A Lighting Study to Stand the Test of Time: Exploring the Results of a Residential Lighting Study Designed to Produce Lasting Data

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ABSTRACT

The Energy Independence and Security Act of 2007 (EISA) and the increasing presence in the market of new lighting technologies like LEDs and EISA-compliant halogens are two factors that will likely lead to rapid change in the residential lighting market in the coming years—change that means hours-of-use (HOU) estimates based on specific lighting technologies are likely to become obsolete very quickly. This presents evaluators with a conundrum: how to design a study that applies to current market conditions and program designs, while allowing for the development of HOU data that will adapt to changing technologies and regulations in the future. In short, how can we design a study that will stand the test of time?

By developing estimates at the room level and logging both efficient and inefficient bulbs, the Northeast Residential Lighting HOU study was designed to develop HOU estimates that are not tied to specific technologies and can be updated over time by combining location-specific HOU estimates with data on where energy-efficient bulbs are being installed. Using this approach, the study increases its shelf life by eliminating the need for additional costly HOU studies in response to new technologies or changes in where households are installing bulbs. This paper presents HOU data for eight different combinations of income and housing types across eight areas for both efficient and inefficient bulb types. It also explores findings regarding snapback or "take back" behavior, which can be difficult to measure in upstream programs.

Background

The Northeast Residential Lighting HOU study was designed as one of the largest and most comprehensive residential lighting HOU studies ever conducted. Owing to the complexity and comprehensiveness of the study, this paper is one of three being presented at IEPEC Long Beach 2015. This paper presents overall approaches and results and discusses the unique study design elements that allow the estimates to be updated over time through follow-up lighting inventory studies. Throughout this paper we make references to material that is covered in more depth in companion papers:

- *Are You Turned On? A Hierarchical Modeling Approach for Estimating Lighting Hours of Use*, Wilson-Wright et al., focuses on specific modeling techniques applied to the data.
- *What Light through Yonder Window Breaks? Methods to Study the Effects of Urban Canyons on Lighting Usage,* Walker et al., focuses on the results of solar shading analysis performed for high-rise apartments in Manhattan.

Overview

The objective of this study was to provide updated load shapes, coincidence factors (CFs), and HOU estimates for 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. During study development, evaluators identified increasing saturation levels and the diversification of the energy-efficient lighting market as two possible threats to study longevity. To help increase the shelf-life of the study, it was designed with a large sample and a focus on gathering data by room type rather than by bulb type. Therefore, unlike previous studies, the focus of this study was broader, encompassing all types of residential lighting including traditional incandescent bulbs, CFLs, LEDs, fluorescent tubes, and halogen bulbs.

The study began in November 2012 and was completed in May 2014—with loggers in the field between November 2012 and July 2013.[1] The study took advantage of saturation studies in New York and Massachusetts (NMR Massachusetts 2013, NMR New York 2013). To complement the Base Study,[2] NYSERDA also funded a oversample of high-rise households in Manhattan. This study also 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). NMR, Cadmus, and DNV GL coordinated the development of protocols and methods to ensure comparable data. Table 1 provides an overview of the number of households included from each study by area. Note that all of the studies were conducted concurrently and with the same field protocols so that data could be combined and analyzed together.

Table 1. Participants by State and Study

Bulb Type	Base Study	Low-Income Study	*EnergyWise* Study	High-Rise Study	Total
Connecticut	90	--	--	--	90
Massachusetts	137	261	--	--	398
New York	138	--	60	121	319
Rhode Island	41	--	--	--	41
Total	**406**	**261**	**60**	**121**	**848**

Key Takeaways

Little evidence to support separate HOU estimates for households based on home type or income. Authors found relatively few significant differences in HOU estimates at the household level between households in the same areas regardless of home type or demographic characteristics.

Downstate New York households have significant higher lighting usage. Data reveal that while Connecticut, Massachusetts, Rhode Island, and Upstate New York have statistically similar HOU, the usage in Downstate New York is statistically higher, supporting previous findings that different areas may require separate HOU estimates.

[1] Additional details on logging period can be found in the methods section of this paper: here.
[2] In this paper, 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.

Efficient bulbs have significantly higher HOU estimates. Comparisons of inefficient and efficient bulb HOU suggest that households typically replace the lights they use most frequently. While we offer three theories to explain these differences, evidence from another recent study suggests that the differences may simply be due to the greater need to replace the bulbs that are used more frequently. Based on this, we should observe efficient-bulb HOU converging with all-bulb HOU over time as saturation levels increase.

No association between saturation and efficient bulb HOU. Consistent with previous work performed in the Northeast (NMR 2009), no consistent pattern emerged between the percentage of sockets filled with efficient bulbs and the HOU for those bulbs. This was also true across all bulb types in our regression models, as household saturation was consistently not a significant predictor of HOU.

HOU Results and Analysis

Throughout this paper, eight separate area estimates are presented—five produced by the hierarchical model and three produced by separate standalone models—as described in detail in the more methods-heavy companion paper also being presented at IEPEC 2015 (Wilson-Wright et al.). Unless otherwise specified, all data presented are weighted and all sample sizes (n) reflect logger counts. Results are presented as *mean (90% CI)*. Significant differences across areas are denoted with letters *a* through *h*:

a. Statistically different from CT
b. Statistically different from MA
c. Statistically different from RI
d. Statistically different from UNY
e. Statistically different from Overall
f. Statistically different from Manhattan
g. Statistically different from DNY
h. Statistically different from NYSERDA

Due to the vast amount of data collection for this study, we were able to analyze and present HOU in many different ways. In total, the authors examined over 1,700 data breakdowns. Data were analyzed by eight modeled areas (described above), nine room categories, eight categories of home type and income level, and three categories of bulb efficiency. Given the breadth of the study, we are limited to presenting only the high-level takeaways in this paper. However, additional detailed analysis is available in the full report, which can be downloaded here, and in an accompanying data viewer[3] developed specifically for this project, which allows users to query various load shapes developed for the study.

Differences Between Areas

When the team began to analyze HOU across areas, it became apparent that when compared to the same type of bulbs the efficient, inefficient, and all bulb HOU estimates for Connecticut, Massachusetts, Rhode Island, and Upstate New York were all very similar—in fact, the authors found no significant differences in HOU estimates at the household level between any of these four areas. Even at the room level, only nine significant differences exist.[4] In contrast, the estimates for Manhattan, Downstate New York (excluding Nassau and Suffolk Counties), and NYSERDA (a combination of Upstate and Downstate New York) diverged significantly from the other four areas. Figure 1 provides the household-level daily HOU estimate for each of the eight modeled areas, as well as the confidence intervals.

[3] Available upon request
[4] When comparing the same bulb types and same room types.

The confidence interval around the Overall all bulb estimate is the narrowest (2.6 to 2.8 HOU); each tenth represents just six minutes. Therefore, it can be said with 90% confidence that actual all bulb HOU fall within a twelve-minute range. The Rhode Island estimate has the widest confidence interval (2.4 to 2.8 HOU, a 24-minute range) because Rhode Island had the fewest loggers. Compared to each of the hierarchical models, the Manhattan and Downstate New York HOU estimates are significantly higher (3.9 and 4.1, respectively). Further, these estimates have much wider confidence intervals than those from the hierarchical model; this is true across all models for Downstate New York, Manhattan, and NYSERDA Overall.

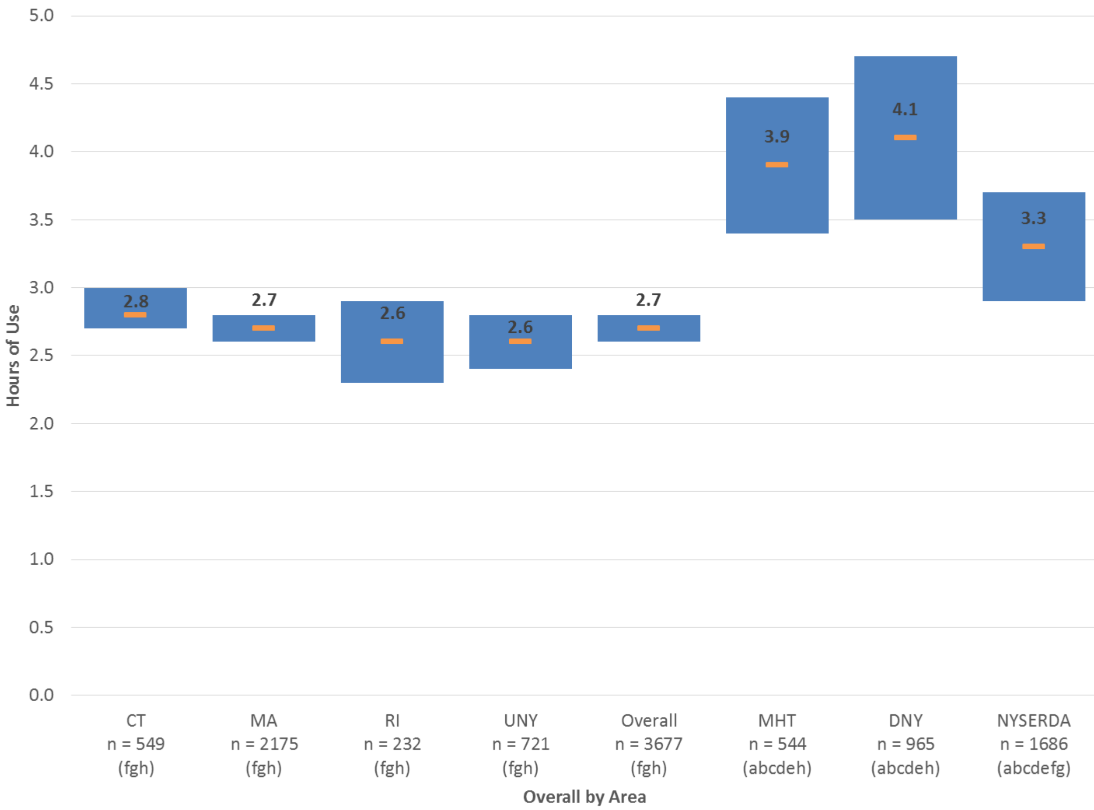

Figure 1. All Bulb HOU in Downstate New York and Manhattan Diverge from the other Areas[5]

Differences Between Room Types

Among the five hierarchical models out of 80 room-by-room comparisons, we found only nine significant differences, further supporting the conclusion that the four areas of Connecticut, Massachusetts, Rhode Island, and Upstate New York have similar residential lighting HOU. Given this, we limit our discussion of room-by-room differences in HOU to the model applied to the Overall Northeast (excluding Downstate New York), which adequately represents the four areas, and the Downstate New York model, which includes Manhattan households. As Figure 2 illustrates, in the Overall model, HOU varies widely by room type, with exteriors (4.1) and kitchens (5.6) presenting the highest daily HOU and bathrooms (1.7), other rooms (1.7), and bedrooms (2.1) averaging the lowest. The Downstate model shows a similar pattern, with kitchens (7.0) having higher HOU than the other room types and bathrooms (3.2), other rooms (3.2), and bedrooms (3.6) averaging the lowest usage

[5] Figure shows HOU for all bulb types. The study found that efficient bulbs are used, on average, significantly more hours per day compared to inefficient bulbs. Additional details on efficient and inefficient bulb HOU are included in the 2014 NMR report.

(relatively). Given the smaller sample sizes in the Downstate region, it is not surprising that the confidence intervals are much wider.

Still, evidence in both models suggests that not all usage is created equal and that some room types have greater lighting usage. Further, looking at the Overall model, the breakdown of usage makes intuitive sense with rooms that are commonly used more frequently averaging the highest daily usage.

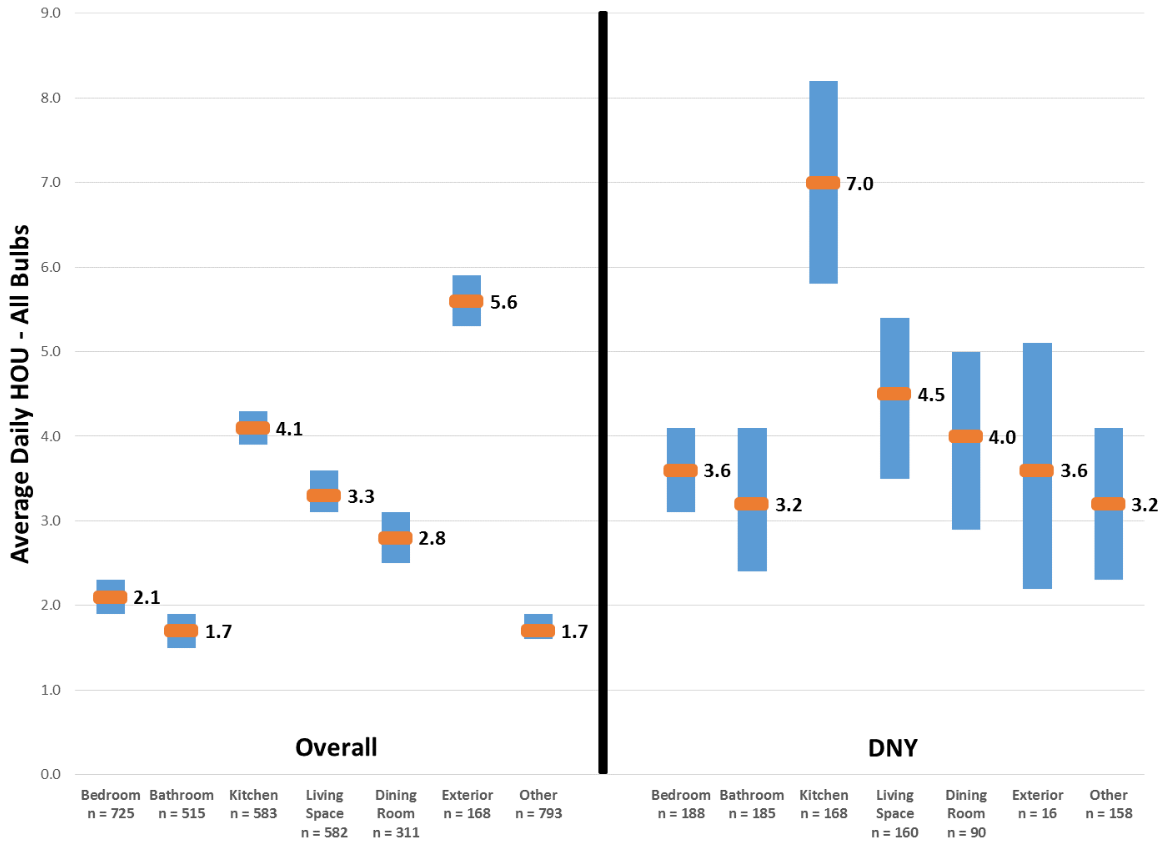

Figure 2. HOU Varies Widely by Room Type

Differences by Home Type and Income

A key area of interest at the outset of the study was an examination of differences in household HOU by the key demographic factors of home type and income status. To this end, we examined HOU data by eight categories:

- Single-family (SF)
- Multifamily (MF)
- Low-Income (LI)
- Non-Low-Income (NLI)
- Low-Income Single-Family (LI SF)
- Low-Income Multifamily (LI MF)
- Non-Low-Income Single-Family (NLI SF)
- Non-Low-Income Multifamily (NLI MF)

We then compared models for each category within an individual area. For example, we 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). Out of 28 comparisons, there were very few (four) significant differences. Next, we compared each of the eight categories across the five hierarchical models (i.e., each area and the Overall model). For example, we 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.

Such minor differences in HOU estimates across Connecticut, Massachusetts, Rhode Island, and Upstate New York further support using the HOU room-by-room estimates from the Overall hierarchical model for all households in these areas regardless of income or home type. This was an unexpected but important finding from the study.

We performed a similar analysis comparing the Downstate New York estimates for each of the eight categories and found that there were only nine significant differences. Again, this was an unexpected outcome, but it served to help simplify further analysis because it also supported the continued use of a single model to represent all of Downstate New York.[6]

Differences by Bulb Efficiency

Figure 3 shows the HOU estimates for all bulbs in each of the areas 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. Significant differences within an area are denoted with an asterisk (*), and significant differences across areas are labeled with a letter *a* through *h*, found in the legend along with sample size (n).

Efficient bulb HOU estimates are universally significantly higher compared to inefficient bulb HOU estimates. Similar to all bulb HOU estimates, estimates for inefficient and efficient bulbs across each of the estimates obtained from a hierarchical model are all statistically similar, ranging from 3.0 to 3.1. Similarly, while the estimates from the Manhattan, Downstate New York, and the NYSERDA models diverge from the other four, the same pattern of higher efficient bulb HOU remains. In addition, the trend observed at the household level continues when room-by-room estimates are examined.

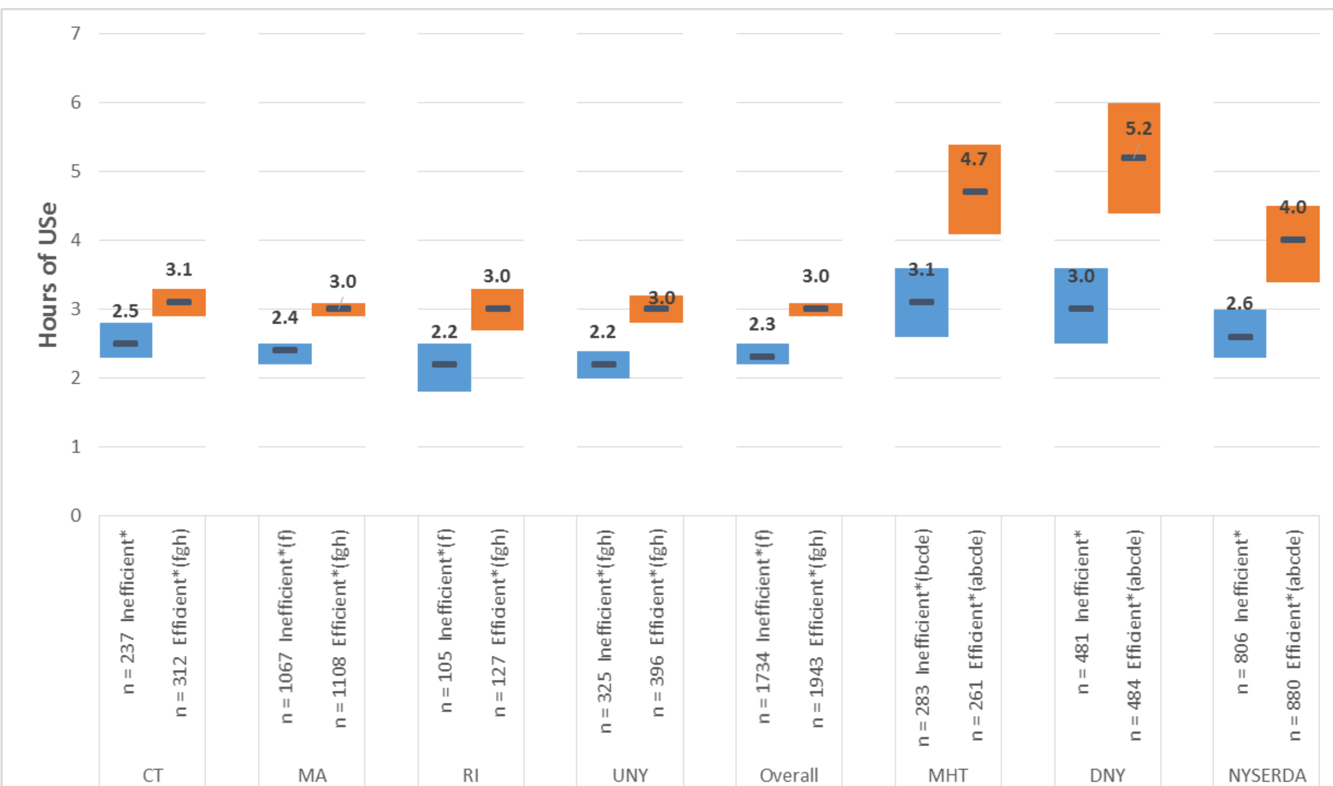

Figure 3. Efficient Bulb HOU are Universally Significantly Higher than Inefficient Across all Models

[6] Details on significant differences can be found in the 2014 NMR report.

To further explore the root causes of differences in HOU estimates for inefficient and efficient bulbs, the team examined unweighted and unadjusted analyses of HOU estimates. As Table 2 shows, CFL and fluorescent HOU estimates are significantly higher compared to both incandescent and halogen estimates. Unfortunately, at the time of this study, LEDs had not yet been adopted in high enough quantities to comprise a significant amount of our sample, and the resulting confidence interval surrounding LED HOU estimates is quite wide.

Table 2. Daily Average HOU Overall by Bulb Efficiency (Unweighted)

Bulb Type	n	All Households	90% Confidence Interval
All	4,642	2.95	± 0.12
Efficient[1]	2,427	3.35	± 0.17
Inefficient[2]	2,215	2.51	± 0.14
Incandescent	2,109	2.49	± 0.14
CFL	1,922	3.16	± 0.17
Fluorescent	475	4.04	± 0.40
Halogen	106	2.86	± 0.52
LED	30	4.30	± 1.74

[1] Includes CFL, fluorescent, and LED bulbs.
[2] Includes incandescent and halogen bulbs.

Next, we explored the possibility that households were installing efficient bulbs in specific rooms or fixture types with higher HOU. However, this analysis revealed that efficient bulb usage was significantly higher in all room types and in all fixture types, leading the authors to conclude that neither room type nor fixture type plays a role in explaining the differences in efficient HOU.

Finally, the authors looked for other factors that may be related to efficient bulb saturation. To investigate, we calculated unweighted HOU for several breakdowns by CFL saturation as well as 1) total number of sockets in the home, 2) total number of rooms in the home, and 3) total number of fixtures in the home. Each of the variables considered was broken into quartiles of the distribution at the household level. While analysis revealed some patterns for efficient bulbs, similar patterns appear in the corresponding inefficient bulb data. In other words, the patterns of HOU for efficient and inefficient bulbs appear to mirror each other, except that the efficient HOU are always a bit higher. This suggests that, for some reason, efficient bulbs typically have a higher level of usage than inefficient bulbs across the Overall region.

The differences in bulb efficiencies may support one of three competing theories among some lighting program implementers and evaluators about how households use efficient bulbs. The three theories are:

Differential socket selection, which occurs when a household targets installing efficient bulbs in the fixtures that are used most frequently in any given room. In this scenario, household lighting preferences are static. The team believes it would be reasonable for the Sponsors to claim higher HOU caused by differential socket selection because the efficient bulbs are operating for the same HOU as the inefficient bulbs replaced.

Shifting usage, which occurs when a household installs an efficient bulb in a socket and then begins to use that socket in lieu of sockets containing inefficient bulbs. In this scenario, the team believes it would be reasonable for the Sponsors to claim savings for the shift in usage because HOU for the fixture that is used more frequently offsets usage from inefficient fixtures. This theory does not discount the possibility that the fixture selected was already the most frequently used fixture in a given room.

Increased usage (snapback), which occurs when a household installs an efficient bulb in a socket and begins using that socket more because the cost to operate that light is lower. In this scenario, any increased HOU that occurs as a result of snapback should be excluded when the Sponsors claim energy savings.

Another finding from the analysis was the lack of association between saturation and efficient bulb HOU—that is, no consistent pattern emerged between the percentage of sockets filled with efficient bulbs and the HOU for those bulbs. This was also true across all bulb types in our regression models, as household saturation was consistently not a significant predictor of HOU. Consistent with previous work by NMR, the relationship is virtually non-existent (NMR 2009).

Given the lack of association between saturation and efficient HOU may be an indication that households have not yet reached the point where they have begun to install efficient bulbs in infrequently used sockets. If this is the case, over-time as efficient bulb saturation increases, efficient HOU should decrease until they become equal with HOU estimates for all bulbs. At the time of the study, efficient saturation in the Northeast was between 35-40% on average (depending on area). In addition, relatively few households had high-levels of efficient bulb saturation one-half had saturations of 35% or less and three-quarters had saturations of less than 54%.

Subsequent to this study, the authors had the opportunity to explore potential for shifting usage and increased usage as part of the 2014 and 2015 residential lighting panel studies undertaken in Massachusetts (Barclay et al.). The results of this study indicate that customers do not consciously choose to shift or increase usage when replacing inefficient bulbs with efficient ones. This suggests that any difference in usage may be explained by households installing efficient bulbs in fixtures that are used most frequently in any given room. This explanation makes intuitive sense because bulbs that are used more frequently are the most likely to be in need of replacement, and, as the panel study reveals, customers are likely to replace bulbs only at the end of their useful life. Still, the findings rely on self-reported data and should be treated with appropriate caution.

The authors think that a conservative approach may be justified, at least initially, and suggest assuming that the difference between efficient and all-bulb HOU is caused equally by the behaviors posited by all three theories. As explained above, only one of the three scenarios (increased usage) should be excluded when calculating energy savings. Adjusting for potential snapback reduces household HOU from 3.0 in the Overall model to 2.9, and from 5.2 HOU to 4.8 in Downstate New York. Area-specific room-by-room HOU estimates can be found in the full report.

Comparison to Recent Studies

In this section we briefly compare findings from the Northeast Residential Lighting HOU Study to other recent studies throughout North America. As Table 3 shows, recent studies provide a wide range of estimated HOU for residential lighting. When viewing the data in the table below, it is important to note that aside from the first three studies listed, all of the studies reported HOU for CFLs only. To aid with comparisons, the Team presents the HOU from the three most recently completed studies for both all bulbs and efficient bulbs.

Table 3. Daily Average HOU Overall by Region

Region	Year	All Bulb HOU Estimate	Efficient HOU Estimate
Connecticut, Massachusetts, Rhode Island, and Upstate New York	2014	2.7 (All Bulbs)	3.0 (Efficient)
Downstate New York	2014	4.1 (All Bulbs)	5.2 (Efficient)
Massachusetts Low Income Households	2014	2.6 (All Bulbs)	2.8 (Efficient)
Connecticut, Massachusetts, Rhode Island, and Vermont	2009	n/a	2.8
Massachusetts, Rhode Island, and Vermont	2004	n/a	3.2
Maryland (EmPOWER)	2011	n/a	3.0
California (PG&E, SCE, and SDG&E service areas)	2010	n/a	1.9
California (PG&E, SCE, and SDG&E service areas)	2005	n/a	2.3
Pacific Northwest	2010	n/a	1.9 (existing)
North Carolina and South Carolina	2011	n/a	2.5 (North) 2.7 (South)
Ohio	2010	n/a	2.8
Illinois	2012	n/a	2.7

Conclusions

We found little evidence to support separate HOU estimates for households based on home type or income and found that many of the areas in the Northeast have similar lighting habits. However, we did find that Downstate New York households have significantly different lighting usage compared to the rest of the areas included in the study.

Further, the study indicates that HOU vary widely by room type, and we suggest that program administrators, implementers, and evaluators carefully consider these differences when designing, operating, and evaluating lighting programs. For example, direct-install programs with a strategy aimed at replacing 100% of inefficient lighting should consider using the all-bulb room-by-room HOU estimates, whereas upstream lighting programs should consider (at least in the near term) using the snapback-adjusted household efficient HOU estimates. Data also suggest installation strategies for direct-install programs that install a limited number of bulbs. Such programs should focus on installing bulbs in high-use fixtures in high-use rooms and should claim the higher HOU.

Comparisons of inefficient and efficient bulb HOU suggest that households typically replace the lights they use most frequently. While we offer three theories to explain these differences, evidence from another recent study suggests that the differences may simply be due to the greater need to replace the bulbs that are used more frequently. If this is true, we should observe efficient-bulb HOU converging with all-bulb HOU over time as saturation levels increase. Still, with efficient bulb saturations hovering around 35-40%, it may be some time before an equilibrium is reached and efficient HOU begin to approach all-bulb estimates.

As mentioned earlier, this study was designed so that HOU estimates developed could be updated as the type of rooms where bulbs are being installed occur over time. For upstream programs, this can be accomplished by periodically tracking room-by-room saturation levels and calculating a weighted average household HOU based on the room-by-room estimates and relative changes in saturation. This adjustment may not be necessary for direct-install programs if programs are careful to track room type when installing bulbs. In fact, given the wide variance in room-by-room HOU estimates, it is important for direct-install programs to collect such data and calculate savings based on specific room estimates.

Finally, the authors offer a word of caution to evaluators and program administrators who may wish to use results from this study in other jurisdictions. While the lack of difference in household HOU between much of the Northeast may suggest that results are transferable between jurisdictions, we caution other areas against relying on this study for HOU estimates. Recent studies have shown a wide range of estimated HOU for residential lighting. Even within this study we found significant differences between Downstate New York and other areas. Further the Uniform Methods Protocols stress caution and go on to conclude that extrapolation of data from one region to another has not been successful in the past and recommend that program administrators collect data specific to their region and program directly through a metering study.

Methods

For this evaluation, trained technicians visited each site twice. During the first visit, technicians collected detailed lighting inventory data and installed time-of-use light meters (loggers).[7] The second visit consisted of removing the loggers installed during the first visit.

Early on in project development, the authors identified two key populations that are often overlooked: low-income and multifamily households. In an effort to ensure that the study was as comprehensive as possible and also to enable separate analysis for low-income and multifamily households, the Base Study set targets to recruit one-half of visits from multifamily properties and achieve proportional visits with low-income households.[8,9]

Recruitment

While the authors attempted to keep the sample similar in each area, the strategies differed somewhat both within and across areas. Households were identified for the on-sites in three different ways: random-digit dial (RDD) telephone surveys, customer lists, and an address lookup. The reasons for these differences were primarily due to lack of customer lists for New York households and the need to maintain comparability to prior efforts in Massachusetts. For all areas except that covered by the Massachusetts Low-Income Study, households were recruited by telephone using computer-assisted telephone interviewing (CATI).[10] The Massachusetts Low-Income Study obtained customer names and addresses from a list of customers receiving the low-income rate and did not have reliable phone numbers. Recruitment for this study was carried out using postcards that explained the study and encouraged customers to call to arrange an appointment.

In New York, NYSERDA funded the inclusion of an additional oversample of high-rise homes located in Manhattan. Additional details on the development of the high-rise sample can be found in the high-rise-specific paper also being presented at IEPEC 2015 (Walker et al.). Regardless of identification or recruitment method, the NMR team offered all potential study participants incentives that varied by area and study.

Data Collection

All homes included in the sample required two on-site visits. During the first visit, trained technicians collected detailed lighting inventory data and installed time-of-use light meters (loggers).

[7] For this study, we used a combination of Hobo UX 90 and DENT TOU-L loggers to record on/off instances. Logger types and protocols were consistent across all areas.
[8] Defined based on eligibility for the Low Income Heating Energy Assistance Program [LIHEAP in 2012].
[9] Initially, multifamily properties were defined as any homes with two or more units, but during analysis the definition of multifamily was adjusted to better align with how the Sponsors define single-family and multifamily programs; therefore, in this paper, unless otherwise specified, multifamily households are defined as properties with five or more units.
[10] Massachusetts and New York Base Study households were recruited in conjunction with longer 15-minute consumer telephone surveys.

The second visit consisted of removing the loggers installed during the first visit. Technicians followed a comprehensive set of on-site procedures to ensure uniformity in data collection, followed by quality control checks among 5% of homes.

Technicians installed an average of seven loggers per home—eight for single-family homes and six for multifamily homes. Loggers were placed on unique circuits (a circuit is a set of bulbs or fixtures operated by the same switch) throughout each home with the goal of installing one logger in each of the following room types for single-family homes: dining rooms, exteriors, living spaces, bedrooms, bathrooms, and kitchens, and two loggers in other room types. Protocols for multifamily homes were similar except for dining rooms and exteriors, which were included in the other room types category.

During the removal visits, technicians were provided with pre-filled forms containing the logger ID, location, fixture type, bulb type, bulb shape, and socket type for each logger installed at each site. The technician confirmed the characteristics for each bulb and performed a state test to determine whether or not the logger had accurately recorded event data during the time it was installed. Additional information recorded upon retrieval included total time shown on the logger; any changes to the bulb, logger, or fixture during the time the logger was installed as reported by the homeowner; and the homeowner's estimated typical usage for each monitored fixture.

Data Cleaning, Sample Attrition, and Outlier Detection

As is common in studies of this size, the authors assumed that some attrition would take place due to loggers being damaged, stolen, or otherwise unrecoverable. In total, 5,730 loggers were installed and data was obtained for 5,494 loggers—2,627 from the base study and 2,867 from the following three studies combined: the Massachusetts Low-Income Study, the National Grid NY *EnergyWise* Study, and the NYSERDA High-Rise Study. For each logger, the HOU for each day of the study period were calculated. Analysts performed quality assurance and quality control on the daily logger data. The authors adopted a very conservative approach, and the only loggers removed were those for which it was not reasonable to assume the recorded data were correct—namely, those exhibiting obvious flickering or those that were on continuously for over three consecutive weeks *and* whose unexpectedly high observed usage did not agree with self-reported usage for the bulb in question.

Preliminary data cleaning ultimately resulted in the removal of data for 364 loggers, leaving 5,130 loggers across all areas. Of the 5,130 loggers included after cleaning, an additional 488 loggers were dropped because they were missing one or more of the variables that contributed to the regression analysis, or because they had corrupt IDs. This left us with a total of 4,642 loggers for analysis.

Logging Period

The period with the greatest number of loggers was between February and July of 2013 (six months), and a substantial number of loggers (greater than 1,500) were deployed in each month from December 2012 through July 2013 (eight months). On average, loggers were installed for 143 days, with 84% of loggers in the field for at least 121 days and 31% in the field for at least 151 days. Loggers were installed on average for the following number of days in each area: CT – 147 days, MA – 145 days, RI – 216 days, Upstate NY – 123 days, and Downstate NY – 132 days.[11]

This approach to logging a partial year is consistent with the guidelines recommended by the Uniform Methods Protocol for upstream lighting programs (Dimetrosky). According to the protocols, "*Due to the seasonality of lighting usage, logging should (1) be conducted in total for at least six months and (2) capture summer, winter, and at least one shoulder season—fall or spring. At a minimum,*

[11] Additional details on the logging period can be found in the more methods-heavy companion paper also being presented at IEPEC 2015 (Wilson-Wright et al.).

loggers should be left in each home for at least three months (that is, two waves of three-month metering will attain six months of data). All data should be annualized using techniques such as sinusoidal modeling to reflect a full year of usage."

HOU Modeling

In this paper, the authors provide a summary of modeling required to develop HOU estimates, but do not delve into model specifics or elaborate on techniques. Instead, as mentioned previously, interested readers are directed to the more methods-heavy companion paper also being presented at IEPEC 2015 (Wilson-Wright et al.). Developing HOU estimates consisted of the following steps:

- **Creating Annual Data Sets.** Since each logger was installed for only a portion of the year, it was necessary to annualize the data. To this end, the authors fit a sinusoid model to each logger.
- **Adjusting HOU Estimates.** Using the annualized estimates, the authors performed a weighted regression analysis to estimate the adjusted HOU for each room in each area of the study. 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 leveraged data from each of these areas to refine 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.

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