Extreme meteorological year (XMY) weather files represent the extremes of climate that the building will experience. An XMY starts from the same period of record as the TMY, but the methodology purposely selects more extreme months (Crawley and Lawrie 2015).
- Future typical meteorological year (FTMY) weather files attempt to represent future-looking weather changes that result from a changing climate. There are a wider range of methodologies to develop FTMY files and the time horizons represented vary anywhere from ten to hundred years in the future.

Of these weather file types, TMY3 files are the most readily available and the most commonly used for building performance simulation.

1.1.1.1 Weather File Use Cases

The "Weather and Climate in Building Performance Simulation" chapter by Crawley and Barnaby also summarizes simulation applications and their required weather data (pp. 194-195):

- **Engineering studies:** Can often use simple energy data such as bin temperature data.
- **Equipment sizing:** Most common data available are percentiles representing the average number of hours that a design condition will be exceeded.
- **Energy design and compliance analysis of fully conditioned buildings**: Representative single-year hourly data are sufficient.
- **Performance of un- or semi-conditioned buildings:** To analyze passive solar design and other "floating space temperature" problems, typical data are often not adequate; analyzing more extreme conditions or studying multiple years is recommended.
- **Model calibration, building troubleshooting, control optimization, and actual savings estimation:** Requires weather data observed during the study period at or near the building site; historical data are generally of little use.

- **Natural ventilation design:** Local wind conditions are highly variable and data from airport stations are notoriously unreliable for nearby sites, but custom data sets for wind driven ventilation studies are difficult to assemble.
- **Daylighting studies:** Although hourly illuminance data are sufficient to estimate electrical savings from sensor-control of lighting systems, detailed lighting studies involving visual comfort or control dynamics can require sub-hourly data.
- **Renewable energy systems:** The output of solar electric systems depends on short-term variation and spectral make-up of incident radiation. Wind turbine output is proportional to the cube of wind velocity. Standard hourly data may produce unreliable results, so sources with sub-hourly data are recommended.
- **Resiliency and extreme weather events:** TMY data is insufficient for determining the potential for the safety and habitability during heat waves, cold spells, or power outages.

These applications can be at the building level or in aggregate, such as estimating the overall savings from proposed code changes or energy efficiency program portfolios.

Crawley and Barnaby note "the practitioner must consider the processes being simulated and take care to select appropriate weather data as boundary conditions…Serious modeling errors can result from the use of inappropriate data. Conversely, there are situations where simple or representative data are sufficient; in these cases, seeking more detailed or 'accurate' information has little value. (p. 195)"

1.2 Literature Review and Stakeholder Interviews

This section provides information on various weather generators and weather data simulators, comparing the data they integrate and the output they provide. This includes climate models used and file types created. The reports and studies included in this review provide some insight to the validity and reliability of different file types and methodologies. Microsoft Excel spreadsheets were created to compare these differences; they are included as an appendix to this report.

1.2.1 Weather Generators and Simulators

Many different platforms and databases are available to provide access to future climate data, through either download from file generators or visualization by weather simulators. Most weather files are created to be used in building energy simulation applications, such as EnergyPlus and OpenStudio. While generators create and provide future weather data sets for simulation, simulators provide interactive graphics to demonstrate how and where the climate is changing. Some tools offer more localized data, specific to a state or region, while others provide information for multiple locations around the world.

Each data generator and simulator uses one or more of the emission scenarios developed by the Intergovernmental Panel on Climate Change (IPCC): A1FI, A1B, B1, A2, RCP 4.5, or RCP 8.5. These scenarios are applied to global climate models (GCMs), and regional climate models (RCMs) in some cases. While most of the reviewed generators and simulators specified the source of the GCMs used, not all elaborated on which specific models were used.

1.2.1.1 Generator Examples

The following section contains a summary of the weather generators included in this study. Information about weather simulators can be found the Weather Simulator appendix.

The following are generators included in this review:

- **Climate Change World Weather Generator** (CCWorldWeatherGen), developed by the University of Southampton Energy and Climate Change Division https://energy.soton.ac.uk/ccworldweathergen/
- **WeatherShift**, developed by Arup North America Ltd., Argos Analytics LLC, and Slate Policy and Design, http://www.weather-shift.com/heat
- **Climate Data Toolkit**, developed by Slipstream https://slipstreaminc.org/tools/climate-data-toolkit
- **Chartered Institution of Building Services Engineers (CIBSE) Weather Data Packages,** developed by CIBSE, Exeter University, UK Climate Impacts Programme (UKCIP), and Arup https://www.cibse.org/weatherdata
- **Meteonorm,** developed by Meteotest AG https://meteonorm.com
- **Advanced WEather GENerator** (AWE-GEN-2d), developed by the Institute of Environmental Engineering—Hydrology and Water Resources Management and the Faculty of Engineering and the Environment at the University of Southampton https://hyd.ifu.ethz.ch/research-data-models/awe-gen-2d.html
- **White Box Technologie**s, developed by: http://weather.whiteboxtechnologies.com/home

CCWorldWeatherGen, Climate Data Toolkit, and AWE-GEN-2d offer free downloadable climate data. WeatherShift, CIBSE, White Box, and Meteonorm require payment—whether per file or through a license fee. CCWorldWeatherGen, WeatherShift, White Box, and Meteonorm provide global coverage, which means that they can generally take an EnergyPlus Weather Data (.epw) format file for any location and use it to create a future weather file for that location. WeatherShift also has data for 259 cities around the world available for download through their interactive online platform, though only data for New York City is available for the State of New York. The other generators offer coverage at a more regional scale. For example, CIBSE provides data for 14 locations within the United Kingdom, and Climate Data Toolkit provides data for 16 locations across the United States—though none in New York State. When looking at the State, CCWorldWeatherGen, WeatherShift, White Box, and Meteonorm are more relevant applications due to their versatility in input data. They accept .epw files that can be downloaded from secondary sources, so any file that exists for a location in New York State can be turned into a future file using these programs.

In addition to varying locations, timescales also differ slightly between generators. WeatherShift and Meteonorm use and/or offer past, current, and future data, generally spanning from the 1980s to 2099. White Box also develops past, current, and future data, but the future data is generally developed through contracted requests (their files used later in this study were for the years 2035, 2055, and 2075). The other generators offer current and future data: CCWorldWeatherGen has data for the 2020s, 2050s and 2080s; Climate Data Toolkit has data for two individual years for each city, representing the years with the lowest and highest annual average dry-bulb temperature, within the period of 2041–2070*;* and CIBSE has data for 2020–2100. The time series used by AWE-GEN-2d for the input data is case dependent, but they try to use at least a 30-year time span for historical data. Their generated data is also case dependent, but they try to simulate a long, continuous range of years to capture the future climate, such as 2020 to 2100.

1.2.1.2 Generator Methodologies

As described by Dru Crawley in his March 2020 presentation, Climate Data in a Warming World, there are different methodologies used to create future climate data: dynamic downscaling, statistical models, morphing, and analog scenarios. The two most common methodologies found within the material included in the review are statistical methods and morphing.

Dynamic downscaling is a physics-based method used to downscale GCM results, "i.e. regional weather simulations driven by boundary conditions extracted from future climate simulations" (Muehleisen et al 2020, 400). GCMs are available at a rough spatial grid between 100km–300km and, generally, both generators and simulators will downscale the data to provide more detailed information. Dynamic downscaling is not bound by historical data and observations. Data also remain physically consistent across variables with this method. However, dynamic downscaling creates large data sets and, therefore, requires powerful computational resources and certain amount of expertise.

Statistical methods, stochastic models use and adjust observed data based on altered frequency distributions of weather variables to generate synthetic weather. Stochastic methods allow simulations to consider extreme weather conditions beyond what has been historically observed while remaining statistically accurate to respective locations. Along with extreme conditions, this method produces simulations that cover a wide range of possible climate conditions. Nonetheless, stochastic methods may not produce the most accurate climate variables within the simulated models because they rely on statistics based on historical observations, which influence the assumption that future weather patterns will resemble those historically recorded.

Morphing, or time series adjustment, is a common type of statistical method that "morphs" current TMY-type data sets. This method applies algorithms that either shift, stretch, or shift and stretch data to align with climate predictions.

According to Moazami, Nik, et al. in "Impacts of future weather data typology on building energy performance: Investigating long-term patterns of climate change and extreme weather conditions," morphing is a simple method that does not require a large amount of computing power. It is more flexible than other methods in that it can be applied to a large number of weather files from around the world, while still taking local climate conditions into account. However, the morphing method fails to consider the extremes of future weather conditions and does not capture the details of the potential changes in diurnal weather patterns. Due to differences in reference timeframes and files chosen to represent present day, there tends to be under- or overestimations of climate change impacts when using morphing methods. Additionally, because the climate variables are morphed individually, there tends to be lapses in consistency between the climate variables, shifting relationships between one another in comparison to how they are currently observed.

Analog scenarios find existing locations that align with future climate predictions.

1.2.1.3 Output

For temporal resolution, all generators reviewed output data at least hourly; in some cases, they also provided data every minute, day, and/or month. The future climate files produced by the generators all provide data in EnergyPlus Weather (EPW) format. CCWorldWeatherGen offers the download of TMY2 data sets and morphed data sets for future periods. CIBSE provides TRY (Test Reference

Year) and DSY (Design Summer Year) and uses those files to create data for future periods. This can be downloaded in Excel, EDSL Tas, and EPW formats. Meteonorm creates TMY2, TMY3, and TRY data sets, and offers downloads in over 30 file formats for use in solar thermal, PV simulations, and building simulation programs.

The online simulators offer downloads in raster formats, such as netCDF, geoTIFF, png, or as Excel spreadsheets. Future Urban Climates and CityBES did not offer any download options, though it could be assumed that screen captures could be taken as a form of download.

The generated climate files generally provide information on temperature, wind, radiation, precipitation, and humidity. The specific intentions listed by each generator and simulator, as to the reason the data set was created, varied from helping future proof buildings to the analysis of climate and energy. The most common intention listed was to assist in building, urban development, and infrastructure design.

1.2.1.4 Comparison Table of Weather Files

The tables attached to this report were used to compare the various components used for the generators, simulations, and reports. The first table, Table_Generators+Simulators, includes information on the generators and simulators, such as the following:

- Type (generator or simulator)
- Cost
- Coverage (global or regional)
- Output / Download Format
- Climate Scenario
- Climate Model Source
- Climate Model
- Variables / Parameters
- Resolution (spatial and temporal)
- Methodology
- Timescale
- Intended Use

The other two tables, Table_GENstudies and Table_FILEstudies, compare information for the different reports included in this review. Both tables include categories such as the following:

- Location
- Weather File Source
- Weather File Type
- Climate Scenario
- Methodology

1.2.2 Literature Review and Interview Summary

The literature review and stakeholder interviews showed a rich field of work centered on weather files with newer data—both using data from more recent years and incorporating newly available data, such as solar data from the Integrated Solar Database (ISD) and the National Solar Radiation Database. The following section summarizes the findings and general lessons learned from the literature review and interviews.

Weather generator studies: Various reports have studied and compared weather files created by different weather generators. As each generator uses different combinations of scenario information, climate model data, and methodology, the resulting climate files differ as well. Summaries of reports that explore how these differences in output affect building simulations and inform design strategies can be found in the Weather Generator Studies appendix.

Weather files studies: Similar to the studies that looked at the validity of the weather file generators, recent reports investigate the effectiveness of different file types and their creation using different climate model combinations. The general trend of these studies looks at how accurately weather file types, such as Typical Meteorological Year, represent both current and projected weather conditions. The Weather File Studies appendix contains a summary of the reports reviewed.

Stakeholder interviews: The team conducted interviews with key stakeholders outside of and within NYSERDA to gain additional insight into how and why different weather files are developed and used. An overview of the interviewees, their current work, and individual interviews is included in the External Stakeholders Interviews and NYSERDA Interviews appendices.

1.2.2.1 Weather File Types and Availability

While TMY3 weather files have historically been the industry standard for annual energy simulation, newer weather file formats are now readily available.

TMY3: TMY3 data is available from sources such as the NREL Data Catalog, EnergyPlus, Climate.OneBuilding, and White Box Technologies (24 New York locations are available).

TMYx, XMY, and AMY: Climate.OneBuilding provides TMYx weather files, while White Box Technologies has been developing TMYx (also called TMY4) weather files for specific locations. In addition to providing TMYx weather files using traditional TMY methods, White Box can also generate “trended” TMYx files that reflect warming trends seen in recent time periods. In California, these updated TMYx files are being used for code development (untrended) and utility incentive calculations (trended). White Box also provides AMY weather files for recent years, which can be used for engineering assessments of actual performance. Resilient Buildings provides a data set for 16 locations around NYS that includes AMY, XMY-minimum, XMY-maximum, TMY-30 (1986–2015), and TMY-7 (2009–2015) files.

FTMY: Active research is underway to develop FTMY weather files, which includes morphing and downscaling methodologies. Morphed FTMY files are available for purchase from WeatherShift for any location that has an .epw file.

1.2.2.2 NYSERDA Weather File Usage

NYSERDA interviews included staff from GHG Pathways, New Construction, Advanced Buildings, Codes and Standards, and Building Electrifications. More detailed information about these interviews, identified use cases, and example projects can be found in the NYSERDA Interviews appendix.

In general, NYSERDA New Construction Programs rely on third-party standards to demonstrate that program requirements are met. For Residential New Construction, these include Passive House Institute US (PHiUS), Passive House Institute (PHI), American National Standards Institute/Residential Energy Services Network/International Code Council (ANSI/RESNET/ICC), and ENERGY STAR® Multifamily High-rise/ENERGY STAR Multifamily New Construction. For Commercial New Construction, savings are calculated as compared to an ASHRAE 90.1 baseline. While the New Construction interviewees would be open to considering alternate weather data, changes to the current methodologies are reliant on the third-party standards. The New Construction team would like to incorporate climate resilience and has considered asking proposers to use FTMYs in their modeling, but they need more information on the requirements that they should request.

Codes and Standards (C&S), which currently uses TMY3 data, is one potential candidate for considering alternate weather data. However, it should be noted that depending on the compliance path, C&S also relies on several third-party standards and protocols, so care would need to be taken to maintain compatibility if considering a switch in weather data. There are also practical issues that arise. For example, more stringency may be needed to address increased cooling needs, but should cold weather measure specifications become more lenient for a warming climate?

The Advanced Buildings team uses both TMY and AMY data, so updated TMY files and recent historical AMY data could be useful to the team's work, particularly for measurement and verification projects that collect performance data. As an example, in the study Development and Testing of Fisonic Devices at the Woolworth Building in New York City (described in the NYSERDA Weather File Usage appendix), monthly average temperatures for the past 30 years from a local weather station were entered into a regression equation to estimate total annual space heating steam consumption to normalize the results to historical data.

Longer term studies such as the recent Pathways to Deep Decarbonization in New York State and the ongoing Carbon Neutral Buildings Roadmap have more complicated weather data requirements. Using data more recent than the 1991–2005 TMY3 period of record would likely provide more accurate results for the near future, but it is unclear how well that will predict longer term horizons, such as studies out to 2050. On the other hand, currently there are no standard protocols for using or vetting FTMY data.

1.2.2.3 Use Cases for Newer Weather Files

A number of key use cases for newer weather files were identified through the literature review and stakeholder interviews:

- TMYx: Codes and standards analyses, utility incentives, EEM optimization, and weather normalization for measured data.
- AMY: Measured performance in actual buildings.
- XMY: Resiliency design.
- FTMY: Longer term analyses (e.g., 2050 State goals).

TMY3: For comparative analyses, such as those that analyze total energy savings as compared to a baseline, results are less sensitive to the type of weather data used since some of the effects cancel out in annual simulations. For example, actual building performance as compared to modeled predictions may see decreased heating and increased cooling energy, but the total annual energy savings as compared to baseline is often similar. In addition, HVAC equipment sizing already incorporates safety factors of 20–50%, so sizing should still be sufficient with older data for the lifetime of HVAC equipment (about 15 years).

TMYx: Updated TMY files can incorporate recent weather changes into codes and standards analyses, EEM optimization, and weather normalization for measured data. Peak demand, end use breakdowns (e.g., heating, cooling, domestic hot water), and absolute energy usage are sensitive to the weather file selected. Accurately modeling the end use breakdowns is especially important when considering fuel choice options for electrification and decarbonization analyses. TMYx files are publicly available for limited locations.[2] The California Energy Commission (CEC) and the Pacific Gas and Electric Company (PG&E) recently contracted White Box Technologies to create custom TMYx files with data through 2017. PG&E and the other California investor-owned utilities (IOUs) opted for trended versions for the years 2006–2017 (which reflect warming in recent years) to support their Energy Efficiency programs, including their use in building energy simulations and spreadsheet calculations to determine energy savings from program activities and for normalizing that savings for weather variability. The CEC opted to use an untrended TMYx set for the years 1998–2017 to support Title-24 needs. White Box provided sample versions of these files for New York City and Buffalo as a courtesy for use in this analysis.

Interviewees also flagged that photovoltaic (PV) predictions are especially sensitive to weather data, although NREL's National Solar Radiation Database (NSRDB) satellite data is now readily available and a significant improvement over the previous data sets that were calculated. In 2012, the NSRDB changed from using "mainly empirical modeling and data collected at stations to using a physics-based modeling approach that provides solar radiation data for the entire United States in gridded segments (4 km x 4 km) using geostationary satellites." The TMYx and FTMY White Box files used in the Analysis for New York City and Buffalo do use this data, but it was not available when TMY3 data was developed.)

2 http://climate.onebuilding.org/ and Resilient Buildings Lab Data (https://resilientbuildings.org/data/)

AMY: Interviewees noted that TMY data is not appropriate for analyses that assess actual performance and that historical data (AMY files) should be used. (TMY files are still useful to weather normalize in the use of regression analysis with measured data.) In California, PG&E recently contracted White Box Technologies to develop AMY files for the last five years for use by consultants and contractors performing engineering assessments of actual building performance.

XMY: As our climate changes, there is an increased interest in resiliency design and passive survivability. Interviewees noted that all typical year formats are insufficient when assessing the impact of more extreme weather events and that XMY data should be considered for more resilient design. Here, designers can analyze building performance at the tail end of the weather distributions, which is especially important for measures with longer lifetimes, such as building shells which can last fifty years or more. In this case, end use disaggregation should be considered (as opposed to total annual performance) to better understand shifting load patterns and how that may impact design.

FTMY: Active research is underway to develop future looking weather files for longer term analyses, which includes morphing and downscaling methodologies. However, there are only a limited number of published studies that use FTMY data. The WeatherShift website notes that:

> Over 60 companies and research institutions have already taken advantage of the future climate files provided by WeatherShift to help provide a more resilient future for our built environment all over the world. Leading organizations that have been early adopters of WeatherShift data include Arup, Atelier 10, Beca, Center for Sustainable Building Research at University of Minnesota, DLR Group, HGA, Norman Disney Young, Renu Engineering, Stantec, TLC Engineering.

“Generating Future Weather Files for Resilience,” written by members of the WeatherShift team, describes several use cases including: 2015 ASHRAE Energy Modeling Competition, the design of campus buildings in California and Massachusetts, the Mesa City Center design in Arizona, and a New York Museum design competition (Dickerson 2016). “Sensitivity of Passive Design Strategies to Climate Change: Thermal Comfort Performance of Natural Ventilation in the Future,” uses future weather files from WeatherShift to run building energy simulations that look at the sensitivity and feasibility of achieving thermal comfort through natural ventilation. The study compares building performance both with and without natural ventilation for three different locations over time and the results showed that natural ventilation can help, to an extent, both now and in the future, but it largely depends on location and projected climate (Aijazi and Brager 2018).

1.2.2.4 Challenges to Switching Weather Data Formats

Through the literature and stakeholder review process, several challenges emerged that are applicable to NYSERDA and the field in general.

Collective action problem: Interviewees also noted that weather data choices are often a collective action problem that affects multiple stakeholders. For example, switching the weather analyzed during the codes and standards process should also affect the later incentive calculations, which often rely on national and international standards.

Cost-effectiveness calculations: There is also concern about how switching weather data will affect cost effectiveness calculations. For example, in some cases fuel switching decarbonization efforts may show less savings with warmer files due to decreased heating needs in the baseline. However, predicting cost effectiveness has many variables, so it is not at all obvious which way it might shift. For example, warmer files may result in decreased heating needs, but increased cooling needs—and gas and electric rates are both changing over time—so it is entirely possible that fuel switching decarbonization efforts may show more savings.

Lack of vetted data: A key challenge when considering a switch to future-looking weather files is that there is a lack of vetted data available in formats that can be used in building simulation tools. Weather files generated based on dynamic downscaling that account for both typical and extreme weather are the most reliable for simulations (Moazami et al 2019). Downscaling has the potential to provide high-resolution information, but the process is complex and computationally intensive, and dynamically downscaled FTMY weather files are not available in building simulation-ready TMY-type formats. Presented in October 2020, "Nationwide Impacts of Future Weather on the Energy Use of Commercial Buildings" describes the conversion of the dynamic downscaled global climate models into "weather data suitable for building energy simulation" (400) for ASHRAE climate zones 2A–8 (excepting 6B) for the single years of 2045 and 2090 (Muehleisen et al 2020). However, this is emerging research for a small number of locations and for single year (FMY) weather files and not "future" TMY (FTMY) files created from multiple years of FMY data. Furthermore, the authors note that it is "a very computationally intense alternative to morphing or stochastic weather generation…that can easily require weeks of computing time on even the world's largest supercomputers." (401)

Morphed FTMY data is readily available, but several recent studies have raised concerns over using morphed data. In one, the results showed that data output from RCMs increase time and computation demand without providing any significant advantage over a TMY analysis, and that using commonly available climate tools can lead to errors in building energy simulations (Dias et al 2019). Another compared CCWorldWeatherGen and WeatherShift to identify potential consequences that could arise from their differences. The study found that each generator uses different patterns in their application of morphing, resulting in different weather file outputs. For example, WeatherShift only modifies certain meteorological parameters as it morphs data (Moazami et al 2017).

> While a morphed weather file does have a realistic temporal variation of weather variables, the morphing procedure does not necessarily maintain the proper physical relationships between variables. The atmosphere is a highly nonlinear coupled system and a series of linear transformations applied to variables will not maintain those non-linear relations. Furthermore, expected changes of intensity, duration, and frequency of weather events such as heat waves, cold waves, clouds, and precipitation will not be reflected in the morphed files because the temporal variation follows that of the weather of today. (Muehleisen et al 2020, 401)

1.3 Analysis

The analytical portion of this study was split into two main tasks:

1. Weather File Analysis
2. EnergyPlus Modeling

The Weather File Analysis first explored the data variation of all available weather file types for three New York State locations that represented a wide range of climate types in the State. Then, the EnergyPlus Modeling task was designed to understand how building energy use may be affected by switching to a different weather file type. The team focused on envelope-dominated buildings (such as single-family or multifamily building types) which will be more affected by a change in weather than internal-load dominated buildings like large offices.

Table 1 provides an overview of the weather files explored for both of these tasks. For both steps, TMY3 weather files were used as the baseline, which were then compared to TMYx (also called TMY4), XMY, and FTMY.

TMYx Files: TMYx files were publicly available from Climate.OneBuilding and Resilient Buildings. As a professional courtesy to support the study, Joe Huang from White Box Technologies created custom TMYx files for the years 2001–2018: one using typical TMY methodologies and another trended version that represents the overall warming trend seen during the time period. The development of these files followed the same approach that he used for the Update of California Weather Files for Use in Utility Energy Efficiency Programs and Building Energy Standard Compliance Calculations, which is discussed in the Weather File Studies and External Stakeholder Interviews appendices.

XMY Files: XMY-min and XMY-max files were both publicly available from Resilient Buildings.

FTMY Files: Also, as a professional courtesy, Joe Huang collaborated with Parag Rastogi to generate downscaled FTMY files in New York City and Buffalo for 2035, 2055, and 2075, building on Parag's paper "On the sensitivity of buildings to climate: The interaction of weather and building envelopes in determining future building energy consumption," described in the Literature Review above. FTMY files were also purchased from WeatherShift. The WeatherShift tool adjusts weather files for future climatic conditions based on Representative Concentration Pathways RCP 4.5 (moderately aggressive mitigation) and RCP 8.5 (business as usual). Future time periods are available by decade from 2020 through 2090. As a mid-range scenario, the team selected RCP 8.5 for 2030, which represents business as usual projections from 2021–2040. FTMY files from WeatherShift provide 10th, 50th, and 90th percentiles of warming for the selected RCP and time period.

Table 1. Analysis Overview

TASK 3: MODELING			Step 1: Weather File Analysis			Step 2: E+ Modeling	
			NYC-JFK	Buffalo	Saranac / Indian Lake	NYC-JFK	w/ ddy edit
Set #1 TMY3 vs. TMYx	EnergyPlus	TMY3 (1991-2005)	x	x	x	x	-
	Climate.OneBuilding	TMYx (2004-2018)	x	x	x	x	x
	Resilient Buildings	TMYx (2009-2015)	x	x	x	x	
	Resilient Buildings	TMYx (1986-2015)	x	x	x	x	
	White Box	TMYx (2001-2018)	x	x		x	x
	White Box	TMYx-Trended (2001-2018)	x	x		x	x
Set #2 TMY3 vs. XMY	EnergyPlus	TMY3 (1991-2005)	x	x	x	x	
	Resilient Buildings	XMY-min	x	x	x	x	
	Resilient Buildings	XMY-max	x	x	x	x	
Set #3 TMY3 vs. FTMY	EnergyPlus	TMY3 (1991-2005)	x	x	x	x	-
	White Box/Rastogi	2035	x	x		x	x
	White Box/Rastogi	2055	x	x		x	x
	White Box/Rastogi	2075	x	x		x	x
	WeatherShift	RCP-8.5 10th percentile	x	x	x	x	
	WeatherShift	RCP-8.5 50th percentile	x	x	x	x	
	WeatherShift	RCP-8.5 90th percentile	x	x	x	x	

1.3.1 Weather File Analysis

This section describes the Weather File Analysis conducted for NYC-JFK, Buffalo, and Saranac Lake for all available weather file types, grouped by TMY3 versus TMYx, XMY, and FTMY.

1.3.1.1 Location Selection

Table 2 summarizes the types of weather files available for New York State locations. FTMY files are also available for purchase from WeatherShift for any location with a .epw file. To provide a wide climatic range, while choosing locations with the most files types available, working with NYSERDA, the team selected Buffalo, New York City, and Saranac Lake as the representative cities for NYS climate zones to explore in depth.

Table 2. Available Weather File Types for New York State

	Climate Zones		TMY-3 and more recent TMY data						FTMY data		
	IECC	NYS Climate (ClimAID)	Energy-Plus	Climate. One-Building	Resilient Buildings		White Box		White Box / Rastogi		
			TMY3	TMYx	XMY-min XMY-max	TMY-30 TMY-7	TMY4	TMY4 trended	Future weather years		
NY LOCATIONS			1991-2005	2004-2018	2009-2015	1986-2015	2001-2018	2001-2018	2035	2055	2085
Albany.Intl.AP	5	5	•	•	•	•					
Binghamton-Greater.Binghamton.AP-Link.Field	6	3	•	•	•	•					
Buffalo.Niagara.Intl.AP	5A	1	•	•	•	•	•	•	•	•	•
Chautauqua.County-Jamestown.AP			•	•							
Elmira-Corning.Rgnl.AP	5	3	TMY2	•	•	•					
Farmingdale-Republic.AP			•	•							
Glens.Falls-Bennett.Meml.AP			•	•							
Monticello-Sullivan.County.Intl.AP			•	•							
New.York-Central.Park.Obs-Belvedere.Castle	4	4	•	•	"NYC"	"NYC"	•	•	•	•	•
New.York-Kennedy.Intl.AP	4A	4	•	•	"NYC"	"NYC"	•	•	•	•	•
New.York-LaGuardia.AP			•	•							
Newburgh-Stewart.Intl.AP			•	•							
Niagara.Falls.Intl.AP			•	•							
Poughkeepsie-Dutchess.County.AP			•	•							
Rochester-Greater.Rochester.Intl.AP	5	1	•	•	•	•					
Saranac.Lake-Adirondack.Rgnl.AP / Indian Lake	6A	7	•	•	•	•					
Syracuse.Hancock.Intl.AP	5	6	•	•	•	•					
Utica-Oneida.County.AP			•								
Watertown-Fort.Drum-Wheeler-Sack.AAF	6	6	•	•	•	•					
Watertown.Intl.AP	6A	6	•	•							
Westhampton-Gabreski.AP			•	•							
White.Plains-Westchester.County.AP			•	•							

* WeatherShift FTMY files are available for purchase for any location with an .epw file.

1.3.1.2 Heating Degree Days and Cooling Degree Days

Heating degree days (HDD) are used to predict how much energy is needed to heat a building, and cooling degree days (CDD) measure the energy demand to cool a building. This analysis was conducted with Ladybug for Grasshopper. The temperature baselines were set to 65°F for both the heating and cooling degree days.[3] This indicates that once the outside temperature drops below 65°F, people within a building will generally begin heating the interior space. Conversely, when the outside temperature rises above 65°F, the building is generally cooled.

HDD and CDD were analyzed for each weather file for Buffalo, NYC, and Saranac Lake. The stacked bar charts below compare the HDD and CDD across the different weather files for Buffalo, NYC, and Saranac Lake. The bar on the far left represents the "baseline" TMY3 weather file (EnergyPlus 1991–2005). From left to right, the other bars are:

- TMYx (also called TMY4)
    - Climate.OneBuilding TMYx (2004-2018)
    - Resilient Buildings TMYx (2009-2015)
    - Resilient Buildings TMYx (1986-2015)
    - White Box TMYx (2001-2018)
    - White Box TMYx-Trended (2001-2018)
- XMY
    - Resilient Buildings XMY-min
    - Resilient Buildings XMY-max
- FTMY
    - White Box/Rastogi 2035
    - White Box/Rastogi 2055
    - White Box/Rastogi 2075
    - WeatherShift RCP-8.5 10th percentile
    - WeatherShift RCP-8.5 50th percentile
    - WeatherShift RCP-8.5 90th percentile

For consistency, the order of weather files on this chart is used throughout the rest of the analysis.

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[3] According to "Responding to Climate Change in New York State: The ClimAID Integrated Assessment for Effective Climate Change Adaptation in New York State," the relation between daily mean temperature and 65°F defines both heating and cooling degree days. A heating degree day is when the daily mean temperature falls below 65°F, and cooling degree days occur when the daily mean temperature rises above 65°F.

The results are compared to HDD and CDD gathered from the New York Climate Change Science Clearinghouse for the years 2034–2039, 2064–2069, and 2094–2099, the NYCCSC HDD and CDD were significantly higher than the results from all of the weather file types analyzed in all three locations. For the FTMY sets, CDD increase and HDD decrease over time or with increased warming percentile. The increase in CDD is outweighed by the decrease in HDD, resulting in a lower number of total HDD+CDD annually.

Figure 1. Heating and Cooling Degree Days by Weather File Type in New York City

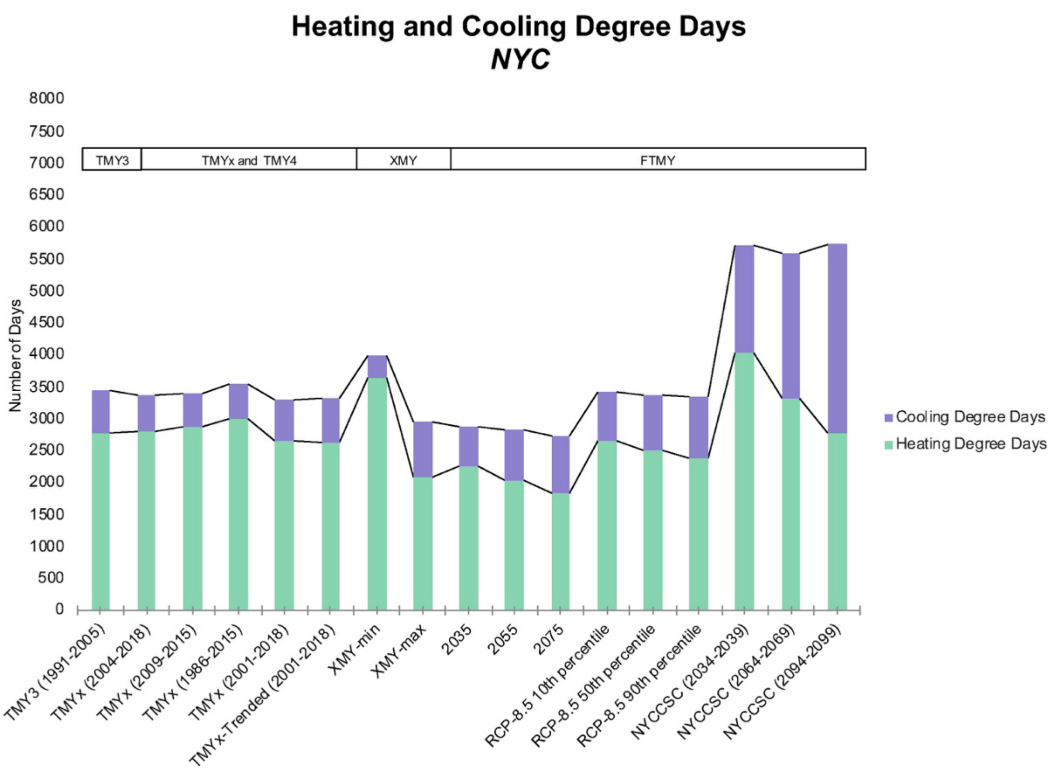


Figure 2. Heating and Cooling Degree Days by Weather File Type in Buffalo, New York

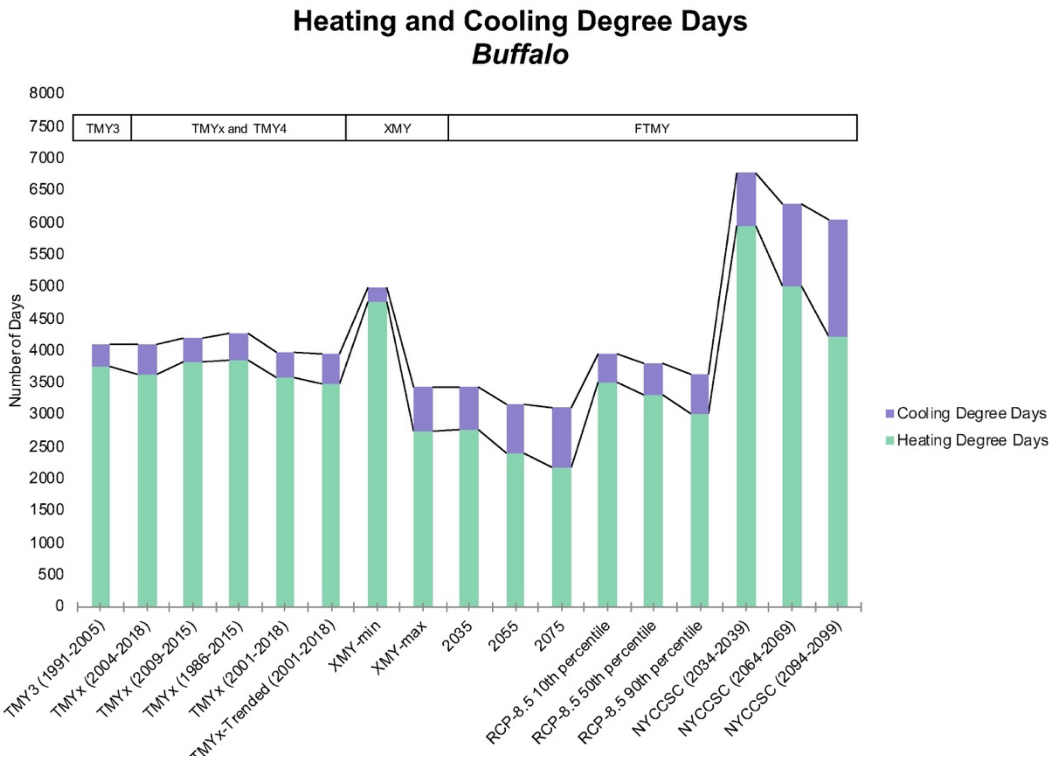
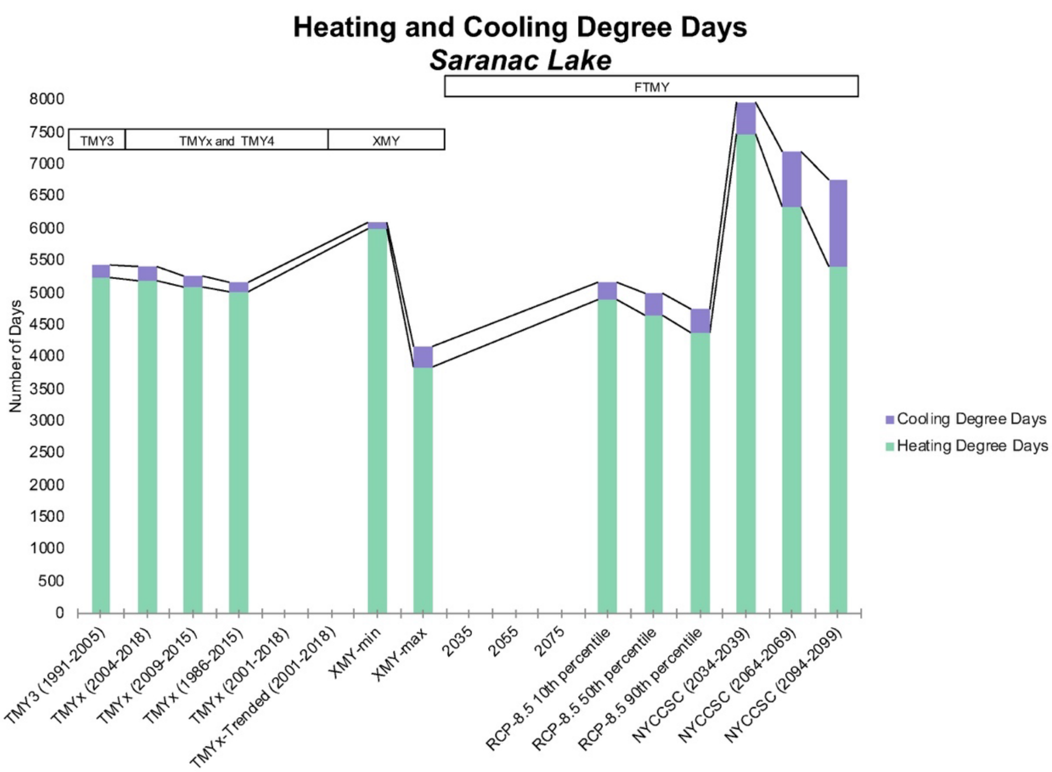


Figure 3. Heating and Cooling Degree Days by Weather File Type in Saranac Lake, New York



1.3.1.3 Monthly Temperatures

Figure 4 shows a box-and-whisker plot for TMY3 versus XMY-max and XMY-min outdoor air temperatures in Buffalo by month. The boxes represent the middle 50th percentile of the temperature points for each month, with a horizontal line across the box for the average. The "whiskers" show the top and bottom 25th percentiles, with outliers marked as dots. As expected, the two sets of FTMY files, White Box/Rastogi and WeatherShift, both show generally warmer temperatures than the TMY3 baseline. The WeatherShift FTMY files are generated by morphing the TMY3 data and as a result, we see similar patterns across the data. For example, in all four weather files we see high outliers in March and November (represented as dots at the end of the whisker). In all four sets, we also see a noticeably tighter range for the middle 50th percentile in November than in December. In contrast, the Whitebox/Rastogi files use a stochastic methodology instead of morphing. Here, we do not see the outlier patterns in March and November, and the range of the middle 50th percentile is comparable in November and December.

Figure 4. TMY3 versus FTMY Air Temperature by Month in Buffalo, New York

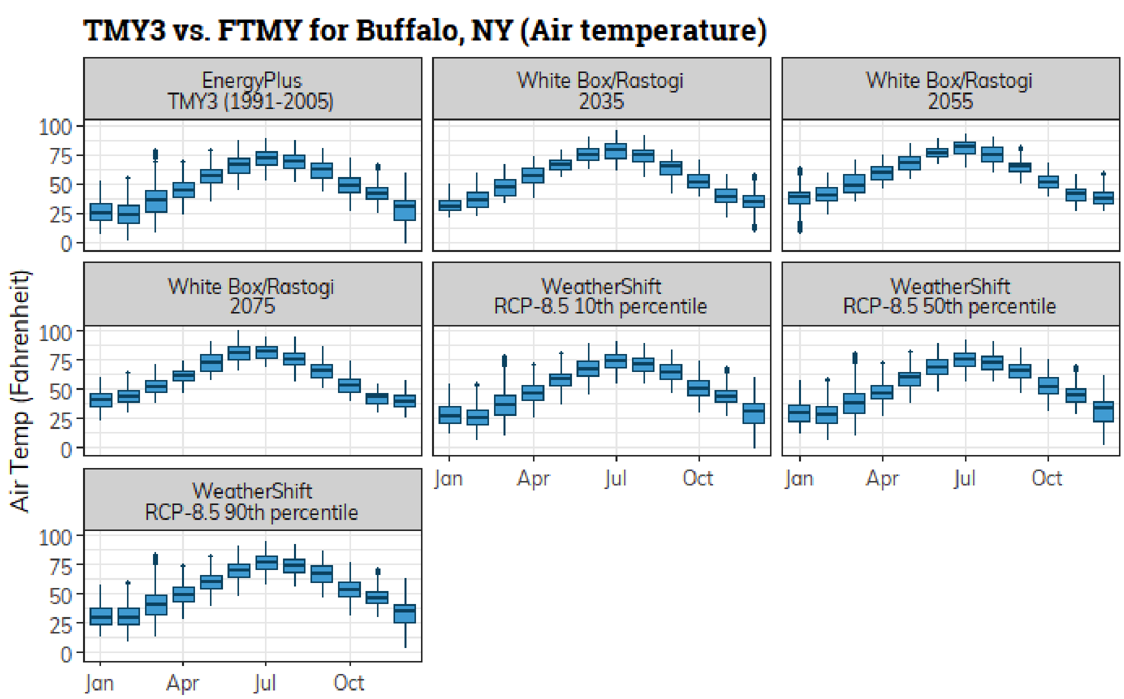
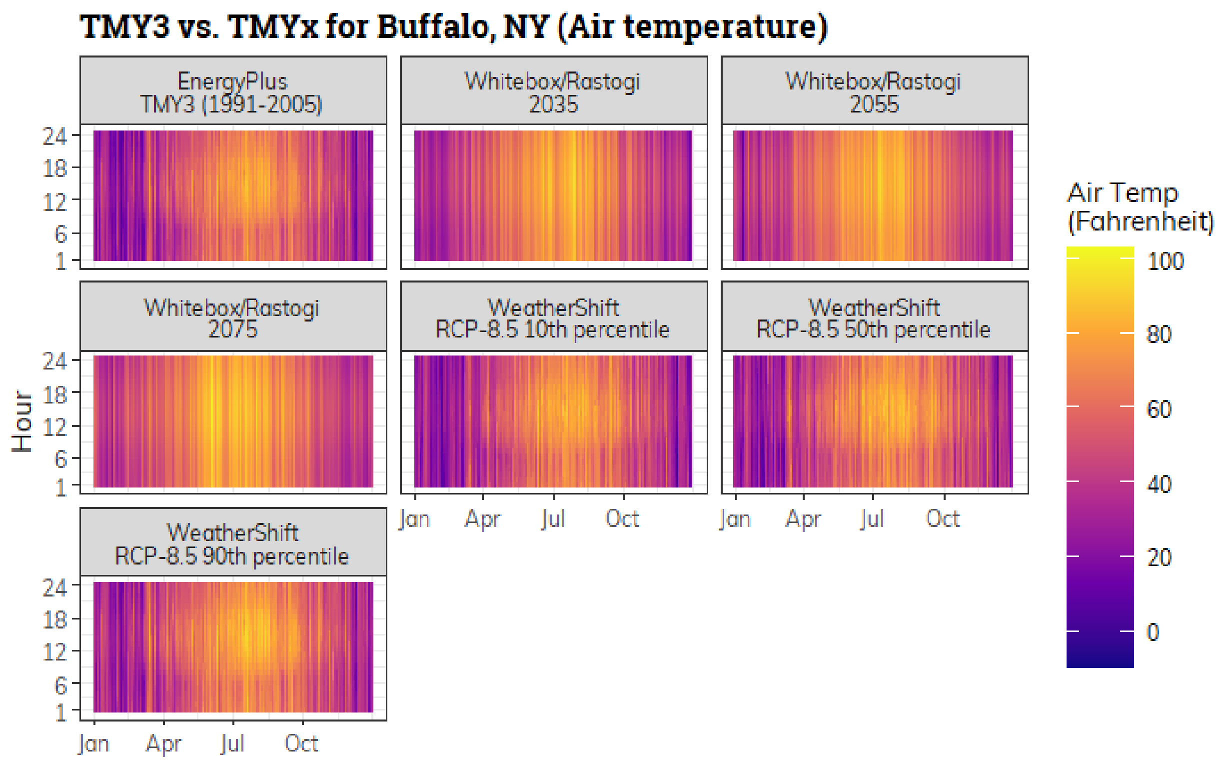


Figure 5 shows a heatmap of TMY3 and FTMY file air temperatures in Buffalo, the same set of data shown in Figure 5. In each chart, months are on the x-axis and hours of the day are on the y-axis. For each heat map, the bottom left corner shows the morning temperature on January and the upper right-hand corner shows the late-night temperature on December 31st. Again, as expected, looking across the White Box/Rastogi files (2035–2075) and the WeatherShift files (10th percentile to 90th percentile) shows a clear warming pattern—both in the winter and summer. The warm March outliers shown in the box-and-whisker plots are also visible as a brighter orange band just before April in the TMY3 and WeatherShift files, but not in the White Box/Rastogi files.

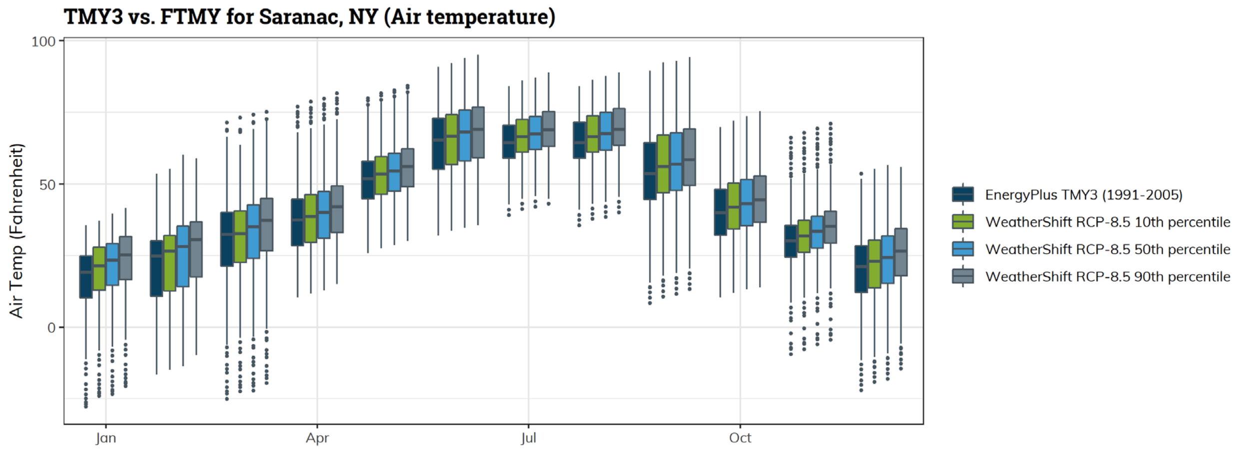
Figure 5. TMY3 versus TMYx Air Temperature by Month in Buffalo, New York



The Weather File Analysis section of the appendix provides heatmaps and box-and-whisker plots for TMY3 versus TMYx, XMY, and FTMY weather files for Buffalo, NYC, and Saranac Lake.

Figure 5 shows a box-and-whisker plot TMY3 versus WeatherShift FTMY monthly temperature in Saranac Lake, NY. White Box/Rastogi data was not available for this location, but by comparing just the TMY3 and WeatherShift data, the morphed shift upwards is clearly visible—each monthly plot is nearly identical, but just shifted slightly upwards with increasing RCP-8.5 warming percentile.

Figure 6. TMY3 versus FTMY Air Temperature by Month in Saranac Lake, New York



1.3.1.4 Passive Strategies

This section compares the applicability of passive strategies across weather file types for New York City, Buffalo, NY, and Saranac Lake, NY.

Psychrometric charts graphically represent parameters including dry-bulb temperature, wet-bulb temperature, enthalpy, relative humidity, humidity ratio, and dew-point temperature, and how they affect comfort levels. The charts are typically used to inform design decisions and the inclusion of passive design strategies. The psychrometric chart below was created using Ladybug for Grasshopper,[4] a plugin for Rhino.[5] It summarizes the number of hours that adaptive comfort and passive strategies are effective during the year, including the following:

- Adaptive comfort: Clothing levels set to 0.5 clo (summer attire), 1 clo (3-piece suit), and 2 clo (winter attire).
- Passive strategies: Evaporative cooling, thermal mass and night ventilation, occupant use of fans, capture internal heat gain, and passive solar heat gain.

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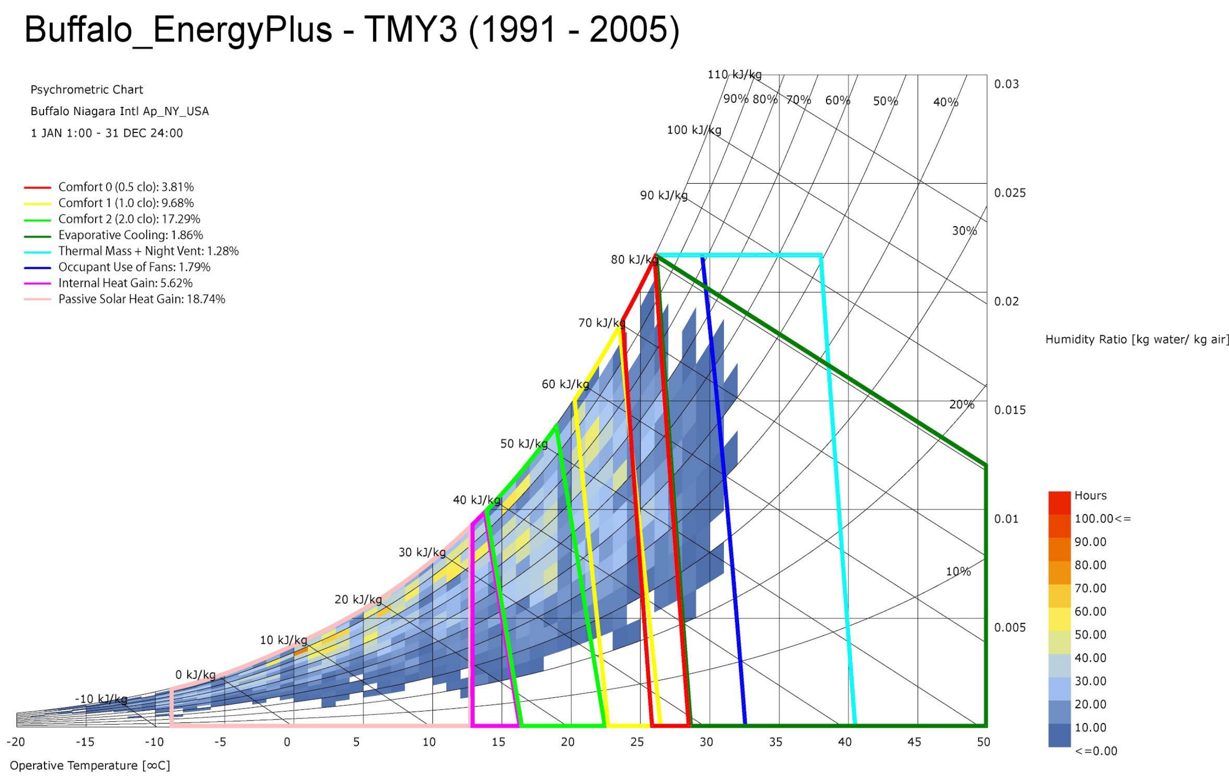
4 Food4Rhino (https://www.food4rhino.com/app/ladybug-tools) "Ladybug allows you to import and analyze standard weather data in Grasshopper; draw diagrams like Sun-path, wind-rose, radiation-rose, etc; customize the diagrams in several ways; run radiation analysis, shadow studies, and view analysis."

5 Rhino3D Features (https://www.rhino3d.com/6/features) "Rhino can create, edit, analyze, document, render, animate, and translate NURBS* curves, surfaces, and solids, point clouds, and polygon meshes. There are no limits on complexity, degree, or size beyond those of your hardware."

The percent of hours per year that these strategies are effective in providing comfort are represented by the colored boxes. In these charts, the comfortable range is defined as -1 to 1 Predicted Mean Vote (PMV).[6]

Figure 7. Psychrometric Chart for Buffalo, NY—TMY3 (1991–2005)

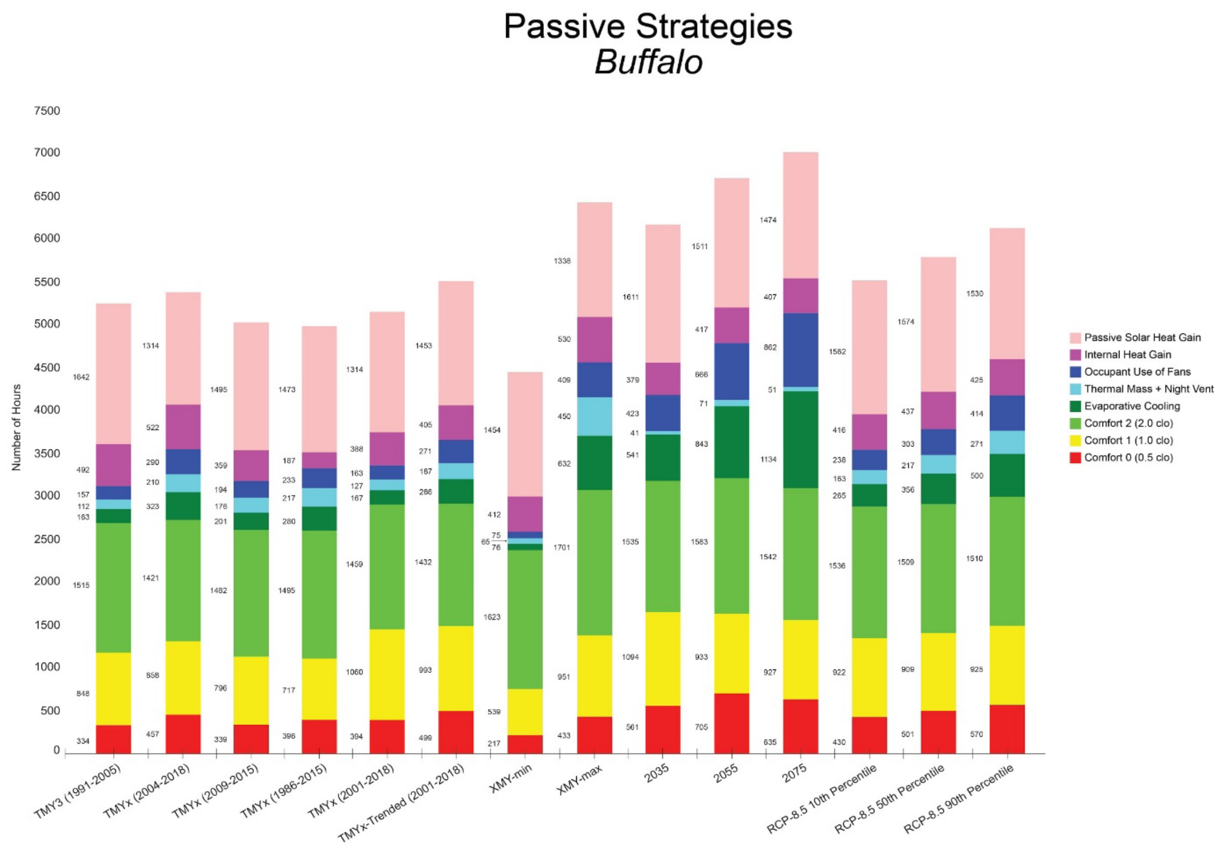


The psychrometric chart above is generated for the TMY3 weather file in Buffalo. The same chart was created for each available weather file in New York City, Buffalo, and Saranac Lake. The full set of charts can be found in the Psychrometric Charts appendix.

6 Grasshopper Docs (https://grasshopperdocs.com/components/ladybug/psychrometricChart.html) "The specific human energy balance model used by the psychrometric chart is the Predicted Mean Vote (PMV) model developed by P.O. Fanger. PMV is a seven-point scale from cold (-3) to hot (+3) that is used in comfort surveys. Each integer value of the scale indicates the following: -3:Cold, -2:Cool, -1:Slightly Cool, 0:Neutral, +1:Slightly Warm, +2:Warm, +3:Hot. The range of comfort is generally accepted as a PMV between -1 and +1 and this is what defines the range of the comfort polygon on the psychrometric chart."

The stacked bar charts below illustrate and compare how the hours of effective passive strategies (taken from the psychrometric charts) change across the different weather files for Buffalo, NYC, and Saranac Lake. As with the HDD/CDD charts above, the bar on the far left represents the “baseline” TMY3 weather file (EnergyPlus 1991–2005). From left to right, the other bars are TMYx (also called TMY4), XMY, and FTMY weather files.

Figure 8. Passive Strategies for Buffalo, New York



In all three locations, the warmer weather files all result in a higher number of hours for the passive strategies. For example, in the FTMY weather files, the White Box/Rastogi files increase the number of hours over time (2035–2075), while the WeatherShift files increase the number of hours with increased warming percentile. The XMY-max (warm year) files all have a higher number of hours as compared to the TMY3 file, while the XMY-min (cold year) files have a lower number of hours. However, the distribution of the hours within these totals varies. For example, in the FTMY White Box/Rastogi files, the potential for fans and evaporative cooling increases from 2035–2075, but there is little potential for thermal mass + night ventilation. For the WeatherShift files, all three strategies increase with increased warming percentile.

Figure 9. Passive Strategies for New York City

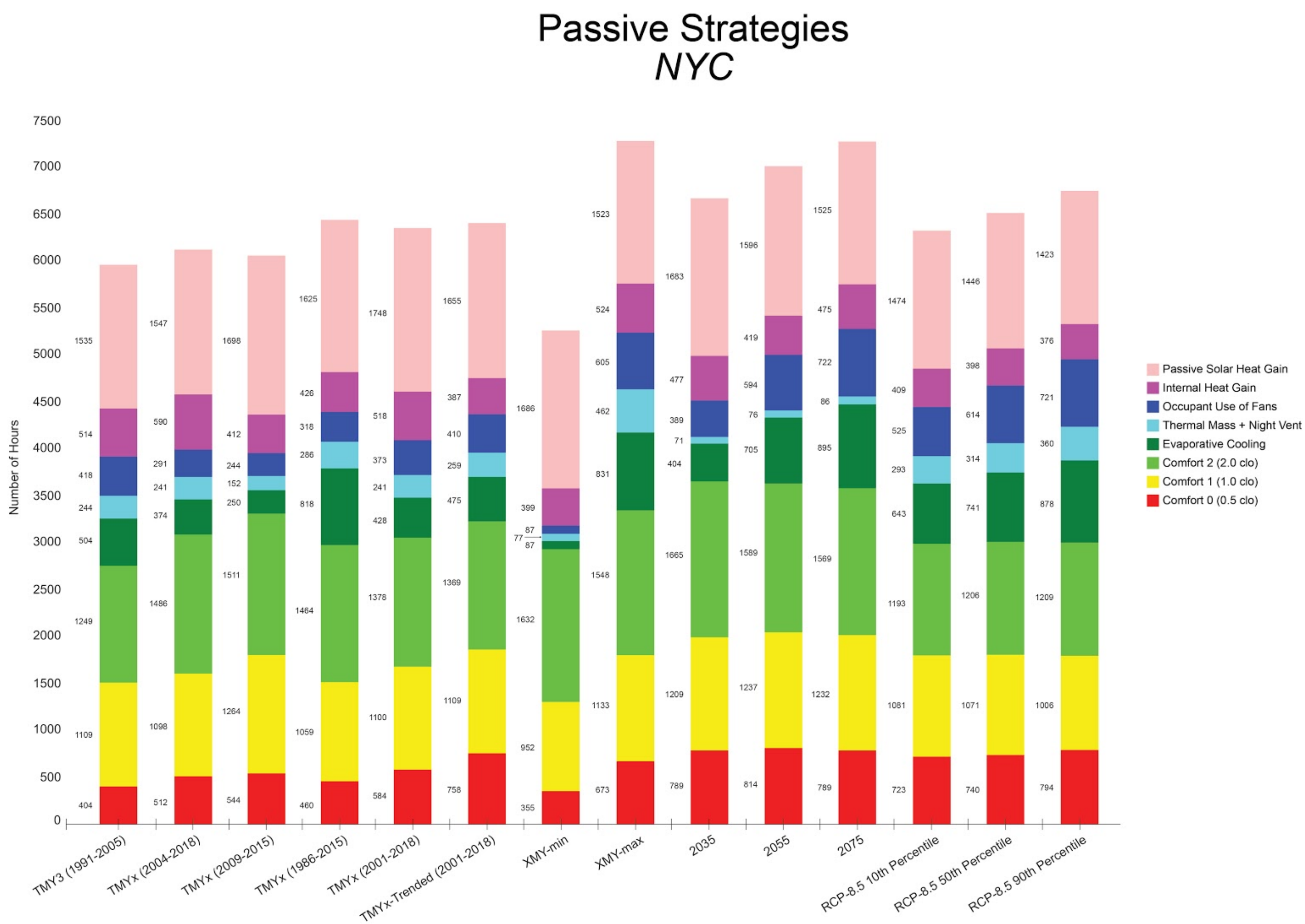
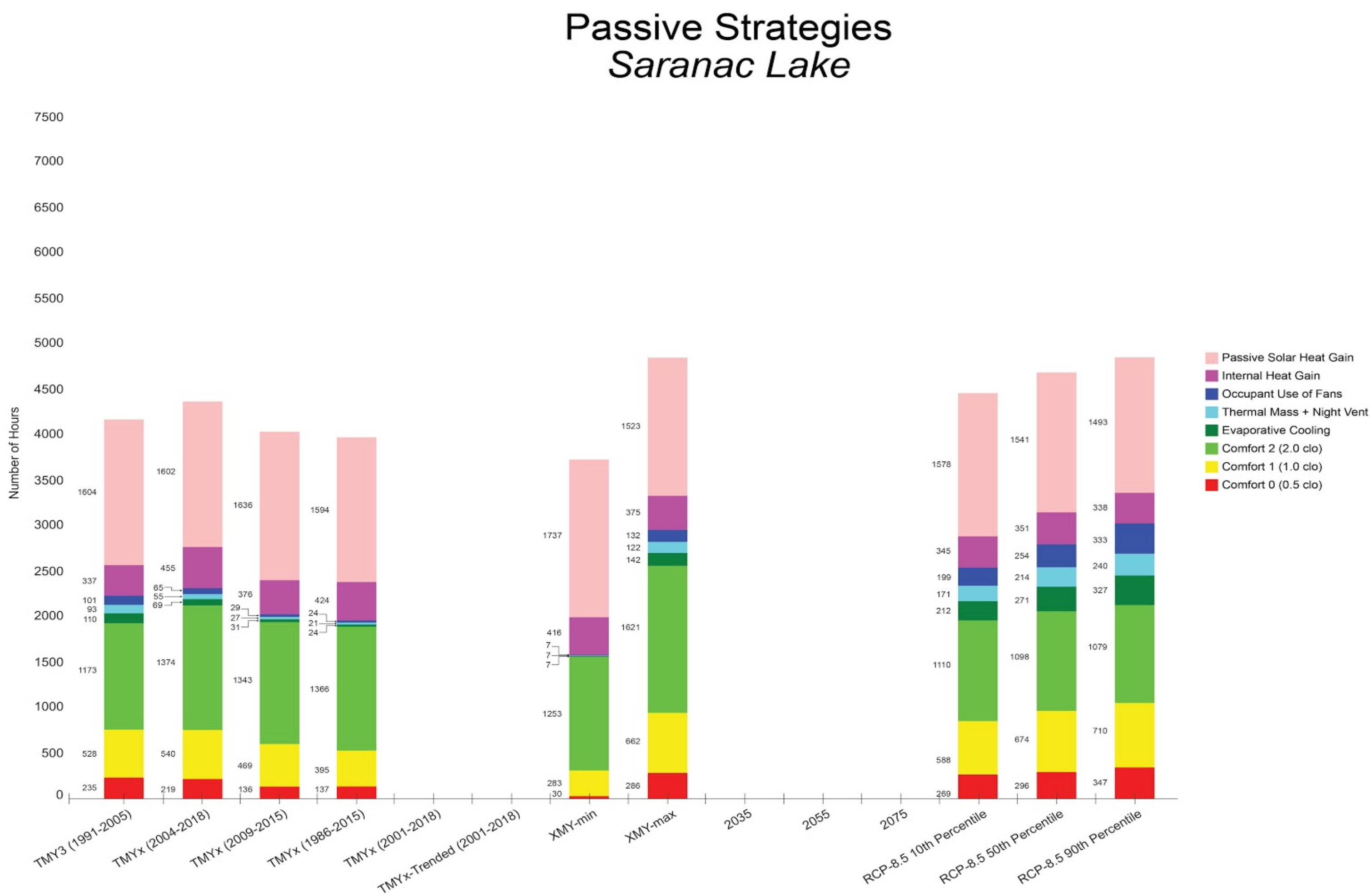


Figure 10. Passive Strategies for Saranac Lake, New York

Custom TMYx and FTMY files were created by Joe Huang (White Box) and Parag Rastogi for the study for Buffalo and NYC, but not Saranac Lake. These file types were left on the stacked bar charts for an easier comparison across locations.



1.3.2 EnergyPlus Modeling Exercise

Working with NYSERDA and incorporating feedback from the Stakeholder interviews, the team developed an exploratory modeling task to understand how building energy use may be affected by switching to a different weather file type.

The team focused on envelope-dominated buildings (such as single-family or multifamily building types) which will be more affected by a change in weather than internal-load dominated buildings like large offices. Furthermore, an envelope remains unchanged for the duration of the building's life—50 years or more—while HVAC equipment would be replaced 2–3 times during that period, so the envelope choices will see a greater change in climate over their lifespan.

1.3.2.1 Prototype Models

Resource Refocus previously developed EnergyPlus models for the Energy Savings and Cost-Effectiveness Analysis of the Residential Provisions of the 2018 International Energy Conservation Code, as Modified for the Provisions of the 2020 Energy Conservation Construction Code of New York State. These NYS-2020 models are representative of minimally code compliant new construction single-family and low-rise multifamily buildings in each of the three climate zones in the State. The 2020 code analysis was generally a comparative analysis to understand energy and cost savings of the proposed code changes, as compared to the previous code baseline. However, as noted during the Stakeholder interviews, comparative analyses results are less sensitive to the type of weather data used since some of the effects cancel out. For example, actual building performance as compared to modeled predictions may see decreased heating and increased cooling energy, but the total annual energy savings as compared to baseline is often similar.

For this exploratory study, the team opted to analyze absolute results (rather than savings over a baseline). Using NYS-2020 EnergyPlus models, the team compared site energy, end-use breakdowns, equipment run times, and peak demand under various weather files.

Since this was an exploratory study, the team wanted to focus on one building type to run through the simulations for each of the available weather files. To simplify this analysis, the team selected the electric-only heat pump example, rather than a mixed-fuel scenario.

Construction weights for single-family and multifamily buildings in the three New York climate zones were included in the NYS-2020 Code analysis. These weights were available for four foundation types and three fuel types. The team selected an unheated basement for the foundation,[7] since it was the most common heat pump foundation type, and single-family construction since it is more envelope-dominated.

1.3.2.2 ASHRAE Design Conditions

ASHRAE Standard 90.1-2019, Energy Standard for Buildings Except Low-Rise Residential Buildings and Standard 90.2-2018, Energy Efficient Design of Low-Rise Residential Buildings specify the heating and cooling design conditions to use for sizing HVAC equipment. This information can be found in the design day (.ddy) file that comes with standard TMY3 weather file packages. ASHRAE updates design conditions every four years in the ASHRAE Fundamentals Handbook, with the newest data set scheduled to be released on 2021.

If a user wants to run an EnergyPlus file in a new location, they should replace the "Site:Location" and "SizingPeriod:DesignDay" objects in the .idf input file using information gathered from the .ddy file. The Site:Location object specifies the latitude, longitude, time zone, and elevation. The SizingPeriod:DesignDay specifies the annual heating and cooling design conditions, which include a winter and summer design day and the weather conditions for those days. The heating and cooling design conditions are specified by the percent of the annual weather conditions covered and are available for different levels:

- Dry-bulb temperature corresponding to 99.6% and 99.0% annual cumulative frequency of occurrence (cold conditions) for heating system design.
- Dry-bulb temperature corresponding to 0.4%, 1.0%, and 2.0% annual cumulative frequency of occurrence (warm conditions) and mean coincident wet-bulb temperature for cooling system design.

One of the levels is typically selected for sizing heating and cooling systems in buildings. The NYS-2020 Code analysis used 99.6% heating and 0.4% cooling conditions, which are the most stringent of all available levels. However, during stakeholder interviews, it was suggested that this analysis should use the less slightly less stringent 1% cooling conditions to follow ASHRAE 90.1 and 90.2 guidelines. This means switching a design dry-bulb temperature, which would be exceeded

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7 Energy Savings and Cost-Effectiveness Analysis of the Residential Provisions of the 2018 International Energy Conservation Code, as Modified for the Provisions of the 2020 Energy Conservation Construction Code of New York State.

on average for 35 hours in the year of record, to a lower dry-bulb temperature threshold, which would be exceeded on average for 88 hours in the year of record. For example, in the Buffalo TMY3 ddy file, the 1% dry-bulb design temperature was 28.9°C, while the 0.4% was 30.3°C.

So, the NYS-2020 Code EnergyPlus .idf files were updated to switch from 0.4% to 1% cooling design conditions in New York City and Buffalo. The switch from 0.4% to 1% results in slightly lower design dry-bulb temperatures for cooling system sizing calculations resulting in smaller cooling capacity. These changes resulted in a slight increase in EUI and peak demand. The ASHRAE Cooling Design Conditions section in the appendix includes the EUI and peak demand end use breakdowns that resulted from these changes.

In the modeling exercise, the most accurate way to compare the effect of varying weather files would be to create a new EnergyPlus .idf input file for each weather file, using design conditions from the .ddy file associated with that weather file. However, as discussed earlier, only six out of the 13 weather file types provide this information (the TMYx file from Climate.OneBuilding and all five of the White Box files). The Design Days Edits in EnergyPlus section of the appendix compares the results in New York City before and after the design conditions were updated. In each case the site EUI changed by 0.1 kBtu/sf or less and the peak demand varied by 0.1 kBtuh or less. So, for the purposes of this exploratory analysis, we expect that the lack of updated design conditions for the Resilient Buildings and WeatherShift files would not have been a strong driver in changes to the overall energy usage and peak demand.

1.3.3 EnergyPlus Results

This section summarizes the results for the EnergyPlus modeling exercise. The NYS-2020 EnergyPlus files used for this analysis were single-family homes with a heat pump and an unheated basement. Since this was an exploratory study, the analysis was originally scoped to explore the results of all the available weather files in a single location, New York City. However, these runs were completed in less time than expected, so additional runs for Buffalo were also included.

1.3.3.1 New York City

Figure 11 shows the site energy use intensity (EUI) for a single-family home in New York City broken down by end uses. Four of these end-uses (interior lighting, exterior lighting, water systems, and interior equipment) are unaffected by the weather file and grouped at the bottom of the stacked bar charts. The remaining three end uses (heating, cooling, and fans) are affected by the weather file and their breakdown is included in the stacked bar chart. The bar on the far left represents the "baseline" TMY3 weather file (EnergyPlus 1991–2005). From left to right, the other bars are in the same order as the stacked bar charts above.

In most cases there is a decrease in heating as compared to the TMY3 baseline, resulting in a slight decrease in the overall EUI. For the TMYx weather files, there is a decrease in heating and an increase in cooling for the Climate.OneBuilding and the White Box untrended files. The Resilient Buildings TMYx files show a decrease in cooling, but a slight increase in heating, resulting in a slight increase in the overall EUI. As expected, the Resilient Buildings XMY-min (extreme cold year) has increased heating and decreased cooling, while the XMY-max (extreme hot year) shows the reverse. For the FTMY files, both sets show a general decrease in heating and increase in cooling over time, resulting in a downward trend for total EUI. The White Box/Rastogi FTMY files show more pronounced differences as compared the TMY3 baseline.

Figure 11. End Use EUI by Weather File Type for New York City

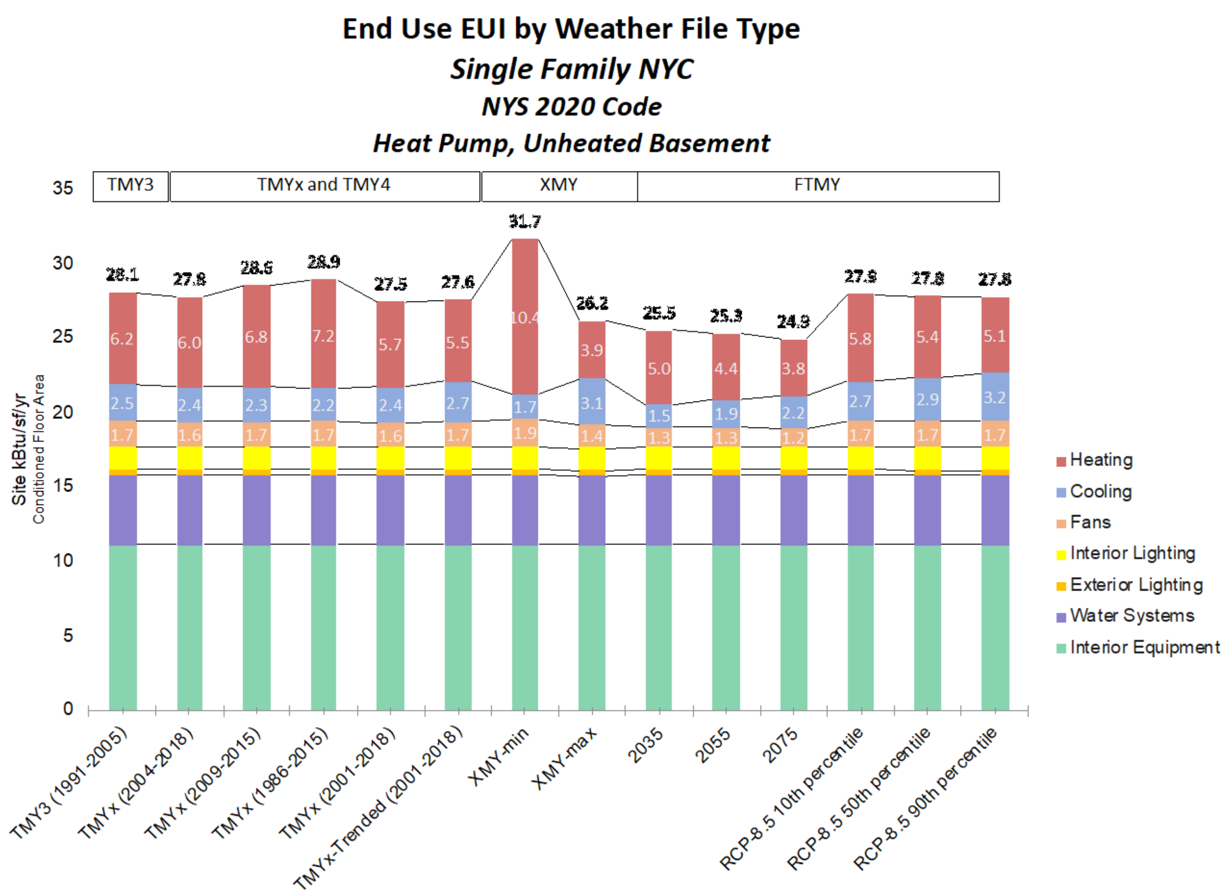


Figure 12 shows the peak demand broken down by the same set of end uses in the same order of weather files. Since this is a heat pump model, peak demand always occurs in the winter months and ranges anywhere from December 20th to February 20th. In the NYC runs, this peak demand always occurs in the early morning hours. Since the peak demand does not occur on the same day across the weather file types, there are slight differences in the end uses that are not affected by the weather file, but the key driver in peak demand differences is from heating. The general trends are the same as those in the EUI end use breakdown. In most cases there is a slight decrease in peak demand. For the TMYx weather files, again, this is true for the Climate.OneBuilding and the White Box files, while the Resilient Buildings data sets also show an increase in peak demand heating. As expected, the Resilient Buildings XMY-min (extreme cold year) has increased peak demand heating, while the XMY-max (extreme hot year) shows the reverse. For the FTMY files, both sets show a general decrease in heating over time, resulting in a downward trend for peak demand. The White Box/Rastogi FTMY files show more pronounced decreases as compared to the TMY3 baseline.

Figure 12. Peak Demand End Use Breakdown by Weather File Type for New York City

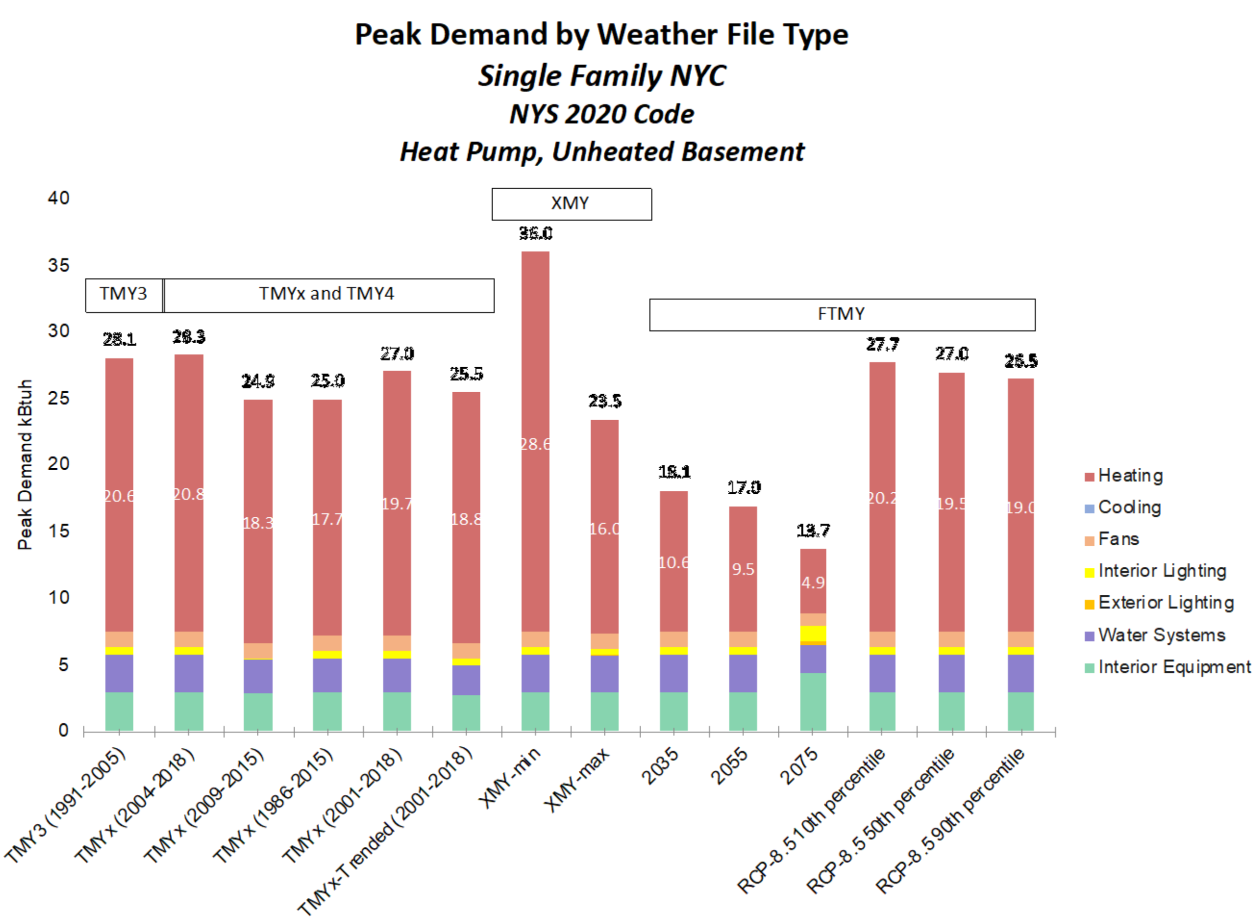
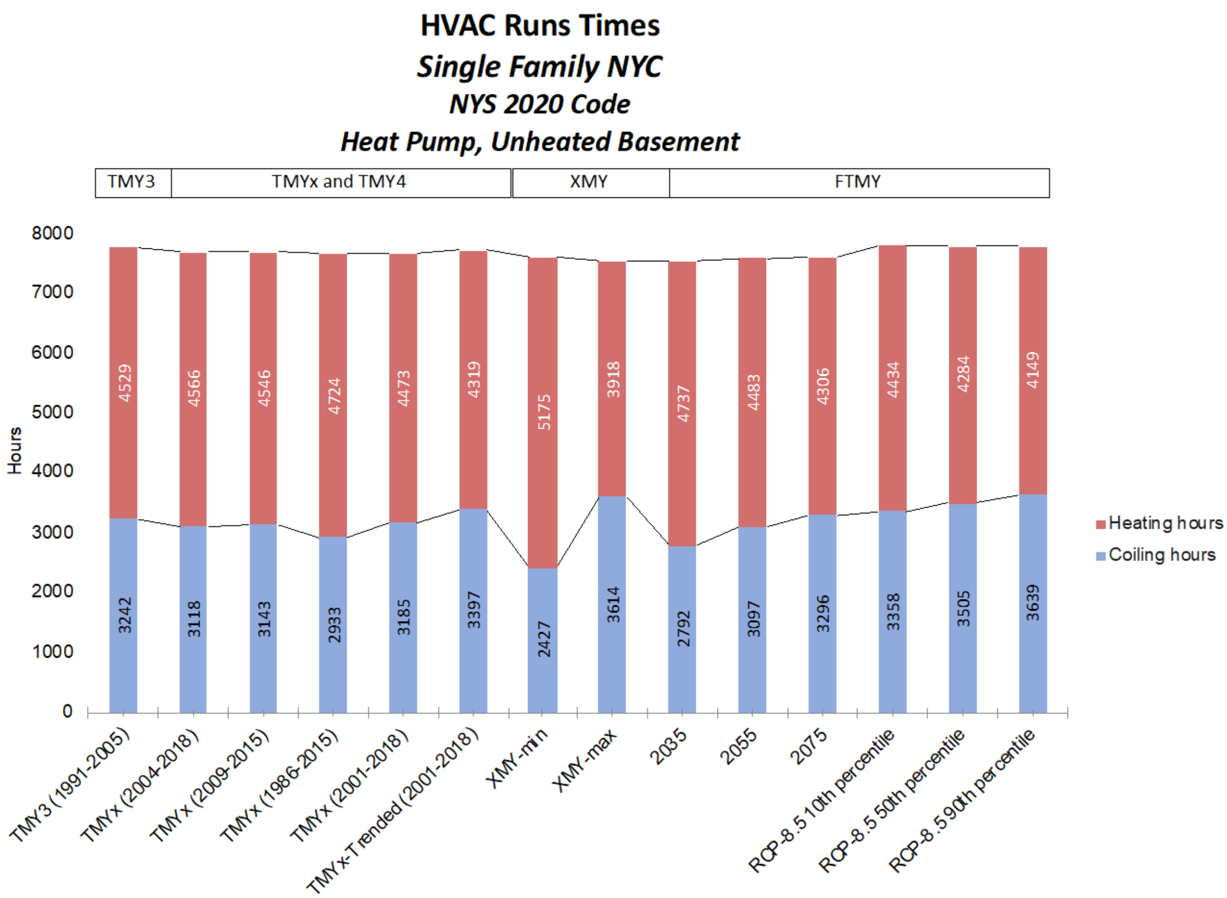


Figure 13 shows the number of hours that the heating and cooling equipment runs for each weather file. While the total number of hours remains almost constant across the weather files, in general there is a decrease in the heating hours and an increase in the cooling hours (with the exception of the XMY-min file).

Figure 13. HVAC Run Times by Weather File Type for New York City



1.3.3.2 Buffalo

Figure 14 shows the site energy use intensity (EUI) for a single-family house in Buffalo broken down by end use. In general, the same trends seen in New York City are also observed in Buffalo, but with more pronounced differences. In most cases there is a decrease in heating and an increase in cooling as compared to the TMY3 baseline, resulting in a slight decrease in the overall EUI. Again, for the TMYx weather files, this is true for the Climate.OneBuilding and the White box files, while the Resilient Buildings data sets also show a decrease in cooling, but a slight increase in heating, resulting in a slight increase in the overall EUI. Again, as expected, the Resilient Buildings XMY-min (extreme cold year) has increased heating and decreased cooling, while the XMY-max (extreme hot year) shows the reverse. For the FTMY files, both sets show a general decrease in heating and increase in cooling over time, resulting in a downward trend for total EUI, with the White Box/Rastogi FTMY files show more pronounced differences as compared the TMY3 baseline.

Figure 14. End Use EUI by Weather File Type for Buffalo, New York

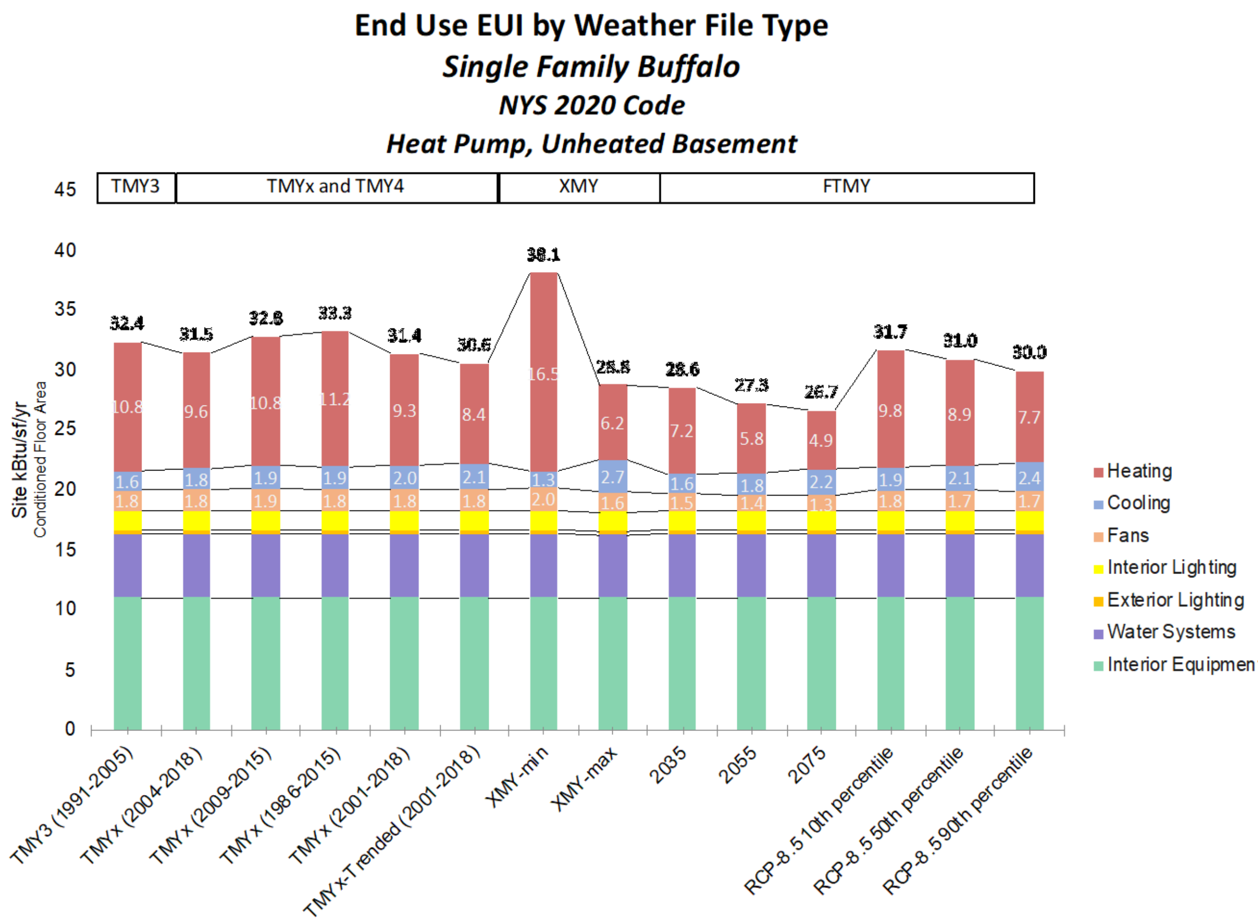


Figure 15 shows the peak demand broken down by end use. Since this is a heat pump model, peak demand always occurs in the winter months and ranges anywhere from December 11th to March 6th. These peaks occur in the early morning hours, with the exception of the XMY-max and the White Box/Rastogi 2055 files, which occur at 19:00 and 22:00, respectively. As in NYC, since the peak demand does not occur on the same day across the weather file types, there are slight differences in the end uses that are not affected by the weather file, but heating is the key driver in peak demand differences. In most cases there is a decrease in peak demand. For the TMYx weather files, this is true for the more recent Resilient Buildings file and the trended White Box file, but the other three show slight increases in peak demand heating. Interestingly for the White Box/Rastogi FTMY files types the peak demand is as follows:

- December 27, 2035 at 07:15—17.2 kBtuh
- January 12, 2055 at 22:00—23.8 kBtuh
- January 25, 2075 at 06:15—12.2 kBtuh

While peak heating demand is higher in 2055 than in 2035 or 2075, total EUI still trends down over time. In addition, as seen in Figure 16, heating run time increases and cooling run time decreases over time.

For the other weather file types, again, while the total number of hours remains almost constant across the weather files, in general there is a decrease in the heating hours and an increase in the cooling hours (with the exception of the XMY-min file).

Figure 15. Peak Demand End Use Breakdown by Weather File Type for Buffalo, New York

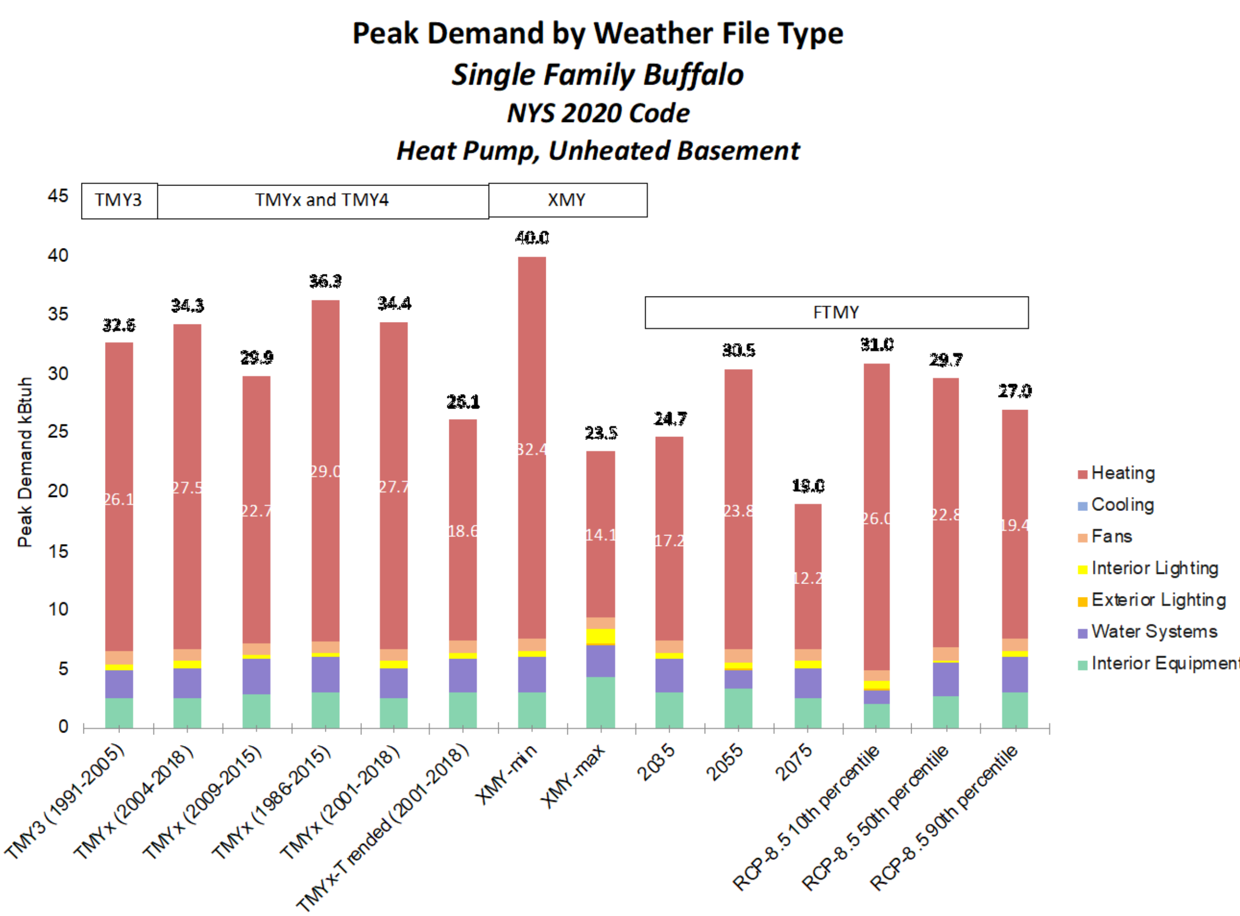
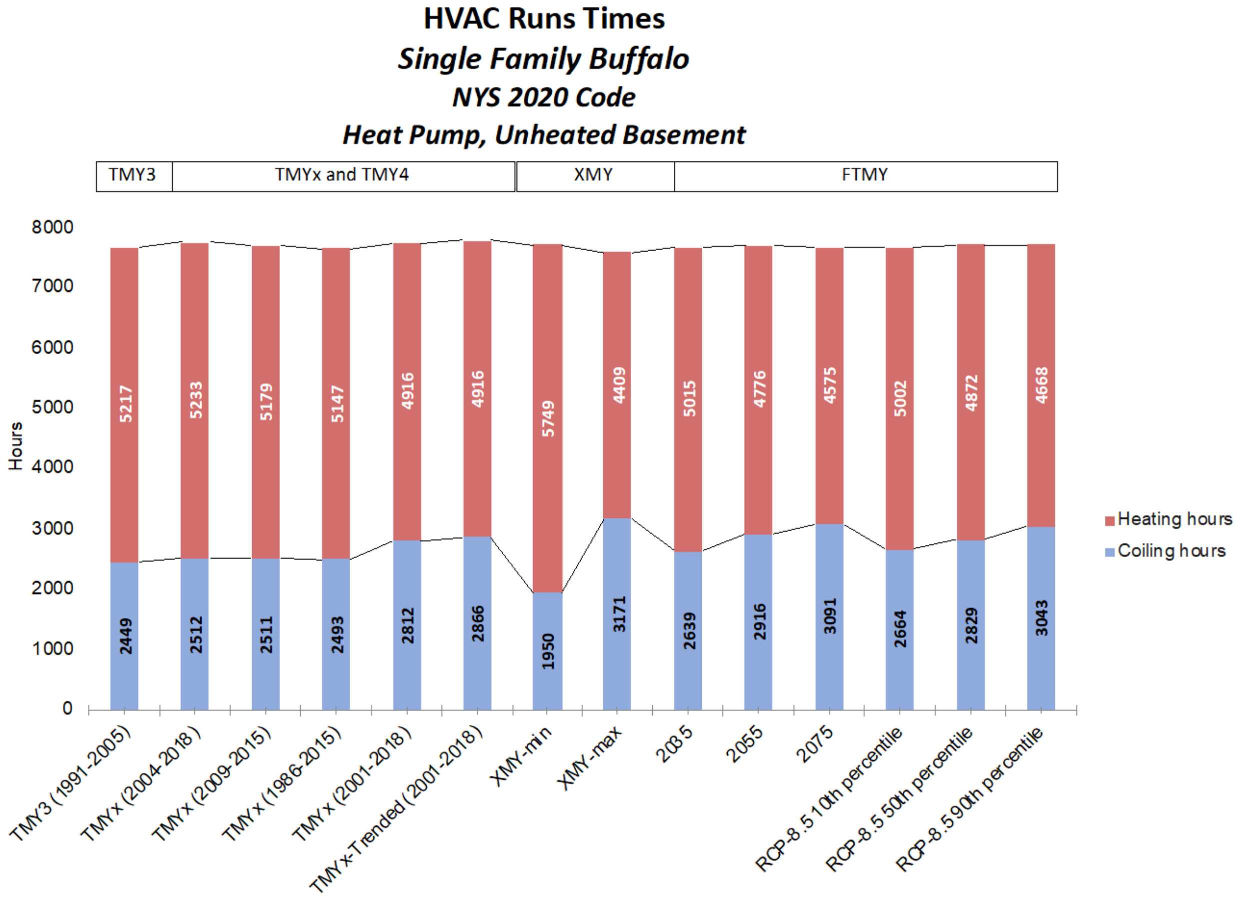


Figure 16. HVAC Run Times by Weather File Type for Buffalo, New York



1.3.3.3 Overall Results

Table 3 summarizes the percent difference from the TMY3 baseline for site, heating, cooling, and fan EUI; peak demand, peak heating demand; and heating and cooling equipment run times for NYC and Buffalo. The color scale shows the largest decreases in green and the largest increases in red, with the yellow gradient in between. In general, the overall trend for increased heating and decreased cooling is more pronounced in Buffalo. For both cities, the largest shifts are seen in the XMY files and the White Box/Rastogi FTMY files. However, even within the TMYx set, percent differences ranged from -22% to 34%, both of which occur in Buffalo for the White Box trended file. In both cities, across all weather file types, the Resilient Buildings TMYx and XMY-min files are the only ones that show an increase in heating. In Buffalo, the XMY-min file is the only one to show a decrease in cooling. In NYC, half of the files show a decrease in cooling, while the other half show an increase.

Table 3. EnergyPlus Results: Summary for Buffalo and New York City

			NYC								Buffalo							
			Site EUI kBtu/sf	Heating kBtu/sf	Cooling kBtu/sf	Fans kBtu/sf	Peak Demand kBtuh	Peak Heating kBtuh	Heating Hrs	Cooling Hrs	Site EUI kBtu/sf	Heating kBtu/sf	Cooling kBtu/sf	Fans kBtu/sf	Peak Demand kBtuh	Peak Heating kBtuh	Heating Hrs	Cooling Hrs
TMY3	EnergyPlus	TMY3 (1991-2005)	**28.1**	**6.2**	**2.5**	**1.7**	**28.1**	**20.6**	**3242**	**4529**	**32.4**	**10.8**	**1.6**	**1.8**	**32.6**	**26.1**	**5217**	**2449**
TMYx	Climate.OneBuilding	TMYx (2004-2018)	-1%	-3%	-4%	-3%	1%	1%	-4%	1%	-3%	-11%	11%	4%	5%	5%	0%	3%
	Resilient Buildings	TMYx (2009-2015)	2%	10%	-6%	-1%	-11%	-11%	-3%	0%	1%	0%	19%	7%	-8%	-13%	-1%	3%
		TMYx (1986-2015)	3%	17%	-10%	1%	-11%	-14%	-10%	4%	3%	4%	19%	4%	11%	11%	-1%	2%
	Whitebox	TMYx (2001-2018)	-2%	-8%	-2%	-6%	-4%	-4%	-2%	-1%	-3%	-14%	24%	4%	6%	6%	-6%	15%
		TMYx-Trended (2001-2018)	-2%	-12%	8%	-2%	-9%	-9%	5%	-5%	-5%	-22%	34%	4%	-20%	-29%	-6%	17%
XMY	Resilient Buildings	XMY-min	13%	68%	-33%	10%	28%	38%	-25%	14%	18%	54%	-18%	14%	23%	24%	10%	-20%
		XMY-max	-7%	-37%	25%	-14%	-17%	-22%	11%	-13%	-11%	-42%	67%	-9%	-28%	-46%	-15%	30%
FTMY	Whitebox/Rastogi	2035	-9%	-20%	-38%	-24%	-36%	-49%	-14%	5%	-12%	-33%	0%	-16%	-24%	-34%	-4%	8%
		2055	-10%	-29%	-25%	-25%	-40%	-54%	-4%	-1%	-16%	-46%	12%	-23%	-7%	-9%	-8%	19%
		2075	-11%	-39%	-12%	-27%	-51%	-76%	2%	-5%	-18%	-54%	37%	-25%	-42%	-53%	-12%	26%
	WeatherShift	RCP-8.5 10th percentile	-1%	-6%	9%	0%	-1%	-2%	4%	-2%	-2%	-9%	18%	-1%	-5%	0%	-4%	9%
		RCP-8.5 50th percentile	-1%	-12%	19%	0%	-4%	-5%	8%	-5%	-4%	-18%	31%	-2%	-9%	-13%	-7%	16%
		RCP-8.5 90th percentile	-1%	-17%	30%	0%	-6%	-8%	12%	-8%	-7%	-29%	50%	-5%	-17%	-26%	-11%	24%

1.4 Discussion

The literature review and stakeholder interviews revealed an active field of emerging research into weather files. The following section discusses overall challenges to switching weather data formats and high-level findings from the analysis, followed by a discussion of the implications for NYSERDA.

1.4.1 Challenges to Switching Weather Data Formats

Collective Action Problem: Interviewees noted that weather data choices are often a collective action problem that affects multiple stakeholders. For example, weather files are used by both Codes and Standards for measure analysis and by programs for incentive calculations. Switching the weather analyzed during the Codes and Standards process should also affect the later incentive calculations, but these often rely on national and international standards, which may not have the flexibility to accommodate new files.

FTMY Methodology and Data Availability: A key challenge when considering a switch to future-looking weather files is that there is a lack of vetted data available in formats that can be used in building simulation tools. Dynamically downscaled projections are considered to be more robust than morphed data, but they require significant computation efforts and expertise that are not readily available (Moazami et al 2019, Muehleisen et al 2020). Research by climatologists can develop terabytes of data to predict various future scenarios but condensing this information into a single typical year format is a significant undertaking. Currently, dynamically downscaled FTMY weather files are not available in building simulation-ready TMY-type formats.

Designer, consultants, and researchers have turned to FTMY weather files, which are readily available through tools that use morphing (e.g., WeatherShift's website states that over 60 companies and research institutions have used their files). However, several recent studies have raised concerns that morphed data cannot produce psychometrically/atmospherically correct weather (e.g., properly linked spatial-temporal changes in dry-bulb and wet-bulb temperatures, solar radiation, and wind). Argonne National Lab's report Nationwide Impacts of Future Weather on the Energy Use of Commercial Buildings, states that:

> The atmosphere is a highly nonlinear coupled system and a series of linear transformations applied to variables will not maintain those non-linear relations. Furthermore, expected changes of intensity, duration, and frequency of weather events such as heat waves, cold waves, clouds, and precipitation will not be reflected in the morphed files because the temporal variation follows that of the weather of today. (Muehleisen et al 2020, 401)

Looking forward, it is clear that more research is needed to convert dynamic downscaled GCMs into weather data suitable for building energy simulation. At this point, downscaling GCMs to RCMs to FTMY data is not available. The Argonne National Lab study, which was just published this October, is the closest effort that we found to making dynamically downscaled FTMY data. This work makes use of dynamically downscaled RCMs that were also developed by Argonne (Zobel et al 2017) for ASHRAE climate zones 2A–8 (excepting 6B) for the single years of 2045 and 2090 (Muehleisen et al 2020). The work is a promising step toward making dynamically downscaled FTMY files available, but in its current state, there are still limitations:

- This is emerging research for a small number of locations and for single year (FMY) weather files and not "future" TMY (FTMY) files created from multiple years of FMY data.
- The current Argonne RCMs stored data at three-hour timesteps, which needed to be linearly interpolated for the hourly weather files (radiation values at sunrise and sunset are probably the biggest concern here). After feedback from the buildings team, they plan to store hourly data in the future, but at this point this is not available. We also noted that IECC RCP scenarios are also in three-hour time steps (Bass et al 2020).
- Dynamic downscaling computations can take weeks on supercomputers.
- Even if the computational power is available, building scientists still need expertise from atmospheric scientists for guidance on which GCM to use. Right now, downscaling from one GCM to RCM to a single year generates 10s of TB of data (and this was at three-hour timesteps), so exploring many combinations of GCMs and years still is not feasible.

We reached out to the Argonne team and these files are not generally publicly available, but the team was able to share the .epw files with us for 4A, 5A, 6A (New York City, Buffalo, and Rochester, MN). (We did not receive the files until November, so they are not included in this analysis.)

It would be helpful to encourage better connections between the atmospheric scientists that develop these enormous data sets and the building engineers who want to boil the information down into usable future weather files so that they can work together to make dynamically downscaled FTMY files available for analyses.

Lack of Standardization: At a higher level, there is a clear need to standardize protocols for future weather files, for both the methodologies used to created them and the protocols for their use. There is also a need for better data sharing in general, such as publicly releasing the weather data used for projections and policy analysis and clearly documenting methodologies used to develop FTMY files. Right now, teams are working in isolation, there is no way to validate data, and no way to compare analyses since the methodologies used to develop FTMY files are often black box. ASHRAE does provide some guidance on climatic design, including the following:

- The design conditions in the ASHRAE Fundamentals Handbook Chapter 14 Climatic Design Information are updated every four years, with the next release due in 2021.
- ASHRAE Standard 169-2020 (which follows the data in Chapter 14 but lags slightly due to review cycles) continues to show shifting climate zones with each release, with locations categorized into warmer zones.
- Technical Committee 2.5 will be releasing a new chapter on Global Climate Change, but the material is not available for review yet.

1.4.2 Weather File Analysis and Modeling

Buffalo, New York City, and Saranac Lake were selected as the representative cities to explore in depth (based on their climatic range and weather file availability). The weather file analysis compared HDD, CDD, hourly temperatures, and the potential for passive design strategies across weather file types.

Of note for the HDD and CDD, *both* the HDD and CDD gathered from the NYCCSC were significantly higher than those seen in all of the weather file types analyzed in all three locations, indicating more extreme summers and winters. In contrast, for the FTMY sets, CDD increase and HDD decrease over time or with increased warming percentile. The increase in CDD is outweighed by the decrease in HDD, resulting in a lower number of total HDD+CDD annually.

In all three locations, the warmer weather files all result in a higher number of hours for which the passive strategies can achieve comfort (based on the psychrometric chart analysis). However, the distribution of the hours within these totals varies. For example, in the FTMY White Box/Rastogi files, the potential for fans and evaporative cooling increases from 2035 to 2075, but there is little potential for thermal mass + night ventilation. For the WeatherShift files, all three of these strategies increase with increased warming percentile.

In the exploratory modeling exercise to understand how building energy use may be affected by switching to a different weather file type, the team focused on envelope-dominated buildings which will be more affected by a change in weather than internal-load dominated buildings like large offices. Absolute results (rather than savings over a baseline) were analyzed because comparative analyses results are less sensitive to the type of weather data used since some of the effects cancel out.

For this limited analysis, the overall trend is for decreased heating and increased cooling, and this is more pronounced in Buffalo than in NYC. For both cities, the largest shifts are seen in the XMY files and the White Box/Rastogi FTMY files. In both cities, across all weather file types, the Resilient Buildings TMYx and XMY-min files are the only ones that show an increase in heating. In Buffalo, the XMY-min file is the only one to show a decrease in cooling. In NYC, half of the files show a decrease in cooling energy needed, while the other half show an increase.

In general, site EUI and peak demand decrease over time or with increased climate projection percentiles for this single-family heat pump example. But this occurs with a general shift from heating to cooling needs. If a mixed fuel case were explored—when the peak demand is likely to be driven by air conditioning in the summer months—we would expect to see an increase in peak demand over time.

1.4.3 So, What Does This Mean for NYSERDA?

Use Cases for Newer Weather Files: A number of key use cases for newer weather files were identified through the literature review and stakeholder interviews that may be applicable to NYSERDA:

- TMYx: Codes and Standards analyses, utility incentives, EEM optimization, and weather normalization for measured data. These newer data sets also make use of NSRDB satellite solar data, which is a significant improvement over the previous data sets that were calculated. Updated solar data is especially useful to PV predictions.
- AMY: Measured performance in actual buildings.
- XMY: Resiliency design.
- FTMY: Longer term analyses (e.g., 2050 State goals). In general, interviewees noted that careful attention to weather data is required since there are currently no standard protocols for FTMY file development and no vetting process for that data.

As discussed above, there is a general consensus that historical weather files are insufficient for properly modeling future scenarios. The challenge is that dynamically downscaled FTMY files are not available yet, but there are concerns over the accuracy of morphed data. Morphed data sets are being used out of convenience and necessity, but more research is needed to determine if these are good enough for decisions in the near term in the absence of a better alternative.

File selection aside, what types of analyses will be especially affected?

Decarbonization and Electrification/Fuel switching: Building electrification is a pillar of decarbonization goals. In the coming years, New York State expects to see a significant shift from gas to heat pumps for heating and domestic hot water. With this switch, some buildings that do not currently have air conditioning would add this load when installing a heat pump. In parallel, over time, it is expected that the number of HDD will decrease and CDD will increase, resulting in higher cooling loads statewide.

Predicting carbon intensity for the lifetime of a building is challenging because there are many moving pieces: (1) warming climate, (2) shifting from gas to electric use, (3) increasingly clean electric grid. Designers need to use the best information available to make informed decisions for efficient, low-carbon measure selection; selecting an appropriate weather file is definitely a piece of this decision-making process. In parallel, code officials and program designers need information about which measures to incentivize for long-term success.

Peak loads: The results of our limited analysis show that peak demand is especially sensitive to the weather file selection, with up to a 50% shift with the White Box / Rastogi files as compared to the TMY3 baseline. Our test case was an all-electric building with a heat pump, which peaks in the winter. So, in this case there was an overall decrease in winter peak demand with increased temperature. A mixed fuel building would have an electric peak in the summer driven by air conditioning, and with warming trends, we would expect to see an increase in peak demand with warming temperatures. Both cases have the potential for a significant shift in peak demand at the building level, but in opposite directions, presenting a challenge to resource planning. To further complicate planning at the grid level, as discussed above, with electrification, the State can expect to see increased electric load in both the winter and the summer as customers switch away from gas heating.

Resiliency: The research reviewed generally shows that with warming trends, energy consumption is expected to increase in strongly cooling dominated climates and decrease in strongly heating dominated climates in the long term. New York State is heating dominated and we do not expect that to change, but we do expect to see a decrease in HDD and an increase in CDD. Our exploratory analysis in Buffalo, New York City, and Saranac Lake predicts that with warming trends, we will see: (1) a general decrease in heating and an increase in cooling energy and (2) the number of available hours for passive strategies will increase with warming trends.

So, there may be more ability to leverage passive design strategies, but designers need guidance now to make decisions that will be advantageous in the long term. What should proactive designers today do to increase passive survivability in the long term? Resilient design should be prepared to handle both sustained stresses (such as increased average temperatures) and shocks (such as an increase in extreme weather events). What analysis methodologies and weather files should NYSERDA recommend now for future-proofing design? In the absence of the availability of dynamically downscaled FTMY data are morphing or statistical FTMY methods sufficient? Or should designers consider analyses with XMY for extreme conditions? At this point, more research is needed.

The NYC Mayor's Office of Resiliency has developed Climate Resiliency Design Guidelines. Most recently updated in September 2020:

> The primary goal of the Guidelines is to incorporate forward-looking climate change data in the design of City capital projects. Codes and standards that regulate the design of facilities already incorporate historic weather data to determine how to design for today's conditions. However, historic data does not accurately represent the projected severity and frequency of future storms, sea level rise, heat waves, and precipitation. The climate is already changing and will continue to change in significant ways over the full useful life of facilities designed today, threatening to undermine capital investments and impede critical services if they are not designed for future conditions. (5)

The document provides guidance on which timescale of climate projections to select based on both the useful life of the building overall and the useful life of building components (e.g., distinguishing mid-term electrical, HVAC, and mechanical components from the longer-term overall building design decisions). The guidelines do not provide weather files, but they do provide overall statistics on projected mean temperature changes, extreme events, and basic HVAC design condition information. For example, the 1% cooling design conditions provided for the useful life of today's HVAC equipment is 98°F, significantly higher than the 91°F 1% cooling design conditions from historical data.

Codes and Standards and Programs: In New York State, Codes and Standards and programs currently both rely on TMY3 data, as does most of the country. One exception is California, which has switched away from TMY3 weather files for several State applications:

- TMYx data for codes
- Trended TMYx data for some utility incentive calculations
- AMY data available for measurement and verification

But California is also unique because it has its own set of codes. Codes in New York are based on IECC and program incentives rely heavily on third-party protocols. So, any weather file updates would need to be coordinated in conjunction with existing protocols.

Even within our limited modeling test case, we saw quite a bit of variability on the impact on end use breakdowns and peak demand. Right now, code measures are selected based on historical weather data, but these recommendations may shift if future weather trends were considered. This is especially relevant for envelope design, which has a long useful life. As an example, climate zone 5A does not currently have a solar heat gain coefficient (SHGC) requirement for windows, but 4A, which is warmer, does. Should cooler zones become more stringent on heat reducing envelope measures to account for warming trends? Furthermore, Codes and Standards only use a limited number of climate zones, so counties are matched as closely as possible. Counties matched on the edge of a climate zone may be more affected by warming trends since measures are selected by historical data, and they were already matched on the edge of this data.

Suggested expansions to this preliminary analysis are discussed in the next section.

1.4.4 Next Steps

Weather File Selection: This study was an exploratory study to assess whether NYSERDA should consider more detailed studies into newer weather files. As discussed above, there is a general consensus that weather files based on historical data are increasingly inaccurate tools for estimating future performance, especially for buildings (and measures) that will have a lifetime of 30 years or more. For FTMY file development, there is also agreement that weather files generated based on dynamic downscaling are the most reliable for simulations (Moazami et al 2019). However, the process is complex and computationally intensive, and dynamically downscaled FTMY weather files are not available in building simulation-ready TMY-type formats. In the absence of this data, more research is needed to understand:

- When is morphed data sufficient?
- How does the accuracy of morphed files compare to stochastically generated files?
- Can XMY analyses provide similar guidance to FTMY data?

Our exploratory weather file analysis focused on visualizations of psychometrics and temperature distributions, but some of the shifts between files were subtle. It would be helpful to expand this analysis to specifically focus on the differences between the files, as opposed to just visually representing the files next to one another. This way, we could more easily see the times of years that have the most variation and learn more about how that might affect heating and cooling load shifts throughout the year. We also received Argonne's dynamically downscaled weather files after the analysis was already completed, so it would be helpful to add these files to the comparison to explore the differences in FTMY methodologies.

Modeling Analysis: The EnergyPlus modeling exercise only considered a single-family unheated basement heat pump model as a first test case. It would be informative to explore how the results change when considering other building types and mixed-fuel scenarios. The modeling exercise also only considered absolute energy use results, rather than comparative savings. Even for the cases where the overall EUI was similar, there was an overall trend for decreased heating and increased cooling. Several questions arise:

- How would this shifting end use breakdown affect building performance analyses, especially for measure cost effectiveness? How does shifting from heating to cooling affect electrification efforts?
- How could weather file uncertainty analysis be integrated into building performance analyses?
- How might the changing peak demand affect resource planning?

The modeling exercise only looked at two locations. And for the WeatherShift files, the modeling exercise only considered one future time period. Within this limited set, there were significant differences within the TMYx and FTMY results. Further analysis is needed to better understand the methodological differences in creating these weather files to provide recommendations on which methods are more trustworthy.

It would be informative to expand the analysis to include:

- Argonne's dynamically downscaled 2045 and 2090 files in New York City and Buffalo.
- Mixed fuel examples.
- Measure level analysis, especially for envelope design (insulation and fenestration requirements).

- Impact on Codes and Standards measure cost-effectiveness.
- Expanded building types, including multifamily and commercial building types (especially ones with high window-to-wall ratios).
- Greenhouse gas emissions.

This work could be completed by revisiting the models used in the most recent code updates, or by working with the Carbon Neutral Buildings Roadmap team. Arup is conducting the energy modeling analysis, which focuses on the four priority sectors with nine core building types in three New York climate zones and three vintages, resulting in thousands of simulation runs.

Opening discussions with major external stakeholders: Identifying ideal weather file types for various use cases, developing these weather files, and fine tuning the methodologies to apply these weather files requires engagement of a wide range of stakeholders. For example, a shift in weather file usage in programs would require coordination with the third-party protocols such as PHI, PHUIS, ANSI/RESNET/ICC, and ENERGY STAR, so it would be helpful to understand these organizations' thinking on future weather file selection. As another example, dynamically downscaled FTMY weather files are not yet available. Successfully creating them would take careful coordination between atmospheric scientists and building scientists to ensure the necessary data is saved at the correct timesteps and to select the models best suited to creating psychometrically accurate data sets.

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Appendix A Literature Review

A.1 Weather Simulators

The simulators included in this review are:

- **CAL-Adapt**, developed by the Geospatial Innovation Facility at the University of California, Berkeley with funding and oversight provided by the California Energy Commission https://cal-adapt.org/tools/
- Climate Toolbox's Future Climate Projections, developed by the University of Idaho https://climatetoolbox.org/tool/climate-mapper
- **Future Urban Climates**, developed by the University of Maryland Center for Environmental Science https://fitzlab.shinyapps.io/cityapp/
- **CityBES**, developed by Lawrence Berkeley National Laboratory - Laboratory Directed Research and Development (LDRD) Program https://citybes.lbl.gov/?sf_ecbo=1 https://citybes.lbl.gov/CityBES.pdf
- **NYCCSC Climate Data Grapher,** developed by Cornell University's Northeast Regional Climate Center, and displayed through the New York Climate Change Science Clearinghouse (NYCCSC), developed by NYSERDA https://www.nyclimatescience.org

All the simulators included in this review are free and focused on providing information to regional areas. While Climate Toolbox, Future Urban Climates, and CityBES all simulate future climate scenarios for locations across the United States, Future Urban Climates specifies 540 particular cities, 14 of which are in New York State, and CityBES looks at ten cities, with New York City being the only city representing New York State. CAL-Adapt focuses specifically on climatic changes in California. The NYCCSC Climate Data Grapher looks at the northeastern U.S., simulating climate change for Connecticut, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, and Vermont, but going into much more detail for New York than for other states.

A.1.1 Weather Generator Studies

Various reports have studied and compared weather files created by different weather generators. As each generator uses different combinations of scenario information, climate model data, and methodology, the resulting climate files differ as well. The following reports explore how these differences in output affect building simulations and inform design strategies.

“Impacts of future weather data typology on building energy performance—Investigating long-term patterns of climate change and extreme weather conditions,” by Moazami, Nik, et al. (2019), studies the advantages of using some methods of file generation over others, and investigates which type of weather file is more suitable and reliable for building simulations. The authors found that only using Typical Meteorological Year (TMY) is not sufficient. Weather files generated based on dynamic downscaling that account for both typical and extreme weather are the most reliable for simulations.

“Evaluation of current and future hourly weather data intended for building designs: a Philadelphia case study,” by Yassaghi, Mostafavi, et al. (2019), reviewed methods for generating future and current files for building simulation by comparing the outputs of different weather generators: CCWorldWeatherGen, AWE-GEN, and Meteonorm. This study—which used TMY, TMY2, TMY3 files—found that single year TMY files do not capture the predicted trends of warming and that there are quite a few differences between generator output, creating significant variance among the resulting simulations.

“Comparison of methodologies for generation of future weather data for building thermal energy simulation,” by Dias, Carrilho da Graça, at al. (2019), compares two methods used to create future climate data: morphing through CCWorldWeatherGen and developing Typical Meteorological Year of future climates (F-TMY). The results showed that data output from RCMs increase time and computation demand without providing any significant advantage over a TMY analysis, and that using commonly available climate tools can lead to errors in building energy simulations.

“Critical Analysis of Software Tools Aimed at Generating Future Weather Files with a View to Their Use in Building Performance Simulation,” by Moazami, Carlucci, et al. (2017), compares CCWorldWeatherGen and WeatherShift to identify potential consequences that could arise from their differences. The study found that each generator uses different patterns in their application of morphing, resulting in different outputs. For example, WeatherShift only modifies certain meteorological parameters as it morphs data.

“Sensitivity of Passive Design Strategies to Climate Change: Thermal Comfort Performance of Natural Ventilation in the Future,” by Aijazi and Brager (2018), uses future weather files from WeatherShift to run building energy simulations that look at the sensitivity and feasibility of achieving thermal comfort through natural ventilation. The study compares building performance both with and without natural ventilation for three different locations over time. The results showed that natural ventilation can help, to an extent, both now and in the future, but it largely depends on location and projected climate.

CIBSE's "TM36: Climate Change and the Indoor Environment" (2005) uses similar methodologies, generation strategies, and locations as those used to generate CIBSE's Weather Data Packages. The purpose of the report was to investigate the effect that climate change has on summertime thermal comfort and energy use in the United Kingdom, the extent and increase of thermal discomfort and summertime overheating, and the ability and effectiveness of passive measures in improving indoor thermal comfort. The report found that while passive design can help reduce energy demands, it will be impossible to only use passive measures for some buildings. Strategies like natural ventilation and thermal mass may still be helpful but must be designed carefully. With rising temperatures, these techniques may increase interior temperatures by allowing in and/or retaining too much heat. The TM36 report has been archived by CIBSE, but updated information is available through more recent reports, such as TM49— which is more aligned with the current Weather Data Packages.

A.1.2 Weather File Studies

Similar to the studies that looked at the validity of the weather file generators, the following reports investigate the effectiveness of different file types and their creation using different climate model combinations. The general trend of these studies looks at how accurately weather file types, such as Typical Meteorological Year, represent both current and projected weather conditions.

"A New Approach to Model the Effect of Climate Change on the Building Sector: A Climate Models Data Fusion," by Tumminia, Guarino, et al. (2019), presents a "data-fusion" model that integrates data from multiple climate change models to improve the capacity of climate and energy predictions. Their study found that there is wide variation among the output of different climate models and that building simulations require more than one climate model for more valid results.

"Should We Be Using Just 'Typical' Weather Data in Building Performance Simulation," by Crawley and Lawrie (2019), proposes using eXtreme Meteorological Year (XMY) climatic data to assess building performance and energy demands. The results show that climatic response would be better analyzed using XMYs rather than TMYs, and that building simulation should include at least more than a single typical year of weather data.

"Making energy simulation easier for future climate—Synthesizing typical and extreme weather data sets out of regional climate models (RCMs)," by Vahid M. Nik (2016), suggests a simpler method to decrease the number of simulations needed to study the impacts of climate change in energy and buildings. The study synthesizes three sets of weather data, one typical and two extreme, from one or more RCMs in an attempt to decrease the number of data sets necessary without losing quality or detail. The results show that this method provides an accurate estimation of future conditions and the combination of extreme and typical weather data proves similar to the original RCM data in reflecting climate uncertainties.

"Update of California Weather Files for Use in Utility Energy Efficiency Programs and Building Energy Standard Compliance Calculations," by Joe Huang of White Box Technologies (2020), documents 2018 efforts to develop two customized versions of "typical year" California weather files:

- Trended data for utility programs: To be used by Pacific Gas and Electric Company (PG&E) and other investor-owned utilities (IOUs) to support their Energy Efficiency programs, including their use in building energy simulations and spreadsheet calculations to determine energy savings from program activities and for normalizing that savings for weather variability. This version uses the most recent 12-year period of record (2006–2017), and therefore reflects the warming trend observed in recent years.
- Title-24 Code Compliance (not trended): To support the California Energy Commission's Title-24 needs, this version extends the period of record from 12 to 20 years (1998–2017) and uses statewide "typical months" rather than the trended approach.

This project also provided utility consultants and contractors with historical weather files (AMY) over the last five years for the same California locations to be covered by the "typical year" weather files for engineering assessments of actual building performance. All three sets included:

- Expanded set of 117 weather stations maintained by the National Atmospheric and Oceanic Administration that are located throughout continental California (the CZ2010 standard used 86 weather stations)
- Combined data from two primary sources, the Integrated Solar Database (ISD) for weather station data maintained by the National Center for Environmental Information and the National Solar Radiation Database for solar radiation data. The result of this update are weather files of high resolution and accuracy.

ASHRAE 2021 Fundamentals Handbook (unpublished draft) Chapter 14 Climatic Design Information: The 2021 chapter update provides the climatic design information for 9237 locations in the United States, Canada, and around the world, an increase of 1119 stations from the 2017 ASHRAE Handbook—Fundamentals. Most locations use data from 1994–2019 (the 2017 version used 1990–2014). Site-specific coefficients for the clear-sky solar radiation model have been recalculated, based on the latest atmospheric information available.

"On the sensitivity of buildings to climate: The interaction of weather and building envelopes in determining future building energy consumption" by Rastogi (2016) presents results for "two related but independent proposals for sensitivity and uncertainty analyses in building simulation, particularly to weather. The first is a novel, generalizable procedure for generating synthetic weather data to carry out a Monte Carlo experiment with a building simulation model. The second is a technique for training emulators or response surfaces to rapidly obtain estimates of performance outputs from simulation models, using Gaussian Process regression on small training data sets. The two parts, together and separately, enable the quantification of the lack of knowledge about an input, and the impact of this uncertainty on the final results. This work is a step towards practical tools for the use of building simulation in a stochastic paradigm. Both elements of the thesis contribute toward explicitly estimating the uncertainty in the results of building simulation, using empirical or data-driven techniques."

Appendix B Weather File Analysis

This section contains the full set of box-and-whisker and heat map charts generated during the Weather File Analysis piece of the Modeling task. Results are presented for the three selected locations: Buffalo, New York City, and Saranac Lake. For each of these, the charts are categorized by TMY3 versus TMYx, XMY, and FTMY data.

B.1 Buffalo

TMYx

Figure B-1. TMY3 versus TMYx Air Temperature by Month in Buffalo, New York

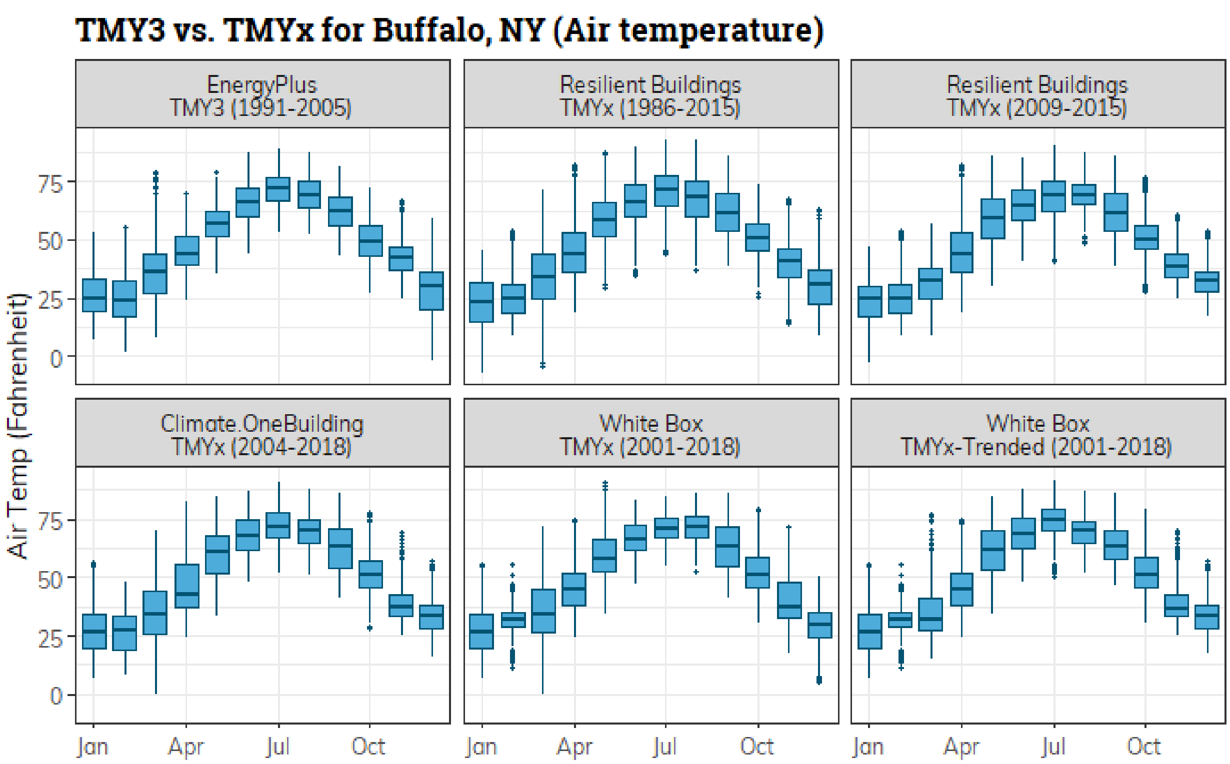


Figure B-2. TMY3 versus TMYx Air Temperature by Month, May through October in Buffalo, New York

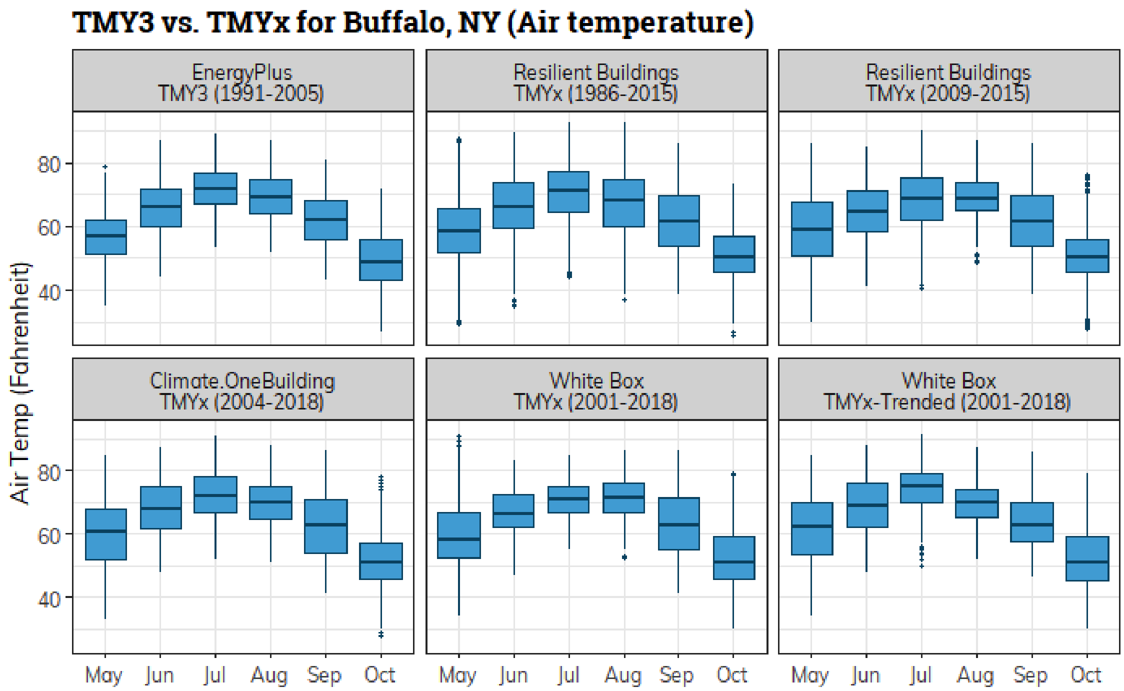


Figure B-3. TMY3 versus TMYx Air Temperature by Month, November through April in Buffalo, New York

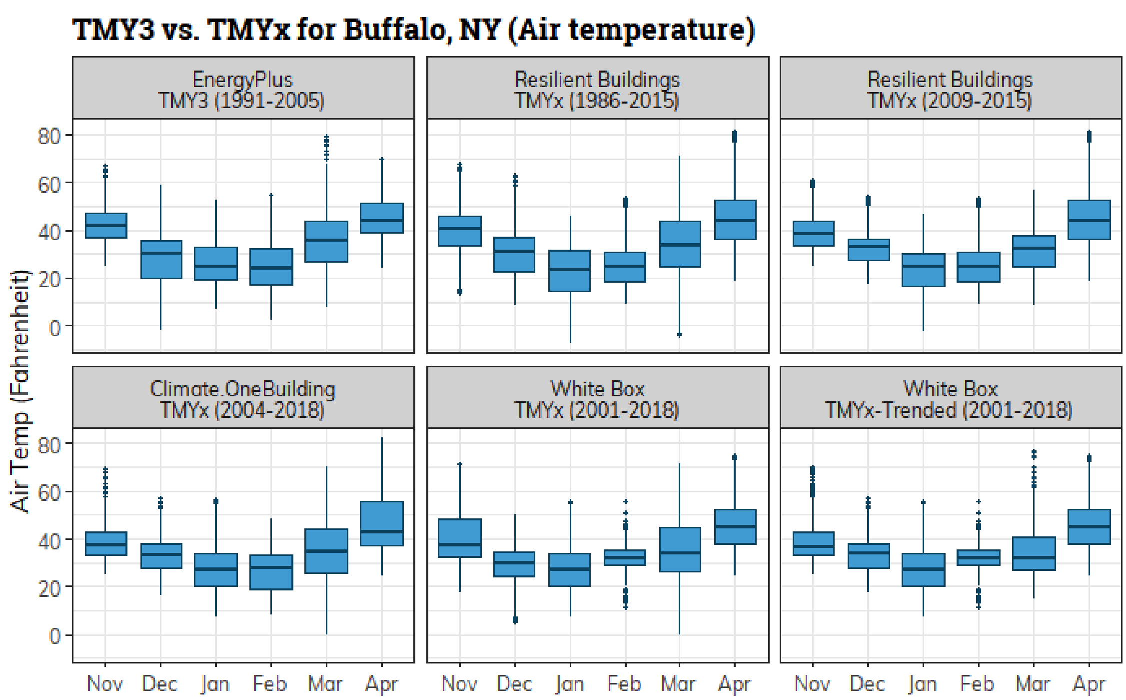


Figure B-4. TMY3 versus TMYx Air Temperature by Month in Buffalo, New York

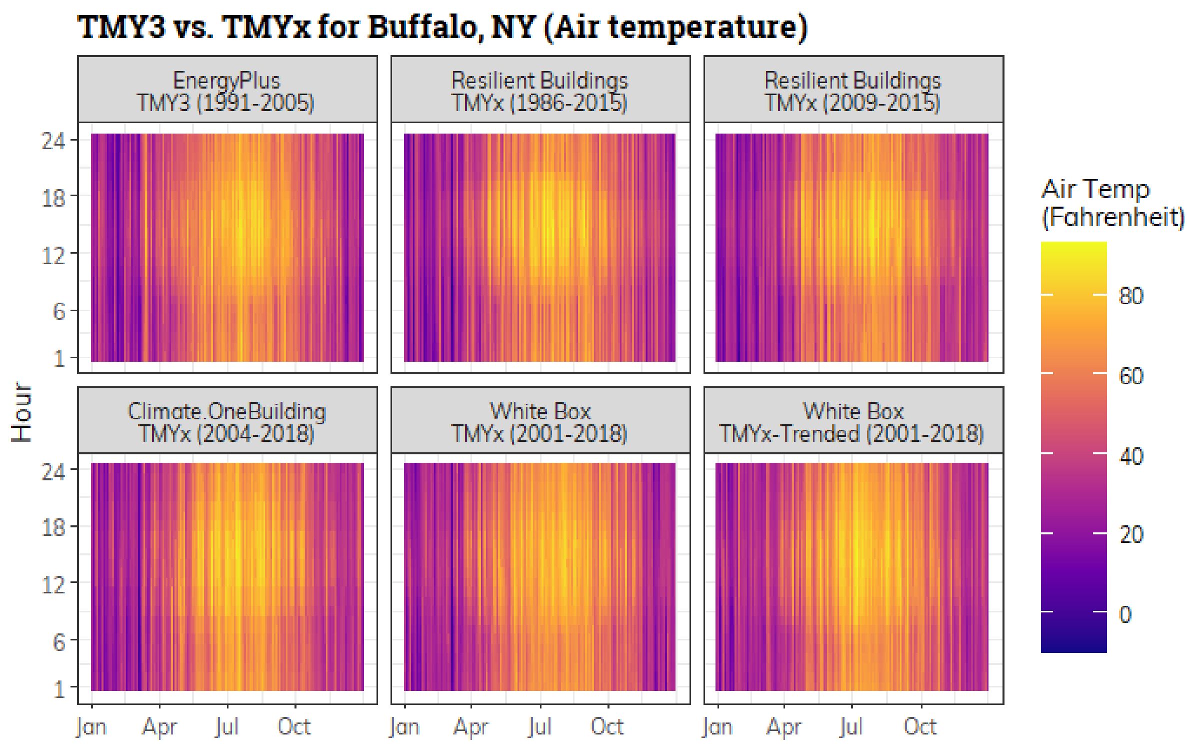
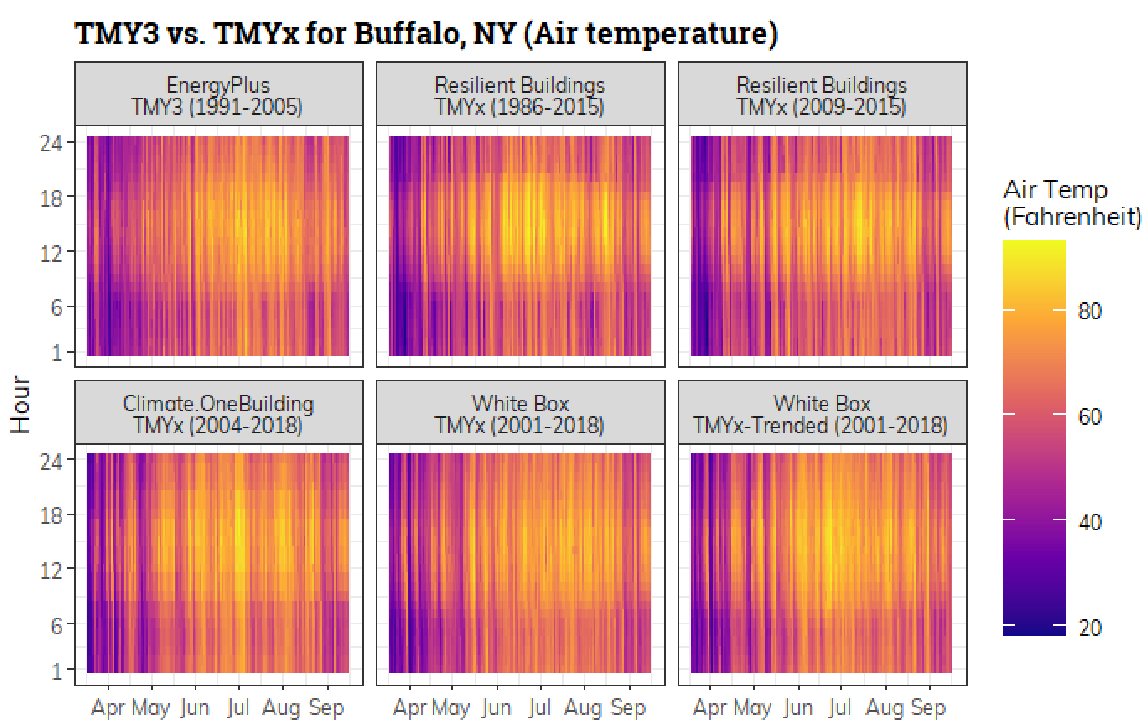


Figure B-5. TMY3 versus TMYx Air Temperature by Month, April through September in Buffalo, New York



XMY

Figure B-6. TMY3 versus XMY Air Temperature by Month in Buffalo, New York

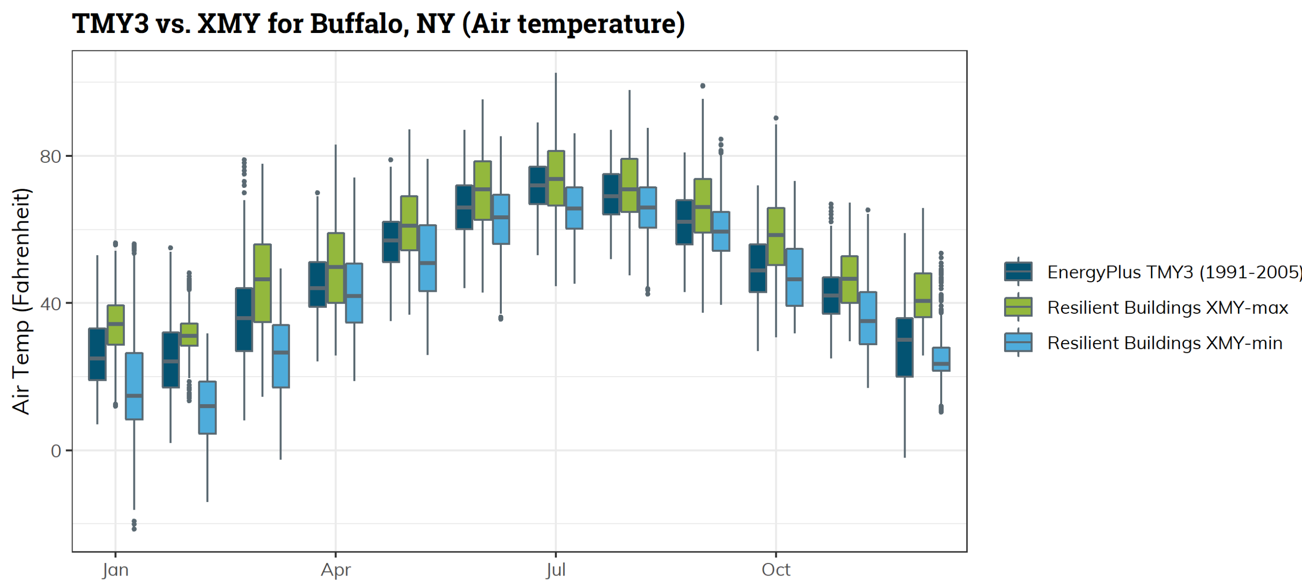
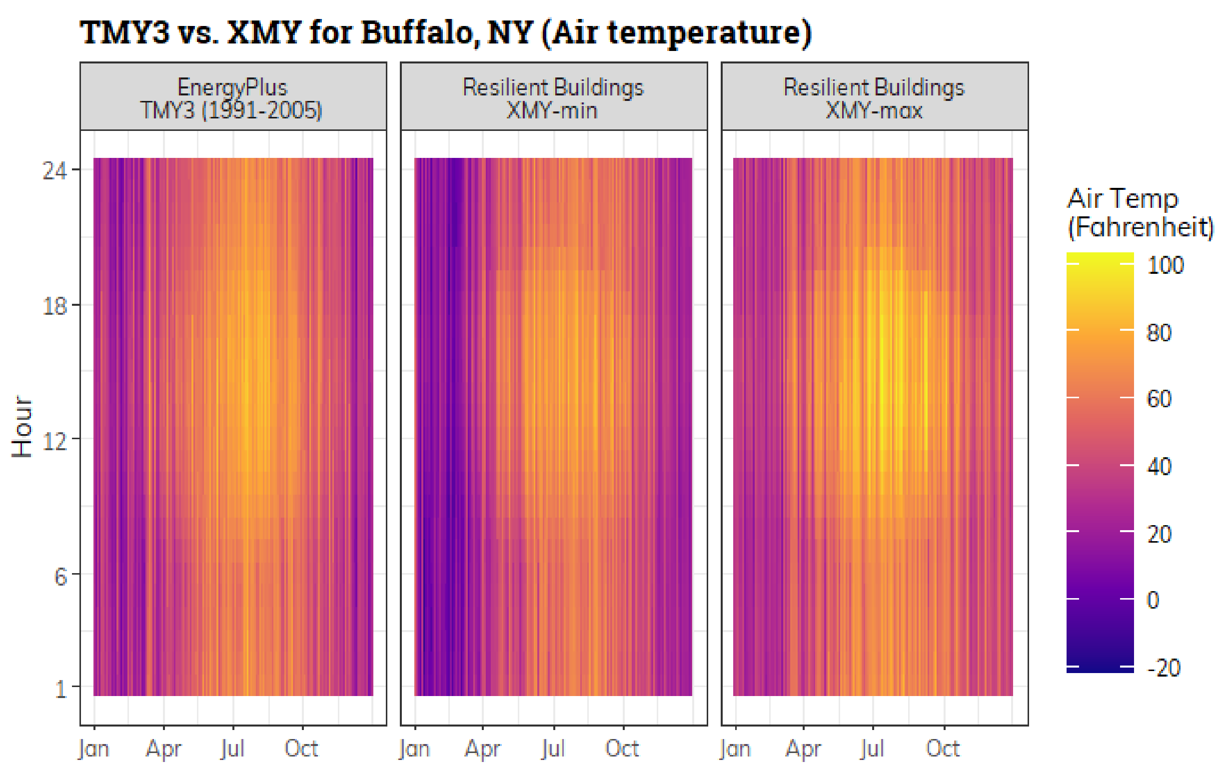
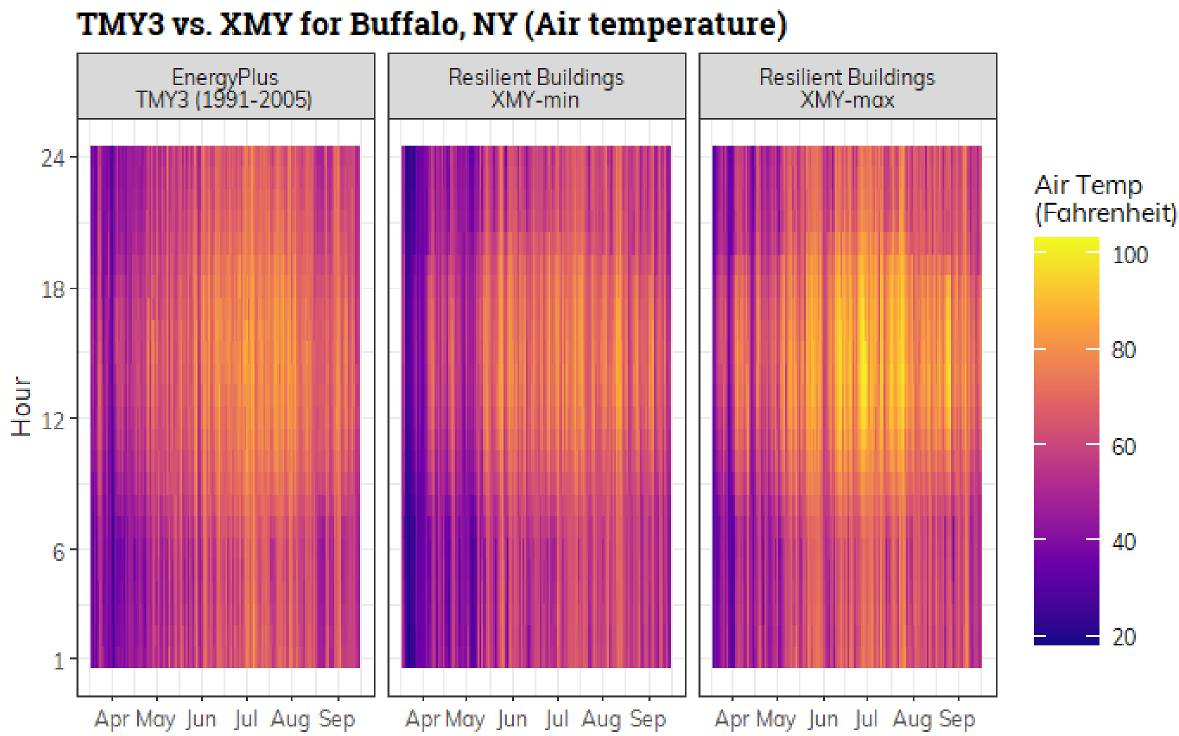


Figure B-7. TMY3 versus XMY Air Temperature by Month in Buffalo, New York



FigureB-8. TMY3 versus XMY Air Temperature by Month, April through September in Buffalo, New York



FTMY

Figure B-9. TMY3 versus FTMY Air Temperature by Month in Buffalo, New York

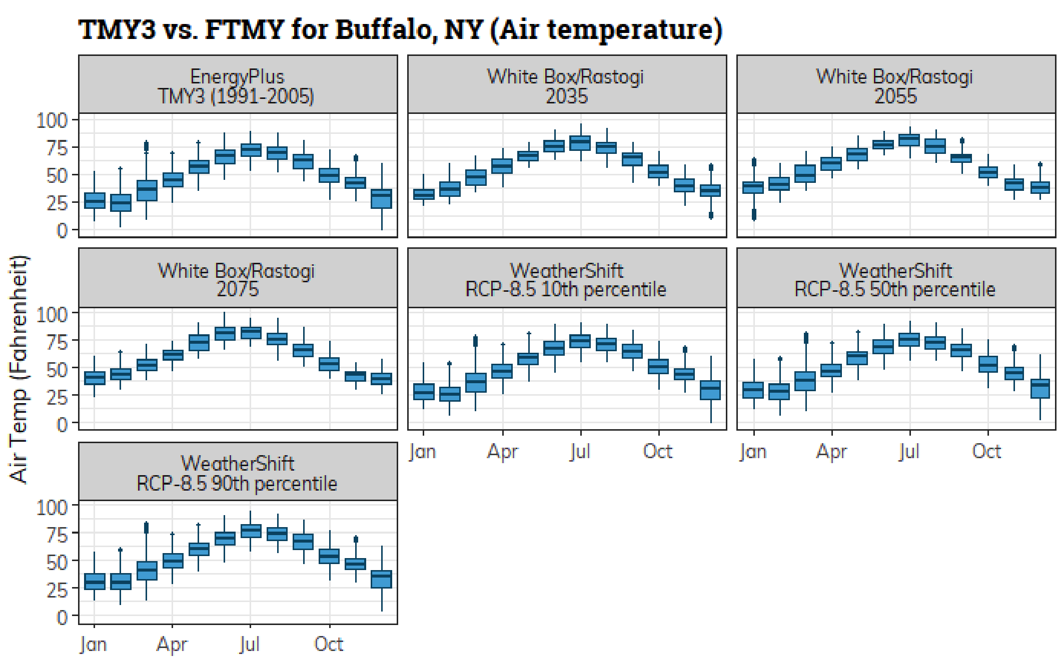


Figure B-10. TMY3 versus FTMY Air Temperature by Month, May through October in Buffalo, New York

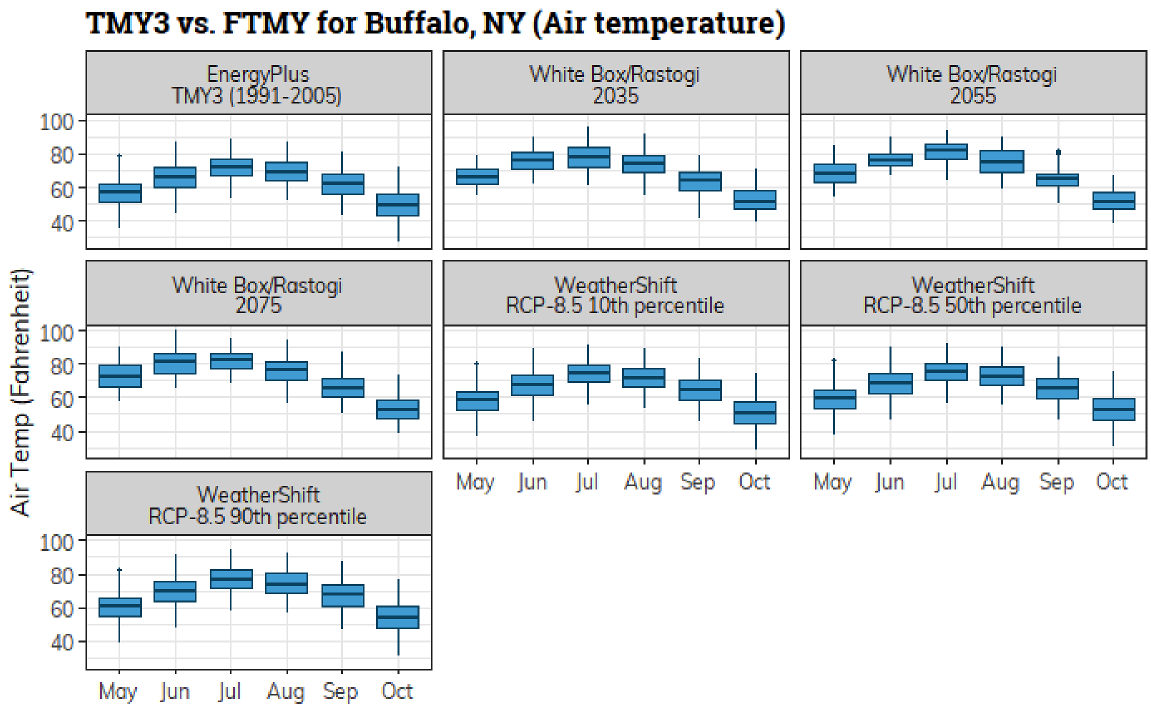


Figure B-11. TMY3 versus FTMY Air Temperature by Month, November through April in Buffalo, New York

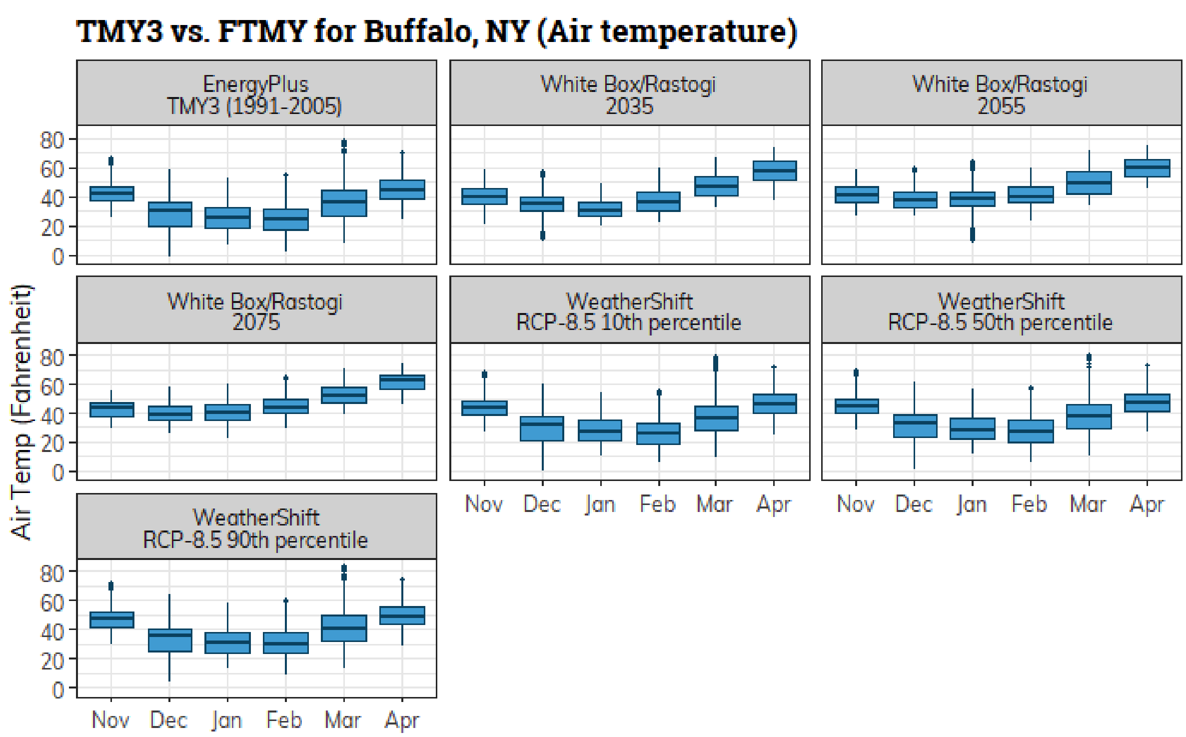


Figure B-11. TMY3 versus FTMY Air Temperature by Month in Buffalo, New York

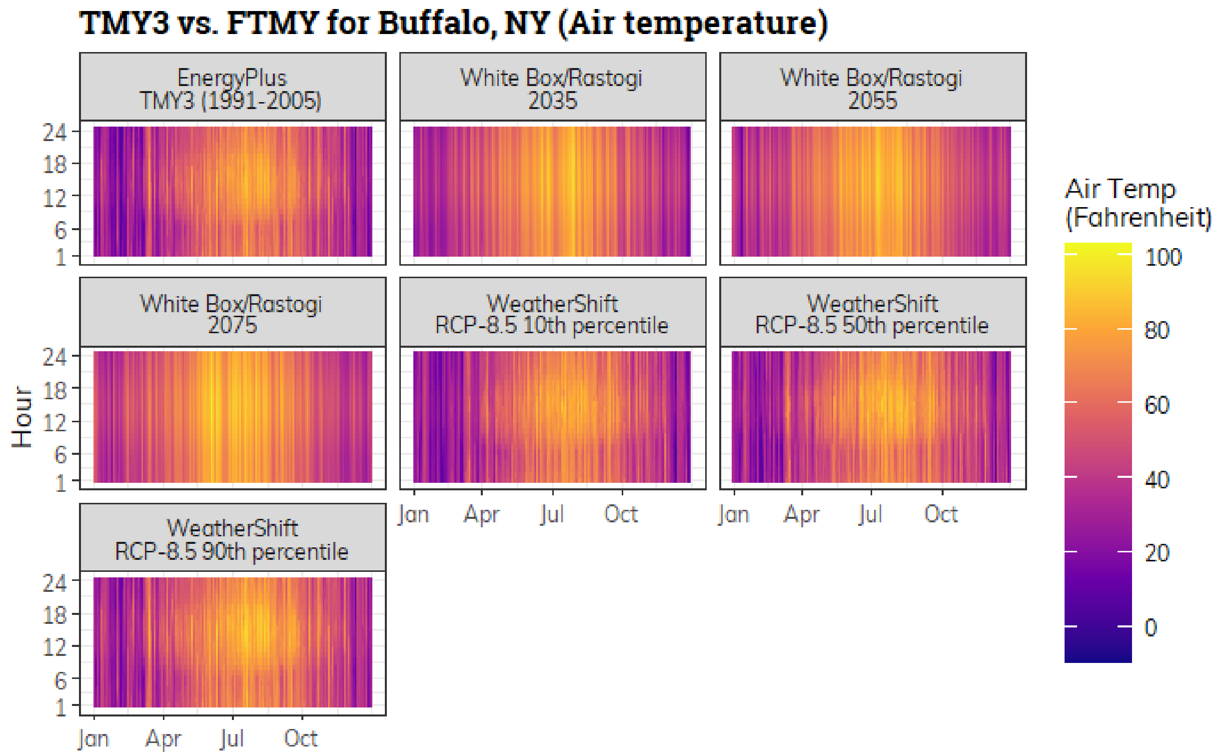
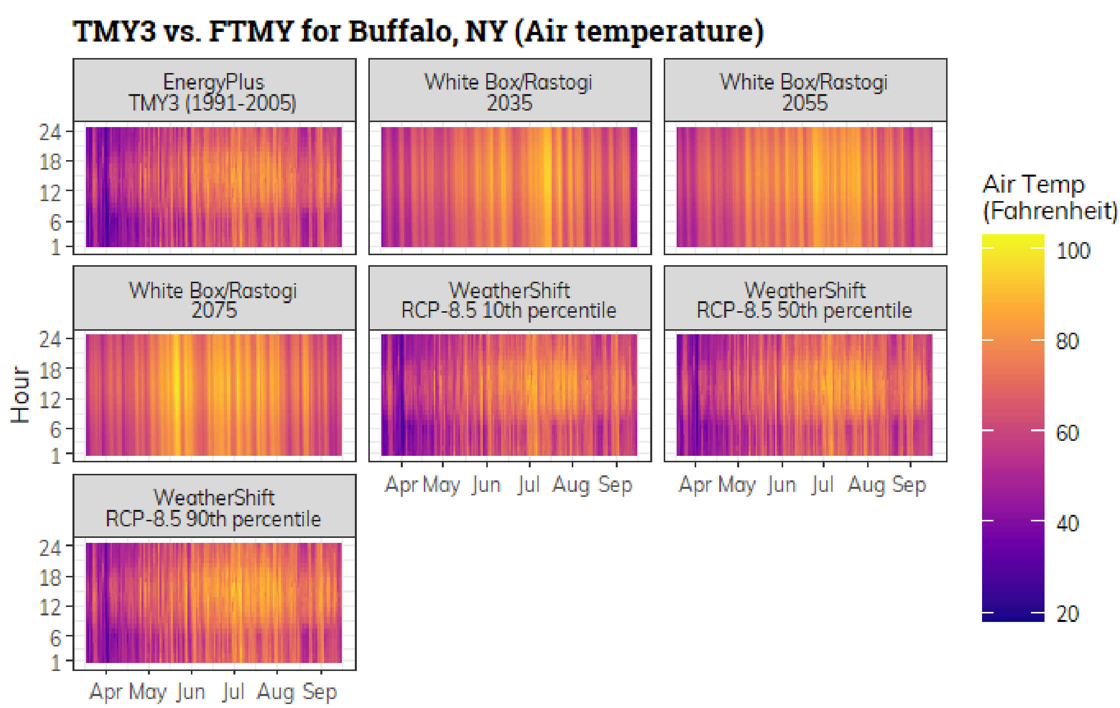


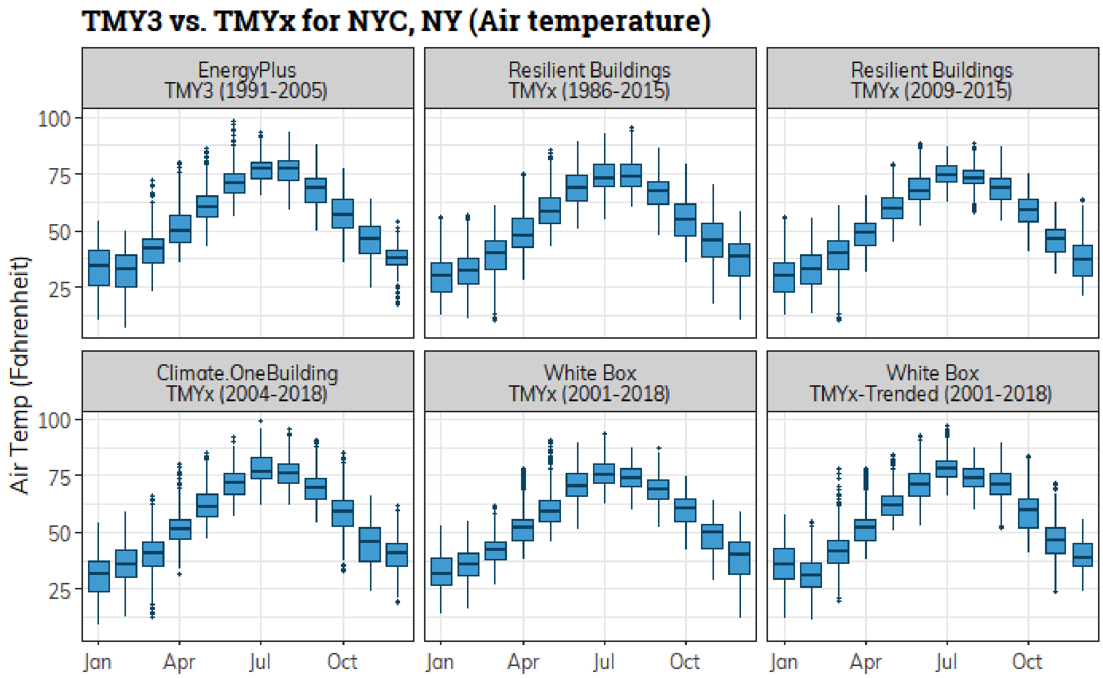
Figure B-12. TMY3 versus FTMY Air Temperature by Month, April through September in Buffalo, New York



B.2 New York City

TMYx

Figure B-13. TMY3 versus TMYx Air Temperature by Month in New York City



FigureB-14. TMY3 versus TMYx Air Temperature by Month, May through October in New York City

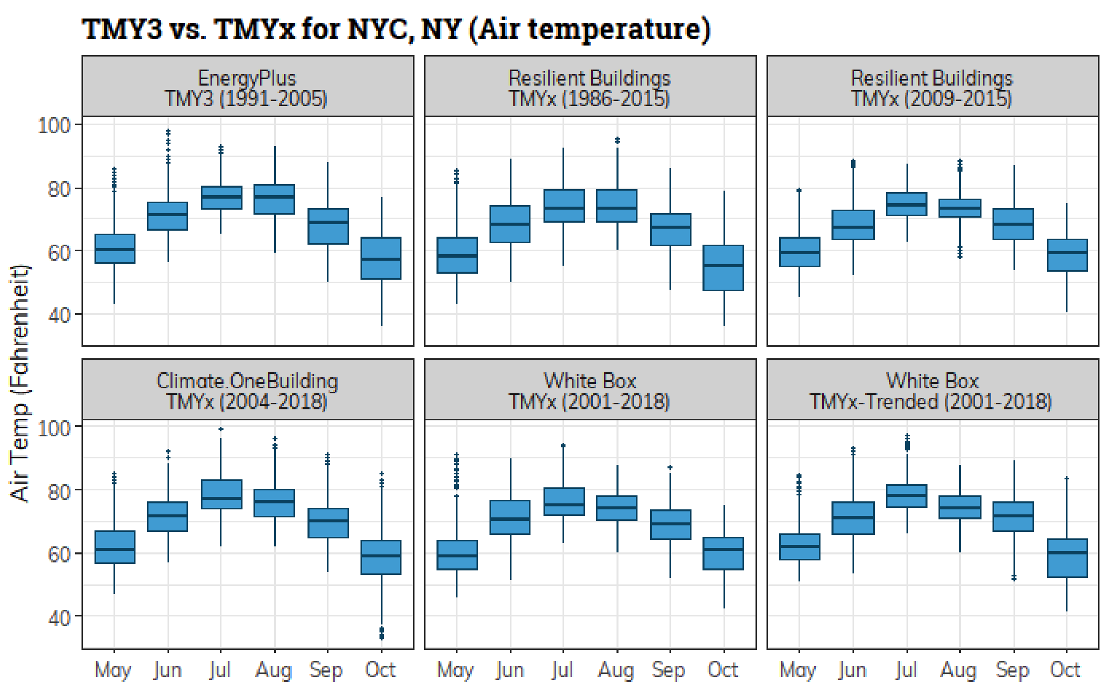


Figure B-15. TMY3 versus TMYx Air Temperature by Month, November through April in New York City

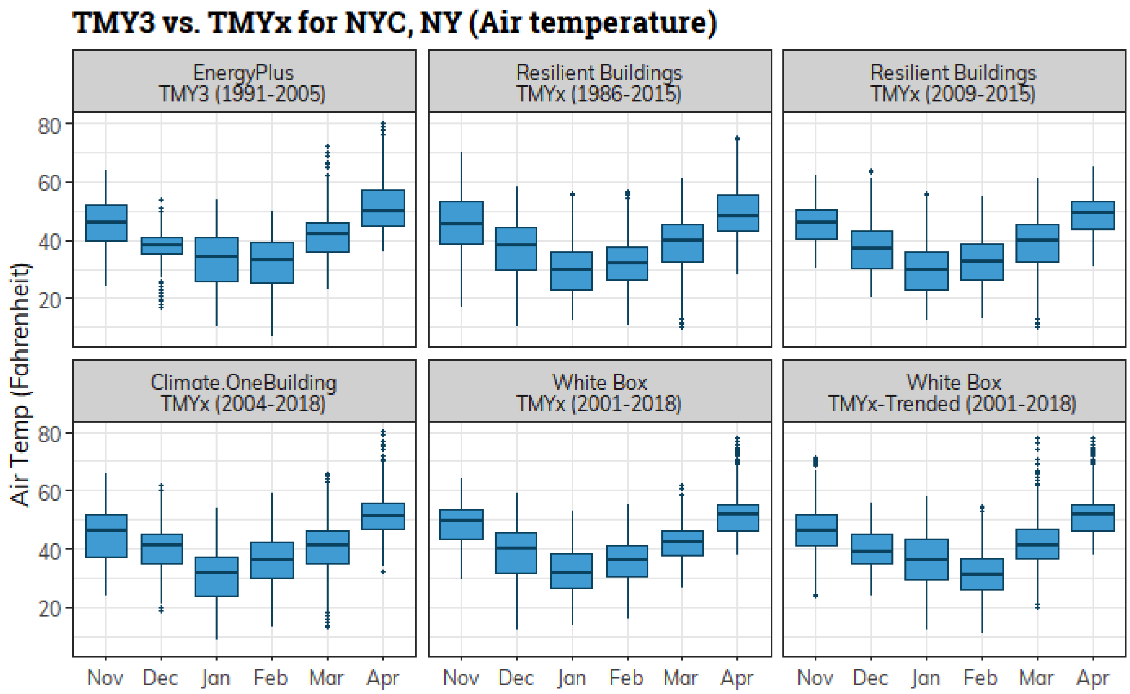


Figure B-16. TMY3 versus TMYx Air Temperature by Month in New York City

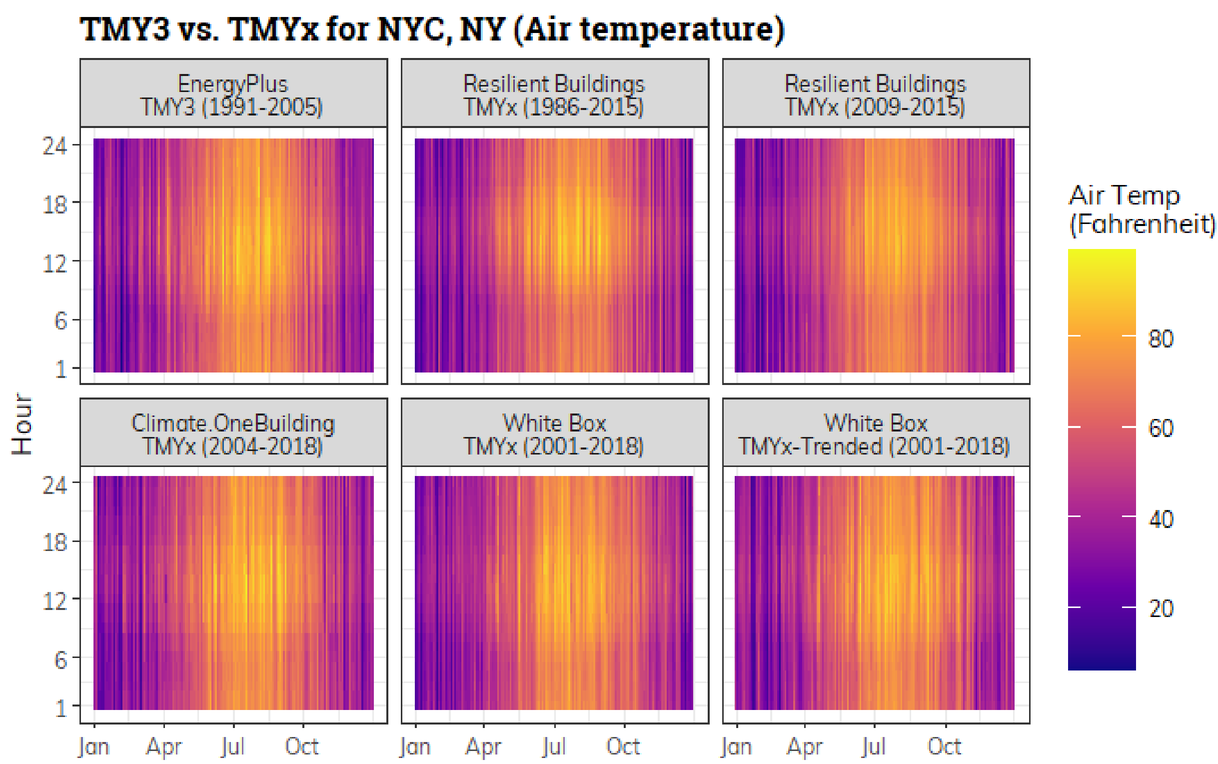
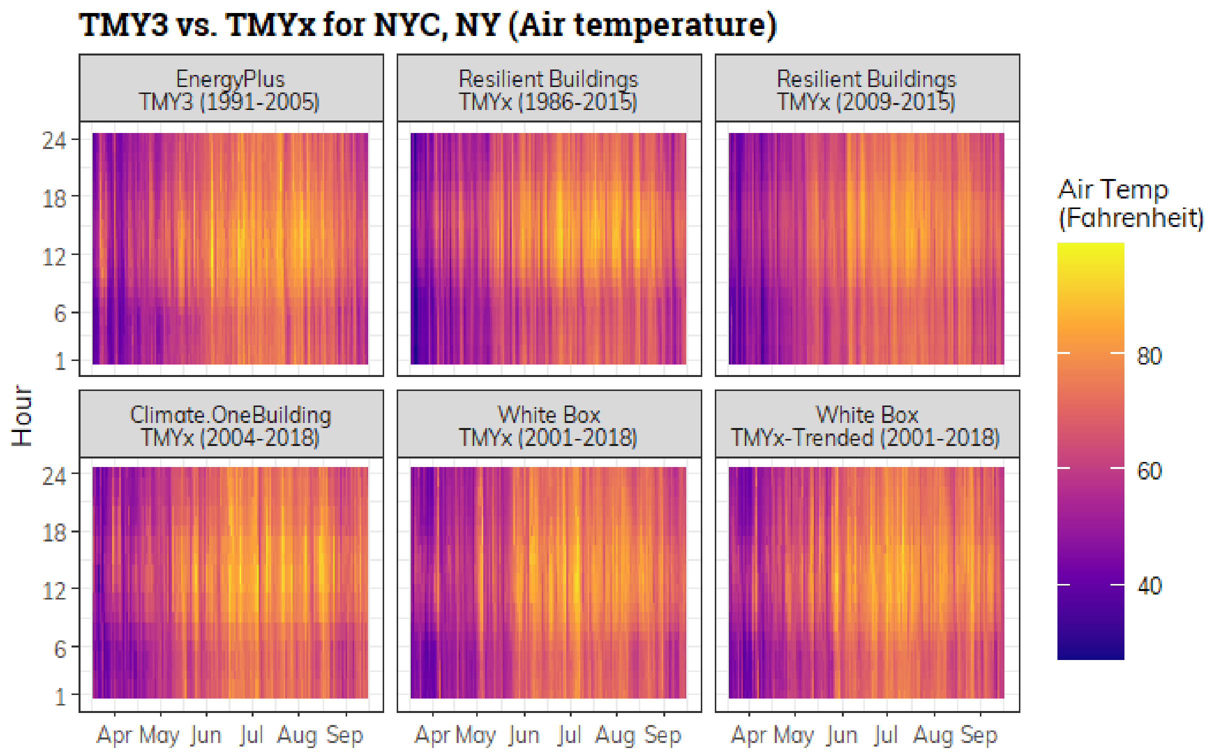


Figure B-17. TMY3 versus TMYx Air Temperature by Month, April through September in New York City



XMY

Figure B-18. TMY3 versus XMY Air Temperature by Month in New York City

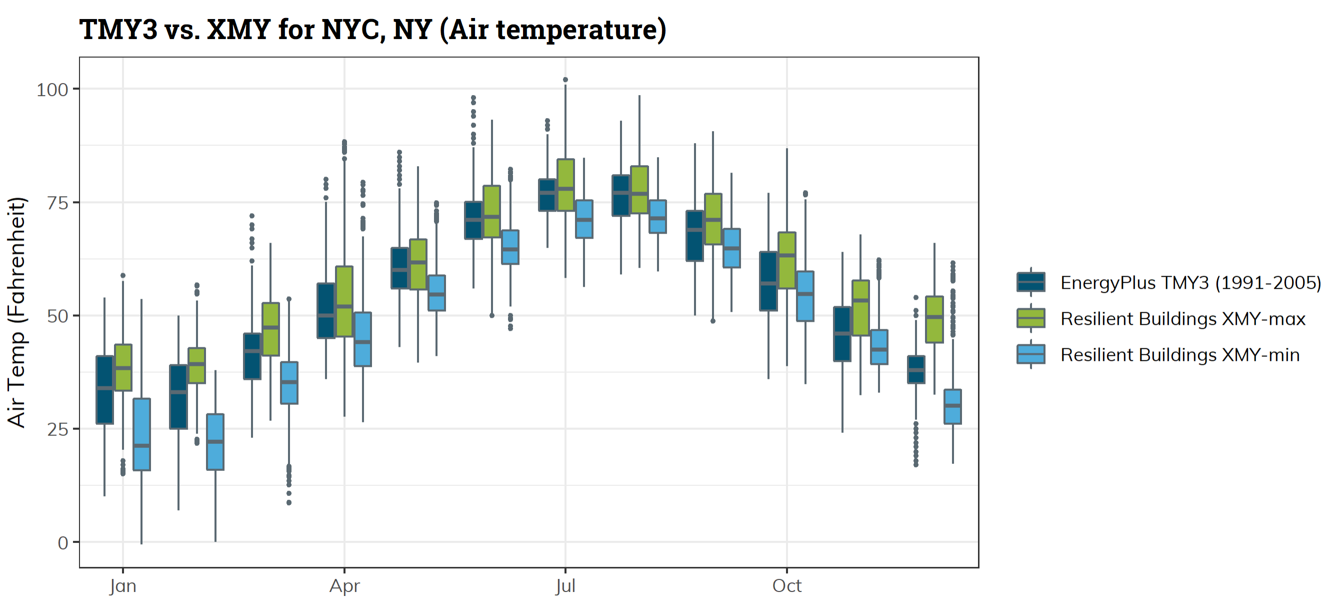


Figure B-19. TMY3 versus XMY Air Temperature by Month in New York City

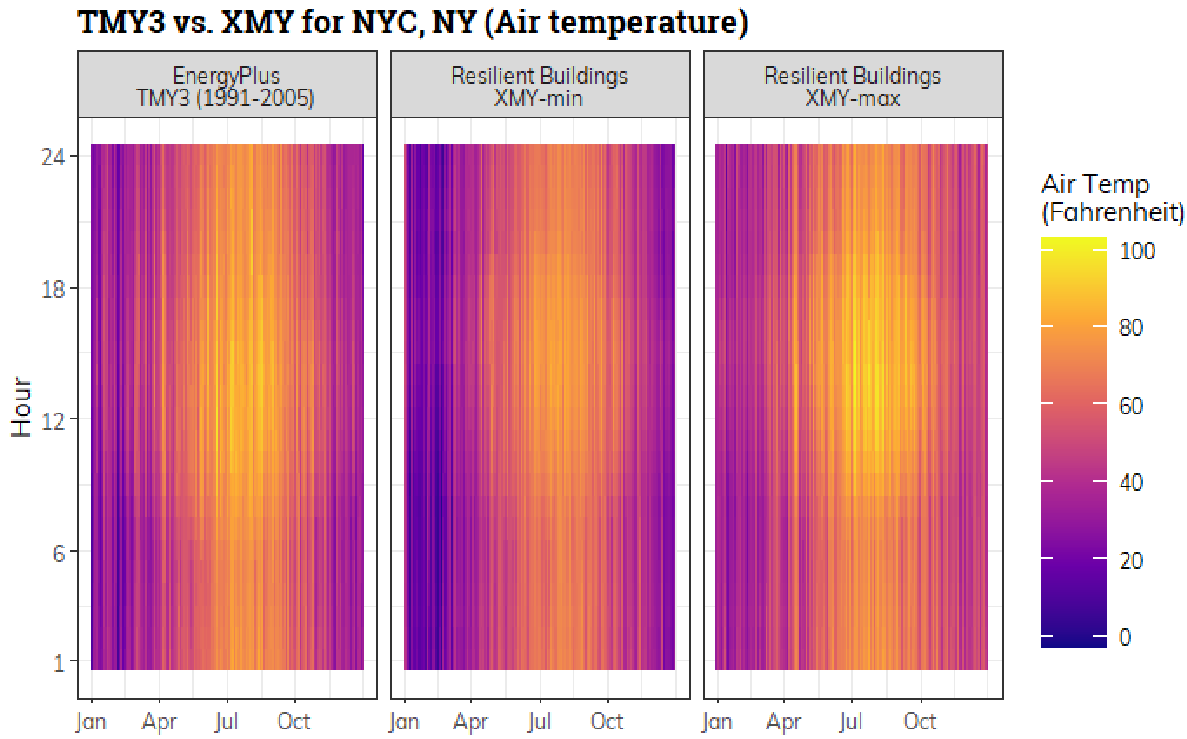
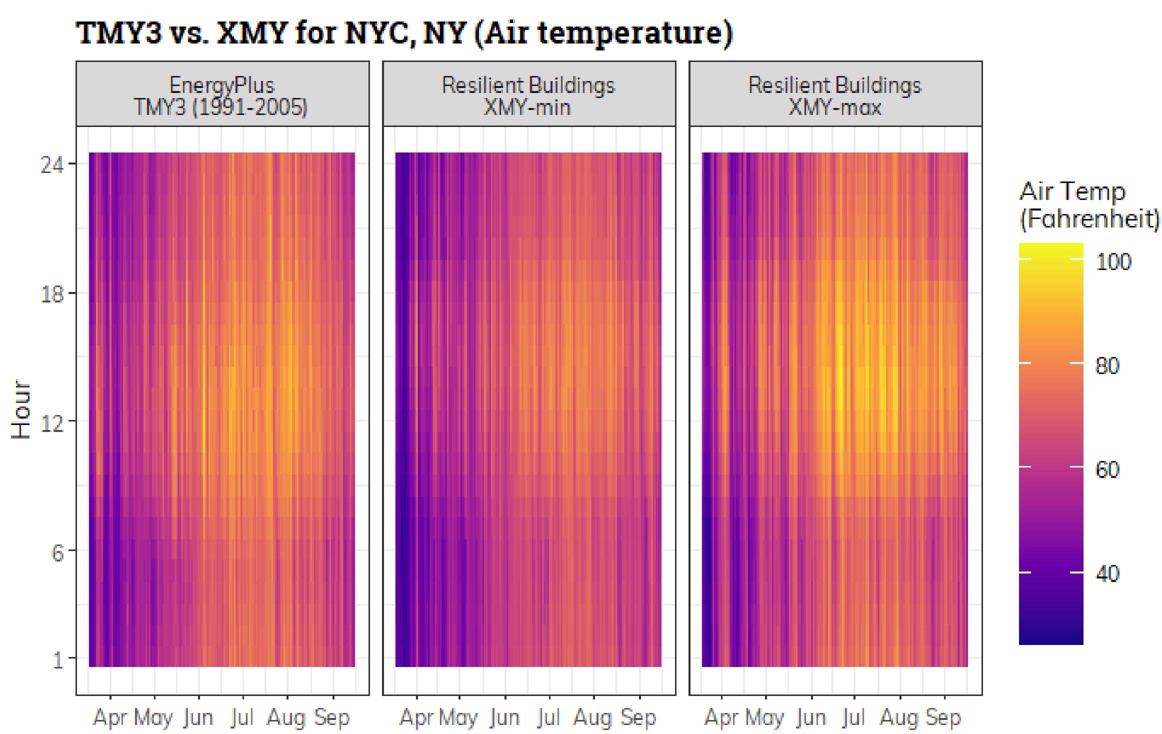
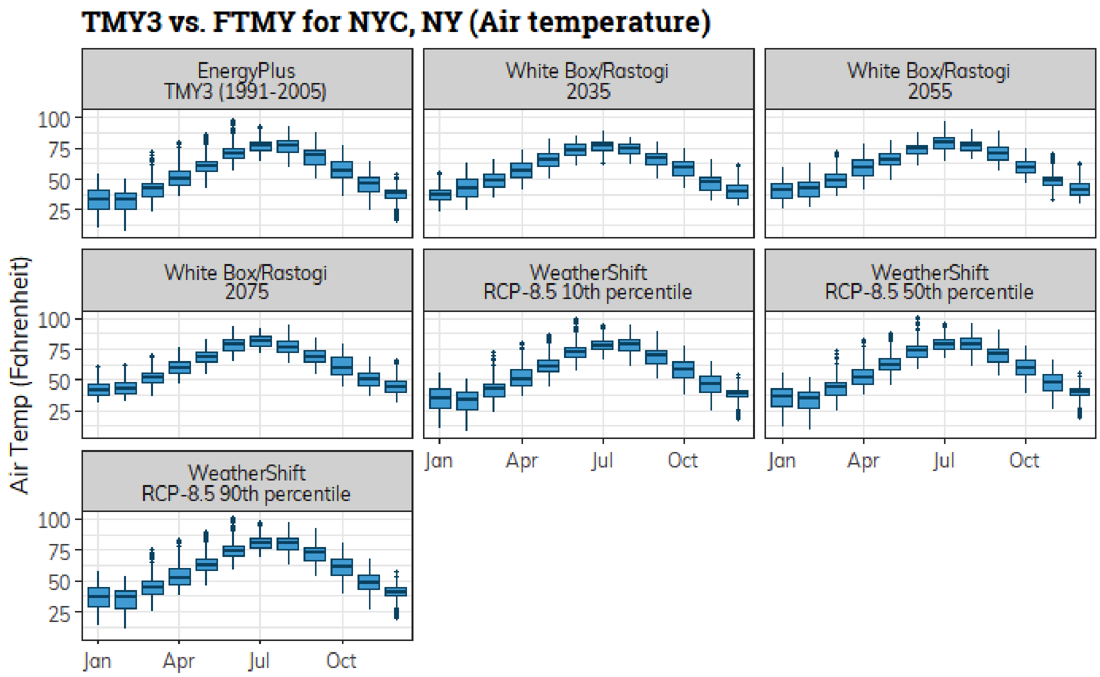


Figure B-20. TMY3 versus XMY Air Temperature by Month, April through September in New York City



FTMY

Figure B-21. TMY3 versus FTMY Air Temperature by Month in New York City



FigureB-22. TMY3 versus FTMY Air Temperature by Month, May through October in New York City

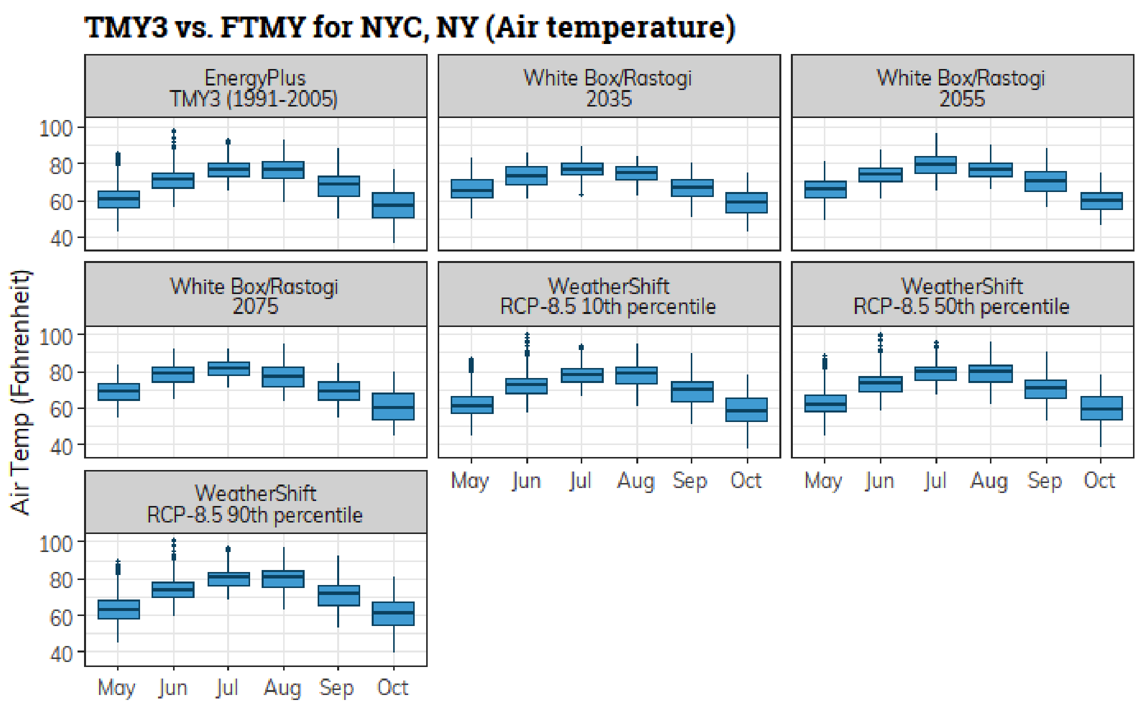
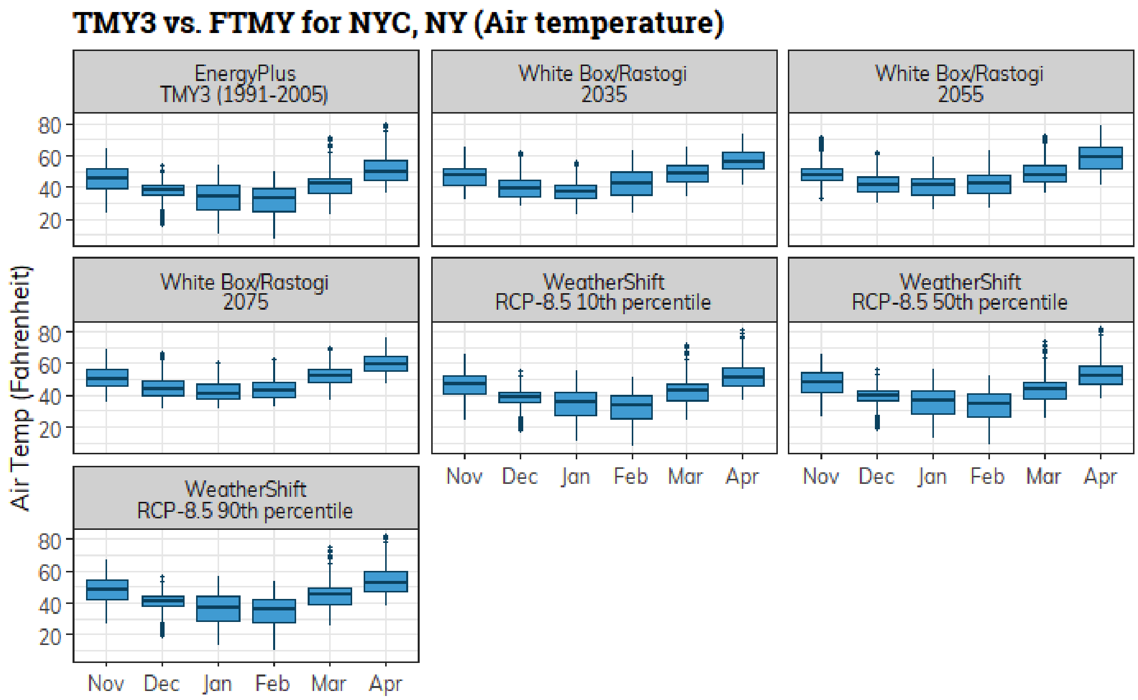


Figure B-23. TMY3 versus FTMY Air Temperature by Month, November through April in New York City



FigureB-24. TMY3 versus FTMY Air Temperature by Month in New York City

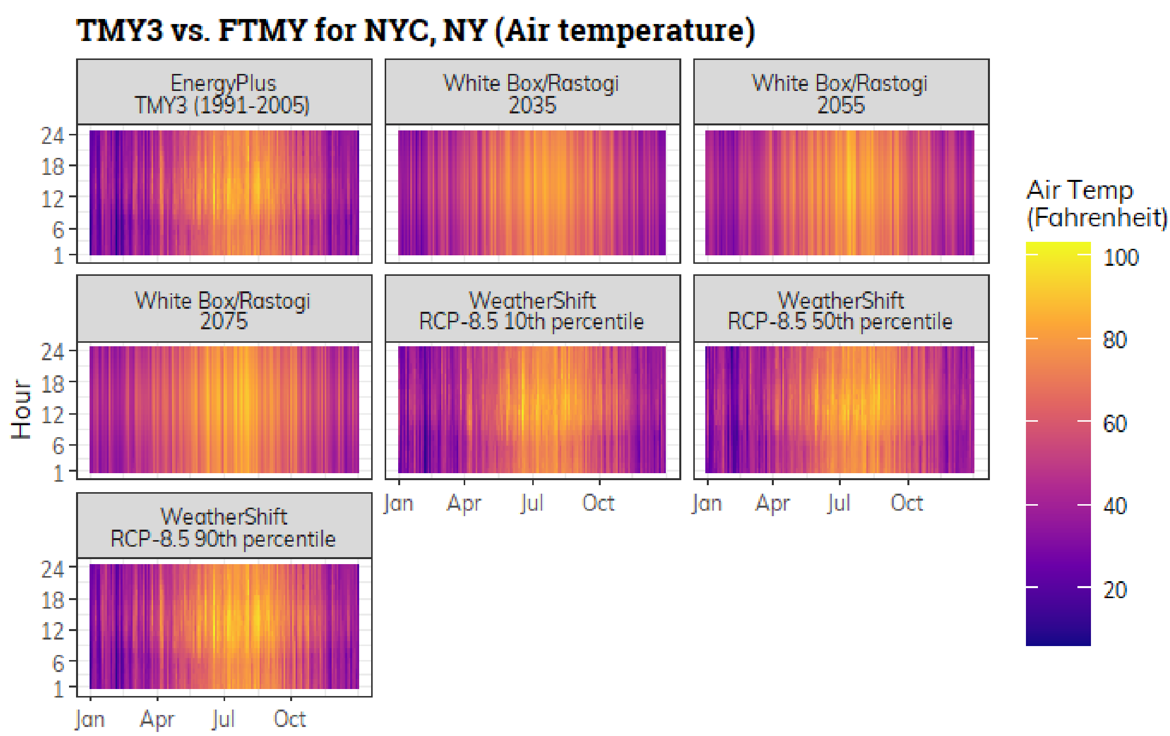
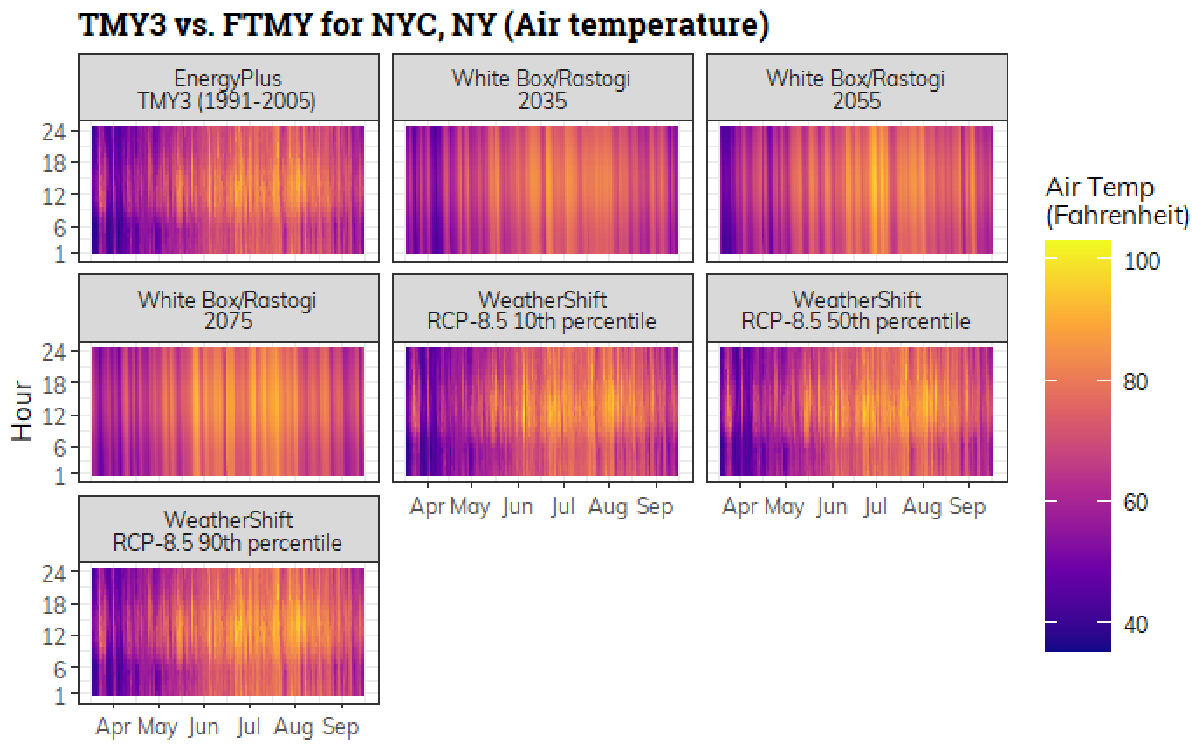


Figure B-25. TMY3 versus FTMY Air Temperature by Month, April through September in New York City



B.3 Saranac Lake

TMYx

Figure B-26. TMY3 versus TMYx Air Temperature by Month in Saranac Lake, New York

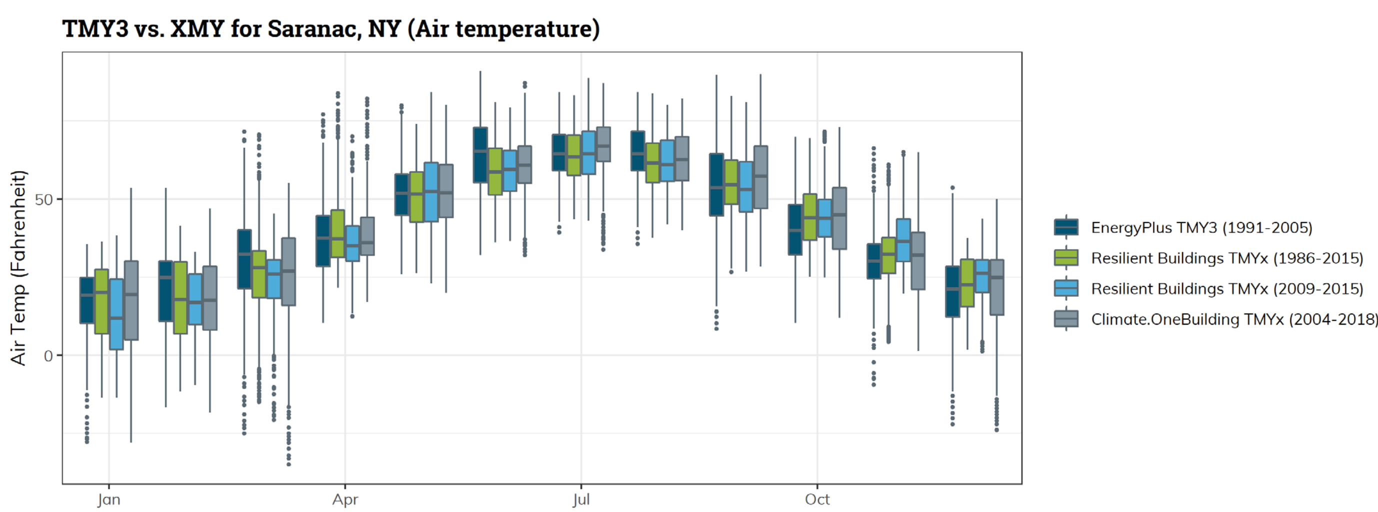


Figure B-27. TMY3 versus TMYx Air Temperature by Month in Saranac Lake, New York

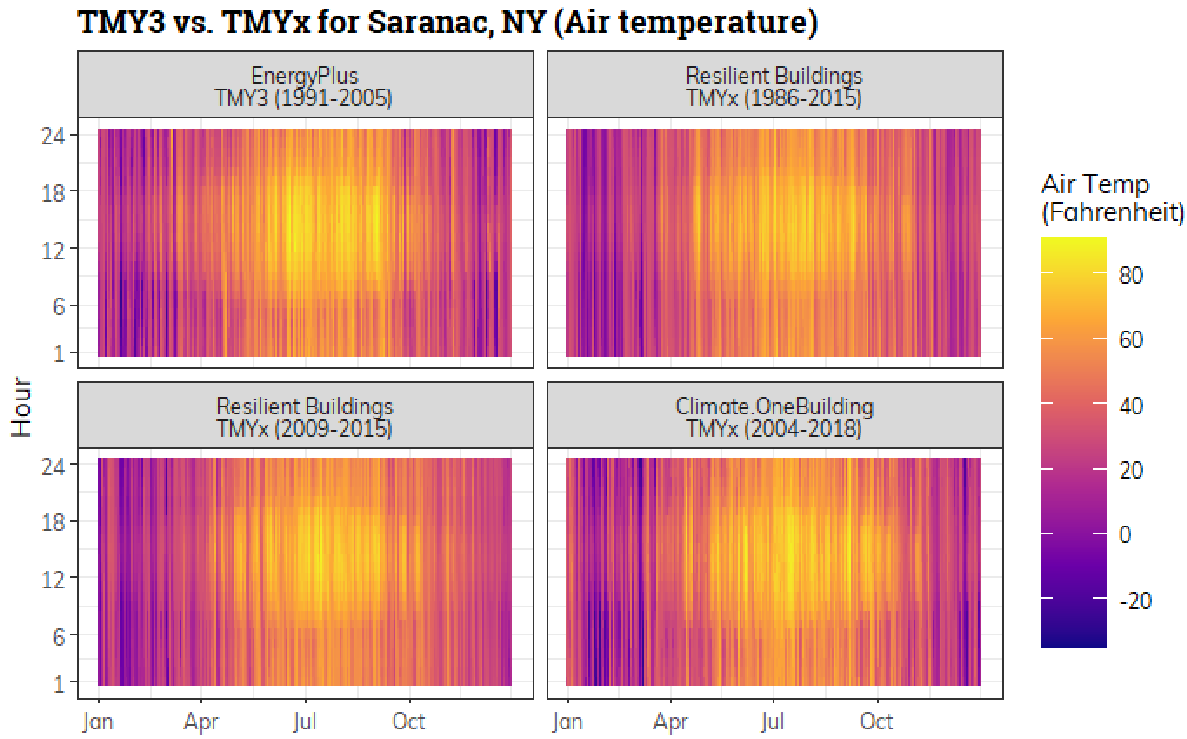
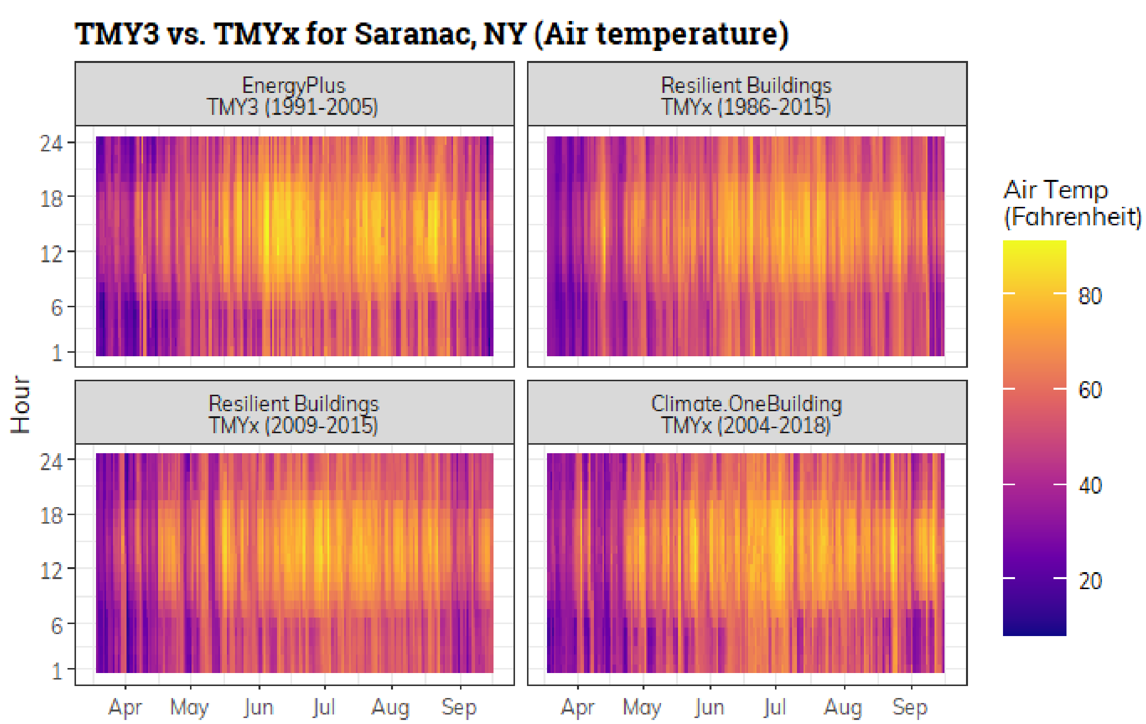
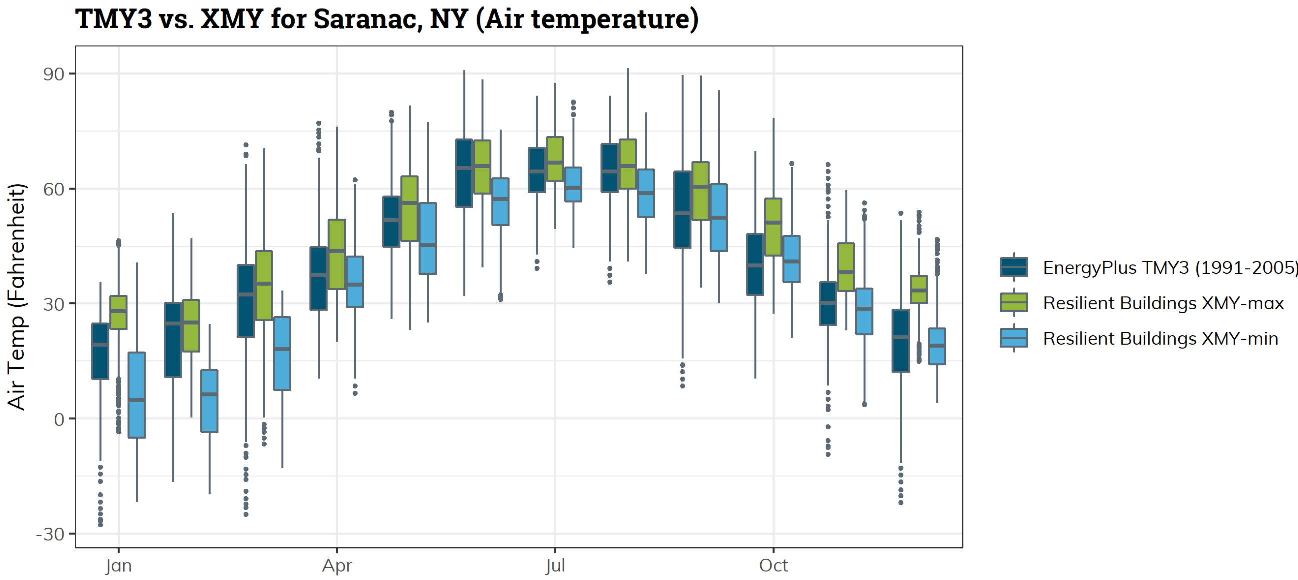


Figure B-28. TMY3 versus TMYx Air Temperature by Month, April through September in Saranac Lake, New York



XMY

FigureB-29. TMY3 versus XMY Air Temperature by Month in Saranac Lake, New York



FigureB-30. TMY3 versus XMY Air Temperature by Month in Saranac Lake, New York

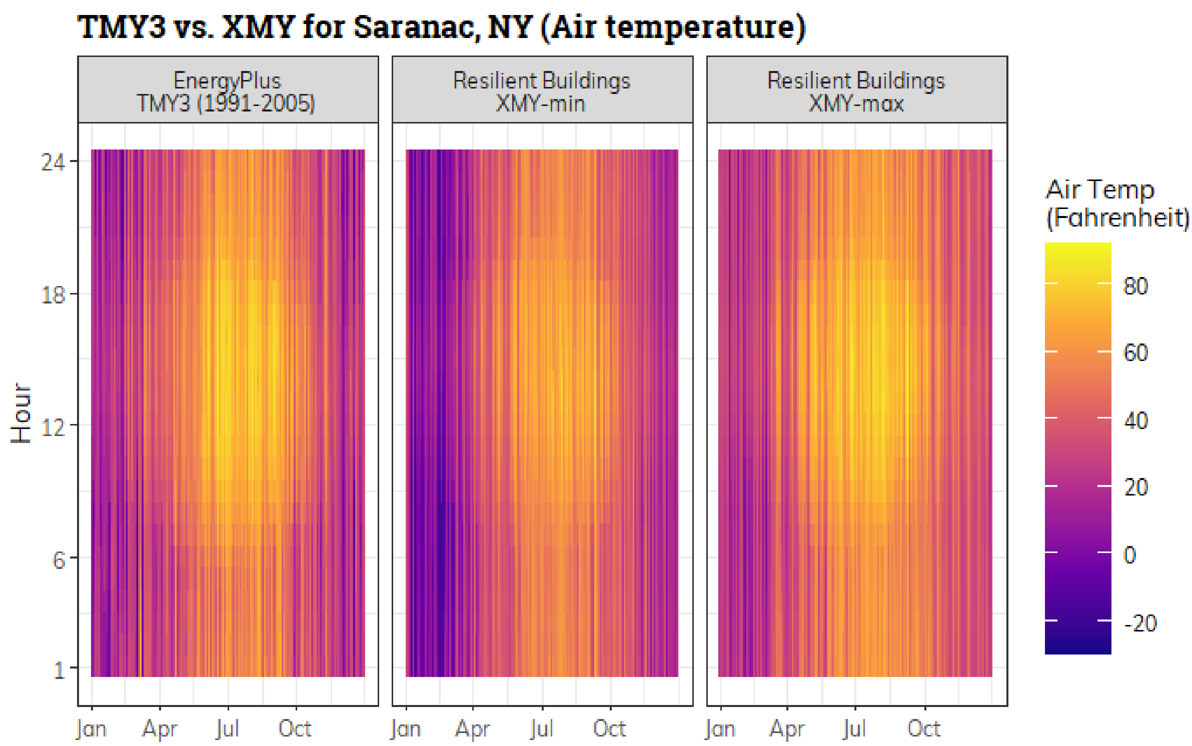
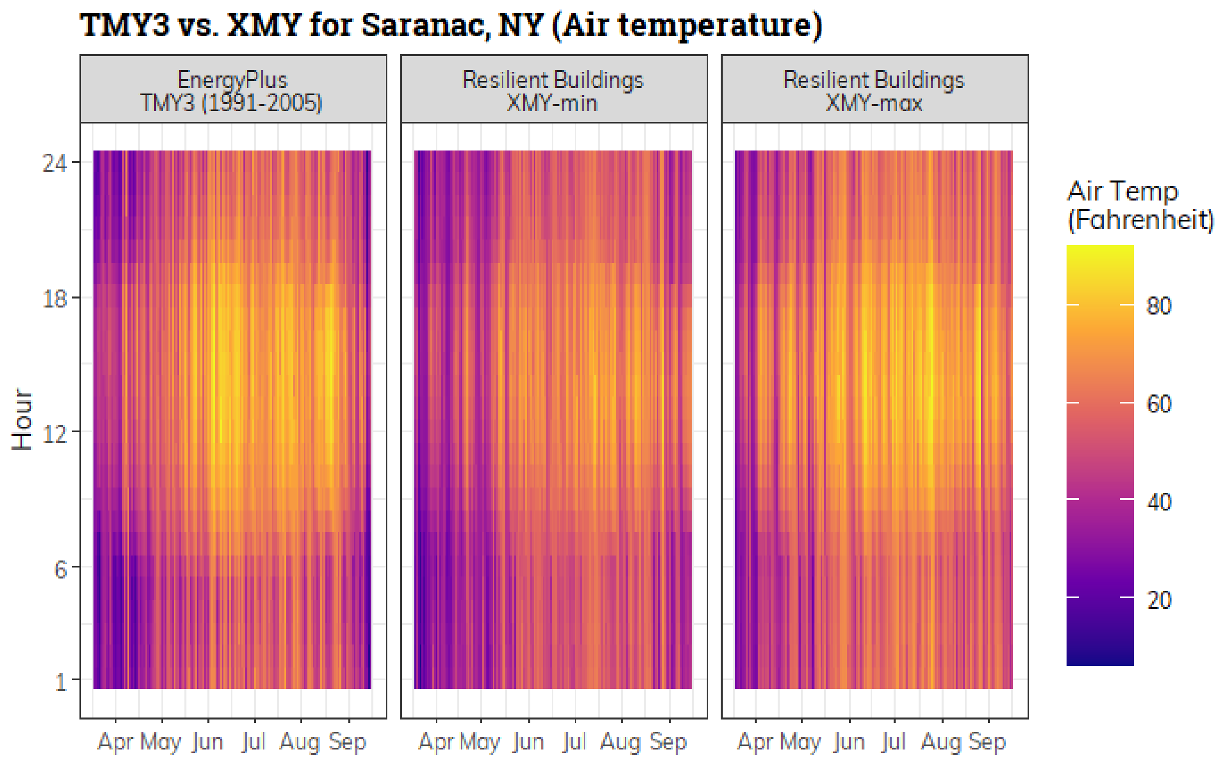


Figure B-31. TMY3 versus XMY Air Temperature by Month, April through September in Saranac Lake, New York



FTMY

Figure B-32. TMY3 versus FTMY Air Temperature by Month in Saranac Lake, New York

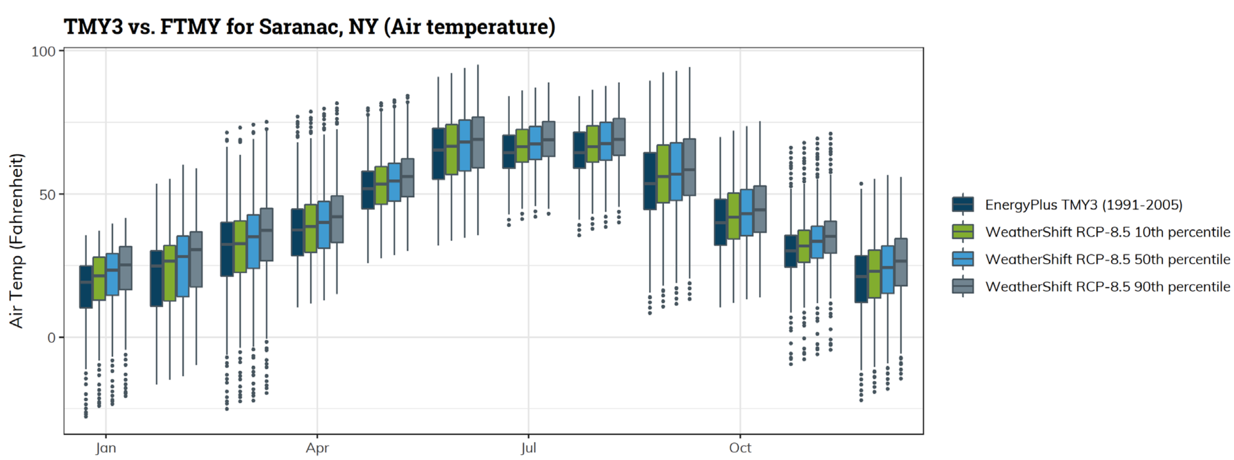


Figure B-33. TMY3 versus FTMY Air Temperature by Month in Saranac Lake, New York

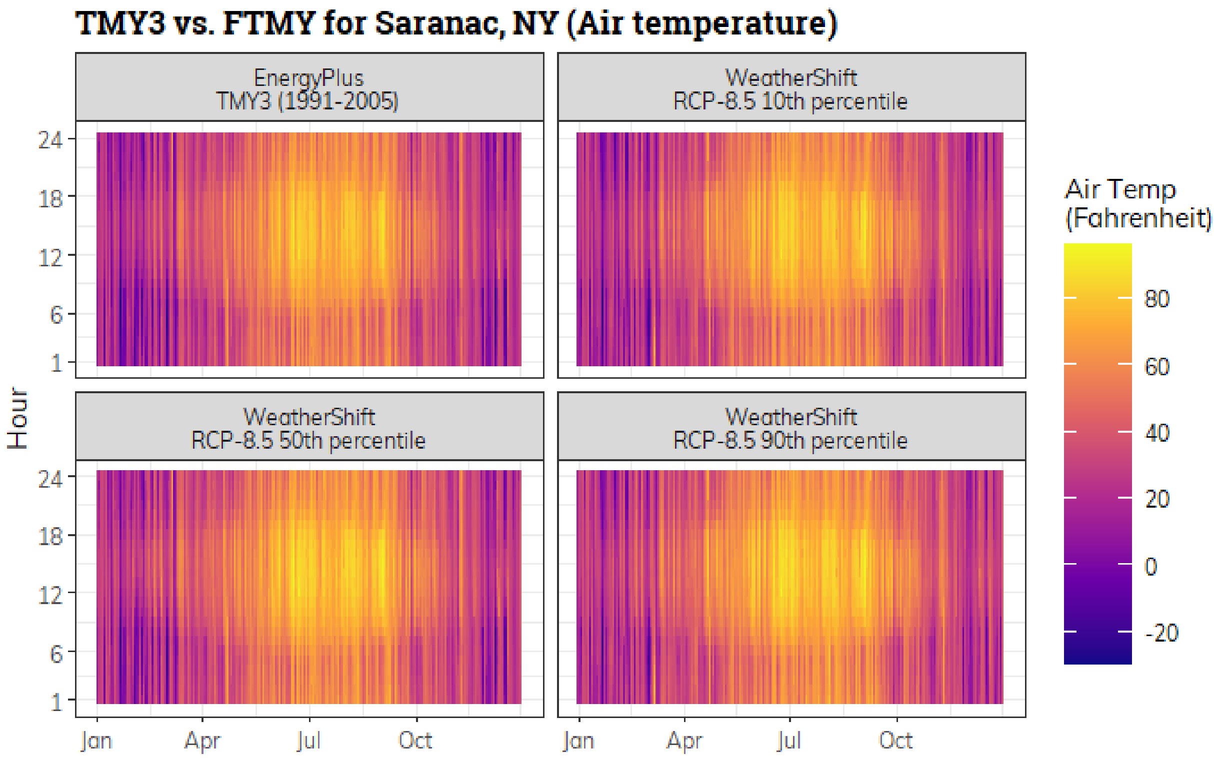
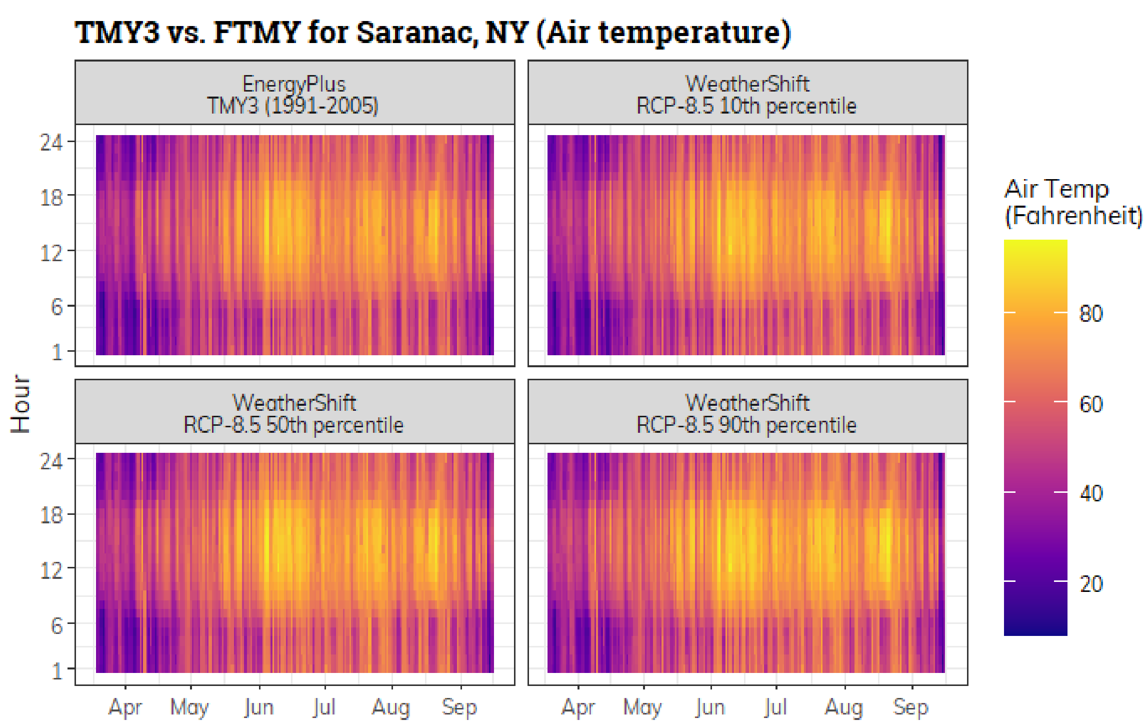


Figure B-34. TMY3 versus FTMY Air Temperature by Month, April through September in Saranac Lake, New York



B.4 Psychrometric Charts

Buffalo

Figure B-35. Psychrometric Chart for Buffalo—TMYx (2004–2018)

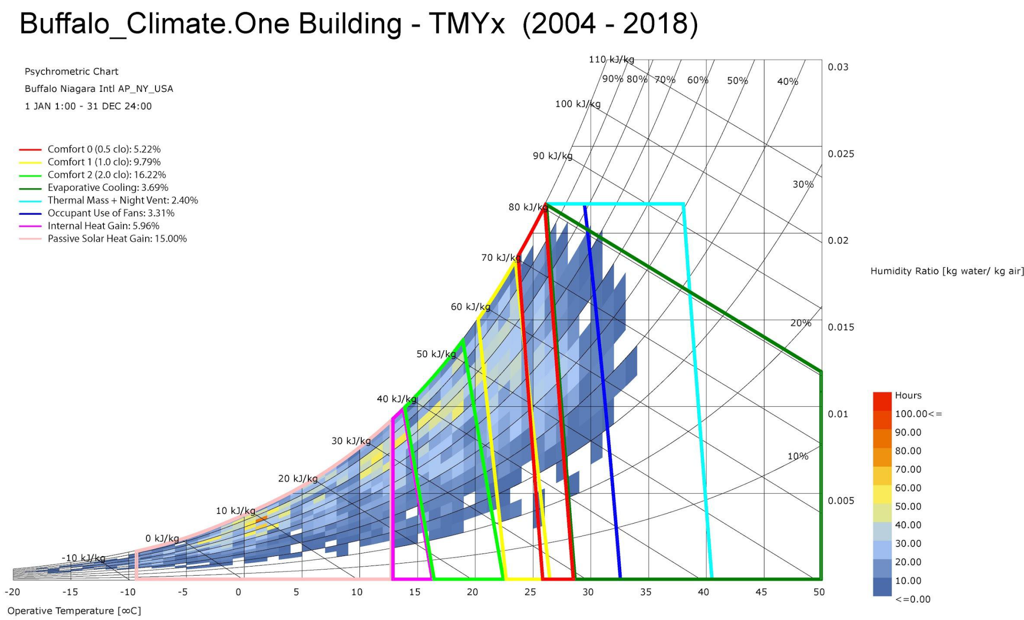


Figure B-36. Psychrometric Chart for Buffalo—TMYx (2009–2015)

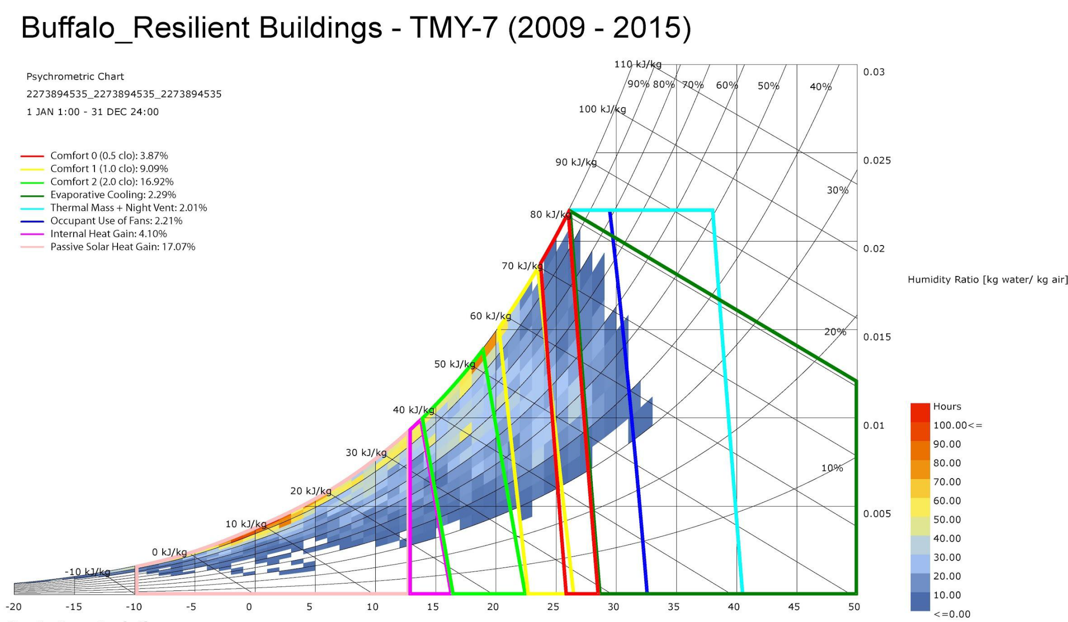
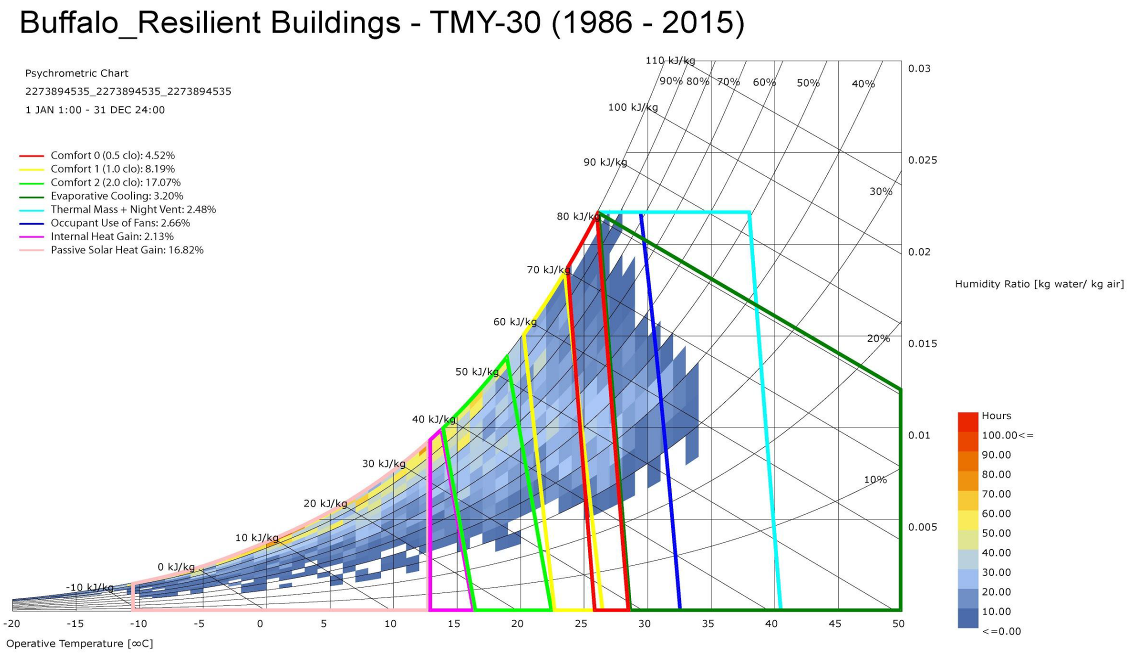


Figure B-37. Psychrometric Chart for Buffalo—TMYx (1986–2015)



FigureB-38. Psychrometric Chart for Buffalo—XMY-min

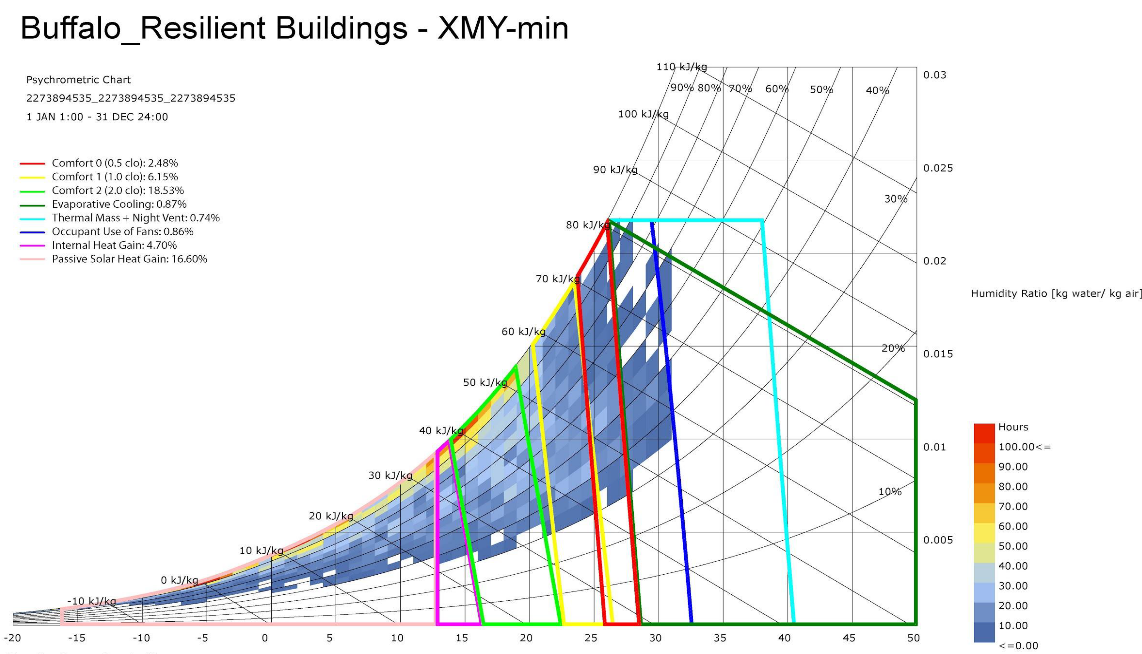
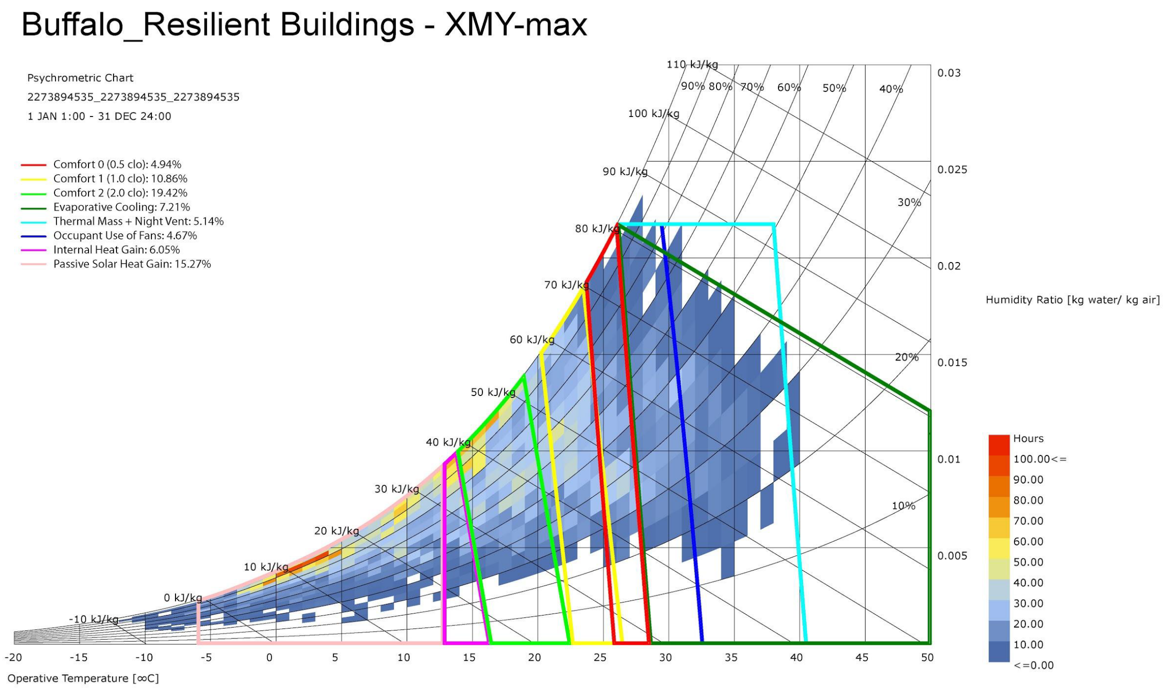


Figure B-39. Psychrometric Chart for Buffalo—XMY-max



FigureB-40. Psychrometric Chart for Buffalo—TMYx (2001–2018)

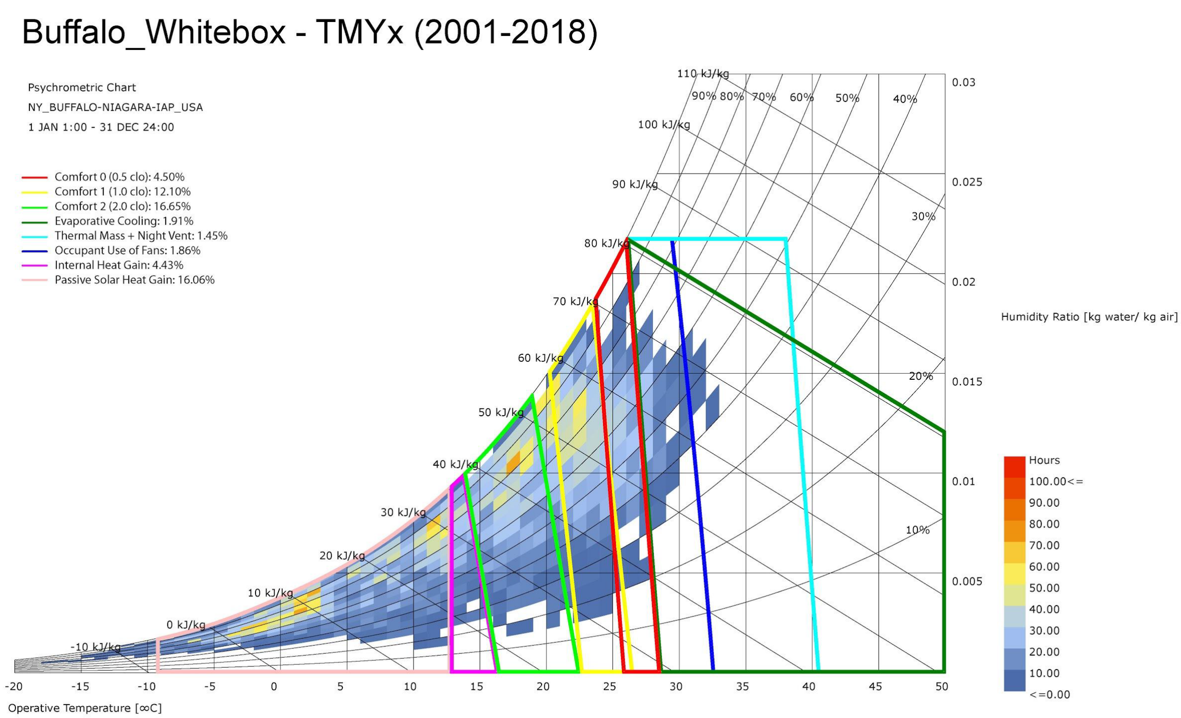


Figure B-41. Psychrometric Chart for Buffalo—TMYx Trended (2001–2018)

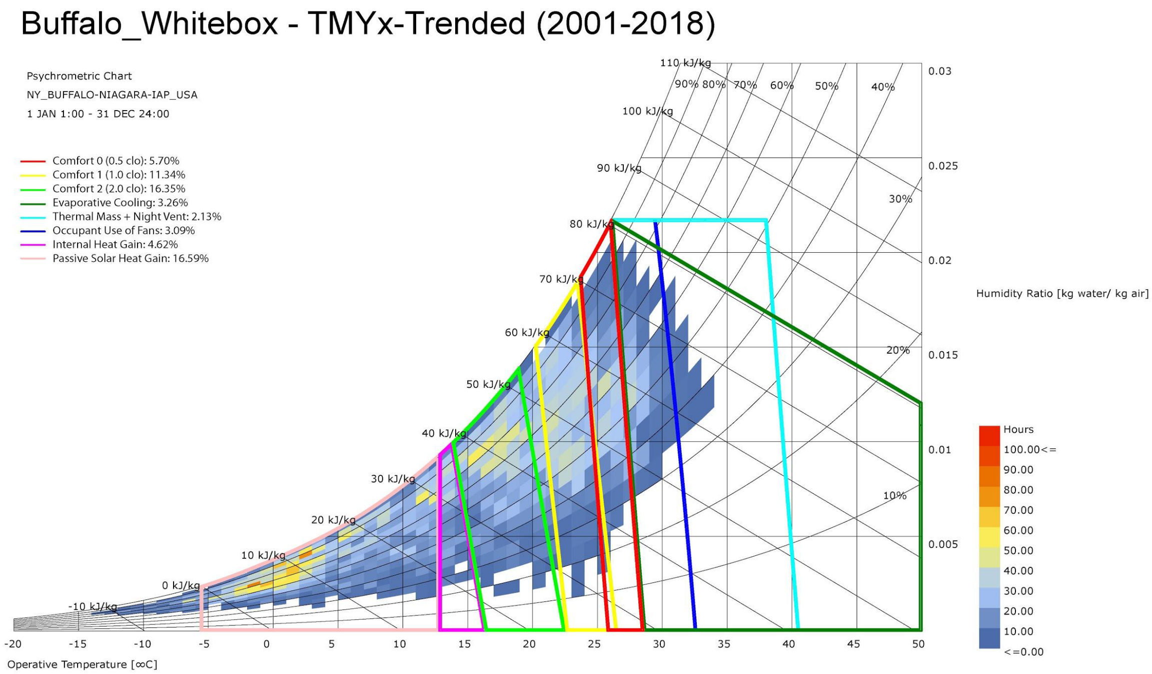


Figure B-42. Psychrometric Chart for Buffalo—2035

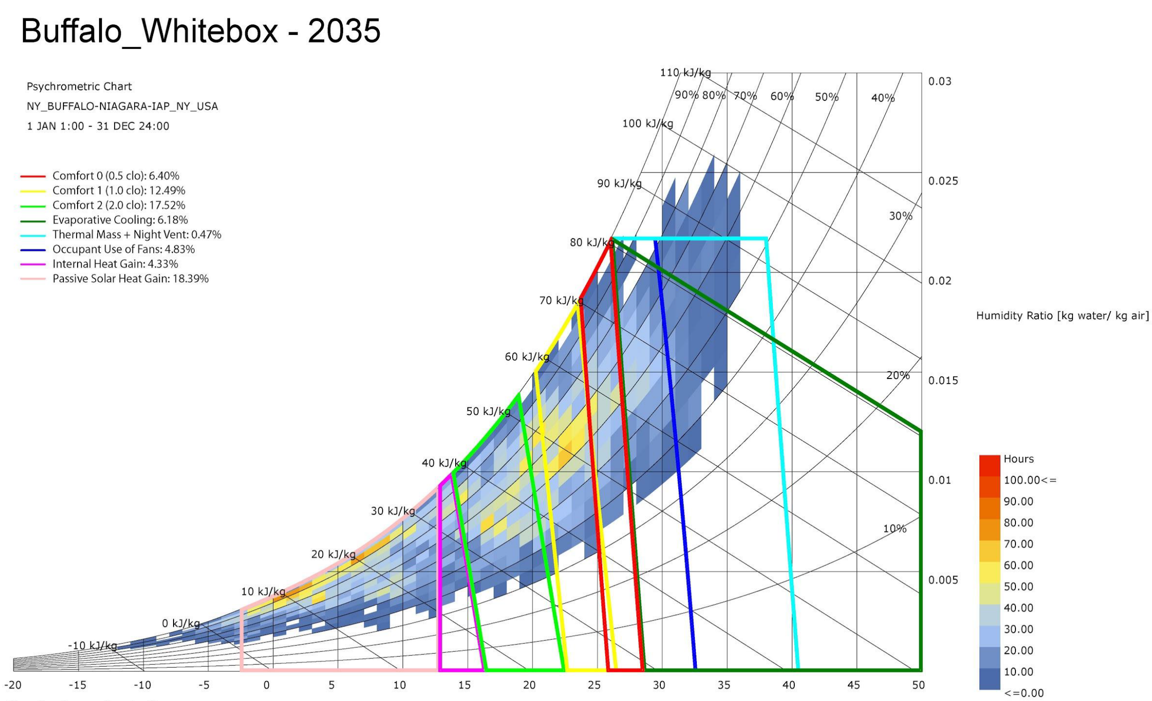


Figure B-43. Psychrometric Chart for Buffalo—2055

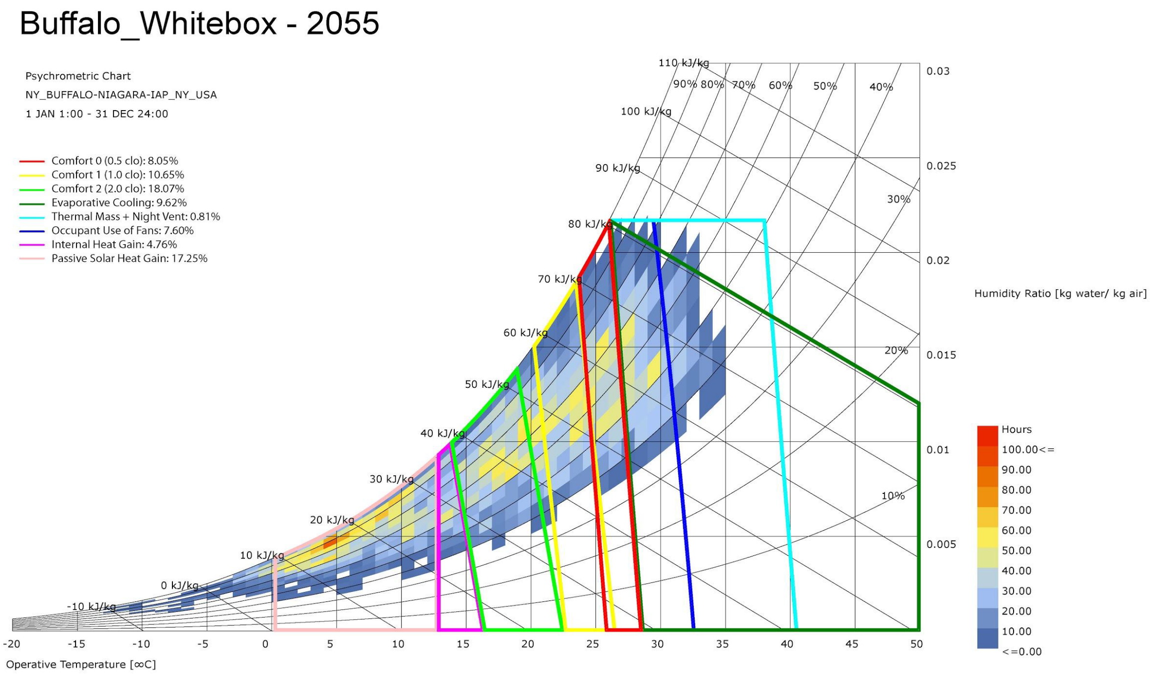
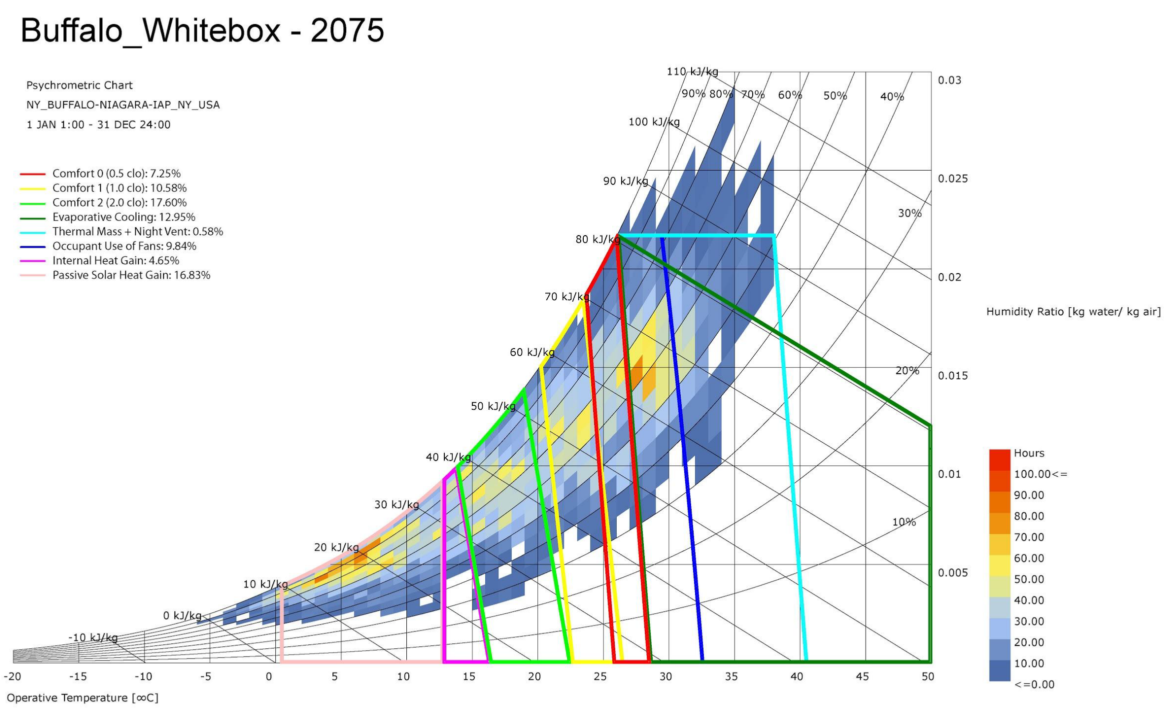


Figure B-44. Psychrometric Chart for Buffalo—2075



FigureB-45. Psychrometric Chart for Buffalo—RCP-8.5 10th Percentile

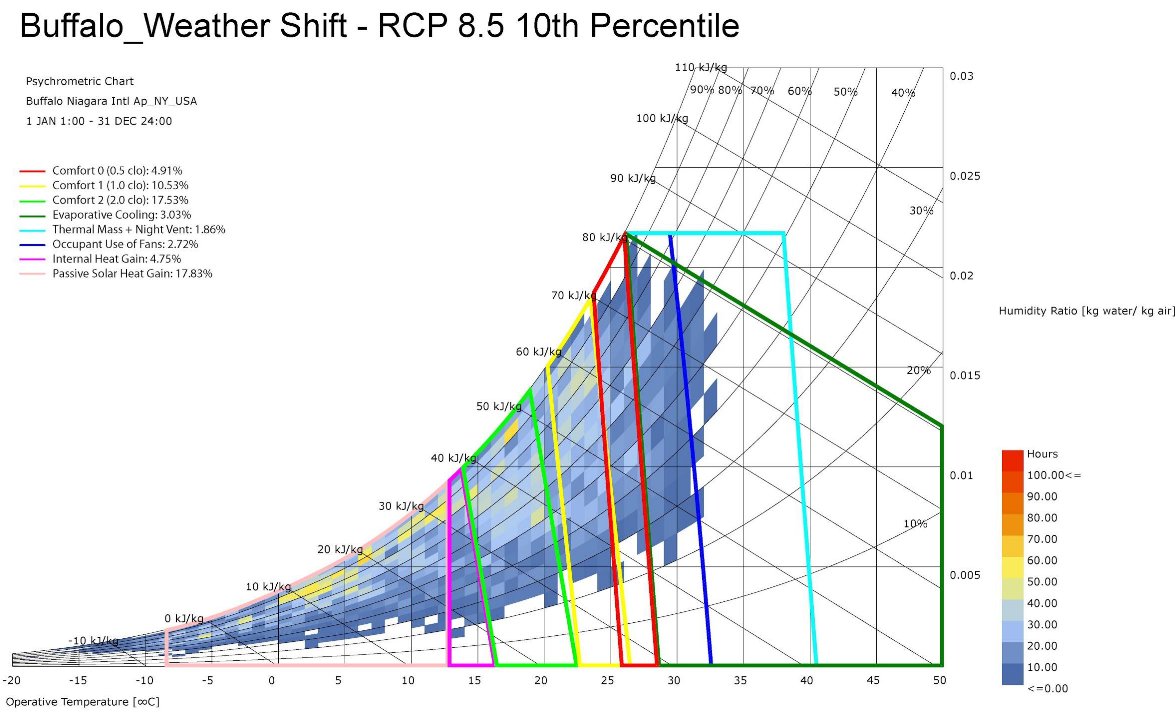
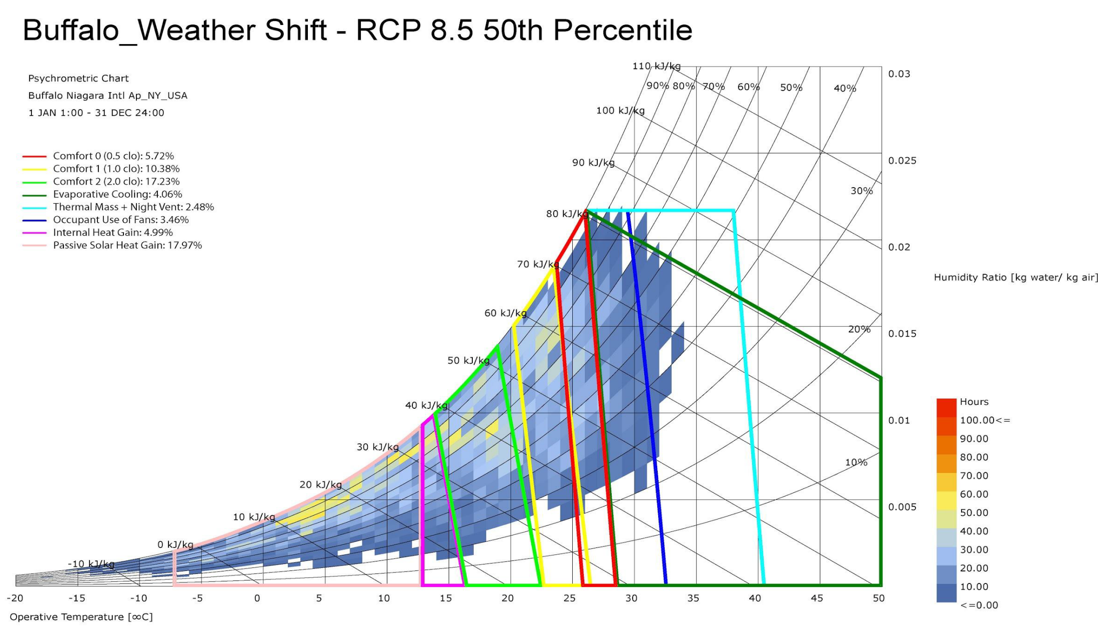
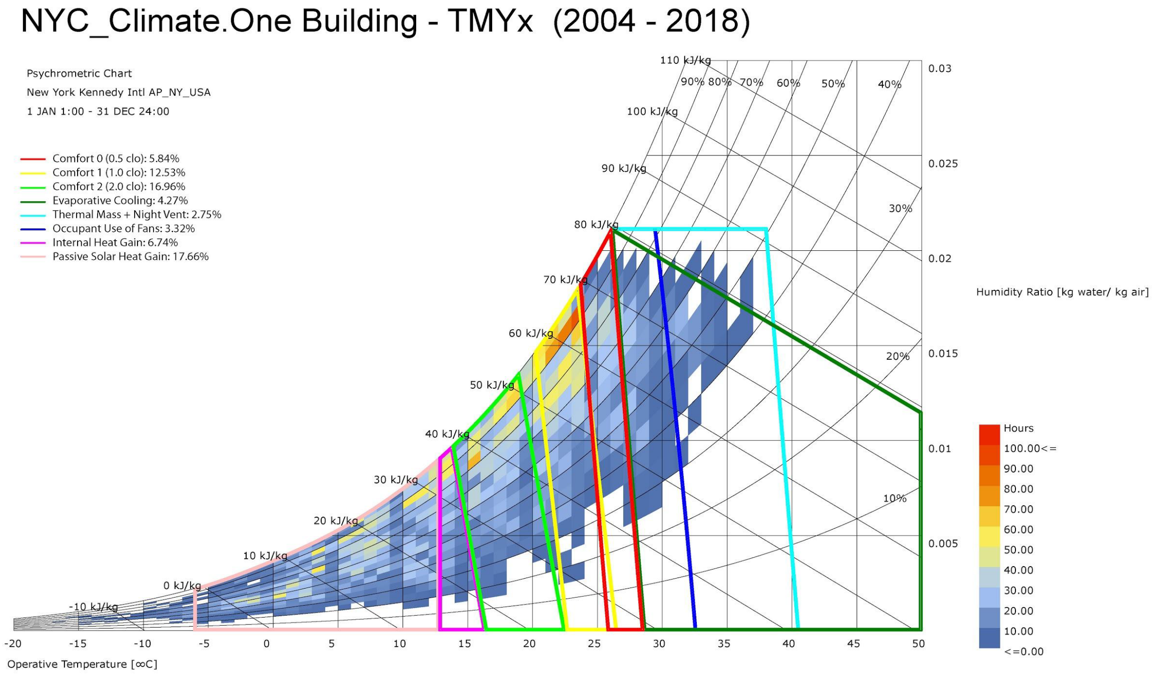


Figure B-46. Psychrometric Chart for Buffalo—RCP-8.5 50th Percentile



New York City

Figure B-47. Psychrometric Chart for New York City—TMYx (2004–2018)



FigureB-48. Psychrometric Chart for New York City—TMYx (2009–2015)

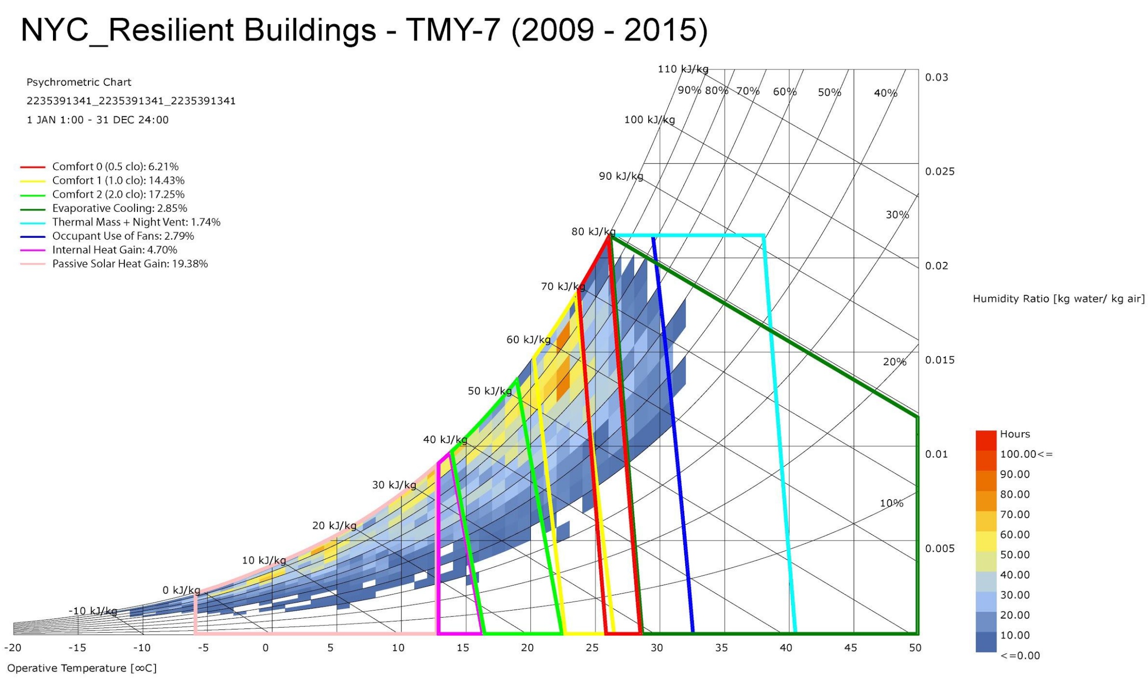


Figure B-49. Psychrometric Chart for New York City—TMYx (1986–2015)

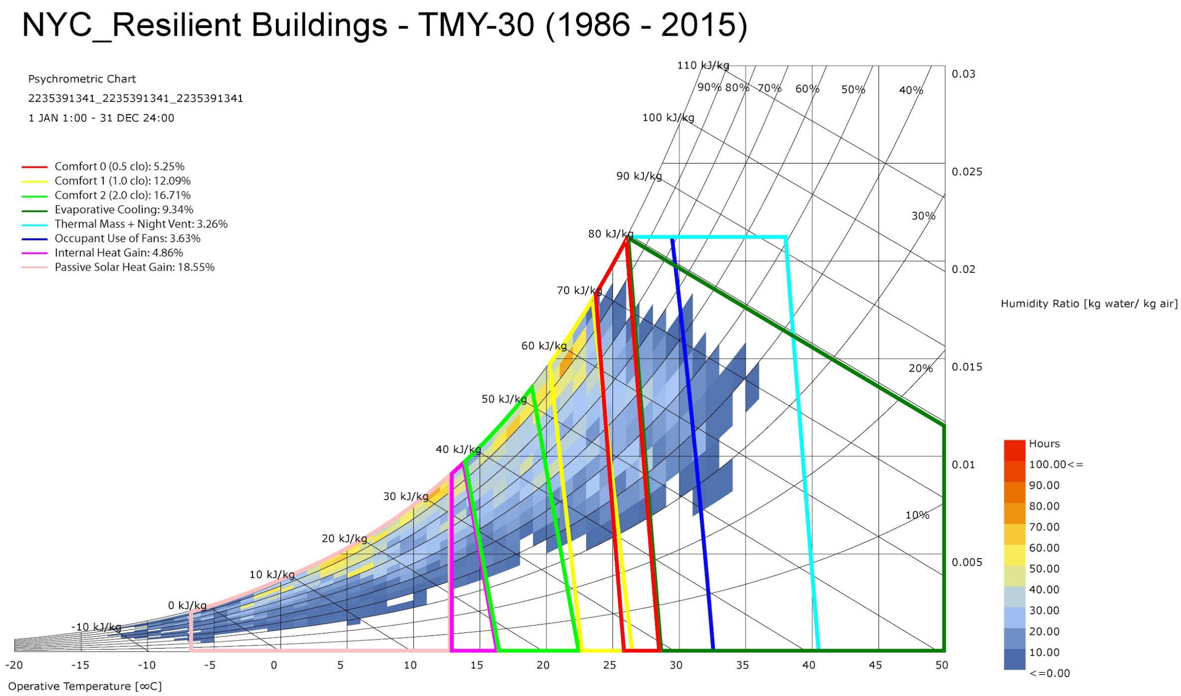


Figure B-50. Psychrometric Chart for New York City—XMY-max

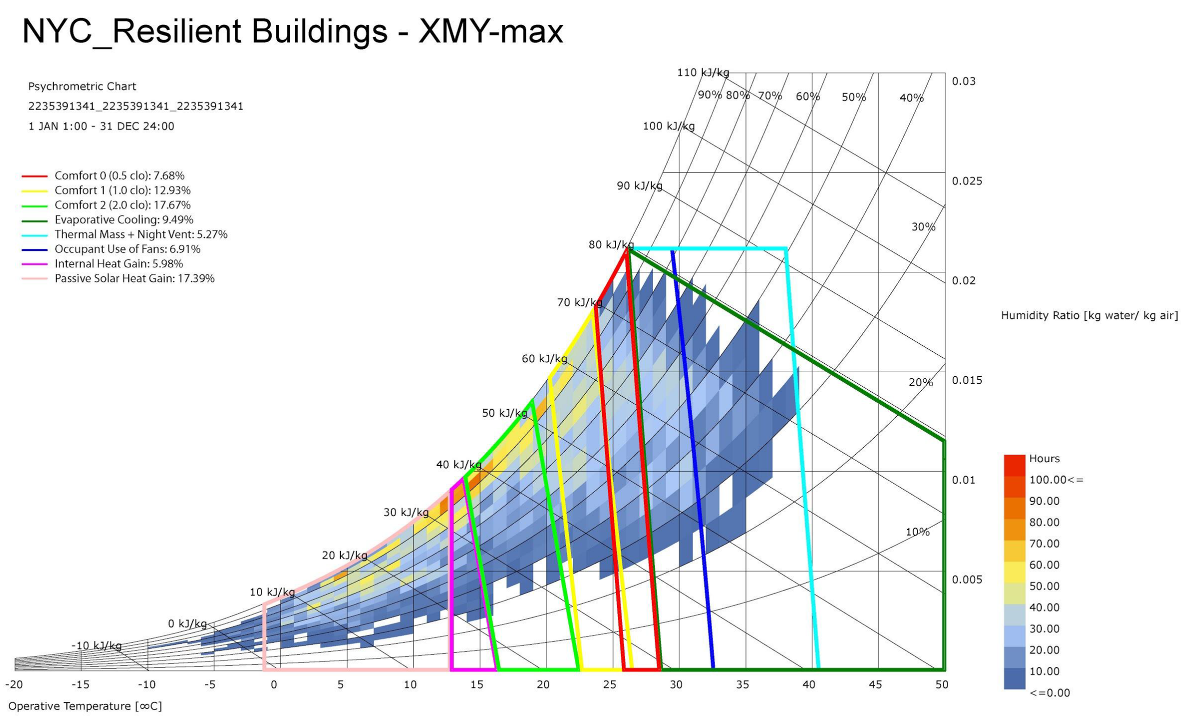


Figure B-51. Psychrometric Chart for New York City—XMY-min

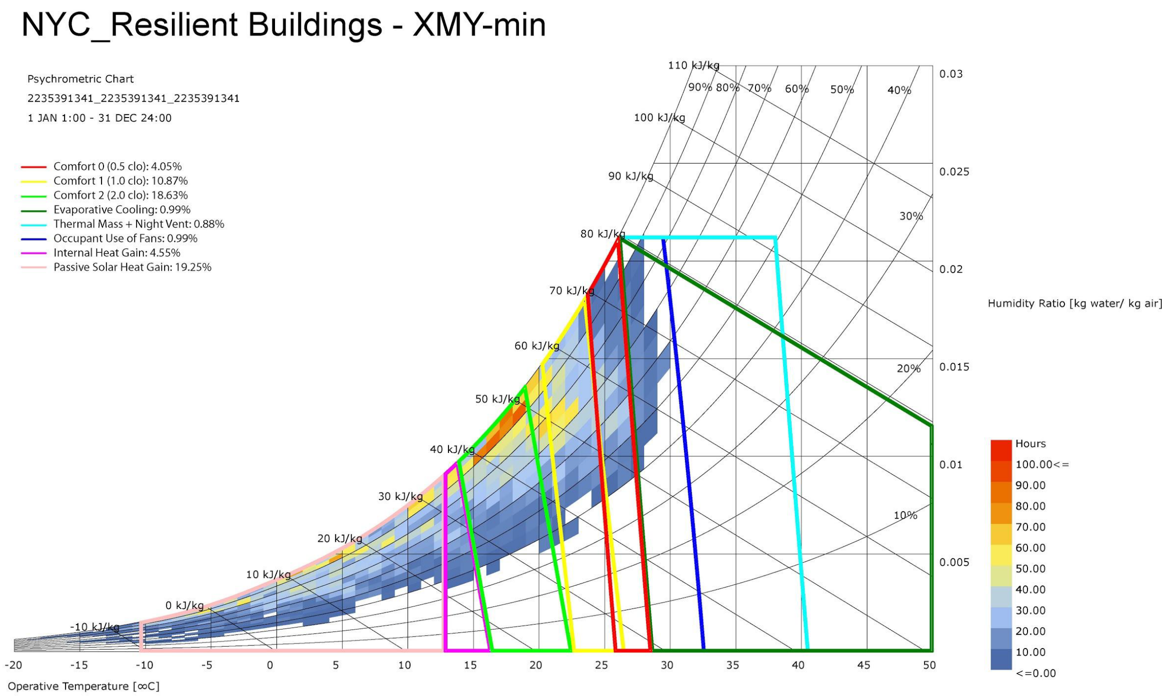


Figure B-52. Psychrometric Chart for New York City—TMYx (2001–2018)

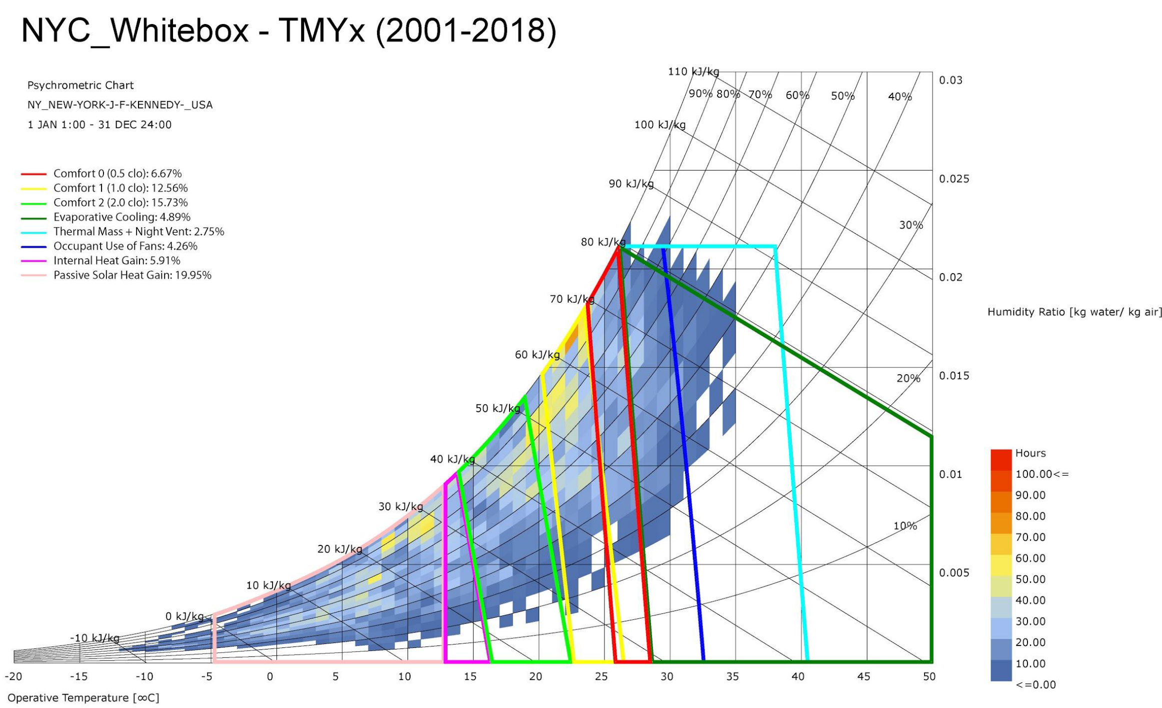


Figure B-53. Psychrometric Chart for New York City—TMYx Trended (2001–2018)

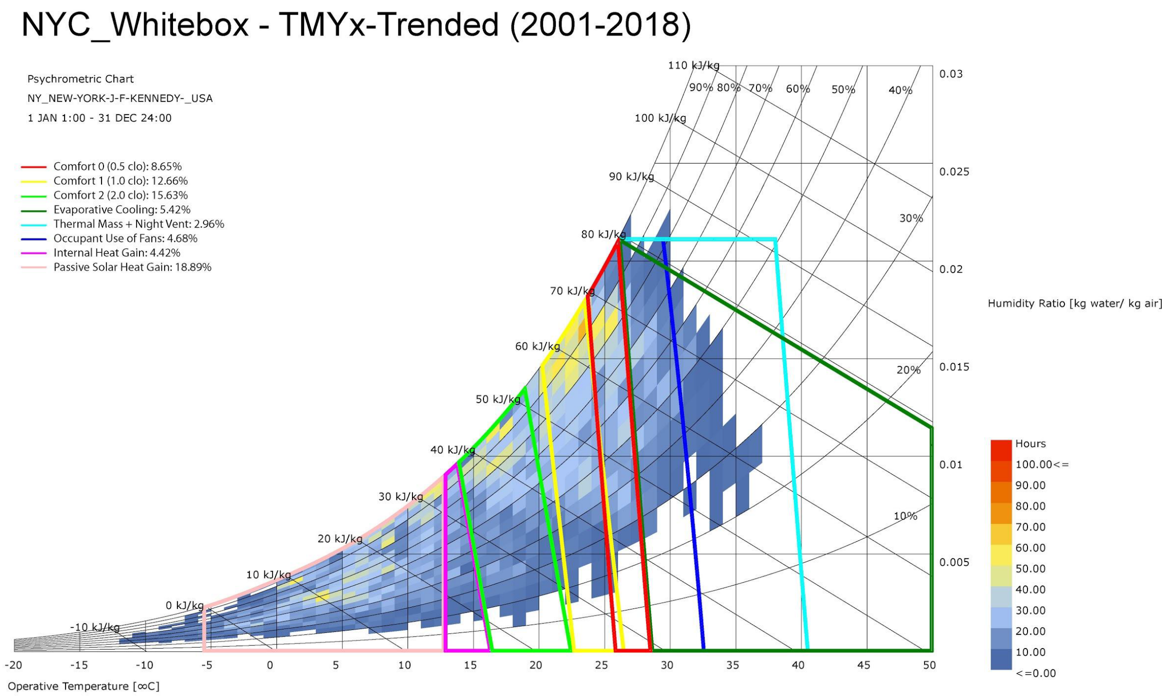


Figure B-54. Psychrometric Chart for NYC—2035

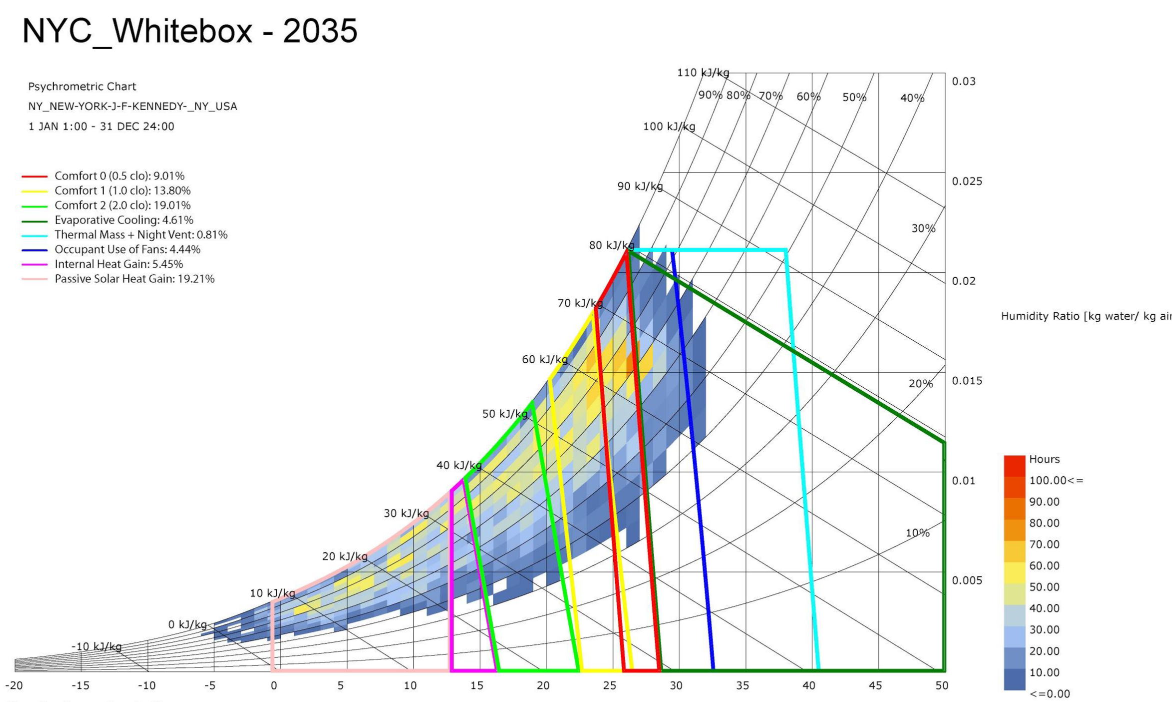


Figure B-55. Psychrometric Chart for NYC—2055

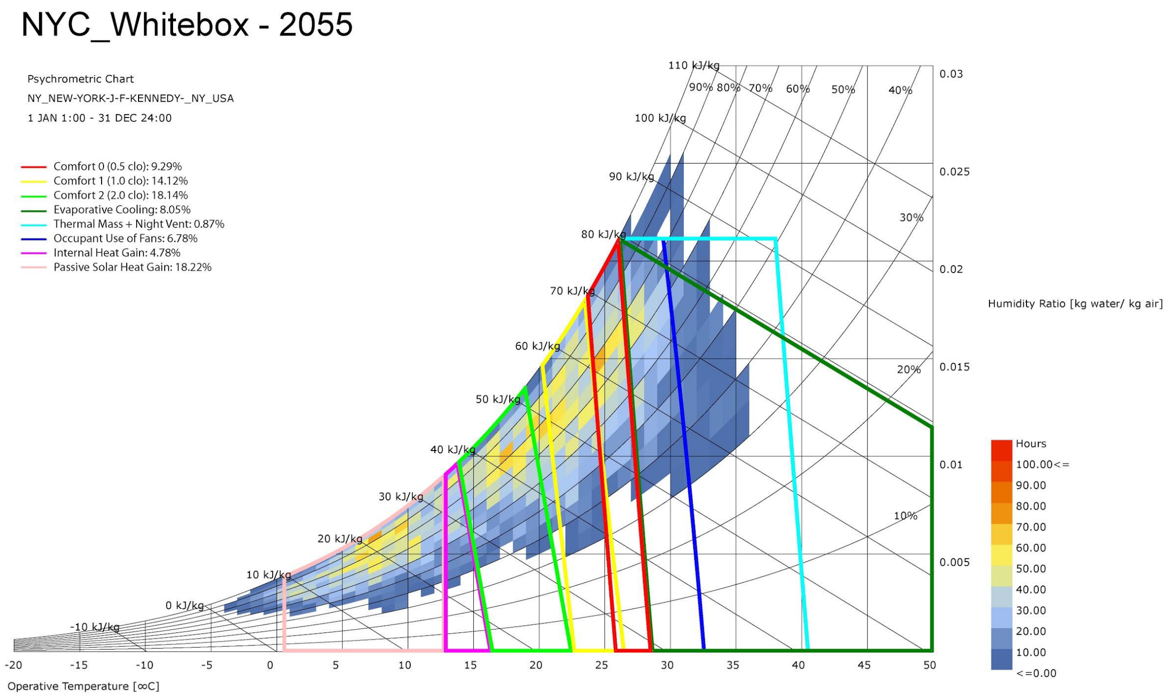


Figure B-56. Psychrometric Chart for NYC—2075

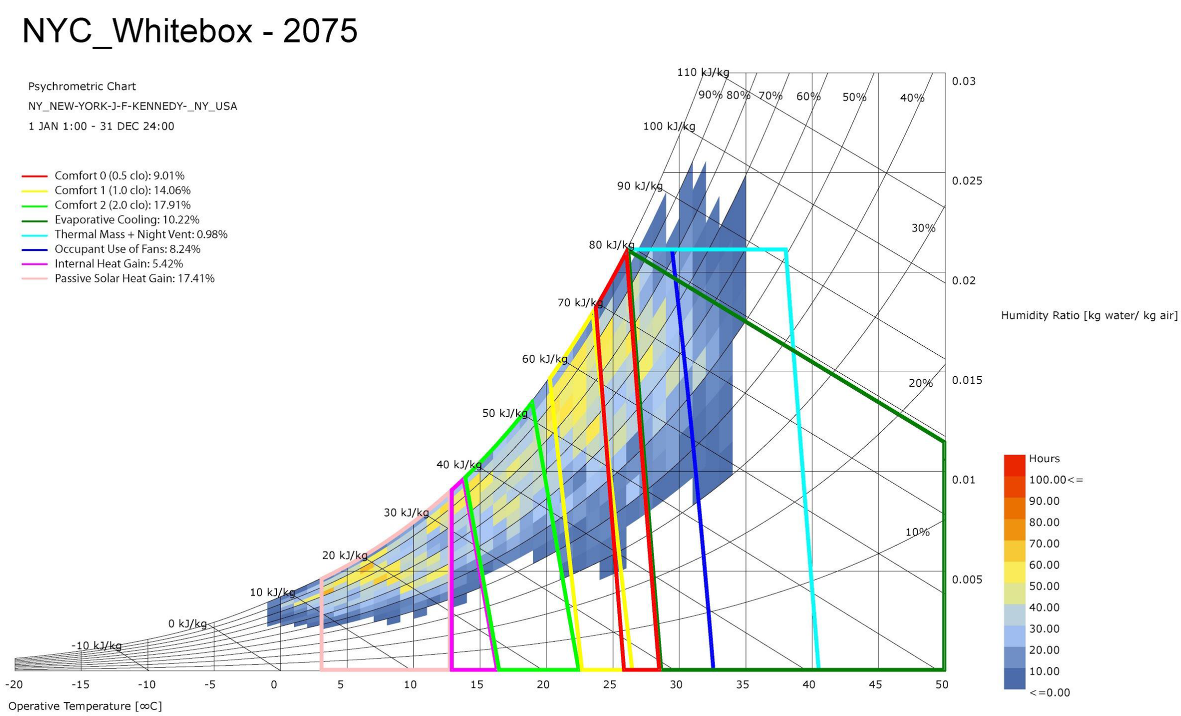


Figure B-57. Psychrometric Chart for NYC—RCP-8.5 10th Percentile

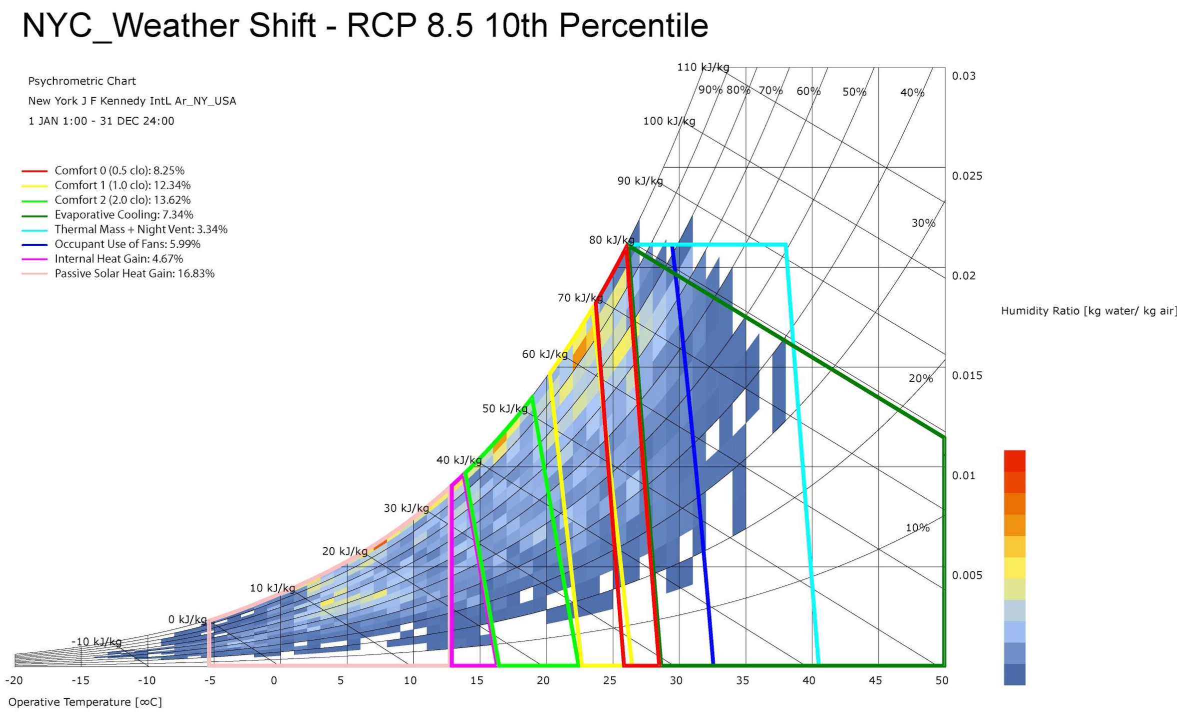
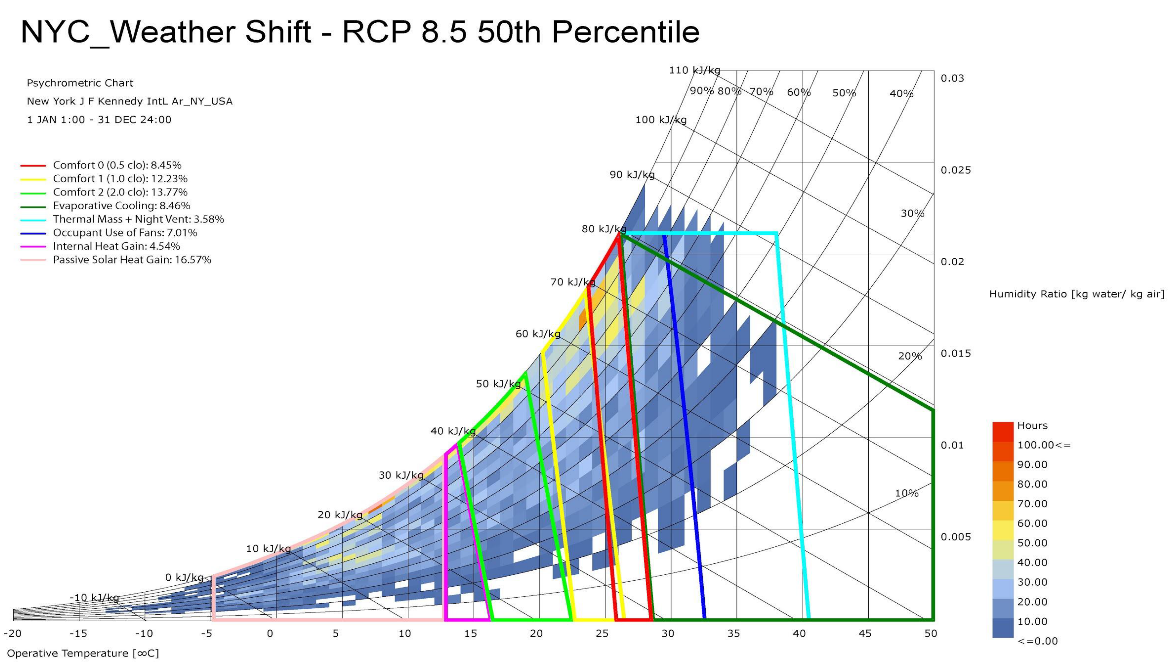


Figure B-58. Psychrometric Chart for NYC—RCP-8.5 50th Percentile



Saranac Lake

Figure B-59. Psychrometric Chart for Saranac Lake—TMYx (2004–2018)

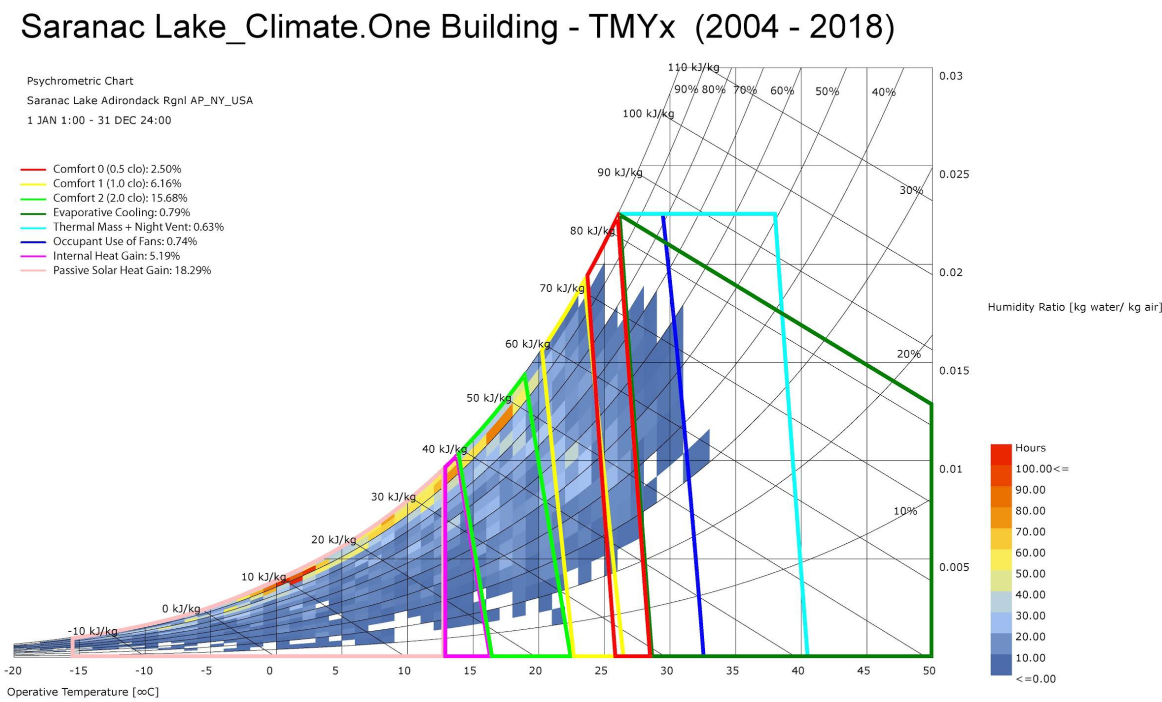


Figure B-60. Psychrometric Chart for Saranac Lake—TMYx (2009–2015)

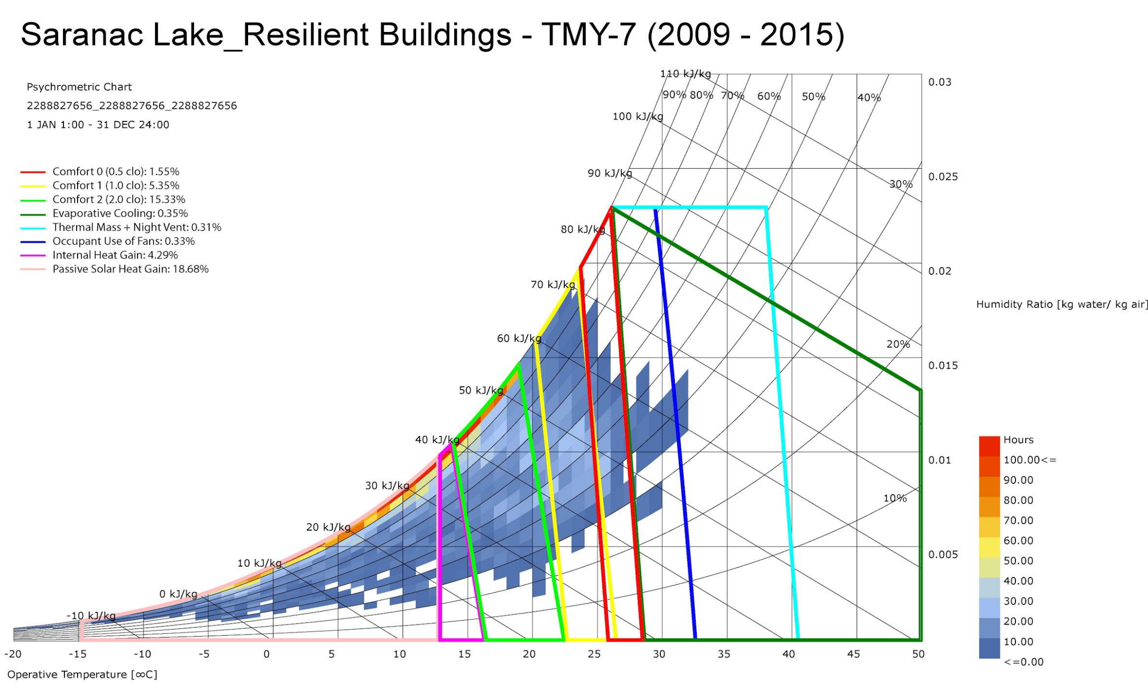


Figure B-61. Psychrometric Chart for Saranac Lake—TMYx (1986–2015)

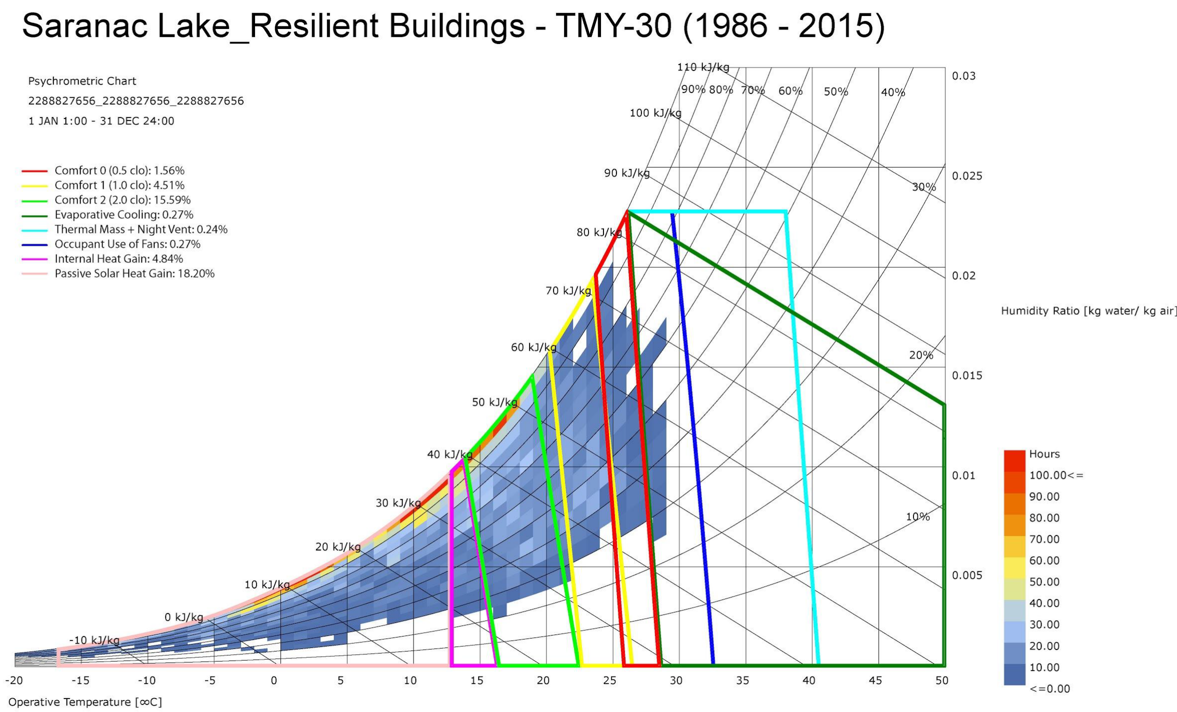


Figure B-62. Psychrometric Chart for Saranac Lake—XMY-min

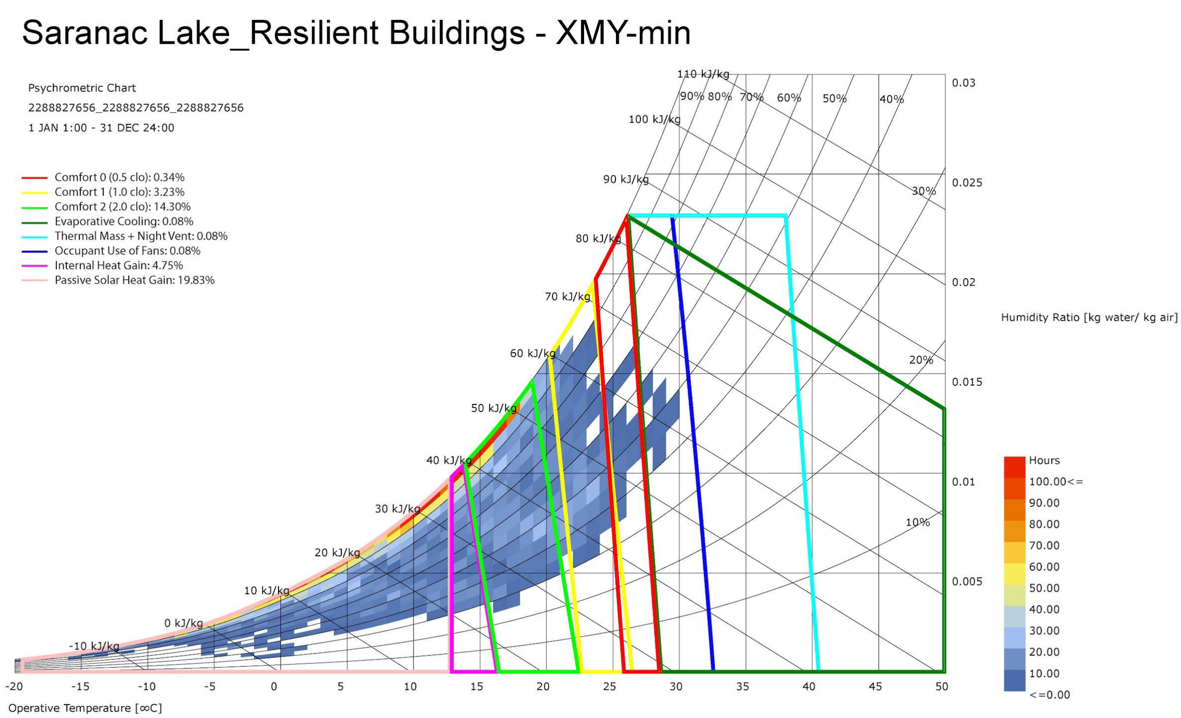


Figure B-63. Psychrometric Chart for Saranac Lake—XMY-max

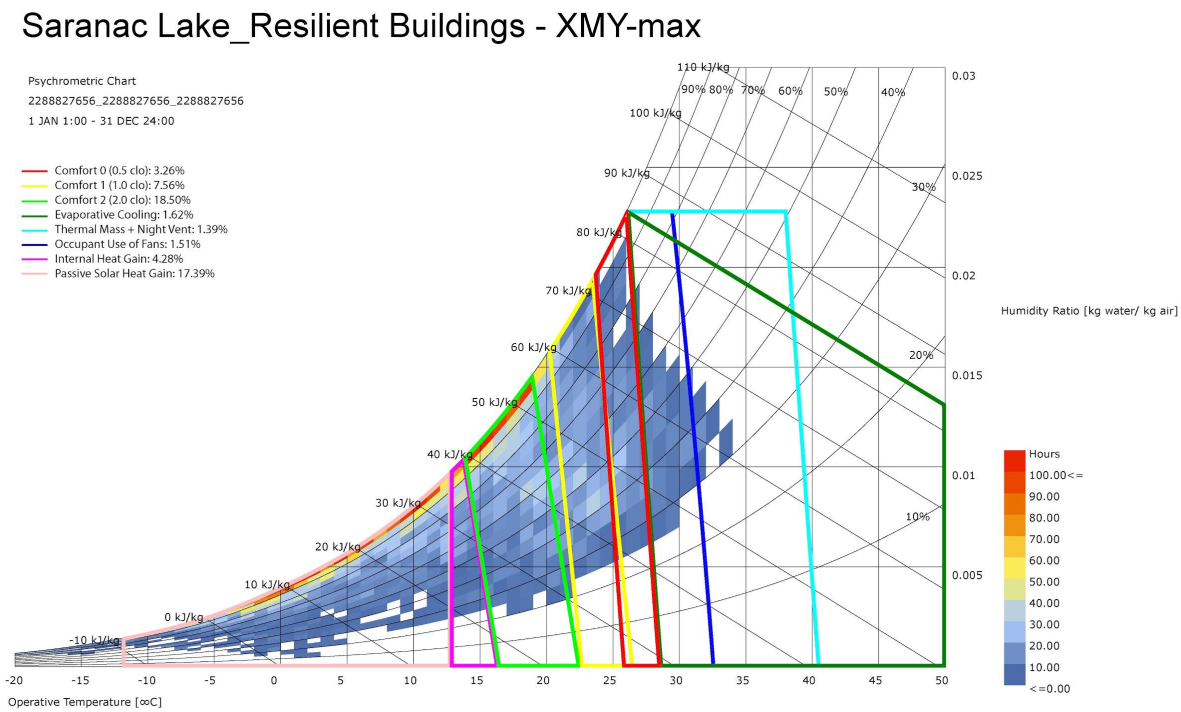


Figure B-64. Psychrometric Chart for Saranac Lake—RCP-8.5 10th Percentile

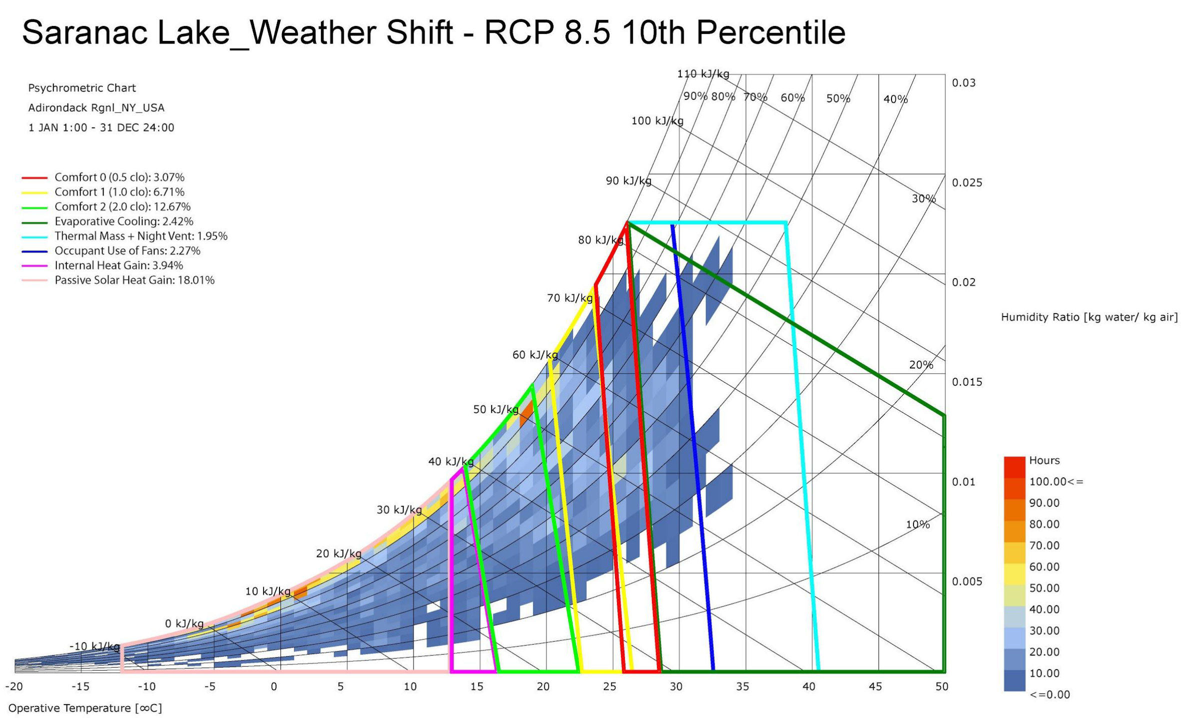
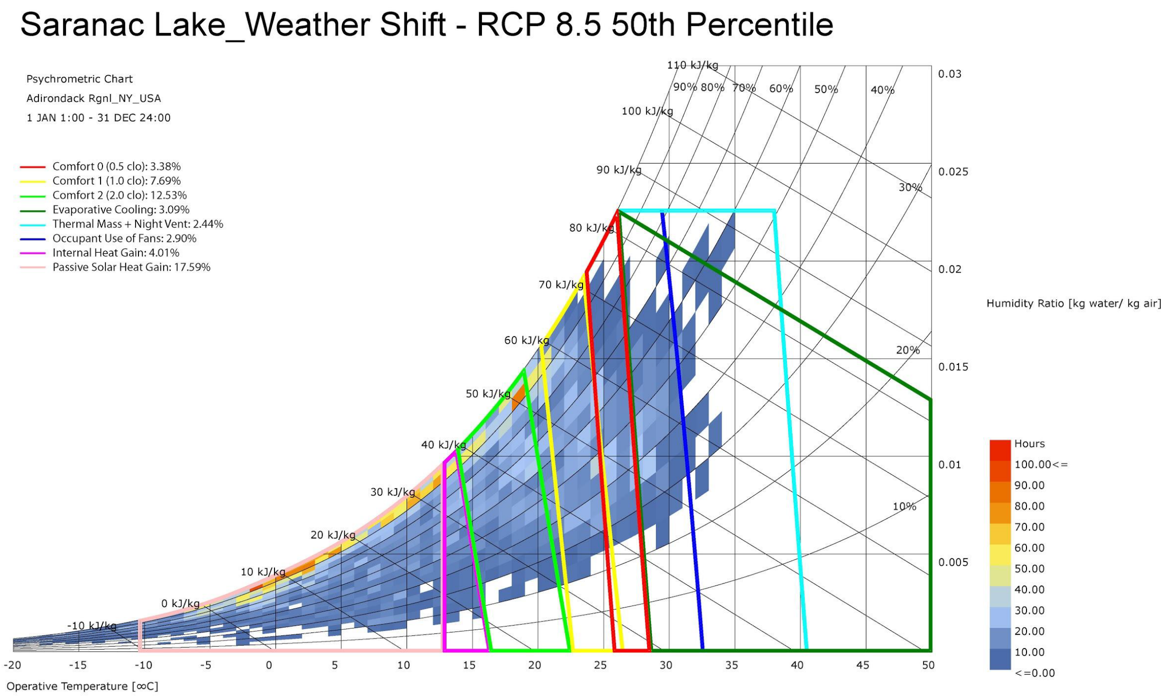


Figure B-65. Psychrometric Chart for Saranac Lake—RCP-8.5 50th Percentile



Appendix C EnergyPlus Results

This section provides supplemental analysis that was conducted during the Modeling task.

C.1 ASHRAE Cooling Design Conditions

ASHRAE Standard 90.1-2019, Energy Standard for Buildings Except Low-Rise Residential Buildings and Standard 90.2-2018, Energy Efficient Design of Low-Rise Residential Buildings specify the heating and cooling design conditions to use for sizing HVAC equipment. This information can be found in the design day (.ddy) file that comes with standard TMY3 weather file packages. ASHRAE updates design conditions every four years in the ASHRAE Fundamentals Handbook, with the newest data set scheduled to be released on 2021.

If a user wants to run an EnergyPlus file in a new location, they should replace the "Site:Location" and "SizingPeriod:DesignDay" objects in the .idf input file using information gathered from the .ddy file. The Site:Location object specifies the latitude, longitude, time zone, and elevation. The SizingPeriod:DesignDay specifies the annual heating and cooling design conditions, which include a winter and summer design day and the weather conditions for those days. The heating and cooling design conditions are specified by the percent of the annual weather conditions covered and are available for different levels:

- Dry-bulb temperature corresponding to 99.6% and 99.0% annual cumulative frequency of occurrence (cold conditions) for heating system design
- Dry-bulb temperature corresponding to 0.4%, 1.0%, and 2.0% annual cumulative frequency of occurrence (warm conditions) and mean coincident wet-bulb temperature for cooling system design

One of these levels is typically selected for sizing heating and cooling systems in buildings. The NYS-2020 Code analysis used 99.6% heating and 0.4% cooling conditions, which are the most stringent of all available levels. However, during stakeholder interviews, it was suggested that this analysis should use the less slightly less stringent 1% cooling conditions to follow ASHRAE 90.1 and 90.2 guidelines. This means switching a design dry-bulb temperature which would be exceeded on average for 35 hours in the year of record, to a lower dry-bulb temperature threshold which would be exceeded on average for 88 hours in the year of record. For example, in the Buffalo TMY3 ddy file, the 1% dry-bulb design temperature was 28.9°C, while the 0.4% was 30.3°C.

So, the NYS-2020 Code *EnergyPlus* .idf files were updated to switch from 0.4% to 1% cooling design conditions in New York City and Buffalo. The switch from 0.4% to 1% results in slightly lower design dry-bulb temperatures for cooling system sizing calculations resulting in smaller cooling capacity. Figure 83 and Figure 84 show the EUI and peak demand end use breakdowns that resulted from these changes. These changes resulted in a slight increase in EUI and peak demand.

Figure C-1. End Use Breakdown for 1.0% (left) versus 0.4% (right) Cooling Design Day in New York City

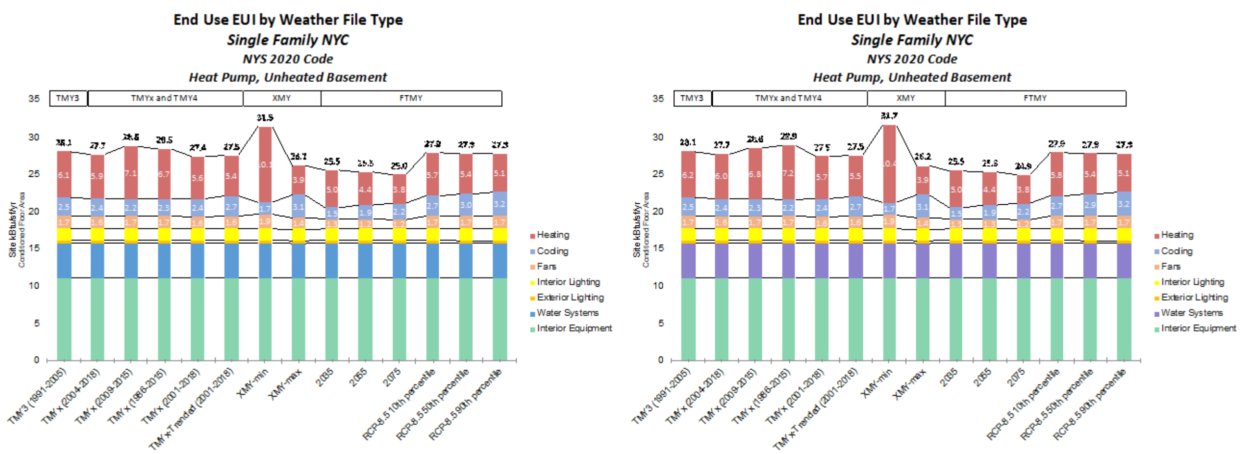
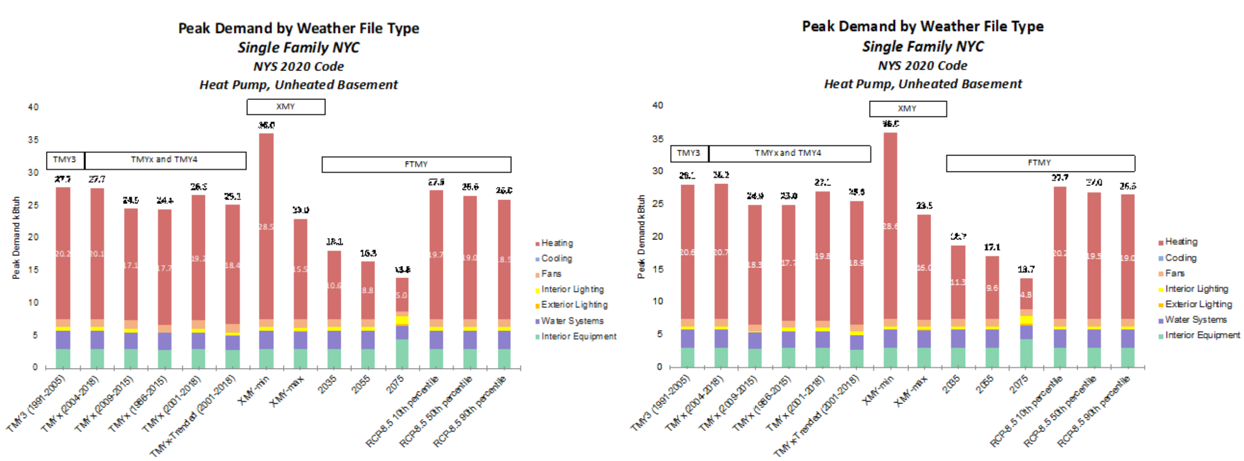


Figure C-2. Peak Demand Breakdown for 1.0% (left) versus 0.4% (right) Cooling Design Day in New York City



C.2 Design Days Edits in EnergyPlus

In the modeling exercise, the most accurate way to compare the effect of varying weather files would be to create a new *EnergyPlus* .idf input file for each weather file, using design conditions from the .ddy file associated with that weather file. However, as discussed earlier, only 6 out of the 13 weather file types provide this information (the TMYx from Climate.OneBuilding and all 5 of the White Box files). Figure 85 and Figure 86 compare the results in New York City before and after the design conditions were updated. In each case the site EUI changed by 0.1 kBtu/sf or less and the peak demand varied by 0.1 kBtuh or less. So, for the purposes of this exploratory analysis, we expect that the lack of updated design conditions for the Resilient Buildings and WeatherShift files would not have been a strong driver in changes to the overall energy usage and peak demand.

Figure C-3. End Use Breakdown with and without Design Day Edits in New York City

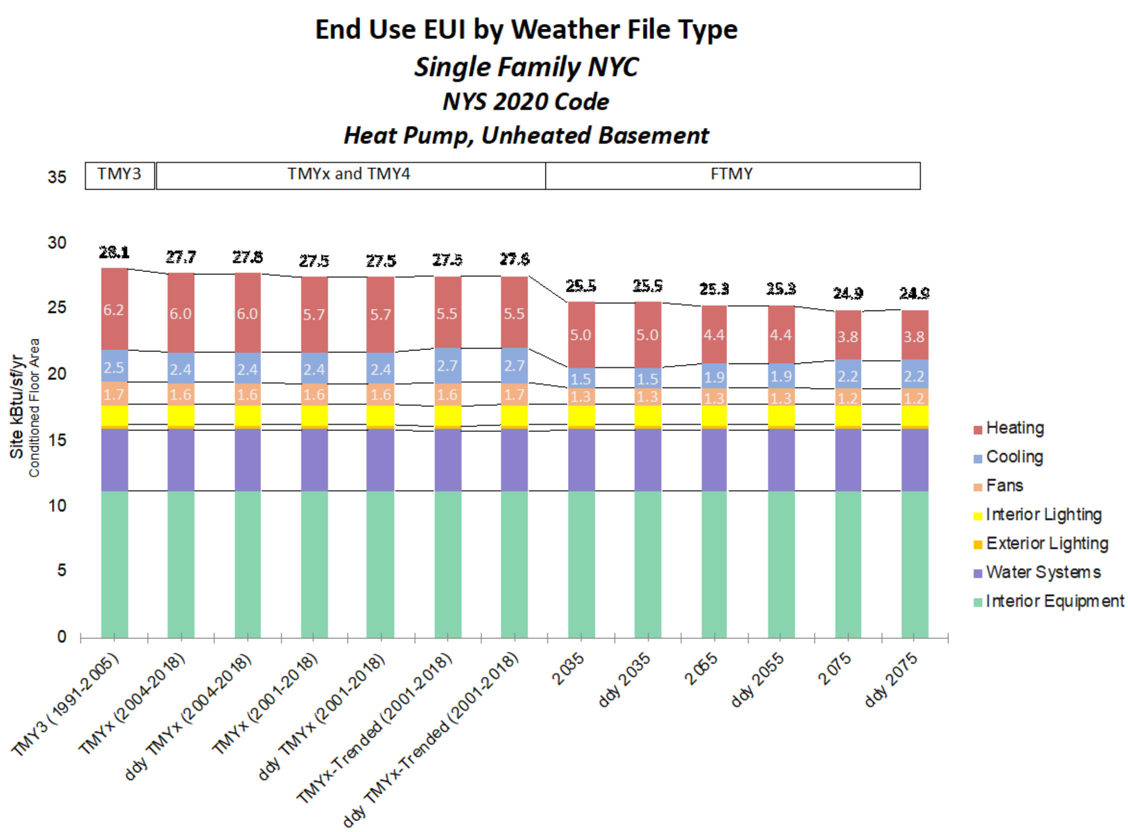
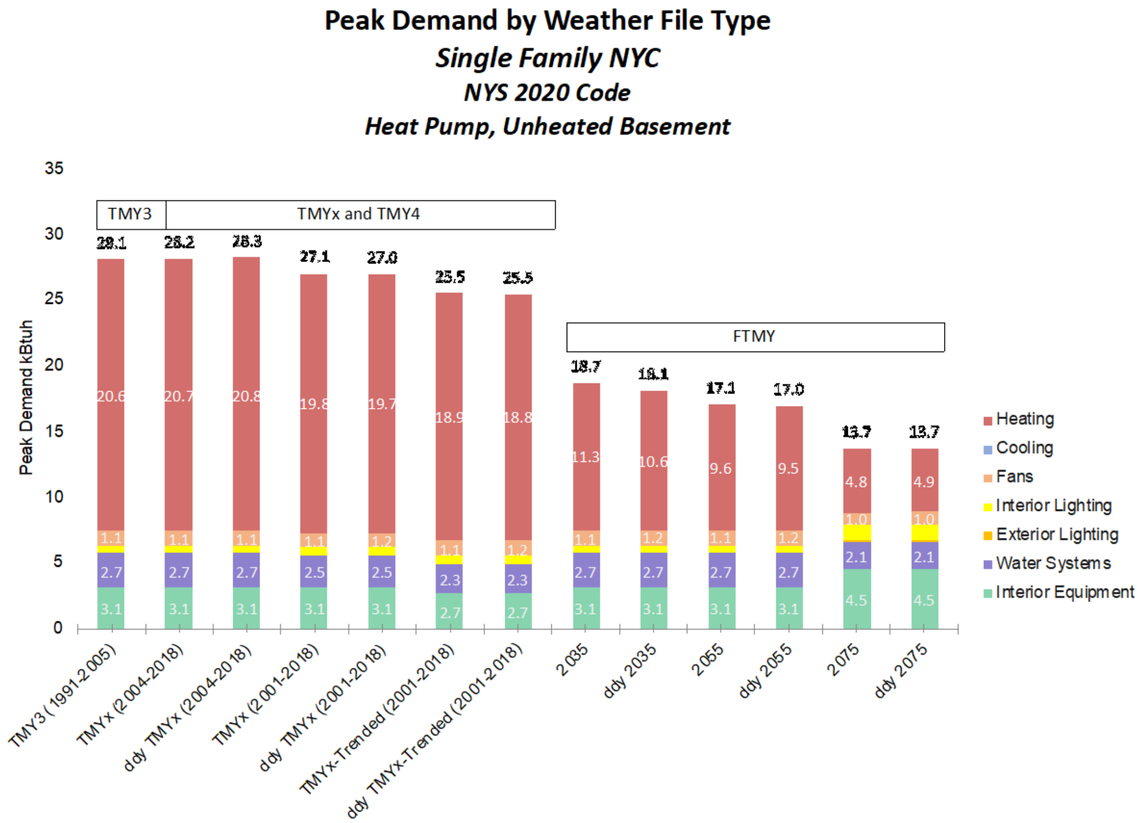


Figure C-4. Peak Demand Breakdown with and without Design Day Edits in New York City



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