# Northeast Residential Lighting Hours-of-Use Study

## *FINAL*

**5/5/2014**

**Submitted to:**

**Connecticut Energy Efficiency Board**

**Cape Light Compact**

**Massachusetts Energy Efficiency Advisory Council**

**National Grid Massachusetts**

**National Grid Rhode Island**

**New York State Energy Research and Development Authority**

**Northeast Utilities**

**Unitil**

**Submitted by:**

**NMR Group, Inc.**

**DNV GL**

50-2 Howard Street, Somerville, MA 02144
Phone: (617) 284-6230 Fax: (617) 284-6239
www.nmrgroupinc.com

# Abstract

The purpose of this study was to provide updated information to the Connecticut Energy Efficiency Board, the Massachusetts Program Administrators (Cape Light Compact, National Grid Massachusetts, Northeast Utilities, and Unitil), National Grid Rhode Island, and the New York State Energy Research and Development Authority (hereafter "the Sponsors") to assist in the calculations of demand and energy savings for lighting programs. Specifically, this report presents load shapes, coincidence factors (CFs), and daily hours of use (HOU).

Based on data collected from 4,462 loggers, the evaluators performed a series of regression models to estimate HOU. They concluded that the region comprising Connecticut, Massachusetts, Rhode Island, and Upstate New York had a household daily HOU of 2.7 hours for all bulbs and 3.0 for efficient bulbs, with HOU by room type varying from a low 1.7 in bathrooms to a high of 6.7 on the exterior of homes. Hours of use for Downstate New York exceeded those for the other areas included in the study, with a daily HOU of 4.1 for all bulbs and 5.2 for efficient bulbs for the household; room-specific estimates varied from 3.2 for bathrooms to 7.7 for kitchens.

The evaluators also provide detailed HOU estimates by room type, home type (i.e., single-family or multifamily), and income level for the region overall and for each individual area included in the analysis. Additionally, the report presents load shapes as well as well as coincidence factors for winter and summer peak period and winter and summer peak hours to aid in load planning and the calculation of peak demand savings.

Other topics addressed include comparisons of HOU for efficient and inefficient bulb types and comparisons to other existing HOU studies both in the Northeast region and throughout the United States.

## Additional Attachments – Data Tools

Due to the vast amount of data collected for this study, the Team was able to analyze and present HOU data in many different ways. In total, the team created and analyzed over 1700 breakdowns (eight modeled areas by eight room types by eight classifications of home and income, plus a model including all homes, all across three bulb types). While the results of these models are summarized and presented in this report, NMR wanted to provide the Sponsors with access to all of the data. Therefore, as attachments to this report, NMR has provided two Excel-based data viewing tools that the Sponsors can explore on their own or with assistance from NMR. Both tools were designed to be intuitive, and pulling up data breakdowns requires only that the user select the data desired using drop down lists.

**HOU Calculator – *Northeast HOU Calculator.xls***

The first tool, the 'Northeast HOU Calculator.xls' provides an efficient way to view, edit, and update HOU estimates by room and bulb type. Instructions for the tool are included within the Excel document.

**Load Shape Data Viewer – *Northeast Load Shape Data Viwers.xls***

The second tool, the 'Northeast Load Shape Data Viewer.xls' provides an efficient way to view load shape data generated by the study. As with the HOU calculator, instructions for the tool are included within the Excel document.

## Contents

## Tables

# Figures

# Executive Summary

The purpose of this study was to provide updated information to the Connecticut Energy Efficiency Board, the Massachusetts Program Administrators (Cape Light Compact, National Grid Massachusetts, Northeast Utilities, and Unitil), National Grid Rhode Island, and the New York State Energy Research and Development Authority (hereafter "the Sponsors") to assist in the calculations of demand and energy savings for lighting programs. Specifically, this report presents load shapes, coincidence factors (CFs), and daily hours of use (HOU).

Following are the principal tasks completed as part of this project:

- Sample design
- Recruitment
- Onsite data collection
- Analysis and reporting

To help control costs, the study took advantage of previously planned lighting saturation studies in New York and Massachusetts; the results of the saturation studies are presented under separate cover.[1,2] To complement the Base Study,[3] NYSERDA also funded an oversample of high-rise households in Manhattan. In addition, this study leveraged data collected as part of two additional concurrent studies: the *Massachusetts Low-Income HOU Study* (conducted by Cadmus) and the *National Grid New York EnergyWise Study* (conducted by DNV GL).[4] NMR, Cadmus, and DNV GL coordinated the development of protocols and methods to ensure comparable data.

## Methodology

A brief overview of the methodology is presented here in the Executive Summary; for complete details, please refer to Section 2.

### Sample Design, Recruitment and Onsite Visits

For this evaluation, the Team collected data through onsite visits to 848 homes located throughout Connecticut, Massachusetts, New York (excluding Nassau and Suffolk Counties), and Rhode Island. All sites required two visits. During the first visit, the Team collected detailed

[1] NMR, *Massachusetts Onsite Lighting Saturation Report.* Delivered to the Massachusetts Program Administrators on June 7, 2013.

[2] NMR, RIA, and Apex, *Draft Market Effects, Market Assessment, Process and Impact Evaluation of the NYSERDA Statewide Residential Point-of-Sale Lighting Program: 2010-2012.* Delivered to NYSERDA on December 13, 2013.

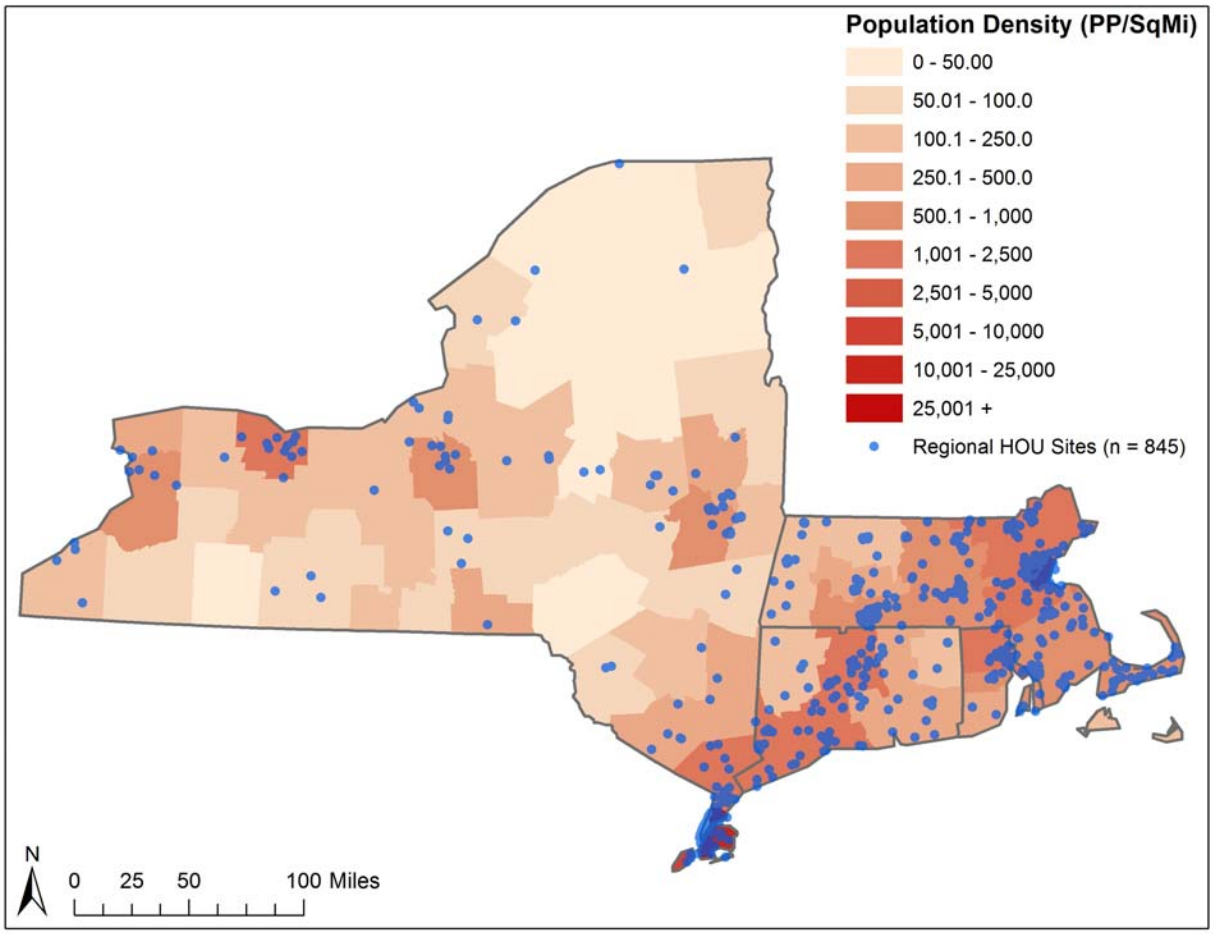
[3] In this report, Base Study refers to all data collection in Connecticut and Rhode Island and to a subset of data collection in Massachusetts and New York excluding: the High-Rise Oversample, the Cadmus Low-Income HOU Study, and the National Grid New York *EnergyWise* Study. Additional details on the breakdown of households and loggers from each study can be found in section 2.3.

[4] Cadmus, *Massachusetts Low Income Metering Study.* Delivered to the Massachusetts program Administrators on March 5, 2014.

lighting inventory data and installed time-of-use light meters (loggers). The second visit consisted of removing loggers installed during the first visit. In New York, NYSERDA funded the inclusion of an additional oversample of high-rise homes located in Manhattan in order to determine if high-rise households in densely populated New York City behave differently in terms of lighting usage.

The Team offered all potential study participants incentives that varied by area and study (that is, the region-wide study in all four states, and the separate study of high-rise apartments in Manhattan). Sections 2.1 and 2.2 provide additional detail on sample design, recruitment methods, and onsite visit protocols. Figure ES-1 provides an overview of the sample included in the final analysis, along with population density.

**Figure ES-1: Site Locations with Population Density**




## Sample Attrition, Data Cleaning, and Treatment of Outliers

Altogether, over 5,730 loggers were installed between December 2012 and March 2013. Logger installations were timed to be as close to the winter solstice as practical, given project constraints and the impact of storms.[5] Logger installation began November 26th in Rhode Island and all of the loggers in Rhode Island were installed prior to December 21, 2012. Logger installation in the other areas began in January 2013 and was completed by the end of March 2013. Logger retrieval began in June 2013 and continued through August 2013. The greatest number of loggers was deployed between February and July 2013 (six months). A substantial number of loggers (greater than 1,500) was deployed in each month from December 2012 through July 2013 (eight months). Attrition due to customers moving, damage to loggers, and lost loggers reduced the sample about 4%.

The Team was very careful in identifying and removing loggers with HOU values that might be considered outliers. While some loggers recorded very high usage over the study period, the percentage of these loggers was small (approximately 1%). In addition, the Team implemented quality assurance and control procedures during logger installation and removal that reduced errors associated with loggers recording incorrect data (described in Section 2.2). Removing outliers and data cleaning (see Section 2.3) reduced the number of loggers included in the final analysis to 4,642. Of the 4,642 loggers included in the final analysis, 84% were installed for at least 121 days and 31% of the loggers were installed for at least 151 days. On average loggers were installed for 143 days.

## Coefficient of Variation

Section 2.4 in the main report provides a summary of the coefficients of variation (CV) assumed when calculating the original onsite sample sizes, final sample sizes used in the analysis, the updated CV found by this study, and the sample size required by the updated CV to achieve 90/10 precision.[6] The team utilized a stratified sampling design and room specific CVs throughout the states to ensure adequate sample to model HOU at the room level, a household sample and CV has been calculated and presented for hypothetical purposes. Because the CVs for lighting were unknown during study design, the Team assumed a CV of 0.7 to calculate onsite sample size for specific rooms in which lighting use was expected to be fairly similar across the sample. For the "other" category of rooms, which included a number of miscellaneous rooms with various uses, a CV of 1.0 was used because the Team could not be confident that lighting usage would be consistent across the sample.

After completing the study and estimating HOU, the Team recalculated the observed CVs for each room type. Lighting use within each room type was more variable than the Sponsors and Team members anticipated, with CVs hovering around 1.0 but reaching as high as 1.38 for bathrooms and 1.6 for the "other" room type. Overall, the CV is 1.20. Further discussion of the CVs can be found in Section 2.4.

---

[5] The study received approval November 14, 2012. There were two notable storms that impacted the completion of onsite visits for this study: Superstorm Sandy and Winter Storm Nemo. Additional details on the impact of these storms on the study schedule can be found in Section 2.2.
[6] The CV is equal to the standard deviation divided by the mean.

## Weighting

To account for differences in demographics and lighting inventories in the final sample and the population, the Team relied on a complex weighting scheme. For each logger, the Team applied a premise weight that controlled for home type (single-family or multifamily)[7] and income (low-income or non-low-income). Also at the logger level, the Team used room weights that adjusted for the total number of bulbs in a given room type as well as the total number of logged bulbs in each room type. Room-level weights were further broken out by efficient and inefficient bulb types. For a complete overview of weights, please see Section 2.5.

## HOU Modeling

Developing HOU estimates consisted of three modeling steps:

- Creating annual datasets (Section 2.6.1)
- Adjusting HOU estimates (Section 2.6.2)
- Applying a hierarchical model (Section 2.6.3)

A summary of each modeling steps is included here in the Executive Summary. Detailed descriptions of each of the steps are included in Section 2.

**Creating Annual Datasets.** Since each logger was installed for only a portion of the year—between five and nine months—the Team had to annualize the data. To annualize the data the Team fit a sinusoid model to each logger.[8] The Team drew upon the methods outlined in the KEMA/Cadmus California Upstream Lighting Program Evaluation.[9] The Team fitted separate weekend and weekday models for each logger. For any loggers not conforming well to the sinusoid model, the analysts took additional steps to prepare annualized estimates based on average daily usage over the period logged (described in Section 2.6.1).

**Adjusting HOU Estimates.** Using the annualized estimates, the Team performed a weighted regression analysis to estimate the adjusted HOU for each room in each area of the study. In this step, only loggers for each individual area were used to develop area-specific estimates, and all loggers were used to develop estimates for the overall region. Based on outputs from this model, it was clear that Connecticut, Massachusetts, Rhode Island, and Upstate New York all had comparable usage patterns and that usage patterns for Downstate New York (including Manhattan) were significantly different.

**Applying a Hierarchical Model.** Due to the similar use patterns in four of the areas (CT, MA, Upstate NY, and RI), the Team sought a way to leverage data from each of these areas to refine

[7] To align with how the Sponsors define single family and multifamily programs, this study defines single family as: single-family detached, single-family attached, and two-to-four unit properties. Multifamily households are defined as properties with five or more units.
[8] The evaluators will provide an image of this model type in the final report, but a quick Google image search for "sinusoidal model" will show the shape.
[9] KEMA, Inc. and the Cadmus Group, Inc. *Final Evaluation Report: Upstream Lighting Program Volume 1*. Prepared for California Public Utilities Commission, Energy Division. February 8, 2010.

area-specific estimates. To accomplish this, the Team fit a multi-level hierarchical model. The advantage of this type of modeling approach is the ability to use information from all four areas to help inform area-specific estimates. In a hierarchical model, the observations specific to an area form the basis of the estimates for that area, while observations from outside that area also inform and help refine the area-specific estimates.[10,11] The hierarchal model is particularly beneficial for areas where fewer loggers were installed, thereby providing more refined (tighter precision and adjusted means) HOU estimates compared to individual models fit to each area separately.

Throughout this report, eight separate area estimates are presented—five produced by the hierarchical model and three produced by separate standalone models—as described in Section 2.6.3. For the sake of clarity, the team presents below a brief overview of the data informing each of the estimates, and the reader may find it helpful to refer to this overview when reading the summary of results that follows:

**Hierarchical Models**

**Connecticut (CT):** A product of the hierarchical model described in Section 2.6.3. The 549 loggers from Connecticut inform the core of Connecticut estimates. The core estimates were then refined through a hierarchical model that drew upon all loggers installed in Massachusetts, Rhode Island, and Upstate New York.

**Massachusetts (MA):** A product of the hierarchical model described in Section 2.6.3. The 2,175 loggers from Massachusetts inform the core of Massachusetts estimates. The core estimates were then refined through a hierarchical model that draws upon all loggers installed in Connecticut, Rhode Island, and Upstate New York.

**Rhode Island (RI):** A product of the hierarchical model described in Section 2.6.3. The 232 loggers from Rhode Island inform the core of Rhode Island estimates. The core estimates were then refined through a hierarchical model that drew upon all loggers installed in Connecticut, Massachusetts, and Upstate New York.

**Upstate New York (UNY):** A product of the hierarchical model described in Section 2.6.3. The 721 loggers from Upstate New York inform the core of Upstate New York estimates. This includes the 299 loggers from the National Grid *EnergyWise* Study. The core estimates were then refined through a hierarchical model that drew upon all loggers installed in Connecticut, Massachusetts, and Rhode Island.

**Overall Excluding Downstate New York (Overall):** A product of the hierarchical model described in Section 2.6.3, the Overall estimates collapse the modeled data from the four areas described above. The 3,677 loggers from Connecticut, Massachusetts, Rhode Island, and Upstate New York make up the core of Overall estimate. As with the other estimates above, the Overall estimate excludes all loggers from Downstate New York (including Manhattan).

---

[10] Cnaan, A., Laird, N.M., & Slasor, P. "Tutorial in Biostatistics: Using the Generalized Linear Mixed Model to Analyze Unbalanced Repeated Measure and Longitudinal Data." Statistics in Medicine 16 (1997): 2349-2380.
[11] Fitzmaurice, G.M., Laird, N.M., & Ware, J.H. *Applied Longitudinal Analysis, 2nd Ed*. New York: Wiley, 2011.

**Standalone Models**

**Manhattan (MHT):** A product of a standalone model (as described in Section 2.6.3), the 544 loggers from Manhattan inform the Manhattan estimates.

**Downstate New York (DNY):** A product of a standalone model (as described in Section 2.6.3), the 965 loggers from Downstate New York, including the 544 loggers from Manhattan, inform the Downstate New York estimates.

**NYSERDA Service Area (NYSERDA):** A product of a standalone model (as described in Section 2.6.3), the 1,686 loggers from New York—the 721 loggers from Upstate New York and the 965 loggers from Downstate New York (including the 544 loggers from Manhattan)—inform the NYSERDA Overall estimates.

### Derivation of Load Curves

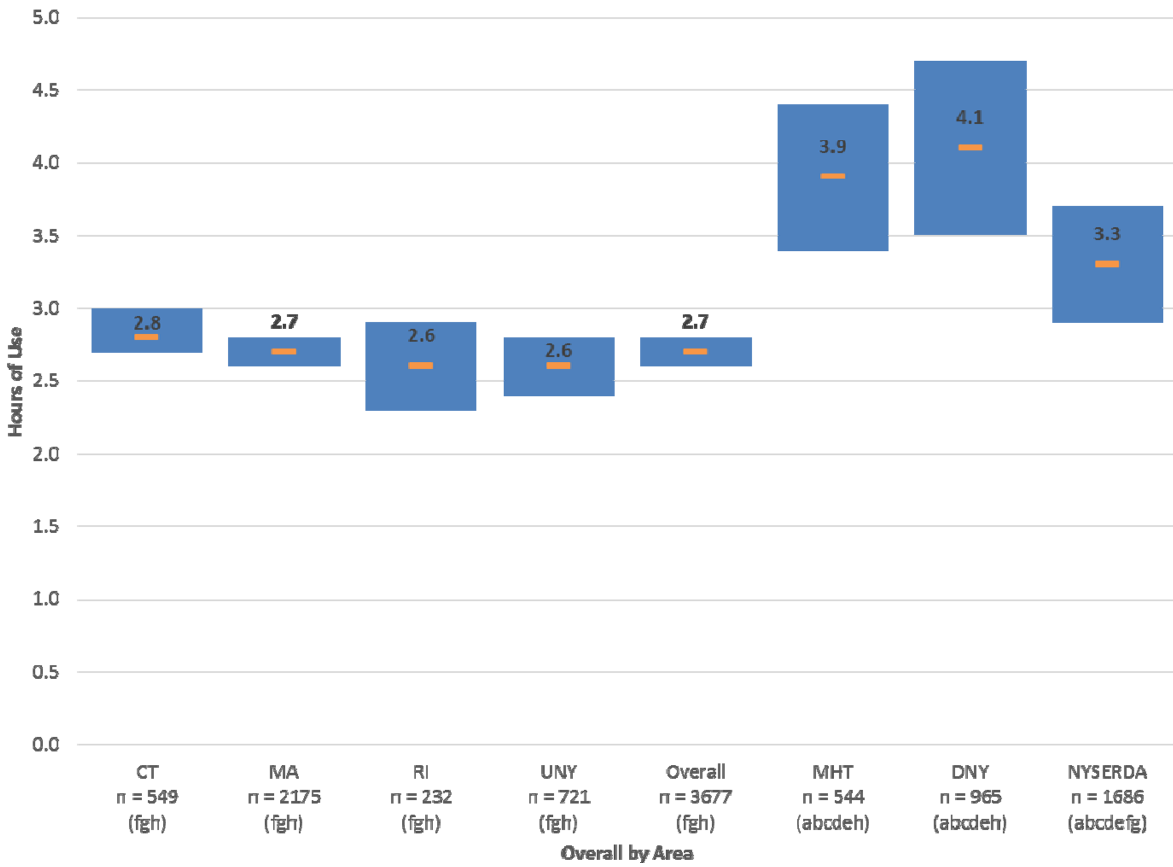
As with the HOU modeling, since each logger was installed for only a portion of the year—between five and nine months—the Team had to annualize the data to generate a full year of monthly load curves for the eight geographies included in the study. In general, adequate actual logged lighting load data were available for February through July for all areas. For any months lacking sufficient data, the Team modeled lighting usage as a function of average hours of daylight. This method relies on the relationship between lighting and average daylight hours. To compare the fit of the model, the Team compared the modeled load curves to actual load curves for months with sufficient data. Comparing the actual versus modeled load curves across 304 combinations of area, home type, and income the overall performance is quite good, with average root mean squared error (MSE) around 0.01. Additional discussion of these methods is included in Section 2.7.

## HOU Analysis Results

When the Team began to analyze HOU across areas, it became apparent that the HOU estimates for Connecticut, Massachusetts, Rhode Island, and Upstate New York were all very similar and that the estimates for Manhattan, Downstate New York (which excludes Nassau and Suffolk Counties), and NYSERDA (a combination of Upstate and Downstate New York) diverged from the other areas. For reasons explained in detail in Section 2.6, the similarity of Connecticut, Massachusetts, Rhode Island, and Upstate New York justified their use in a hierarchical model that did *not* include the divergent areas of Manhattan or Downstate New York.

To simplify the discussion in this Executive Summary, the Team will first compare the four similar areas informed by the hierarchical model and then discuss the NYSERDA area standalone models. Figure E-2 below shows the household level daily HOU estimates for each of the eight models as well as the confidence intervals around the point estimates. Each of the five estimates from the hierarchical model is statistically similar to the others. Estimates for Manhattan and Downstate New York are statistically higher compared to the other models.

Figure E-2: Household HOU Estimates by Area[1,2]




[1] – The Overall model includes CT, MA, RI, and UNY. The Overall model excludes MHT and DNY.
[2] – The DNY model includes MHT.
Statistically different at the 90% confidence level from:
[a] – Connecticut
[b] – Massachusetts
[c] – Rhode Island
[d] – Upstate NY
[e] – Overall
[f] – Manhattan
[g] – Downstate NY
[h] – NYSERDA Overall

## HOU Analysis Results – Hierarchical Models: All Bulbs

The Team found no significant differences in HOU estimates at the household level between any of the areas included in the hierarchical models. Even at the room level, only nine significant differences exist—discussed in detail in Section 3.2.1—out of 80 comparisons between the five sets of estimates obtained from the hierarchical model.[12] It is important to note that none of the areas are significantly different from each other at the household level, and even at the room level only one significant difference exists between the Overall model and any of the four areas included in the Overall model.

Further, the Team examined HOU estimates in these four areas by the following eight categories of home type and income levels:

[12] That is, the individual model for each of the four areas plus the overall model.

- Single-Family Households (SF)
- Multifamily[13] Households (MF)
- Low-Income Households (LI)
- Non-Low-Income Households (NLI)
- Low-Income Single-Family Households (LI SF)
- Low-Income Multifamily Households (LI MF)
- Non-Low-Income Single-Family Households (NLI SF)
- Non-Low-Income Multifamily Households (NLI MF)

The team then compared models for each category within an individual area. For example, the Team compared Massachusetts single-family household estimates to each of the other seven breakdowns for Massachusetts at the household level (28 separate comparisons for each area). Across the eight categories within a specific area there were only four significant differences. These four differences are discussed in detail in Section 3.3.

The Team also compared each of the eight categories across the five areas (i.e., each area and the Overall model). For example, the Team compared Massachusetts low-income households to low-income households in each of the other four areas (ten comparisons for each of the eight categories of home type and income). Across the areas, there were only three significant differences among the five areas, again discussed in detail in Section 3.3.

With such minor differences in HOU estimates across Connecticut, Massachusetts, Rhode Island, and Upstate New York and with relatively few differences at the home type and income level, ***the Team recommends that the Sponsors consider adopting the HOU room-by-room estimates from the Overall hierarchical model for all households regardless of income or home type***. This approach is echoed by the recently completed Massachusetts Low-Income Study and has the advantage of simplifying reporting and evaluations in the future. Table ES-1 provides the room-by-room estimates by area. Results are presented as *mean (90% CI)*.

[13] To align with how the Sponsors define single family and multifamily programs, this study defines single family as: single-family detached, single-family attached, and two-to-four unit properties. Multifamily households are defined as properties with five or more units.

### Table ES-1: HOU Estimates by Area and Room – All Bulbs

| Room | CT | MA | RI | UNY | Overall[1] |
|---|---|---|---|---|---|
| Bedroom | 2.6 (2.2, 3.1) bdefg | 2.0 (1.8, 2.3) afgh | 2.6 (2.0, 3.3) dg | 1.7 (1.3, 2.1) acfgh | 2.1 (1.9, 2.3) afgh |
| Bathroom | 1.5 (1.1, 2.0) fgh | 1.8 (1.5, 2.0) fgh | 1.2 (0.6, 1.8) fgh | 1.9 (1.5, 2.4) fgh | 1.7 (1.5, 1.9) fgh |
| Kitchen | 4.6 (4.0, 5.1) fgh | 4.0 (3.7, 4.3) fgh | 3.8 (3.0, 4.5) fgh | 4.1 (3.7, 4.6) fgh | 4.1 (3.9, 4.3) fgh |
| Living Space | 3.8 (3.3, 4.3) d | 3.3 (3.0, 3.6) g | 3.4 (2.7, 4.2) | 3.1 (2.6, 3.5) afgh | 3.3 (3.1, 3.6) g |
| Dining Room | 3.2 (2.6, 3.9) f | 2.7 (2.3, 3.1) fg | 3.5 (2.6, 4.6) | 2.5 (1.9, 3.1) fg | 2.8 (2.5, 3.1) fg |
| Exterior | 6.0 (5.6, 6.5) bdegh | 5.5 (5.2, 5.8) acg | 6.6 (6.0, 7.1) bdegh | 5.5 (5.1, 5.8) acg | 5.6 (5.3, 5.9) acg |
| Other | 1.7 (1.4, 2.0) fgh | 1.7 (1.5, 1.9) fgh | 1.6 (1.2, 2.0) fgh | 1.7 (1.4, 2.0) fgh | 1.7 (1.6, 1.9) fgh |
| Household | 2.8 (2.7, 3.0) fgh | 2.7 (2.6, 2.8) fgh | 2.6 (2.3, 2.9) fgh | 2.6 (2.4, 2.8) fgh | 2.7 (2.6, 2.8) fgh |

[1] – The Overall model includes CT, MA, RI, and UNY. The Overall model excludes MHT and DNY.
[a] – Statistically different at the 90% confidence level from Connecticut
[b] – Statistically different at the 90% confidence level from Massachusetts
[c] – Statistically different at the 90% confidence level from Rhode Island
[d] – Statistically different at the 90% confidence level from Upstate NY
[e] – Statistically different at the 90% confidence level from the Overall model
[f] – Statistically different at the 90% confidence level from Manhattan
[g] – Statistically different at the 90% confidence level from Downstate NY
[h] – Statistically different at the 90% confidence level from NYSERDA Overall

## HOU Analysis Results – Standalone NYSERDA Models: All Bulbs

Comparing Manhattan, Downstate New York, and NYSERDA (i.e., the combined Upstate and Downstate areas) to each other, there were only four statistically significant differences at the household level, the room level, or even among the eight home type and income categories. However, it is important to note that the all NYSERDA households (3.3) at the household level are significantly lower compared to both Manhattan and Downstate New York.

Further, the Team examined HOU estimates in these three areas by the following eight categories of home type and income levels:

- Single-Family Households (SF)
- Multifamily[14] Households (MF)
- Low-Income Households (LI)
- Non-Low-Income Households (NLI)
- Low-Income Single-Family Households (LI SF)
- Low-Income Multifamily Households (LI MF)
- Non-Low-Income Single-Family Households (NLI SF)

[14] To align with how the Sponsors define single family and multifamily programs, this study defines single family as: single-family detached, single-family attached, and two-to-four unit properties. Multifamily households are defined as properties with five or more units.

- Non-Low-Income Multifamily Households (NLI MF)

The team then compared models for each category within an individual area. For example, the Team compared Downstate New York single-family household estimates to each of the other seven breakdowns for Downstate New York at the household level (28 separate comparisons for each area). Across the eight categories within a specific area there were nine significant differences. Additional details on differences are discussed in in Section 3.3. Table ES-3 provides the room-by-room estimates by area. Results are presented as *mean (90% CI)*.

**Table ES-2: HOU Estimates by Area and Room – All Bulbs**

| Room | MHT | DNY[1] | NYSERDA[2] |
|---|---|---|---|
| Bedroom | 3.4 (2.9, 4.0) abde | 3.6 (3.1, 4.1) abcdeh | 2.8 (2.4, 3.2) bdeg |
| Bathroom | 2.7 (2.2, 3.3) abcde | 3.2 (2.4, 4.1) abcde | 2.8 (2.2, 3.5) abcde |
| Kitchen | 6.3 (5.6, 7.1) abcde | 7.0 (5.8, 8.2) abcde | 5.8 (5.0, 6.6) abcde |
| Living Space | 3.9 (3.3, 4.6) d | 4.5 (3.5, 5.4) bde | 4.0 (3.3, 4.6) d |
| Dining Room | 4.5 (3.6, 5.3) abdeh | 4.0 (2.9, 5.0) bde | 3.2 (2.5, 3.9) f |
| Exterior | -- | 3.6 (2.2, 5.1) abcde | 4.7 (3.7, 5.7) ac |
| Other | 3.4 (2.4, 4.5) abcde | 3.2 (2.3, 4.1) abcde | 2.4 (1.9, 2.9) abcde |
| Household | 3.9 (3.4, 4.4) abcdeh | 4.1 (3.5, 4.7) abcdeh | 3.3 (2.9, 3.7) abcdefg |

[1] – The DNY model includes MHT.
[2] – The NYSERDA model includes UNY and DNY (including MHT)
[a] – Statistically different at the 90% confidence level from Connecticut
[b] – Statistically different at the 90% confidence level from Massachusetts
[c] – Statistically different at the 90% confidence level from Rhode Island
[d] – Statistically different at the 90% confidence level from Upstate NY
[e] – Statistically different at the 90% confidence level from the Overall model
[f] – Statistically different at the 90% confidence level from Manhattan
[g] – Statistically different at the 90% confidence level from Downstate NY
[h] – Statistically different at the 90% confidence level from NYSERDA Overall

## HOU Analysis Results – Special Considerations for NYSERDA

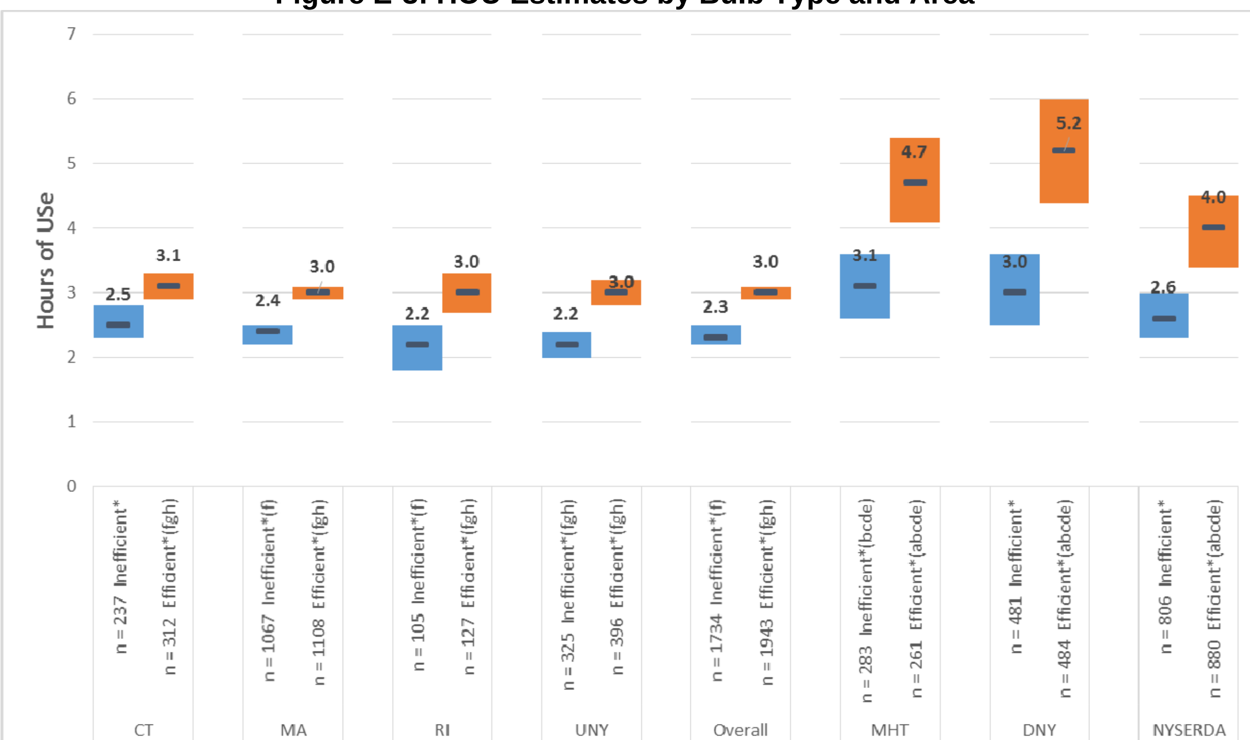
The models show that Downstate New York differs from Upstate New York. In fact, the divergence of Downstate New York is so strong that, when the Team combined both NYSERDA regions and compared the household HOU results between the combined NYSERDA area and Upstate alone, the models showed statistically significant differences. In short, if Downstate is in a model, it differs from Upstate New York—not to mention the other three states also included in this study. The divergence of Upstate New York and Downstate New York estimates and the vastly different housing stock and demographics in each area may help to explain the difference in the NYSERDA service area model. Given the divergence in HOU estimates and the fact that both Upstate and Downstate models are significantly different from the NYSERDA model, ***NYSERDA should consider adopting separate HOU estimates for Upstate New York and***

***Downstate New York. The Team recommends that NYSERDA consider adopting the Overall model room-by-room estimates for Upstate New York presented in Table ES-1 and the Downstate New York model estimates presented in Table ES-2 for Downstate New York.***

## Inefficient versus Efficient Bulbs HOU

While the Team did not find many significant differences between areas, home types, and income types, it did uncover significant differences comparing HOU by bulb efficiency. HOU estimates for efficient bulbs are significantly higher than HOU estimates for inefficient bulbs within each of the eight individual models. Estimates for inefficient and efficient bulbs across the five sets of estimates obtained from the hierarchical model, are all statistically similar, meaning that use of inefficient bulbs does not vary much across the areas, and neither does use of efficient bulbs. Figure E-3 shows the HOU estimates by area broken out by the type of bulb (inefficient vs. efficient). Inefficient bulbs include halogens and incandescent bulbs, and efficient bulbs include CFLs, LEDs, and fluorescent bulbs. For each bulb type, the figure provides the means as well as the confidence intervals around the mean. Results are presented as *mean (90% CI)*.

**Figure E-3: HOU Estimates by Bulb Type and Area**




Statistically different at the 90% confidence level from:

a – Connecticut
b – Massachusetts
c – Rhode Island
d – Upstate NY
e – Overall
f – Manhattan
g – Downstate NY
h – NYSERDA Overall

The differences in bulb efficiencies may be evidence supporting one of three competing theories put forth by some lighting program implementers and evaluators about how households use efficient bulbs. The first theory, differential socket selection, is that households select higher-use locations for their high-efficiency light bulbs. The second theory, shifting usage, holds that a household installs an efficient bulb in a socket and then begins to use that socket in lieu of sockets containing inefficient bulbs. The third theory, increased usage, asserts that snapback occurs—using an efficient product more than the non-efficient one it replaced. However, this evaluation did not collect any data to determine which of these three theories is correct, or the proportion of the difference between efficient and inefficient HOU that is attributable to each type of behavior. In the absence of clear evidence supporting one theory over the others, the Team suggests assuming that the difference between efficient and all-bulb HOU is caused equally by the behavior posited by all three theories, with each accounting for one-third of the total difference between efficient and all-bulb HOU. The team thinks it would be reasonable for residential lighting programs to claim savings based on two of the three theories—differential socket selection and shifting usage—and reduce savings based on the third theory, increased usage (snapback). Therefore, the Team recommends adjusting efficient HOU by subtracting one-third of the difference between efficient and all-bulb HOU.

Table ES-3 and Table ES-4 present the efficient HOU estimates by room from the hierarchical model and the three standalone models. Table ES-5 and Table ES-6 present the HOU estimates adjusted for snapback. As with the all-bulb HOU estimates, the Team recommends that the Sponsors consider using the Overall model for Connecticut, Massachusetts, Rhode Island, and Upstate New York. NYSERDA should consider using two estimates: one for Upstate New York and one for Downstate New York.

**Table ES-3: HOU by Area for Efficient Bulbs—Unadjusted for Snapback**

| Room | CT | MA | RI | UNY | Overall |
|---|---|---|---|---|---|
| Bedroom | 2.8 (2.4, 3.3) [bdefg] | 2.3 (2.0, 2.6) [acfgh] | 3.1 (2.4, 3.7) [bdefg] | 2.2 (1.7, 2.6) [acfgh] | 2.4 (2.2, 2.6) [acfgh] |
| Bathroom | 1.8 (1.3, 2.2) [fgh] | 2.2 (1.9, 2.5) [fgh] | 1.7 (1.0, 2.4) [fgh] | 2.1 (1.7, 2.6) [fgh] | 2.1 (1.8, 2.3) [fgh] |
| Kitchen | 4.7 (4.2, 5.3) [fgh] | 4.2 (3.9, 4.5) [fgh] | 4.2 (3.4, 5.0) [fgh] | 4.3 (3.9, 4.8) [fgh] | 4.3 (4.1, 4.6) [fgh] |
| Living Space | 4.0 (3.5, 4.5) | 3.6 (3.3, 3.9) [fg] | 3.7 (2.9, 4.5) [g] | 3.3 (2.8, 3.8) [fgh] | 3.6 (3.4, 3.9) [fg] |
| Dining Room | 3.5 (2.9, 4.2) [fg] | 3.1 (2.6, 3.5) [fgh] | 3.9 (2.8, 5.0) | 2.9 (2.3, 3.5) [fgh] | 3.1 (2.8, 3.5) [fgh] |
| Exterior | 6.7 (6.1, 7.3) [bdegh] | 5.8 (5.5, 6.2) [ac] | 6.7 (6.1, 7.4) [bdegh] | 5.7 (5.2, 6.2) [ac] | 6.0 (5.6, 6.3) [ac] |
| Other | 2.0 (1.7, 2.3) [fgh] | 2.0 (1.7, 2.2) [fgh] | 1.7 (1.3, 2.1) [fgh] | 2.0 (1.7, 2.3) [fgh] | 2.0 (1.8, 2.1) [fgh] |
| Household | 3.1 (2.9, 3.3) [fgh] | 3.0 (2.9, 3.1) [fgh] | 3.0 (2.7, 3.3) [fgh] | 3.0 (2.8, 3.2) [fgh] | 3.0 (2.9, 3.1) [fgh] |

[1] – The Overall model includes CT, MA, RI, and UNY. The Overall model excludes MHT and DNY.
[a] – Statistically different at the 90% confidence level from Connecticut
[b] – Statistically different at the 90% confidence level from Massachusetts
[c] – Statistically different at the 90% confidence level from Rhode Island
[d] – Statistically different at the 90% confidence level from Upstate NY
[e] – Statistically different at the 90% confidence level from the Overall model
[f] – Statistically different at the 90% confidence level from Manhattan
[g] – Statistically different at the 90% confidence level from Downstate NY
[h] – Statistically different at the 90% confidence level from NYSERDA Overall

## Table ES-4: HOU by Area for Efficient Bulbs—Unadjusted for Snapback

| Room | MHT | DNY | NYSERDA |
|---|---|---|---|
| Bedroom | 4.2 (3.3, 5.0) abcde | 4.4 (3.6, 5.2) abcdeh | 3.3 (2.8, 3.8) bdeg |
| Bathroom | 3.5 (2.8, 4.3) abcde | 4.6 (3.4, 5.8) abcde | 3.6 (2.8, 4.5) abcde |
| Kitchen | 6.7 (5.8, 7.6) abcde | 7.7 (6.4, 9.0) abcde | 6.3 (5.4, 7.1) abcde |
| Living Space | 4.7 (3.9, 5.5) bde | 5.1 (4.1, 6.2) bcde | 4.3 (3.5, 5.0) d |
| Dining Room | 5.4 (4.3, 6.4) abde | 5.4 (4.1, 6.6) abde | 4.1 (3.3, 4.9) bde |
| Exterior | -- | 4.8 (3.0, 6.6) ac | 5.4 (4.3, 6.5) ac |
| Other | 4.1 (2.9, 5.3) abcde | 3.9 (2.8, 5.0) abcde | 2.9 (2.2, 3.6) abcde |
| Overall | 4.7 (4.1, 5.4) abcde | 5.2 (4.4, 6) abcdeh | 4.0 (3.4, 4.5) abcdeg |

[1] – The DNY model includes MHT.
[2] – The NYSERDA model includes UNY and DNY (including MHT)
[a] – Statistically different at the 90% confidence level from Connecticut
[b] – Statistically different at the 90% confidence level from Massachusetts
[c] – Statistically different at the 90% confidence level from Rhode Island
[d] – Statistically different at the 90% confidence level from Upstate NY
[e] – Statistically different at the 90% confidence level from the Overall model
[f] – Statistically different at the 90% confidence level from Manhattan
[g] – Statistically different at the 90% confidence level from Downstate NY
[h] – Statistically different at the 90% confidence level from NYSERDA Overall

## Table ES-5: HOU by Area Adjusted for Snapback

| Room | CT | MA | RI | UNY | Overall |
|---|---|---|---|---|---|
| Bedroom | 2.8 (2.4, 3.1) bdefg | 2.2 (2.0, 2.4) acfgh | 2.9 (2.4, 3.4) bdefg | 2.0 (1.7, 2.3) acfgh | 2.3 (2.1, 2.5) acfgh |
| Bathroom | 1.7 (1.3, 2.0) fgh | 2.0 (1.8, 2.3) fgh | 1.6 (1.1, 2.1) fgh | 2.1 (1.7, 2.4) fgh | 2.0 (1.8, 2.1) fgh |
| Kitchen | 4.7 (4.3, 5.1) bfgh | 4.2 (3.9, 4.4) afgh | 4.1 (3.5, 4.6) fgh | 4.3 (3.9, 4.6) fgh | 4.2 (4.1, 4.4) fgh |
| Living Space | 3.9 (3.5, 4.3) dg | 3.5 (3.3, 3.7) fgh | 3.6 (3.0, 4.2) fg | 3.2 (2.9, 3.6) afgh | 3.5 (3.4, 3.7) fgh |
| Dining Room | 3.4 (2.9, 3.9) fg | 3.0 (2.6, 3.3) fgh | 3.8 (3.0, 4.6) df | 2.8 (2.3, 3.2) cfgh | 3.0 (2.8, 3.3) fgh |
| Exterior | 6.5 (6.0, 6.9) bdegh | 5.7 (5.5, 6.0) acg | 6.7 (6.2, 7.2) bdegh | 5.7 (5.3, 6.0) ac | 5.8 (5.6, 6.1) acg |
| Other | 1.9 (1.7, 2.1) fgh | 1.9 (1.7, 2.0) fgh | 1.7 (1.4, 2.0) fgh | 1.9 (1.7, 2.1) fgh | 1.9 (1.8, 2.0) fgh |
| Household | 3.0 (2.8, 3.2) fgh | 2.9 (2.8, 3.0) fgh | 2.9 (2.7, 3.1) fgh | 2.8 (2.7, 3.0) fgh | 2.9 (2.8, 3.0) fgh |

[1] – The Overall model includes CT, MA, RI, and UNY. The Overall model excludes MHT and DNY.
[a] – Statistically different at the 90% confidence level from Connecticut
[b] – Statistically different at the 90% confidence level from Massachusetts
[c] – Statistically different at the 90% confidence level from Rhode Island
[d] – Statistically different at the 90% confidence level from Upstate NY
[e] – Statistically different at the 90% confidence level from the Overall model
[f] – Statistically different at the 90% confidence level from Manhattan
[g] – Statistically different at the 90% confidence level from Downstate NY
[h] – Statistically different at the 90% confidence level from NYSERDA Overall

**Table ES-6: HOU by Area Adjusted for Snapback**

| Room | MHT | DNY | NYSERDA |
|---|---|---|---|
| Bedroom | 3.9 (3.3, 4.5) abcdeh | 4.1 (3.6, 4.7) abcdeh | 3.2 (2.8, 3.5) bdefg |
| Bathroom | 3.3 (2.7, 3.8) abcde | 4.1 (3.3, 5.0) abcde | 3.4 (2.8, 4.0) abcde |
| Kitchen | 6.6 (5.9, 7.2) abcde | 7.5 (6.5, 8.4) abcdeh | 6.1 (5.4, 6.7) abcdeg |
| Living Space | 4.4 (3.8, 5.0) bcde | 4.9 (4.1, 5.7) abcde | 4.2 (3.6, 4.7) bde |
| Dining Room | 5.1 (4.3, 5.8) abcdeh | 4.9 (4.0, 5.8) abdeh | 3.8 (3.2, 4.4) bdefg |
| Exterior | -- | 4.4 (3.1, 5.7) abce | 5.2 (4.4, 6.0) ac |
| Other | 3.9 (3.0, 4.8) abcdeh | 3.7 (2.9, 4.5) abcdeh | 2.7 (2.3, 3.2) abcdefg |
| Overall | 4.5 (4.0, 5.0) abcdeh | 4.8 (4.3, 5.4) abcdeh | 3.7 (3.4, 4.1) abcdefg |

[1] – The DNY model includes MHT.
[2] – The NYSERDA model includes UNY and DNY (including MHT)
[a] – Statistically different at the 90% confidence level from Connecticut
[b] – Statistically different at the 90% confidence level from Massachusetts
[c] – Statistically different at the 90% confidence level from Rhode Island
[d] – Statistically different at the 90% confidence level from Upstate NY
[e] – Statistically different at the 90% confidence level from the Overall model
[f] – Statistically different at the 90% confidence level from Manhattan
[g] – Statistically different at the 90% confidence level from Downstate NY
[h] – Statistically different at the 90% confidence level from NYSERDA Overall

## Load Shape Analysis

The Team developed hourly load shapes by month for each area based on logger data collected for the study. The Team also calculated coincidence factors (CFs) in two ways for each area:

1. Using the data that informed the monthly load shapes for the three New England states included in the study, the Team calculated CFs during the New England Independent System Operator (ISO-NE) summer and winter on-peak and Seasonal Peak hours. According to ISO-NE, the winter on-peak hours are during non-holiday weekdays from 5:00 to 7:00 PM. The summer on-peak hours are during non-holiday weekdays from 1:00 to 5:00 PM.[15]
2. The Team also prepared estimates based on peak data from the two Independent System Operators covering the area of the Sponsors.

[15] While NYSERDA does not fall within the ISO-NE area and is instead included at the New York Independent System Operator (NYISO), the New York technical manual published by the New York Department of Public Service (DPS) currently provides summer CFs based on the ISO-NE peak period. Therefore, the study provides updated CFs for NYSERDA areas during the same summer and winter peak periods.

a. The Team prepared estimates based on ISO-NE's 2013 Seasonal Peak Data for Connecticut, Massachusetts, and Rhode Island. According to the ISO-NE Seasonal Peak Data Summary, in 2013 the winter peak period occurred on January 24, 2013 at the hour ending 19 and the summer peak hour occurred on July 19, 2013 at the hour ending 17.
b. The Team prepared estimates based on the NYISO's peak hour. Based on NYISO actual load data for 2013, the peak occurred on July 7, 2013 at the hour ending 19.

Figure ES-4 displays one load curve in the Executive Summary as a visual accompaniment to the data presented in Table ES-7. Section 3.4.3 of the main document presents additional load curves for each area. In each load curve, the shaded area represents the relevant summer and winter peak periods (1:00 to 5:00 PM in the summer and 5:00 to 7:00 PM in the winter, based on the hour ending). The average percentage of bulbs turned on during summer and winter peak periods is shown in the upper left, and the calculated confidence interval is displayed for each hour. All of the load curves for each of the areas show a similar pattern of low usage starting around midnight, ramping up beginning in the hour ending at 6:00 AM, building until around noon, and then flattening off. In each area there is also a ramp-up in usage entering the evening hours at around hour ending at 6:00 or 7:00 PM (near the end of the winter peak period). ***As with HOU estimates, the team recommends that the Sponsors consider adopting the Overall load curve and resulting coincidence factors across Connecticut, Massachusetts, Rhode Island, and Upstate New York.*** In addition, unlike with HOU estimates, the all bulb and efficient bulb coincidence factors are statistically similar for the Overall model and as such there is no need to adopt an all bulb estimate and a separate efficient specific estimate. ***Turning to Downstate New York and Manhattan, the Team recommends that NYSERDA adopt the Downstate New York model to represent Downstate New York and Manhattan as the two models are statistically similar.*** Results in Table ES-7 are presented as *mean (90% CI)*.

The Team leaves it up to the Sponsors to decide when it is appropriate to use the winter and summer peak period estimates versus the ISO specific peak hour estimates. Both estimates are presented together in the tables below.

**Figure ES-4: Overall Load Curve for Summer and Winter (Weekday) – All Bulbs**

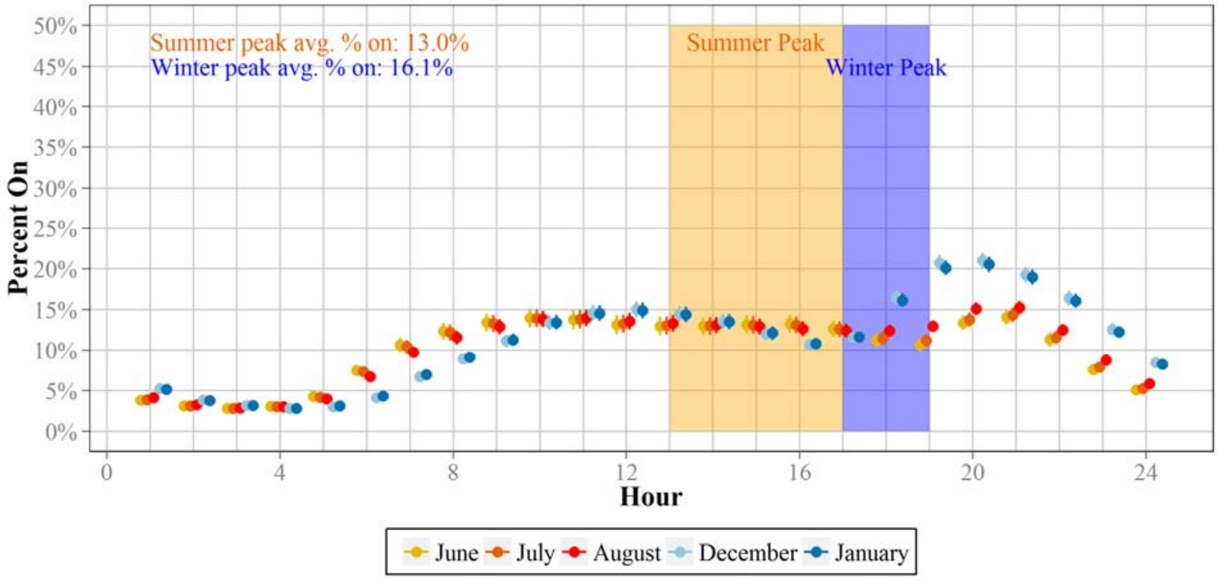


**Table ES-7: Peak Period Coincidence Factors and Confidence Intervals – All Bulbs**

| Region | Winter Peak Period Dec. & Jan. (5 PM – 7PM) | Summer Peak Period June, July and August (1 PM – 5PM) | ISO-NE Seasonal Peak Hour (Winter) January 24, 2013 Hour Ending 19 | ISO-NE Seasonal Peak Hour (Summer) July 19, 2013 Hour Ending 17 | NYSO Peak Hour July 7, 2013 Hour Ending 19 |
|---|---|---|---|---|---|
| CT | 17% (15%, 19%) [d] | 16% (13%, 18%) [bd] | 22% (19%, 24%) | 16% (13%, 18%) | n/a |
| MA | 16% (15%, 17%) | 12% (11%, 14%) [ac] | 19% (18%, 20%) | 12% (10%, 13%) | n/a |
| RI | 16% (13%, 19%) | 19% (15%, 24%) [bde] | 19% (16%, 22%) | 17% (13%, 21%) | n/a |
| UNY | 14% (11%, 16%) [ae] | 11% (9%, 13%) [acf] | n/a | n/a | 9% (8%, 11%) |
| Overall[1] | 16% (15%, 17%) [d] | 13% (12%, 14%) [c] | 20% (19%, 21%) | 13% (12%, 15%) | n/a |
| MHT | 27% (24%, 30%) [h] | 17% (15%, 19%) [h] | n/a | n/a | 19% (17%, 21%) |
| DNY | 28% (25%, 31%) [h] | 17% (15%, 19%) [h] | n/a | n/a | 19% (17%, 21%) |
| NYSERDA | 22% (19%, 24%) [fg] | 14% (12%, 15%) [fg] | n/a | n/a | 15% (13%, 16%) |

[1] – For the ISO-NE Seasonal Peak Hours, the Overall estimates presented include only data from CT, MA, and RI.
[2] – The Overall model includes CT, MA, RI, and UNY. The Overall model excludes MHT and DNY.
[3] – The DNY model includes MHT.
[4] – The NYSERDA model includes UNY and DNY (including MHT)
[5] – In this table, significance testing is limited to comparing CT, MA, RI, UNY and Overall to each other and MHT, DNY, and NYSERDA.
[a] – Statistically different at the 90% confidence level from Connecticut
[b] – Statistically different at the 90% confidence level from Massachusetts
[c] – Statistically different at the 90% confidence level from Rhode Island
[d] – Statistically different at the 90% confidence level from Upstate NY
[e] – Statistically different at the 90% confidence level from the Overall model
[f] – Statistically different at the 90% confidence level from Manhattan
[g] – Statistically different at the 90% confidence level from Downstate NY
[h] – Statistically different at the 90% confidence level from NYSERDA Overall

## Considerations

### Consider Adopting the Overall model HOU and coincidence factors for CT, MA, RI, and Upstate New York

With such minor differences in HOU estimates across Connecticut, Massachusetts, Rhode Island, and Upstate New York and with relatively few differences at the home type and income level, the Team recommends that the Sponsors consider adopting the HOU room-by-room estimates from the Overall hierarchical model for all households in these four areas. The Overall model has the greatest level of precision owing to the larger sample sizes and is statistically similar to each of the individual area models on a room-by-room basis and by each of the eight categories of home type and income. By adopting room-by-room estimates, the Sponsors will have the flexibility to apply separate estimates based on specific program data. For example, if direct install program data include room type, the Sponsors can apply estimates for specific room types.

Further, room-by-room estimates provide the ability to update and revise HOU estimates periodically for upstream programs based on room-level socket saturation. For example, if saturation data indicate that saturation is increasing more quickly in kitchens relative to other room types, this would results in an increase to household HOU.

### Consider Adopting Two Models for NYSERDA Area

Given the divergence of the Upstate New York model from both the Downstate and even the NYSERDA area model, NYSERDA should consider using the Overall hierarchical model (i.e., the four area model discussed above) for Upstate and the stand-alone Downstate New York for Downstate New York and Manhattan. NYSERDA may also want to consider whether or not higher lighting operating hours and coincidence factors among Downstate households may justify programmatic differences for Upstate and Downstate, such as higher incentives in the latter.