MEMORANDUM

To:	Massachusetts Program Administrators (PAs) and Energy Efficiency Advisory Council (EEAC) Consultants
From:	The Residential Evaluation Team
Subject:	Lighting Interactive Effects Study Results
Date:	June 15, 2016

Summary

This memo details the findings of the Lighting Interactive Effects study conducted for the Program Administrators (PAs) and Energy Efficiency Advisory Council (EEAC) consultants in order to better understand and report the true impact of energy efficient lighting retrofits.

The goal of this study was to determine a statewide average for the heating, ventilation, and air conditioning (HVAC) impacts of residential lighting measures, quantified using interactive effects[1] (IE) factors. To accomplish this, the Residential Evaluation Team ("the team") developed and calibrated hourly building energy simulation models for single family, low-rise multifamily and high-rise multifamily structures. The team weighted the model results using socket saturations for each building type and Massachusetts-specific housing stock data to arrive at one statewide average.

Table 1 details the findings from our analysis. Note these values may be updated later in 2016 or early in 2017 as improved housing characteristic information becomes available through the forthcoming residential baseline study.

Table 1: Average IE Factor in Massachusetts for the Residential Upstream Lighting Initiative

Factor	Average IE Factor
Electric Energy IE Factor	1.01
Electric Demand IE Factor - Winter	0.93
Electric Demand IE Factor - Summer	1.20
Heating Fuel IE Factor (Btu/kWh)	2,295

[1] Lighting interactive effects are calculated using the total HVAC and lighting savings for a given fuel divided by lighting savings.

The following sections provide additional details on the IE factors developed in Massachusetts, methodology, and additional tables showing a breakdown of results by building type.

Introduction

Energy-efficient lighting fixtures emit less heat than higher wattage fixtures, which increases the heating load in the winter and decreases the cooling load in the summer in conditioned spaces. This study attempts to determine the heating, ventilation, and air conditioning impacts, quantified using interactive effect factors, from energy efficient lighting retrofits. The following are the IE factors estimated during this analysis:

- Electric Energy IE Factor – the ratio between the total annual energy savings (primary lighting and secondary HVAC impacts) and the primary, lighting-only savings.
- Electric Demand IE Factor – the ratio using the total kW savings for lighting and HVAC end-uses and the primary lighting kW savings during the winter and summer peak periods.
- Heating Fuel IE Factor – the ratio of the whole-building heating fuel increase to the electric energy savings resulting from the lighting retrofit.

Each of the IE factors listed above defines secondary impacts of HVAC energy caused by the primary electricity savings from reduced-wattage lighting efficiency installations.

Methodology

The evaluation team presented preliminary findings for the Lighting Interactive Effects study in early April, 2015 to assist with planning efforts. Due to the time sensitivity around the planning figures and the uncertainty of the Residential Customer Profiling study data, the evaluation team developed preliminary results based on a previous study conducted for the Home Energy Savings (HES) program. Since the inputs were heavily biased towards single family homes and only those participants in the HES program, the team was asked to reassess the results by incorporating multi-family building types using recent data developed during the low income multi-family billing analysis and non-low income billing analysis. The team also looked to other available sources for HVAC saturations and building types to calculate a statewide average for lighting interactive effects from lighting retrofits to be used for the upstream lighting program.

This section provides more details on the specific activities and results from the Lighting Interactive Effects study. The section will begin by discussing the various modeling approaches for each building type followed by the methodology for weighting the final results.

Single Family Models

The single family models remain unchanged from the original analysis with the exception of rerunning the models using a new weather file location. The original analysis used the weather location of Worcester Massachusetts and it was deemed more appropriate to use the typical meteorological year (TMY) data set derived for the location of Norwood Massachusetts due to its heating degree days (HDD) and cooling degree days (CDD) being a more accurate representation of the statewide average.

To reiterate the original single family methodology, the evaluation team developed models using building characteristics compiled from three sources:

1. HES program dataset containing audit data from 2010-2013[2]
2. Existing model inputs used in the High Efficiency Heating Equipment (HEHE) Impact Evaluation[3]
3. The HES Realization Rate analysis completed in 2013[4]

The team constructed four models using BEopt[5] (with EnergyPlus as the engine) based on heating type (electric and non-electric) and number of stories (1 and 2 stories)[6]. The models were then calibrated to billing data[7] which included statewide HES participants from 2010-2013. Next, the team disaggregated the billing data using Navigant's end-use disaggregation tool with customized inputs for the HES participants. Models were then calibrated to within 1-2% of the end-use consumption calibration targets, helping to ensure an accurate reflection of an average home in Massachusetts. In addition to calibrating to customer billing data, the team incorporated efficient lighting load shapes developed for the Market Adoption model.

After calibration, the team modeled three different cooling types for each heating type:

- Central air conditioner (CAC)[8]
- Room air conditioner
- No cooling

The evaluation team then adjusted each model using a simple 20% decrease in lighting consumption to model the efficient case to represent the post condition after a lighting retrofit. Finally, the team extracted and analyzed the modeled hourly load shapes to determine the specific IE Factors.

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[2] The HES dataset contained audit information for participants and was used to inform the HES Impact Evaluation. A detailed report can be found on the EEAC website at: http://ma-eeac.org/wordpress/wp-content/uploads/Home-Energy-Services-Impact-Evaluation-Report_Part-of-the-Massachusetts-2011-Residential-Retrofit-and-Low-Income-Program-Area-Evaluation.pdf)

[3] HEHE modeling inputs used in the Impact Evaluation can be found on the EEAC website at: http://ma-eeac.org/wordpress/wp-content/uploads/High-Efficiency-Heating-Equipment-Impact-Evaluation-Final-Report.pdf

[4] The HES realization rate analysis was an extension of the HES Impact Evaluation. The analysis involved estimating PA specific results for inclusion in vendor specific tools.

[5] https://beopt.nrel.gov/

[6] The complete list of model inputs are available in a supporting document, *MA Lighting Interactive Effects Model Inputs (Single Family, Low-Rise and High-Rise Multifamily)_20May2016.xlxs*.

[7] Calibration is to the program data and cooling type models are derived after calibration.

[8] Ideally, the models would have been calibrated to hourly room AC and central AC cooling loadshapes. However, these are not currently available in Massachusetts. Instead, the evaluation team adjusted the cooling demand using a diversity factor of 0.9 for CAC conditions and using a 0.5 for a room air conditioner to account for variations between our models and the real life situations found in people's homes. The diversity factor accounts for such variations as people not always being home, not all rooms being conditioned all the time and other behavioral differences such as how a customer uses the equipment (i.e., cooling setbacks). The evaluation team chose 0.9 and 0.5 based on their professional judgement and findings from a recent room air conditioner study in New York City (explanation of the runtimes can be found on page 24), http://www.coned.com/energyefficiency/PDF/EEPS_CY1_Residential_Room_AC_Impact_Evaluation_Report.pdf).

Low-Rise Multifamily Models

The evaluation team utilized a similar process for modeling low-rise structures as the single family modeling. Due to the lack of available program data for multifamily building characteristics, the team developed simulation model inputs based on building characteristics compiled from two sources:

1. Single family modeling inputs discussed in the previous section
2. Department of Energy (DOE) Residential Prototype Building Models for the Multifamily low-rise apartment building type[9]

The team then built two models using BEopt (EnergyPlus engine) based on heating type and calibrated to pre-normalized annual consumption (pre-NAC) values estimated in the Low Income and Standard Income billing analyses.[10] The evaluation team again utilized Navigant's end-use disaggregation tool with customized inputs for multifamily participants to 1) separate the pre-NAC data into calendar months and 2) determine calibration targets for all end-uses. The team chose Norwood as the centralized weather location to reflect an average of coastal weather patterns and those found inland while also to remain consistent with the single family models.

Models were then calibrated to within 1-2% of end-use consumption for the electrically heated home. Due to large heating targets derived from the Low Income billing analysis (i.e., 620 heating therms per year for a 950 square foot unit), the team felt that calibrating the model to those targets would produce a model that was unrepresentative of statewide low-rise multifamily residential buildings. Therefore, the evaluation team chose to use the calibrated electric model as a proxy and merely changed the heating type, appliance fuel types and other modeling inputs that may be different between an electrically heated home and one including a non-electric fuel type. This allowed for consistency between the low-rise models and kept the modeling parameters to within reasonable thresholds.

Once baseline models were finalized, the team modeled the three cooling types discussed above and decreased the lighting consumption by 20% decrease in lighting consumption to simulate the post condition of a lighting retrofit. The resulting load shapes were extracted and analyzed to determine the specific IE Factors for the low-rise multifamily building type.

High-Rise Multifamily Models

The high-rise modeling process was different than the other building types due to the lack of available data for high-rise structures. The evaluation team leveraged the DOE Commercial Prototype Building Models[11] and ran the models basically unchanged. The results were compared to the pre-NAC data

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[9] The residential prototype models are EnergyPlus models customized to Massachusetts specific inputs. The evaluation team utilized the IECC 2006 energy code as the reference code. The DOE models can be found at https://www.energycodes.gov/development/residential/iecc_models.

[10] The Low Income billing analysis included an analysis of gas consumption only while the Standard Income analysis focused on electric consumption. Both analyses have yet to be published.

[11] The DOE commercial prototype models are EnergyPlus models developed by climate zone and building code. The evaluation team chose the climate zone 5A model for Chicago and the ASHRAE 90.1 building code. The team adjusted the weather location to Boston due to the high prevalence of high-rise structures in the Boston area.

calculated in the Low Income and Standard Income billing analyses. Due to the unknowns about building characteristics and heating equipment, the evaluation team deemed the models to be satisfactory.

The evaluation then decreased the lighting power density by 20% to reflect a typical lighting retrofit. The resulting load shapes were extracted and analyzed to determine the specific IE factors for the high-rise multifamily building type.

Weighting Model Results

In determining a single statewide average for HVAC interactive effects, the evaluation team concluded it was not appropriate to simply weight the models by building type saturations and instead developed a weighting scheme using an estimate of socket saturations for the state of Massachusetts. Since the final value will be used for the upstream lighting program, this approach allows the statewide value to accurately reflect where the bulbs are being installed rather than the numbers of housing units in Massachusetts.

Table 2 details the inputs used to arrive at the estimate of socket saturations.

Table 2: Socket Saturations Used to Weight Building Simulation Model Results

Building Type	# of Housing Units [a]	Occupied Units	Percent of Units	Average # of Sockets [b]	Sockets by Building Type	Percent of Sockets
Single Family	2,212,233	1,993,599	79%	55.7	110,959,847	**88%**
Low-Rise Multifamily	288,075	259,605	10%	30.1	7,806,424	**6%**
High-Rise Multifamily	292,011	263,152	10%	30.1	7,913,084	**6%**
Total	**2,792,319**	**2,516,356**	**100%**	**52.5**	**126,679,354**	**100%**

[a] Housing Data Source: 2014 American Community Survey (ACS) data for 5 year estimates.
[b] Socket Data Source: 2015 Lighting Market Assessment (NMR)

Results

As discussed previously, the evaluation team presented preliminary findings for the Lighting Interactive Effects study in early April, 2015 to assist with planning efforts. Since the inputs were heavily biased towards single family homes and only those participants in the HES program, the team was asked to reassess the preliminary results by incorporating multi-family building types. Additionally, the team adjusted the weather location for single family and low-rise multifamily building types from Worcester to Norwood Massachusetts to more accurately align with a statewide average of heating and cooling degree days.

Table 3 details the preliminary results from the analysis in early April, 2015 compared to the updated results which incorporate multi-family building types and the new weather file location.

Table 3: Overall Results Compared to Preliminary Analysis

Factor	Average IE Factor		
	Preliminary Single Family Results	Updated Single Family Results	Updated Overall Results [a]
Electric Energy IE Factor	1.02	1.02	**1.01**
Electric Demand IE Factor - Winter	0.93	0.94	**0.93**
Electric Demand IE Factor - Summer	1.28	1.18	**1.20**
Heating Fuel IE Factor	2,237	2,369	**2,295**

[a] Primary heating type weightings are estimated at 6% electric to 94% non-electric for single family homes developed using the HES Impact Study and 25% electric to 75% non-electric for low-rise multifamily homes developed using the MA RASS study[12]

The results varied slightly from the preliminary analysis with the exception of the summer electric demand IE factor. The large reduction is solely due to the new results applying a diversity factor when the preliminary analysis neglected to make the adjustment. The electric energy IE factor had a minimal decrease after incorporating the multi-family building types which the evaluation team believes is due to the higher prevalence of electric resistance heating in the multifamily building type. The heating fuel IE factor had a fairly minimal increase which is likely caused by the change in weather file location and recalibration of the model. Overall, the changes varied only slightly from the preliminary results.

To further extrapolate the updated results, Table 4 details the summary for all calculated interactive effects by building type.

Table 4: Overall Results by Building Type

Model	HVAC IF Energy	HVAC IF Demand (Winter)	HVAC IF Demand (Summer)	Heating Fuel IE (Btu/kWh)	Weighting
Single Family	1.02	0.94	1.18	2,369	88%
Low-Rise Multifamily	0.90	0.85	1.18	1,783	6%
High-Rise Multifamily	1.12	0.90	1.43	1,769	6%
Overall [a]	**1.01**	**0.93**	**1.20**	**2,295**	**100%**

[a] Primary heating type weightings are estimated at 6% electric to 94% non-electric for single family homes developed using the HES Impact Study and 25% electric to 75% non-electric for low-rise multifamily homes developed using the MA RASS study[13]

The following sections provide detailed descriptions of each interactive factor and offer more granularity of the modeling results by building, heating and cooling types. Additional results are provided in the Appendix.

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[12] Equipment saturations from the Massachusetts Residential Appliance Saturation Survey (RASS) which can be found at http://ma-eeac.org/wordpress/wp-content/uploads/11_MA-Residential-Appliance-Saturation-Survey_Vol_1.pdf

[13] Equipment saturations from the Massachusetts Residential Appliance Saturation Survey (RASS) which can be found at http://ma-eeac.org/wordpress/wp-content/uploads/11_MA-Residential-Appliance-Saturation-Survey_Vol_1.pdf

Electric Energy IE Factor

As mentioned previously, each of the factors analyzed explains secondary impacts of HVAC energy caused by the primary electricity savings from reduced-wattage lighting efficiency installations. After simulating the various building type scenarios, the team began its review by analyzing the Electric IE Factor. The Electric IE Factor can be defined as:

- The ratio between the total annual energy savings (primary lighting and secondary HVAC impacts) and the primary, lighting-only savings or simply stated,

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

Table 5 details the results for the average Electric IE Factor.

Table 5: Average Electric Energy IE Factors by Cooling Configuration and Heating Fuel

Factor	Single Family		Low-Rise MF		High-Rise MF	Cooling Weights [a]	Overall
	Electric	Non-Electric	Electric	Non-Electric	Electric/Non-Electric [b]		
Central Air Conditioner	0.57	1.06	0.48	1.06	1.12	23%	1.03
Room Air Conditioner	0.57	1.06	0.49	1.06	-	58%	1.02
No Cooling	0.48	0.98	0.42	0.99	-	19%	0.94
Overall [c]	0.55	1.05	0.47	1.05	1.12	-	**1.01**

[a] Cooling types are weighted using estimates from the MA RASS study
[b] The high-rise model is a blend of electric and gas.
[c] Primary heating type weightings are estimated at 6% electric to 94% non-electric for single family homes developed using the HES Impact Study and 25% electric to 75% non-electric for low-rise multifamily homes developed using the MA RASS study

In comparing the results by building type, the single family and low-rise models returned similar results in all categories except for the electric-heated IE factors. The low-rise MF electrically heated models find consistently lower IE factors (from 0.06 to 0.11) for all cooling types than the IE factors for electrically heated single family homes. The high-rise models returned even higher IE factor by 0.09 to 0.11 than the other building types. The scope of this research did not include researching the differences in the IE factors. The differences, however, are small enough that the evaluation team deemed the results to be satisfactory.

Likely hypotheses also are generally supportive of the differences seen. It is likely that part of the high-rise model differences are due to internal heat loads and much higher saturation of central air-conditioning. The very low saturation of electric heat in single family housing versus in low-rise multifamily could mean there is a greater selectivity for less common building or occupant characteristics in single family electric heated homes versus electric heated multifamily.

The overall average Electric IE Factor found by weighting the cooling and heating fuel types is 1.01 showing that an average lighting retrofit will result in an additional 1% savings attributable to the secondary HVAC impacts from the efficient bulbs.

Electric Demand IE Factor

The team then analyzed the 8760[14] load shapes developed from simulation models to calculate the Electric Demand IE Factor. The Electric Demand IE Factor[15] can be defined as:

- The ratio using the total kW savings for lighting and HVAC end-uses and the primary lighting kW savings during the winter and summer peak periods or simply stated,

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

Table 6 details the results for the average Electric Winter IE Factor. The hypothesis from greater internal heat load for high-rise multifamily again support the difference and direction in the winter demand IE factor for this type of building versus the others.

Table 6: Average Electric Winter Demand IE Factors by Cooling Configuration and Heating Fuel

Factor	Single Family		Low-Rise MF		High-Rise MF	Cooling Weights [a]	Overall
	Electric	Non-Electric	Electric	Non-Electric	Electric/Non-Electric [b]		
Central Air Conditioner	0.38	0.98	0.47	0.98	0.90	23%	0.93
Room Air Conditioner	0.38	0.98	0.47	0.98	-	58%	0.93
No Cooling	0.38	0.98	0.47	0.98	-	19%	0.93
Overall [c]	0.38	0.98	0.47	0.98	0.90	-	**0.93**

[a] Cooling types are weighted using estimates from the MA RASS study
[b] The high-rise model is a blend of electric and gas.
[c] Primary heating type weightings are estimated at 6% electric to 94% non-electric for single family homes developed using the HES Impact Study and 25% electric to 75% non-electric for low-rise multifamily homes developed using the MA RASS study

Table 7 details the results for the average Electric Summer IE Factor. Greater internal heat loads in high-rise multifamily also could explain the IE factor and differences being even greater for summer demand.

Table 7: Average Electric Summer Demand IE Factors by Cooling Configuration and Heating Fuel

Factor	Single Family		Low-Rise MF		High-Rise MF	Cooling Weights [a]	Overall
	Electric	Non-Electric	Electric	Non-Electric	Electric/Non-Electric [b]		
Central Air Conditioner	1.34	1.34	1.34	1.36	1.43	23%	1.34
Room Air Conditioner	1.18	1.18	1.17	1.19	-	58%	1.18
No Cooling	1.00	1.00	1.00	1.00	-	19%	1.00
Overall [c]	1.18	1.18	1.18	1.19	1.43	-	**1.20**

[a] Cooling types are weighted using estimates from the MA RASS study
[b] The high-rise model is a blend of electric and gas.

[14] 8,760 are all the hours in a year.
[15] Peak periods align with the ISO NE as winter peak in December-February, hours 6-7pm and summer peak in June-August, hours 2-5pm.

[c] Primary heating type weightings are estimated at 6% electric to 94% non-electric for single family homes developed using the HES Impact Study and 25% electric to 75% non-electric developed using the MA RASS study

In comparing the results in Table 7, the models returned very comparable results by building type. The overall average Electric Winter and Summer Demand IE Factor are found to be 0.93 and 1.20 for an average home in Massachusetts.

Heating Fuel IE Factor

The team then analyzed the gas consumption developed from simulation models to calculate the Heating Fuel IE Factor. The Heating Fuel IE Factor can be defined as:

- The ratio of the whole-building heating fuel increase (Btu) to the electric energy savings (kWh) resulting from the lighting retrofit or simply stated,

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

Table 8 details the results for the average Heating Fuel IE Factor, with a focus on Gas homes[16].

Table 8: Heating Fuel IE Factor (Cost) for Non-Electric Heating Homes (Btu/kWh)

Factor	Single Family		Low-Rise MF		High-Rise MF	Cooling Weights [a]	Overall
	Electric	Non-Electric	Electric	Non-Electric	Electric/Non-Electric [b]		
Central Air Conditioner	-	2,500	-	2,362	1,769	23%	2,276
Room Air Conditioner	-	2,526	-	2,387	-	58%	2,334
No Cooling	-	2,541	-	2,371	-	19%	2,345
Overall [c]	-	2,523	-	2,378	1,769	-	**2,295**

[a] Cooling types are weighted using estimates from the MA RASS study
[b] The high-rise model is a blend of electric and gas.
[c] Primary heating type weightings are estimated at 6% electric to 94% non-electric for single family homes developed using the HES Impact Study and 25% electric to 75% non-electric for low-rise multifamily homes developed using the MA RASS study

The overall average Heating Fuel IE Factor is found to be 2,295 which indicates that a lighting retrofit will have an average of 2,295 Btu increase in consumption per kWh reduced in lighting.

Savings Overlap Analysis

In addition to the modeling exercise detailed above, the evaluation team reviewed current program savings estimates across the residential portfolio to provide proper guidance for applying the interactive effects to lighting measures installed through other residential initiatives[17]. In other words, the team wanted to prohibit programs from getting dinged twice if lighting interactive effects are already

[16] Applicable to fossil fuel heating, such as oil and propane.
[17] Any upstream bulbs assumed to go to the Commercial and Industrial (C&I) sectors, should use the appropriate C&I IE factor rather than the residential IE factors.

accounted for through methodologies like billing analyses or accurately account for these if the effects have not been factored into the savings estimates.

The evaluation team identified five initiatives where direct install lighting measures are being installed and therefore susceptible to the secondary HVAC interactive effects. These initiatives are:

- Home Energy Services
- Single Family Low Income
- Multifamily Low Income
- Residential New Construction (Low Rise)
- Multifamily (Standard Income)

The evaluation team then identified the methodologies used to estimate electric and gas savings for each of the initiatives listed above, and summarizes the recommended application of interactive effects in Table 9[18]. HES used a billing analysis to estimate savings for gas and electric measures which would have included all interactive effects, so no adjustment is necessary at this time. However, both the Single Family and Multifamily Low Income initiatives performed a billing analysis on gas measures only and did not attempt to estimate the electric interactive effects of the direct install lighting measures. The Residential New Construction initiative uses a model to estimate savings, and the model does not take into account any interactive effects. Therefore, savings estimates for all three of these initiatives could be improved by applying IE factors as shown in the table below.

At this time, the evaluation methodology for the Multifamily Standard Income initiative is under revision, and any necessary adjustments for interactive effects should be revisited when that evaluation is finalized.

Table 9: Lighting IE Factors to Be Applied in Massachusetts Residential DI Programs

Factor	HES	Low Income Single Family	Low Income Multi Family	Residential New Construction (Low Rise)	Multifamily Standard Income
Electric Energy IE Factor	N/A	✓	✓	✓	TBD
Electric Demand IE Factor - Winter	N/A	✓	✓	✓	TBD
Electric Demand IE Factor - Summer	N/A	✓	✓	✓	TBD
Heating Fuel IE Factor (Btu/kWh)	N/A	N/A	N/A	✓	TBD

N/A = not applicable because interactive effects are calculated through billing analysis or modeling
TBD = application of interactive effects is still to be determined

[18] The PAs can use the upstream default IE factors in Table 1 as placeholder values, but also may use custom values that account for program specific heating fuel types, air-conditioning saturation, and other building characteristics as they are available (and if not available then continue to use the default values). In addition, the upstream default IE factors may also be updated later in 2016 or early in 2017 as improved housing characteristic information becomes available through the residential baseline study.

Appendix A: Unweighted Results by Building Type

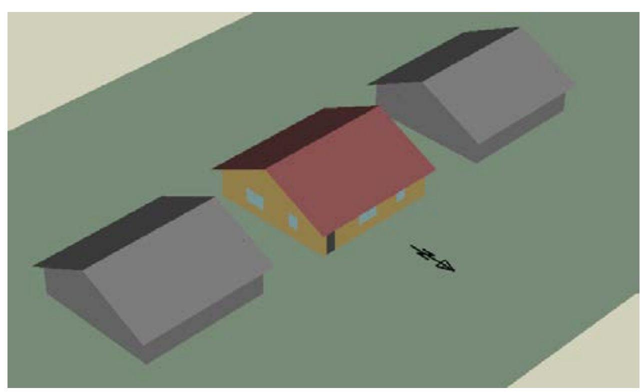
Results

The evaluation team utilized a high number of models over multiple building types to ensure specificity at a more granular level and allow the aggregation to likely be more accurate. The following sections detail the IE factors of the modeling categories for each building type prior to application of heating and cooling weights along with primary building inputs used to develop each model.

Single Family Results

The single family models remain unchanged from the original analysis with the exception of rerunning the models using a new weather file location. The team constructed four models using BEopt (with EnergyPlus as the engine) based on heating type (electric and non-electric) and number of stories (1 and 2 stories)[19]. The following table provides the primary building inputs used to develop the single family models.

Table 10: Primary Model Inputs – Single Family

Building Parameters	Electric - Floor 1	Electric - Floor 2	Gas - Floor 1	Gas - Floor 2
Vintage	Existing Construction			
Location (Representing 8 Climate Zones)	Zone 5A: Norwood Mem AP - TMY3			
Heating Fuel Type	100% Efficiency Baseboard	100% Efficiency Baseboard	Gas Furnace 81% AFUE	Gas Furnace 81% AFUE
Building Type (Principal Building Function)	Single Family - Detached			
Total Floor Area (sqft)	1,296	1,980	1,440	2,160
Aspect Ratio	1.5			
Number of Floors	1	2	1	2
Building shape				

* Building shape shows the 1 story model but the 2 story model is of similar shape with an additional story.

[19] The complete list of model inputs are available in a supporting document, *MA Lighting Interactive Effects Model Inputs (Single Family, Low-Rise and High-Rise Multifamily) 20May2016.xlxs*.

The results were weighted by model category using the participant counts from the HES Impact Study completed in 2010-2013. This allowed the evaluation team to derive a single model to use when developing the overall statewide average. Similarly, the cooling weights were estimated using the Massachusetts RASS study from 2009 to derive one value that represents an average single family home in Massachusetts.

The following tables detail the various IE factors by model category and cooling type for single family homes.

Table 11: Electric Energy IE Factors by Cooling Configuration and Heating Fuel – Single Family

Model	Electric - Floor 1	Electric - Floor 2	Gas - Floor 1	Gas - Floor 2	Cooling Weights [a]	Overall
Central Air Conditioner	0.57	0.57	1.06	1.06	23%	1.03
Room Air Conditioner	0.57	0.57	1.06	1.06	58%	1.03
No Cooling	0.49	0.48	0.98	0.98	19%	0.95
Overall [b]	0.56	0.55	1.04	1.05	-	**1.02**

[a] Cooling types are weighted using estimates from the MA RASS study
[b] Primary heating types are estimated at 6% electric to 94% non-electric developed using the HES Impact Study

Table 12: Electric Winter Demand IE Factors by Cooling Configuration and Heating Fuel – Single Family

Model	Electric - Floor 1	Electric - Floor 2	Gas - Floor 1	Gas - Floor 2	Cooling Weights [a]	Overall
Central Air Conditioner	0.37	0.39	0.98	0.98	23%	0.94
Room Air Conditioner	0.37	0.39	0.98	0.98	58%	0.94
No Cooling	0.37	0.39	0.98	0.98	19%	0.94
Overall [b]	0.37	0.39	0.98	0.98	-	**0.94**

[a] Cooling types are weighted using estimates from the MA RASS study.
[b] Primary heating types are estimated at 6% electric to 94% non-electric developed using the HES Impact Study

Table 13: Electric Summer Demand IE Factors by Cooling Configuration and Heating Fuel – Single Family

Model	Electric - Floor 1	Electric - Floor 2	Gas - Floor 1	Gas - Floor 2	Cooling Weights [a]	Overall
Central Air Conditioner	1.31	1.36	1.35	1.33	23%	1.34
Room Air Conditioner	1.17	1.19	1.19	1.17	58%	1.18
No Cooling	0.99	1.00	1.00	1.00	19%	1.00
Overall [b]	1.17	1.19	1.19	1.17	-	**1.18**

[a] Cooling types are weighted using estimates from the MA RASS study
[b] Primary heating types are estimated at 6% electric to 94% non-electric developed using the HES Impact Study

Table 14: Heating Fuel IE Factor for Non-Electric Heating Homes (Btu/kWh) – Single Family

Model	Electric - Floor 1	Electric - Floor 2	Gas - Floor 1	Gas - Floor 2	Cooling Weights [a]	Overall
Central Air Conditioner	-	-	2,542	2,475	23%	2,347
Room Air Conditioner	-	-	2,555	2,509	58%	2,372
No Cooling	-	-	2,574	2,521	19%	2,385
Overall [b]	-	-	2,555	2,503	-	2,369

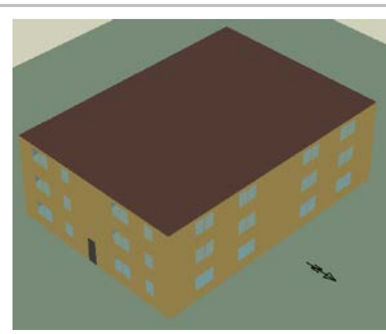
[a] Cooling types are weighted using estimates from the MA RASS study

[b] Primary heating types are estimated at 6% electric to 94% non-electric developed using the HES Impact Study

Low-Rise Multi-family Results

The evaluation team utilized a similar process for modeling low-rise structures as the single family modeling. The team built two models using BEopt (EnergyPlus engine) based on heating type and calibrated to pre-normalized annual consumption (pre-NAC) values estimated in the Low Income and Standard Income billing analyses. The following table provides the primary building inputs used to develop the low-rise multifamily models.

Table 15: Primary Model Inputs – Low-Rise

Building Parameters	Electric	Gas
Vintage	Existing Construction	
Location (Representing 8 Climate Zones)	Zone 5A: Norwood Mem AP - TMY3	
Heating Fuel Type	100% Efficiency Baseboard	Gas furnace 81% AFUE
Building Type (Principal Building Function)	Multifamily	
Building Prototype	Low-Rise Apartment	
Total Floor Area (sqft)	11,400	
Floor Area per Unit (sqft	950	
Aspect Ratio	2	
Number of Floors	3	
Building shape		

The results were weighted by primary heating type and cooling type using estimates from the 2009 Massachusetts RASS study. The following tables detail the various IE factors by model category and cooling type for low-rise multifamily units.

Table 16: Electric Energy IE Factors by Cooling Configuration and Heating Fuel – Low-Rise

Model	Electric	Gas	Cooling Weights [a]	Overall
Central Air Conditioner	0.48	1.06	23%	0.91
Room Air Conditioner	0.49	1.06	58%	0.92
No Cooling	0.42	0.99	19%	0.85
Overall [b]	0.47	1.05	-	**0.90**

[a] Cooling types are weighted using estimates from the MA RASS study
[b] Primary heating types are estimated at 25% electric to 75% non-electric developed using the MA RASS study

Table 17: Electric Winter Demand IE Factors by Cooling Configuration and Heating Fuel – Low-Rise

Model	Electric	Gas	Cooling Weights [a]	Overall
Central Air Conditioner	0.47	0.98	23%	0.86
Room Air Conditioner	0.47	0.98	58%	0.85
No Cooling	0.47	0.98	19%	0.85
Overall [b]	0.47	0.98	-	**0.85**

[a] Cooling types are weighted using estimates from the MA RASS study
[b] Primary heating types are estimated at 25% electric to 75% non-electric developed using the MA RASS study

Table 18: Electric Summer Demand IE Factors by Cooling Configuration and Heating Fuel – Low-Rise

Model	Electric	Gas	Cooling Weights [a]	Overall
Central Air Conditioner	1.38	1.36	23%	1.35
Room Air Conditioner	1.17	1.19	58%	1.19
No Cooling	1.00	1.00	19%	1.00
Overall [b]	1.18	1.19	-	**1.19**

[a] Cooling types are weighted using estimates from the MA RASS study
[b] Primary heating types are estimated at 25% electric to 75% non-electric developed using the MA RASS study

Table 19: Heating Fuel IE Factor for Non-Electric Heating Homes (Btu/kWh) – Low-Rise

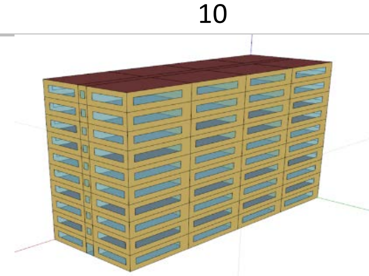
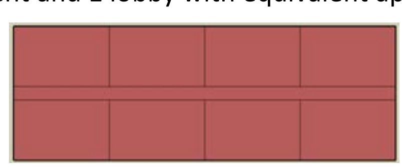
Model	Electric	Gas	Cooling Weights [a]	Overall
Central Air Conditioner	-	2,362	23%	1,771
Room Air Conditioner	-	2,387	58%	1,789
No Cooling	-	2,371	19%	1,777
Overall [b]	-	2,378	-	**1,783**

[a] Cooling types are weighted using estimates from the MA RASS study
[b] Primary heating types are estimated at 25% electric to 75% non-electric developed using the MA RASS study

High-Rise Multifamily Results

The high-rise modeling process was different than the other building types due to the lack of available data for high-rise structures. The evaluation team leveraged the DOE Commercial Prototype Building Models and ran the models basically unchanged. The following table provides the primary building inputs used to develop the high-rise multifamily models.

Table 20: Primary Model Inputs – High-Rise

Building Parameters	High-Rise Model
Vintage	New Construction
Location (Representing 8 Climate Zones)	Zone 5A: Boston Logan Intl AP - TMY3
Heating Fuel Type	Gas, Electricity
Building Type (Principal Building Function)	Multifamily
Building Prototype	High-Rise Apartment
Total Floor Area (sqft)	84,360 (152 ft x 55.5 ft)
Floor Area per Unit (sqft)	950
Aspect Ratio	2.75
Number of Floors	10
Building shape	
Thermal Zoning	Each floor has 8 apartments except ground floor (7 apartment and 1 lobby with equivalent apartment area) 

The results were modeled using a combination of electric and gas heating with a central air conditioner. The following table details the various IE factors for high-rise multifamily application.

Table 21: Overall Results for High-Rise Multifamily

Model	HVAC IF Energy	HVAC IF Demand (Winter)	HVAC IF Demand (Summer)	Heating Fuel IE	Weighting
Electric - High Rise	1.12	0.90	1.43	1,769	100%