Residential Lighting Deep Dive Brief: A Comparison of Savings Assumptions across the Northeast and Mid-Atlantic

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About NEEP

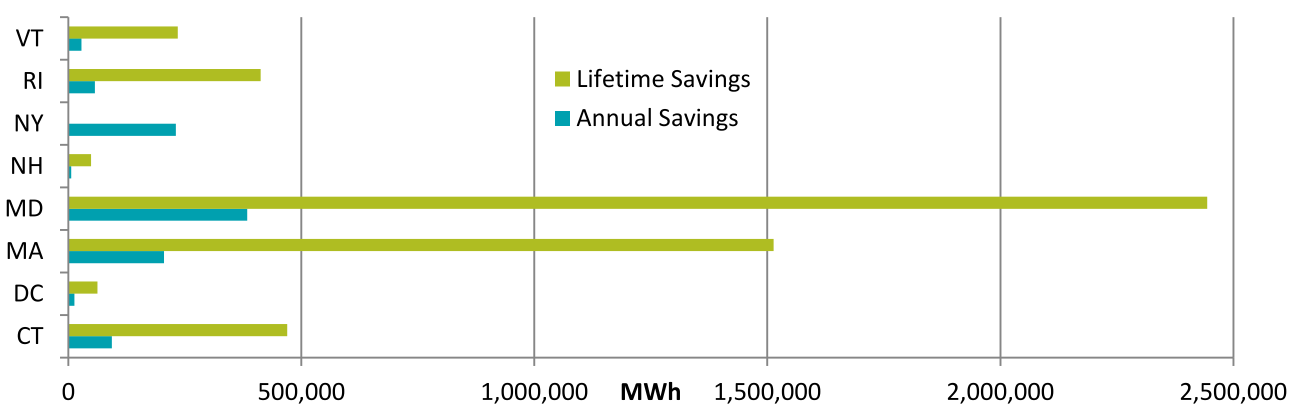
NEEP was founded in 1996 as a non-profit whose mission is to serve the Northeast and Mid-Atlantic to accelerate energy efficiency as an essential part of demand-side solutions that enable a sustainable regional energy system. Our vision is that the region will fully embrace next generation energy efficiency as a core strategy to meet energy needs in a carbon-constrained world.

Introduction

Residential Lighting is a critical efficiency measure, with 2013 gross program savings from retail lighting programs reaching over 1 TWH for the Northeast and Mid-Atlantic states that report to REED, as shown in Figure 1.[1] Upstream residential lighting represents a very significant portion of energy savings in the region and in 2015, NEEP focused on residential lighting research and market analysis in several ways to support state program administrator and regulator needs to help inform program strategies and designs. NEEP has provided several briefings and webinars informed by a combination of NEEP's Market Strategies research, analysis of lighting data from the Regional Energy Efficiency Database (REED), and research on underlying savings assumptions. In August 2015, NEEP issued *The State of our Sockets* paper[2] which provided an overview of the state of residential lighting market transformation. This was followed by a Residential Lighting Workshop in October where NEEP provided, among other things, a comparative overview of residential lighting savings assumptions across states in the region.[3] Building on these efforts, this 'deep dive' brief takes a closer look at variations in residential lighting savings assumptions across the region. This brief is intended to **help states understand key similarities and differences in various parameter assumptions, where and why some are warranted, and where there may be opportunities for improved consistency across the states.**

As residential lighting programs are selling millions of lightbulbs, a small difference in savings assumptions applied to each bulb can lead to a significant difference in savings impact. Since the size of the program and population served varies considerably between states in the region, in order to compare program impacts between states, NEEP looked at the lifetime cost of gross saved energy values across the states for residential lighting programs. When looking at this important parameter, we found a 3.5 fold difference between the highest and lowest costs.

Figure 1: 2013 Gross Annual and Lifetime Savings for Lighting (MWh)



In trying to understand why there is such a spread in cost of saved energy values across the states, we focused on comparing a range of underlying assumptions that inform savings estimates. For this analysis, we did not look into the cost differences, but rather focused on savings calculation itself (formula or algorithm) for gross and net

[1] Data for Gross Annual 2013 savings from www.reed.neep.org and state filings. States included in analysis are: CT, DC, MA, MD, NH, NY, RI, and VT.
[2] *The State of our Sockets*, NEEP, August 2015. http://www.neep.org/state-of-our-sockets
[3] See in particular the slides 65-85 of the master slide deck. Add info on other key areas of focus from workshop, which are not core to this briefing report.

savings, as well as the range of input parameters: delta watts, hours of use (HOU), measure life, in-service rates, and interactive effects. We also looked at the underlying evaluation methods and results used to estimate the various input parameters, using the EM&V Forum's *Standardized EM&V Methods Reporting Forms* ('EM&V Reporting Forms') as a way to provide easy comparison, focusing on two key HOU studies. The analysis reviews each of these areas and provides observations, conclusions and recommendations for states.

The analysis focuses on standard CFLs and LEDs as they presently provide the majority of savings in residential lighting portfolios. It also considers decorative and directional LEDs as NEEP's 2015 Residential Lighting Strategy (RLS) reports[4] recommends that programs shift their focus toward these lamp types in the future, particularly as the pending federal standard EISA 2020, which impacts the standard lighting categories, does not impact those categories. Our analysis does not include residential direct install and retrofit lighting measures which typically have specific evaluation assumptions applied to them. Those retrofit measures were not the focus of this analysis, but many of our conclusions and discussions similarly apply. This research examined residential lighting input assumptions from the following states' most recent Technical Reference Manual (TRM) updates in the Northeast and Mid-Atlantic: Connecticut, District of Columbia, Maryland, Massachusetts, New York, Rhode Island and Vermont.[5] We also included values used by New Hampshire program administrators. The dates of the TRMs analyzed are shown in Table 1.

Table 1: Publish Dates of TRMs used in analysis

State	MD	DC	VT	MA	CT	NY	RI
Date Published	Jun-15	Sep-15	Oct-15	June/Oct-15	Oct-15	Jun-15	Oct-15

This brief was informed and reviewed by program administrators, residential lighting program and evaluation experts, and state regulatory staff. More information on what informed each input value can be found in Appendix A: List of Supporting Studies for TRM Values. Appendix B: Comparison of Evaluation Methodologies and Results for Hours of Use Studies provides a summary comparison of the key HOU studies, with links to the completed digital EM&V Methods Reporting Forms.

[4] See http://neep.org/northeast-and-mid-atlantic-residential-lighting-strategy-2015-2016-update

[5] Maine, New Jersey, and Pennsylvania were not included in this research because those states do not currently participate in the EM&V Forum or NEEP sponsorship. Delaware was not included because program administrators do not administer retail residential lighting programs. The New York values are from the 2015 TRM, but are not necessarily in use as NYSERDA did not run retail residential lighting programs in 2015 and PSEG-Long Island uses their own values from their TRM developed by Opinion Dynamics.

Analysis:

Gross and Adjusted Gross Savings Formulas

The most obvious place to look for similarities or differences in evaluation assumptions is to examine the formula used to estimate **gross savings** from a residential lighting program, as provided and defined in state TRMs. The formulas we found for the states included in this analysis are presented in Table 2. While there are some similarities among states in the algorithm used to estimate gross savings, there are also clear differences. One of the largest differences is that some states include certain savings adjustments like an in-service rate (ISR) and an interactive effects factor (e.g., Waste Heat Factors (WHF) in Maryland) in their gross savings formula that other states either do not apply or do not apply until later (i.e., to determine adjusted gross or net savings.) Another key difference is while some explicitly state the savings are gross (Rhode Island), many other states use different descriptions to refer to this savings. In some cases, the formulas presented in the TRM may actually be what would be considered **adjusted gross savings.** In other cases, such as Massachusetts, what would be considered their gross savings formula is listed as a Primary Energy Impact, and a Secondary Energy Impacts which include interactive effects is listed at a different point in the TRM.

Table 2: Savings Formulas by State from TRMS

State	Savings Description	Gross Savings Formula
CT	Lost Opportunity Gross Energy Savings	ΔKWh = Interactive Effect Value x (WattΔ x HOURS x 365 / 1000)
DC	Annual Energy Savings	ΔKWh = ((ΔWatts) / 1000) x HOURS x ISR x WHFE
MA	Primary Energy Impacts	ΔkWh = ΔkW x hours
MD	Annual Energy Savings	ΔKWh = ((Wattbase - WattEE) / 1000) x ISR x HOURS x (WHFeHeat + (WHFeCool - 1))
NH	Gross Savings	ΔKWh = (WattΔ x HOURS x 365 / 1000) x ISR
NY	Annual Electric Energy Savings	ΔkWh = (units x leakage) x ΔW / 1000 x HOURS x 365 x (1 + HVACc)
RI	Gross Savings	Gross kWh = Qty × ΔkW x HOURS
VT	Energy Savings	ΔKWh = ((ΔWatts) / 1000) x HOURS x ISR x WHFE

Adjusted Gross Savings: The change in energy consumption and/or demand that results directly from program-related actions taken by participants in an efficiency program, regardless of why they participated. **It adjusts for such factors as data errors, installation/ in-service and persistence rates, and hours of use**, but does not adjust for free-ridership or spillover. *EM&V Forum Glossary V2.1*

The variations in the formulas above are important to note because energy efficiency savings are reported to regulators as either Adjusted Gross Savings or Net Savings, where differing savings formulas and definitions make comparison of results challenging. The EM&V Forum developed a Glossary of Terms & Definitions[6] in 2011 that define gross, adjusted gross and net savings, however through this deep dive exercise, we can see that lack of consistency remains in TRMs across the region. Further, the algorithms above are not in all cases consistent with what's recommended for residential lighting in the US

[6] See http://www.neep.org/emv-forum-glossary-terms-and-acronyms

DOE EE Savings Protocols[7]. Some of the key differences in the algorithms are whether or not states take into account an in-service rate adjustment or adjustment for the interactive effects between more efficient lighting and HVAC systems at that level in their calculations, as summarized in Table 3.

Table 3: Factors Included in Savings Formulas by State

	DC	MD	NH	NY	VT	CT	MA	RI
In-Service Rate	Yes	Yes	Yes	Yes	Yes	Yes in net savings	Yes in adjusted gross savings	Yes, in adjusted gross savings
Interactive Effects	Yes	Yes	No	Yes	Yes	Yes	Yes in adjusted gross savings	No[8]

Most states apply an in-service or installation rate to report gross or adjusted gross savings. Connecticut is the exception, as they apply it in the net savings calculation. Most states also account for interactive effects; in the case of Massachusetts, which released a new TRM in late 2015, accounting for residential lighting interactive effects was a new addition. As such, the reported residential lighting savings are not fully comparable across the states in REED (pre-2015 data) as a result of differing algorithms. We take a closer look below at in-service rates and interactive effects to better understand the impact of those inputs.

In-Service Rate Values

The **in-service rate (ISR)** is defined as the percentage of incentivized lighting measures that are installed in a socket within the program administrator's service territory. Table 4 details the ISR values for the states in this analysis. For those states that include an in-service rate factor in their gross savings formula, the ISR for CFLs is lower in all cases than for an LED and the range in values is wider. While typically ISR is something that adjusts over time in its impact on lifetime savings, as a bulb that might have had an 80% chance of being installed in year 1 may have a 95% chance of being installed in year 2, the first year ISR is all that is presented within TRMs. In-service rate values are typically based either on an agreed upon assumption or an evaluation study. We look further into the EM&V methods used to develop in-service rate values in Appendix B.

Table 4: First Year In-Service Rate Values by State for CFL and LED bulbs

CT*	DC	MD	MA*	NH	NY	RI**	VT
CFL = 0.63	CFL = 0.92	CFL = 0.88	CFL = 0.95	CFL = 0.62	No value provided	CFL = 0.95	CFL = 0.77
LED = 0.82	LED = 0.95	LED = 0.95	LED = 1	LED = 0.95	No value provided	LED = 0.98	LED = 0.90

*Applied during net savings calculation **Applied as a gross savings adjustment

Interactive Effects

The **interactive effects factor** captures the influence of one technology's application on the energy required to operate another application. An example is the reduced cooling needed during the summer in a facility as a result of replacing inefficient lighting with more efficient lighting, and corresponding need to increase electric, gas or oil-fueled space heating during the winter. Table 5 shows TRM interactive effect values used by states.

[7] See http://www.energy.gov/eere/about-us/ump-protocols
[8] While reviewers of this document indicated that RI had added an interactive effect based on the same analysis that prompted MA to introduce an interactive effect consideration in their 2016-2018 TRM, we could not find evidence that this interactive effect had actually been included in the most recent TRM for RI.

Table 5: Energy Interactive Effects Values for Lamps Installed Where the Existence or Type of Heating or Cooling is Unknown

CT	DC	MA	MD	NY	VT
1.04	CFL Cooling Savings: 1.122 LED Cooling Savings: 1.09 CFL Heating Penalty: Calculated LED Heating Penalty: Calculated	There is a heat loss of 2,237 Btu/kWh counted for bulbs sold upstream	Cooling Savings = 1.09 Electric Heating Penalty = 0.894	No Value provided in TRM	WHe = 1 for residential

Each state takes a slightly different approach to reporting interactive effects. Some provide a stated value for different heating fuel source while others do not provide that level of detail. For values based on evaluations, further details are listed in Appendix A: List of Supporting Studies for TRM Values. Connecticut includes an average interactive effects factor of 1.04 in its gross energy savings formula based on an evaluation study performed by NMR in 2014. Maryland's cooling savings value is based on a BGE Residential Energy Use Survey performed in 2005 that found that 78% of homes had central cooling within the study area. The heating penalty for lighting that's installed in an unknown residence in Maryland is based on default values to arrive at 0.894. DC's cooling savings factor for CFL lighting is estimated at 1.122 based on the 0.45 ASHRAE lighting waste heat cooling factor for Washington DC[9], and assumes that 68% of homes have central cooling in DC, based on 2009 EIA data.[10] The cooling savings factor for LED lighting in DC is based on the same study that Maryland uses to estimate its cooling savings, which is why those cooling factors are the same. The heating penalties in DC are calculated values based on (1) the percentage of lighting savings that occur in a location that must be heated, (2) the percentage of homes with electric heating, and (3) the efficiency of the heating equipment.

Hours of Use, Measure Life and Delta Watts

Putting in-service rates and interactive effects aside, the next set of questions focuses on the major savings parameters: hours of use (HOU), measure life and delta watts. Specifically, how do results vary for states if we simply look at gross savings as ΔkWh = ΔkW*hours? The following table identifies the range of differences in the hours of use and the delta watts. These key parameters are the largest values contributing to the end result, i.e. annual gross and net lighting savings, and as shown in Table 6, there are significant differences across states in these key parameters. For lifetime savings differences, the measure life values are also very impactful and will be discussed later in this document. The differences in these values are key drivers in the variation of results across states and are key factors that drive the 3.5 fold difference in lifetime cost of gross saved energy.

Table 6: Range of Variation in Parameters for Standard CFLs and LEDs (with State and Vintage of Study)

Parameter	HOU-CFL		HOU-LED		Delta Watt CFL		Delta Watt LED**	
Max	3.9	DC (2014)	3.9	DC (2014)	49.0	MA (2014)	38.2	DC (2013)
Min	2	NH	2	NH	32.7	DC, VT (2011)	33.0	RI (2012 Model)
% difference	95%		95%		50%		16%	
# states examined	8		8		5		5	
**For DC and VT, simple average of two wattage categories was used for comparison with single deemed value from other states								

[9] See http://lighting.bki.com/pubs/b6_tab1.htm
[10] See http://www.eia.gov/consumption/residential/data/2009/xls/HC7.10%20Air%20Conditioning%20in%20South%20Region.xls

To comprehensively document the range of variation in the region, TRMs and program administrators were consulted, and the detailed level findings from this exploration are discussed in the following sections.

Hours of Use Value

The **hours of use** is defined as the number of hours per day on average that the lighting in question is turned on. These values are presented in Table 7, loosely from low to high.

Table 7: Hours of Use by State for Retail Residential Lighting Programs

	NH	MD	CT	RI	VT	NY	MA	DC
Standard CFL Bulb	2	2.46	2.9	2.9	2.6	3.2	3.3	3.9
Standard LED Bulb	2	2.46	2.9	2.9	3.3	3.2	3.3	3.9
Decorative LED Bulb	2	2.46	2.9	2.9	3.3	3.2	3.3	3.9
Directional LED Bulb	2	2.46	2.9	2.9	3.3	3.2	3.3	3.9

In May 2014, NMR Group Inc. published the results of a Northeast Residential Lighting Hours of Use Study that was sponsored by a collection of program administrators, energy efficiency advisory boards, and state energy offices in Connecticut, Massachusetts, Rhode Island, and New York (NYSERDA). The study included a range of suggested values for different applications and saturations. Most of the states in the region use this study to inform their hours of use, though Maryland and New Hampshire do not. While NYSERDA participated in the study, individual New York utilities did not, and the statewide TRM does not refer solely to the NMR report. While Massachusetts had been using 2.9 hours/day based on the NMR report for all measures up until 2015, since these bulbs are sold through retail and it is not possible to know if they were installed in a home or in a commercial application, they adjusted the hours of use for the 2016-2018 plan to account for the 7% of retail lamps estimated to be purchased for commercial applications that are assumed to have an 8.45 hours/day. This is based on a 2015 Cross-Sector Sales Research analysis. The District of Columbia uses 3.9 hours per day based on the NMR study's findings for the New York Manhattan metro area, which they consider to be most similar to Washington DC. That higher value was reached based on a high number of occupants per room.

Vermont uses a different value for CFLs and LEDs. The CFL value of 2.6 hours of use per day is based on the NMR study which found that value for homes in Upstate New York, which they consider to be most similar to Vermont. Vermont's value of 3.3 hours of use per day for their LED bulbs is based on the assumption that these will be installed in the highest use locations due to their high cost. Although this is a plausible assumption, it differs from the assumptions made by all other states studied that assume the same hours of use value for their CFL and LED bulbs.

Maryland's hour of use values are based on the EmPOWER Maryland Evaluation Year 5 Residential Lighting Program: Hours of Use/Metering Study, which was published in April of 2015. As part of its most recent TRM update, Maryland and the District of Columbia conducted a comprehensive review of HOU studies from the Northeast, other Mid-Atlantic states, and other states in the U.S. before opting to use the values found in their impact estimation.

New Hampshire does not currently have a public TRM (although plans to develop on in the near future). Its 1.97 HOU value is based on a 2012 impact evaluation study for its Residential ENERGY STAR® Lighting Program

Impact Evaluation, where this value is the lowest value used in the region. See Appendix B for a review of this study and key EM&V elements, as compared to the other HOU studies reviewed for this brief.

Finally, in the case of New York, the New York Statewide TRM includes a 3.2 HOU per day value derived based on information from several states, including: 2003 logger data from Massachusetts, Rhode Island, and Vermont, 2008 Connecticut program savings documentation, and 2005-2006 data from Efficiency Maine. New York considered these various data sources and arrived at a 3.2 estimated HOU value for both CFLs and LEDs. However, our understanding is that NYSERDA and PSEG-Long Island do not necessarily use this TRM value to calculate their lighting savings.

Delta Watt Value

The **delta watt** is the differences in energy use between the efficient bulb incented through the program and the inefficient bulb being replaced. Typically for retail lighting programs, the exact bulb being replaced is not known once the customer leaves the store, and therefore a **baseline** is typically calculated based on the expected mix of other technologies available in the market. Programs keep track of what efficient bulbs are sold, and the delta watt is established based on the efficient wattage and the baseline. Standard CFLs and LEDs are tracked based on their lumen output, and binned using incandescent equivalencies (100W, 75W, 60W, 40W). The baseline takes into account the expected mix of the different lumen bins.

This added nuance makes delta watt comparison between states particularly difficult; typically, neither the baseline value nor the distribution of lumen bins is presented within the TRM. In some cases, a delta watt value is not presented, but rather a formula to calculate delta watt based on the efficient wattage bulb is presented. Without more information about the measure mix for these states or the baseline assumptions being used, it is difficult to assess how different the states' assumptions are. Table 8 shows the deemed delta watt value or calculation used by states in this analysis. It is worth noting that Massachusetts has different delta watt values established for years into the future. We chose to present the 2015 TRM values to better compare with other 2015 TRM values in different states.

The delta watt values are presented with three different methods in the states that were looked at for this analysis. Massachusetts employs a complex market adoption model to determine delta watt values for years into the future. This model takes into account socket saturation, market trends, legislative changes, and several other factors to arrive at those values. The TRM reflects the final value the model determines. Massachusetts also trues up their values based on the year-end incented measure mix. While Massachusetts does not have separate TRM categories for decorative or directional LEDs, the values reported for decorative at what is listed as "EISA Exempt," and those reported for directional are actually new additions to the 2016-2018 TRM where "reflectors" was added as a new category. Rhode Island's delta watt value is based on the demand allocation methodology described in Cadmus Demand Impact Model as well as variant of the market adaption model.

Table 8: Delta Watt Values by State for Retail Residential Lighting Programs

	MD	CT	NY	DC	VT	MA	NH	RI
Standard CFL	Calculated based on wattage of efficient lamp. Baselines: 100W Equivalent = 72W 75W Equivalent = 53W 60W Equivalent = 43W 40W Equivalent = 29W	Calculated ratio: .75 x Watt pre / Watt post Or 3.0 if pre wattage unknown	2.53 x CFL watts for incandescent replacement, 1.55 x CFL watts for halogen replacement	32.7	32.7	49	39.7	44
Standard LED	Calculated based on wattage of efficient lamp. Baselines: 100W Equivalent = 72W 75W Equivalent = 53W 60W Equivalent = 43W 40W Equivalent = 29W If unknown assume 14.5W	Calculated ratio: .75 x Watt pre / Watt post Or 3.4 if pre wattage unknown	Calculated by (units x wattsbaselline) - (units x wattsee)	< 15W = 30.1 >=15W = 46.2	< 15W = 30.1 >=15W = 46.2	37	33.7	33
Decorative LED	I f actual LED lumens is known, use equivalent baseline wattage from TRM table[11] If unknown assume 14.5W	4.0 wattage ratio	Calculated by (units x wattsbaselline) - (units x wattsee)	<15W = 43.3 15<=W<25 = 53 >=25W = 73.3	<15W = 33.7 15<=W<25 = 31 >=25W = 45.3	46*	55.7	44
Directional LED	If actual LED lumens is known, use equivalent baseline wattage from TRM table.[12] If unknown use 14.5W	5.0 wattage ratio	Calculated by (units x wattsbaselline) - (units x wattsee)	<20W = 44.8 >=20W = 100.5	<20W = 44.8 >=20W = 100.5	47.6 **	46.2	44

* Listed as EISA Exempt 2015 ** Reflectors are listed stand-alone values from 2016-18 TRM

In Maryland, Connecticut, and New York, the delta watt values are estimated based on the wattage of the efficient bulb incented through the program. In Maryland's case a table is used to arrive at the wattage of the baseline bulb, and in Connecticut's case a formula is used to arrive at the correct wattage ratio to use in the savings equation, but the result of each is that the delta watt is calculated based on the wattage of the efficient bulb incented through the program.

Vermont and DC take a hybrid approach between the two methods outlined above. For their CFL bulbs, an average delta watt was determined based on values presented in the Residential Lighting Strategy report published in March 2012 and adjusting for market changes for each year since 2012. For its LED bulbs, however, delta watt was determined based on the wattage of the efficient bulb incented through the program using a year's worth of LED sales data for Efficiency Vermont from a cross section of product brands and geography.

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[11] Full table available at http://www.neep.org/sites/default/files/resources/Mid-Atlantic_TRM_V5_FINAL_5-26-2015.pdf page 58
[12] Full table available at http://www.neep.org/sites/default/files/resources/Mid-Atlantic_TRM_V5_FINAL_5-26-2015.pdf page 58

Measure Life Value

The **measure life**, sometimes called the effective useful life (EUL), refers to the number of years that a particular measure is expected to be installed and in working condition. This is very impactful on the lifetime savings for a program. Table 9 includes the values and binning that the states analyzed used for measure life.

Table 9: Measure Life Values by State for Retail Residential Lighting Programs

	CT	DC	MA	MD	NH	NY	RI	VT
Standard CFL Bulb	4	EUL reduced each year until 2020	EUL reduced each year until 2020	EUL reduced each year until 2020	5	Coupon - 5 Markdown - 7	4	EUL reduced each year until 2020
Standard LED Bulb	10	< 15W = 15 >=15W = 15	10	20	20	TRM does not specify an EUL for LEDs	8	< 10W = 15 >=10W = 15
Decorative LED Bulb	10	<15W = 15 15<=W<25 = 10.5 >=25W = 10.5	19 (EISA exempt)	16.7	20	TRM does not specify an EUL for LEDs	17	<15W = 15 15<=W<25 = 12.5 >=25W = 12.5
Directional LED Bulb	10	<20W = 15 >=20W = 15	19 (EISA exempt)	20	20	TRM does not specify an EUL for LEDs	17	<20W = 15 >=20W = 15

The measure life values for CFLs are all being handled in a similar way; because Phase II of EISA is expected to raise the standard for general service lighting, CFLs are assumed to be the new baseline in 2020; states are accounting for this standard by reducing the effective useful life of a standard CFL bulb each year until 2020.

There is wide variation across states in the measure life values assumed for LED bulbs. While LED bulbs are known to be long-lasting from an engineering perspective, in many cases the lives of the bulbs are capped for one reason or another. For example, assumptions for omnidirectional LED bulbs vary from 20 years in Maryland to 8 years in Rhode Island. In Maryland lifetimes are capped at 20 years, in Vermont and DC they're capped at 15 years, and in Connecticut they are capped at 10 years through a negotiation to reflect Phase 3 of EISA legislation, expected to impact LEDs in 2025. Massachusetts makes a similar adjustment for Standard LEDs, discounting the lifetime to 10 years. The measure lives for decorative bulbs vary widely as well from 19 years in Massachusetts to 10 years in Connecticut. Massachusetts and Rhode Island's values are based on the expected useful life from ENERGY STAR. Maryland uses the expected useful life of 15,000 hours from ENERGY STAR and divides it by their value for hours of use (2.46) to get 16.7 years. DC and Vermont break the decorative LEDs into wattage bins and calculate the measure life using the weighted average of sales data obtained by Vermont Energy Investment Corporation (VEIC), who manages the TRMs for both Vermont and DC, and Connecticut caps the measure life to the lifetime of the fixture. Finally, the measure life for directional LEDs follows a similar pattern as it does for omnidirectional LEDs. Again, in Maryland lifetimes are capped at 20 years, in Vermont and DC they're capped at 15 years, and in Connecticut at 10 years to reflect the lifetime of the fixture.

Unlike the assumptions for the CFLs, all of the measure life values shown in TRMs reflect expectations about the life of the measure based on assumptions about the operation of the bulb or fixture. However, because federal lighting standards will go into effect in 2020, at which time the baseline for lighting will change, it is possible that program administrators are including legislatively-based measure life estimates for LEDs in the TRM, similar to their practice for CFLs, when reporting lifetime program savings for LEDs. Similar to gross savings algorithms, this may be a case of factors being taken into account at different times in the savings calculation process.

Net Savings Formulas

As with the formulas that calculate gross savings from residential lighting programs, another obvious place to look for similarities or differences in assumptions is to examine **net savings formulas**. These formulas take into account factors such as free-ridership and spillover. Table 10 shows the range of formulas used.

Table 10: Net Savings Formulas by State for Retail Residential Lighting Programs

	Algorithm	Information
CT	Net kWh = gross kWh x (1 – FR + SO) x ISR	
DC	Net kWh = ΔkWh x (1 - LLFi) x (1 - FR + SPL) x RPFi	ΔkWh = gross customer annual kWh savings for measure LLFi=line loss factor for period i RPFi= rating period factor for period i
MA	Net kWh = adj gross kWh x NTG adj gross kWh = gross kWh x RRE x SPF x ISR NTG = (1 – FR + SOP + SONP) or NTG is a single values with no distinction of FR, SOp, SOnp, and/or other factors that cannot be reliably isolated.	SPF= Savings Persistence factor SOP=participant spillover SONP=non participant spillover RRE=Realization Rate for electric energy (kWh)
MD	Net kWh = adj gross kWh x NTG	
NH	Net kWh = (WattΔ x HOURS x 365 / 1000) x ISR	NH net and gross algorithms are the same
NY	Net kWh = gross kWh x NTG	NY applies a 0.9 NTG ratio to all measures in TRM
RI	Net kWh = gross kWh × SPF × ISR x RRE × NTG	SPF= Savings Persistence factor RRE=Realization Rate for electric energy (kWh)
VT	Net kWh= ΔkWh x (1 - LLFi) x (1 – FR + SO) x RPFi	ΔkWh = gross customer annual kWh savings for measure LLFi=line loss factor for period i RPFi= rating period factor for period i

Massachusetts and Rhode Island include all of their gross savings adjustments (realization rate, savings persistence factor, and in-service rate) along with free-ridership, participant, and non-participant spillover. Connecticut includes the adjustment made for interactive effects as part of its gross savings calculation plus free-ridership, spillover, and an in-service rate. Notably, Connecticut is the only state studied that included the in-service rate adjustment as part of the net savings calculation.

Maryland's net savings calculation includes the adjustments in its gross savings calculation for interactive effects and in-service and it applies a net to gross ratio to get net savings values. Vermont and DC calculate net savings by including the adjustments made to their gross savings (in-service rate and interactive effects) and they also apply free-ridership and spillover. They also apply a line loss factor at this time to get their savings at the generator level, which is different than how any of the other states studied calculate net savings.

Net Savings Values

Most states use a Net-to-Gross Ratio (NTG), which is either given as a single ratio combining the behavioral parameters of free ridership and spillover by some states (in upstream program evaluations net effects of free ridership and spillover cannot necessarily be disaggregated) or calculated as 1-FR*SO as shown in the table of algorithms in the preceding table. The NTG ratio has the widest range of variation of any of the parameters associated with residential lighting impacts. This ratio, coupled with the differences in the core gross savings, is the other significant driver of variations in impacts across states.

Table 11: Net Savings Input Values by State for Retail Residential Lighting Programs

State	Measure Name	FR	SOP	SONP	NTG	LLF
CT	CFL Bulbs	19%	0%		81%	
	LED Bulbs	0%	0%		100%	
DC	Standard CFL	0%	0%		*92%**	8%**
	LED	0%	0%		*92%**	8%**
MA 2015 TRM	CFL screw-in Bulbs	57%	0%	0%	43%	
	LED Lamp	0%	0%	0%	100%	
MD	Efficient Lamps (LED and CFL)				66%	
NY	All measures				90%	
RI	CFL Screw-in Bulbs	7%	0%	0%	93%	
	Standard LED	10%	0%	0%	90%	
	EISA exempt LED	10%	0%	0%	90%	
VT	Residential Standard CFL	40%	0%		*48%**	12%**
	LED Lamp	6%	25%		*107%**	12%**

*Note NTG for DC and VT was not provided in TRMs, but was calculated using formulas and inputs from TRM. This value accounts for Line Loss Factors (LLF). **The Line Loss values presented are the average values from the TRM.

Table 11 shows the variables as well as the calculated NTG for 2015 TRMs, though these values change frequently. All Massachusetts program administrators base the NTG factors on the Massachusetts ENERGY STAR® Lighting Program: 2010 Annual Report. While the Mid-Atlantic TRM does not currently include net savings parameters, EmPOWER Maryland's recent impact evaluation study estimated net impacts. For Connecticut, the CFL free ridership is based on the 2010 Results of the Multistate CFL Modeling Effort evaluation from NMR.

The NTG for Vermont and DC were calculated as the NTG formula included line loss factor values that differ based on the time of year for a program. Vermont and DC are the only two states to include a line-loss factor explicitly in the TRM savings calculation; however NEEP suspects that all states factor in line-loss in the savings calculation at some points along the way.

Conclusions and Recommendations

Summary of Findings

Using the lens of REED and knowing that there is a 3.5 time spread in lifetime cost of saved energy for lighting, what does this closer look at comparing the key savings parameters across the states tell us?

1) While this brief demonstrates that many values go into development of program impacts, several of the parameters, specifically in-service rates and interactive effects, are relatively low contributors to overall variation, either because their range of variation is within 10-20% across states, they have relatively small value and thus do not significantly modify the core determinants of impacts, or both. To understand variations in cost of saved energy from lighting, delta watts, hours of use, net to gross ratios, and to some extent, measure life, are the core drivers.
2) Delta watts is an important parameter, but states are calculating and reporting that information in several different ways. Without providing more detailed information about specific distributions of the measure mix (baseline values and distribution of lumen bins within TRMs), detailed comparisons are very challenging to make.
3) Hours of use are based on very recent field studies across the region, and the variations seem to reflect assumptions about location of where measures are installed (i.e., high use areas), and also likely differences across the region in housing characteristics, daylight, etc.
4) Measure life is a topic that presents possible opportunity for increased consistency in approach; if some states are accounting for federal standards within the TRM, and others accounting for the same standards at a different point in the savings calculation, it is hard to understand if differences are real. Some states further model different EISA scenarios, making comparison of measure life challenging.
5) Net to gross ratios are a measure of customer behavior, and reflect the extent that free-ridership and spillover effect are estimated to determine savings that are attributable to a program. As such, NTG is closely tied to a state's history and experience with program delivery. The differences in NTG values suggest there may be opportunity for increased consistency or updating of evaluation activity in some states.

Based on our analysis of TRMs, we found that some differences in parameter values were clearly resulting from state-specific results and choices, and some have differences that are not as clear. Overall, most parameters in most states are well documented in TRMs, and most if not all of the studies referenced are less than five years, although in the case of NTG analysis for lighting, the market is changing so fast that studies are quickly out dated. There were several differences in classification of measures, and to some extent in evaluation methodology for HOU estimates, as provided in Appendix B. While these differences may seem semantic, they can make significant impacts on the savings a program can claim for the promotion of the same lightbulb, and ultimately impact that cost-effectiveness of a large program. As stated earlier, with lifetime cost of gross saved energy varying by 3.5 fold across states, some of the differences in practices and in parameter values have a major impact on overall program impacts. One significant difference in practice relates to the use of product-specific tracking system data or categories of products versus deemed values for the core impact of delta watts. When delta watts are calculated and tracked for every product, the state has the most granular understanding of the measure mix for the program. This has the important advantage of enabling program administrators to follow trends in the market for lighting products. However, without some understanding of the measure mix a program actually promotes, such as what proportion are 100W equivalent versus 40W equivalent, it is impossible to draw comparisons of calculated delta watts across states.

This brief helps illustrate the value of TRMs in providing transparency and clear documentation of the inputs that determine impacts. Several insights stem from the investigation of measure life in this study. One is that measure life can differ based on whether the measure is being considered from an engineering/operational perspective or from a legislative perspective (i.e., rated life vs effective useful life.) Both types of information about a measure are useful to program administrators, however, it would help if TRMs could be explicit about whether the values are being used for planning or to report impacts, or both. Also, measure life is the one value with perhaps the widest array of types of sources. This is largely driven by the uncertainty around EISA 2020, where efforts to undertake scenario/uncertainty analysis are appropriate, and coordination across states for these analysis would help to build greater consistency in EUL assumptions.

Glossaries produced by the Regional EM&V Forum and also by U.S. DOE (as part of the SEE Action Impact Evaluation Guide) have contributed to the effort of establishing a common understanding of key EM&V concepts and terms. However, as shown by this brief, a common understanding of the terms has not yet translated into common translation into operational definitions that are consistent across states. This is evident from the difference in variables included in the algorithms for gross and net savings.

Recommendations

We propose several specific recommendations as well as some overarching recommendations to help improve understanding of impacts as well as to provide insights to assist in use or interpretation of interstate comparisons.

Common Definitions:
There is an opportunity for increased consistency across states in the treatment of algorithms that operationally define gross, adjusted gross, and net savings. While we recognize that some policies, for example forward capacity market requirement for gross savings, may influence what program administrators do or do not include in estimates, at a minimum, increased transparency and documentation of all the parameter values included in the savings algorithms would go a long way in enabling analysts to construct the most meaningful comparisons. For example, there is the Uniform Methods Protocol[13] for residential lighting programs, which calls for the equation for gross savings that includes in-service rate and interactive effects. The purpose of protocols and common definitions is to improve consistency, but clearly further progress needs to be made. Even across protocols, there is a need for increased clarity and consistency in definitions. We recommend that programs document their inputs and equations and convene conversations to establish common understanding and usage of terminology.

TRMs:
Regular updates to TRMs and greater transparency in underlying EM&V methods that are driving various assumptions in the TRM is critically important to be able to track whether differences are justified or not. For

[13] See http://www.energy.gov/sites/prod/files/2015/02/f19/UMPChapter21-residential-lighting-evaluation-protocol.pdf

example, accountability of the value for the baseline used to calculate delta watts is very important as a delta watt value is a computed value from the baseline less the efficient wattage. While efficient wattages don't vary much, baselines certainly can, and thus produce widely different delta watt values for the same measure. We recommend that where possible, TRMs include information and documentation of baseline assumptions (either directly, or provided as a source document). This will facilitate future comparisons of gross impacts. We also recommend that TRMs include algorithms and parameters and source documentation for both net savings and gross savings parameters.

Gross Savings:
We recommend that Forum states use consistent definitions and formulas for calculating 'gross' and 'adjusted gross savings' for lighting, per the Forum's Glossary of Terms and Definitions, and algorithms provided. This would help to ensure consistency in reported data (e.g., in REED, and for regional energy efficiency forecasting purposes) and allow for improved comparability of results. .

Measure Life:
While variation in many of the other parameters can be explained and to a large extent justified by inherent differences between states and programs (HOU, measure mix that defines delta watts, free ridership, for example), LED measure life offers opportunity for increased consistency across states or programs. A meta-analysis or regional discussion could explore the potential for consistency focused on estimation method, sources, treatment of legislative factors, or consensus on deemed values. The EISA has been a driver toward consistency with CFLs.

Net Savings:
Net savings calculations also present an opportunity for increased consistency in algorithms. In the forthcoming Regional EM&V Forum *Net Savings Guidelines*, NEEP will be presenting information to assist in this effort.

Overall, we see opportunity for NEEP's Regional Energy Efficiency Database (REED) and Residential Lighting Initiative to help work with states, program administrators, and evaluators to ensure we have the best systems in place to understand the impacts of our programs in the Northeast and Mid-Atlantic.

Appendix A: List of Supporting Studies for TRM Values

State	Para-meter	Parameter Info	Measure	Supporting Study/Info
MD	ISR		CFL	EmPOWER Maryland Evaluation Year 5 (June 1, 2013 – May 31, 2014) Residential Lighting Program: Hours of Use/Metering Study
MD	ISR		CFL	New England Residential Lighting Markdown Impact Evaluation
MD	ISR		CFL	Impact Evaluation of the Massachusetts, Rhode Island, and Vermont 2003 Residential Lighting Programs
MD	ISR		LED	EMV Emerging Tech Research Report
DC	ISR		CFL	EmPOWER Maryland Evaluation Year 5 (June 1, 2013 – May 31, 2014) Residential Lighting Program: Hours of Use/Metering Study
DC	ISR		CFL	New England Residential Lighting Markdown Impact Evaluation
DC	ISR		CFL & LED	Impact Evaluation of the Massachusetts, Rhode Island, and Vermont 2003 Residential Lighting Programs
VT	ISR		CFL	Based on TAG 2011 agreement to use recommendation from NEEP RLS, 2011
VT	ISR		LED	SMARTLIGHT QA 2012.docx
MA	ISR		CFL	Baseline Sensitivity Analysis Spreadsheet, 2014 Report Version
MA	ISR		LED	N/A
CT	ISR		CFL & LED	Residential Lighting Study (Segments 2,3)
RI	ISR		CFL & LED	N/A
MD	HOU		CFL & LED	EmPOWER Maryland Evaluation Year 5 (June 1, 2013–May 31, 2014) Residential Lighting Program: Hours of Use/Metering Study
DC	HOU		CFL & LED	Northeast Residential Lighting Hours of Use Study
VT	HOU		CFL & LED	Northeast Residential Lighting Hours of Use Study
MA	HOU		CFL & LED	Northeast Residential Lighting Hours of Use Study, Massachusetts Residential Lighting Cross-Sector Sales Research
CT	HOU		CFL & LED	Northeast Residential Lighting Hours of Use Study
RI	HOU		CFL & LED	Residential Lighting Markdown Impact Evaluation
NH	HOU		CFL & LED	NH CORE Residential ENERGY STAR® Lighting Program Impact and Process Final Evaluation Report (DNV KEMA - June 2012)
NY	HOU		CFL and LED	Extended residential logging results by Tom Ledyard, RLW Analytics Inc. and Lynn Hoefgen, Nexus Market Research Inc., May 2, 2005, p.1. Conducted during 2003 in Massachusetts, Rhode Island, and Vermont.
MD	Interactive Effects	Cooling Savings	CFL	The value is estimated at 1.09 (calculated as 1 + (0.78*(0.33 / 2.8)). Based on assumption that 78% of homes have central cooling (based on BGE Residential Energy Use Survey, Report of Findings, December 2005; Mathew Greenwald & Associates).

State	Para-meter	Parameter Info	Measure	Supporting Study/Info
MD	Interactive Effects	Heating Penalty	CFL	[16] Calculated using defaults; 1-((0.47/1.67) * 0.375) = 0.894 [17] This means that heating loads increase by 47% of the lighting savings. This is based on the average result from REMRate modeling of several different building configurations in Wilmington, DE, Baltimore, MD and DC. [18] These default system efficiencies are based on the applicable minimum Federal Standards. In 2006 and 2015 the Federal Standard for Heat Pumps was adjusted. While one would expect the average system efficiency to be higher than this minimum, the likely degradation of efficiencies over time mean that using the minimum standard is appropriate. [19] Calculation assumes 59% Heat Pump and 41% Resistance which is based upon data from Energy Information Administration, 2009 Residential Energy Consumption Survey. Average efficiency of heat pump is based on assumption 50% are units from before 2006 and 50% after. [20] Based on KEMA baseline study for Maryland.
MD	Interactive Effects	Cooling Savings	LED	The value is estimated at 1.09 (calculated as 1 + (0.78*(0.33 / 2.8)). Based on assumption that 78% of homes have central cooling (based on BGE Residential Energy Use Survey, Report of Findings, December 2005; Mathew Greenwald & Associates).
MD	Interactive Effects	Heating Penalty	LED	[163] Calculated using defaults; 1+ ((0.47/1.67) * 0.375) = 0.894 [164] This means that heating loads increase by 47% of the lighting savings. This is based on the average result from REMRate modeling of several different building configurations in Wilmington, DE, Baltimore, MD and DC. [165] These default system efficiencies are based on the applicable minimum Federal Standards. In 2006 the Federal Standard for Heat Pumps was adjusted. While one would expect the average system efficiency to be higher than this minimum, the likely degradation of efficiencies over time mean that using the minimum standard is appropriate. [166] Calculation assumes 59% Heat Pump and 41% Resistance which is based upon data from Energy Information Administration, 2009 Residential Energy Consumption Survey. Average efficiency of heat pump is based on assumption 50% are units from before 2006 and 50% after. [167] Based on KEMA baseline study for Maryland.
DC	Interactive Effects	Cooling Savings	CFL	The value is estimated at 1.122 (calculated as 1 + (0.68*(0.45) / 2.5)). Based on 0.45 ASHRAE Lighting waste heat cooling factor for Washington DC (http://lighting.bki.com/pubs/b6_tab1.htm) and assuming typical cooling system operating efficiency of 2.5 COP (accounting for distribution losses, inadequate airflow etc.) Assuming 68% of homes have central cooling, based on 2009 EIA data for DC.

State	Para-meter	Parameter Info	Measure	Supporting Study/Info
DC	Interactive Effects	Heating Penalty	CFL	Calculated based on data from different source. Footnotes: [22] This means that heating loads increase by 50% of the lighting savings. This is based on the average result from REMRate modeling of several different configurations of homes in DC. [23] Based on data from United States Census Bureau Historical Data of House Heating Fuel Tables: http://www.census.gov/hhes/www/housing/census/historic/fuels.html [24] These default system efficiencies are based on the applicable minimum Federal Standards. In 2006 the Federal Standard for Heat Pumps was adjusted. While one would expect the average system efficiency to be higher than this minimum, the likely degradation of efficiencies over time mean that using the minimum standard is appropriate. [25] Calculation assumes 59% Heat Pump and 41% Resistance which is based upon data from Energy Information Administration, 2009 Residential Energy Consumption Survey: see HC6.10 Space Heating in South Region.xls. Average efficiency assumption assumes 50% HP before 2006 and 50% after."
DC	Interactive Effects	Cooling Savings	LED	The value is estimated at 1.09 (calculated as 1 + (0.78*(0.31 / 2.8)). Based on assumption that 78% of homes have central cooling (based on BGE Residential Energy Use Survey, Report of Findings, December 2005; Mathew Greenwald & Associates).
DC	Interactive Effects	Heating Penalty	LED	Calculated using defaults; 1- ((0.50/1.67) * 0.24) = 0.928 [89] This means that heating loads increase by 50% of the lighting savings. This is based on the average result from REMRate modeling of several different configurations of homes in DC. [90] These default system efficiencies are based on the applicable minimum Federal Standards. In 2006 the Federal Standard for Heat Pumps was adjusted. While one would expect the average system efficiency to be higher than this minimum, the likely degradation of efficiencies over time mean that using the minimum standard is appropriate.
VT	Interactive Effects	Cooling Savings	CFL & LED	No report referenced
VT	Interactive Effects	Cooling Savings	LED	No report referenced
MA	Interactive Effects	None	CFL / LED	
CT	Interactive Effects		CFL & LED	CT Residential Lighting interactive effect
RI	Interactive Effects	None	CFL & LED	
MD	Delta Watt	Base Wattage	CFL	Base wattage is based upon the post first phase of EISA wattage and wattage bins consistent with ENERGY STAR, v1.1
MD	Delta Watt	Watt Ratio	CFL	EmPOWER Maryland Evaluation Year 5 (June 1, 2013 – May 31, 2014) Residential Lighting Program: Delta Watts Multiplier
MD	Delta Watt	Base Wattage	LED	Average wattage of replacement incandescent bulb was 61.2W. LED wattage from delta watts table. RLW Analytics, New England Residential Lighting Markdown Impact Evaluation, January 20, 2009.
MD	Delta Watt	Watt Ratio	LED	EmPOWER Maryland Evaluation Year 5 (June 1, 2013 – May 31, 2014)

State	Para-meter	Parameter Info	Measure	Supporting Study/Info
				Residential Lighting Program: Delta Watts Multiplier
DC	Delta Watt	Base Wattage	CFL	Residential Lighting Strategy Report
DC	Delta Watt	Delta Watt	CFL	DC SEU CFL Wattage Analysis.xlsx
DC	Delta Watt	Base Wattage	LED	The baseline wattage used for each individual product is determined using the "DW Mapping" Tab. The source of the assumptions is provided in column E. This is based on review of a year's worth of LED sales data for Efficiency Vermont from a cross section of product brands and geography.
DC	Delta Watt	Delta Watt	LED	2013 EVT LED Sales Review.xls
VT	Delta Watt	Delta Watt	CFL	Based on TAG 2011 agreement to use recommendation from NEEP RLS, 2011. See 'CFL TAG 2011.xls' for more details.
VT	Delta Watt	Delta Watt	LED	See 2015 LED TRM Update.xlsx for details on how the baseline was determined based on a year's worth of LED sales data from a cross section of product brands and Vermont geography.
MA	Delta Watt	Delta Watt	CFL & LED	Baseline Sensitivity Analysis Spreadsheet, 2014 Report Version.
CT	Delta Watt	Watt Ratio	CFL	The Watt ratio is modified to reflect the (to be implemented 2012 through 2014) 2007 EISA federal standards (Ref [4]) which will require new General Service incandescent bulbs to have about 75% lower wattage. Non-General Service bulbs continue to use the established Watt ratio, while all General Service bulbs use 75% of this established Watt ratio. The EISA federal standard requires incandescent bulbs to use 75% of the wattage of standard General Service incandescent bulbs. 4/3 is the Watt ratio reflecting this.
CT	Delta Watt	Watt Ratio	LED	Northeast Residential Lighting Hours of Use Study
RI	Delta Watt	Delta Watt	CFL	Estimated using the demand allocation methodology described in: Cadmus Demand Impact Model (2012), Prepared for the Massachusetts Program Administrators.
RI	Delta Watt	Delta Watt	LED	Estimated using the demand allocation methodology described in: Cadmus Demand Impact Model (2012), Prepared for the Massachusetts Program Administrators.
NH	Delta Watt	Delta Watt	CFL	Use baseline wattage of 58.98 and efficient wattage of 19.28, based on blended halogen/incandescent baseline
NH	Delta Watt	Delta Watt	LED	Use baseline wattage of 44.5 and efficient wattage of 10.79, based on blended halogen, incandescent, and CFL baseline
MD	EUL	Standard CFL Bulb (accounting for EISA standard)	CFL	Calculated starting with an average observed life (5.2 years) of compact fluorescent bulbs with rated life of 8000 hours (8000 hours is the average rated life of ENERGY STAR bulbs. See http://www.energystar.gov/index.cfm?c=cfls.pr_crit_cfls. Observed life is based on Jump et al "Welcome to the Dark Side: The Effect of Switching on CFL Measure Life" and is due to increased on/off switching. The 5.2 years is adjusted upwards due to the assumption that 57% of the 9% not installed in the first year eventually replace CFLs (based on 32 out of 56 respondents purchased as spares; Nexus Market Research, RLW Analytics, October 2004; "Impact Evaluation of the Massachusetts, Rhode Island, and Vermont 2003 Residential Lighting Programs", table 6-4). Measure life is therefore calculated as (5.2 + (((0.57 * 0.09)/0.92) *5.2) = 5.5 years. Note, a provision in the Energy Independence and Security Act of 2007 requires that by January 1, 2020, all lamps meet efficiency criteria of at least 45 lumens per watt, in essence making the CFL baseline. Therefore after 2014 the measure

State	Para-meter	Parameter Info	Measure	Supporting Study/Info
				life will have to be reduced each year to account for the number of years remaining to 2020.
MD	EUL	Standard	LED	The ENERGY STAR Spec for Integrated Screw Based SSL bulbs requires lamps to maintain >=70% initial light output for 25,000 hrs in a residential application for omnidirectional and directional bulbs, and 15,000 hrs for decorative bulbs. Lifetime capped at 20 years. (Rated Life/HOU)
MD	EUL	Decorative LED Bulb	LED	The ENERGY STAR Spec for Integrated Screw Based SSL bulbs requires lamps to maintain >=70% initial light output for 25,000 hrs in a residential application for omnidirectional and directional bulbs, and 15,000 hrs for decorative bulbs. Lifetime capped at 20 years. (Rated Life/HOU)
MD	EUL	Directional LED Bulb	LED	The ENERGY STAR Spec for Integrated Screw Based SSL bulbs requires lamps to maintain >=70% initial light output for 25,000 hrs in a residential application for omnidirectional and directional bulbs, and 15,000 hrs for decorative bulbs. Lifetime capped at 20 years. (Rated Life/HOU)
DC	EUL	Standard CFL Bulb (accounting for EISA standard)	CFL	A provision in the Energy Independence and Security Act of 2007 requires that by January 1, 2020, all lamps meet efficiency criteria of at least 45 lumens per watt, making the baseline equivalent to a present day CFL. The residential measure life will be reduced in 2015 to 5 years and in 2016 to 4 year etc. to account for the number of years remaining to 2020.
DC	EUL		LED	A year's worth of LED sales data was reviewed and the rated life averaged (see 2013 EVT LED Sales Review.xls). 105 All lifetimes are capped at 15 years.
VT	EUL	Standard CFL Bulb (accounting for EISA standard)	CFL	Lifetime is a function of the average hours of use for the lamp. Most CFL's have a rated lifetime of 10,000 hours. However, units that are turned on and off more frequently have shorter lives and those that stay on for longer periods of time have longer lives. Also note: a provision in the Energy Independence and Security Act of 2007 requires that by January 1, 2020, all lamps meet efficiency criteria of at least 45 lumens per watt, in essence making the CFL baseline. Therefore the analysis period (i.e. the life of the savings) for any measure that lasts beyond 2020 will be reduced to the number of years remaining to 2020.
VT	EUL		LED	Lifetime is a function of the average hours of use of the luminaire. All rated life assumptions, except where noted, are based on a weighted average of the January to November 2014 Efficiency Vermont sales data. See '2015 LED Sales Review.xls'. Note all lifetimes are capped at 15 years (although their rated life/hours is higher.
MA	EUL	Standard CFL Bulb (accounting for EISA standard)	CFL	The calculated measure life for screw-in bulbs is 8, based on a component life of 8,000 and hours of use of 1,058.5. 19 MA PAs (2015). 2013-15 MA Lighting Worksheet
MA	EUL		LED	MA PAs (2015). 2013-15 MA Lighting Worksheet
CT	EUL	Standard CFL Bulb (accounting for EISA standard)	CFL	Based on Ref [d], Ref [b], and Ref [e]. References [d] and [b] present a CFL switching degradation factor (SDF) of 0.523 to calculate Effective Useful Life (EUL): EUL = Rated lifetime hours * SDF / (annual hours). Based on 2.8 hr/day from NMR 2009. [2] General Service CFLs have been capped at 4 years to reflect measure persistence
CT	EUL		LED	LED Bulbs are rated at 25,000 hour life, but have been capped here to the fixture lifetime.

State	Para-meter	Parameter Info	Measure	Supporting Study/Info
RI	EUL	Standard CFL Bulb (accounting for EISA standard)	CFL	MA Residential Lighting Worksheet 2016
RI	EUL		LED	MA Residential Lighting Worksheet 2016
NH	EUL		CFL & LED	Use mathematic calculation based on ENERGY STAR rated life and program HOU, capped at 20 years
NY	EUL		CFL	GDS Associates
MD	Net Savings		CFL & LED	NTG Research EY4
DC	Net Savings		CFL & LED	N/A
VT	Net Savings		CFL & LED	N/A
MA	Net Savings		CFL & LED	Massachusetts ENERGY STAR® Lighting Program: 2010 Annual Report
CT	Net Savings	Free ridership	CFL	2010 Results of the Multistate CFL Modeling Effort
CT	Net Savings		LED	N/A
RI	Net Savings		CFL & LED	EnergyWise 2008 Program Evaluation
NY	Net Savings		All	All values in entire TRM are given .9 NTG for program estimation purposes.

Appendix B: Comparison of Evaluation Methodologies and Results for Hours of Use Studies

Our review of hours of use (HOU) assumptions used to calculate residential lighting savings varied by 95 percent. To examine differences between the high and low HOU values for residential lighting programs, NEEP compared the EM&V methods supporting those HOU values using the NEEP EM&V Methods summary forms. As NEEP reviewed specific studies that informed evaluation assumptions, we looked at key information from the three cited HOU studies, and completed the digital EM&V Methods Reporting Forms[14], using the study level form.

The EM&V Method Reporting Forms were developed with input from evaluation experts, program administrators, state energy, environmental regulatory staff, state energy offices, and ISO/RTO, and were adopted by the EM&V Forum Steering Committee in July 2014. NEEP has piloting these forms in MA, and will be further testing them with other states in early 2016 before making modifications to the forms based on the pilot results. As such, the completed forms for the purposes of this Residential Lighting brief are to provide an example of the usefulness of this standardized reporting tools using Version 1.0 of the forms, and how the forms can allow for comparison of methods for similar types of studies. The ultimate vision for this effort is to develop a database where completed evaluation study forms can be stored and queried by users to readily download study results and compare across states. This tool can help to improve consistency in savings assumptions and evaluation methods across the region, where appropriate.

NEEP compared the EM&V methods used in the following impact evaluations:

- The 2014 NEEP Regional HOU study (the Regional study) which produced the 3.9 HOU value (highest in the region);
- The 2015 EmPower Maryland EY5 study (the MD study) which produced the 2.5 HOU value; and
- The 2012 New Hampshire CORE Residential ENERGY STAR® Lighting Program Impact Evaluation (the NH study) which produced the 1.97 HOU value (lowest in the region).

Comparison of the **General Information** shows the Regional study was more comprehensive than the statewide MD study and the statewide NH study. While the MD study focused on the Residential upstream lighting program for program administrators in MD only and the NH study focused on the statewide lighting program for NH utilities only, the Regional study included four states (MA, RI, CT, and NY), included low-income and multifamily in-unit measures, included retrofit installations in addition to lost-opportunity, and included rebate and direct install programs in addition to upstream.

Comparison of the **Study Summary and Results** sections confirms the differences in HOU results. The NH study shows an average HOU of 1.97 hours/day (719.4 hours/year) and the MD study showed an average HOU of 2.46 hours/day. These values are both lower than the 2.71 average HOU from the Regional study. The regional highest HOU result of 3.9 hours per day is based on loggers in the downstate NY area where buildings are

[14] The EM&V Reporting Forms, including a Program level form and Study level form can be viewed at Digital EM&V Methods Reporting Forms.

typically more densely packed and, therefore, have less access to daylight. The NH study indicates the low HOU value may be due to lighting products in less-used sockets due to saturation of CFLs in the market.

Comparison of the **EM&V Methods** for Gross Savings shows both studies use similar methods to estimate HOU values, including visual (on-site) verification inspection to verify lighting installation (III.3) and measurement of lighting HOU (III.4) for a sample of program participants. The NH study included 306 loggers at 75 participant homes; the MD study included measurement at 878 loggers at 111 participant homes;[15] and the Regional study obtained data for 5,494 loggers at 848 homes across four states (III.2).

The measurement periods are as follows:

- NH study – 2 to 4 weeks in August (summer)
- MD study – 7 months from March/April 2014 to September/October 2014
- Regional study – up to 10 months between November 2012 and September 2013

The Uniform Methods Project protocol for estimating HOU for residential lighting measures states:

> *"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... All data should be annualizing techniques such as sinusoidal modeling to reflect a full year of usage."*

Both the MD and the Regional study meet the logger duration requirements; the NH study falls short of the minimum logger duration with only 2 to 4 weeks of data collection. However, all three studies did annualize their estimates of annual average HOU values.

Our review of the EM&V methods indicate the three studies follow similar methods to estimate annual HOU for residential lighting measures, but differ in sample sizes and meter duration. While possible these differences influence the different HOU results, other factors—such as difference in programs and population—may also influence the different results.

Readers can review the completed NEEP EM&V Summary Forms at NEEP EM&V Methods Reporting Forms - Residential Lighting. To access the forms:

- Go to **http://191.237.21.11/fmi/webd#NEEP_ResLightingEvaluations** [16]
- Enter the username "PUBLIC" with no password to review the completed forms
- On the Home Page, click "Go to Eval record" beneath the **Impact Evaluation Study**
- Enter the appropriate record number for the study of interest:
    - 1 for the Regional (NMR) HOU Study
    - 2 for the EmPower MD HOU study
    - 3 for the NH HOU study

For questions regarding use or interpretation of the forms, please contact EMVmethodsforms@neep.org.

[15] MD samples sizes are based on final use of data (not including missing loggers or screened logger data).
[16] If you have any trouble with this link, either try to cut and paste it into your browser, or try **https** (instead of http) for the URL.