MEMORANDUM

To: Scott Dimetrosky, EEB Evaluation Consultant

From: Matt Rusteika, Zack Tyler, & Tom Mauldin, NMR Group

Date: December 20, 2014

Re: R67: Residential Lighting Interactive Effects Memo

This memo details the findings of the Lighting Interactive Effects analysis which NMR Group, Inc. conducted for the Connecticut Energy Efficiency Board (EEB). The findings contained herein are applicable for lighting-based measures whose savings estimates are based on deemed or engineering-based methods. They are not applicable to lighting measures whose savings are based on a billing analysis or simulation modelling that accounts for lighting retrofits since these analysis results inherently account for interactive effects.[1]

1 Summary of Results

Compact fluorescent light bulbs (CFLs) and light-emitting diodes (LEDs) emit substantially less heat than incandescent bulbs because they convert a much larger percentage of the energy used into light. For this reason, replacing incandescent bulbs with more efficient bulbs results in a small but real impact on the amount of energy consumed by heating, ventilation, and air-conditioning (HVAC) systems. This is referred to as *interactive effects* (IE). Failure to take these interactive effects into account can lead to inaccurate estimation of savings from lighting retrofits.

NMR conducted four separate analyses as part of this study to measure interactive effects in Connecticut residential units. Table 1 summarizes the results of each IE factor analysis. Precision estimates describe variation among the IE factors only; sampling error is detailed in Table 16.

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[1] Lighting interactive effects reported here may be used to help calibrate heating and cooling-based measures from whole home retrofit programs.

Table 1: Interactive Effects Factors Summary

Factor	*Number of Sites*	Average IE Factor	Precision at the 90% Confidence Level	
			Number	Percent
Electric energy IE factor[a]	*180*	1.04	± 0.013	± 1%
Electric demand IE factor[a]	*180*	1.05	± 0.003	± <1%
Heating fuel IE factor[b,c]	*180*	1,902	± 38	± 2%
Gas takeback factor[b,d]	*48*	0.56	± 0.024	± 4%

[a] Proportionally weighted to reflect statewide saturation percentage of ducted central air conditioning systems—see Section A.2.

[b] Weighted with heating fuel proportional weight—see Section A.2.

[c] In BTU/kWh.

[d] Includes only sites that heat primarily with natural gas.

Each analysis calculates a different factor with which lighting retrofit savings can be adjusted to account for the changes in heating and cooling usage that result from the installation of efficient lighting. REM/Rate™[2] energy models initially developed for the Connecticut Weatherization Baseline Assessment[3] were used to simulate these interactive effects.

The electric energy analysis results in an average electric IE factor of 1.04. This means that an efficient lighting retrofit in the average Connecticut home will result in 104% of the electric energy savings attributable to the efficient bulbs alone due to interactive effects.

Concurrently, the same retrofit will result in a heating IE factor of 1,902 BTU/kWh. This means that for every kWh saved in lighting, 1,902 BTU in additional annual heating usage will result, on average. This translates to about 0.07 MMBtu annually per bulb, or 1.8 MMBtu annually from a 25-bulb retrofit (the maximum number of efficient bulbs installed through the Home Energy Solutions (HES) program). The heating IE factor applies only to homes that heat with a fuel other than electricity, because heating system interactive effects for electric-heated homes are captured in the electric IE factors.

The analysis also results in a gas takeback factor of 0.56. This means that for the average gas-heated home in Connecticut, 56% of the energy saved by installing more efficient bulbs is negated by the increase in gas heating requirements. The gas takeback factor is essentially the same as the heating IE factor, except that it is unitless and applies only to gas homes. Because it equates electricity and gas, it is best viewed as a way to contextualize interactive effects rather than measure them. It is included in this study because it is a common method of describing interactive effects for gas-heated homes.

2 Introduction

About ninety percent of the energy consumed by incandescent light bulbs is given off as heat. More efficient CFLs and light emitting diodes (LEDs) emit substantially less heat because they convert a much larger percentage of the energy they use into light. For this reason, replacing incandescent bulbs with

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[2] REM/Rate is a residential energy analysis software that is commonly used to model the performance of residential buildings—the software is most notably used by the ENERGY STAR® Homes program.

[3] NMR Group, Inc. "Single-Family Weatherization Baseline Assessment" *Submitted to the Connecticut Energy Efficiency Fund, Connecticut Light & Power, and the United Illuminating Company*, May 30, 2014.

more efficient CFLs or LEDs results in a small but real impact on the amount of energy consumed by HVAC systems. This is referred to as *interactive effects*. Failure to take these effects into account can lead to inaccurate estimation of savings from lighting retrofits.

NMR used the REM/Rate models that were developed for the Connecticut Weatherization Baseline Assessment to calculate lighting IE factors for homes in Connecticut. Four types of interactive effects factor were assessed.

An **electric energy IE factor** greater than 1.0 indicates that there are additional electric savings due to the lighting retrofit beyond the savings at the lighting end use, while a factor less than 1.0 indicates that interactive effects lead to a decrease in the expected savings from the lighting retrofit. Program electric savings are multiplied by this factor to adjust for the electric energy interactive effects of lighting retrofits. The **electric demand IE factor** is interpreted in the same way.

The **heating fuel IE factor** is expressed in BTU (or heating fuel units such as gallons of oil) per kWh of lighting savings. A positive value indicates an increase in fuel use for heating. This equation is not fuel-specific, and therefore it can be used to determine heating fuel IE factors for all non-electric fuels.

Finally, the **gas takeback factor** is commonly used to adjust lighting savings in gas homes specifically. Like the electric IE factor, it is unitless—kWh in lighting savings are converted to ccf[4] of natural gas. The gas takeback factor represents the proportion of lighting savings that are negated due to increased gas consumption. For example, a factor of 0.5 would indicate that 50% of lighting energy savings at a given home, or due to a given program, are negated by the increase in heating requirements.

Examples of how to adjust savings to account for interactive effects using these factors can be found in Appendix B.

2.1 Scope of Work

NMR developed IE factors for use in program savings calculations by:

- Developing a REM/Rate model for each of the 180 sites in the sample that is identical to the as-built model except for a 25-bulb efficient lighting upgrade;
- Calculating IE factors based on primary heating fuel and cooling configuration;
- Calculating statewide electric and heating fuel IE factors.

2.1.1 Sampling and Weighting

The same 180 single-family homes which NMR audited for the Weatherization Baseline Assessment were used to model interactive effects for the Lighting Interactive Effects study. The Baseline Assessment focused exclusively on single-family homes, both detached (stand-alone homes) and attached (side-by-side duplexes and townhouses that have a wall dividing them from attic to basement and that pay utilities separately). However, because the analysis showed that cooling configuration—specifically, whether or not a central cooling system is present—is the main determinant of interactive

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[4] Ccf refers to hundred cubic feet of natural gas.

effects, as opposed to the level of air infiltration or size of the home, NMR considers it likely that the factors are applicable to multifamily units as well.

In order to account for the fact that multifamily units are less likely to have central air conditioning than single-family homes, a weight based on American Housing Survey data was applied; more details regarding the weighting schemes used for this study and the sampling plan for the Weatherization Baseline can be found in Appendix A.

2.1.2 Analysis of REM/Rate Data

NMR incorporated lighting data which was gathered for the 2012 Connecticut Efficient Lighting Saturation and Market Assessment[5] (hereafter, the Saturation Study) into each of the 180 REM/Rate models.[6] Each model was assigned a number of bulbs consistent with the home's size, and the bulbs were divided between inefficient and efficient[7] types. The hours-of-use input was also derived from Saturation Study findings. Two models were developed for each of the 180 sites: a baseline or "as-is" model, and an upgrade model.

In order to create the upgrade models, the baseline models were altered by changing the wattages of a maximum of 25[8] of the inefficient bulbs to the average wattage of CFLs found in the Saturation Study—This is consistent with Home Energy Solutions (HES) program guidelines, which limit the number of efficient bulbs installed at any given home to 25.[9] The wattages were the only inputs that were changed in the upgrade models relative to the baseline models.

Table 2 describes other model inputs and compares them to findings from the recent Northeastern Lighting Hours-of-Use (HOU) study.[10] The daily hours-of-use estimate provided by the Saturation Study—which the REM/Rate models utilized—is similar to findings from the HOU study (and actually sits exactly between the HOU study estimate for all bulbs of 2.7 hours/day and efficient bulbs of 2.9 hours/day). A larger number of sockets per home was modeled for this study than was found in the HOU study; however, because IE factors are calculated as ratios, the number of sockets does not directly affect the estimated IE factors.

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[5] NMR Group, Inc. "Connecticut Efficient Lighting Saturation and Market Assessment." *Submitted to the Connecticut Energy Efficiency Fund, Connecticut Light & Power, and the United Illuminating Company*, October 2, 2012.

[6] As part of the Weatherization Baseline Study data collection efforts, information was collected on light fixtures but not on light bulbs. For this reason, results from the Efficient Lighting Saturation and Market Assessment were leveraged to estimate the baseline saturation of energy efficient light bulbs.

[7] Efficient bulb types used in calculating the baseline or "as-is" average efficient wattages included CFLs, LEDs, and efficient halogens. The inefficient bulb entries included incandescents only.

[8] For smaller homes, i.e. those less than 1,400 s.f., the number of upgraded bulbs was 22. For all others, 25 upgraded bulbs were modeled.

[9] The limit on the number of efficient bulbs that can be installed during an HES retrofit has fluctuated in the past, and may again in the future. The 25-bulb figure is current as of the date of this memo.

[10] NMR Group, Inc. "Northeast Residential Lighting Hours-of-Use Study." Submitted to Connecticut, Massachusetts, Rhode Island, and New York sponsors, May 5, 2014.

Table 2: Model Input Comparison

Input	Lighting IE Study	Northeast HOU Study
Total number of sockets per home	78	57
Hours-of-use per day (indoor)	2.8	2.9

Saturation Study data was used to model bulbs rather than data from more recent studies, such as the HOU study, because the data from that study included substantially more households; in addition, the other studies collected less of the information relevant to this study during more abbreviated on-site visits. The HVAC impacts per bulb are the same regardless of how many bulbs are upgraded in the models, and therefore the IE factors are the same irrespective of number of sockets.

2.1.3 Peak Demand and Coincidence Factors

In order to assess peak demand savings, NMR used REM/Rate demand estimates as a starting point. After reaching out to Architectural Energy Corporation (AEC), the developers of REM/Rate, NMR determined that REM/Rate assumes coincidence factors when assessing peak demand. NMR removed these pre-existing coincidence factors and applied Connecticut-specific coincidence factors to provide a more accurate estimate of the peak demand impacts.

Table 3 displays the coincidence factors applied in this study. The heating and cooling coincidence factors are from the 2013 Connecticut Program Savings Documentation.[11] The factors for lighting are taken from a recent Northeast Residential Lighting Hours-of-Use Study conducted by NMR and DNV GL.[12]

Table 3: Peak Coincidence Factors[13]

End Use	Summer	Winter
Heating	0.00	0.50
Cooling	0.59	0.00
Lighting	0.13	0.20

Accounting for EISA

The Energy Independence and Security Act of 2007 (EISA) mandated that efficiency standards for light bulbs increase in stages starting in 2012. As a result, the baseline bulb against which lighting program savings are measured has become more efficient, causing savings to diminish. The Connecticut Program Savings Document (PSD) uses a system of “watt ratios” in its savings equations in order to adjust for the EISA change in standards. These ratios ensure that the program does not credit itself with savings that are attributable to the law.

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[11] http://www.ctenergyinfo.com/2013%20Program%20Savings%20Documentation%20-%20Final.pdf

[12] NMR Group, Inc. & DNV GL. “Northeast Residential Lighting Hours-of-Use Study.” *Submitted to Connecticut Energy Efficiency Board* on March 14, 2014. Page XVII.

[13] The REM/Rate data export provides demand information in kW to six significant digits.

The interactive effects factors in this memo were developed using baseline bulb wattages which are greater than the maximum of 43 watts that a 60-watt equivalent bulb is required to use under EISA (Table 4).

Table 4: Model Interior Bulb Wattages

Floor Area Group	Baseline	Upgrade
< 1,400 square feet	52.9	16.1
1,400 to < 2,000 square feet	51.3	15.2
2,000+ square feet	55.6	16.5

While the use of these baselines potentially overstates energy and demand savings at the lighting end use, EISA changes in standards have no impact on interactive effects. This is because for every decrease in savings at the lighting end use, there is a directly proportional decrease in whole-house savings, and as a result the factors remain identical regardless of how lighting savings fluctuate. The single most influential determinant of interactive effects is HVAC configuration—in particular, whether or not a ducted central cooling system is present—not lighting wattages.

The interactive effects factors that this study provides are to be applied to the program's lighting savings after they are adjusted using the watt ratios in the PSD.

3 Interactive Effects Factors

This section describes the four types of IE factor. Examples of how to adjust savings to account for interactive effects using these factors can be found in Appendix B.

3.1 Electric Energy Interactive Effects

The electric IE factor is a unitless multiplier used to adjust electric savings from lighting retrofits to account for changes in space conditioning requirements.

- For homes with no electric heating or cooling equipment, the electric IE factor will be equal to 1.0, indicating that lighting savings require no adjustment.
- For homes with electric heating equipment, the factor is usually less than one—because Connecticut is in a heating-dominated climate, electric savings for cooling are generally less than the increased electric usage for heating associated with the lighting retrofit.
- For homes with electric cooling equipment but non-electric heating equipment, the factor will generally be greater than 1.0, indicating that the electric savings resulting from the lighting retrofit will be greater than the savings achieved at the lighting end use alone.

The electric IE factor is calculated in the following manner:

$$Electric\ IE\ Factor = \frac{Whole\ Building\ Annual\ Electric\ Energy\ Savings}{Lighting\ Annual\ Electric\ Energy\ Savings}$$

Table 5 describes the results of the electric IE factor analysis. Overall, the statewide electric IE factor is 1.04, meaning that CFL retrofits will actually result in 104% of the electric energy savings achieved at the lighting end use alone.

Table 5: Electric Energy IE Factors by Cooling Configuration[a]

Cooling configuration	***Number of Homes***	**Avg**	**Min**	**Max**
Overall	*180*	*1.04*	*0.61*	*1.19*
Central air conditioner	*77*	1.10	0.71	1.19
Room air conditioner(s)	*68*	1.04	0.61	1.14
Heat pump	*13*	0.96	0.63	1.12
No cooling	*22*	0.99	0.91	1.00

[a] Proportionally weighted to reflect statewide saturation percentage of ducted central air conditioning systems—see Section A.2.

Table 6 presents electric IE factors by cooling configuration and heating fuel type. When electric heating equipment is absent or is not the primary heating mechanism in the home, the average electric IE factor is greater—about 1.07 vs. 0.73 for electrically-heated homes. Sites heated primarily with something other than electricity comprise 166 (92%) of 180 sites in the sample.

The electric energy IE factor is 1.0 among homes that heat with fossil fuels or biomass[14] and have no cooling equipment, indicating that the electric savings due to lighting retrofits in these homes require no adjustment.

Table 6: Average Electric Energy IE Factors by Cooling Configuration & Heating Fuel[a]

Cooling configuration	**Overall**	**Primary Heating Fuel**		
		Oil, LP, or Biomass	**Natural Gas**	**Electric**
Overall	*1.04*	*1.07*	*1.08*	*0.73*
Central air conditioner	1.10	1.10	1.11	0.71
Room air conditioner(s)	1.04	1.08	1.09	0.69
Heat pump	0.96	1.06	1.10	0.82
No cooling	0.99	0.99	1.00	-
Number of homes	*180*	*118*	*48*	*14*

[a] Proportionally weighted to reflect statewide saturation percentage of ducted central air conditioning systems—see Section A.2.

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[14] "Biomass" refers to wood pellets or cord wood. Five sites in the sample (3%) heat primarily with one of these fuels.

3.1.1 Electric Energy Impact Per Bulb

Table 7 displays the additional electric savings due to interactive effects in annual kWh per upgraded bulb. The analysis shows that each efficient bulb replacing an incandescent bulb will result in 1.72 kWh/year in electric energy savings over and above the savings attributable to the new bulb itself. For homes with no electric heating equipment, those savings are greater—in these homes, lighting retrofits will result in extra savings of about 3 kWh/year per upgraded bulb.

In homes without electric heating equipment, interactive effects lead to each bulb realizing 108% of the electric savings attributable to the bulb by itself. In homes that primarily use electric heating equipment, however, interactive effects result in a bulb that only realizes 93% of its expected savings. Statewide, the analysis showed that each bulb upgrade results in savings of 104% of the savings attributable to the bulb itself due to interactive effects.

Table 7: Average HVAC Electric Energy Savings Per Upgraded Bulb[a]

Cooling configuration	***Number of Homes***	**Annual Extra Electric Savings in kWh/bulb**		
		Overall	**No Electric Heating**	**Has Electric Heating**
Overall	*180*	*1.72*	*3.02*	*- 2.71*
Central air conditioner	*77*	3.69	4.24	0.43
Room air conditioner(s)	*68*	1.58	3.41	- 3.13
Heat pump	*13*	- 1.53	3.07	- 6.89
No cooling	*22*	- 0.21	0.00	- 1.55
Average lighting kWh savings per bulb	*180*	*38.0*	*38.0*	*38.0*
Actual per-bulb savings accounting for IE as a percentage of per-bulb lighting savings	*180*	*104%*	*108%*	*93%*

[a] Proportionally weighted to reflect statewide saturation percentage of ducted central air conditioning systems—see Section A.2.

3.2 Electric Summer Peak Demand Interactive Effects

The electric summer peak demand IE factor[15] is calculated in the same manner as the electric energy IE factor, except it uses summer peak demand savings instead of consumption savings:

$$Electric\ Demand\ IE\ Factor = \frac{Whole\ Building\ Summer\ Peak\ Electric\ Demand\ Savings}{Lighting\ Summer\ Peak\ Electric\ Demand\ Savings}$$

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[15] The REM/Rate models detected no changes in winter peak demand due to the lighting retrofit. This is most likely because heating from incandescent lighting is essentially replaced with heating from electric resistance.

As Table 8 demonstrates, electric summer peak demand IE factors do not vary substantially by cooling configuration. On average, a lighting retrofit will result in 105% of the summer peak demand savings attributable to lighting alone due to interactive effects.

Table 8: Average Electric Summer Peak Demand IE Factors by Cooling Configuration[a]

Cooling configuration	***Number of Homes***	**Electric Demand IE Factor**
Overall	*180*	*1.05*
Central air conditioner	*77*	1.06
Room air conditioner(s)	*68*	1.06
Heat pump	*13*	1.06
No cooling	*22*	1.00

[a] Proportionally weighted to reflect statewide saturation percentage of ducted central air conditioning systems—see Section A.2.

3.3 Heating Fuel Interactive Effects

The heating fuel IE factor is a ratio of the whole-building heating fuel increase to the electric energy savings resulting from a lighting retrofit. It is calculated in the following manner:

$$Heating\ Fuel\ IE\ Factor = \frac{Whole\ Building\ Annual\ Heating\ Fuel\ Increase}{Lighting\ Annual\ Electric\ Savings}$$

Table 9 expresses the heating fuel IE factor in BTU/kWh—the annual increase in heating fuel use in BTU per annual kWh of lighting savings. This factor accounts for interactive effects on heating requirements only for homes that are not heated with electricity; the electric IE factors in Sections 3.1 and 3.2 account for heating interactive effects in electric-heated homes.

Replacing incandescent bulbs with more efficient bulbs results in 1,902 BTU in *increased* heating consumption on average per kWh of electricity saved at the lighting end use. The heating IE factor for gas-heated homes is larger because these homes tend to be less efficient—based on Home Energy Rating System (HERS) scores—than other homes.[16]

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[16] The HERS Index compares homes to the 2004 International Energy Conservation Code (IECC) with some modifications reflecting the 2006 IECC. Scores can range from less than zero to well over 100. A score of 100 indicates that a home was built to the specifications of the 2004 IECC (with 2006 IECC modifications), while a score of zero indicates a net zero energy home. The average HERS score among homes heated with natural gas in this study is 124, while the average among all other homes in this study is 117.

Table 9: Heating Fuel IE Factors – BTU/kWh

Heating fuel	***Number of Homes***	**Heating IE Factor in BTU/kWh**[a]
Oil, LP, or biomass	*118*	1,887
Natural gas	*48*	1,941
Overall	*166*	*1,902*

[a] Weighted with heating fuel proportional weight—see Section A.2.

Table 10 presents the same information as Table 9, converted from BTU to units of heating fuel. On average, homes heated with fossil fuels will use an extra 0.01 to 0.02 units of fuel per kWh of lighting savings.

Table 10: Heating Fuel IE Factors – Units of Fuel/kWh[a]

Heating fuel	***Number of Homes***	**Heating IE Factor in Fuel Units/kWh**
Oil (gallons)	*112*	0.014
Natural gas (ccf)	*46*	0.019
LP (gallons)	*3*	0.019
Biomass (MMBtu)	*3*	0.002
Overall (MMBtu)	*166*	*0.002*

[a] Weighted with heating fuel proportional weight—see Section A.2.

3.3.1 Heating Fuel Impact Per Bulb

Table 11 describes the impact on heating fuel use per upgraded bulb. On average, each upgraded bulb will result in about 0.07 MMBtu/year in additional heating requirements. This represents 0.06% of the average home's annual heating fuel use measured in MMBtu. Assuming an HES retrofit of 25 bulbs—the maximum currently allowed in that program—the impact on heating fuel use would represent 1.5% of the average home's existing annual heating fuel use.

Table 11: HVAC Heating Fuel Impacts Per Upgraded Bulb

Heating fuel type	***Number of Homes***	**Annual MMBtu Increase per Bulb**[a]
Overall	*166*	*0.07*
Oil, LP, or biomass	*118*	0.07
Natural gas	*48*	0.07
Average annual MMBtu consumption per home for non-electric heating	*166*	*123.1*
Per-bulb IE heating fuel impact as a percentage of annual heating consumption	*166*	*0.06%*
25-bulb IE heating fuel impact as a percentage of annual heating consumption	*166*	*1.5%*

[a] Weighted with heating fuel proportional weight—see Section A.2.

3.4 Gas Takeback Factor

The gas takeback factor is a commonly used to describe the amount of additional natural gas usage that will result from an efficient lighting retrofit. It describes the proportion of lighting savings that is negated by the increase in heating requirements. The gas takeback factor is essentially the same as the heating IE factor, except that it is unitless and applies only to gas homes. Because it equates electricity and gas, it is best viewed as a way to contextualize interactive effects rather than measure them. The gas takeback factor is calculated in the following manner:

$$Gas\ takeback\ factor = \frac{Increase\ in\ Annual\ Whole\ Building\ Natural\ Gas\ Use}{Annual\ Lighting\ Electricity\ Savings * 0.03412\frac{ccf}{kWh}}$$

As the above equation demonstrates, lighting savings are converted from kWh to ccf for the purposes of calculating this factor.

Table 12 details the results of the gas takeback factor analysis. There is no factor for homes heated with something other than gas. Among gas-heated homes, the average gas takeback factor is 0.56, meaning that 56% of the lighting savings are negated by the increase in gas use that results from the retrofit. The factor ranges from 0.352 to 0.881 for individual homes.

Table 12: Gas Takeback Factor

Statistic	**Gas Takeback Factor**
Number of homes	*48*
Average	0.56
Minimum	0.35
Maximum	0.88

[a] Weighted with heating fuel proportional weight—see Section A.2.

4 Comparison of Results

Lighting interactive effects studies have been conducted in a number of other states in recent years, including New York, California, Minnesota, Maryland, Vermont, and a consortium of states in the Northwest, as well as a national study in Canada. Other jurisdictions have used a variety of methodologies for calculating IE factors. The majority, like this study, have used building energy simulation software, but at least one—the consortium of states in the Northwest—used a spreadsheet approach.

New York. The 2010 study "New York Standard Approach for Estimating Savings from Energy Efficiency Programs" [17] notes that DOE-2 single-family prototype models were used to calculate interactive effects factors for seven regions of the state, within five HVAC configuration categories.

California. The California Energy Commission and California Public Utilities Commission (CPUC) relied on DOE-2 prototype models in developing IE factors. Documentation detailing the results of this modeling is accessible on the Database for Energy Efficiency Resources (DEER) website.[18]

Canada. The Canadian Centre for Housing Technology sponsored a 2005 study that made use of the Centre's testing facility and HOT2000[19] energy modeling software to calculate interactive effects. The study simulated energy use for 11 cities in nine of the 13 Canadian provinces.

Minnesota. The 2014 Minnesota Technical Reference Manual notes that DOE-2/Equest building simulation was used to calculate interactive effects factors. The prototype models used to calculate

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[17] Jacobs, P., B. Evans, N. Hall, P. Horowitz, R. Ridge, G. Peach, R. Prahl, 2010, "New York Standard Approach for Estimating Energy Savings from Energy Efficiency Programs", New York Department of Public Service, October 15, 2010. Page 289.

[18] http://www.deeresources.com

[19] HOT2000 is an energy analysis and design software for residential buildings that is produced by Natural Resources Canada and used mostly in Canada.

Minnesota's interactive effects factors were based on the California DEER prototypes and altered to take local building codes and construction practices into account.

Northwest states. The Regional Technical Forum (RTF) of the Northwest Power and Conservation Council used a spreadsheet approach to arrive at a single electric IE factor for all residential buildings. The spreadsheet is available for download from the RTF website.[20]

Maryland. A study conducted by Lisa Gartland of Opinion Dynamics Corp. in 2011 used an unspecified building energy modeling software to analyze interactive effects in retail and office buildings in Maryland. This report is not available publicly, but a draft version is referenced in a 2012 CPUC study which includes a literature review.[21]

Vermont. The 2013 Efficiency Vermont Technical Reference Manual, which delineates the IE factors in use in the state, makes no mention of the methods used to calculate them. The manual indicates that the residential electric IE factor is 1.0—Vermont does not adjust lighting savings in residential buildings to account for interactive effects. The factor of 1.03 given in Table 13 is applicable to lighting upgrades in commercial buildings.

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[20] http://rtf.nwcouncil.org/measures/res/archive/ResCFLLighting_v2_1.xlsm

[21] Hirsch, James J. "A Study of the Sensitivity of DEER HVAC Interactive Effects Factors to Modeling Parameters". *Submitted to California Public Utilities Commission Energy Division*, March 28, 2012.

4.1 Electric Energy IE Factor Comparison

Table 13 compares electric IE factors from other studies with the factors from this analysis. Average electric energy IE factors range from 1.03 to 1.22 among the other jurisdictions.

Table 13: Comparison of Electric Energy IE Factor Results

Jurisdiction	**Average IE Factor**
Connecticut overall	1.04
Excluding homes heated primarily by electricity	*1.07*
Excluding homes heated by electricity in any amount	*1.08*
New York[a]	1.05
California[22]	1.06
Canada[23]	1.18
Minnesota[b, 24]	1.08
Northwest States[25]	1.09
Maryland (commercial buildings)	1.22
Vermont (commercial buildings)[26]	1.03

[a] New York factor is for gas-heated sites with cooling equipment, which is the category most directly comparable to the overall Connecticut sample.

[b] Minnesota factor is for single-family homes with known cooling configurations.

4.2 Electric Demand IE Factor Comparison

Electric demand IE factors are found in the documentation from New York, California, and Minnesota. Values vary substantially from 1.00 to 1.66. This analysis resulted in an average summer peak demand IE factor of 1.05, with values ranging from 1.00 to 1.08. These values are similar to those found in the New York documentation, where an average factor of 1.07 and a range of 1.00 to 1.14 are given.

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[22] CPUC, 2014, "DEER2014-Lighting-IE_and_Adjustment-Factor-Tables-17Feb2014.xlsx", Database for Energy-Efficient Resources, Version 2014.

[23] Parekh, A., M. C. Swinton, F. Szadkowski, M. Manning, 2005, "Benchmarking of Energy Savings Associated with Energy Efficient Lighting in Houses", National Research Council Canada. NRCC-50874.

[24] Minnesota, 2012b, "ResidentialCFLs_v01.xls", Deemed Savings Database, Minnesota Department of Commerce.

[25] Northwest Power and Conservation Council, 2011, "ResCFLLighting_v2_1.xlsm", posted on the "Current measures" section of the Regional Technical Forum web site, August 30, 2011.

[26] Efficiency Vermont, 2013. "Technical Reference User Manual, Measure Savings Algorithms and Cost Assumptions", Efficiency Vermont, Burlington, VT.

Table 14: Comparison of Electric Demand IE Factor Results[27]

Jurisdiction	Average Demand IE Factor
Connecticut	1.05
New York	1.07
California	1.37
Minnesota	1.25

The electric demand IE factor from this analysis applies to summer peak demand only—the analysis did not show any impact on winter peak demand due to interactive effects. Documentation from the other jurisdictions does not specify how "peak" is defined.

4.3 Gas Takeback Factor Comparison

The analysis conducted for this study resulted in an average gas takeback factor of 0.56, with a range of 0.35 to 0.88. Gas takeback factor values range from 0.26 to 0.89 among the other jurisdictions. As Table 15 demonstrates, the analysis conducted for this study resulted in a gas takeback factor value that is equal to the overall average of the factors utilized by other jurisdictions.

Table 15: Comparison of Gas Takeback Factor Results

Jurisdiction	Average Gas Takeback Factor
Connecticut	0.56
New York	0.68
California (CPUC study) [28]	0.67
California (PG&E field study)	0.58
Canada	0.77
Minnesota	0.26
Northwest States	0.87
Maryland (commercial buildings)	0.27
Vermont (commercial buildings)	0.36
Overall average	*0.56*

The average gas takeback factor for all regions of New York State is 0.68, greater than the average of 0.56 shown by this analysis. The New York documentation suggests that the most likely reason for the

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[27] In the New York documentation, commercial lighting retrofit savings are adjusted using a summer peak demand IE factor, but the residential savings equations are not labeled as such. There is no indication in the California or Minnesota documentation as to the seasonality of the electric demand IE factors provided.

[28] Hirsch, James J. "A Study of the Sensitivity of DEER HVAC Interactive Effects Factors to Modeling Parameters". *Submitted to California Public Utilities Commission Energy Division*, March 28, 2012.

difference is substantial geographic variation: gas takeback factors for New York regions range from 0.41 (Binghamton) to 0.85 (Massena). The factors for New York City and Poughkeepsie, the regions closest to Connecticut, are 0.67 and 0.73 respectively...

Appendix A Sampling and Weighting

This Appendix describes the sampling plan and weighting schemes used for this study.

A.1 Sampling Plan

The same 180 single-family homes which NMR audited for the Weatherization Baseline Assessment were used to model interactive effects for the Lighting Interactive Effects study. The Baseline Assessment focused exclusively on single-family homes, both detached (stand-alone homes) and attached (side-by-side duplexes and townhouses that have a wall dividing them from attic to basement and that pay utilities separately).Multifamily units—even smaller ones with two to four units—were excluded from the study due to the complexity and concomitant added costs of including them in the evaluation.

The evaluators relied on a disproportionately stratified design that aimed to achieve 10% sampling error or better at the 90% confidence level across all of Connecticut and also for several subgroups of interest (Table 16, shaded cells). This level of precision means that one can be 90% confident that the results are a reasonably accurate description of all the single-family homes in Connecticut. All precisions are based on a coefficient of variation of 0.5.[29]

Table 16: Sample Design, Planned and Actual (with Sampling Error)

Single-family Segment	Planned Sample Size	Actual Sample Size	Precision
Overall	180	180	**6%**
Low-income	68	34	14%
Non-low-income	76	146	**7%**
Income eligibility not identified	36[a]	0[a]	n/a
Fuel oil heat	109	111	**8%**
All other heating fuels	71[b]	69[b]	**10%**
Own	159	177	**6%**
Rent	21	3	47%

[a] The survey approach for identifying household income asked respondents if their income was above or below a certain amount based on their family size. This unobtrusive approach meant that the evaluators were able to identify the income status for all participants in the onsite study.

[b] The evaluators planned for 47 of these homes to heat with natural gas, and 46 of the homes in the final sample actually did so.

The final sample, however, did not achieve 90/10 precision for low-income households—although the sampling error of 14% is close to the desired 10%—and sampled fewer than expected renters (although the evaluators had not expected to achieve 90/10 precision for renters). These are traditionally difficult

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[29] The coefficient of variation measures the dispersion of data in a series of data points; it is commonly used to estimate sampling error when measuring the efficiency of measures installed in weatherization efforts.

groups to sample,[30] but three factors directly related to this study further limited the evaluators' ability to achieve 90/10 precision for the low-income households and to visit the expected number of rental households. Two of these factors stem from the HES requirement that renters receive permission from their landlords before receiving HES services.

First, when recruiting for the study, the evaluators informed possible participants that they would have to get landlord approval before taking part in the study; at that point, many renters indicated they did not want to take part in the study. Second, renters that did originally express interest in the study were ultimately unable or unwilling to secure landlord permission prior to the onsite visit. Because a disproportionately high number of households that rent single-family homes also qualify as low-income, the difficulty in securing participants who rent also limited the evaluators' ability to sample as many low-income households as designed.

A third reason for the lower than expected renter and low-income participation relates to the structure of buildings. When scheduling onsite visits, the evaluators discovered that many interested survey respondents who had originally indicated that they lived in single-family attached homes actually lived in multifamily homes or attached homes that were not completely separate units (i.e., they were not separated from attic to basement or they shared utilities).

NMR achieved 90/10 precision for oil-heated households and for households of all other fuel types combined. This reflects the fact that about 62% of single-family homes in Connecticut are heated with oil, and NMR could not promise—and did not achieve—90/10 precision for any other single heating fuel type with a sample size of 180 (the size chosen by the EEB and DEEP from a list of options provided by the evaluators).

A.2 Weighting

The data in this analysis was adjusted to population proportions using two separate proportional weights.

Cooling configuration weight. For the electric energy and electric demand IE factors, a weight based on American Housing Survey (AHS) 2011 estimates of the saturation of ducted central air conditioning systems in Connecticut was applied. This weighting scheme is based on two categories: (1) housing units that have a ducted central air conditioner or heat pump, and (2) housing units that have no cooling equipment or use room air conditioners only.

The central air conditioning saturation percentage in the sample of single-family homes used for this study closely mirrors that of single-family homes in Connecticut, according to the 2011 AHS. This would normally preclude weighting. However, in order for the factors contained in this memo to be applicable to multifamily units in addition to single-family homes, a weight based on the 2011 AHS was applied to adjust for differences in central air conditioning saturation between single- and multifamily units. Table 17 details the cooling configuration weights.

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[30] Underrepresentation of renters and low-income respondents is common in telephone surveys. For example, see Galesic, M., R. Tourangeau, M.P. Couper (2006), "Complementing Random-Digit-Dial Telephone Surveys with Other Approaches to Collecting Sensitive Data," *American Journal of Preventive Medicine*, Volume 35, Number 5.

Table 17: Cooling Configuration Proportional Weights

Weighting Category	CT Population: AHS 2011	Sample	Proportional Weight
Central AC or HP present	134,954	90	0.6412
Central AC or HP not present	285,965	90	1.3588

This study assumes that the interactive effects impact of each bulb upgraded from an incandescent to a CFL or LED would be roughly the same regardless of the physical size or configuration of the home, an assumption which is borne out by the preliminary modeling and research done for this study as well as the 2014 Northeast Residential Lighting Hours-of-Use Study.[31]

Heating fuel weight. For the heating fuel IE and gas takeback factors, a weight originally developed for use in the Weatherization Baseline Assessment was applied. This weight is based on a count of Connecticut households gathered from the American Community Survey (ACS) 2008-2010 three-year estimates, and broken out by fuel type and income status.

Two categories of primary heating fuel type served as the basis for this weighting scheme: (1) oil, propane, and biomass, and (2) gas and electricity. By combining the income and primary heating fuel categories, the evaluators established four weighting categories: (1) low-income with oil, propane, or biomass heating; (2) low-income with gas or electricity; (3) not low-income with oil, propane, or biomass; and (4) not low-income with gas or electricity.

This weight was applied to the results of this analysis because it corresponds to the original sampling plan under which the data used for this study was gathered. In addition, the four weighting categories resulted in baseline weights that were very close to one for all four categories, suggesting that the sample closely resembled the population in terms of heating fuel even prior to weighting the data. Table 18 details the heating fuel proportional weights.

Table 18: Heating Fuel & Income Proportional Weights

Weighting Category	CT Population: ACS ’08-‘10	Sample	Proportional Weight
Oil, LP, or biomass (low-income)	128,495	20	1.296
Gas or electric (low-income)	72,766	14	1.048
Oil, LP, or biomass (not low-income)	475,295	98	0.978
Gas or electric (not low-income)	216,042	48	0.908

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[31] NMR Group, Inc. *Northeast Residential Lighting Hours-of-Use Study*. Submitted to Connecticut Energy Efficiency Board et al. May 5, 2014.

Appendix B Savings Adjustment

This section provides examples for how program- or home-level savings can be adjusted using interactive effects factors.

B.1 Electric Energy IE Factor

The 2014 Connecticut Program Savings Documentation (PSD)[32] provides the following lighting retrofit gross energy savings equation:

$$AKWH = \frac{Watt\Delta * h * 365\frac{days}{year}}{1000\frac{W}{kW}}$$

where:

AKWH = Annual electric energy savings in kWh/year

WattΔ = Delta watts—the difference between the wattage of the lower efficiency baseline bulb(s) and the wattage of the new bulb(s)

h = Hours-of-use per day

In order to adjust lighting retrofit gross energy savings for interactive effects, the equation is altered in the following manner:

$$AKWH = \frac{Watt\Delta * h * 365\frac{days}{year}}{1000\frac{W}{kW}} * IEe$$

where:

IEe = Electric energy IE factor

The following example uses overall average hours-of-use and IE factor values and a delta-Watts of 47 (corresponding to a 13-Watt upgrade CFL and a 60-Watt pre-retrofit incandescent):

$$AKWH = \frac{47 * 2.77 * 365}{1000} * 1.04$$

In this example, the pre-adjustment electric energy savings would be 47.5 kWh/year per bulb, while the post-adjustment savings would be 49.9 kWh/year per bulb.

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[32] "Connecticut Program Savings Document: 9th Edition for 2014 Program Year". The United Illuminating Company and Connecticut Light & Power Company. January 6, 2014.

B.2 Electric Demand IE Factor

The PSD provides the lighting retrofit gross summer peak electric demand savings equation below:

$$SKW = \frac{Watt\Delta * CFs}{1000 \frac{W}{kW}}$$

where:

SKW = Summer peak electric demand savings

WattΔ = Delta watts, the difference between the wattage of the lower efficiency baseline bulb(s) and the wattage of the new bulb(s)

CFs = Summer lighting coincidence factor

In order to adjust lighting retrofit gross summer peak electric demand savings, the equation is altered in the following manner:

$$SKW = \frac{Watt\Delta * CFs}{1000 \frac{W}{kW}} * IEd$$

where:

IEd = Electric demand IE factor

The following example uses overall average hours-of-use and IE factor values and a delta-Watts of 47 (corresponding to a 13-Watt upgrade CFL and a 60-Watt pre-retrofit incandescent):

$$SKW = \frac{47 * 0.13}{1000} * 1.05$$

In this example, the pre-adjustment summer peak electric demand savings would be 0.0061 kW per bulb, while the post-adjustment savings would be 0.0064 kW per bulb. Winter peak electric demand savings require no interactive effects adjustment.

B.3 Heating Fuel IE Factor

The following equation is used to calculate the amount of the additional heating requirement that results from a CFL retrofit in non-electric-heated homes.

$$AMMBTU = \frac{Watt\Delta * h * 365\frac{days}{year}}{1{,}000\frac{W}{kW}} * \frac{-IEh}{1{,}000{,}000\frac{BTU}{MMBtu}}$$

where:

AMMBTU = Annual heating requirement increase in MMBtu/year

WattΔ = Delta watts, the difference between the wattage of the lower efficiency baseline bulb(s) and the wattage of the new bulb(s)

h = Hours-of-use per day

IEh = Heating fuel IE factor in BTU/kWh

The following example uses overall average hours-of-use and IE factor values and a delta-Watts of 47 (corresponding to a 13-Watt upgrade CFL and a 60-Watt pre-retrofit incandescent):

$$AMMBTU = \frac{47 * 2.77 * 365}{1000} * \frac{1{,}902}{1{,}000{,}000}$$

In this example, the annual increase in heating requirements resulting from the CFL retrofit is equal to 0.09 MMBtu/year per bulb.