Load Forecast Uncertainty Modeling: Phase 1 Study Results

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System & Resource Planning

Load Forecasting Task Force

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Agenda

- Introduction & Motivation
- Background – LFU Modeling Approach
- Temperature/Humidity Indices used in LFU Modeling
- Long-Term Historical Weather Distributions
- Coincident vs. Non-Coincident LFU Results and Trends
- Inter-annual Trends in System Load and Weather
- Recommendations for Future Work (Phase 2)

Introduction & Motivation

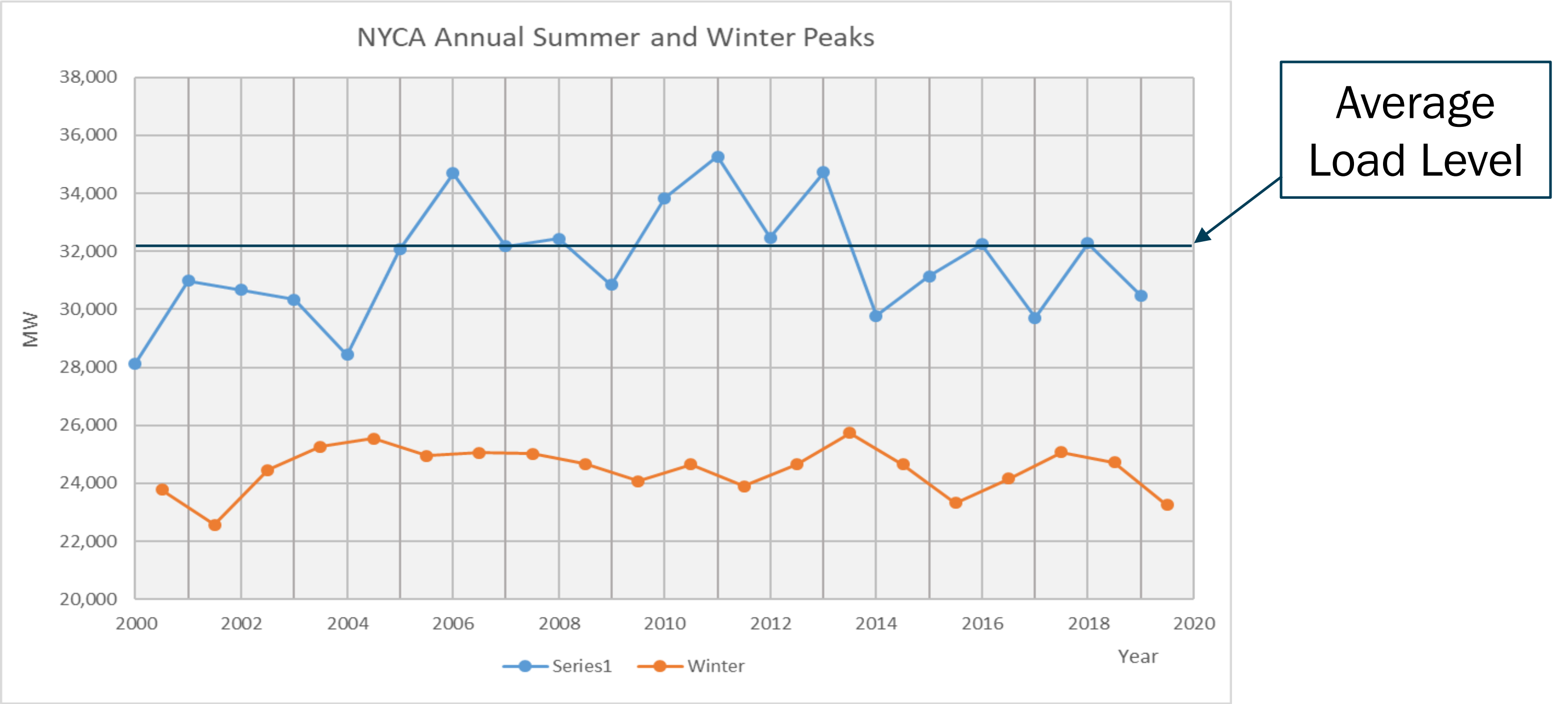
Introduction & Motivation

- Load patterns are continuing to change across the New York Control Area (NYCA). Factors that drive changes in load are:
  - Economic activity and demographic changes (e.g. Employment, Households, Population, Gross State Product)
  - End-use technologies (Lighting, Heating, Cooking, Plug-Loads, EVs) and associated Energy Efficiency gains
  - Distributed Energy Resources (Solar, Storage, Combined Heat/Power, others)
  - A more active and “engaged” system load: Demand Management Programs, Time-of-Use Rates, Smart Devices
- Weather is also key driver in the year-over-year variability of the NYCA peak loads
- A better understanding of the variability of Temperature-Humidity relationships across the NYCA will better inform future Load Forecast Uncertainty (LFU) Modeling efforts and process updates
- Provide additional background materials to stakeholders on the LFU Modeling approach

New York ISO

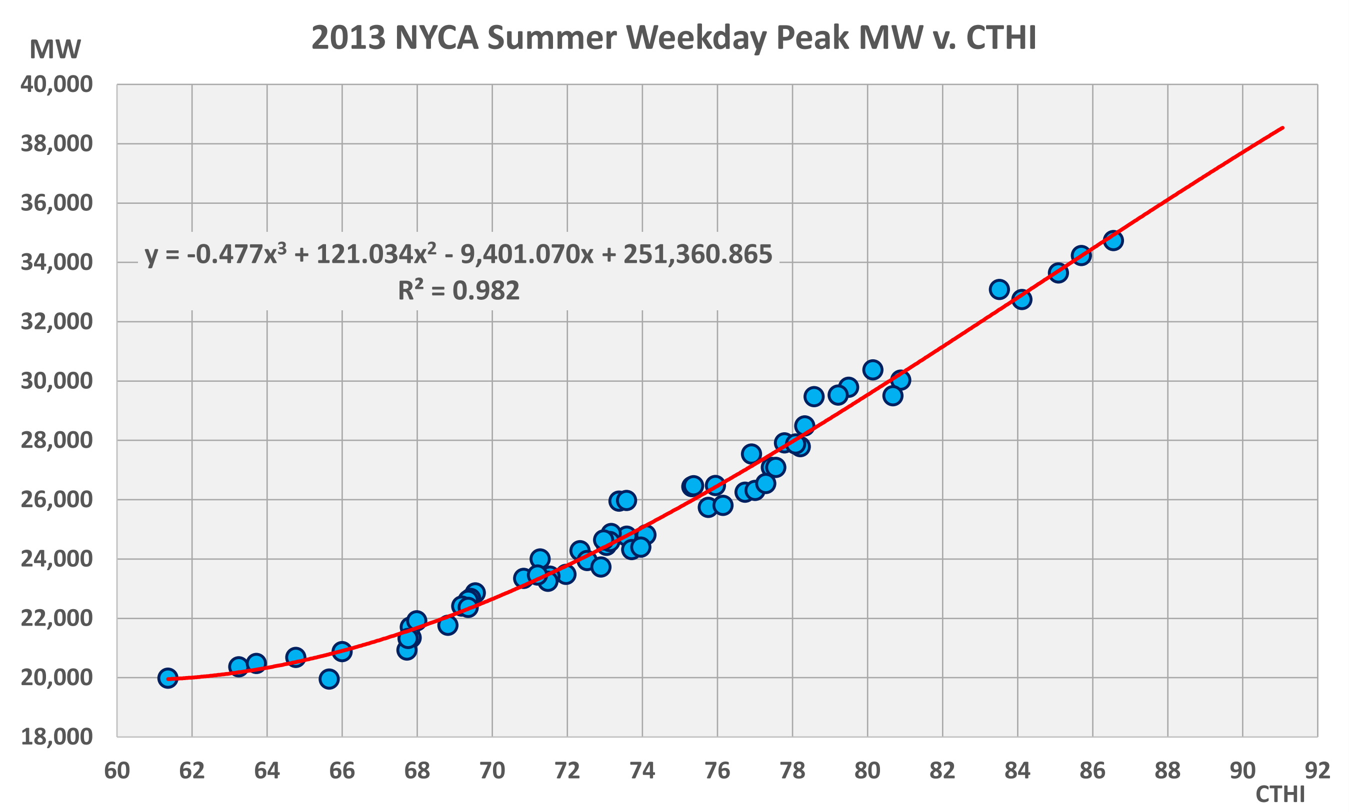
Background - LFU Modeling Approach

NYCA Summer and Winter Peaks



LFU Models provide a "Per-Unit" (PU) multipliers to be used in scaling the load shapes in the NYSRC Installed Reserve Margin (IRM) and NYISO Reliability Needs (RNA) reliability simulation software General Electric Multi-Area Reliability Simulation (MARS)

Modeling Load Response to Weather



Predictors of Peak Loads

- Good: Temperature

- Better: Temperature and Humidity Index

- Best: Cumulative (Lagged) Temperature Humidity Index

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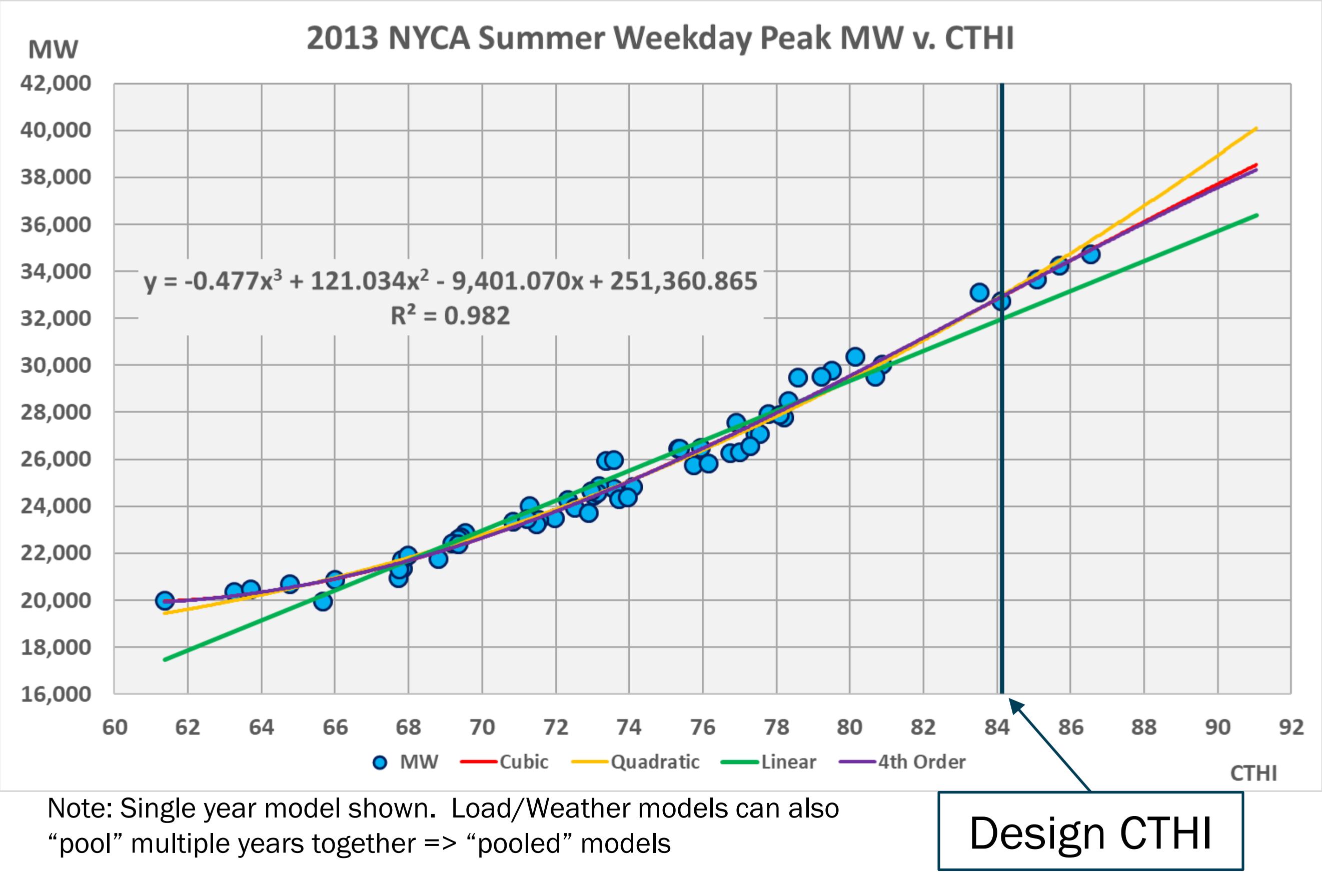
Modeling Load Response to Weather



Note: Single year model shown. Load/Weather models can also "pool" multiple years together => "pooled" models

<u>Fit of Models for Load/Weather Relationship</u>

- Good: Linear

- Better: Quadratic

- Best: 3rd/4th Order Polynomial and Neural Networks

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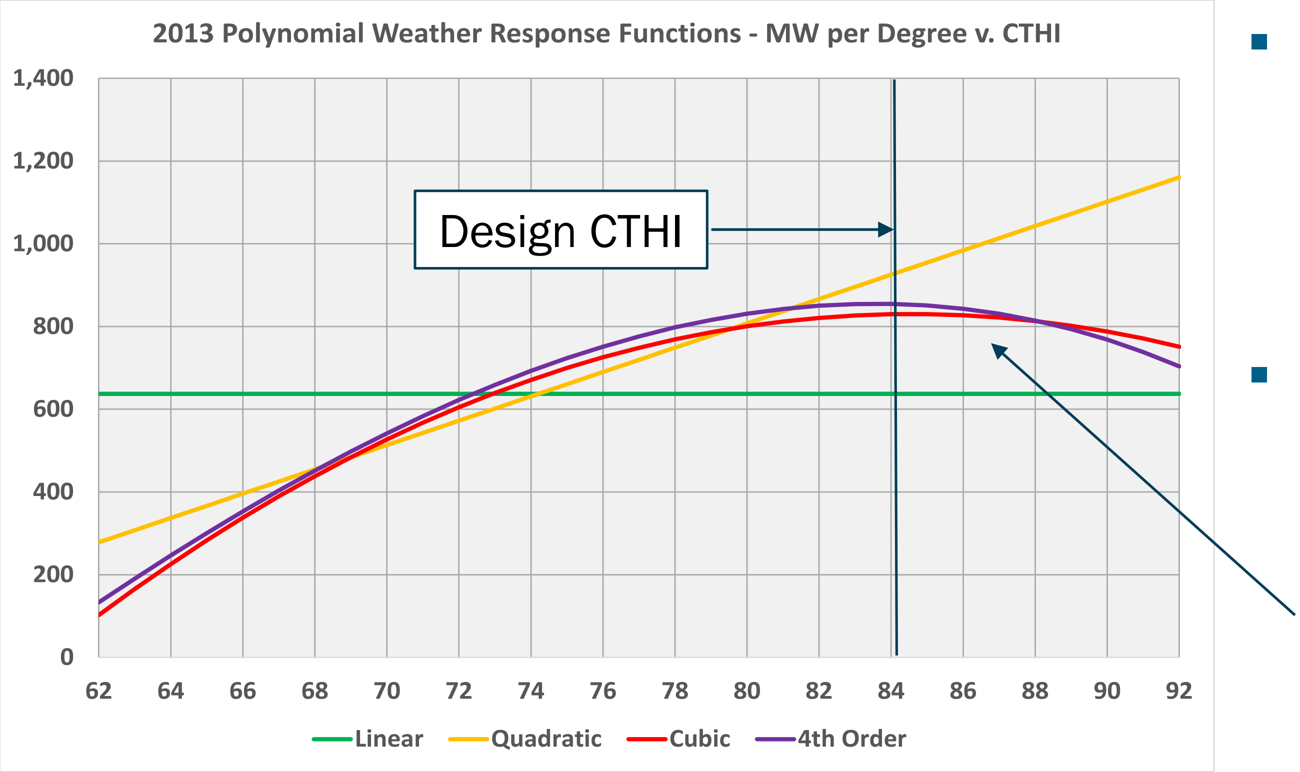
Weather Response Function



- First derivative of the weather-load model gives the weather response function (dMW/dT)
- Weather response function is examined to see how saturation of loads is handled

NYSRC Policy: This relationship must be established using the last 10 years of data

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Extreme Temperature Analysis

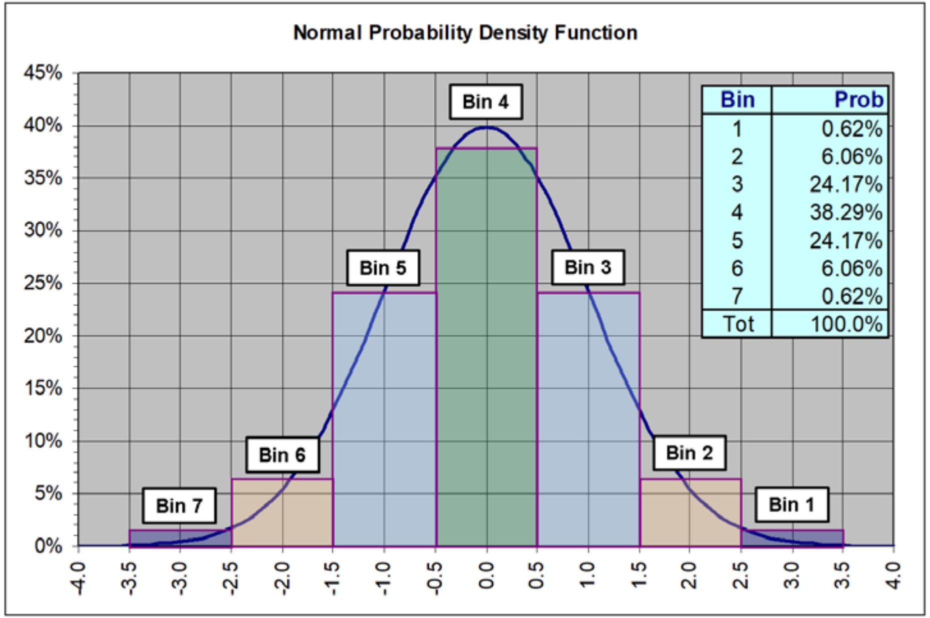
LFU Model has two parts:

1) Distribution of extreme temperatures that coincide with Peak producing loads

2) load/weather relationship (weather response function)

Bin Definitions:

- Based on the continuous normal distribution
- 99.7% of all weather values fall within 3 standard deviations of the mean



Bin	Mid-Point	z Begin	End	Cumulative Probability	Bin Probability	CTHI
1	3	2.5	3.5 ->	1.00000	0.00621	90.80
2	2	1.5	2.5	0.99379	0.06060	88.54
3	1	0.5	1.5	0.93319	0.24173	86.28
4	0	-0.5	0.5	0.69146	0.38292	84.02
5	-1	-1.5	-0.5	0.30854	0.24173	81.77
6	-2	-2.5	-1.5	0.06681	0.06060	79.51
7	-3	<- -3.5	-2.5	0.00621	0.00621	77.25

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Creating the LFU Multipliers

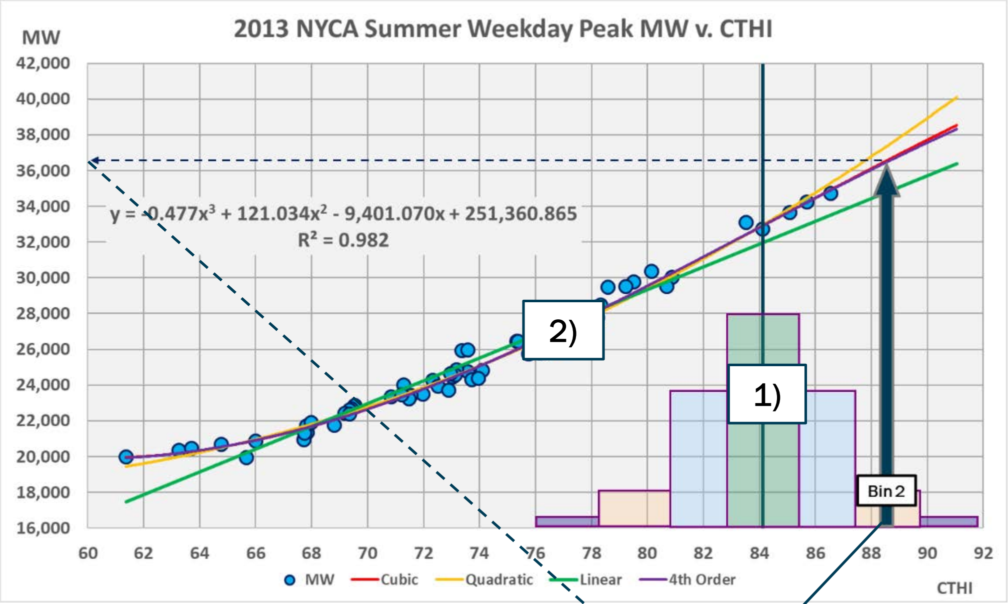
LFU Model has two parts:

1) Distribution of extreme temperatures that coincide with peak producing loads

2) load/weather relationship (weather response function)

Bin Definitions:

- Based on the continuous normal distribution
- 99.7% of all weather values lie within 3 standard deviations of the mean



Bin	Mid-Point	Z Begin	Z End	Cumulative Probability	Bin Probability	CTHI	Load	PU Load
1	3	2.5	3.5 ->	1.00000	0.00621	90.80	38,399	115.6%
2	2	1.5	2.5	0.99379	0.06060	88.54	36,549	110.2%
3	1	0.5	1.5	0.93319	0.24173	86.28	34,701	104.7%
4	0	-0.5	0.5	0.69146	0.38292	84.02	32,827	99.0%
5	-1	-1.5	-0.5	0.30854	0.24173	81.77	30,969	93.4%
6	-2	-2.5	-1.5	0.06681	0.06060	79.51	29,143	87.9%
7	-3	<- -3.5	-2.5	0.00621	0.00621	77.25	27,390	82.6%

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LFU Modeling – Distribution of Load

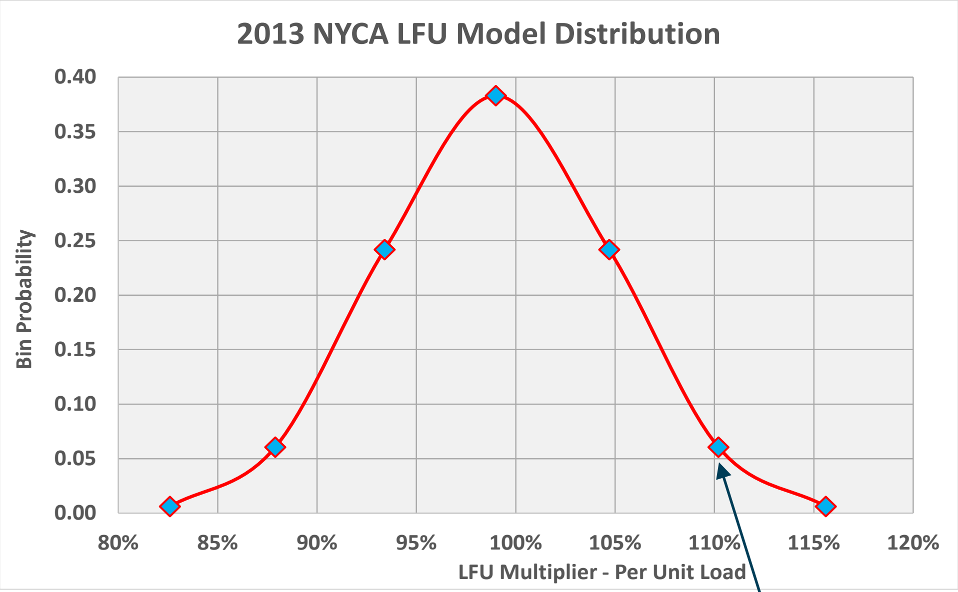
LFU Model has two parts:

1) Distribution of extreme temperatures that coincide with peak producing loads

2) load/weather Relationship (weather response function)

Bin Definitions:

- Based on the continuous normal distribution
- 99.7% of all weather values lie within 3 standard deviations of the mean



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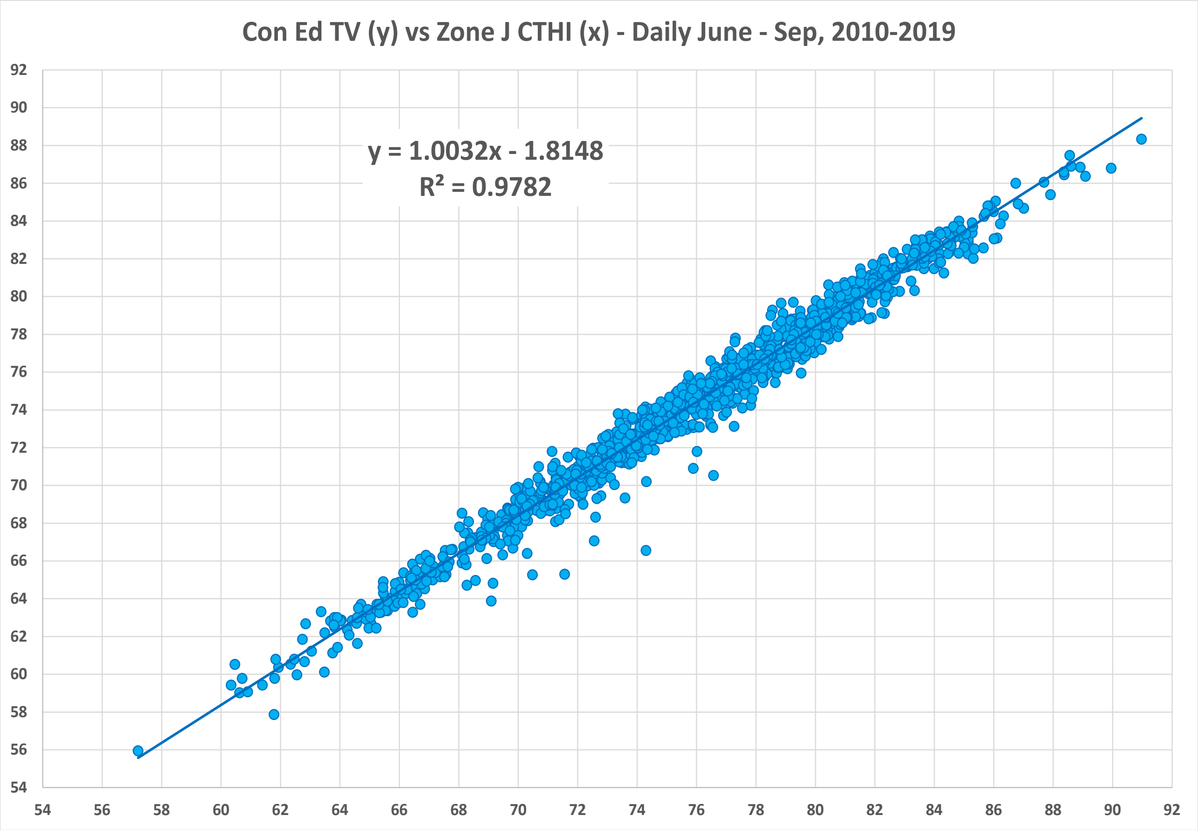
Temperature & Humidity Index Comparison

Temperature-Humidity Indices

- **NYISO uses a Cumulative Temperature Humidity Index (CTHI)**
  - Lagged 3-day weighted average of peak daily Temperature-Humidity Index
  - Top hour from each day used (3 hours total used in calculation)
  - 70 / 20 / 10 % day weighting (e.g.: today / yesterday / day before yesterday)
- **Con Edison uses their Temperature Variable (TV) [Based on atmospheric virtual temperature]**
  - Lagged 3-day weighted average of peak daily Temperature-Humidity Index
  - Top 3 hours from each day used (9 hours total used in calculation)
  - Same day weighting as CTHI
- **LIPA/PSEG employs a modified Temperature Humidity Index with a 4-hour averaging window (THI4)**
  - No multi-day lagged component
  - An average of the 4 hours immediately preceding the peak load hour are included

Con Ed TV vs. NYISO CTHI



- Summer values of each variable shown for Zone J
- Good agreement between the two variables

Con Ed TV vs. NYISO CTHI – LFU Impacts

2011-13 LFU Model Using TV				
Bin	StDev	TV	MW	LFU
1	3	90.76	12,565	111.6%
2	2	88.52	12,080	107.3%
3	1	86.27	11,566	102.7%
4	0	84.03	11,032	97.9%
5	-1	81.78	10,487	93.1%
6	-2	79.54	9,942	88.3%
7	-3	77.29	9,407	83.5%
Design	0.43	84.99	11,263	100.0%

2011-13 LFU Model Using CTHI				
Bin	StDev	CTHI	MW	LFU
1	3	93.36	12,563	111.7%
2	2	90.79	12,097	107.6%
3	1	88.21	11,567	102.9%
4	0	85.64	10,990	97.8%
5	-1	83.06	10,386	92.4%
6	-2	80.48	9,771	86.9%
7	-3	77.91	9,163	81.5%
Design	0.43	86.74	11,243	100.0%

- Both variables produce similar LFU results in the upper bins
- Some divergence in the lower bins
- The expected LOLE impact between these two variables is small

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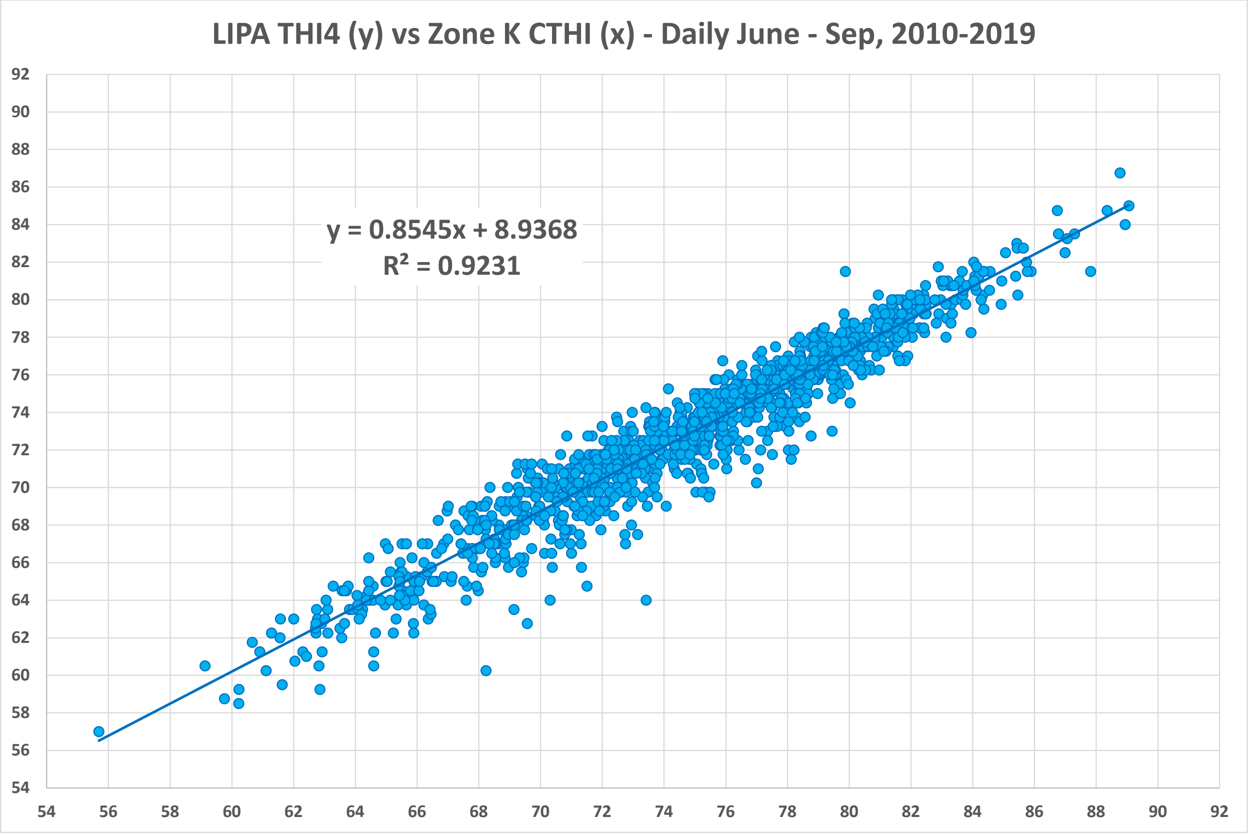
LIPA THI4 vs. NYISO CTHI



- Summer values of each variable shown for Zone K
- Generally good agreement between the two variables
- Difference in scale between the two variables (e.g., a 1 degree increase in THI4 corresponds to 0.85 degrees of CTHI)

LIPA THI4 vs. NYISO CTHI – LFU Impacts

2011-13 LFU Model Using THI4				
Bin	StDev	THI4	MW	LFU
1	3	89.02	6,288	114.9%
2	2	86.62	6,104	111.5%
3	1	84.22	5,826	106.4%
4	0	81.83	5,475	100.0%
5	-1	79.43	5,073	92.7%
6	-2	77.03	4,643	84.8%
7	-3	74.63	4,208	76.9%
Design	0	81.83	5,475	100.0%

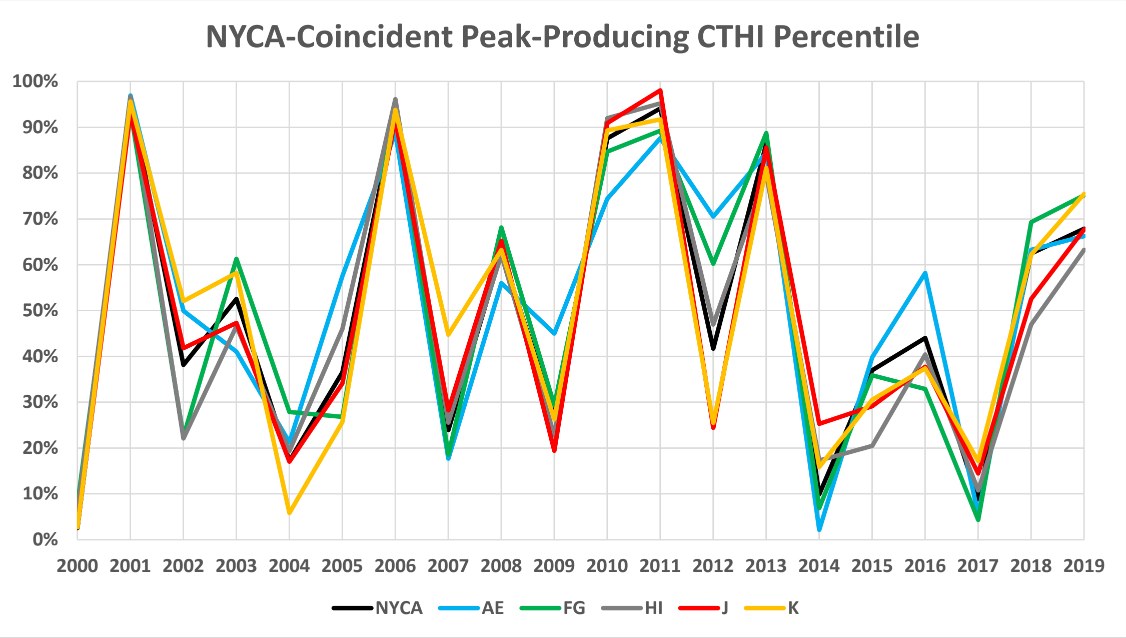
2011-13 LFU Model Using CTHI				
Bin	StDev	CTHI	MW	LFU
1	3	93.46	6,450	118.3%
2	2	90.55	6,201	113.7%
3	1	87.64	5,861	107.5%
4	0	84.74	5,453	100.0%
5	-1	81.83	5,003	91.7%
6	-2	78.92	4,535	83.2%
7	-3	76.01	4,075	74.7%
Design	0	84.74	5,453	100.0%

- Simple LFU models using both variables produce different impacts
- THI4 has more saturation than CTHI (e.g., slowed growth in demand at higher temperatures)
- Actual LFU load-weather model structure employed in the LFU development cycle between LIPA and NYISO is different

Long-Term Historical Weather Distributions

LFU Modeling Areas – Coincidence w/NYCA

- Goal: Compare regional peak load producing weather extremes with the NYCA-wide peak load producing weather extremes
- Analysis: Collect and compare temperature-humidity values from 2000-2019 across the LFU Modeling regions and NYCA
- Results: Peak producing weather conditions for the LFU modeling areas are very close to one another and the NYCA

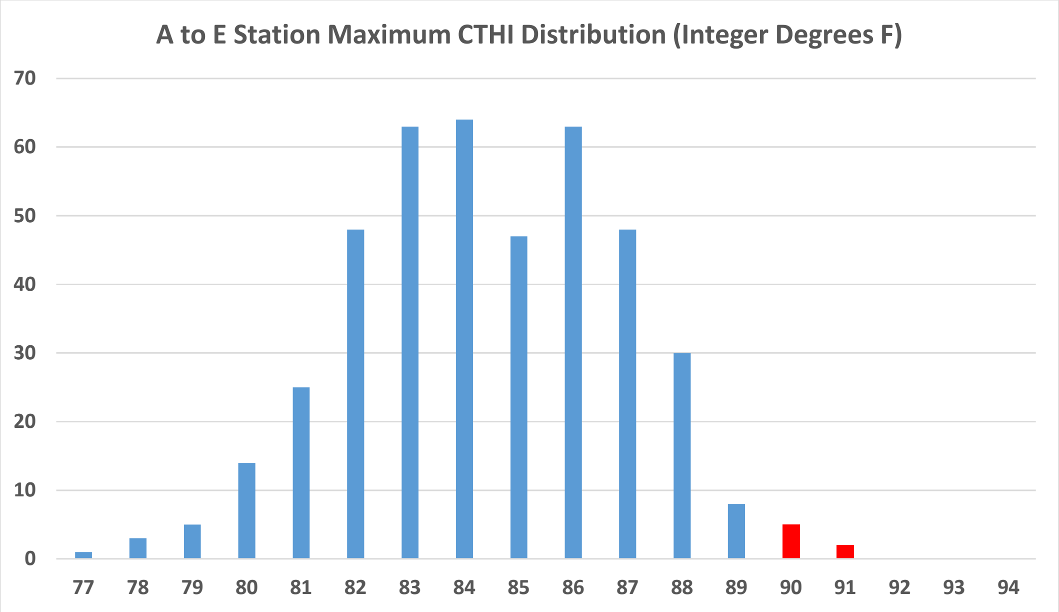


MARS modeling simulations assume extreme coincidence of weather across all areas of the state. The results here show this to be a viable assumption.

NYCA Peak-Producing CTHI Statistics, 2000 - 2019				
Area	Average CTHI	Standard Deviation	Correlation with NYCA	Percentile at NYCA 99th
A to E	82.04	2.49	0.934	96%
F & G	84.55	2.45	0.961	100%
H & I	85.12	2.53	0.967	96%
Zone J	85.64	2.58	0.967	96%
Zone K	84.74	2.91	0.960	98%
NYCA	83.79	2.52	--	99%

Historical Extreme Temperature-Humidity Analysis

- Goal: Compare observed peak temperature-humidity values from 1950-2020
- Analysis: Pool weather stations together by LFU modeling region and compute distributions. Weather stations need to include at least 10% weight against load to be included
- Result: Station data from Zones A-E show that extreme (e.g. Bin 1) temperatures are possible



Station / Area	A to E	Binghamton	Buffalo	Elmira	Rochester	Syracuse	Utica	Total Stations
Maximum	87.13	87.34	88.36	90.22	89.38	90.98	90.54	90.98
Bin 1 Value	89.67	--	--	--	--	--	--	89.67
Observations Above	0	0	0	5	0	1	1	7
Percent	0.0%	0.0%	0.0%	6.7%	0.0%	1.3%	1.3%	1.3%

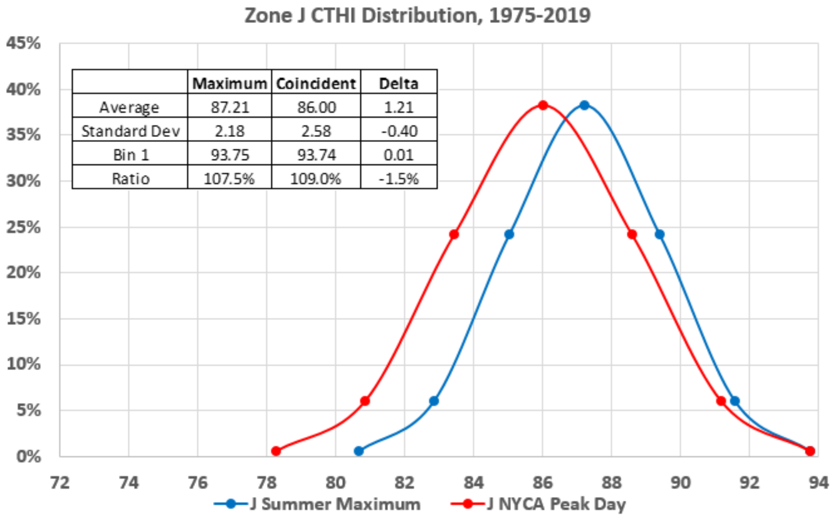
Historical Extreme Temperature-Humidity Analysis

- Result: Composite results from all areas and stations show that the extreme weather conditions currently used for the Bin 1 levels are possible at the station level, and that temperature values exceeding physical extreme weather limits are not being used in the LFU models
- Caveat: The weather has not been extreme enough across all weather stations in a given area in any given year for the composite area CTHI values to exceed their respective Bin 1 value.

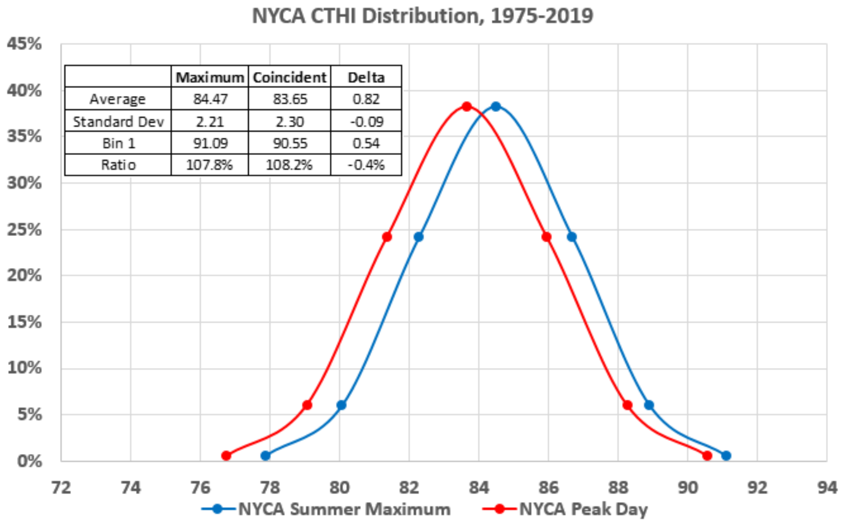
AVERAGES	Areas Average	Stations Average
Maximum	90.16	92.77
Bin 1 Value	92.23	92.23
Delta	-2.07	0.53
Observations Above	0.0	2.0
Percent	0.0%	0.5%

Historical Extreme Temperature Humidity Analysis

- Goal: Compare temperature-humidity distributions and extreme values from 1950-2020
- Analysis: Compile and compare the summer maximum CTHI and the peak load producing CTHI distributions for all LFU modeling regions and the NYCA.
- Results: Coincident peak day weather is more variable than summer maximum. Peak producing temperatures have a wider distribution but do not exceed summer maximum extreme values.



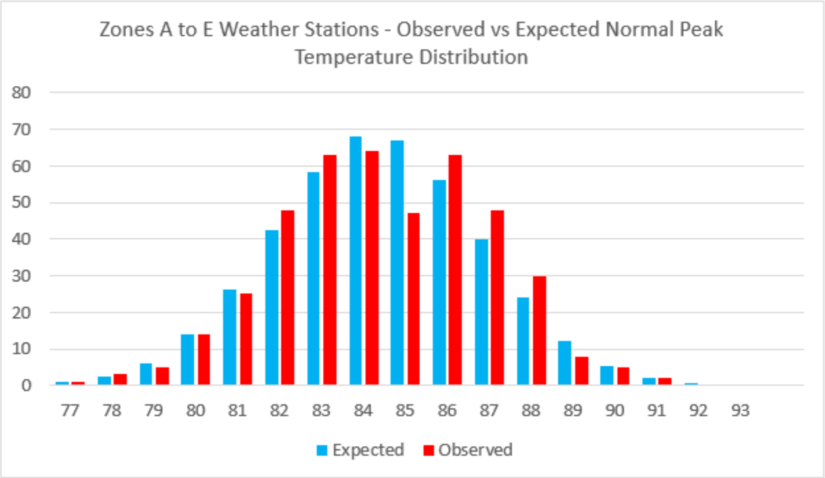
	Maximum	Coincident	Delta
Average	87.21	86.00	1.21
Standard Dev	2.18	2.58	-0.40
Bin 1	93.75	93.74	0.01
Ratio	107.5%	109.0%	-1.5%



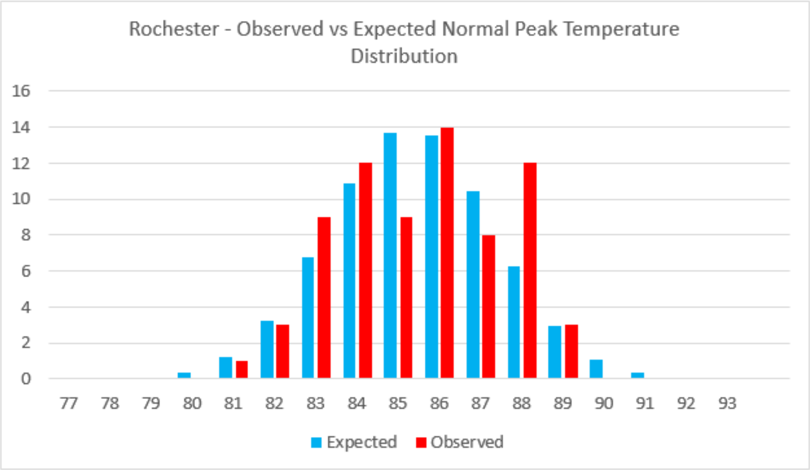
	Maximum	Coincident	Delta
Average	84.47	83.65	0.82
Standard Dev	2.21	2.30	-0.09
Bin 1	91.09	90.55	0.54
Ratio	107.8%	108.2%	-0.4%

Historical Extreme Temperature-Humidity Analysis

- Goal: Compare observed peak temperature-humidity values from 1950-2020
- Analysis: Compare weather station and LFU modeling area distributions against expected normal values (apply Chi-squared tests for normality); Pool together weather station data by region (increases sampling for the analysis).
- Result: All tests revealed the assumption of a normal distribution for use in modeling the extreme temperature distributions is valid



Stat	12.9891
P-value	29.4%



Stat	8.9384
P-value	25.7%

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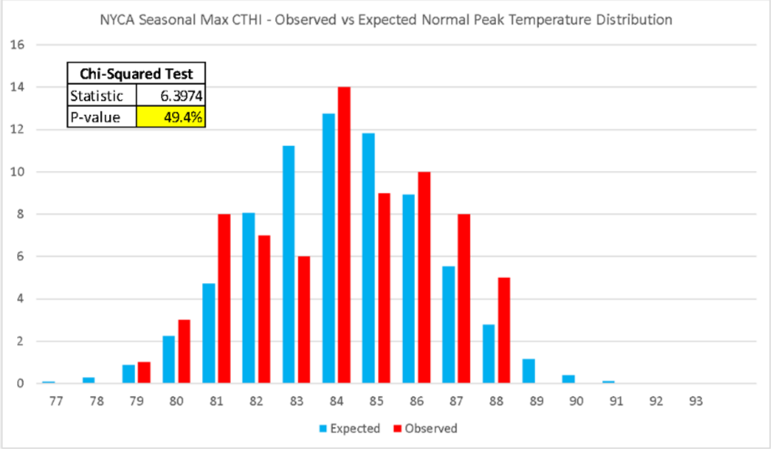
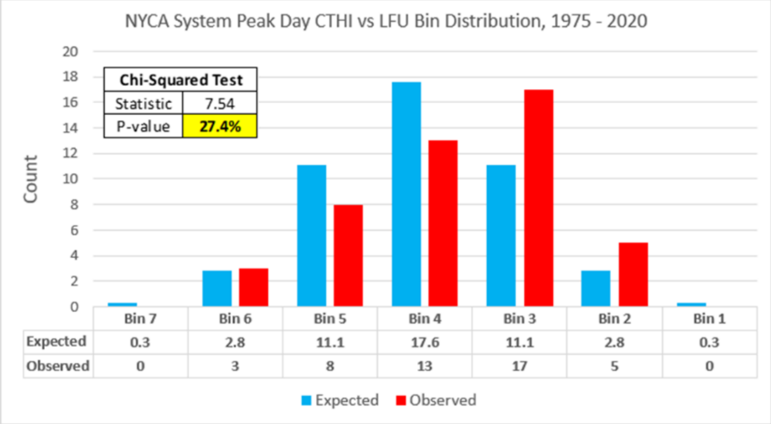
Historical Extreme Temperature-Humidity Analysis





Result: All tests revealed the assumption of a normal distribution for use in modeling the extreme temperature distributions is valid

Chi-Squared Test	Bins	Years	Statistic	P-value	Normal
A to E Pooled Stations	Integer Degrees	71	12.99	29.4%	YES
F&G Pooled Stations	Integer Degrees	71	7.17	62.0%	YES
H&I Pooled Stations	Integer Degrees	71	7.81	64.8%	YES
Zone J Pooled Stations	Integer Degrees	71	13.81	18.2%	YES
Zone K Pooled Stations	Integer Degrees	71	4.03	91.0%	YES
Rochester	Integer Degrees	71	8.94	25.7%	YES
NYCA Maximum	Integer Degrees	71	6.40	49.4%	YES
NYCA Coincident Peak	LFU Bins	45	7.54	27.4%	YES
Central Park Dry Bulb	Integer Degrees	145	11.34	50.0%	YES

*CTHI unless noted otherwise

*Seasonal Maximum unless noted otherwise

Coincident vs Non-Coincident LFU Results and Trends

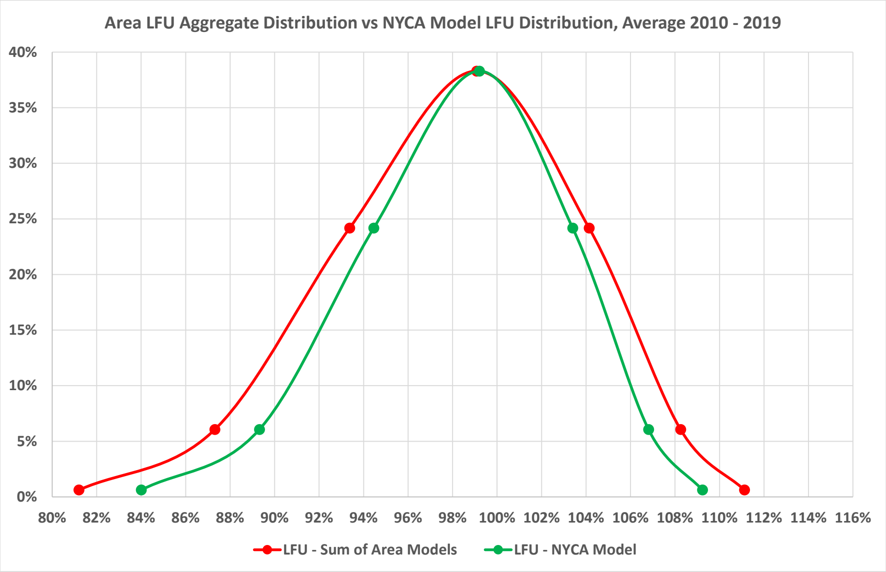
LFU NYCA-Wide vs. Area Models

- Goal: Compare the LFU results from a NYCA-wide model against the sum of individual LFU area models to review differences in LFU results and trends
- Analysis: Use NYCA-wide model as a control relative to the total of the five area models. Construct and compare pooled models from 2010-11, 2012-13, 2014-15, 2016-17, and 2018-19
- Results: Sum of the area models produces larger Bin 1 values on average. There is noticeable variability in the models year over year (e.g., 2014-15).

Bin 1 Simple Model LFU Results - Pooled Models						
Model	LFU - Sum of Area Models	LFU - NYCA Model	MW - Sum of Area Models	MW - NYCA Models	Delta %	Delta MW
2010-11	108.6%	107.2%	35,330	34,843	1.5%	487
2012-13	111.3%	111.0%	36,485	36,422	0.2%	63
2014-15	110.5%	113.4%	35,778	36,725	-2.9%	-947
2016-17	114.5%	109.5%	37,038	35,391	5.0%	1,647
2018-19	110.7%	105.1%	35,504	33,677	5.6%	1,827

LFU NYCA-Wide vs. Area Models

Results: Standalone NYCA-wide model, on average, produces a more compact load probability distribution than the sum of the areas



Average Simple Model LFU Results (2010 - 2019), Sum of Area Models and NYCA Control Model							
Bin	CTHI	LFU - Sum of Area Models	LFU - NYCA Model	MW - Sum of Area Models	MW - NYCA Models	Delta %	Delta MW
B1	90.8	111.1%	109.2%	36,027	35,412	1.9%	615
B2	88.5	108.3%	106.8%	35,096	34,503	1.4%	594
B3	86.3	104.1%	103.4%	33,763	33,399	0.7%	365
B4	84.0	99.1%	99.2%	32,124	32,043	-0.1%	81
B5	81.8	93.4%	94.5%	30,274	30,508	-1.1%	-234
B6	79.5	87.3%	89.3%	28,310	28,846	-2.0%	-537
B7	77.3	81.2%	84.0%	26,327	27,131	-2.8%	-804

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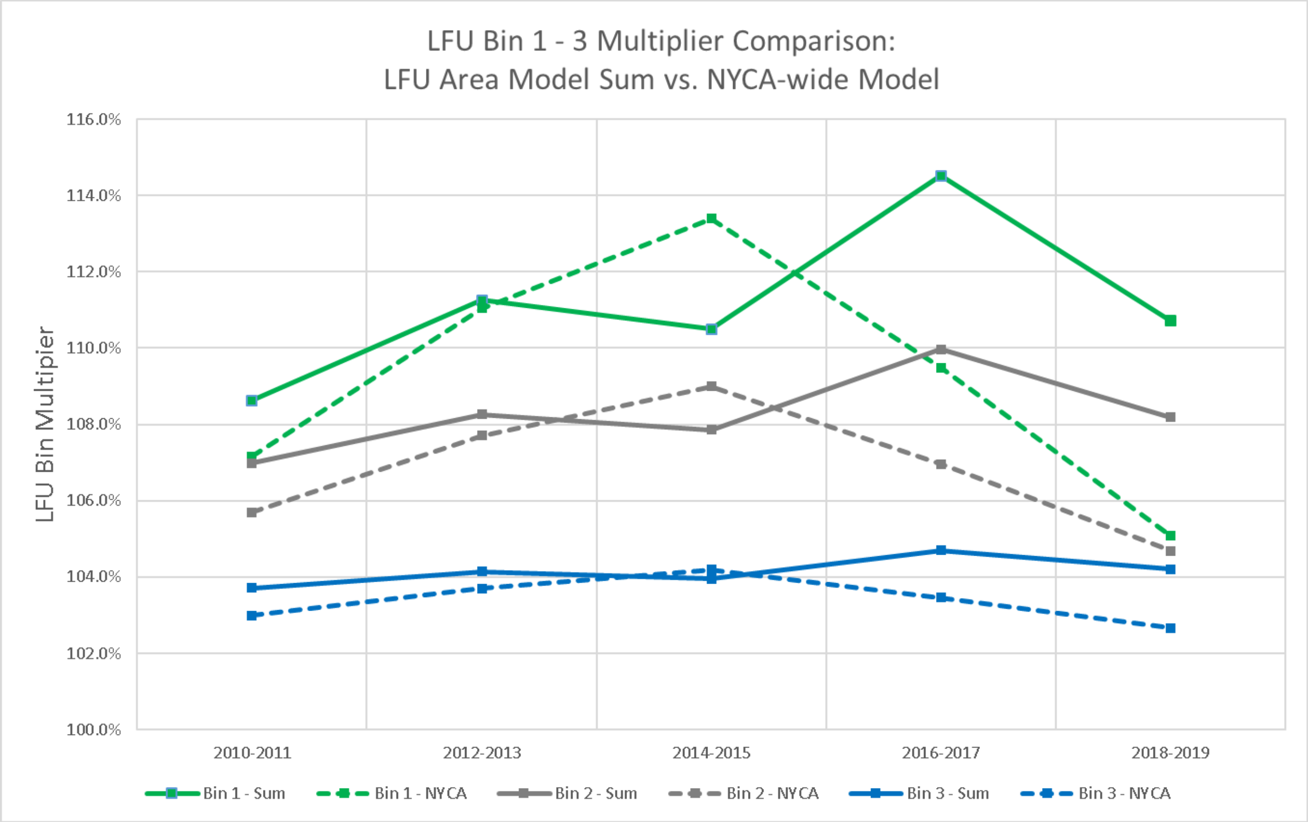
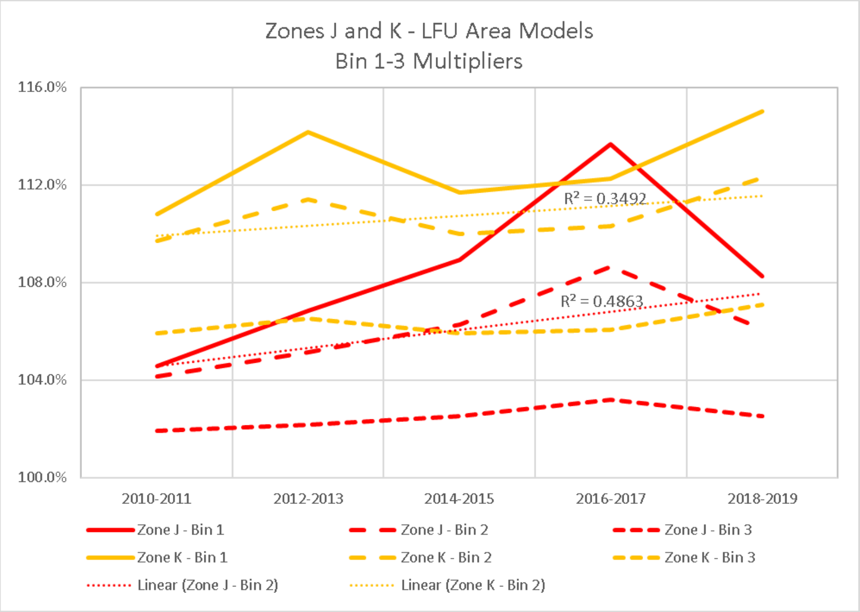
LFU NYCA-Wide vs. Area Models

Results: Sum of area model results have trended in a different direction than the NYCA-wide model results



LFU NYCA-Wide vs. Area Models

LFU Area	Bin	2010-2011	2012-2013	2014-2015	2016-2017	2018-2019
Zones A-E	1	109.2%	113.0%	109.3%	113.9%	109.8%
	2	107.1%	109.1%	107.2%	109.8%	107.7%
	3	104.0%	104.7%	104.0%	105.1%	104.3%
Zones F&G	1	112.4%	113.5%	113.0%	122.1%	113.1%
	2	109.2%	109.7%	109.5%	114.1%	109.6%
	3	104.8%	104.9%	104.9%	106.5%	104.9%
Zones H&I	1	113.4%	114.2%	115.9%	110.8%	111.6%
	2	109.3%	109.7%	110.5%	107.9%	108.2%
	3	104.0%	104.0%	104.3%	103.5%	103.6%
Zone J	1	104.6%	106.9%	108.9%	113.7%	108.3%
	2	104.1%	105.2%	106.3%	108.6%	106.1%
	3	101.9%	102.2%	102.5%	103.2%	102.5%
Zone K	1	110.8%	114.2%	111.7%	112.3%	115.0%
	2	109.7%	111.4%	110.0%	110.3%	112.3%
	3	105.9%	106.5%	105.9%	106.1%	107.1%



Results: Flat to slightly increasing trend in LFU results for Zones A-E and F-G, downward trend in Zones H-I, and generally increasing trend in Zones J & K

LFU Trends - NYCA-Wide Models

- Goal: Identify long-term trends in the NYCA-wide LFU results
- Analysis: Compile and tabulate trends for multiple NYCA-wide models. Include both single year annual (2001-2019) and pooled-models (4 year rolling models 2000-2019)

Year	Constant MW	Linear Coef	Squared Coef	Cubed Coef	Slope MW	Design MW	Bin 1 MW	Bin 1 LFU	Bin 2 LFU	Bin 3 LFU
2001	19,725	-181.1	49.7	-1.02	436	30,042	31,404	104.5%	104.0%	102.3%
2002	20,794	-350.6	55.9	-1.02	570	30,710	33,226	108.2%	106.2%	103.1%
2003										
2004	19,439	114.3	25.2	-0.44	559	30,807	33,929	110.1%	106.9%	103.3%
2005	19,304	180.5	18.4	-0.13	842	32,814	38,563	117.5%	111.1%	104.9%
2006	20,556	-191.4	50.3	-0.90	669	32,782	36,103	110.1%	107.3%	103.5%
2007	21,016	-226.3	52.8	-0.96	644	32,958	36,003	109.2%	106.8%	103.4%
2008										
2009	19,703	-59.9	41.1	-0.67	750	32,944	37,183	112.9%	108.7%	104.1%
2010	20,670	-277.5	57.2	-1.07	624	32,470	35,213	108.5%	106.4%	103.2%
2011	20,556	-205.1	49.0	-0.81	751	33,003	37,128	112.5%	108.6%	104.1%
2012	19,342	84.1	31.1	-0.44	812	33,503	38,506	114.9%	109.8%	104.5%
2013	19,930	-31.4	35.1	-0.48	830	33,159	38,339	115.6%	110.2%	104.7%
2014	19,866	-198.0	48.8	-0.77	823	32,996	37,717	114.3%	109.7%	104.5%
2015	18,300	86.1	34.5	-0.60	711	32,285	36,248	112.3%	108.4%	104.0%
2016	19,048	-106.1	48.3	-0.88	694	32,465	35,938	110.7%	107.6%	103.7%
2017	17,694	164.6	27.6	-0.41	778	32,188	36,930	114.7%	109.7%	104.5%
2018	18,917	-226.1	60.6	-1.21	595	31,944	34,154	106.9%	105.7%	103.0%
2019	18,483	-310.4	69.7	-1.44	539	31,446	32,857	104.5%	104.4%	102.6%

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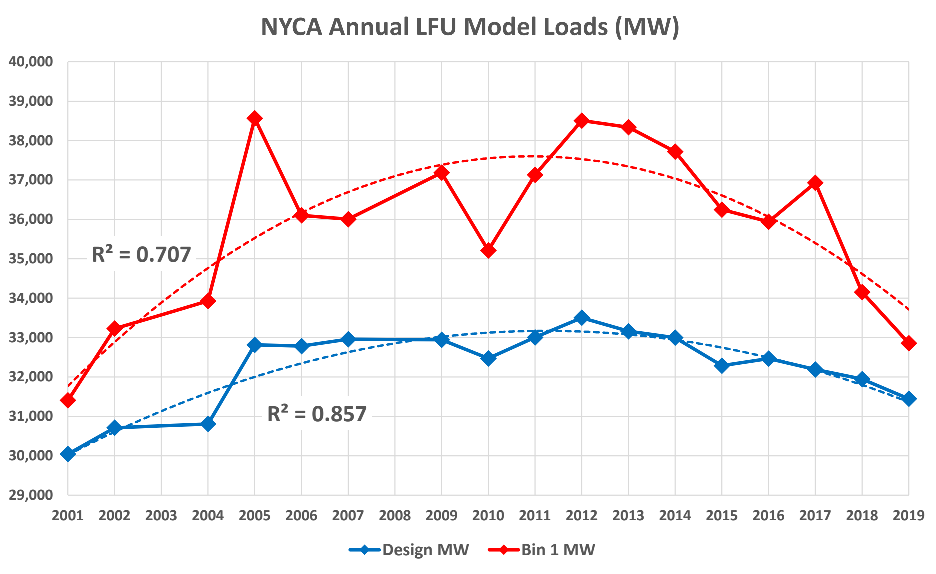
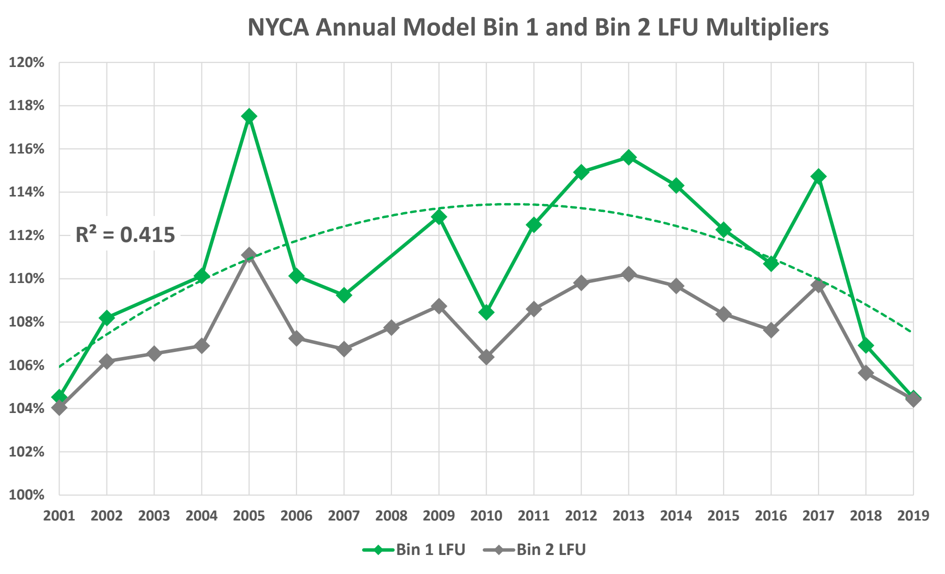
LFU Trends - NYCA-Wide Models

Results: Both the design peak MW and the Bin 1 peak MW increase across the 2000s, before levelling off and beginning to decline through the late 2010s





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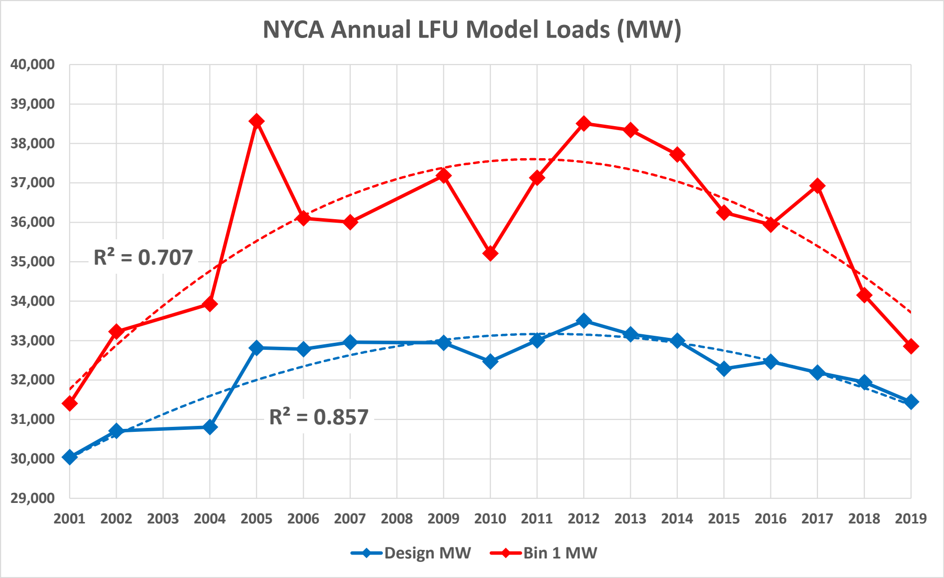
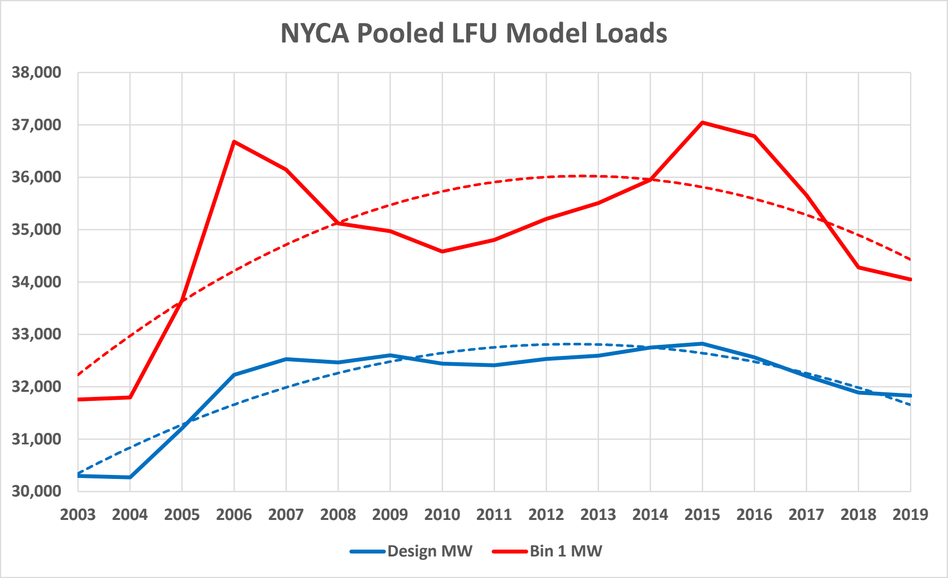
LFU Trends - NYCA-Wide Models

Results: Pooled models that cover the same period show similar trends and less inter-annual variability





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Recommendations for Future LFU Work (Phase 2 Study)

Recommendations on Future Work:

LFU Bins

- Our study showed that we cannot statistically reject the use of the continuous normal distribution for use in modeling extreme temperatures

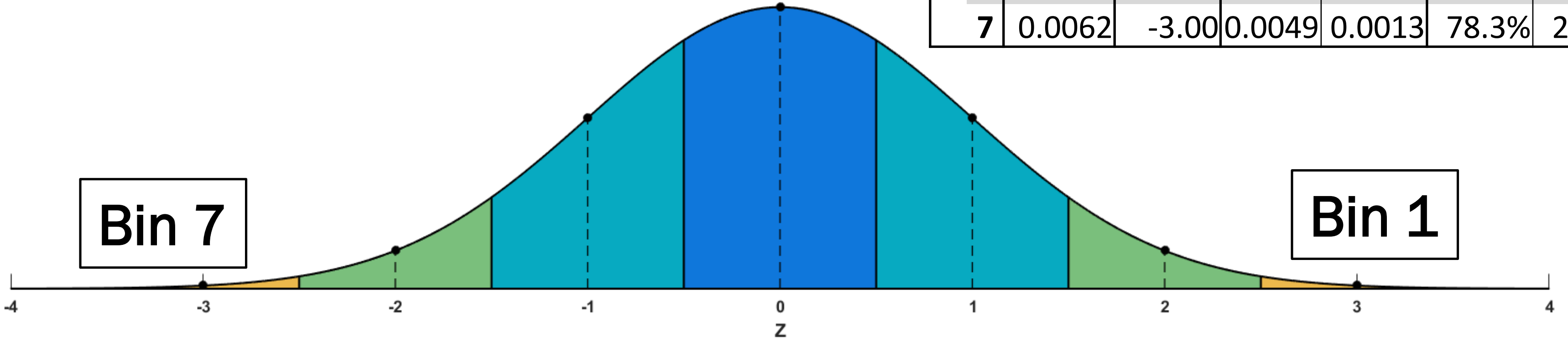
- Near-term recommendation for the 2022 IRM Study: Slightly update the standard normal distribution bin values used to better reflect the observed temperature-humidity probability distributions. Perform impact analysis with MARS.

2022 IRM Study - LFU Bins

Near-term recommendation for the 2022 IRM Study: Slightly update the standard normal distribution bin values used to better reflect the temperature probability distribution

LFU Bin	Weight	Z	Area Left	Area Right	Percent Left	Percent Right
1	0.0062	3.00	0.0013	0.0049	21.7%	78.3%
2	0.0606	2.00	0.0165	0.0441	27.3%	72.7%
3	0.2417	1.00	0.0918	0.1499	38.0%	62.0%
4	0.3830	0.00	0.1915	0.1915	50.0%	50.0%
5	0.2417	-1.00	0.1499	0.0918	62.0%	38.0%
6	0.0606	-2.00	0.0441	0.0165	72.7%	27.3%
7	0.0062	-3.00	0.0049	0.0013	78.3%	21.7%

Current LFU Bin Structure

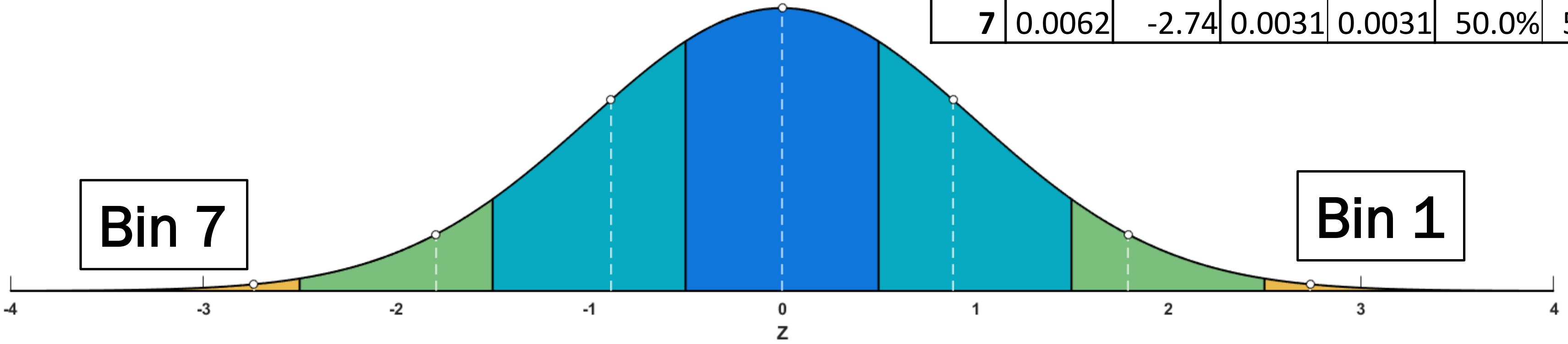


2022 IRM Study - LFU Bins

- Near-term recommendation for the 2022 IRM Study: Slightly update the standard normal distribution bin values used to better reflect the temperature probability distribution
- Perform impact analysis with MARS

Proposed LFU Bin Structure

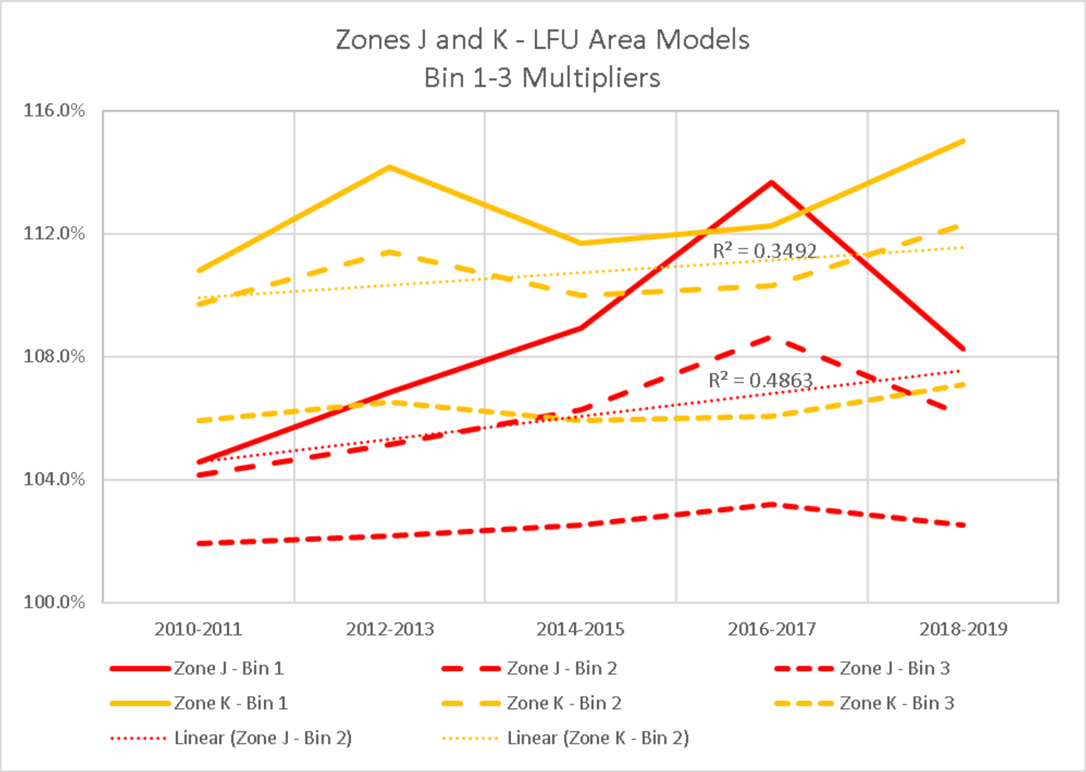
LFU Bin	Weight	Z	Area Left	Area Right	Percent Left	Percent Right
1	0.0062	2.74	0.0031	0.0031	50.0%	50.0%
2	0.0606	1.79	0.0303	0.0303	50.0%	50.0%
3	0.2417	0.89	0.1209	0.1209	50.0%	50.0%
4	0.3830	0.00	0.1915	0.1915	50.0%	50.0%
5	0.2417	-0.89	0.1209	0.1209	50.0%	50.0%
6	0.0606	-1.79	0.0303	0.0303	50.0%	50.0%
7	0.0062	-2.74	0.0031	0.0031	50.0%	50.0%



Recommendations on Future Work:

Expand Analysis on Regional Weather Sensitivity

Consider expanding the examination of regional LFU models in order to track the evolution of regional weather sensitivity at a more granular level – 25 models evaluated in this study. An updated analysis would expand to over 100 models.



Recommendations on Future Work:

Load Shapes, BTM Solar, LFU Bin Distributions

1. Load Shapes: Perform an updated load duration analysis to include examination of 2019 and 2020 load profiles against the currently used load shapes for the 2023 IRM and 2022 RNA studies.
2. Select load shapes from the most recent 5 year window. This will allow examination of the modeling of net loads (current practice) vs. gross load (net loads + estimated BTM solar generation profiles added back).
3. The study of alternate temperature bin structures may be warranted with longer weather data sets
   - Proposal: Explore and validate the use of model based load shapes. If successful, load shape models can be used to create long time series of load-weather relationships (e.g., simulate 300+ years of load values using existing weather data plus scenarios)
   - Benefits: Examine the current system's response to 2002 weather. Affords additional climate scenario modeling (e.g., more heat waves and cold snaps, evolution of shoulder month loads)

Questions?