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Massachusetts Electric and Gas Program Administrators

Stage 2 Results—Commercial and Industrial New Construction Non-Energy Impacts Study—Final Report

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Part of the Special and Cross-Cutting Evaluation Program Area

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1. EXECUTIVE SUMMARY

This report presents the methodology and results of the 2015 Non-Energy Impact (NEI) Study of energy efficiency measures supported through the Massachusetts Program Administrators' (PAs) Commercial and Industrial (C&I) New Construction (NC) Programs. This study was conducted in two separate phases by DNV GL and Tetra Tech (the Evaluation Team) under the Cross-Cutting Research area for the Massachusetts PAs and the Energy Efficiency Advisory Council (EEAC) consultants. Findings from Stage 1, which focused on recommending an approach to estimate NEIs, were summarized in a separate document; this current report provides the findings from Stage 2.

A major consideration when estimating NEIs for NC measures was distinguishing between NEIs resulting from the measure being *new* versus being *energy efficient.* Because the facilities considered in this analysis were either new or substantially renovated, some type of new equipment would be installed regardless of participation in an energy efficiency program. Consequently, NEIs associated with the early retirement of existing equipment are excluded from this study, and only NEIs associated with moving from the baseline "new" technology to a more energy-efficient piece of equipment are relevant. NEIs evaluated in this report include any positive or negative effects other than energy savings that are attributable to the adoption of more energy-efficient equipment. Examples of positive NEIs include reduced labor or non-labor operations and maintenance (O&M) costs, and increased revenue. Negative NEIs include increased labor or O&M costs, or reduced productivity or sales.

1.1 OBJECTIVES

The purpose of this study was to quantify the dollar value of participant NEIs for C&I NC projects completed in 2013, and to estimate gross NEIs per unit of energy savings resulting from NC electric and gas measures separately.

The study was completed in two stages. Stage 1 determined the best approach for estimating NEIs from NC measures. Based on the results of the Stage 1 research, this Stage 2 analysis focuses on the NEIs associated with "true" new construction measures only. True new construction measures are defined as:

- New buildings/facilities
- Major renovations.

However, this does <u>not</u> include early retirement, upstream, or replace on failure (ROF)/natural replacement.[1]

[1] As of 2013, the PAs included four types of projects under the new construction program: new buildings, major retrofits, replacement of measures at the end of their useful life (replace on failure/natural replacement), and measures installed through the upstream program. For reasons documented in the Stage 1 research, the Evaluation Team decided to focus this analysis on new buildings and major retrofits only, defined herein as "true" new construction.

A more detailed list of objectives for each stage of the analysis is provided in Section 2.2 of this report.

1.2 OVERVIEW OF APPROACH

To quantify the NEIs associated with the NC program in 2013, the Evaluation Team first reviewed the methodology used in a related study that examined NEIs associated with the 2012 C&I Retrofit program.[2] The Evaluation Team considered using the same approach as the 2012 study, but ultimately decided a different approach was needed for new construction. A two-stage approach was selected to address uncertainty regarding respondents' ability to conceptualize cost and revenue differences associated with program-rebated measures relative to a hypothetical scenario using non-efficient technologies.

In Stage 1 of this study, DNV GL conducted two major tasks to determine the most effective means of obtaining NEI information for NC measures:

1. We analyzed the 2013 program tracking data and the 2012 C&I NEI Retrofit study results
2. We conducted in-depth interviews with four groups of market actors (PA staff, design firms, manufacturers and suppliers, and customer energy managers and operations groups).[3]

Stage 1 of this study found that, in contrast to the situation for retrofit measures addressed in the 2012 report, interview respondents often have difficulty self-reporting NEIs associated with NC measures. For NC, respondents do not have an observed point of comparison to gauge the difference between operating costs and/or sales for the new energy-efficient equipment versus costs/sales for a hypothetical baseline equipment that is "new, but not energy efficient."

Therefore, Stage 2 of this study did not rely on self-reports to quantify project-level NEIs, but did use data collected through interviews to inform the analysis. NEIs were instead estimated through the following basic steps.

- True NC projects were identified from the PAs' tracking data, and a sample of measures was drawn from those true NC projects.
- An engineering/lifecycle cost analysis was performed for each sampled measure.
- The NEI per energy savings results from these analyses were rolled up to the appropriate benefit-cost (BC) categories used by the PAs.

The engineering approach employed data from published sources, data from interview responses, and information from PA tracking data.

[2] Final Report – Commercial and Industrial Non-Energy Impacts Study. Prepared by DNV GL for the Massachusetts Program Administrators and EEAC Consultants. June 29, 2012.
[3] A more comprehensive discussion of preliminary and Stage 1 research is provided in 5.2APPENDIX B: of this report.

A more comprehensive discussion of our Stage 2 study approach is provided in Section 3 of this report.

1.3 KEY FINDINGS & RECOMMENDATIONS

Based on our analysis, the total annual value of NEIs for 2013 NC program participants that conducted true NC projects was roughly $488,000 per year, across 957 measures installed in 2013. These results include the Custom – Comprehensive Design Analysis (CDA) performance path-based measure.[4] Table 1 provides a breakdown of savings by project track.[5]

Table 1. Estimated Annual NEIs

Project Track	Annual NEI
Custom Electric	$ 89,261
Prescriptive Electric	$ 372,353
Custom Gas	$ (3,643)
Prescriptive Gas	$ 30,151
Total	**$ 488,122**

Table 2 and Table 3 show DNV GL's recommended unit NEI estimates for each of the measure categories used in the PAs' BC analysis. For each of the BC measure categories, we show the unit NEI in dollars per kWh or per therm and its statistical significance. These NEI estimates are derived using the engineering-based analysis that we conducted on a sample of 255 of the population of 957 NC measures installed in 2013. For BC measure categories for which we had sufficient sample data, the recommended value is based on data from that specific category alone. In other cases, it was necessary to combine similar measure categories at the sampling or analysis stage (herein referred to as a "sample category"). For example, DNV GL recommends using the prescriptive commercial kitchen NEI estimate for the Custom Food Service benefit cost category since there were no custom commercial kitchen measures in the sample frame.

We provide NEI estimates for several measure categories even though they are not statistically significant at the 10% significance level or better. We recommend using these estimates for the PAs' BC model. In these cases, the lack of statistical significance is likely due to small sample sizes, and the estimates provided are the best available from the study. Where the NEI estimate is listed as "N/A" in the tables, the respective measure category did

[4] The total annual value is calculated by summing the products of DNV GL's derived $NEI/unit of energy savings factor and the PAs' reported 2013 annual energy savings for each measure. CDA projects constitute a single measure category in the PAs' BC analysis, although they likely involve the installation of multiple technologies or measures to meet the requisite performance path-based standard for the whole building or building system.

[5] The estimates shown in Table 1 are intended to illustrate the estimated magnitude of the total annual NEIs realized for true NC projects in 2013 because they include NEIs for some measure categories that did not meet the test for statistical significance.

not appear in our sample. Where the NEI estimate is listed as a zero, the analysis indicates that the NEI for that measure category is negligible.

DNV GL recommends that the PAs apply the electric and gas NEIs presented in Table 2 and Table 3, respectively. However, we note the following limitations to our analysis:

- The approach used to isolate true NC projects (and their measures) limits this study to those measures contained in the Dodge data or tax assessors' data that were the basis for the study samples.
- This study focuses on operational cost impacts only, as these are the changes that can be quantified under our engineering-based approach. Further research is required to explore whether there are additional sources of NEIs.

A more comprehensive discussion of Stage 2 study findings and recommendations is provided in Section 5 of this report.

Table 2. Recommended Electric NEI Estimates by PA Benefit-Cost Measure Category

	Benefit- Cost Category	Sample Category	Overall NEI/kWh	Statistically Significant?	Source of Recommended NEI
Custom					
	CHP	N/A	**N/A**	Not Studied	Not Sampled
	Comprehensive Design	Comprehensive Design	**$ 0.001**	Not Recommended	Custom Electric Comprehensive Design
	Compressed Air	Compressed Air	**$ 0.026**	b	Custom Compressed Air
	Food Services	Commercial Kitchen	**$ 0**	0	Prescriptive Electric Commercial Kitchen
	HVAC	HVAC	**$ 0.001**	a	Custom Electric HVAC/Heat Recovery
	Lighting	Lighting	**$ 0.003**	a	Custom Electric Lighting
	Motors & VFD	Motors	**$ 0**	0	Custom Electric Motors
	Other	Other	**$ 0**	0	Custom Electric Other
	Process	Industrial Process	**$ 0.013**	b	Custom Electric Industrial Process
	Refrigeration	Refrigeration	**$ 0.012**	b	Custom Electric Refrigeration
	Overall	**Overall**	**$ 0.006**	**c**	**Custom Electric Overall**
Prescriptive					
	Compressed Air	Compressed Air	**$ 0.038**	c	Prescriptive Compressed Air
	Food Services	Commercial Kitchen	**$ 0**	0	Prescriptive Electric Commercial Kitchen
	HVAC	HVAC	**$ 0**	0	Prescriptive Electric HVAC
	Lighting	Lighting	**$ 0.020**	c	Prescriptive Electric Lighting
	Motors & VFD	Motors	**$ 0**	0	Prescriptive Electric Motors
	Overall	**Overall**	**$ 0.016**	**c**	**Prescriptive Electric Overall**

a: Recommended, but not well determined ($.10 < p \le .50$)

b: Recommended, statistically significant at 90% confidence ($p \le .10$)

c: Recommended, statistically significant at 99% confidence ($p \le .01$)

0: NEIs are determined to be negligible

Not Recommended: $p > .5$

Not Studied: No measures of this type in our sample

Table 3. Recommended Gas NEI Estimates by PA Benefit-Cost Measure Category

	Benefit- Cost Category	Sample Category	Overall NEI/Therm	Statistically Significant?	Source of Recommended NEI
Custom					
	Building Shell	Building Shell	$ 0	0	Custom Gas Building Shell
	Comprehensive Design	Comprehensive Design	$ (0.004)	a	Custom Gas Comprehensive Design
	Condensing Boiler	Boilers	$ (0.006)	a	Custom Gas Boilers
	Combination Boiler/Hot Water Heater	Boilers	$ (0.006)	a	Custom Gas Boilers
	Condensing Unit Heater	Other Gas Heating	$ 0	0	Custom Gas Other Gas Heating
	Food Services	Commercial Kitchen	$ 3.399	b	Prescriptive Gas Commercial Kitchen
	Furnace	Other Gas Heating	$ 0	0	Custom Gas Other Gas Heating
	Heat Recovery	HVAC/ Heat Recovery	$ 0.000	a	Custom HVAC/ Heat Recovery
	Heating	Other Gas Heating	$ 0	0	Custom Gas Other Gas Heating
	Hot Water	HVAC/ Heat Recovery	$ 0.000	a	Custom HVAC/ Heat Recovery
	HVAC/ Heat Recovery	HVAC/ Heat Recovery	$ 0.000	a	Custom HVAC/ Heat Recovery
	Infrared Heaters	Other Gas Heating	$ 0	0	Custom Gas Other Gas Heating
	Other	Other	$ (0.032)	a	Custom Gas Other
	Process	Industrial Process	$ 0.007	Not Recommended	Custom Gas Industrial Process
	Overall	**Overall**	$ (0.005)	**b**	**Custom Gas Overall**
Prescriptive					
	Combination Oven	Commercial Kitchen	$ 3.399	b	Prescriptive Gas Commercial Kitchen
	Condensing Boiler	Boilers	$ (0.084)	c	Prescriptive Gas Boilers
	Combination Boiler/Hot Water Heater	Boilers	$ (0.084)	c	Prescriptive Gas Boilers
	Condensing Unit Heater	Other Gas Heating	$ 0.053	c	Prescriptive Gas Other Gas Heating
	Convection Oven	Commercial Kitchen	$ 3.399	b	Prescriptive Gas Commercial Kitchen
	Conveyer Oven	Commercial Kitchen	$ 3.399	b	Prescriptive Gas Commercial Kitchen
	Food Services	Commercial Kitchen	$ 3.399	b	Prescriptive Gas Commercial Kitchen
	Fryer	Commercial Kitchen	$ 3.399	b	Prescriptive Gas Commercial Kitchen
	Furnace	Other Gas Heating	$ 0.053	c	Prescriptive Gas Other Gas Heating
	Griddle	Commercial Kitchen	$ 3.399	b	Prescriptive Gas Commercial Kitchen
	Heating	Other Gas Heating	$ 0.053	c	Prescriptive Gas Other Gas Heating
	Hot Water	HVAC/ Heat Recovery	$ 0.242	a	Prescriptive Gas HVAC/ Heat Recovery
	HVAC/ Heat Recovery	HVAC/ Heat Recovery	$ 0.242	a	Prescriptive Gas HVAC/ Heat Recovery
	Infrared Heaters	Other Gas Heating	$ 0.053	c	Prescriptive Gas Other Gas Heating
	Rack Oven	Commercial Kitchen	$ 3.399	b	Prescriptive Gas Commercial Kitchen
	Steamer	Commercial Kitchen	$ 3.399	b	Prescriptive Gas Commercial Kitchen
	Overall	**Overall**	$ 0.235	**a**	**Prescriptive Gas Overall**

a: Recommended, but not well determined (.10 < p ≤ .50)

b: Recommended, statistically significant at 90% confidence (p ≤ .10)

c: Recommended, statistically significant at 99% confidence (p ≤ .01)

0: NEIs are determined to be negligible

Not Recommended: p >.5

2. INTRODUCTION

DNV GL and Tetra Tech (the Evaluation Team) were engaged by the Massachusetts Program Administrators (PAs) and the Energy Efficiency Advisory Council (EEAC) to quantify participant non-energy impacts (NEIs) associated with the 2013 Commercial and Industrial (C&I) New Construction program. This study was conducted in two separate phases. Findings from Stage 1, which focused on recommending an approach to estimate NEIs, were summarized in a separate document in March 2015. This current report provides the findings from Stage 2.

2.1 BACKGROUND

The New Construction (NC) program is administered by the Massachusetts PAs for both electric and gas measures. It provides incentives and technical services to C&I customers that are building new facilities, undergoing major renovations of an existing facility, or replacing failed equipment (replace on failure or natural replacement measures). It also provides incentives for upstream lighting and HVAC measures.

For NC measures, the issue of NEIs resulting from a measure being new versus being energy efficient is of particular interest, since some type of new equipment would have been installed regardless of participation in an energy efficiency program. Therefore, only NEIs associated with moving from a standard piece of new equipment to an energy efficient piece of new equipment are relevant. NEIs associated with the early retirement of existing equipment are not relevant to this study, and as discussed in Section 2.3, NEIs for replace on failure/natural replacement and upstream measures are not analyzed in this study.

2.2 EVALUATION OBJECTIVES

The Evaluation Team identified the following objectives for this study:

Stage 1 objectives:

1. Review NC measures installed during 2013 to define these measures in terms of (1) types of new construction, and (2) measure category/end use.
2. Assess the effectiveness and most appropriate means of establishing baseline conditions for NEI computations and eliciting self-reported responses through in-depth interviews (IDIs) with various market actors.
3. Determine whether NEIs from NC measures are best estimated from self-reports from participants and/or other market actors, engineering review, Delphi panel, or other techniques.
4. Recommend an approach for the Stage 2 analysis.

Stage 2 objectives:

1. Employ the techniques identified through Stage 1 to establish baseline conditions for participant NEIs associated with true NC measures (i.e., excluding replace on failure/natural replacement and upstream measures).

2. Use an engineering-based approach to quantify the dollar value of participant NEIs for true C&I NC projects completed in 2013. NEIs include any positive or negative effects other than energy savings that are attributable to energy efficiency programs experienced by program participants. Examples of positive NEIs include reduced labor or non-labor operations and maintenance (O&M) costs. Negative NEIs include increased labor or O&M costs.
3. Estimate gross NEIs per unit of energy savings resulting from NC electric and gas measures separately.

2.3 STUDY APPROACH

In Stage 1 of this study, the Evaluation Team conducted a literature review, data mining, and in-depth interviews to meet the Stage 1 research objectives. The Stage 1 evaluation approach is described in more detail in Appendix B.

This Stage 1 research uncovered the following key findings, which provided direction for the Stage 2 research.

- **The analysis of NEIs associated with NC measures should focus on true new construction only.** While the PAs currently include replace on failure/natural replacement and 100% of upstream measures in the New Construction programs—in addition to what we define as “true” new construction measures (i.e., major renovation and new buildings)—the Evaluation Team concluded that the Stage 2 research should focus on true NC only.
- **Self-reports by end users would not provide an effective means for estimating NEIs associated with most NC measures.** Self-reported NEIs from customers or other market actors were not likely to provide meaningful results, since interview respondents had difficulty conceptualizing differences in operations relative to a hypothetical baseline that is new, but not energy efficient. Facility managers reported that if NEIs were assessed on NC projects, they were typically determined by design engineers during the project or facility design phase. This was particularly true of heating and cooling measures.
- **Self-reports by engineering firms would likely provide valuable insights to estimating NEIs across the range of projects for which they perform engineering services.** Given engineering firms’ breadth of knowledge across multiple projects, we concluded it would be valuable to conduct in-depth interviews with this group to gather information regarding key parameters to consider, and scenarios for which those factors may vary when estimating NEIs.
- **An engineering-based approach is warranted to estimate NEIs**. The data mining results suggested that we could utilize the standardized formulas developed through the 2012 C&I NEI Retrofit study as a basis for many NEI computations. DNV GL’s engineers could use measure descriptions, technical reference manuals, and data provided by existing C&I market characterization studies to construct sets of scenarios for examining operational cost and revenue impacts that result from using energy-efficient equipment, compared to standard efficiency measures. Engineers could then use their expertise in conjunction with the available data to construct estimates of these cost and revenue impacts for each measure category.

Based on these Stage 1 research findings—summarized in greater detail in a March 2015 report to the PAs and EEAC[6]—the Evaluation Team recommended (and subsequently employed) an engineering-based approach in Stage 2 to estimate NEIs associated with measures installed through the PAs' New Construction programs.

Stage 2 of this project consisted of the following tasks:

1. **Selection of a sample of true NC measures.** We combined the PAs' tracking data with the Dodge Players database[7] and tax assessors' data to isolate true NC projects, and then selected a sample of measures by BC measure category for our analysis.[8]
2. **Definition of baseline technology for each sampled measure.** We reviewed the Massachusetts Technical Reference Manual (TRM) and other sources to define the appropriate baseline for each sampled measure.
3. **Engineering/life-cycle cost analysis.** We estimated the difference in the average annual life-cycle cost between the baseline and energy-efficient technologies to reflect the NEI for each sampled measure.
4. **Estimation of NEI per unit energy savings.** We computed the average NEI per unit of energy savings to identify statistically significant NEIs for each of the measure categories used in the PAs' benefit cost analysis.

[6] Stage 1 Results and Stage 2 Detailed Research Plan—Commercial and Industrial New Construction Non-Energy Impacts Study—Commercial and Industrial New Construction Non-Energy Impacts Study. Prepared for the Massachusetts Program Administrators and EEAC Consultants. Prepared by DNV GL and Tetra Tech. March 20, 2015.

[7] This database contains information on all known new construction and major renovation projects in the Commonwealth.

[8] For NC measures contained in the PAs' tracking data, DNV GL will provide the PAs with a separate Excel file that maps the estimated NEIs to their appropriate true NC measure. For more recent program years, the PAs have implemented internal processes to isolate true new construction to which the NEI estimates can be more readily applied.

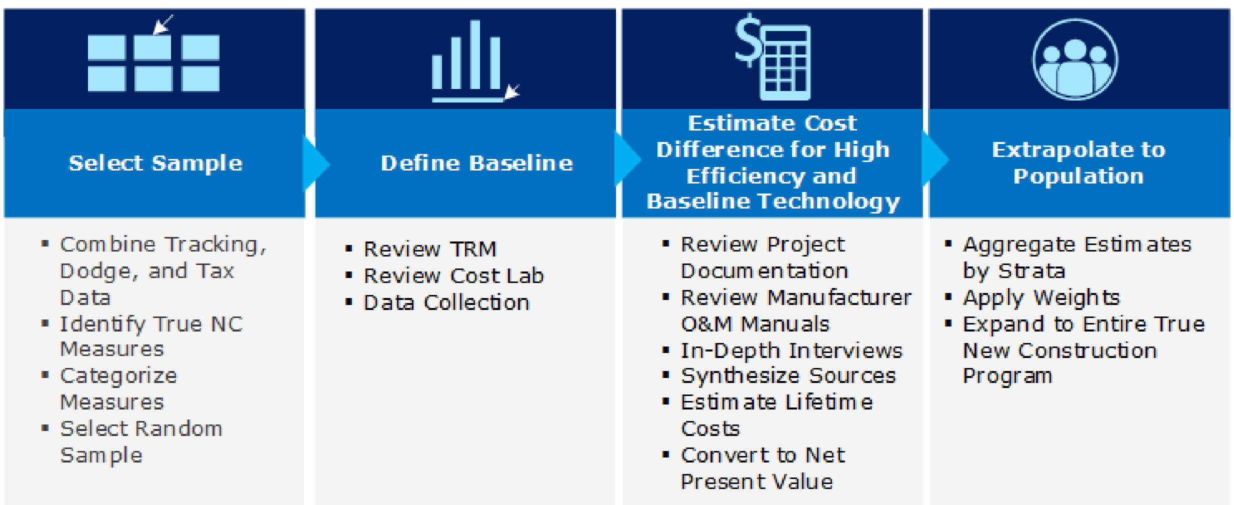
3. METHODOLOGY

3.1 OVERVIEW OF APPROACH

For this evaluation, we used an engineering cost-estimating approach to determine NEIs for true NC projects. We limited the analysis to impacts on operations and maintenance costs. Previous research shows that other sources of NEIs, such as changes in productivity, revenue, and comfort, may also result from energy efficiency measures; however, this study was limited to NEIs resulting from life-cycle cost differences due to the use of an engineering based approach. While in-depth interviews were not used to obtain NEI estimates, we did conduct a limited number of interviews with building owners, engineering firms, and public officials to inform the analysis and provide specific values of parameters needed in the engineering analysis.

Figure 1 provides a high-level overview of our approach, which consisted of four general steps.

Figure 1. Overview of NEI Estimation Process



1. First, we combined the PAs' tracking data with the Dodge Players database and tax assessors' data to isolate true NC projects, and then selected a sample of measures by BC measure category for our analysis.

2. Next, we reviewed the TRM, data contained in and required by Cost Lab, and other sources to construct data collection instruments and define the appropriate baseline for each sampled measure. CostLab is cost estimation software described in detail in Appendix A.

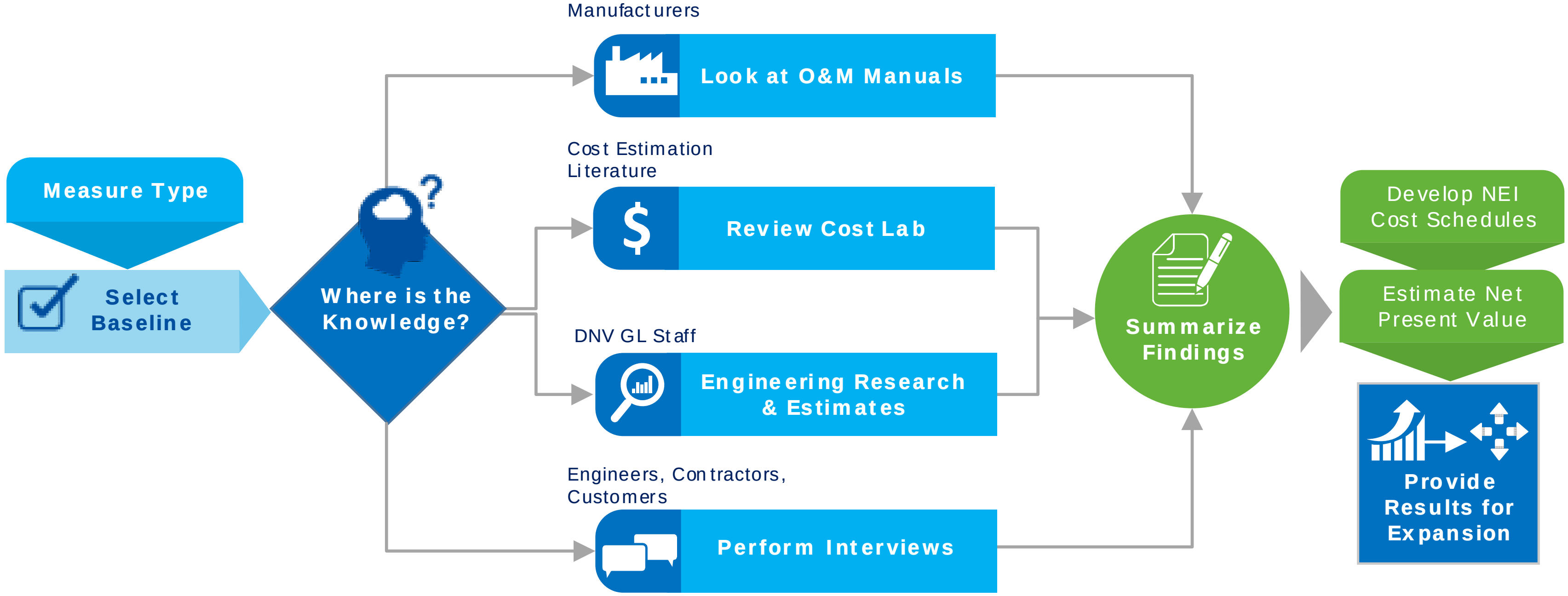
3. In the third step, we estimated the difference in the average annual life-cycle cost between the baseline and energy-efficient technologies to reflect the NEI for each sampled measure.

4. Finally, we computed the average NEI per unit of energy savings to identify statistically significant NEIs for each of the measure categories used in the PAs' BC analysis.

3.2 DATA ACQUISITION

The engineering analysis required data from a variety of sources to develop and corroborate the assumptions used to construct NEI estimates, as shown in Figure 2, which also depicts the flow of information used in our analysis. Each of these sources is discussed in the paragraphs that follow.

Figure 2. Sources of Information used in the Engineering Analysis



Manufacturers' operations and maintenance manuals. Manufacturer-produced operations and maintenance (O&M) manuals were used to provide manufacturer-recommended maintenance and repair schedules, a valuable input to life-cycle cost estimation.

CostLab software. CostLab is cost-estimation software produced by CBRE Whitestone that provides estimates for building O&M costs that many institutions and large businesses use to set their O&M budgets. While CostLab does not offer sufficient detail to differentiate between less and more efficient equipment, it does provide a good reference point for the O&M costs associated with the average piece of equipment or building system. We used these estimates in many cases to establish the baseline costs of ownership to which we would compare our efficient equipment estimates. CostLab provides costs in terms of annual maintenance, periodic repair, and replacement costs.

DNV GL staff. DNV GL's expertise in life-cycle costing provided a valuable resource for developing life-cycle cost estimates, as we were able to leverage engineers experienced in high-performance building design support. Our engineers have significant hands-on experience with Massachusetts-based facilities, enabling them to produce well-informed estimates for the lifetime costs of ownership of most pieces of equipment; we used the other sources of data as checks on our in-house estimates.

In-depth interviews. We performed 30 in-depth interviews with building owners, engineering firms, and public officials, as discussed in the section below.

In general, we attempted to find multiple sources of information to corroborate our findings. Where sources disagreed with one-another, we generally ranked them in the following ways:

- Operations and Maintenance Manuals
- Technical Reference Manual
- CostLab (for baseline costs)
- Interviewees
- DNV GL staff.

This ranking, however, had many exceptions in cases where a particular individual from either DNV GL or an interviewee was clearly the most knowledgeable source as determined by our team of engineers. In some cases, where one source made a positive estimate and the other negative, we chose not to make an estimate at all.

3.2.1 In-depth interview data collection details

In this section, we describe and review the in-depth interviews that provided a primary source of information for the engineering analysis. While the Stage 1 analysis found that end-use self-reports alone would not provide meaningful NEI estimates, the interviews with end users and other market actors provided other valuable information used in the engineering analysis. The in-depth interviews mostly provided procedural information to guide the methodology behind the engineering estimates, and sometimes provided specific data to be used directly in the engineering estimates. We asked each group of market actors to provide the following general insights:

- What benefits or costs do respondents see from energy-efficient equipment on new construction projects?
- How do these differ depending upon whether the project is a new building or a major renovation?
- What are the important technical, structural, and other parameters for determining whether these benefits are present?
- What sources of information can be used to provide estimates for these parameters?
- What are the values for specific technical parameters identified by the engineering staff through our initial review of the sampled measures and life-cycle cost computations?

The in-depth interviews provided the following general insights.

Public officials from government agencies. The Massachusetts Division of Capital Asset Management and Maintenance (DCAMM) provided a number of Facility Operations and Management Plans (FOMP) used to conduct benchmark costing of new facilities in the Commonwealth. While the reports do not compare energy efficient to less efficient options, they do provide a valuable source for assessing the impact of building features on general cost projections.

Engineering firms and contractors. Contractors and engineering firms who bid/perform maintenance contracts provided valuable insights into many of the technical and cost parameters necessary for computing NEIs. These contractors and engineers were better able to provide useful information than other respondent groups because they could compare their experiences across projects. We contacted a number of engineering firms who discussed sources of NEIs outside of O&M, but their responses indicated that, while “these probably exist, I can’t imagine how you’d quantify that.” These responses confirmed our decision to focus primarily on operations and maintenance NEIs in this study.

Building owners (program participants). Owners of industrial, food service, and grocery facilities provided useful information about the lifetimes, maintenance regimens, and certain other NEIs associated with their equipment. The true new construction projects that we reviewed included very few industrial projects. The industrial projects included in our sample were primarily injection-molding machines and uninterruptable power supplies. Our industrial respondents were unwilling to offer quantifiable data to support production increases or decreases for either of these measures. We suspect that injection-molding machines may offer small decreases in downtime, but we were unable to verify this with respondents.

Table 4 presents further details of the in-depth interview findings. These interview results are split into the following categories:

- Maintenance – How does routine maintenance recommended by manufacturers differ between energy efficient and baseline equipment?

- Repair – How does the requirement for repairs differ over the lifetime of energy efficient equipment and baseline equipment?
- Replacement – How do the lifetimes of efficient and baseline equipment differ?
- Other – NEIs that do not fit into one of the other categories. Often associated with unquantified production increases.

Table 4. Summary of Stage 2 In-Depth Interview Findings

Technology	Respondent Type	NEI Category	Interview Findings
Boilers	Contractor	Maintenance	On energy efficiency boilers, exhaust fans and heat exchangers require more frequent maintenance.
		Replacement	Lifespans of condensing vs. non-condensing equipment is a debated topic. Over the years, the quality of condensing equipment has improved in some ways, but decreased in other ways. No contractors were willing to offer specific guidance on the impacts in lifespan associated with a condensing heat exchanger, though many thought there would be a reduction.
Comprehensive Design	Contractor	Other NEI	There aren't any NEIs associated with an increased level of insulation or air sealing in the building shell. Materials selection has more to do with extending or shortening the life, though this is unrelated to MassSave.
	Engineer	Maintenance	There are a lot of items related to controls that can increase maintenance costs. Each additional sensor point requires additional maintenance. This is extremely site-specific in terms of how often they maintain their sensor points and what kind (brand, type, model) of sensors they use.
		Other NEI	There are several code-compliance paths for energy. For comprehensive design projects, a building simulation model is used and compared to a baseline model. In some cases, this allows a building owner to install a less-efficient building system (e.g., a high percentage of glazing) by increasing the efficiency of another component (e.g., lighting). We were unable to identify any specific examples of NEIs being affected by this type of tradeoff.
	Owner	Maintenance	A lot of the energy efficient technologies associated with laboratories require cleaning and calibration. Control settings are often over-ridden. Not able to quantify any experiment-specific benefits of improved controls.
			Similarly to engineers, owners found that controls can be difficult to set up, configure, commission, and keep operating well.
Compressed Air	Engineer	Maintenance	Screw compressors are designed to last the life of the system, compared to reciprocating compressors which require periodic rebuilds.
Food Service	Owner	Maintenance	Some new equipment may require additional water filtration or de-scaling, but this varies more by manufacturer than by efficiency level.
		Other NEI	Efficient equipment performs more effectively, and can cook a higher volume of food using the same amount of space, faster and at a higher quality which results in less waste.
		Repair	There may be differences with regard to reduced repair and cleanup requirements for energy efficient equipment, but responses were inconsistent and not quantifiable.

Summary of Stage 2 In-Depth Interview Findings (Continued)

Technology	Respondent Type	NEI Category	Interview Findings
Hot Water	Contractor	Maintenance	Annual maintenance for energy efficient equipment is typically increased due to descaling requirements.
		Repair	High efficiency equipment—especially indirect or tankless equipment—generally lasts longer and requires fewer repairs such as anode replacements.
		Replacement	Tankless equipment life varies by manufacturer.
Industrial Process	Owner	Maintenance	Uninterruptible Power Supply systems do not offer NEIs. Typically they do not fail but are replaced when they become obsolete because of new technologies. Maintenance is not different between different systems.
			Injection Molding Machines can be oil-filled, hybrid, or full electric. Oil changes result in the primary difference between the different options, with full electric systems not requiring them at all.
		Other NEI	There may be some site-specific NEIs associated with VFDs controlling conveyor belt speed.
Lighting	Contractor	Replacement	Recycling bulbs can add a couple hundred dollars per job. Energy efficient bulbs last longer, reducing recycling costs for the customer over time.
			It is often faster and cheaper to replace an entire fixture versus replacing a ballast.
			Ballasts are replaced every 3-5 years.
	Owner	Maintenance	LEDs require very little maintenance, but no building owners we contacted have replaced their larger LED fixtures yet.
		Repair	Fixtures are often fully replaced rather than simply replacing the ballasts.
		Replacement	Ballasts typically replaced every five years for fluorescents.
			Owners indicate that small LED fixtures seem to have a high failure rate, similar to halogen bulbs.
Motors	Engineer	Other NEI	For energy efficient motors: -There is a reduction of inrush current due to soft start. -Reduced heat due to running at partial load. -The ability to adjust speed which increases productivity. -There is reduced upfront work due to packaged systems coming pre-programmed.
		Replacement	For energy efficient motors: -Bearings can wear faster causing premature failure. -Additional electric components susceptible to failure. -Electrical flux concentrates at specific points inside motor, causing premature failure.
	Owner	Other NEI	Using VFDs offer no NEIs.
Other Gas Heating	Owner	Maintenance	Infrared heaters require less maintenance than other heating methods due to fewer moving parts and a simpler design.
Refrigeration	Contractor	Maintenance	LED lights in refrigerated cases have less maintenance than fluorescent.
		Replacement	There is a suspicion that items in cases which reduce the amount of heat that needs to be removed increases the compressor lifetime, but they cannot quantify this.
		Other NEI	Energy efficient refrigeration equipment might reduce food spoilage, but unable to quantify this effect.

3.3 ENGINEERING ANALYSIS SAMPLE DESIGN

The first step in the engineering analysis was to identify true NC measures that were part of NC projects for which NEI estimates would be produced. The 2013 C&I program tracking database contains data for the PAs' NC programs; while the upstream projects included as part of this program are explicitly identified in the data, there is not a similar identifier for constructing a frame of true NC projects as distinct from replace on failure/natural replacement measures. Therefore, the first step in constructing the sample design was to isolate the true NC measures and stratify or group those measures into the most appropriate segments for sampling.

We matched records from the 2013 C&I program tracking database to records in the Dodge data to eliminate replace on failure/natural replacement measures. We supplemented that analysis with a review of the year the tracked building was constructed (contained in the tax assessors' data) to identify additional new buildings. We identified approximately 20 percent of project locations in the PA NC tracking data as true NC (244 out of 1,206 locations), and determined that approximately 6 percent of all 2011–2013 NC projects listed in the Dodge data (244 out of 4,095 locations) participated in one of the PAs' NC energy efficiency programs. We identified 957 true new construction measures at these 244 locations.

Next, we stratified the true new construction measures by measure type, dividing the population of true new construction projects into four tracks: Prescriptive Electric, Prescriptive Gas, Custom Electric, and Custom Gas. Within each of these tracks, we grouped the individual true NC measures into sample strata (sample categories) according to the specific measure categories/types and end uses that the PAs require for their BC models. This formed the sample frame for the sample of measures used in this study.

We selected the sample in a way that produces an optimally allocated sample for NEI ratio or factor estimation—in this case, NEI$/unit of energy saved. An optimal sample provides the best possible precision for a particular sample size. The sample design was projected to provide relative precision of overall electric or gas NEIs of about 8% to 14% at the 90% confidence level. However, projections for individual measures varied, and in this study, the focus is on individual measure categories, not an overall value for each fuel type.

Table 5 presents the sample frame and sample allocation for prescriptive and custom electric and gas measures. Our sample consisted of 50 custom electric measures drawn from 9 measure types, 114 prescriptive electric measures drawn from 7 measure types, 30 custom gas measures drawn from 7 measure types, and 61 prescriptive gas projects drawn from 4 measure types. This resulted in an overall sample of 255 true NC measures out of a population of 957 measures in the 2013 program tracking data.

Table 5. Sample Design for Engineering Analysis and Expected Relative Precisions

Fuel Type	Project Track	Sample Category	Population Measures	Population Savings (kWh/Therms)	Sampled Measures	Optimistic Relative Precisions	Conservative Relative Precisions
Electric	Custom	Comprehensive Design	13	2,845,172	8	26%	36%
		Compressed Air	5	802,770	4	13%	18%
		HVAC	17	2,348,957	6	33%	47%
		Industrial Process	5	1,565,025	5	0%	0%
		Lighting	24	2,998,970	15	12%	17%
		Motors	4	612,932	4	0%	0%
		Other	2	567,487	2	0%	0%
		Refrigeration	13	2,040,845	5	40%	58%
		Building Shell	1	80,240	1	0%	0%
		Subtotal	**84**	**13,862,398**	**50**	**10%**	**14%**
	Prescriptive	Commercial Kitchen	1	1,364	1	0%	0%
		Compressed Air	23	533,826	10	21%	30%
		HVAC	134	1,104,397	15	29%	41%
		Industrial Process	1	5,389	1	0%	0%
		Lighting	440	2,977,041	49	12%	17%
		Motors	113	2,537,183	37	12%	18%
		Other	1	73,616	1	0%	0%
		Subtotal	**713**	**7,232,816**	**114**	**8%**	**11%**
Gas	Custom	Comprehensive Design	10	267,011	8	11%	16%
		HVAC/ Heat Recovery	12	155,143	7	21%	29%
		Industrial Process	2	20,608	2	0%	0%
		Other	7	46,534	5	11%	16%
		Boilers	10	90,000	5	32%	46%
		Building Shell	1	57	1	0%	0%
		Other Gas Heating	2	46,466	2	0%	0%
		Subtotal	**44**	**625,819**	**30**	**8%**	**12%**
	Prescriptive	Commercial Kitchen	14	8,897	9	20%	29%
		HVAC/ Heat Recovery	27	4,520	13	23%	33%
		Boilers	68	79,296	34	12%	17%
		Other Gas Heating	7	2,138	5	24%	35%
		Subtotal	**116**	**94,851**	**61**	**10%**	**14%**
		Total	**957**	**21,815,884**	**255**		

3.4 SELECTING BASELINES

After stratifying and selecting the sample of measures, the first step in estimating NEIs for each measure was to define the baseline technology from which we could measure facility cost changes relative to the installed energy efficient technology. When estimating NEIs for specific measures, the choice of baseline is crucial. Specific features of the baseline equipment will dictate its maintenance and repair schedules, which is why it is important to choose the correct baseline. For prescriptive measures included in the TRM, we used the associated baselines defined in the TRM; these baselines are typically based upon the

International Energy Conservation Code (IECC) prescriptive code-compliance path. For example, in the IECC, the baseline for an energy-efficient centrifugal air-cooled chiller is a less-efficient centrifugal air-cooled chiller rather than a different kind of chiller.

However, we could utilize TRM baselines only to the extent that they gave us the information we needed. This was limited, because the TRM does not always identify the baseline and efficient equipment features that correlate most strongly with NEIs. As an example, the TRM does not specify a baseline compressor type (such as scroll, screw, or reciprocating) for the High-Efficiency Air Compressor measure. In cases where the TRM did not specify the applicable equipment characteristics, or where the TRM did not address the choice of baseline (such as for custom measures), we selected the most commonly installed code-compliant equipment type as the baseline using our own expertise and experience and the results of our in-depth interviews.

Performance path-based projects, classified as a single BC measure category “Custom – Comprehensive Design Analysis (CDA),” posed a particular challenge for identifying baseline technologies. These performance path-based projects involve the installation of multiple measures across multiple measure categories (e.g., lighting and HVAC) but receive incentives based on the extent to which the new or renovated building or building system as a whole exceeds the efficiency required by code. As noted, for prescriptive and custom measures that are not performance path-based, the baseline is defined in comparison to a specific piece of equipment, using the TRM as a guide where applicable. For performance path-based projects, however, the baseline is not defined based on the equipment but for the building or building system as a whole. The baseline is typically defined by the building simulation modeling assumptions identified in ASHRAE 90.1-2007 Appendix G. In this situation, the baseline for a centrifugal chiller installed in a CDA project could be a screw chiller or even several unitary rooftop units.

To assist in the development of baseline conditions for the performance path-based measure, DNV GL requested that the PAs provide full documentation of the projects. In some cases, the program documentation clearly communicated how the baseline was defined. Where this was missing, the Evaluation Team members used their industry experience and, where appropriate, customer interviews, to determine which baseline code-compliant building system would mostly likely have been installed in the absence of program support.

3.5 ESTIMATING THE COST DIFFERENCES: BASELINE AND ENERGY EFFICIENT TECHNOLOGIES

To estimate the cost differential between the baseline and energy efficient technologies, we constructed detailed cost schedules for the baseline and energy-efficient technologies, which formed the basis for the NEI estimates. Our engineers used repair, replacement, and maintenance costs for baseline and energy-efficient technologies provided by CostLab, our technical knowledge, and reported maintenance and replacement schedules outlined in the manufacturer O&M manuals. Our engineers also used the information obtained from the in-depth interviews to develop or corroborate these costs.

Next, the costs were classified into three types for further analysis:

- *Annual maintenance* – Routine maintenance recommended by manufacturers, such as annual oil changes for reciprocating air compressors. The frequency and costs for maintenance activities can differ between baseline and installed equipment.
- *Periodic repair* – Many types of equipment require repairs during their lifetimes, while other types are not repaired but simply disposed of. For example, a reciprocating air compressor is likely to require a simple rebuild every three years whereas a screw compressor does not. Other types of equipment are simply disposed of rather than repaired, such as many types of light fixtures.
- *Replacement* – For equipment for which the baseline option is likely to fail before the end of the useful life of the energy-efficient equipment, we included and amortized the cost of replacement of the option with a shorter lifetime. We considered the type of equipment that would be installed as a replacement to represent the baseline condition, and found that owners replace equipment in-kind with similar equipment in most cases, except for lighting. Given the rapid adoption of more energy efficient LED lighting, we assumed that baseline lighting equipment would be replaced in-kind with a similar type of lighting for the first replacement cycle, but with LED lighting for subsequent replacement cycles. This is discussed in more detail below.

Once we developed the NEI cost schedules and cost breakdowns, the life-cycle costs were amortized to provide the average annual cost of maintaining the baseline and energy-efficient equipment using the following formula:

$$A = P\frac{r(1+r)^n}{(1+r)^n - 1}$$

Where:

A = payment Amount per year

P = initial Principal (loan amount)

r = interest rate per year

n = total number of payments or periods

Once all costs were included, we calculated the net present value using the following formula:

$$NPV = \sum\left(\frac{A}{(1+r)^n}\right)$$

Where:

A = cost Amount per year

r = interest rate per year

n = applicable number of payments

We assumed the following in computing the NPV of life-cycle costs:

- *Planning horizon* – For each line item, we defined the measure life of the longer-lasting piece of equipment (installed or baseline) to contrast the life-cycle costs.
- *Discount rate* – We applied a discount rate of 0.44%, as reported in the 2016–2018 Three-Year Plan.[9]
- *Capital replacement* – Equipment replaced prior to the end of the planning horizon was assumed to be replaced in-kind and amortized over its useful life. The annual payment of that equipment appeared as a liability starting in the year the equipment was replaced until the end of the planning horizon. For example, if the baseline technology will be replaced in year 10 of a 15-year planning horizon, we amortized the value of the new equipment starting in year 10 over a 10-year planning horizon, so there would be a replacement cost appearing as a liability in years 10 through 15. The difference in the average annual cost of the energy-efficient and baseline technologies is the estimated NEI for each measure.

3.5.1 NEI computations by measure category

This section provides detailed examples of NEI computations for two measure categories. The first example is for lighting, which is the most basic NEI computation. The second is for the performance path-based measure category, which is the most complex NEI computation. Details of NEI computations for all measure categories are provided in Appendix A of this report.

A. Example of cost differences – lighting measures

Table 6 provides an example of this process for lighting measures. The table includes all of the costs associated with the maintenance and repair of the fixtures over the 15-year lifetime defined in the TRM. For presentation purposes, these costs are aggregated to reflect the cost per fixture, assuming three lamps per fixture for fluorescent and a standard 3-lamp equivalent LED.

The table shows that the baseline T8 fixture requires lamp changes approximately every three years, and replacement fixtures every five years. However, LED fixtures require replacement only every ten years. Further, because LEDs are brighter than T8s (baseline), they require fewer fixtures to light a given area, reducing the labor and equipment costs associated with the lamp replacements. While this is not directly shown in Table 6, it is imbedded in the costs for bulb and fixture replacements. This table presumes that a larger number of fixtures and bulbs must be installed under a T8 scenario. For a detailed representation of the actual numbers affected by this issue, see Table 76 in Appendix A.

[9] http://ma-eeac.org/wordpress/wp-content/uploads/2016-2018-DRAFT-Electric-Gas-Energy-Efficiency-Plan.pdf.

We used differences such as these to calculate the NPV of the life-cycle costs and amortize to provide the average annual cost of owning each technology. The difference between the average annual amortized cost of the baseline and energy-efficient technologies reflect the NEI associated with that measure.

The Evaluation Team decided that we would assume that a fixture is replaced with the same kind of fixture during its first replacement in the analysis period. The second time it is replaced, it is replaced with an LED fixture to reflect the rapid adoption of LEDs in the marketplace. The grey areas in Table 6 represent this time period during which bulb changes are no longer necessary due to the LED being installed.

The values in red represent costs that occur during the analysis period but for which the entire value is not captured during the analysis period. For these items, we amortize the value of that cost over the lifetime of its utility, take a single year's worth of that amortized cost, and apply it to each year of the analysis period after its occurrence.

For example, in the table below a T8 fixture is presumed to be replaced with an LED fixture in year 10. LED fixtures last ten years, but there are only five years remaining in the analysis period. Therefore, we amortized the cost of the LED fixture over ten years to get $14 per year. Applying this $14 for each of the remaining five years accounts for the fact that the LED fixture will continue to be in-place and in operation after our analysis period (for five more years), and so much of its value remains.

We estimate NPV costs of $209 and $81 for a T8 and LED fixture, respectively, over an analysis period of 15 years. As a result, the estimated NEI for an efficient LED fixture is $129 relative to the baseline T8 fixture.

Table 6. Example of NPV of Costs for a Sampled Lighting Fixture Measure (Assuming 3 Lamps per Fixture) *

Type	Cost Category	Costs by Year (values measured in dollars)															Net Present Value		
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Measure Totals		NEI
Baseline T8	Bulb Change	0.0	0.0	9.9	0.0	9.9	0.0	0.0	9.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	29.0	209	129
	Recycle	0.0	0.0	3.2	0.0	3.2	0.0	0.0	3.2	0.0	3.2	0.0	0.0	0.0	0.0	0.0	12.3		
	Fixture Replacement	0	0	0	0	89	0	0	0	0	14	14	14	14	14	14	168.1		
Efficient LED	Bulb Change	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	81	
	Recycle	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		
	Fixture Replacement	0	0	0	0	0	0	0	0	0	14	14	14	14	14	14	80.9		

*Items shown in red reflect the annual cost of replacing the fixture with an LED fixture amortized over 10 years. For fixture replacement costs, we assume that T8 fixtures would be replaced in-kind in Year 5, but with an LED fixture in Year 10.

B. Example of cost differences – (Special Case) performance path-based measure category

This section describes our approach for estimating NEIs associated with the performance path-based (CDA project) measure. Estimating NEIs for the performance path-based measure category requires a different approach than that used for prescriptive or traditional custom measures. Custom-comprehensive projects are incentivized based on the extent to which the savings from the overall project (or collection of individual measures installed) performs relative to the applicable baseline or code (as modeled). This posed the following challenges for estimating NEIs for this measure category:

- Program tracking records for these projects report savings for the overall project under a single “Custom – Comprehensive Design Analysis (CDA)” measure, rather than reporting on the savings associated with the individual measures installed.
- The PAs’ tracking records often do not report the individual measures installed; rather, they simply list the measures collectively and singly as "Comprehensive Design – Custom,” one for electric and one for gas.
- It was possible for some projects reported singly under the “CDA – Gas” measure to also involve the installation of some electric measures, and vice-versa, even though savings were only reported for the fuel under which the project was reported. Without a database that linked projects under both the electric and gas programs, we could not readily determine whether these projects appeared in both the electric and gas databases, or identify them in the other database even if we expected them to be there.
- The total CDA project savings reported in the PA tracking data sometimes were not entirely consistent with the reported (or modeled) sum of the measure- or equipment-level savings estimated in the underlying documentation provided by the PAs (see Step 2 below).

In the text below, we first describe our general approach to estimating the NEIs for the performance path-based measure, which addressed the concerns mentioned above, then we provide an illustrative example of the NEI estimation process for this measure.

Our approach to estimating the NEIs for the performance path-based measure includes seven general steps:

1. *Select a sample of CDA projects* – We selected a sample of CDA projects (both electric and gas) from the 2013 program tracking data. This step is similar to the first step in estimating NEIs in other measure categories. However, it is important to note that these projects were listed in the tracking data under a single measure category (i.e., CDA – Electric or CDA – Gas) and did not indicate which individual measures or technical equipment were actually installed. The sample of projects drawn included 8 custom-comprehensive electric projects and 8 custom-comprehensive gas projects.
2. *Identify line items (the specific equipment) installed from paper documentation* – Because many of the records in the program tracking data did not provide detailed descriptions of the actual measures/technologies installed, we requested that the PAs provide the paper project documentation (e.g., Technical Assistance (“TA”) studies) detailing the measures installed on each sampled project. The paper documentation contained the necessary information for identifying the measures/technologies installed, identifying the baseline, and estimating life-cycle costs. We used this information to estimate NEIs associated with each line item installed using the subsequent steps.
3. *Identify the baseline technologies* – Incentives for the performance path-based measure are based on the extent to which the new or renovated building or building system (as a whole) exceeds the efficiency required by code. Selecting the baseline was particularly challenging because it is not defined based on the equipment, but for the building or building system as a whole. For example, the baseline is typically

defined by the building simulation modeling assumptions as defined in ASHRAE 90.1 Appendix G. In this situation, the baseline for a centrifugal chiller installed in a CDA project could be a screw chiller or even several unitary rooftop units. We relied on the paper documentation to assist in defining the baseline for each installed measure or technology. In some cases, the program documentation clearly communicated how the baseline was defined. In cases where the baseline was different than that assumed for prescriptive measures by the TRM, we used the alternate baseline provided in the project paperwork. The chiller portion of the example found in Appendix A.2.1 provides one example of this. Where the PAs were not able to provide paper documentation, the Evaluation Team used its industry experience and, where appropriate, customer interviews, to determine which baseline code-compliant building system would mostly likely have been installed in the absence of the program.

4. *Estimate NEIs for each line item separately*[10] – Based upon the number, size, and other specifications for the actual equipment installed, we estimated the NPV of the life-cycle cost differences between the energy-efficient and baseline technologies for each line item identified in the paper documentation. Since many of the NEIs for these line items corresponded directly to their prescriptive counterparts, we used the same prescriptive-based NEI calculation formulas or specs developed previously. In this case, we added them to the set of NEI formulas for the performance-based measure. Further, we considered the combined operational cost impact of all line items for a sampled project, as some line items may have joint impacts on operational costs.

5. *Isolate NEIs to a single fuel type* – CDA projects reported in the electric and gas tracking data reported only savings associated with the respective fuel, and we were not able to readily determine whether the projects appeared in the other fuel type's program tracking records. Therefore, for each sampled project, we restricted the analysis to include NEIs associated with those line items that were relevant to the source program tracking database's fuel type. In other words, if the project record was identified from the gas program tracking database, we considered only line items that were relevant to gas measures (and gas savings). In our sample, none of the measures that affected both gas and electric savings (such as heat recovery or building shell) resulted in any quantifiable NEIs, so we did not have to determine how to split the NEIs between the electric and gas measures.

6. *Calculate the total NEI for each sampled project* – Next, we combined (summed) the NEIs for all of the individual measures/technologies or line items associated with the relevant fuel type.

7. *Calculate NEI / kWh or therm for the measure category* – Finally, we calculated the NEI per kWh or per therm factor across all sampled projects.

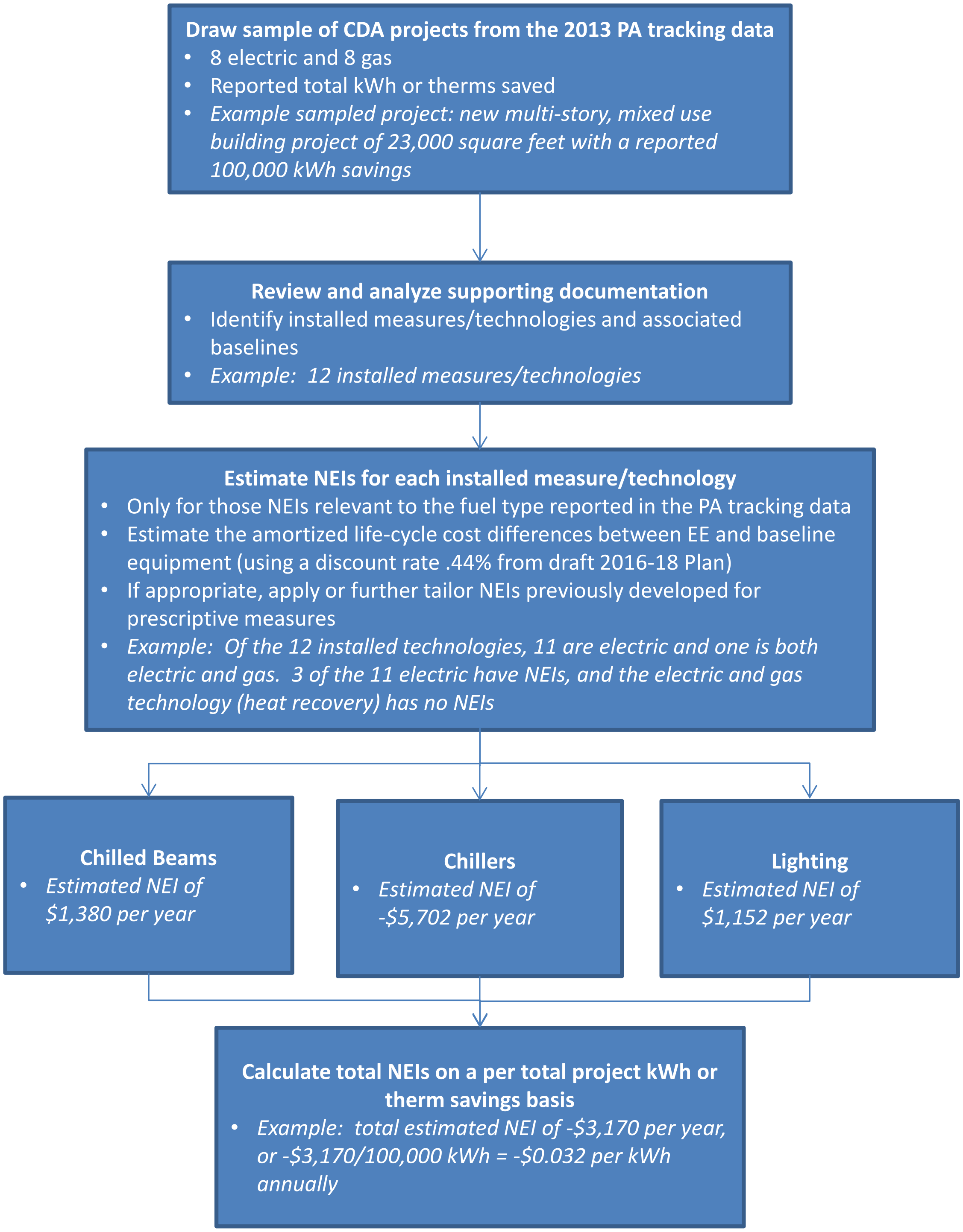
[10] Detailed descriptions of the NEI computations are provided in Appendix A.

C. Example of NEI Computations for Performance Path-Based Projects

Figure 3 illustrates how we calculated savings for one sample NC CDA project.

(Example) CDA project description: The building is an approximately 23,000-square-foot, multi-story, mixed-use building for which the program claimed approximately 100,000 kWh electric savings. The program did not claim any gas savings.

Figure 3. Process for Estimating NEIs Resulting from Performance Path-Based Measure



Section A.2.1 (Appendix A) provides additional detail on how we calculated savings for this sample NC CDA project.

3.6 ESTIMATE NEI PER UNIT OF ENERGY SAVINGS FACTOR FOR EACH MEASURE CATEGORY

Once we estimated the NEIs for each sampled measure (and the performance path-based measure category for each of the sampled CDA projects), the final step was to calculate the estimated NEI per unit of energy savings for the group of measures represented by our sample. This analysis was done at the sample BC measure level. We apply a weighting factor (w_{Aj}), which is the sampling case weight, for each sampled measure's estimated NEI to construct a "weighted" NEI for the population of measures in the respective BC or measure category. This factor is computed by dividing the total number of measures in a stratum (i.e., the total population of measures in the BC measure category – see Table 5) by the number of sampled measures in that stratum.

Similarly, the same factor is applied to the energy savings (kWh or therms) reported for each sampled measure. Finally, the sum of the total weighted NEIs is divided by the sum total weighted savings to derive the NEI per unit of energy savings factor, R_I, ($ per kWh or therm) for the stratum (e.g., BC measure category).

The NEI factor R_I was calculated using the following formula:

$$R_I = \frac{\sum_{j \varepsilon A} G_{Ij} w_{Aj}}{\sum_{j \varepsilon A} G_{Tj} w_{Aj}}.$$

Where:

G_{Ij} = evaluation estimate of gross non energy impacts for sampled measure *j (or CDA project j)*

G_{Tj} = tracking estimate of gross savings for sampled measure *j*

w_{Aj} = sample expansion factor for individual measure j is equal to the total number of measures in the stratum for that measure divided by the number of sampled measures in the stratum.

The tables in Appendix A provide detailed calculations for each sample or BC measure category.

4. RESULTS

The estimated total annual value of NEIs for 2013 NC program participants that conducted true NC projects was $488,122 per year, across the total population of 957 true NC measures installed in 2013, including 13 electric projects and 10 gas projects listed under the single performance path-based CDA measure category.[11] Table 7 provides a breakout of estimated NEIs by project track.[12] The following discussion details the results of the engineering analysis. We first discuss the general results from the engineering analysis, and then discuss several special considerations in the analysis.

Table 7. Estimated Annual NEIs

Project Track	Annual NEI
Custom Electric	$ 89,261
Prescriptive Electric	$ 372,353
Custom Gas	$ (3,643)
Prescriptive Gas	$ 30,151
Total	**$ 488,122**

Table 8 and Table 9 present the estimated NEI factors (NEI/kWh or therm), whether that factor is statistically different from zero for each measure type, and average annual NEIs per measure (computed by multiplying the factor times the average annual savings per measure).

In most cases, we developed and report NEI estimates by measure and fuel for prescriptive and custom measures separately, with the exception of custom commercial kitchen. We present the prescriptive commercial kitchen NEI estimate for the Custom Food Service benefit cost category, since there were no custom commercial kitchen measures in the sample frame.

At the PAs' request, we have also broken out our NEI estimates by those expected for replacement (i.e., reduced replacement costs or the increased measure life of the more efficient equipment) and those expected for changes in operations and maintenance.

[11] The total annual value is calculated by summing the products of DNV GL's derived $NEI/unit of energy savings factor and the weighted 2013 annual energy savings for each sampled measure.
[12] The estimates shown in Table 7 are intended to illustrate the estimated magnitude of the total annual NEIs realized for true NC projects in 2013 because they include NEIs for some measure categories that did not meet the test for statistical significance.

Table 8. Electric NEI Results of Engineering Analysis by PA Benefit-Cost Category, Project Track, and Measure Type

Benefit- Cost Category	Sample Category	Average Annual NEI per Measure	Lifetime Replacement NEI/ kWh	Operations and Maintenance NEI/ kWh	Overall NEI/kWh	90% CI Low	90% CI High	Statistically Significant?	Source of Recommended NEI
Custom									
CHP	N/A	N/A	N/A	N/A	**N/A**	N/A	N/A	Not Studied	Not Sampled
Comprehensive Design	Comprehensive Design	$ 207	$ 0.002	$ (0.001)	**$ 0.001**	$ (0.007)	$ 0.009	Not Recommended	Custom Electric Comprehensive Design
Compressed Air	Compressed Air	$ 1,155	$ 0	$ 0.026	**$ 0.026**	$ 0.002	$ 0.050	b	Custom Compressed Air
Food Services	Commercial Kitchen	$ 0	$ 0	$ 0	**$ 0**	$ 0	$ 0	0	Prescriptive Electric Commercial Kitchen
HVAC	HVAC	$ 330	$ 0.001	$ 0.001	**$ 0.001**	$ (0.002)	$ 0.005	a	Custom Electric HVAC/Heat Recovery
Lighting	Lighting	$ 320	$ 0.003	$ (0.000)	**$ 0.003**	$ (0.001)	$ 0.007	a	Custom Electric Lighting
Motors & VFD	Motors	$ 0	$ 0	$ 0	**$ 0**	$ 0	$ 0	0	Custom Electric Motors
Other	Other	$ 0	$ 0	$ 0	**$ 0**	$ 0	$ 0	0	Custom Electric Other
Process	Industrial Process	$ 3,990	$ 0.000	$ 0.013	**$ 0.013**	$ 0.004	$ 0.022	b	Custom Electric Industrial Process
Refrigeration	Refrigeration	$ 3,657	$ 0.003	$ 0.009	**$ 0.012**	$ 0.003	$ 0.021	b	Custom Electric Refrigeration
Overall	**Overall**	**$ 1,063**	**$ 0.002**	**$ 0.004**	**$ 0.006**	**$ 0.002**	**$ 0.009**	**c**	**Custom Electric Overall**
Prescriptive									
Compressed Air	Compressed Air	$ 1,717	$ 0	$ 0.038	**$ 0.038**	$ 0.033	$ 0.042	c	Prescriptive Compressed Air
Food Services	Commercial Kitchen	$ 0	$ 0	$ 0	**$ 0**	$ 0	$ 0	0	Prescriptive Electric Commercial Kitchen
HVAC	HVAC	$ 0	$ 0	$ 0	**$ 0**	$ 0	$ 0	0	Prescriptive Electric HVAC
Lighting	Lighting	$ 757	$ 0.014	$ 0.007	**$ 0.020**	$ 0.013	$ 0.028	c	Prescriptive Electric Lighting
Motors & VFD	Motors	$ 0	$ 0	$ 0	**$ 0**	$ 0	$ 0	0	Prescriptive Electric Motors
Overall	**Overall**	**$ 522**	**$ 0.009**	**$ 0.006**	**$ 0.016**	**$ 0.010**	**$ 0.021**	**c**	**Prescriptive Electric Overall**

a: Recommended, but not well determined (.10 < p ≤ .50)

b: Recommended, statistically significant at 90% confidence (p ≤ .10)

c: Recommended, statistically significant at 99% confidence (p ≤ .01)

0: NEIs are determined to be negligible

Not Studied: No measures of this type in our sample

Not Recommended: p >.50

Table 9. Gas NEI Results of Engineering Analysis by PA Benefit-Cost Category, Project Track, and Measure Type

Benefit- Cost Category	Sample Category	Average Annual NEI per Measure	Lifetime Replacement NEI/ Therm	Operations and Maintenance NEI/ Therm	Overall NEI/Therm	90% CI Low	90% CI High	Statistically Significant?	Source of Recommended NEI
Custom									
Building Shell	Building Shell	$ 0	$ 0	$ 0	**$ 0**	$ 0	$ 0	0	Custom Gas Building Shell
Comprehensive Design	Comprehensive Design	$ (117)	$ 0	$ (0.004)	**$ (0.004)**	$ (0.008)	$ 0.000	a	Custom Gas Comprehensive Design
Condensing Boiler	Boilers	$ (73)	$ 0	$ (0.006)	**$ (0.006)**	$ (0.013)	$ 0.001	a	Custom Gas Boilers
Combination Boiler/Hot Water Heater	Boilers	$ (73)	$ 0	$ (0.006)	**$ (0.006)**	$ (0.013)	$ 0.001	a	Custom Gas Boilers
Condensing Unit Heater	Other Gas Heating	$ 0	$ 0	$ 0	**$ 0**	$ 0	$ 0	0	Custom Gas Other Gas Heating
Food Services	Commercial Kitchen	$ 2,732	$ 0	$ 3.399	**$ 3.399**	$ 0.961	$ 5.836	b	Prescriptive Gas Commercial Kitchen
Furnace	Other Gas Heating	$ 0	$ 0	$ 0	**$ 0**	$ 0	$ 0	0	Custom Gas Other Gas Heating
Heat Recovery	HVAC/ Heat Recovery	$ 4	$ 0	$ 0.000	**$ 0.000**	$ (0.000)	$ 0.001	a	Custom HVAC/ Heat Recovery
Heating	Other Gas Heating	$ 0	$ 0	$ 0	**$ 0**	$ 0	$ 0	0	Custom Gas Other Gas Heating
Hot Water	HVAC/ Heat Recovery	$ 4	$ 0	$ 0.000	**$ 0.000**	$ (0.000)	$ 0.001	a	Custom HVAC/ Heat Recovery
HVAC/ Heat Recovery	HVAC/ Heat Recovery	$ 4	$ 0	$ 0.000	**$ 0.000**	$ (0.000)	$ 0.001	a	Custom HVAC/ Heat Recovery
Infrared Heaters	Other Gas Heating	$ 0	$ 0	$ 0	**$ 0**	$ 0	$ 0	0	Custom Gas Other Gas Heating
Other	Other	$ (277)	$ 0	$ (0.032)	**$ (0.032)**	$ (0.092)	$ 0.029	a	Custom Gas Other
Process	Industrial Process	$ 72	$ 0	$ 0.007	**$ 0.007**	$ (0.011)	$ 0.025	Not Recommended	Custom Gas Industrial Process
Overall	**Overall**	**$ (83)**	**$ 0**	**$ (0.005)**	$ (0.005)	**$ (0.008)**	**$ (0.001)**	**b**	**Custom Gas Overall**
Prescriptive									
Combination Oven	Commercial Kitchen	$ 2,732	$ 0	$ 3.399	**$ 3.399**	$ 0.961	$ 5.836	b	Prescriptive Gas Commercial Kitchen
Condensing Boiler	Boilers	$ (137)	$ 0	$ (0.084)	**$ (0.084)**	$ (0.111)	$ (0.057)	c	Prescriptive Gas Boilers
Combination Boiler/Hot Water Heater	Boilers	$ (137)	$ 0	$ (0.084)	**$ (0.084)**	$ (0.111)	$ (0.057)	c	Prescriptive Gas Boilers
Condensing Unit Heater	Other Gas Heating	$ 17	$ 0	$ 0.053	**$ 0.053**	$ 0.043	$ 0.063	c	Prescriptive Gas Other Gas Heating
Convection Oven	Commercial Kitchen	$ 2,732	$ 0	$ 3.399	**$ 3.399**	$ 0.961	$ 5.836	b	Prescriptive Gas Commercial Kitchen
Conveyer Oven	Commercial Kitchen	$ 2,732	$ 0	$ 3.399	**$ 3.399**	$ 0.961	$ 5.836	b	Prescriptive Gas Commercial Kitchen
Food Services	Commercial Kitchen	$ 2,732	$ 0	$ 3.399	**$ 3.399**	$ 0.961	$ 5.836	b	Prescriptive Gas Commercial Kitchen
Fryer	Commercial Kitchen	$ 2,732	$ 0	$ 3.399	**$ 3.399**	$ 0.961	$ 5.836	b	Prescriptive Gas Commercial Kitchen
Furnace	Other Gas Heating	$ 17	$ 0	$ 0.053	**$ 0.053**	$ 0.043	$ 0.063	c	Prescriptive Gas Other Gas Heating
Griddle	Commercial Kitchen	$ 2,732	$ 0	$ 3.399	**$ 3.399**	$ 0.961	$ 5.836	b	Prescriptive Gas Commercial Kitchen
Heating	Other Gas Heating	$ 17	$ 0	$ 0.053	**$ 0.053**	$ 0.043	$ 0.063	c	Prescriptive Gas Other Gas Heating
Hot Water	HVAC/ Heat Recovery	$ 39	$ 0.327	$ (0.085)	**$ 0.242**	$ (0.174)	$ 0.657	a	Prescriptive Gas HVAC/ Heat Recovery
HVAC/ Heat Recovery	HVAC/ Heat Recovery	$ 39	$ 0.327	$ (0.085)	**$ 0.242**	$ (0.174)	$ 0.657	a	Prescriptive Gas HVAC/ Heat Recovery
Infrared Heaters	Other Gas Heating	$ 17	$ 0	$ 0.053	**$ 0.053**	$ 0.043	$ 0.063	c	Prescriptive Gas Other Gas Heating
Rack Oven	Commercial Kitchen	$ 2,732	$ 0	$ 3.399	**$ 3.399**	$ 0.961	$ 5.836	b	Prescriptive Gas Commercial Kitchen
Steamer	Commercial Kitchen	$ 2,732	$ 0	$ 3.399	**$ 3.399**	$ 0.961	$ 5.836	b	Prescriptive Gas Commercial Kitchen
Overall	**Overall**	**$ 260**	**$ 0.011**	**$ 0.224**	$ 0.235	**$ (0.007)**	**$ 0.477**	**a**	**Prescriptive Gas Overall**

a: Recommended, but not well determined (.10 < p ≤ .50)
b: Recommended, statistically significant at 90% confidence (p ≤ .10)
c: Recommended, statistically significant at 99% confidence (p ≤ .01)
0: NEIs are determined to be negligible
Not Recommended: p >.50

Treatment of the Comprehensive Design (CDA) measure. The CDA measure is an important part of the NC program and constitutes 18% of custom electric savings and 40% of custom gas savings. While a custom comprehensive project may contain both gas and electric saving technologies, we only consider the NEIs related to gas saving technologies for those projects recorded under the gas program, and NEIs related to electric saving technologies for those projects recorded under the electric program. There is one example of a project in our sample that is filed under both programs. However, this particular project did not result in any gas NEIs.

As shown in Table 8 and Table 9 we did not find statistically significant NEIs for the custom-comprehensive electric measures, but did find statistically significant NEIs for the custom-comprehensive gas measures. We recommend our estimate of -$.004/therm be used in the BC model for comprehensive gas measures, and do not recommend the NEI estimate for comprehensive electric measures be included.

NEIs for refined lighting categories. NEIs associated with lighting consist largely of differences in replacement and maintenance costs due to the longer lifetime of efficient bulbs. There were additional benefits with lamp replacement when fewer efficient lamps were needed to provide the same lumens as the baseline lamp. These cost savings were specific to the lamp type installed relative to the baseline standard efficiency T8 lamp. Therefore, it was relatively straightforward to estimate NEIs by lamp type as well. Table 10 shows the NEIs associated with the different lighting measure groups found within the program tracking data. While not currently used for benefit-cost reporting, these data could be valuable in promoting different lighting technologies and used in potential future analysis of NEIs associated with the upstream lighting program.

Of interest in this breakout is the relatively large difference in NEIs between identical measure types in the custom and prescriptive programs. Using the program data, we identified that custom lighting projects tend to replace few higher-wattage bulbs (e.g., metal halide) with an LED equivalent, whereas prescriptive projects tend to replace many lower wattage bulbs (T8) with an LED equivalent. This results in greater O&M savings per kWh for the prescriptive projects. Prescriptive T5 measures have the same replacement cycle as baseline T8s, but T5s have a higher price than T8s, resulting in negative NEIs even though they are brighter and require fewer lamps per lumen. Similarly, program-tracking data show that custom performance lighting consists largely of T5 fixtures, resulting in a negative NEI estimate.

Table 10. Lighting NEIs by Lamp Type

Measure Type	Measure Subtype	Ratio (NEI/kWh)	Statistically Significant?	2013 Weighted Amortized NEI
Custom Lighting	LEDs	$ 0.009	No	$2,525
	Other Lighting	$ 0.001	No	$497
	Performance Lighting	$ 0.004	No	$4,670
Prescriptive Lighting	LEDs	$ 0.036	Yes	$256,838
	Performance Lighting	$ 0.017	No	$38,398
	T5 Lighting	$ (0.001)	Yes	($3,693)
	High Bay LEDs	$ 0.048	Yes	$41,331
	T8 Lighting	$ -	N/A	

Comparison of NC NEI results to 2012 C&I Retrofit NEI results. As part of our analysis, we also compared the current results to the results calculated as part of the 2012 C&I Retrofit study. See Appendix C for the results of this comparison.

5. CONCLUSIONS, RECOMMENDATIONS AND CONSIDERATIONS, AND LIMITATIONS

5.1 CONCLUSIONS

Using the engineering approach discussed in this report, DNV GL was able to produce statistically significant NEI estimates for a range of measures sponsored by the Massachusetts New Construction Program. We have estimated total annual NEIs of $488,122 for the 957 identified true new construction measures installed in 2013, including 23 projects listed under the single performance path-based CDA measure category. These estimates include an overall NEI factor of $.006/kWh for custom electric measures, $.016/kWh for prescriptive electric measures, $-0.005/therm for custom gas measures, and $0.235/therm for prescriptive gas measures.

The engineering-based approach used for this evaluation allowed NEI estimates to be identified for specific measures within each of the PAs' benefit-cost measure categories. The breadth of measures within a specific category can result in low or insignificant overall NEIs for the category. Regardless, knowledge of the measure-specific NEIs can assist program planners and implementers in promoting measures that lead to higher overall benefits for customers.

5.2 RECOMMENDATIONS AND LIMITATIONS

Based on the results of this study, DNV GL provides the following recommendations and considerations:

Recommendation 1: The PAs should apply the recommended electric and gas NEIs presented in Table 2 and Table 3, respectively. These NEIs should be applied to the annual energy savings (kWh or therm) for each of the respective BC categories. Except performance based measures, NEIs reported here do not reflect interactive savings across measure groups. While not all of the recommended NEIs were statistically significant at a confidence interval of 90%, these estimates were based on rigorous quantification of life-cycle cost differences between energy-efficient and baseline efficiency measures. Our analysis demonstrates that there is substantial evidence to suggest that these cost differences should be anticipated for those measures that have a non-zero estimated NEI value. For measure categories for which we found too much variance among the sampled measures, we recommend a value of zero, as there was not sufficient evidence to suggest a positive or negative NEI.

Recommendation 2: Conduct further research to explore whether the NEIs estimated in this study can be applied to upstream program measures. The approach used in this analysis may be transferable to estimating NEIs for upstream programs, although additional research would be required to distinguish which measures sold through the upstream program are replace on failure/natural replacement or true new construction. In particular, NEIs for upstream lighting would largely consist of cost savings resulting from bulb replacements and waste disposal. Additional research is needed to examine whether NEIs associated with productivity or revenue increases are also relevant to upstream lighting measures. Future research could focus on how to apply the engineering-based analysis to relevant upstream measures.

Recommendation 3: Review the 2012 C&I Retrofit NEI results to assess whether the NEIs estimated in this study can be applied to replace on failure/natural replacement measures. While this study did not explicitly estimate NEIs associated with measures installed in replace on failure /natural replacement of existing equipment, many of the NEIs estimated in this study may also be applicable to such measures, especially since the PAs are taking steps to distinguish ROF measures in their tracking systems. However, we believe NEIs for ROF measures had already been evaluated and estimated as part of the 2012 Retrofit C&I NEI study. That study identified ROF measures by their free-ridership score, and their NEIs were adjusted to reflect the percentage of the NEI resulting from the measure being energy efficient based on a self-reported interview response. The Evaluation Team recommends that the PAs revisit the 2012 Retrofit study to assess the extent to which these ROF-measure NEIs can be isolated and subsequently updated or replaced by the NEI estimates provided in this study.

Consideration 1: The PAs should consider the advantages of adapting their benefit-cost models to accommodate more equipment- or technology-level NEI estimates. This NEI research was governed by how the PAs currently report NEI values at a more aggregate BC measure category level. However, the engineering approach taken for this analysis demonstrates that there are substantial differences in the positive and negative impacts associated with the different measure types and technologies within those categories. This consideration has two separate components:

1. **BC analysis and reporting.** The PAs currently track and report on costs and benefits in their BCA models at the measure category or end use level. Our analysis shows that NEIs for measures within those categories can vary considerably. In cases where a particular measure or technology has large negative NEIs and limited energy savings, the PAs may achieve greater economic return by shifting resources away from it. This would enable them to evaluate the optimal measure mix from a total benefit perspective.
2. **Program marketing.** The PAs could also consider focusing their marketing efforts and program support on measures with greater acceptance of efficient technologies. Further, identifying measures with negative NEIs will help the PAs isolate the potential barriers to their adoption. In cases where there are negative NEIs but large energy impacts, marketing staff could develop mitigation strategies to offset the potential increased O&M costs in order to increase their adoption.

Consideration 2: The PAs should consider collecting and recording more precise measure-level descriptions, including ex ante savings estimates, in their program tracking data for their custom CDA projects. Currently, only the paper documentation provided by two of the PAs contained sufficient measure-level information to estimate NEIs, and very little of this more detailed information is being recorded in the program tracking data. Further, recording such detailed measure-level data could help resolve any discrepancies between the paper documentation and the project savings ultimately recorded in the tracking data. This precluded us from developing an approach for estimating NEIs for performance path-based projects based on the relative mix of technologies. With improved data, it would be possible to construct more customized NEI estimates that could be adjusted depending upon the relative mix of the specific measures installed for a given CDA project. This may become increasingly important as the PAs' customers move toward greater reliance on performance path-based measures.

DNV GL identifies the following limitations in this study:

- The approach used to isolate true NC projects limited this study to those measures contained in the Dodge data or tax assessors' data.
- This study was focused on operational cost changes only. Because the measures installed were new construction, we could not justify including productivity or revenue increases, as our analysis did not find such changes would occur from an engineering perspective. Further research is required to explore whether there are additional sources of NEIs.

APPENDIX A: MEASURE-SPECIFIC NEI ESTIMATES

This appendix provides detailed descriptions and calculations of the NEIs estimated in this report, and their key sources of data and information.

- Section A.1 describes the CostLab software used to calculate NEIs in this study
- Section A.2 provides summary tables outlining the life-cycle costs and sources of NEIs for each measure category.

A.1 OVERVIEW OF COSTLAB SOFTWARE

CostLab is cost-estimation software produced by CBRE Whitestone that provides estimates for building O&M costs that many institutions and large businesses use to set their O&M budgets. It serves as the building maintenance industry's premier cost estimating source, and is even recommended by RS Means as a superior service for this purpose. While CostLab does not offer sufficient detail to differentiate between less and more efficient equipment, it does provide a good reference point for the O&M costs associated with the average piece of equipment or building system.

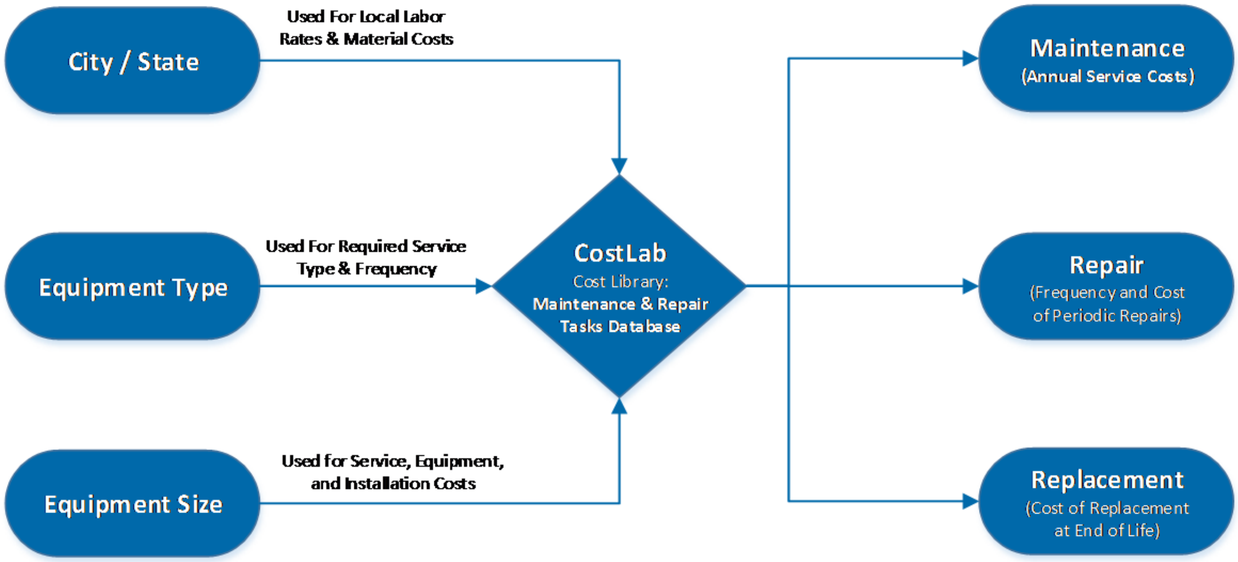
We used these estimates in many cases to establish the baseline costs of ownership to which we would compare our efficient equipment estimates. CostLab provides costs in terms of annual maintenance, periodic repair, and replacement costs.

The CostLab cost library itself is based on a number of sources gathered and updated over the course of many years. These sources include the following:

- Maintenance costs reported by the Department of Defense
- Maintenance costs reported by state building offices, including DCAMM in Massachusetts
- Feedback from CBRE Whitestone customers.

While it is possible to adjust CostLab to estimate costs for specific buildings, we simply used the estimates from the cost library database. As shown below in Figure 4, we input the geographical location for our analysis (we used Boston, Massachusetts) and the equipment type size, and CostLab provided us with maintenance, repair, and replacement costs, which we assigned to the baseline condition for some measures in our analysis.

Figure 4. Diagram of How We Used CostLab



While CostLab was useful for assigning values to some measures, other sources (including O&M manuals and interviews) provided more useful and detailed values for the majority of measures. We used CostLab for the measures and purposes shown in Table 11. CostLab data informed our thinking about other measures and inputs to other calculations, but we only used their data directly in these cases.

Table 11. Measures Incorporating CostLab Estimates

Category	Measure	CostLab Outputs Used
Gas HVAC	All Gas Heating Measures	Maintenance, Repair, and Replacement Costs
Electric HVAC	High-Efficiency Chillers	Cooling tower replacement cost.
Compressed Air	Zero Loss Condensate Drains	Hourly rate for air leak repairs
Lighting	All Lighting Measures	Maintenance and Repair costs

A.2 DISCUSSION AND ESTIMATION OF NEIS BY SAMPLE CATEGORY

This section provides detailed descriptions of the engineering analysis for each measure category. It is organized by fuel type (electric then gas), sample category, then BC measure category. For each BC measure category, the relevant equipment types are discussed (both baseline and energy efficiency); and, if applicable, NEIs are then estimated separately for custom and/or prescriptive applications.

Each measure category section contains a discussion of the following items:

- Baseline and efficient options
- Types of NEIs associated with the technology
- Costs of NEIs when they occur
- The schedule in which NEIs occur.

One consideration to keep in mind when reading this material is that we only report costs, which differ between baseline and efficient options. Maintenance, repair, and replacement items that cost the same amount and occur at the same frequency for both baseline and efficient options are ignored in tables and charts, though they may be discussed in text.

While the following sections are broken apart by fuel type (gas vs. electric), NEIs are not driven by the fuel type used but by other considerations. When NEIs for a piece of electric equipment are the same as for the natural gas version of that equipment, we recorded our findings under one fuel's section and referred to those findings from the other fuel's section.

In the data provided by the PAs for true new construction projects, there were not any combined heat and power projects (CHP). These projects are likely to have significant non-energy impacts, but were not sampled and therefore no estimate of NEIs for CHP was made.

A.2.1 Electric – Comprehensive Design

The Mass Save® program defines Comprehensive Design as follows:

> *For new commercial construction buildings over 100,000 square feet the Comprehensive Design Approach (CDA) is available. CDA is a Custom approach designed to maximize electric and gas energy savings and financial incentives for the project. It is a whole-building systems approach with interaction of mechanical and electrical systems, including the building envelope design, for building optimization in energy-saving performance.*[13]

CDA requires a specific analysis of multiple systems integrated into a design. The analysis usually involves an energy model of some kind. The NEIs relating to CDA combine multiple technologies. Analyzing the non-energy impact involves combining many technologies across the utility incentive program.

The Electric - Comprehensive Design measure category includes a wide variety of measures, but the following make up the majority of energy savings. See the applicable sections for estimates of NEIs for these specific measures, which are combined to estimate NEIs for specific projects.

[13] http://www.masssave.com.

Lighting

- Performance Lighting
- Controls
- LEDs

Electric HVAC

- Controls
- Chillers
- Unitary Cooling
- Chilled Beams

Motors

- Variable-frequency drives (VFDs)
- Electrically commutated motors (ECMs)

Building Shell

- Insulation & Air Sealing
- Windows.

Calculation Approach for Sample NC CDA Measure—Continued

Section 3.5.1 of this report provided an overview of how we calculated savings for one sample NC CDA project. In the sample project, the building is an approximately 23,000-square-foot, multi-story, mixed-use building for which the program claimed approximately 100,000 in electric kWh savings. The program did not claim any gas savings.

Here we provide greater detail regarding the calculation for that sample measure. Table 12 shows the baseline system and proposed system for each line item. Table 13, Table 14, and Table 15 present example NPV calculations. Table 16 and Table 17 summarize the NEIs for this CDA measure.

As explained in Section 3.5.1, we restricted this analysis to include NEIs associated with those line items relevant to electric savings. In this example, there was one measure that affected both electric and gas savings (HVAC/Heat Recovery), but this measure does not have any quantifiable NEIs for which we would have had to allocate between electric and gas.

Table 12. Detailed Account of Line-Items Included in Sampled Measure

Category	Measure Name	Gas / Electric	Baseline System	Proposed System
HVAC	Controls	Electric	No DDC system	DDC controls
HVAC	Chilled Beams	Electric	Typical air handling system	Chilled beams with 100% outside air supply for ventilation only
HVAC	Controls	Electric	Typical ventilation system	CO_2 sensor Aircuity system
HVAC	Controls	Electric	No reset	Static pressure reset for VFD energy recovery fans
HVAC	Heat Recovery	Both	No energy recovery	Total exhaust energy recovery. 76% effective
HVAC	Chillers	Electric	DX cooling	Water-cooled VFD chiller with free cooling
HVAC	Fans	Electric	Standard air handlers	Variable speed AHUs with "active induction," oversized steam coils, enthalpy economizers, and airfoil fans
Lighting	Performance	Electric	Code-minimum for labs & offices	10% better than code. Mostly fluorescent. Few LEDs
Lighting	Controls	Electric	No daylighting control	On-off daylighting control in private offices and conference rooms
Lighting	Controls	Electric	Occupancy sensors in required areas	Occupancy sensors in additional areas (doesn't say how many)
Motors	Fans	Electric	Standard VAV boxes	ECM VAV boxes
Motors	Other	Electric	Standard motors in AHUs	NEMA premium motors in AHUs

This measure had NEIs derived from the chilled beam, chiller, and performance lighting line items. The sections that follow discuss the details of the computation for NEIs associated with each of these line items.

- *Chilled Beams* – NEIs for chilled beams consisted of maintenance savings only. We calculated the NEIs for chilled beams using the following NPV table over a 15-year analysis period, with the value calculated per each fan coil unit, or each 1000 ft^2, for a total savings of \$869 x (23,000 ft^2 / 1000 ft^2) = \$19,780 over the lifetime, or \$1,035 if amortized per year. This amortization is not shown in the table below, but can be seen in Table 63 later in the report.

Table 13. Chilled Beams NEI Table

Cate-gory	Type	Cost Category	Costs by Year (values measured in dollars)																				Net Present Value		
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20			
Chilled Beam	Fan Coil	Maintenance	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	0	0	0	0	0	869	869	869
		Repair	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
		Replacement	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
	Chilled Beam	Maintenance	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
		Repair	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
		Replacement	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		

- *Chillers* – This particular chiller project had an unusual baseline-installed combination. The baseline chiller for this site was an air-cooled screw chiller, and the newly installed equipment was a water-cooled screw chiller. We calculated the NEIs over a 20-year analysis period. The comparison between these two options is shown below, for a total NEI of $-61,231 over the lifetime, or $-3,205 if amortized per year. Note that the red text refers to items for which the lifetime of the replacement equipment extended beyond the analysis period. In these cases, the capital cost (for replacement) was amortized over the equipment life and the annualized cost was included for years within the analysis period.

Table 14. Chiller NEI Table

Cate-gory	Type	Cost Category	Costs by Year (values measured in dollars)																				Net Present Value		
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20			
Air Cooled	Screw Chiller	Maintenance	1032	1032	1032	1032	1032	1032	1032	1032	1032	1032	1032	1032	1032	1032	1032	1032	1032	1032	1032	1032	19716	43214	-61231
		Compressors	0	0	0	0	2969	0	0	0	0	2969	0	0	0	0	0	0	0	0	0	602	6297		
		Replacement	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3096	3096	3096	3096	3096	3096	17201		
Water Cooled	Screw Chiller	Maintenance	1032	1032	1032	1032	1032	1032	1032	1032	1032	1032	1032	1032	1032	1032	1032	1032	1032	1032	1032	1032	19716	32336	
		Compressors	0	0	0	0	1666	0	0	0	0	1666	0	0	0	0	1666	0	0	0	0	338	5093		
		Condenser	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1355	1355	1355	1355	1355	1355	7526		
Cooling Tower Add	If WC vs. AC	Maintenance	3208	3208	3208	3208	3208	3208	3208	3208	3208	3208	3208	3208	3208	3208	3208	3208	3208	3208	3208	3208	61289	72110	
		Replacement	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1947	1947	1947	1947	1947	1947	10821		

- *Performance Lighting* – This building had a watts per ft^2 value that was 10% better than code, or approximately 0.90 watts/ft^2, per ASHRAE 90.1 2007. In this case, we assumed that the majority of the building was lit by high-performance lighting like T5 fluorescent lights, assuming a 3-lamp fixture every 80 ft^2. We calculated the NEIs over a 15-year analysis period. The comparison between these two options is shown below, for a total NEI of 23,000 ft^2 / 80 ft^2 x ($-4) = $-1,150 over the lifetime, or -$79 if amortized per year. Note that the red text refers to items for which the lifetime of the replacement equipment extended beyond the analysis period. In these cases, the capital cost (for replacement) was amortized over the equipment life and the annualized cost was included for years within the analysis period.

Table 15. Lighting NEI Table

Type	Cost Category	Costs by Year (values measured in dollars)															Net Present Value		
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Measure Totals		NEI
Baseline T8	Bulb Change	0.0	0.0	9.9	0.0	9.9	0.0	0.0	9.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	29.0	209	-4
	Recycle	0.0	0.0	3.2	0.0	3.2	0.0	0.0	3.2	0.0	3.2	0.0	0.0	0.0	0.0	0.0	12.3		
	Fixture Replacement	0	0	0	0	89	0	0	0	0	14	14	14	14	14	14	168.1		
Efficient T5	Bulb Change	0	0	12	0	12	0	0	12	0	0	0	0	0	0.0	0.0	35.2	213	
	Recycle	0	0.0	2.9	0.0	2.9	0.0	0.0	2.9	0.0	2.9	0.0	0.0	0.0	0.0	0.0	11.2		
	Incentive	0	0	0	0	-25	0	0	0	0	0	0	0	0	0	0	-24.5		
	Fixture Replacement	0	0	0	0	113	0	0	0	0	14	14	14	14	14	14	191.6		

The total NEI savings for this comprehensive design measure was the sum of the NEIs for each line item, or $1,035 + ($-3,205) + ($-79) = $-2,249 per year.

Table 16 below provides a detailed breakdown of NEIs for each measure rolled up within each CDA project. The “Total Annual NEI” column provides a weighted estimate of annual NEIs for each measure. Table 17 provides an overall summary of the CDA sample category.

Table 16. NEIs by Electric CDA Project

CDA Project	Measure Type/ Technology	Custom		
		Average Annual NEI	Total Weighted Annual NEI	Sampled Measures
5	Building Shell	$ -	$ -	2
5	HVAC	$ -	$ -	5
5	**Overall**	**$ -**	**$ -**	**7**
6	HVAC	$ (356.95)	$ (2,900.24)	5
6	Lighting	$ -	$ -	2
6	Motors	$ -	$ -	1
6	**Overall**	**$ (223.10)**	**$ (2,900.24)**	**8**
10	HVAC	$ (444.74)	$ (5,058.88)	7
10	Lighting	$ (27.13)	$ (132.24)	3
10	Motors	$ -	$ -	2
10	**Overall**	**$ (266.21)**	**$ (5,191.12)**	**12**
13	Building Shell	$ -	$ -	1
13	HVAC	$ 2,393.40	$11,667.82	3
13	Lighting	$ (169.83)	$ (551.95)	2
13	Motors	$ -	$ -	1
13	**Overall**	**$ 760.06**	**$11,115.87**	**7**
14	Building Shell	$ -	$ -	1
14	HVAC	$ -	$ -	7
14	Lighting	$ (409.54)	$ (1,331.01)	2
14	Motors	$ -	$ -	3
14	**Overall**	**$ (63.01)**	**$ (1,331.01)**	**13**
22	HVAC	$ 293.81	$ 1,909.76	4
22	Lighting	$ (221.14)	$ (359.34)	1
22	Motors	$ -	$ -	1
22	**Overall**	**$ 159.02**	**$ 1,550.42**	**6**
24	HVAC	$ 15.00	$ 97.50	4
24	Lighting	$ (84.92)	$ (275.98)	2
24	Motors	$ -	$ -	1
24	**Overall**	**$ (15.69)**	**$ (178.48)**	**7**
39	HVAC	$ -	$ -	1
39	Lighting	$ (115.06)	$ (373.95)	2
39	Motors	$ -	$ -	1
39	**Overall**	**$ (57.53)**	**$ (373.95)**	**4**
Overall Weighted Electric CDA		**$ 207**	**$ 2,691**	**8**

Table 17. Summary of NEIs for CDA Projects

	Custom
Sampled Measures (a)	8
Average NEI per Sample Measure	$ 207
Sample Total NEIs (b)	$ 1,656
Sample Total kWh Savings (c)	1,797,427
NEI/kWH (d = b / c)	$ 0.001
90% CI Low	$ (0.007)
90% CI High	$ 0.009
p-value	0.84
Population Measures (2013) (e)	13
Weighted Population Savings kWh (2013) (f = c * (e / a))	2,920,819
Total Estimated Population NEI (g = d * f)	$ 2,691

A.2.2 Electric – Building Shell

As shown in Table 5, the population of building shell measures with electric savings included one custom and zero prescriptive measures installed in 2013. In addition, four of the eight electric custom comprehensive design (CDA) projects we sampled included the installation of at least one building shell measure.

Based on our review of the PA tracking data for these sampled measures, the information obtained in our interviews, and the supporting documentation provided by the PAs for the projects we sampled, we identified at least two types of building shell measures or technologies. Upon further review of the available data and information with which we can characterize and estimate NEIs, the following two types of building shell measures or technologies are considered further in our NEI analysis:

- Insulation & Air Sealing
- High-performance Windows.

The following sections summarize the NEI estimates for each measure type.

Insulation and air sealing

The construction of the building enclosure—especially its air and vapor permeability, color, levels of insulation, resistance to air leakage, and thermal mass—has a significant impact on energy efficiency and occupant comfort. The building enclosure also affects acoustic comfort as it can attenuate site and traffic noise. Selecting materials for the construction of the building enclosure affects resource efficiency, including transport energy, the volume and type of raw materials that must be extracted from the earth, the energy required for manufacturing, and packaging.

It is important to provide an exterior weather barrier with drainage plane to prevent moisture from entering construction cavities. It is also important to design a wall, roof, and foundations system, so that if water enters, it can dry out. Wet or damp construction cavities, attics, and plenums are a major source of mold and can contribute significantly to indoor air quality (IAQ) problems. In addition, moisture can damage the structure and degrade the performance of insulation, increasing energy and operating costs. Many IAQ complaints are related to leaky roofs that have resulted in the growth of mold in a plenum, wall system, attic space, or in part of a foundation space such as a crawl space or utility trench.

Water vapor can enter construction cavities through a process of moisture migration. Moisture migrates from the warm and humid side of the construction assembly to the cold dry side of the construction assembly. The vapor cools as it moves through the wall and, as it reaches dew point conditions, may condense into water molecules that can accumulate to cause damage and create mold. Moisture also follows air leakage through a construction assembly. In addition to correctly installing a vapor retarder, it is important to provide adequate ventilation to dry spaces where moisture can build up. Most building codes require that attics and crawl spaces be ventilated, and some require a minimum one-inch clear airspace above the insulation for ventilation of vaulted ceilings. Even the wall cavity may need to be ventilated in extreme climates.[14]

With this in mind, building envelopes are critical aspects to construction. However, NEIs are difficult to quantify, as the only time that maintenance, repair, or replacement occur is if the building envelope fails due to poor construction. The interviews with manufacturers, contractors, and customers all revealed that nobody expects any NEIs from added insulation or air sealing.

The following table shows the characteristics of the baseline envelope requirements from ASHRAE 90.1 2007. Although exceeding these values offers energy savings, there is no NEI related to the increase.

[14] http://apps1.eere.energy.gov/buildings/publications/pdfs/energysmartschools/nationalbestpracticesmanual31545.pdf.

Table 18. Building Shell ASHRAE 90.1 Guidelines

ASHRAE 90.1 2007—Climate Zone 6		
Prescriptive Fenestration Requirements	**Maximum U Factor**	**R-Value**
Non-metal frame	0.35	2.9
Curtain wall/storefront	0.4	2.5
Entrance door	0.8	1.3
All other metal frame	0.55	1.8
Prescriptive Shell Requirements	**Maximum U Factor**	**R-Value**
Roofs		
Insulation entirely above deck	U-0.048	R-20.0 c.i.
Attic and other	U-0.027	R-38.0
Walls, above-grade		
Mass	U-0.08	R-13.3 c.i.
Steel-framed	U-0.064	R-13+R-7.5 c.i.
Walls, below-grade		
Below-grade wall	C-0.119	R-7.5 c.i.
Floors		
Mass	U-0.064	R-12.5 c.i.

High-performance windows

One common new construction practice in Massachusetts is a curtain wall design instead of the standard steel and reinforced concrete system. One major advantage of the curtain wall is that it can be constructed from much lighter materials (like glass), which allows for the filtration of natural light into the building. It has been reported that a curtain wall design can have additional maintenance to contain air infiltration and water leaks. However, this depends greatly on the quality of construction, and quantifying it is difficult and specific to each building.

Whether a new construction utilizes a curtain wall or a more standard system, the code dictates the glass and assembly U-Value. The interviews resulted in no quantifiable NEIs based strictly on purchasing a window with a more effective U-Value.

Table 19. Building Fenestration ASHRAE 90.1 Guidelines

ASHRAE 90.1 2007—Climate Zone 6		
Prescriptive Fenestration Requirements	**Max U Factor**	**Solar Heat Gain Coefficient**
Non-metal frame	0.35	0.25
Curtain wall/storefront	0.45	
Entrance door	0.8	

Electric – building shell summary

The following tables summarize the NEIs we calculated for the electric building-shell sample categories, as well as the total population of electric building shell measures installed in 2013. We estimated zero NEIs for the one measure in the population.

Table 20. NEI Estimates for Measures in Electric Building Shell Sample Categories

	Custom		
Measure Type/ Technology	Average Annual NEI	Total Weighted Annual NEI	Sampled Measures
Building Shell	$ -	$ -	1
Overall	**$ -**	**$ -**	**1**

Table 21. Overall NEI Estimates for Electric Building Shell Sample Categories

	Custom
Sampled Measures (a)	1
Average NEI per Sample Measure	$ -
Sample Total NEIs (b)	$ -
Sample Total kWh Savings (c)	80,240
NEI/kWH (d = b / c)	$ -
90% CI Low	$ -
90% CI High	$ -
p-value	0.00
Population Measures (2013) (e)	1
Weighted Population Savings kWh (2013) (f = c * (e / a))	80,240
Total Estimated Population NEI (g = d * f)	$ -

A.2.3 Electric – Commercial Kitchen

Commercial kitchen equipment NEIs are based on the equipment taking less time to maintain and clean (fewer labor hours), requiring less cleaning product, or requiring less cooking medium (water or oil).

As shown in Table 5, from the population of commercial kitchen measures[15] with electric savings (zero custom and one prescriptive) installed in 2013, we drew a sample of one prescriptive measure to characterize the types of technologies deployed in NC and their associated NEIs. None of the eight custom comprehensive design (CDA) projects we sampled included the installation of any commercial kitchen measures.

Based on our review of the PA tracking data for these sampled measures, the information obtained in our interviews, and the supporting documentation provided by the PAs for the projects we sampled, we identified at least three types of commercial kitchen measures or technologies. Upon further review of the available data and information with which we can characterize and estimate NEIs, the following three types of commercial kitchen measures or technologies are considered further in our NEI analysis:

- Commercial Ovens
- Commercial Steam Cookers
- Commercial Fryers.

The following sections summarize the NEI estimates for each measure type.

Commercial ovens

The following table shows the characteristics of the baseline and efficient options for this measure.

Table 22. Summary of Efficient and Baseline Options for Commercial Ovens[16]

Characteristic	Baseline	Efficient	NEIs (relative to Baseline)
Annual operation hours[17]	Convection Oven: 3,130 Combination Oven: 3,756	Convection Oven: 3,130 Combination Oven: 3,756	**Maintenance**: Efficient combination ovens reduce water use by 43,800 gallons per year, saving associated water and wastewater costs
Equipment Life	12 years	12 years	

No repair, maintenance, or replacement NEIs were determined to result from replacement of commercial convection ovens.

[15] Commercial kitchen are a sample category not a benefit-cost category.
[16] No conveyor ovens were sampled as part of this analysis.
[17] Based on TRM assumption of 6 day/week operation, or 313 days/year. Convection ovens are assumed to operate 10 hours/day, and combination ovens are assumed to operate 12 hours/day.

NEIs associated with this measure are as follows:

- *Water use* – Convection ovens were not found to have reductions in maintenance costs. Efficient combination ovens reduced water use over the baseline technology, with an associated reduction in costs.[18] Consistent with the TRM, all water is assumed to end its life as wastewater (rather than evaporated), such that wastewater costs decrease with water savings.

The following table shows the schedule of costs associated with the baseline and efficient options for this measure.

Table 23. Cost Schedule for Commercial Ovens

	Combination		Convection	
Year	Baseline	Efficient	Baseline	Efficient
1	W			
2	W			
3	W			
4	W			
5	W			
6	W			
7	W			
8	W			
9	W			
10	W			
11	W			
12	W			

W=Water Use

The table below shows the prices associate with each cost listed above. Each value in the table represents a single letter above.

Table 24. Cost Breakdown for Commercial Ovens (Price For Each Occurrence Shown Above)

	Baseline	Efficient
Size Category	Water Use	Water Use
Full size combination oven	$108	-
Full size	-	-

[18] http://www.fishnick.com/saveenergy/tools/calculators/eovencalc.php.

convection oven		

The following table shows these costs totaled across the analysis period on an NPV basis, as well as the cost differences (NEIs) between baseline and efficient, both on an NPV and annualized basis.

Table 25. Lifetime and Annualized Costs for Commercial Ovens

Category	Baseline Costs* (Analysis Period—$2015)				Efficient Option Costs* (Analysis Period—$2015)				Efficient Option NEIs (relative to baseline)	
	Maintain	Repair	Replace	Total	Maintain	Repair	Replace	Total	Total NPV	Amortized per year
Combination	$ 1,265	$ -	$ -	$ 1,265	$ -	$ -	$ -	$ -	$ 1,265	$ 108
Convection	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -

* Reflects the total NPV cost that would be incurred in accordance to the schedule shown in the previous two tables.

Commercial steam cookers

The following table shows the characteristics of the baseline and efficient options for this measure.

Table 26. Summary of Efficient and Baseline Options for Commercial Steam Cookers

Characteristic	Baseline	Efficient	NEIs (relative to Baseline)
Type	Steam Generator	Boilerless	**Maintenance**: Efficient commercial steamers reduce water use. Each efficient steamer requires more filter replacements and less de-liming maintenance.
Percentage of Time in Constant Steam Mode	40%	40%	
Average Water Consumption Rate (gal/hr.)	40	3	
Idle Energy Electric (kW)	1.2	0.4	
Equipment Life	12 years	12 years	

NEIs associated with this measure are as follows:

- *Maintenance* – Efficient commercial steamers reduce water use over the baseline technology, with an associated reduction in costs.[19] Consistent with the TRM, all water is assumed to end its life as wastewater (rather than evaporated), such that wastewater costs decrease with water savings. Each efficient steamer contains two water filters not included in baseline equipment; these filters are replaced once quarterly for a total of eight filter replacements per year. Efficient steamers require de-liming maintenance once quarterly rather than the once-monthly service required by baseline equipment, resulting in a decrease in both chemical cost and internal staff maintenance time. All of these maintenance requirement changes were corroborated by customer interviews.

[19] http://www.fishnick.com/saveenergy/tools/calculators/eovencalc.php.

The following table shows the schedule of costs associated with the baseline and efficient options for this measure.

Table 27. Cost Schedule for Commercial Steam Cookers

Year	Baseline	Efficient
1	M	M
2	M	M
3	M	M
4	M	M
5	M	M
6	M	M
7	M	M
8	M	M
9	M	M
10	M	M
11	M	M
12	M	M

M=Maintenance

The table below shows the prices associated with each cost listed above. Each value in the table represents a single letter above.

Table 28. Cost Breakdown for Commercial Steam Cookers (Price for Each Occurrence Shown Above)

Size Category	Baseline Maintenance	Efficient Maintenance
All	$966	$3788

The following table shows these costs totaled across the analysis period on an NPV basis, as well as the cost differences (NEIs) between baseline and efficient, both on an NPV and annualized basis.

Table 29. Lifetime and Annualized Costs for Commercial Steam Cookers

Baseline Costs* (Analysis Period—$2015)				Efficient Option Costs* (Analysis Period—$2015)				Efficient Option NEIs (relative to baseline)	
Maintain	Repair	Replace	Total	Maintain	Repair	Replace	Total	Total NPV	Amortized per year
$ 11,266	$ -	$ -	$ 11,266	$ 44,185	$ -	$ -	$ 44,185	$ (32,919)	$ (2,822)

* Reflects the total NPV cost that would be incurred in accordance to the schedule shown in the previous two tables.

Commercial fryers

The following table shows the characteristics of the baseline and efficient options for this measure.

Table 30. Summary of Efficient and Baseline Options for Commercial Fryers

Characteristic	Baseline	Efficient	NEIs (relative to Baseline)
Shortening Capacity	65	65	**Maintenance**: Baseline requires increased fryer oil replacement, filter pads, filter powder, oil filtering, and annual contractor maintenance time.
Equipment Life	12 years	12 years	

NEIs associated with this measure are as follows:

- *Maintenance* – Baseline technology requires higher maintenance costs relative to efficient equipment, including increased fryer oil replacement, filter pads, filter powder, internal maintenance time for oil filtering, and annual contractor maintenance time. Filters are not needed for the efficient equipment, and an estimated 30 minute (minimum) oil filtering operation is reduced from once every two days to once every two months, per customer interviews. The largest proportion of maintenance savings results from average annualized savings of fryer oil replacement due to the self-cleaning operation of the efficient unit. Because burned particles do not contaminate the oil, fryer oil life is greatly increased. Finally, external contractor maintenance time is reduced from once annually to once every three years.

The following table shows the schedule of costs associated with the baseline and efficient options for this measure.

Table 31. Cost Schedule for Commercial Fryers

Year	Baseline	Efficient
1	M	M
2	M	M
3	M	M
4	M	M
5	M	M
6	M	M
7	M	M
8	M	M
9	M	M
10	M	M
11	M	M
12	M	M

M=Maintenance

The following table shows the prices associate with each cost listed above. Each value in the table represents a single letter above.

Table 32. Cost Breakdown for Commercial Fryers (Price For Each Occurrence Shown Above)

Size Category	Baseline Maintenance	Efficient Maintenance
All	$6,983	$130

The following table shows these costs totaled across the analysis period on an NPV basis, as well as the cost differences (NEIs) between baseline and efficient, both on an NPV and annualized basis.

Table 33. Lifetime and Annualized Costs for Commercial Fryers

Baseline Costs* (Analysis Period—$2015)				Efficient Option Costs* (Analysis Period—$2015)				Efficient Option NEIs (relative to baseline)	
Maintain	Repair	Replace	Total	Maintain	Repair	Replace	Total	Total NPV	Amortized per year
$ 81,444	$ -	$ -	$ 81,444	$ 1,513	$ -	$ -	$ 1,513	$ 79,931	$ 6,853

* Reflects the total NPV cost that would be incurred in accordance to the schedule shown in the previous two tables.

Electric – commercial kitchen summary

The following tables summarize the NEIs we calculated for the electric commercial kitchen sample categories, as well as the total population of electric commercial kitchen measures installed in 2013.

Table 34. NEI Estimates for Measures in Electric Commercial Kitchen Sample Categories

Measure Type/ Technology	Prescriptive Average Annual NEI	Prescriptive Total Weighted Annual NEI	Prescriptive Sampled Measures
Convection Oven	$ -	$ -	1
Combination Oven	$ -	$ -	0
Steamer	$ -	$ -	0
Fryer	$ -	$ -	0
Overall	**$ -**	**$ -**	**1**

Table 35. Overall NEI Estimates for Electric Commercial Kitchen Sample Categories

	Prescriptive
Sampled Measures (a)	1
Average NEI per Sample Measure	$ -
Sample Total NEIs (b)	$ -
Sample Total kWh Savings (c)	1,364
NEI/kWH (d = b / c)	$ -
90% CI Low	$ -
90% CI High	$ -
p-value	0.00
Population Measures (2013) (e)	1
Weighted Population Savings kWh (2013) (f = c * (e / a))	1,364
Total Estimated Population NEI (g = d * f)	$ -

A.2.4 Electric – Compressed Air

Compressed air systems are used primarily in manufacturing and auto repair as a critical tool needed to operate many processes. The industrial compressed air system is the “workhorse” of the industrial process as it is required to make many factories operate.

As shown in Table 5, from the population of compressed air measures (5 custom and 23 prescriptive) installed in 2013, we drew a sample of 4 custom and 10 prescriptive measures to characterize the types of technologies deployed in NC and their associated NEIs. We were only able to complete NEI calculations for 3 of the 5 custom measures. None of the eight electric custom CDA projects we sampled included the installation of at least one compressed air measure.

Based on our review of the PA tracking data for these sampled measures, the information obtained in our interviews, and the supporting documentation provided by the PAs for the CDA projects we sampled, we identified four types of compressed air measures or technologies. Upon further review of the available data and information with which we can characterize and estimate NEIs, the following four types of compressed air measures or technologies are considered further in our NEI analysis:

- High-Efficiency Air Compressors
- Refrigerant Air Dryers
- Low-Pressure Drop Filters
- Zero Loss Condensate Drains.

The following subsections describe and present the analytical approach and results of the NEIs estimated for each of these four compressed air measure types or technologies. At the end of this section, we summarize the NEIs estimated across these four measure types/technologies that are used to characterize and quantify the NEI for the entire compressed air sample category, as well as the total population of compressed air measures installed in 2013.

High efficiency air compressors

The following table shows the characteristics of the baseline and efficient options for this measure.

Table 36. Summary of Efficient and Baseline Options for High-Efficiency Air Compressors

Characteristic	Baseline	Efficient	NEIs (relative to Baseline)
Type	Modulating Compressor (Reciprocating)[20]	Rotary Screw	**Size:** HP can be reduced **Repair/Replacement:** Designed to last the life of the system as opposed to periodic rebuilds (every 5 years) **Maintenance:** Oil changes every 3 years as opposed to 3 times per year
Control	Across the line motor control	VFD, Load/No Load or Variable Displacement controlled	
Lubrication	Single or double stage	Oil flooded	
Blow-Down Valve	Blow down valve	No Blow Down Valve	
Equipment Life	15 years	15 years	

NEIs associated with this measure are as follows:

- *Repair/replacement* – All compressors require either replacement or rebuilding. Compressors can be rebuilt many times depending on the conditions of the location (excessive heat, moisture, dust, etc.) and the process use. The interview phase involved conversations with very experienced building engineers. Many of them discussed the lifespan of compressors. They were able to keep compressors running for over 30 years, albeit very inefficiently and well past the useful life. However, this shows that if maintained well, rebuilding a compressor and replacing worn parts results in a very extended lifespan. Reciprocating compressors have fewer moving parts than screw compressors, meaning rebuilding is easier. Reciprocals require rebuilding or replacement every 10,000 hours or around every 5 years. The more efficient rotary screw compressors, on the other hand, last between 20,000 and 25,000 hours (more than 10 years) before requiring similar service or replacement.[21]
- *Maintenance* – Oil changes are the most common maintenance item in compressors. A reciprocating air compressor generally requires oil changes every 3 to 12 months with the assumption that most owners wait a little longer to perform the maintenance than a manufacturer recommends. It was found that most buildings changed the oil three times per year on reciprocal units. On the other hand, for the more efficient rotary screw compressors, Portland Compressor[22] recommends oil should be

[20] The TRM doesn't specifically state that a reciprocating compressor is the baseline. It doesn't mention a compressor type at all. In practical application, a reciprocating compressor is usually seen as the low-cost option.
[21] http://www.plantengineering.com/single-article/rotary-screw-or-reciprocating-air-compressors-which-one-is-right/1563ecc5630401b2d6575680d867854a.html.
[22] Conversation with a service engineer at Portland Compressor.

changed about every 7,000 to 8,000 hours (about every 3 to 4 years). Other maintenance items performed during oil changes are filter cleaning or replacing, oil separator inspection, and general unit cleaning.

Based on our analysis of the NEIs discussed above, the following tables show the schedule and breakdown of costs associated with the baseline and efficient options for this measure/technology. In summary, the key assumptions or inputs used in CostLab included:

- Reciprocating compressors (baseline) are rebuilt every 5 years, rotary screw compressors (efficient option) are not rebuilt or replaced during the analysis period
- 15-year analysis period
- Reciprocating compressors (baseline) are maintained (oil changes) three times per year; rotary screw compressors (efficient option) are maintained once every three years
- Labor assumptions/inputs
- Other assumptions/inputs.

Table 37. Cost Schedule for High-Efficiency Air Compressors

Year	Baseline	Efficient
1	M	
2	M	
3	M	M
4	M	
5	M, R	
6	M	M
7	M	
8	M	
9	M	M
10	M, R	
11	M	
12	M	M
13	M	
14	M	
15	M	M

M=Maintain: oil changes
R=Repair/Replacement: rebuild compressor

The following table shows the prices associate with each cost listed above. Each value in the table represents a single letter above.

Table 38. Cost Breakdown (Price for Each Occurrence Shown Above)

Size Category	Baseline		Efficient	
	Maintain	Repair	Maintain	Repair
1-24 HP	$410	$3,000	$450	n/a
25-50 HP	$410	$10,000	$450	n/a
>50 HP	$410	$12,000	$450	n/a

The following table shows these costs totaled across the analysis period on an NPV basis, as well as the cost differences (NEIs) between baseline and efficient, both on an NPV and annualized basis.

Table 39. Lifetime and Annualized Costs for High-Efficiency Air Compressors

Category	Baseline Costs* (Analysis Period—$2015)				Efficient Option Costs* (Analysis Period—$2015)				Efficient Option NEIs (relative to baseline)	
	Maintain	Repair	Replace	Total	Maintain	Repair	Replace	Total	Total NPV	Amortized per year
1-24 HP	$ 5,975	$ 5,806	$ -	$ 11,781	$ 2,163	$ -	$ -	$ 2,163	$ 9,618	$ 664
25-50 HP	$ 5,975	$ 19,353	$ -	$ 25,328	$ 2,163	$ -	$ -	$ 2,163	$ 23,165	$ 1,599
>50 HP	$ 5,975	$ 23,224	$ -	$ 29,199	$ 2,163	$ -	$ -	$ 2,163	$ 27,036	$ 1,866

* Reflects the total NPV cost that would be incurred over the analysis period in accordance to the schedule shown in the previous table.

Refrigerated air dryers

The following table shows the characteristics of the baseline and efficient options for this measure.

Table 40. Summary of Efficient and Baseline Options for Refrigerated Air Dryers

Characteristic	Baseline	Efficient	NEIs (relative to Baseline)
Type	Non-cycling Refrigerated Air Dryer	Cycling Refrigerated Air Dryer with VFD	**Maintenance**: Frequency is reduced to every 6 years from every 2 years for the baseline non-cycling system.
Equipment Life	15 years	15 years	

NEIs associated with this measure are as follows:

- *Maintenance* – Refrigerator dryers require regular maintenance. For example, refrigerator dryers in factories often draw in dust from the factory, or draw in moisture if vented to the outside. The increased operation time and speed of non-cycling units creates additional heat and draws more dust and dirt that result in additional maintenance needs. A more efficient cycling unit that reduces speed draws in less dust and moisture due to its reduction of full run capacity. Kaeser Compressor[23]

[23] Conversation with service engineer at Kaeser Compressor.

estimates that on a digital scroll and cycling receiver dryer, maintenance frequency is reduced from six years to two.

- *Replacement:* Extending the equipment lifetime is likely but dependent on the environment. Because of this we were unable to justify a lifetime difference.

The following table shows the schedule of costs associated with the baseline and efficient options for this measure.

Table 41. Cost Schedule for Refrigerated Air Dryers

Year	Baseline	Efficient
1		
2	M	
3		
4	M	
5		
6	M	M
7		
8	M	
9		
10	M	
11		
12	M	M
13		
14	M	
15		

M=Maintenance
R=Repair
P=Replacement

The following table shows the prices associate with each cost listed above. Each value in the table represents a single letter above.

Table 42. Cost Breakdown for Refrigerated Air Dryers (Price for Each Occurrence Shown Above)

Baseline	Efficient
Maintain	Maintain
$330	$330

The following table shows these costs totaled across the analysis period on an NPV basis, as well as the cost differences (NEIs) between baseline and efficient, both on an NPV and annualized basis.

Table 43. Lifetime and Annualized Costs for Refrigerated Air Dryers

Baseline Costs* (Analysis Period—$2015)				Efficient Option Costs* (Analysis Period—$2015)				Efficient Option NEIs (relative to baseline)	
Maintain	Repair	Replace	Total	Maintain	Repair	Replace	Total	Total NPV	Amortized per year
$ 2,231	$ -	$ -	$ 2,231	$ 532	$ -	$ -	$ 532	$ 1,699	$ 117

* Reflects the total NPV cost that would be incurred in accordance to the schedule shown in the previous two tables.

Low-pressure drop filters

The following table shows the characteristics of the baseline and efficient options for this measure.

Table 44. Summary of Efficient and Baseline Options for Low-Pressure Drop Filters

Characteristic	Baseline	Efficient	NEIs (relative to Baseline)
Type	Coalescing filter with initial pressure drop of 1-2 lb. psi and end life of 10 psi	Low-pressure filter with initial pressure drop of < 1 psi over and 3 psi at element changes. Must be deep-bed, mist eliminator style on 15-75 hp. compressors.	None
Equipment Life	5 years	5 years	

This measure does not have any NEIs. The following discussion explains this result.

- *Repair* – Repair costs are equivalent for baseline and efficient options because replacement at end of life is more common than repair within product lifetimes. Many of these filters have ten-year manufacturer guarantees.[24]
- *Maintenance* – Similar to repair, these costs are equal for baseline and efficient technologies. The most common aspect of maintaining filters is replacing the filter cartridge. However, differences between baseline and efficient equipment cartridge change frequencies could not be verified. These costs are dependent on specific factory applications rather than technology type.

Zero loss condensate drains

The following table shows the characteristics of the baseline and efficient options for this measure.

[24] Conversation with Parker Hannifin Corp Compressed Air Filters.

Table 45. Summary of Efficient and Baseline Options for Zero Loss Condensate Drains

Characteristic	Baseline	Efficient	NEIs (relative to Baseline)
Type	Timed Solenoid Drains	Zero Loss Condensate Drain	**Maintenance**: The advantage of zero loss condensate drains over timed solenoid drains is to avoid needing to replace filters, treat oily condensate, and fix air leaks at an annual cost savings of $12 per drain, with 5 average drains per facility for a total of $60 per year.
Equipment Life	15 years	15 years	

- *Maintenance* – The advantage of zero loss condensate drains over timed solenoid drains is avoiding the need to replace filters and treat oily condensate. In addition, per manufacturer interview, “If a timed solenoid drain valve opens 3 to 4 times per hour, the cost of the wasted air will be $80 per valve, per year.”[25] Manufacturer interviews estimated five timed solenoid drains per facility. The actual air leakage is an energy saving measure and not applicable to this study, but the reduction in maintenance due to not having to maintain a baseline system is considered and added. The costs to maintain the baseline system is estimated at $12 per drain, which include the costs to repair the air leaks, replace filters, and treat oily condensate.
- *Repair* – A hypothesis was investigated to determine whether zero loss condensate drains require fewer repairs due to more optimal operation using sensors rather than a simple timer. However, quantification of cost savings is dependent on the application and we were not able to make a specific estimate.

The following table shows the schedule of costs associated with the baseline and efficient options for this measure.

[25] Parker Balston, ’Coalescing Compressed Air Filters’.

Table 46. Cost Schedule for Zero Loss Condensate Drains

Year	Baseline	Efficient
1	M	-
2	M	-
3	M	-
4	M	-
5	M	-
6	M	-
7	M	-
8	M	-
9	M	-
10	M	-
11	M	-
12	M	-
13	M	-
14	M	-
15	M	-

M=Maintenance

The following table shows the prices associate with each cost listed above. Each value in the table represents a single letter above.

Table 47. Cost Breakdown for Zero Loss Condensate Drains (Price for Each Occurrence Shown Above)

Baseline	Efficient
Maintain	Maintain
$60	-

The following table shows these costs totaled across the analysis period on an NPV basis, as well as the cost differences (NEIs) between baseline and efficient, both on an NPV and annualized basis.

Table 48. Lifetime and Annualized Costs for Zero Loss Condensate Drains

Baseline Costs* (Analysis Period—$2015)				Efficient Option Costs* (Analysis Period—$2015)				Efficient Option NEIs (relative to baseline)	
Maintain	Repair	Replace	Total	Maintain	Repair	Replace	Total	Total NPV	Amortized per year
$ 869	$ -	$ -	$ 869	$ -	$ -	$ -	$ -	$ 869	$ 60

* Reflects the total NPV cost that would be incurred in accordance to the schedule shown in the previous two tables.

Electric – compressed air summary

The following tables summarize the NEIs we calculated for the electric compressed air sample categories, as well as the total population of electric compressed air measures installed in 2013.

Table 49. NEI Estimates for Measures in Electric Compressed Air Sample Categories

Measure Type/ Technology	Custom			Prescriptive		
	Average Annual NEI	Total Weighted Annual NEI	Sampled Measures	Average Annual NEI	Total Weighted Annual NEI	Sampled Measures
Compressed Air <25 HP Rotary Screw VSD				$ 664	$ 1,527	1
Compressed Air >50 HP Rotary Screw VSD	$ 1,866	$ 3,111	1	$ 3,266	$ 30,050	4
Compressed Air 25- 50 HP Rotary Screw VSD				$ 1,599	$ 7,356	2
Compressor Heat Recovery	$ -	$ -	1			
Cycling Refrigerated Air Dryer with VFD				$ 117	$ 270	1
Zero Loss Condensate	$ 1,599	$ 2,665	1	$ 60	$ 276	2
Low Pressure Drop Filters	$ -	$ -	0	$ -	$ -	0
Overall	**$ 1,155**	**$ 5,776**	**3**	**$ 1,717**	**$ 39,480**	**10**

Table 50. Overall NEI Estimates for Electric Compressed Air Sample Categories

	Custom	Prescriptive
Sampled Measures (a)	3	10
Average NEI per Sample Measure	$ 1,155	$ 1,717
Sample Total NEIs (b)	$ 3,466	$ 17,165
Sample Total kWh Savings (c)	134,314	456,016
NEI/kWH (d = b / c)	$ 0.026	$ 0.038
90% CI Low	$ 0.002	$ 0.033
90% CI High	$ 0.050	$ 0.042
p-value	0.08	0.00
Population Measures (2013) (e)	5	23
Weighted Population Savings kWh (2013) (f = c * (e / a))	223,857	1,048,837
Total Estimated Population NEI (g = d * f)	$ 5,776	$ 39,480

A.2.5 Electric – HVAC

Electric HVAC systems include cooling systems and heat pumps. We also included HVAC controls here. For information on HVAC fan motors and VFDs, see the Motors section of this appendix.

As shown in Table 5, from the population of electric HVAC measures (17 custom and 134 prescriptive) installed in 2013, we drew a sample of 6 custom and 15 prescriptive measures to characterize the types of technologies deployed in NC and their associated NEIs. In addition, all of the eight electric custom CDA projects we sampled included the installation of at least one electric HVAC measure.

Based on our review of the PA tracking data for these sampled measures, the information obtained in our interviews, and the supporting documentation provided by the PAs for the projects we sampled, we identified at least nine types of electric HVAC measures or technologies. Upon further review of the available data and information with which we can characterize and estimate NEIs, the following nine types of electric HVAC measures or technologies are considered further in our NEI analysis:

- Air Conditioners & Heat Pumps
- Geothermal Heat Pumps
- High-Efficiency Chillers
- Chilled Beams (Valence Cooling)
- HVAC Controls
- Fans
- Air Handlers
- Humidification
- Low-Pressure Drop (LPD) Filters.

The following sections summarize the NEI estimates for each measure type.

Air conditioners and heat pumps

The following table shows the characteristics of the baseline and efficient options for these measures.

Table 51. Summary of Baseline and Efficient Options for Air Conditioners and Heat Pumps

Sub-Type	Baseline	Efficient	Equipment Lifetime	NEIs (relative to Baseline)
Air conditioner, Air-cooled	ASHRAE 90.1 2007	Exceeds CEE Specifications	15	None
Air Conditioner, Water-cooled				
Heat Pump, Air-cooled				

Small Direct Expansion (DX) systems are the most common electric HVAC system type used in commercial buildings. All air-cooled DX units require similar maintenance;[26] tasks include the following:

- Inspect ducts, filters, blower, and indoor coil for dirt and other obstructions
- Diagnose and seal duct leakage
- Verify adequate airflow by measurement
- Verify correct refrigerant charge by measurement
- Check for refrigerant leaks

[26] http://energy.gov/energysaver/articles/operating-and-maintaining-your-heat-pump.

- Inspect electric terminals, and, if necessary, clean and tighten connections, and apply nonconductive coating
- Lubricate motors, and inspect belts for tightness and wear
- Verify correct electric control, making sure that heating is locked out when the thermostat calls for cooling and vice versa
- Verify correct thermostat operation.

In general, a heat pump or other direct expansion equipment requires the same maintenance no matter the efficiency level. In other words, a 13 EER split systems has the exact same maintenance needs as a 16 EER unit. These maintenance items include preventative maintenance and parts replacement, tube cleaning, open motor shaft seals and bearing, low-pressure purge, and replacement after catastrophic failure. This remains true across almost all air-cooled DX equipment.

Geothermal heat pumps

To calculate NEIs of geothermal systems, the component can be broken into two categories: DX systems and ground loops. The DX component will be as previously described. The ground loops consist of very few parts including pumps, filters, and valves. Although very little can go wrong with these systems, there is some standard maintenance to be performed. According to one source:

> *The indoor components of the geothermal system are electro-mechanical and will suffer from standard wear and tear over a season. Before the summer begins, a technician must look over the indoor cabinet of the heat pump and check that its motors are lubricated, electrical connections tight, coils clean, and the thermostat correctly calibrated. The outdoor components of the system require special maintenance as well. The technician will not need to dig up the coils, but the manifold needs to be checked, and sometimes open loop systems must have an acid flush to remove deposits. Each maintenance visit will involve a thorough test on the loops to make sure they are not leaking and in need of repairs.*[27]

The amount of testing varies based on whether a system is open or closed loop. However, knowing that annual inspection, water testing, filter cleaning, and heat exchanger maintenance are required, it is safe to assume $500 per season to ensure optimal system performance. In addition, the life of the heat exchanger depends on the maintenance. Research showed that they can last as long as 15 years or much less. Included in the costs was $1,199 for a heat exchanger replacement around the half-life of the equipment.

The following table shows the characteristics of the baseline and efficient options for this measure.

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27 http://www.premierindoor.com/blog/geOthermal-service/does-my-geOthermal-heat-pump-need-maintenance-before-each-summer/.

Table 52. Summary of Baseline and Efficient Options for Geothermal Heat Pumps

Sub-Type	Baseline	Efficient	Equipment Lifetime	NEIs (relative to Baseline)
Heat Pump, Ground Source	Air Source Heat Pump with Resistance Heat Backup	Geothermal System that Exceeds CEE Specifications	15	**Maintenance**: Increased maintenance due to geothermal wells.

NEIs associated with this measure are as follows. Note that these do not include maintenance items shared between the baseline and efficient systems:

- *Maintenance* – A geothermal heat pump system requires an annual check of the manifold, periodic flushes with acid water to clear out mineral deposits, and certain additional maintenance items on the heat pump such as maintaining strainers.

The following table shows the schedule of costs associated with the baseline and efficient options for this measure.

Table 53. Cost Schedule for Geothermal Heat Pumps

Year	Baseline	Efficient
1	-	M
2	-	M
3	-	M
4	-	M
5	-	M
6	-	M
7	-	M
8	-	M
9	-	M
10	-	M
11	-	M
12	-	M
13	-	M
14	-	M
15	-	M

M=Maintenance
R=Repair
P=Replacement

The following table shows the prices associate with each cost listed above. Each value in the table represents a single letter above.

Table 54. Cost Breakdown for Geothermal Heat Pumps (Price For Each Occurrence Shown Above)

Baseline	Efficient
Maintain	Maintain
$-	$2479

The following table shows these costs totaled across the analysis period on an NPV basis, as well as the cost differences (NEIs) between baseline and efficient, both on an NPV and annualized basis.

Table 55. Lifetime and Annualized Costs for Geothermal Heat Pumps

Baseline Costs* (Analysis Period—$2015)				Efficient Option Costs* (Analysis Period—$2015)				Efficient Option NEIs (relative to baseline)	
Maintain	Repair	Replace	Total	Maintain	Repair	Replace	Total	Total NPV	Amortized per year
$ -	$ -	$ -	$ -	$ 35,908	$ -	$ -	$ 35,908	$ (35,908)	$ (2,479)

* Reflects the total NPV cost that would be incurred in accordance to the schedule shown in the previous two tables.

High efficiency chillers

Chiller Compressors: The main items that draw energy and require maintenance in a chilled water system are the compressors. Oil changes, controls, cleaning, and calibration are just some of the needs. Not maintaining a compressor can be one of the most expensive mistakes building operational staff can make.

The types of compressors considered were scroll, screw, and centrifugal. Within these, a few crucial subcategories were considered. A scroll compressor can utilize a variable speed technology often referred to as “digital scroll,” a screw compressor can utilize a variable speed drive or a slide valve, and a centrifugal can utilize a variable speed drive and incorporate an oil-free magnetic bearing technology. Most, however, require the same maintenance to meet factory recommendations, and to optimize performance and lifespan.

Cooling Tower: It is important to understand cooling tower costs as they result to a water-cooled chiller. If a building baseline system is water-cooled, but an efficient air-cooled chiller is chosen, the cooling tower savings should be calculated.

The following table shows the characteristics of the baseline and efficient options for these measures.

Table 56. Summary of Baseline and Efficient Options for High-Efficiency Chillers

Sub-Type	Baseline[28]	Efficient	Lifetime Years	NEIs (relative to Baseline)
Air-cooled Scroll Chiller	ASHRAE 90.1 2007	Exceeds code and the minimum application requirements.	20	**Maintenance**: Magnetic bearing compressors require less frequent oil changes. Water-cooled chillers require more maintenance. **Repair**: For water-cooled chillers, magnetic bearings require fewer repairs. **Replacement**: Water-cooled chillers last longer.
Air-cooled Screw Chiller	ASHRAE 90.1 2007		20	
Air-cooled Centrifugal Chiller with Magnetic Bearings	ASHRAE 90.1 2007[29]		20	
Water-cooled Screw Chiller	ASHRAE 90.1 2007[30]		20	
Water-cooled Centrifugal Chiller	ASHRAE 90.1 2007[30]		20	
Water-cooled Centrifugal Chiller with Magnetic Bearings	ASHRAE 90.1 2007[30] (WC Centrifugal)		20	

NEIs associated with this measure are as follows:

- *Maintenance* – In general, centrifugal compressors require more maintenance than a screw, and a screw requires more than a scroll compressor. However, a magnetic bearing centrifugal compressor does not require oil and therefore offers a unique and valuable NEI by reducing oil changes, oil analysis, oil pump rebuilding, and oil heater/cooler maintenance. One additional cost unique to a magnetic bearing compressor is a circuit board replacement expected in year 15 due to its advanced controls.[31] Compressors with oil-free technology are becoming more popular.
- Where a major NEI takes effect is if an air-cooled chiller is used instead of a water-cooled chiller with a cooling tower. For example, if a design dictates a new building has a 300-ton load and the building is being evaluated for code compliance using a building simulation model, ASHRAE Appendix G requires the energy use to be analyzed with a water-cooled chiller. However, the actual chiller installed could be an air-cooled chiller with a similar efficiency, or something different if ASHRAE Appendix G and modeling is used for code compliance. Therefore, the baseline will be a water-cooled chiller with a cooling tower, and the proposed will be an air-cooled chiller with no cooling tower. This will affect the NEI, as a cooling tower requires additional needs. This can also happen in reverse, where a water-cooled chiller has an air-cooled chiller as a baseline, thus creating negative NEIs.
- *Repair* – Danfoss[31] includes a compressor repair every five years, for which the cost varies by chiller type.

[28] The same type of compressor (screw, scroll, or centrifugal) was used as the baseline and efficient option unless a different base type was listed by the program documentation or identified by the customer.
[29] For some custom projects, a water-cooled chiller may have been used as baseline.
[30] For some custom projects, an air-cooled chiller may have been used as baseline.
[31] Life Cycle Costing Analysis of Water-cooled Chillers, Danfoss TURBOCOR, Spring 2012.

- *Replacement* – While water-cooled chiller compressors can last much longer, cooling towers and air-cooled compressors, on average, require replacement every 15 years.

The following table shows the schedule of costs associated with the baseline and efficient options for this measure.

Table 57. Cost Schedule for High-Efficiency Chillers

Year	Air-Cooled			Water-Cooled		
	Scroll	Screw	Centrifugal Magnetic	Screw	Centrifugal	Centrifugal Magnetic
1	M	M	M	M,C	M,C	M,C
2	M	M	M	M,C	M,C	M,C
3	M	M	M	M,C	M,C	M,C
4	M	M	M	M,C	M,C	M,C
5	M,R	M,R	M	M,C,R	M,C,R	M,C
6	M	M	M	M,C	M,C	M,C
7	M	M	M	M,C	M,C	M,C
8	M	M	M	M,C	M,C	M,C
9	M	M	M	M,C	M,C	M,C
10	M,R	M,R	M,R	M,C,R	M,C,R	M,C,R
11	M	M	M	M,C	M,C	M,C
12	M	M	M	M,C	M,C	M,C
13	M	M	M	M,C	M,C	M,C
14	M	M	M	M,C	M,C	M,C
15	M,R	M,R	M	M,T,R	M,T,R	M,T
16				M,C	M,C	M,C
17				M,C	M,C	M,C
18				M,C	M,C	M,C
19				M,C	M,C	M,C
20				M,C	M,C	M,C

M=Chiller Maintenance
R=Compressor Repair
C=Cooling Tower Maintenance
P=Chiller Replacement
T=Cooling Tower Repair

The following table shows the prices associate with each cost listed above. Each value in the table represents a single letter above.

Table 58. Cost Breakdown for High-Efficiency Chillers (Price for Each Occurrence Shown Above)[32]

Type	Maintain Chiller[33]	Compressor Repair	Maintain Cooling Tower	Replace Cooling Tower[34]
AC Scroll	$1,032	$2,606	-	-
AC Screw	$1,032	$2,969	-	-
AC Mag. Cent.	$724	$6,154	-	-
WC Screw	$1,032	$1,666	$3,208	$28,208
WC Cent.	$1,032	$2,298		
WC Mag. Cent.	$724	$5,250		

The following table shows these costs totaled across the analysis period on an NPV basis, as well as the cost differences (NEIs) between baseline and efficient, both on an NPV and annualized basis.

Table 59. Lifetime and Annualized Costs for High-Efficiency Chillers

Category	Baseline Costs* (Analysis Period—$2015)				Efficient Option Costs* (Analysis Period—$2015)				Efficient Option NEIs (relative to baseline)	
	Maintain	Repair	Replace	Total	Maintain	Repair	Replace	Total	Total NPV	Amortized per year
AC Scroll	Varies	Varies	Varies	Varies	$ 19,716	$ 5,527	$ 6,540	$ 31,783	Varies	Varies
AC Screw					$ 19,716	$ 6,297	$ 17,201	$ 43,214		
AC Mag. Cent.					$ 13,832	$ 6,929	$ -	$ 20,761		
WC Screw					$ 81,005	$ 5,093	$ 18,347	$104,445		
WC Cent.					$ 84,444	$ 7,025	$ 26,630	$118,099		
WC Mag. Cent.					$ 75,121	$ 5,024	$ 10,821	$ 90,966		

* Reflects the total NPV cost that would be incurred in accordance to the schedule shown in the previous two tables.

Chilled beam (valence cooling)

A popular new technology uses chilled water to cool the thermal zone of a building rather than supplying cooling through fan-coil units. This technology saves energy, and is also largely maintenance-free. Fan-coil units require belt maintenance, lubrication, and adjustment. Chilled beams do not have moving parts, and therefore do not require the same maintenance. Both technologies require coil cleaning. The sample data did not give a number of chilled beams or comparable fan-coil units. Therefore, DNV GL opted to use the estimate of one unit per 1,000 ft^2 as the baseline.

The following table shows the characteristics of the baseline and efficient options for this measure.

[32] For a custom project, many of the options in this table can be considered as baseline or efficient. Because of the many possible combinations, we omitted the column associated with "NEIs relative to baseline."
[33] http://www.thermalcare.com/central-chillers/tc-series-central-chillers/air-cooled-vs-water-cooled.php.
[34] CBRE/Whitestone CostLab.

Table 60. Summary of Baseline and Efficient Options for Chilled Beams

Characteristic	Baseline	Efficient	NEIs (relative to Baseline)
Description	Fan Coil Units	Chilled Beam System	**Maintenance**: Less motor bearing greasing, belt changes, and filter changes **Repair**: Reduced repairs due to less mechanical parts
Comparison Units	One Fan Coil Unit per 1000 ft2	One Chilled Beam per 1000 ft2	
Equipment Life	15 years	15 years	

NEIs associated with this measure are as follows:

- *Maintenance* – A fan-coil unit requires motor lubrication once per year, cleaning, belt replacement and adjustment, coil cleaning, filter changes, and drain maintenance.[35] A chilled beam requires regular cleaning just like a fan coil but not the other listed things.[36] Assuming a fan coil can cover 1,000 ft^2, then the reduction in maintenance time compared to a chilled beam can be analyzed.

The following table shows the schedule of costs associated with the baseline and efficient options for this measure.

Table 61. Cost Schedule for Chilled Beams

Year	Baseline	Efficient
1	M	-
2	M	-
3	M	-
4	M	-
5	M	-
6	M	-
7	M	-
8	M	-
9	M	-
10	M	-
11	M	-
12	M	-
13	M	-
14	M	-
15	M	-

M=Maintenance
R=Repair
P=Replacement

The following table shows the prices associate with each cost listed above. Each value in the table represents a single letter above.

35 http://contractingbusiness.com/service/fan-coil-units-extra-maintenance-steps-worth-extra-effort.
36 http://contractingbusiness.com/service/chilled-beam-service-requires-whole-building-knowledge.

Table 62. Cost Breakdown for Chilled Beams (Price for Each Occurrence Shown Above)

Baseline Maintain	Efficient Maintain
$60	-

The following table shows these costs totaled across the analysis period on an NPV basis, as well as the cost differences (NEIs) between baseline and efficient, both on an NPV and annualized basis.

Table 63. Lifetime and Annualized Costs for Chilled Beams

Baseline Costs* (Analysis Period—$2015)				Efficient Option Costs* (Analysis Period—$2015)				Efficient Option NEIs (relative to baseline)	
Maintain	Repair	Replace	Total	Maintain	Repair	Replace	Total	Total NPV	Amortized per year
$ 869	$ -	$ -	$ 869	$ -	$ -	$ -	$ -	$ 869	$ 60

* Reflects the total NPV cost that would be incurred in accordance to the schedule shown in the previous two tables.

HVAC controls

HVAC systems have multitudes of controls; however, only a few were given incentives under our sample. These include dual enthalpy economizers and energy management systems (EMS).

Each of these technologies offer enhanced comfort and safety, which are NEIs, but quantifying those vales was far too dependent on the system type and offered no method of estimating the value. However, calibration of these systems is required.

A baseline for these systems is either an on/off control, or one that floats. These are among the most energy-wasting items in a building. However, focusing on the NEIs, the operational maintenance and retro-commissioning of these controls represent added cost.

EMS systems allow you to more easily implement a retro-commissioning program. The EMS gives you error codes that tell you that maintenance is required. Many EMS operators do certain kinds of maintenance they are told about by their system, but not others. There are as many ways of using an EMS to operate a building as there are EMS operators. There are calibration costs associated with sensors, and additional costs every so often for migrating EMS systems to the newest software versions.

There can also be significant cost savings associated with EMS systems. Depending on the sophistication of the operator, they can find out about equipment operating poorly and correct it, potentially preventing issues that would occur later. These are very difficult to quantify.

Because the costs and benefits of EMS systems are so varied, we decided that we did not have sufficient information to justify any positive or negative NEI cost estimate.

With regard to dual enthalpy economizer controls (DEEC) we determined that the primary difference between baseline and efficient options is the addition of two combination temperature/humidity sensors for each air handling unit. Manufacturers recommend recalibrating these sensors on a regular schedule. Our experience suggests that a majority of customers never calibrate their sensors outside of a periodic retro-commissioning program. The New York City Mayor's Office of Sustainability requires an Energy Efficiency Report (EER) submitted every ten years.[37] Assuming that calibration takes place during this ten-year retro-commissioning cycle, this equals the effective useful life of the equipment and so would not be completed during the life of the DEEC controls.

The following table shows the characteristics of the baseline and efficient options for these measures.

Table 64. Summary of Baseline and Efficient Options for HVAC Controls

Type	Baseline	Efficient	Lifetime Years	NEIs (relative to Baseline)
Dual Enthalpy Economizer Controls (DEEC)	Fixed Dry Bulb Economizer	Dual Enthalpy Economizer	10	None
Energy Management System	None	Energy Management System	15	

Fans

Fans can come in multiple designs, like forward curved, backward curved, radial, and vane axial. None of the information in the selected sample referenced a specific fan style. Also, in general, the fan shape is a method of reducing cost, changing noise, or overcoming pressure. NEIs are not relatable because if a specific style is needed, it inherently becomes the baseline for the design. In some cases a fan type may require more frequent balancing compared to another style. Although this is an NEI, it is probably due to a design constraint like the fan type needing to be explosion proof or to meet a noise constraint. Therefore, fan configuration was not considered valuable as part of this study.

Air handlers

Air handler unit (AHU) incentives are based on a combination of systems within this study. Heat recovery, variable speed drives, economizers, humidification, low-pressure filters, and other systems make up the potential NEIs. The savings and incentives are usually built on prescriptive or energy modeled approaches. The baseline for all AHU systems would be an air handler meeting ASHRAE 90.1 2007 Appendix G guidelines. The proposed system could potentially include a non-air-based design, like a specially designed chilled beam system, radiant heating, or other unique design. However, in the samples chosen, none of these systems were used. Even the samples with chilled beam design used a dedicated outside air unit, meaning a basic AHU was still incorporated. Therefore, we did not find NEIs for AHU systems.

Humidification

Humidification can come in multiple technologies that require specific maintenance. For example, a steam-generated system requires different maintenance than a pressure-driven

[37] http://www.nyc.gov/html/gbee/html/plan/ll87.shtml.

system. However, either way, if humidification is needed, in laboratories for example, there is no standard baseline with which to compare. Because of how specialized the need is for these systems, DNV GL opted to not include the NEIs for this technology. In addition, most incentives for humidification systems are for the boiler or heating element. If a boiler was part of the sample data, the NEIs were considered under the applicable section.

LPD filters

The main benefit of a low-pressure drop (LPD) filter is in the energy saved at the fan motor. It is conceivable that a motor that runs less due to less pressure will run at a lower temperature, thereby run for more hours, and require less maintenance. However, it is more likely in new construction that the motor is sized based on the total pressure required, so an LPD filter equals a smaller horsepower motor requiring similar maintenance to a larger motor. Because of this, DNV GL opted to not include potential NEIs for LPD filters.

Electric – HVAC summary

The following tables summarize the NEIs we calculated for the electric HVAC sample categories, as well as the total population of electric HVAC measures installed in 2013.

Table 65. NEI Estimates for Measures in Electric HVAC Sample Categories

	Custom			Prescriptive		
Measure Type/ Technology	Average Annual NEI	Total Weighted Annual NEI	Sampled Measures	Average Annual NEI	Total Weighted Annual NEI	Sampled Measures
Chiller, Air Cooled Scroll (20 yr)				$ -	$ -	3
Custom Chiller	$ 462	$ 5,604	5			
HVAC Controls	$ -	$ -	1	$ -	$ -	2
Unitary HVAC, Air Cooled	$ -	$ -	1	$ -	$ -	10
Overall	**$ 330**	**$ 5,604**	**7**	**$ -**	**$ -**	**15**

Table 66. Overall NEI Estimates for Electric HVAC Sample Categories

	Custom	Prescriptive
Sampled Measures (a)	7	15
Average NEI per Sample Measure	$ 330	$ -
Sample Total NEIs (b)	$ 2,308	$ -
Sample Total kWh Savings (c)	1,581,827	146,235
NEI/kWH (d = b / c)	$ 0.001	$ -
90% CI Low	$ (0.002)	$ -
90% CI High	$ 0.005	$ -
p-value	0.44	0.00
Population Measures (2013) (e)	17	134
Weighted Population Savings kWh (2013) (f = c * (e / a))	3,841,580	1,306,369
Total Estimated Population NEI (g = d * f)	$ 5,604	$ -

A.2.6 Electric – Industrial Process

As shown in Table 5, from the population of electric industrial process measures (five custom and one prescriptive) installed in 2013, we drew a sample of five custom and one prescriptive measures to characterize the types of technologies deployed in NC and their associated NEIs. None of the eight electric custom CDA projects we sampled included the installation of at least one electric industrial process measure.

Based on our review of the PA tracking data for these sampled measures, the information obtained in our interviews, and the supporting documentation provided by the PAs for the projects we sampled, we identified at least four types of electric industrial process measures or technologies. Upon further review of the available data and information with which we can characterize and estimate NEIs, the following two types of electric industrial process measures or technologies are considered further in our NEI analysis:

- Injection-molding Machines
- Uninterruptible Power Supplies (UPS)

Several other measure types, such as variable frequency drives and lighting, fell into the industrial process category. NEIs for these measures were developed under other sections of this appendix, and can be found in their appropriate sections.

The following sections summarize the NEI estimates for each measure type.

Injection-molding

Injection-molding machines have been used for many years and commonly come as hydraulic, electric, or hybrid machines. Hydraulic has dominated the market for many years. In recent times, electric injection-molding machines have been replacing hydraulic molding machines. In general, the difference between electric and hydraulic injection-molding machines is that one uses oil to pressurize and inject plastic into a mold, and the other requires no oil. The electric machine avoids oil contamination, leaks, changes, and testing, and heats up and cools down faster. This creates less waste, tighter temperatures, and other factors resulting in increased efficiency and reduced maintenance.

NEIs likely include easier use, less oil maintenance, and less scrap. However, due to process privacy concerns, respondents were only willing to share information about oil-related maintenance. Donaldson Filtration Solutions recommends testing oil every 500 hours, or about monthly on average. In interviewing their engineering staff, we found they have a program that costs $2,500 to perform this service. ACO Mold states, "An all-electric machine can offer unmatched repeatability due to the servo drives that are used for injection forward and clamp rather than hydraulic pumps/valves."[38] This reliability cannot easily be quantified, as it is specific to each business.

[38] http://www.acomold.com/electric-vs-hydraulic-injection-molding-machine.html.

The following table shows the characteristics of the baseline and efficient options for this measure.

Table 67. Summary of Efficient and Baseline Options for Injection Molding

Characteristic	Baseline	Efficient	NEIs (relative to Baseline)
Type	Hydraulic	Electric	**Maintenance**: Electric model does not require oil servicing.
Flow	Constant Volume	Variable Volume	

NEIs associated with this measure are as follows:

- *Maintenance*: Donaldson Filtration Solutions recommends servicing oil-filled injection-molding machines every 500 hours, or about monthly on average. In interviewing their engineering staff, we found they have a program that costs $2,500 to perform this service. The size and hours of the process of the injection molding machines (IMM) will greatly vary the NEIs. Since the samples were large facilities, DNV GL assumed the IMMs would be maintained along with other machines on a set quarterly schedule.

The following table shows the schedule of costs associated with the baseline and efficient options for this measure.

Table 68. Cost Schedule for Injection Molding

Year	Baseline	Efficient
1	M	
2	M	
3	M	
4	M	
5	M	
6	M	
7	M	
8	M	
9	M	
10	M	
11	M	
12	M	
13	M	
14	M	
15	M	

M=Maintain

The following table shows the prices associate with each cost listed above. Each value in the table represents a single letter above.

Table 69. Cost Breakdown for Injection Molding (Price For Each Occurrence Shown Above)

Baseline	Efficient
Maintain	Maintain
$5,000	-

The following table shows these costs totaled across the analysis period on an NPV basis, as well as the cost differences (NEIs) between baseline and efficient, both on an NPV and annualized basis.

Table 70. Lifetime and Annualized Costs for Injection Molding

Baseline Costs* (Analysis Period—$2015)				Efficient Option Costs* (Analysis Period—$2015)				Efficient Option NEIs (relative to baseline)	
Maintain	Repair	Replace	Total	Maintain	Repair	Replace	Total	Total NPV	Amortized per year
$ 72,425	$ -	$ -	$ 72,425	$ -	$ -	$ -	$ -	$ 72,425	$ 5,000

* Reflects the total NPV cost that would be incurred in accordance to the schedule shown in the previous two tables.

UPS

Uninterruptible power supplies are critical systems that will continue to grow in popularity as more and more building equipment is controlled by computers and software. UPS systems act as buffers for power spikes, safe shutdowns, and reliability.

UPS efficiency ratings are found on the nameplate of the equipment and represent how much original incoming utility power is used to power critical load versus how much is lost in the operation of the UPS. For example, according to a fact sheet from Emerson Network Power: “A UPS that is 96% efficient passes 96% of the incoming utility power to the load, while a 94% efficient UPS passes 94% of the input power to the output. However, while a side-by-side comparison indicates that a 96% efficient UPS would yield greater energy savings, it is often overlooked that these ‘nameplate’ ratings only represent full load.”[39]

At part load, a machine that has a less efficient rating can become more efficient than its counterpart. In other words, the efficiency savings is not a straightforward calculation and is very dependent on what the UPS is serving. However, the O&M items that represent the NEIs of UPS systems are the same, as shown below.

[39] http://www.emersonnetworkpower.com/documentation/en-us/brands/liebert/documents/white%20papers/conducting%20an%20accurate%20utility%20cost%20analysis%20based%20on%20ups%20efficiency.pdf.

Table 71. UPS Servicing Requirements[40]

Frequency	Task
Quarterly:	Visually inspect equipment for loose connections, burned insulation or any other signs of wear.
Semiannually:	Visually check for liquid contamination from batteries and capacitors.
	Clean and vacuum UPS equipment enclosures.
	Check HVAC equipment and performance related to temperature and humidity.
Annually:	Conduct thermal scans on electrical connections to ensure all are tight and not generating heat, which is the first and sometimes only indication of a problem. A non-evasive diagnostic tool helps technicians identify hot spots invisible to the human eye. Technicians should re-torque if thermal scan provides evidence of a loose connection.
	Provide a complete operational test of the system, including a monitored battery-rundown test to determine if any battery strings or cells are near the end of their useful lives.
Biannually:	Test UPS transfer switches, circuit breakers and maintenance bypasses.

Since the maintenance items are the same across different systems, and the nature of a UPS is predicated on its not needing much maintenance compared to other building systems, the NEIs are zero dollars.

Electric – industrial process summary

The following tables summarize the NEIs we calculated for the electric industrial process sample categories, as well as the total population of electric industrial process measures installed in 2013.

Table 72. NEI Estimates for Measures in Electric Industrial Process Sample Categories

	Custom			Prescriptive		
Measure Type/ Technology	Average Annual NEI	Total Weighted Annual NEI	Sampled Measures	Average Annual NEI	Total Weighted Annual NEI	Sampled Measures
Custom Industrial Process	$ (16)	$ (49)	3			
Injection Molding Electric	$ 10,000	$ 20,000	2			
Other				$ -	$ -	1
Overall	**$ 3,990**	**$ 19,951**	**5**	**$ -**	**$ -**	**1**

40 http://www.facilitiesnet.com/powercommunication/article/UPS-Maintenance-Checklist-Facility-Management-Power-Communication-Feature--9401.

Table 73. Overall NEI Estimates for Electric Industrial Process Sample Categories

	Custom	Prescriptive
Sampled Measures (a)	5	1
Average NEI per Sample Measure	$ 3,990	$ -
Sample Total NEIs (b)	$ 19,951	$ -
Sample Total kWh Savings (c)	1,565,025	5,389
NEI/kWH (d = b / c)	$ 0.013	$ -
90% CI Low	$ 0.004	$ -
90% CI High	$ 0.022	$ -
p-value	0.02	0.00
Population Measures (2013) (e)	5	1
Weighted Population Savings kWh (2013) (f = c * (e / a))	1,565,025	5,389
Total Estimated Population NEI (g = d * f)	$ 19,951	$ -

A.2.7 Electric – Lighting

Lighting energy savings benefits are so well known it has created new business segments in the retrofit and new construction industry. Between high-output T8s, T5s, LEDs, and controls, many new construction projects include the most advanced lighting technologies.

As shown in Table 5, from the population of lighting measures (24 custom and 440 prescriptive) installed in 2013, we drew a sample of 15 custom and 49 prescriptive measures to characterize the types of technologies deployed in NC and their associated NEIs. In addition, all of the eight electric custom CDA projects we sampled included the installation of at least one lighting measure.

Based on our review of the PA tracking data for these sampled measures, the information obtained in our interviews, and the supporting documentation provided by the PAs for the projects we sampled, we identified at least four types of lighting measures or technologies. Upon further review of the available data and information with which we can characterize and estimate NEIs, the following four types of lighting measures or technologies are considered further in our NEI analysis:

- Light Fixtures
- Refrigerated Case Lighting
- Lighting Controls
- Performance Lighting.

The following sections summarize the NEI estimates for each measure type.

Light fixtures

The reduction of life-cycle costs includes extended life, reduced ballast changes, and better lighting distribution. For example, an LED uses less energy and lasts much longer than a T8, and does not require bulb or ballast replacement.

Baseline is an important consideration for lighting. The most common lighting fixture in a non-industrial setting with a 10 ft. ceiling height (the vast majority of our sample) is a three (3) lamp T8 fixture. Using information from various online sources and DNV GL professional judgment, it was determined that the baseline fixture for schools and office spaces would be the 3-Lamp 32-Watt 4' T8. For high bay applications, we considered the baseline to be a 400-watt metal halide. Setting these baseline assumptions proved critical to the life-cycle costing calculations that were performed to assist with creating cost figures for lighting projects.

The interview phase produced a variety of results. Some Massachusetts customers said the "flickering" of the LEDs hurt performance while others said the LEDs' light distribution increased the work performance of the occupants. Universally, customers commented that the smaller LED wall fixtures (PAR16 bulb) required more maintenance and replacements than other technologies. All respondents commented that T5 and T8 ballasts were replaced about every five years, while the lamps were replaced approximately every three years. The LED fixtures require full fixture replacement but none of our respondents had to do it yet due to the longevity of LEDs.

In Massachusetts, it is important to note that rebates for lighting technologies are not only for the lamps but can also be for the ballasts. If the ballast meets an efficiency threshold, then some of the older, less efficient T8 model lamps can still be rebated.[41] While the measures can be rebated, we believe that there will not be any NEIs associated with these cases. Having the more efficient ballast will likely only lead to energy savings, but not produce any non-energy benefits.

The table below shows the characteristics of the baseline and efficient options for this measure. The baseline is always a T8 lamp, but the efficient option can be a T5 and/or an LED. In applications where we were given area (ft^2) only, we assumed 80 ft^2 as a coverage area for a fixture.

[41] http://www.masssave.com/~/media/Files/Business/Applications-and-Rebate-Forms/Retrofit/Lighting-Controls-Retrofit-Form-Mass-Save.pdf.

Table 74. Summary of Efficient and Baseline Options for Light Fixtures

Characteristic	Baseline - T8/HO T8	Efficient – T5	Efficient – LED	NEIs (relative to Baseline)
Type	Linear Fluorescent T8 Fixture	Linear Fluorescent T5 Fixture	Light Emitting Diode Fixture	**Maintenance**: T5 bulbs are brighter than T8s and can light a 20% larger space using the same fixture footprint. This allows for fewer bulb changes. In most conditions, LED fixtures do not require maintenance. **Replacement**: Because T5 lighting layouts require fewer fixtures, on replacement fewer fixtures must be replaced. LED bulb and fixture replacements are less frequent than fluorescent technologies, resulting in a lower labor cost.
Control	Electronic Ballast	Electronic Ballast	Electronic Driver	
Fixture Quantity[42]	1:1	0.9:1	0.9:1	
Fixture Life[43]	10 years	10 Years	10 Years	
Ballast Life[42]	5 Years	5 Years	-	
Bulb Life[42]	3 Years	3 Years	-	

NEIs associated with this measure are as follows:

- *Maintenance:* The only savings from the T5 verses the T8 is the reduction in number of fixtures. A T5 bulb has a smaller diameter than a T8, which makes it closer to the light source and increases the Co-Efficiency of Utilization (CU). In general, a T5 is found to have 10% to 16% increased CU. The NEI utilizes a 10% increase in lighting, which results in less lamps being used at the site.[44]

  All respondents mentioned that there was reduced cost in waste mercury containment, but only one specified that there were savings of "a couple hundred dollars per retrofit." The rest said they could not quantify the savings amount due to it being handled by a "different person or department." Clearwater Services estimates the cost of recycling a fluorescent tube is between six and ten cents per bulb foot, and a pickup fee of between $35 and $50. The common theme from all interviewees was that LEDs are superior to T5 and T8 lights in lifespan, energy consumption, maintenance, and often performance of the tenants.

- *Replacement*: With regard to NEIs, LED fixtures last significantly longer and only need to be replaced every ten years, whereas the T8 and T5 technologies require bulb replacement every three years, and ballast or fixture replacement every five years. Because of the labor costs associated with ballast replacement and the low cost of fixtures when rebates are included, many installers simply replace fixtures (with new bulbs) at the five-year mark rather than changing ballasts and cleaning. This may change as rebates phase out eventually. However, for this study we assumed that lighting rebates will continue to be offered at their current levels throughout the lifetimes of fixtures sold in 2013.

[42] Fixture quantity is based on customer reaction to fixture type. The brightness of T5 fixtures over the T8 baseline caused a reduction in the number of fixtures or bulbs resulting in maintenance saving due to decreased bulbs to change. This does not apply to high bay fixtures.
[43] DNV GL professional opinion.
[44] http://lightingsolutions.ca/blog/t8-vs-t5-fluorescent/.

The following table provides the maintenance cost schedule associated with the baseline and efficient options.

Table 75. Cost Schedule for Light Fixtures

Year	Baseline	T5	LED
1			
2			
3	B,R	B,R	
4			
5	B,F,R	B,F,R	
6			
7			
8	B,R	B,R	
9			
10	F,R	F,R	F
11			
12			
13			
14			
15			

B= Replace Bulbs
F= Fixture or Ballast Replacement (includes new bulbs)[45]
R= Bulb Recycling

The following table shows the prices associate with each cost listed above. Each value in the table represents a single letter above.

[45] We found through this study that fixture and ballast replacements cost about the same amount of money in the majority of space types. For this reason, most lighting maintenance people simply replace fixtures rather than ballasts. In year 10, we assumed all fixtures would be replaced with LEDs.

Table 76. Cost Breakdown for Light Fixture (Per Fixture, Price For Each Occurrence Shown Above)

Fixture Type	Replace Bulbs[46]	Recycle Bulbs[47]	Replace Fixtures[43]	Incentive
Baseline T8 or T8HO[48]	$9.90	$3.17	$89	n/a
Efficient T5	$12.00	$2.88	$113	$-25
LED	n/a	n/a	$139	$-50
Baseline High Bay MH	$50	$0.96	$235	n/a
High Bay T5	$40	$4.80	$225	$-100
High Bay LED	n/a	n/a	$305	$-150

The following table shows these costs totaled across the analysis period on an NPV basis, as well as the cost differences (NEIs) between baseline and efficient, both on an NPV and annualized basis.

Table 77. Lifetime and Annualized Costs for Light Fixtures

Category	Baseline Costs* (Analysis Period—$2015)				Efficient Option Costs* (Analysis Period—$2015)				Efficient Option NEIs (relative to baseline)	
	Maintain	Repair	Replace	Total	Maintain	Repair	Replace	Total	Total NPV	Amortized per year
Efficient T5	$ -	$ 41	$ 168	$ 209	$ -	$ 46	$ 167	$ 213	$ (4)	$ (0.28)
Efficient LED	$ -	$ 41	$ 168	$ 209	$ -	$ -	$ 81	$ 81	$ 128	$ 8.86
High Bay T5	$ -	$ 150	$ 407	$ 557	$ -	$ 136	$ 300	$ 436	$ 121	$ 8.38
High Bay LED	$ -	$ 150	$ 407	$ 557	$ -	$ -	$ 177	$ 177	$ 380	$ 26.25

* Reflects the total NPV cost that would be incurred in accordance to the schedule shown in the previous two tables.
"Repair" costs reflect the bulb replacement and bulb recycling costs. "Replace" costs reflect the fixture replacement costs.

Refrigerated case lighting

Refrigerated case lighting receives the same NEI consideration as standard light fixtures. For a discussion on NEIs associated with the contribution of heat to refrigerated cases, see the Section A.2.10 - Refrigeration.

Lighting controls

Investigating NEIs of lighting controls consisted of searching manufacturer recommendations, talking with engineers internally, and performing interviews. According to a paper by Southern California Edison,[49] the benefits of lighting controls systems are energy savings, improved

[46] CBRE/Whitestone CostLab.
[47] Interview results.
[48] Note that these costs are increased by 10% due to the reduction in efficacy from T8 fixtures. For example, T5 fixtures are 10% more expensive, but due to the reduced light output, T8s cost just as much after installation as T5s for a given space.
[49] https://www.sce.com/wps/wcm/connect/1c694bef-e9cc-47a5-87af-698f8c8e9972/Lightning+Controls5_WCAG.pdf?MOD=AJPERES.

productivity by giving employees control of lighting levels, and reduced maintenance by extending lifespan of the lamps.

In our interviews, some said that LEDs had increased flickering, while others said it was reduced. Regarding maintenance, some respondents said that lighting controls systems required constant "tweaking," which greatly increased service time. Others claimed less fixture maintenance time due to shorter fixture runtimes. Since the NEIs could not be confirmed, denied, or quantified, we did not make an estimate at this time.

Performance lighting

Performance lighting receives the same NEI consideration as standard light fixtures.

In most cases, the program documentation contained information on the approximate numbers of fixtures of each type installed, allowing us to make estimates in the same way. If this information was missing, we selected installed fixtures based on the watts per square foot claimed, according to the following table.

Table 78. Watts per Sq. Ft. Fixture Choices

Watts / Ft2	Fixture Type
0.85–1.00	High-performance T8
0.70–0.84	T5
0.50–0.69	LED

Electric – lighting summary

The following tables summarize the NEIs we calculated for the electric lighting sample categories, as well as the total population of electric lighting measures installed in 2013.

Table 79. NEI Estimates for Measures in Electric Lighting Sample Categories

	Custom			Prescriptive		
Measure Type/ Technology	Average Annual NEI	Total Weighted Annual NEI	Sampled Measures	Average Annual NEI	Total Weighted Annual NEI	Sampled Measures
Baseline T8				$ -	$ -	7
Custom Lighting	$ 78	$ 497	4			
Efficienct LED	$ 789	$ 2,525	2	$ 2,600	$ 256,838	11
Efficient T5				$ (26)	$ (3,693)	16
High Bay LED				$ 1,534	$ 41,331	3
Lighting Controls				$ -	$ -	9
Lighting Performance	$ 365	$ 4,670	8	$ 1,425	$ 38,398	3
Mini LED (PAR16)	$ -	$ -	1			
Overall	**$ 320**	**$ 7,692**	**15**	**$ 757**	**$ 332,873**	

Table 80. Overall NEI Estimates for Electric Lighting Sample Categories

	Custom	Prescriptive
Sampled Measures (a)	15	49
Average NEI per Sample Measure	$ 320	$ 757
Sample Total NEIs (b)	$ 4,807	$ 37,070
Sample Total kWh Savings (c)	1,549,173	1,818,758
NEI/kWH (d = b / c)	$ 0.003	$ 0.020
90% CI Low	$ (0.001)	$ 0.013
90% CI High	$ 0.007	$ 0.028
p-value	0.24	0.00
Population Measures (2013) (e)	24	440
Weighted Population Savings kWh (2013) (f = c * (e / a))	2,478,677	16,331,706
Total Estimated Population NEI (g = d * f)	$ 7,692	$ 332,873

A.2.8 Electric – Motors

As shown in Table 5, from the population of motors measures (4 custom and 113 prescriptive) installed in 2013, we drew a sample of 4 custom and 37 prescriptive measures to characterize the types of technologies deployed in NC and their associated NEIs. In addition, none of the eight electric custom CDA projects we sampled included the installation of at least one motors measure.

Based on our review of the PA tracking data for these sampled measures, the information obtained in our interviews, and the supporting documentation provided by the PAs for the projects we sampled, we identified at least six types of motors measures or technologies (see below for further discussion of those not included here). Upon further review of the available data and information with which we can characterize and estimate NEIs, the following two types of motors measures or technologies are considered further in our NEI analysis:

- Variable Frequency Drives (VFDs)
- HVAC ECM Motors.

The "motors" category in the tracking data also includes several prescriptive measures installed in other systems, including ECM motors, low-energy doors, and anti-sweat heaters. These are listed under the "other" section of this report, as the majority of these three measures—while they are offered under the prescriptive motors program—were actually installed under the custom "other" program.

The following sections summarize the NEI estimates for each measure type included here.

VFDs

Electric motors have been one of the primary drivers of energy efficiency in commercial buildings. The advent of VFDs changed HVAC, process, conveyors, and many other aspects of buildings' energy use.

Motors running at one speed with no variability can operate with minimal maintenance. This is often not the case, however, as motors change the speed with which air, water, and products are moved. Every manufacturer, utility customer, contractor, and engineer interviewed insisted that there are maintenance implications for a motor with VFD compared to one without. The non-energy related advantages and disadvantages can be summarized as follows:

Advantages

- Reduction of inrush current due to soft start
- Reduced heat due to running at part load
- Ability to adjust speed, which increases productivity
- Packaged systems come pre-programmed

Disadvantages

- Bearings can wear faster, causing premature failure
- Additional electric components are susceptible to failure
- Electrical flux concentrates at specific points inside motor, causing premature failure.

These advantages are irregular, do not always occur, and point in different directions, making them difficult to generalize about or measure. For example, while inrush current constantly changing causes thrust on the bearings, which leads to failure and major motor case damage; this is process-dependent and may or may not result in failure. Heat savings is similar. Many motors last well over 50 years, so even if the heat added or subtracted 25% of the life, the motor would still last its entire expected lifespan.

Considering some applications can have hundreds of these motors (hotels, hospitals, large multi-family, etc.), failures are expected. Most building maintenance teams keep spare motors on hand in preparation. However, there appears to be no difference in the need to store more than one between the baseline and efficient options. Another potential point of non-energy savings is in the air balancing often required during retro-commissioning. However, contractor and maintenance staff interviews did not turn up any examples of a building planning to, or having used, this technique.

While our sample did not include any manufacturing VFDs, we did find that NEIs may exist in some cases. One customer who manufactures food products explained that they use VFDs to adjust cook time based on the food being processed. If the product needed less cook time, they sped the motors up, and the opposite if it needed more cook time. However, the VFDs themselves require more maintenance compared to using the previous braking/over-speed system.

Because our interview results yielded inconsistent findings, we do not recommend the deeming of NEIs for VFDs at this time.

The following table shows the characteristics of the baseline and efficient options for this measure.

Table 81. Summary of Efficient and Baseline Options for Variable Frequency Drives

Characteristic	Baseline	Efficient	NEIs (relative to Baseline)
Control	Across the line motor control	Variable Speed	None
Lubrication	Greased Bearing	Greased Bearing	
Equipment Life	15 years	15 years	

There are no NEIs associated with this measure, but the standard action for all motors and controllers are as follows:

- Repair – Larger motors are rewound when burnout occurs. Variable speed controls are either repaired or, more than likely, replaced. Electrically commutated (EC) motors are replaced if they fail due to the low cost and small size.
- Maintenance – All motors require scheduled greasing and removing dust and dirt. All control technologies require scheduled cleaning.

HVAC ECM motors

The most commonly incentivized EC motors were installed on fan coil units, air handlers, and DX units. The baseline option is a permanent split capacitor (PSC) motor. The primary advantage of an EC motor is the variable speed control. Most of these motors are designed to run at a set capacity that is not 100%. An EC motor is more efficient than a PSC motor at the set capacity, when used as a variable speed, or multi-speed. Both technologies are relatively maintenance free. Failure typically results from bearing wear and tear. Both motor types use the same type of bearings, and if they fail, they are usually just replaced with new units. There is nothing measurable to show a non-energy benefit of one over the other.

The following table shows the characteristics of the baseline and efficient options for this measure.

Table 82. Summary of Efficient and Baseline Options for HVAC ECM Motors

Characteristic	Baseline	Efficient	NEIs (relative to Baseline)
Type	Permanently Shaded Coil Motor	Electrically Commutated Motor	None
Lubrication	Greased Bearing	Greased Bearing	
Equipment Life	15 years	15 years	

Electric – motor summary

The following tables summarize the NEIs we calculated for the electric motor sample categories, as well as the total population of electric motor measures installed in 2013.

Table 83. NEI Estimates for Measures in Electric Motor Sample Categories

Measure Type/ Technology	Custom			Prescriptive		
	Average Annual NEI	Total Weighted Annual NEI	Sampled Measures	Average Annual NEI	Total Weighted Annual NEI	Sampled Measures
HVAC ECM Motors				$ -	$ -	10
Refrigerated Case Motors				$ -	$ -	1
Variable Speed Drives	$ -	$ -	4	$ -	$ -	26
Overall	**$ -**	**$ -**	**4**	**$ -**	**$ -**	**37**

Table 84. Overall NEI Estimates for Electric Motor Sample Categories

	Custom	Prescriptive
Sampled Measures (a)	4	37
Average NEI per Sample Measure	$ -	$ -
Sample Total NEIs (b)	$ -	$ -
Sample Total kWh Savings (c)	612,932	1,653,940
NEI/kWH (d = b / c)	$ -	$ -
90% CI Low	$ -	$ -
90% CI High	$ -	$ -
p-value	0.00	0.00
Population Measures (2013) (e)	4	113
Weighted Population Savings kWh (2013) (f = c * (e / a))	612,932	5,051,222
Total Estimated Population NEI (g = d * f)	$ -	$ -

A.2.9 Electric – Other

The electric “other” measure category includes a variety of measures, but the following make up the majority of energy savings. See the applicable sections for estimates of NEIs for these specific measures, which are combined to estimate NEIs for specific projects.

As shown in Table 5, from the population of electric “other” measures (2 custom and 1 prescriptive) installed in 2013, we drew a sample of 2 custom and 1 prescriptive measures to characterize the types of technologies deployed in NC and their associated NEIs. In addition, none of the eight electric custom CDA projects we sampled included the installation of at least one electric “other” measure.

Based on our review of the PA tracking data for these sampled measures, the information obtained in our interviews, and the supporting documentation provided by the PAs for the projects we sampled, we identified at least three types of electric “other” measures or technologies. Upon further review of the available data and information with which we can characterize and estimate NEIs, we chose to analyze the electric “other” measures in the categories defined for the other categories. These included uninterruptible power supplies (UPS), HVAC controls, lighting controls, and high-efficiency motors.

Electric – other summary

The following tables summarize the NEIs we calculated for the electric "other" sample categories, as well as the total population of electric "other" measures installed in 2013.

Table 85. NEI Estimates for Measures in Electric Other Sample Categories

Measure Type/ Technology	Custom			Prescriptive		
	Average Annual NEI	Total Weighted Annual NEI	Sampled Measures	Average Annual NEI	Total Weighted Annual NEI	Sampled Measures
Custom Motors	$ -	$ -	1			
Other	$ -	$ -	1	$ -		1
Overall	**$ -**	**$ -**	**2**	**$ -**	**$ -**	**1**

Table 86. Overall NEI Estimates for Electric Other Sample Categories

	Custom	Prescriptive
Sampled Measures (a)	2	1
Average NEI per Sample Measure	$ -	$ -
Sample Total NEIs (b)	$ -	$ -
Sample Total kWh Savings (c)	567,487	73,616
NEI/kWH (d = b / c)	$ -	$ -
90% CI Low	$ -	$ -
90% CI High	$ -	$ -
p-value	0.00	0.00
Population Measures (2013) (e)	2	1
Weighted Population Savings kWh (2013) (f = c * (e / a))	567,487	73,616
Total Estimated Population NEI (g = d * f)	$ -	$ -

A.2.10 Electric – Refrigeration

This measure category includes energy efficient upgrades to refrigeration systems used in refrigeration of food products in small and large grocery stores, as well as industrial-scale refrigeration systems.

The custom program includes a refrigeration measure category, while the prescriptive program categorizes refrigeration measures as "motors." The prescriptive refrigeration measures (the first three measures listed below) are included in this section for clarity, and because the majority of these measures—while they are offered under the prescriptive program—were actually installed under the custom program.

As shown in Table 5, from the population of refrigeration measures (13 custom and zero prescriptive) installed in 2013, we drew a sample of 5 custom measures to characterize the types of technologies deployed in NC and their associated NEIs. In addition, none of the eight custom CDA projects we sampled included the installation of at least one refrigeration measure.

Based on our review of the PA tracking data for these sampled measures, the information obtained in our interviews, and the supporting documentation provided by the PAs for the projects we sampled, we identified at least four types of refrigeration measures or technologies. Upon further review of the available data and information with which we can characterize and estimate NEIs, the following four types of refrigeration measures or technologies are considered further in our NEI analysis:

- ECM Refrigerated Case Motors
- Low-Energy Doors
- Anti-Sweat Heater Controllers
- Industrial Ammonia Refrigeration System.

The following sections summarize the NEI estimates for each measure type.

ECM refrigerated case motors

The following table shows the characteristics of the baseline and efficient options for this measure.

Table 87. Summary of Efficient and Baseline Options for ECM Refrigerated Case Motors

Characteristic	Baseline	Efficient	NEIs (relative to Baseline)
Motor Type	Permanently Shaded Coil	Electrically Commutated	None
Refrigeration System Configuration	Multiplex Direct Expansion	Multiplex Direct Expansion	
Compressor Type	Reciprocating	Reciprocating	
Refrigerated Cases per Compressor Rack	20	20	
Equipment Life	10 years	10 years	

No NEIs are associated with this measure.

- *Maintenance* – While some manufacturers claim that refrigeration system maintenance costs are reduced due to the use of ECMs, maintenance NEIs could not be verified for this measure. Refrigeration system maintenance is shown to be similar for baseline and proposed cases, including cleaning evaporator coils, drain pans, fans and intake screens, and condenser coils; lubricating motors and hinges; inspecting door gaskets and seals; and checking refrigerant charge as necessary.

Low-energy doors

Low-energy doors reduce the infiltration of heat from outside of a refrigerated space. The following table shows the characteristics of the baseline and efficient options for this measure.

Table 88. Summary of Efficient and Baseline Options for Low-Energy Doors

Characteristic	Baseline	Efficient	NEIs (relative to Baseline)
Door Type	Standard Door	Low Energy Door	None
Refrigeration System Configuration	Multiplex Direct Expansion	Multiplex Direct Expansion	
Compressor Type	Reciprocating	Reciprocating	
Refrigerated Cases per Compressor Rack	20	20	
Compressor Life	10 years	10 years	

No NEIs are associated with this measure.

Anti-sweat heater controllers

Anti-sweat mechanisms heat the customer-facing glass of refrigerated glass in order to eliminate condensation and increase visibility for contained products. Controls on anti-sweat mechanisms reduce the heat input to the refrigerated case by controlling how often anti-sweat heaters are activated.

The following table shows the characteristics of the baseline and efficient options for this measure.

Table 89. Summary of Efficient and Baseline Options for Anti-Sweat Heater Controllers

Characteristic	Baseline	Efficient	NEIs (relative to Baseline)
Heater Control	Always On	Timer or Sensor Control	None
Refrigeration System Configuration	Multiplex Direct Expansion	Multiplex Direct Expansion	
Compressor Type	Reciprocating	Reciprocating	
Refrigerated Cases per Compressor Rack	20	20	
Compressor Life	10 years	10 years	

No NEIs are associated with this measure.

Industrial ammonia refrigeration system

The following table shows the characteristics of the baseline and efficient options for this measure.

Table 90. Summary of Efficient and Baseline Options for Industrial Ammonia Refrigeration Systems

Characteristic	Baseline	Efficient	NEIs (relative to Baseline)
Type	Multiple Split Systems	Single Multi-Compressor Ammonia System	**Maintenance**: External maintenance contracts are more expensive for the more complex ammonia system. **Repairs**: Compressor replacements are reduced from 4 to 2 over a 40-year system life. **Replacement:** Condenser lifetimes are extended from 20 years to at least 50 years.
Equipment Life	Compressor: 10 years Package: 20 years	Compressor: 23 years Condenser: 50 years	

NEIs associated with this measure are as follows:[50]

- *Maintenance* – For large industrial refrigeration systems, maintenance is largely performed by contractors under annual maintenance contracts. These contracts cover routine maintenance and small repairs. The cost for these contracts is more expensive for the more complex ammonia system.
- *Repairs* – The baseline system requires a compressor replacement at 10 years, while the ammonia system requires a condenser replacement at 20 years. These are considered repairs, since the structure of the system remains intact.
- *Replacement* – The baseline system has a condenser lifetime of 20 years, at which time the entire packaged unit is typically replaced. Ammonia systems often last 50 years or more, beyond our analysis period.

The following table shows the schedule of costs associated with the baseline and efficient options for this measure.

[50] Detailed costs for repairs, replacement, and maintenance contract came from an interview with Christopher Murphy from American Other Company.

Table 91. Cost Schedule for Industrial Ammonia Refrigeration Systems[51]

Year	Baseline	Efficient
1	M	M
2	M	M
3	M	M
4	M	M
5	M	M
6	M	M
7	M	M
8	M	M
9	M	M
10	M,R	M
11	M	M
12	M	M
13	M	M
14	M	M
15	M	M
16	M	M
17	M	M
18	M	M
19	M	M
20	M,P	N,R
21	M	M
22	M	M
23	M	M

M=Maintenance R=Compressor Repair
P=Replacement N=Condenser Repair

The following table shows the prices associate with each cost listed above. Each value in the table represents a single letter above.

Table 92. Cost Breakdown for Industrial Ammonia Refrigeration Systems (Price for Each Occurrence Shown Above)

Baseline			Efficient		
Maintenance	Compressor Repair	Replacement	Maintenance	Condenser Repair	Compressor Repair
15,000	120,000	300,000	30,000	110,000	200,000

The following table shows these costs totaled across the analysis period on an NPV basis, as well as the cost differences (NEIs) between baseline and efficient, both on an NPV and annualized basis.

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[51] Detailed costs for repairs, replacement, and maintenance contract came from an interview with Christopher Murphy from American Other Company.

Table 93. Lifetime and Annualized Costs for Ammonia Refrigeration Systems

Baseline Costs* (Analysis Period—$2015)				Efficient Option Costs* (Analysis Period—$2015)				Efficient Option NEIs (relative to baseline)	
Maintain	Repair	Replace	Total	Maintain	Repair	Replace	Total	Total NPV	Amortized per year
$ 654,867	$ 22,779	$ -	$ 677,646	$327,433	$114,846	$ 57,154	$499,433	$ 178,213	$ 8,164

* Reflects the total NPV cost that would be incurred in accordance to the schedule shown in the previous two tables.

Electric – refrigeration summary

The following tables summarize the NEIs we calculated for the electric refrigeration sample categories, as well as the total population of electric refrigeration measures installed in 2013.

Table 94. NEI Estimates for Measures in Electric Refrigeration Sample Categories

Measure Type/ Technology	Custom		
	Average Annual NEI	Total Weighted Annual NEI	Sampled Measures
Custom Other	$ 8,164	$ 21,227	1
Custom Refrigeration	$ 10,123	$ 26,320	1
Refrigerated Case Motors	$ -	$ -	3
Overall	**$ 3,657**	**$ 47,547**	**5**

Table 95. Overall NEI Estimates for Electric Refrigeration Sample Categories

	Custom
Sampled Measures (a)	5
Average NEI per Sample Measure	$ 3,657
Sample Total NEIs (b)	$ 18,287
Sample Total kWh Savings (c)	1,506,974
NEI/kWH (d = b / c)	$ 0.012
90% CI Low	$ 0.003
90% CI High	$ 0.021
p-value	0.03
Population Measures (2013) (e)	13
Weighted Population Savings kWh (2013) (f = c * (e / a))	3,918,132
Total Estimated Population NEI (g = d * f)	$ 47,547

A.2.11 Electric – Overall

The following table shows the overall population NEI estimates for custom and prescriptive electric.[52]

Table 96. Overall Electric NEI Results

Measure Type/ Technology	Custom Electric		Prescriptive Electric	
	Total Annual NEI	Sampled Measures	Total Annual NEI	Sampled Measures
Electric Building Shell	$ -	1		
Electric Commercial Kitchen			$ -	1
Electric Comprehensive Design	$ 2,691.48	8	$ -	0
Electric Compressed Air	$ 5,776.19	3	$ 39,479.77	10
Electric HVAC/ Heat Recovery	$ 5,604.31	7	$ -	15
Electric Industrial Process	$ 19,950.89	5	$ -	1
Electric Lighting	$ 7,691.67	15	$ 332,873.42	49
Electric Motors	$ -	4	$ -	37
Electric Other	$ -	2	$ -	1
Electric Refrigeration	$ 47,546.81	5		
Electric Overall	**$ 89,261.37**	**50**	**$ 372,353.19**	**114**

A.2.12 Gas – Comprehensive Design

The Mass Save® program defines Comprehensive Design as follows:

> *For new commercial construction buildings over 100,000 square feet the Comprehensive Design Approach (CDA) is available. CDA is a Custom approach designed to maximize electric and gas energy savings and financial incentives for the project. It is a whole-building systems approach with interaction of mechanical and electrical systems, including the building envelope design, for building optimization in energy-saving performance.*[53]

CDA requires a specific analysis of multiple systems integrated into a design. The analysis usually involves an energy model of some kind. The NEIs relating to CDA combine multiple technologies. Analyzing the non-energy impact involves combining many technologies across the utility incentive program.

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52 The estimates shown in Table 96 are intended to illustrate the estimated magnitude of the total annual NEIs realized for true NC projects in 2013 because they include NEIs for some measure categories that did not meet the test for statistical significance.

53 http://www.masssave.com.

The Gas - Comprehensive Design measure category includes a wide variety of measures, but the following make up the majority of energy savings. See the applicable sections for estimates of NEIs for these specific measures, which are combined to estimate NEIs for specific projects.

Gas HVAC

- Boilers
- HVAC Controls
- Infrared Heaters
- Hot Water Heaters.

Building Shell

- Insulation & Air Sealing
- Windows.

Table 97 provides a detailed breakdown of NEIs for each measure rolled up within each CDA project. The "Total Annual NEI" column provides a weighted estimate of annual NEIs for each measure. There were a number of Gas CDA projects that contained electric measures. NEIs were not calculated for these measures. Table 98 provides an overall summary of the CDA sample category.

Table 97. NEIs by Gas CDA Project

CDA Project	Measure Type/ Technology	Custom Average Annual NEI	Custom Total Weighted Annual NEI	Custom Measures in CDA Project
27	Boilers	$ (89)	$ (112)	1
27	Building Shell	$ -	$ -	1
27	HVAC	$ -	$ -	3
27	Lighting	$ -	$ -	2
27	Motors	$ -	$ -	1
27	Other Gas Heating	$ -	$ -	1
27	**Overall**	**$ (10)**	**$ (112)**	**9**
30	**Overall**	**$ -**	**$ -**	**1**
31	Boilers	$ (149)	$ (186)	1
31	Building Shell	$ -	$ -	2
31	HVAC	$ -	$ -	3
31	Lighting	$ -	$ -	2
31	Motors	$ -	$ -	1
31	**Overall**	**$ (17)**	**$ (186)**	**9**
32	Boilers	$ (122)	$ (153)	1
32	Building Shell	$ -	$ -	1
32	HVAC	$ -	$ -	1
32	Motors	$ -	$ -	1
32	Refrigeration	$ -	$ -	1
32	**Overall**	**$ (24)**	**$ (153)**	**5**
35	Building Shell	$ -	$ -	1
35	HVAC	$ -	$ -	5
35	Lighting	$ -	$ -	3
35	Other Gas Heating	$ -	$ -	1
35	**Overall**	**$ -**	**$ -**	**10**
49	Boilers	$ (292)	$ (365)	1
49	Building Shell	$ -	$ -	1
49	HVAC	$ -	$ -	3
49	Other Gas Heating	$ (97)	$ (122)	1
49	**Overall**	**$ (65)**	**$ (486)**	**6**
52	Boilers	$ (184)	$ (230)	1
52	Building Shell	$ -	$ -	1
52	HVAC	$ -	$ -	2
52	Lighting	$ -	$ -	2
52	Other Gas Heating	$ -	$ -	1
52	**Overall**	**$ (26)**	**$ (230)**	**7**
54	HVAC	$ -	$ -	8
54	Lighting	$ -	$ -	2
54	**Overall**	**$ -**	**$ -**	**10**
Overall Weighted Gas CDA		**$ (117)**	**$ (1,167)**	**8**

Table 98. Summary of NEIs for Gas CDA Projects

	Custom
Sampled Measures (a)	8
Average NEI per Sample Measure	$ (117)
Sample Total NEIs (b)	$ (934)
Sample Total Therms Savings (c)	246,418
NEI/kWH (d = b / c)	$ (0.004)
90% CI Low	$ (0.008)
90% CI High	$ 0.000
p-value	0.13
Population Measures (2013) (e)	10
Weighted Population Savings Therms (2013) (f = c * (e / a))	308,023
Total Estimated Population NEI (g = d * f)	$ (1,167)

A.2.13 Gas – Boilers

As shown in Table 5, from the population of boilers measures (10 custom and 68 prescriptive) installed in 2013, we drew a sample of 5 custom and 34prescriptive measures to characterize the types of technologies deployed in NC and their associated NEIs. In addition, five of the eight gas custom CDA projects we sampled included the installation of at least one boiler measure.

Based on our review of the PA tracking data for these sampled measures, the information obtained in our interviews, and the supporting documentation provided by the PAs for the projects we sampled, we identified at least two types of boiler measures or technologies. Upon further review of the available data and information with which we can characterize and estimate NEIs, the following type of boiler measures or technologies are considered further in our NEI analysis:

- Condensing boilers.

Condensing boilers

Boilers are the most energy-intensive end use in many Massachusetts facilities. The primary fuel for boilers is natural gas, with energy transferred to steam or hot water for distribution.

There are a variety of configurations for these units, often with designs unique to a manufacturer. The major typical components are the burner, heat exchanger tubes, water treatment unit, flue, and controls.

Modern high-efficiency units take the traditional designs and incorporate a condensing heat exchanger that captures additional energy by extracting latent heat from combustion exhaust.

High-efficiency boilers account for the largest energy savings of any single prescriptive measure in the prescriptive gas tracking data for each of the last five years (2010–2014). DNV GL has performed three separate evaluations on this measure. The current prescriptive gas program utilizes tiers of boiler sizes based on capacity and efficiency. The same size and efficiency designations were utilized for calculating NEIs to produce a common format.

The calculations and estimates shown here are based primarily on CostLab projected maintenance and repair costs, DNV GL internal expertise, and expert interviews. The following table shows the characteristics of the baseline and efficient options for this measure.

Table 99. Summary of Efficient and Baseline Options for Boilers

Characteristic		Baseline	Efficient	NEIs (relative to Baseline)
Type		Massachusetts Building Code Compliant Gas-fired Boiler (ASHRAE 90.1, 2007)	Condensing Hot Water Boiler	**Maintenance**: Efficient technologies require higher maintenance costs, which vary by unit size.
Efficiency	< 300 MBH	82% AFUE	>90% AFUE	
	>300 to 2,500 MBH	80% Thermal Efficiency	> 90% Thermal Efficiency	
	>2,500 MBH	82% Combustion Efficiency	> 90% Thermal Efficiency	
Exclusive Maintenance Requirements		N/A	Condensate Trap Secondary Heat Exchanger	
Equipment Life		25 years	25 years	

NEIs associated with this measure are as follows:

- *Maintenance* – All boilers require annual maintenance, and larger systems are often monitored daily to ensure optimum operating efficiency. The boiler controls must be calibrated to carefully restrict the combustion process within an allowable air variance, and the water levels must be regulated to prevent overheating. Basic cleaning and rust removal allows for gauges and monitoring instruments to be operating and readable. The vent connections and flue must be cleared of obstructions. Monitoring the boiler water blowdown process for steam boilers eliminates the build-up of concentration of dissolved solids in the water. The entrance into boiler piping of air or raw water, per the undetected leakage of water, may lead to pitting, corrosion, and formation of sludge, sediment, or scale.

- High-efficiency boilers require additional maintenance for the condensing heat exchanger. The use of a secondary heat transfer process causes the formation of condensate on the tubing coils, which means that the boiler water must be chemically treated more judiciously than in a traditional system. Residue will build up over time, and can clog condensate traps and drain systems, as well as congest the boiler's combustion chamber. These residues must be cleaned out and managed. Subject matter experts indicated that modern systems typically have advanced control systems and automated sensor alarms to speed the process. In addition, the acidic water must be treated from a condensing boiler in some cases prior to flushing.

- *Repair* – All boilers need repairs during their useful life, requiring labor and materials. Control boards may fail, leaks will form around seals, and heat exchangers may corrode. Air infiltration and scale build-up often are the cause of repairs. Larger systems require lifts or cranes for extensive repairs. High-efficiency units have been found to require additional repair/replacement concerns.

- *Replacement* – Considerable uncertainty exists in the area of lifetime assumptions for new high-efficiency boilers as compared to conventional, standard-efficiency non-condensing units. Due to the condensate, materials are typically specified as corrosion resistant. However, the cabinet and appurtenances often are not. None of our interview respondents was willing to provide an estimate of the shortened lifespan, therefore no calculation adjustment has been made to account for the difference in replacement.
- A review of warranties for condensing units found that condensing boilers typically have a shorter coverage period. This suggests that condensing boilers have up to a 40% shorter lifespan than a non-condensing unit. However, product offerings of high-efficiency technology are only entering the second decade of lifetime, so trustworthy field data is still being accumulated. As the technology matures, a more accurate NEI estimate should be established, which would incorporate the likely early replacement cost of this measure.

The following table shows the schedule of costs associated with the baseline and efficient options for this measure.

Table 100. Cost Schedule for Boilers

Year	Baseline	Efficient
1	M	M
2	M	M
3	M	M
4	M	M
5	M,R	M,R
6	M	M
7	M	M
8	M	M
9	M	M
10	M,R	M,R
11	M	M
12	M	M
13	M	M
14	M	M
15	M,R	M,R
16	M	M
17	M	M
18	M	M
19	M	M
20	M,R	M,R
21	M	M
22	M	M
23	M	M
24	M	M

M=Maintenance
R=Repair

The following table shows the prices associate with each cost listed above. Each value in the table represents a single letter above.

Table 101. Cost Breakdown for Boilers (Price for Each Occurrence Shown Above)

Size Category	Baseline		Efficient	
	Maintain	Repair	Maintain	Repair
<300 MBH	$510	$2,378	$510	$2,760
301 to 499 MBH	$811	$2,738	$1,042	$2,869
500 to 999 MBH	$1,044	$3,473	$1,231	$3,709
1000 to 1699 MBH	$1,639	$4,078	$1,639	$4,685
1700 to 2000 MBH	$3,277	$5,474	$3,277	$5,661

The following table shows these costs totaled across the analysis period on an NPV basis, as well as the cost differences (NEIs) between baseline and efficient, both on an NPV and annualized basis.

Table 102. Lifetime and Annualized Costs for Boilers

Category	Baseline Costs* (Analysis Period—$2015)				Efficient Option Costs* (Analysis Period—$2015)				Efficient Option NEIs (relative to baseline)	
	Maintain	Repair	Replace	Total	Maintain	Repair	Replace	Total	Total NPV	Amortized per year
<300 MBH	$ 12,040	$ 9,008	$ -	$ 21,048	$ 12,040	$ 10,455	$ -	$ 22,495	$ (1,447)	$ (61)
301 to 499 MBH	$ 19,155	$ 10,369	$ -	$ 29,524	$ 24,628	$ 10,868	$ -	$ 35,496	$ (5,972)	$ (253)
500 to 999 MBH	$ 24,656	$ 13,156	$ -	$ 37,812	$ 29,089	$ 14,049	$ -	$ 43,138	$ (5,326)	$ (225)
1000 to 1699 MBH	$ 38,721	$ 15,447	$ -	$ 54,168	$ 38,721	$ 17,744	$ -	$ 56,465	$ (2,297)	$ (97)
1700 to 2000 MBH	$ 77,415	$ 20,735	$ -	$ 98,150	$ 77,415	$ 21,439	$ -	$ 98,854	$ (704)	$ (30)

* Reflects the total NPV cost that would be incurred in accordance to the schedule shown in the previous two tables.

Gas – Boiler Summary

The following tables summarize the NEIs we calculated for the gas-boiler sample categories, as well as the total population of gas boiler measures installed in 2013.

Table 103. NEI Estimates for Measures in Gas Boiler Sample Categories

Measure Type/ Technology	Custom			Prescriptive		
	Average Annual NEI	Total Weighted Annual NEI	Sampled Measures	Average Annual NEI	Total Weighted Annual NEI	Sampled Measures
Boiler	$ (179)	$ (358)	1			
Boiler Condensing - <300MBH All				$ (61)	$ (490)	4
Boiler Condensing - 1000 - 1700 MBH	$ (97)	$ (194)	1	$ (97)	$ (2,333)	12
Boiler Condensing - 1700 - 2000 MBH	$ (30)	$ (179)	3	$ (30)	$ (298)	5
Boiler Condensing - 301 to 499 MBH				$ (253)	$ (2,022)	4
Boiler Condensing - 500 to 999 MBH				$ (225)	$ (3,607)	8
Efficient - Condensing, Standalone, Gas, 75kBTU/h < X < 155kBTU/h				$ (266)	$ (532)	1
Overall	**$ (73)**	**$ (731)**	**5**	**$ (137)**	**$ (9,283)**	**34**

Table 104. Overall NEI Estimates for Gas Boiler Sample Categories

	Custom	Prescriptive
Sampled Measures (a)	5	34
Average NEI per Sample Measure	$ (73)	$ (137)
Sample Total NEIs (b)	$ (365)	$ (4,641)
Sample Total Therms Savings (c)	63,925	55,267
NEI/kWH (d = b / c)	$ (0.006)	$ (0.084)
90% CI Low	$ (0.013)	$ (0.111)
90% CI High	$ 0.001	$ (0.057)
p-value	0.19	0.00
Population Measures (2013) (e)	10	68
Weighted Population Savings Therms (2013) (f = c * (e / a)	127,850	110,534
Total Estimated Population NEI (g = d * f)	$ (731)	$ (9,283)

A.2.14 Gas – Building Shell

As shown in Table 5, from the population of gas building-shell measures (1 custom and zero prescriptive) installed in 2013, we drew a sample of 1 custom measure to characterize the types of technologies deployed in NC and their associated NEIs. In addition, six of the eight gas custom CDA projects we sampled included the installation of at least one gas building shell measure.

Based on our review of the PA tracking data for these sampled measures, the information obtained in our interviews, and the supporting documentation provided by the PAs for the projects we sampled, we identified at least two types of gas building shell measures or technologies. Upon further review of the available data and information with which we can characterize and estimate NEIs, the following two types of gas building shell measures or technologies are considered further in our NEI analysis:

- Insulation & Air Sealing
- High-performance Windows.

Please see Section A.2.2 (Electric – Building Shell) for a discussion of NEI estimates for this measure category. The NEI estimates were calculated in the same way for both electric and gas building shell measures, since the equipment underlying our calculation of NEIs is not fuel-specific for this measure category.

Gas – building shell summary

The following tables summarize the NEIs we calculated for the gas building shell sample categories, as well as the total population of gas building shell measures installed in 2013.

Table 105. NEI Estimates for Measures in Gas Building Shell Sample Categories

Measure Type/ Technology	Custom		
	Average Annual NEI	Total Weighted Annual NEI	Sampled Measures
Building Shell	$ -	$ -	1
Overall	**$ -**	**$ -**	**1**

Table 106. Overall NEI Estimates for Gas Building Shell Sample Categories

	Custom
Sampled Measures (a)	1
Average NEI per Sample Measure	$ -
Sample Total NEIs (b)	$ -
Sample Total Therms Savings (c)	57
NEI/kWH (d = b / c)	$ -
90% CI Low	$ -
90% CI High	$ -
p-value	0.00
Population Measures (2013) (e)	1
Weighted Population Savings Therms (2013) (f = c * (e / a))	57
Total Estimated Population NEI (g = d * f)	$ -

A.2.15 Gas – Commercial Kitchen

Commercial kitchen equipment NEIs are based on the equipment taking less time to maintain and clean (fewer labor hours), requiring less cleaning product, or requiring less cooking medium (water or oil).As shown in Table 5, from the population of commercial kitchen measures with gas savings (zero custom and 14 prescriptive) installed in 2013, we drew a sample of 9 prescriptive measures to characterize the types of technologies deployed in NC and their associated NEIs. None of the eight gas custom CDA projects we sampled included the installation of any commercial kitchen measures.

Based on our review of the PA tracking data for these sampled measures, the information obtained in our interviews, and the supporting documentation provided by the PAs for the projects we sampled, we identified at least three types of commercial kitchen measures or technologies. Upon further review of the available data and information with which we can characterize and estimate NEIs, the following three types of commercial kitchen measures or technologies are considered further in our NEI analysis:

- Commercial Ovens
- Commercial Steam Cookers
- Commercial Fryers.

The following sections summarize the NEI estimates for each measure type.

Commercial ovens

The following table shows the characteristics of the baseline and efficient options for this measure.

Table 107. Summary of Efficient and Baseline Options for Commercial Ovens[54]

Characteristic	Baseline	Efficient	NEIs (relative to Baseline)
Annual operation hours[55]	Convection Oven: 3,130 Combination Oven: 3,756	Convection Oven: 3,130 Combination Oven: 3,756	**Maintenance**: Efficient combination ovens reduce water use by 43,800 gallons per year, saving associated water and wastewater costs
Equipment Life	12 years	12 years	

No repair, maintenance, or replacement NEIs were determined to result from replacements of commercial convection ovens.

NEIs associated with this measure are as follows:

- *Water use* – Convection ovens were not found to have reductions in maintenance costs. Efficient combination ovens reduced water use over the baseline technology, with an associated reduction in costs.[56] Consistent to the TRM, all water is assumed to end its life as wastewater (rather than evaporated), such that wastewater costs decrease with water savings.

The following table shows the schedule of costs associated with the baseline and efficient options for this measure.

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[54] No conveyor ovens were sampled as part of this analysis.

[55] Based on TRM assumption of 6 day/week operation, or 313 days/year. Convection ovens are assumed to operate 10 hours/ day, and combination ovens are assumed to operate 12 hours/day.

[56] http://www.fishnick.com/saveenergy/tools/calculators/eovencalc.php.

Table 108. Cost Schedule for Commercial Ovens

Year	Combination		Convection	
	Baseline	Efficient	Baseline	Efficient
1	W			
2	W			
3	W			
4	W			
5	W			
6	W			
7	W			
8	W			
9	W			
10	W			
11	W			
12	W			

W=Water Use

The table below shows the prices associate with each cost listed above. Each value in the table represents a single letter above.

Table 109. Cost Breakdown for Commercial Ovens (Price for Each Occurrence Shown Above)

Size Category	Baseline Water Use	Efficient Water Use
Full Size Combination Oven	$108	-
Full Size Convection Oven	-	-

The following table shows these costs totaled across the analysis period on an NPV basis, as well as the cost differences (NEIs) between baseline and efficient, both on an NPV and annualized basis.

Table 110. Lifetime and Annualized Costs for Commercial Ovens

Category	Baseline Costs* (Analysis Period—$2015)				Efficient Option Costs* (Analysis Period—$2015)				Efficient Option NEIs (relative to baseline)	
	Maintain	Repair	Replace	Total	Maintain	Repair	Replace	Total	Total NPV	Amortized per year
Combination	$ 1,265	$ -	$ -	$ 1,265	$ -	$ -	$ -	$ -	$ 1,265	$ 108
Convection	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -

* Reflects the total NPV cost that would be incurred in accordance to the schedule shown in the previous two tables.

Commercial steam cookers

The following table shows the characteristics of the baseline and efficient options for this measure.

Table 111. Summary of Efficient and Baseline Options for Commercial Steam Cookers

Characteristic	Baseline	Efficient	NEIs (relative to Baseline)
Type	Steam Generator	Boilerless	**Maintenance**: Efficient commercial steamers reduce water use. Each efficient steamer requires more filter replacements and less de-liming maintenance.
Percentage of Time in Constant Steam Mode	40%	40%	
Average Water Consumption Rate (gal./hr.)	40	3	
Idle Energy Electric (kW)	1.2	0.4	
Equipment Life	12 years	12 years	

NEIs associated with this measure are as follows:

- *Maintenance* – Efficient commercial steamers reduce water use over the baseline technology, with an associated reduction in costs.[57] Consistent with the TRM, all water is assumed to end its life as wastewater (rather than evaporated), such that wastewater costs decrease with water savings. Each efficient steamer contains two water filters not included in baseline equipment; these filters are replaced once quarterly for a total of eight filter replacements per year. Efficient steamers require de-liming maintenance once quarterly rather than the once-monthly service required by baseline equipment, resulting in a decrease in both chemical cost and internal staff maintenance time. All of these maintenance requirement changes were corroborated by customer interviews.

The following table shows the schedule of costs associated with the baseline and efficient options for this measure.

[57] http://www.fishnick.com/saveenergy/tools/calculators/eovencalc.php.

Table 112. Cost Schedule for Commercial Steam Cookers

Year	Baseline	Efficient
1	M	M
2	M	M
3	M	M
4	M	M
5	M	M
6	M	M
7	M	M
8	M	M
9	M	M
10	M	M
11	M	M
12	M	M

M=Maintenance

The table below shows the prices associate with each cost listed above. Each value in the table represents a single letter above.

Table 113. Cost Breakdown for Commercial Steam Cookers (Price for Each Occurrence Shown Above)

Size Category	Baseline Maintenance	Efficient Maintenance
All	$966	$3788

The following table shows these costs totaled across the analysis period on an NPV basis, as well as the cost differences (NEIs) between baseline and efficient, both on an NPV and annualized basis.

Table 114. Lifetime and Annualized Costs for Commercial Steam Cookers

Baseline Costs* (Analysis Period—$2015)				Efficient Option Costs* (Analysis Period—$2015)				Efficient Option NEIs (relative to baseline)	
Maintain	Repair	Replace	Total	Maintain	Repair	Replace	Total	Total NPV	Amortized per year
$ 11,266	$ -	$ -	$ 11,266	$ 44,185	$ -	$ -	$ 44,185	$ (32,919)	$ (2,822)

* Reflects the total NPV cost that would be incurred in accordance to the schedule shown in the previous two tables.

Commercial fryers

The following table shows the characteristics of the baseline and efficient options for this measure.

Table 115. Summary of Efficient and Baseline Options for Commercial Fryers

Characteristic	Baseline	Efficient	NEIs (relative to Baseline)
Shortening Capacity	65	65	**Maintenance**: Baseline requires increased fryer oil replacement, filter pads, filter powder, oil filtering, and annual contractor maintenance time.
Equipment Life	12 years	12 years	

NEIs associated with this measure are as follows:

- *Maintenance* – Baseline technology requires higher maintenance costs relative to efficient equipment, including increased fryer oil replacement, filter pads, filter powder, internal maintenance time for oil filtering, and annual contractor maintenance time. Filters are not needed for the efficient equipment, and an estimated 30 minute (minimum) oil filtering operation is reduced from once every two days to once every two months, per customer interviews. The largest proportion of maintenance savings results from average annualized savings of fryer oil replacement due to the self-cleaning operation of the efficient unit. Because burned particles do not contaminate the oil, fryer oil life is greatly increased. Finally, external contractor maintenance time is reduced from once annually to once every three years.

The following table shows the schedule of costs associated with the baseline and efficient options for this measure.

Table 116. Cost Schedule for Commercial Fryers

Year	Baseline	Efficient
1	M	M
2	M	M
3	M	M
4	M	M
5	M	M
6	M	M
7	M	M
8	M	M
9	M	M
10	M	M
11	M	M
12	M	M

M=Maintenance

The following table shows the prices associate with each cost listed above. Each value in the table represents a single letter above.

Table 117. Cost Breakdown for Commercial Fryers (Price for Each Occurrence Shown Above)

Size Category	Baseline Maintenance	Efficient Maintenance
All	$6,983	$130

The following table shows these costs totaled across the analysis period on an NPV basis, as well as the cost differences (NEIs) between baseline and efficient, both on an NPV and annualized basis.

Table 118. Lifetime and Annualized Costs for Commercial Fryers

Baseline Costs* (Analysis Period—$2015)				Efficient Option Costs* (Analysis Period—$2015)				Efficient Option NEIs (relative to baseline)	
Maintain	Repair	Replace	Total	Maintain	Repair	Replace	Total	Total NPV	Amortized per year
$ 81,444	$ -	$ -	$ 81,444	$ 1,513	$ -	$ -	$ 1,513	$ 79,931	$ 6,853

* Reflects the total NPV cost that would be incurred in accordance to the schedule shown in the previous two tables.

Gas – commercial kitchen summary

The following tables summarize the NEIs we calculated for the gas commercial kitchen sample categories, as well as the total population of gas commercial kitchen measures installed in 2013.

Table 119. NEI Estimates for Measures in Gas Commercial Kitchen Sample Categories

Measure Type/ Technology	Prescriptive		
	Average Annual NEI	Total Weighted Annual NEI	Sampled Measures
Commercial Oven	$ -	$ -	4
Efficient Fryer	$ 6,853	$ 42,641	4
Efficient Steamer	$ (2,822)	$ (4,390)	1
Commercial Steam Cooker	$ -	$ -	0
Overall	**$ 2,732**	**$ 38,250**	**9**

Table 120. Overall NEI Estimates for Gas Commercial Kitchen Sample Categories

	Prescriptive
Sampled Measures (a)	9
Average NEI per Sample Measure	$ 2,732
Sample Total NEIs (b)	$ 24,589
Sample Total Therms Savings (c)	7,235
NEI/kWH (d = b / c)	$ 3.399
90% CI Low	$ 0.961
90% CI High	$ 5.836
p-value	0.02
Population Measures (2013) (e)	14
Weighted Population Savings Therms (2013) (f = c * (e / a))	11,254
Total Estimated Population NEI (g = d * f)	$ 38,250

A.2.16 Gas – HVAC/Heat Recovery

As shown in Table 5, from the population of HVAC / heat recovery measures (12 custom and 27 prescriptive) installed in 2013, we drew a sample of 7 custom and 13 prescriptive measures to characterize the types of technologies deployed in NC and their associated NEIs. In addition, seven of the eight custom CDA projects we sampled included the installation of at least one HVAC / heat recovery measure.

Based on our review of the PA tracking data for these sampled measures, the information obtained in our interviews, and the supporting documentation provided by the PAs for the projects we sampled, we identified at least three types of HVAC / heat recovery measures or technologies. Upon further review of the available data and information with which we can characterize and estimate NEIs, the following three types of HVAC / heat recovery measures or technologies are considered further in our NEI analysis:

- Hot Water Heating
- Heat Recovery
- HVAC Controls.

The HVAC controls measure type is discussed in Section A.2.5, Electric – HVAC. Because NEIs for this measure type are not based upon fuel type, the NEIs for this measure are the same between electric and gas.

Below we summarize the NEI estimates for water heaters and heat recovery.

Water heaters

Hot water is often a necessity in commercial applications for cleaning, personnel hygiene, and food preparation purposes. Conventional water heaters transfer energy from a gas burner to a storage tank or heat exchanger filled with water. Insulated inner and outer shells add insulation and physical protection.

In a tank-style system, a small gas burner heats the tank to the temperature defined by a control system or thermostat, and a pressure relief valve keeps the pressure within safe limits. A sacrificial anode, typically magnesium or aluminum with a steel core, prevents corrosion.

Installation of a high-efficiency water heater is often recommended as a target for energy reduction. There are a number of incentivized options available:

- ENERGY STAR®-certified commercial water heaters include gas storage units that use 25% less energy than a conventional commercial unit by employing more efficient heat exchangers.
- Condensing water heaters add a draft-inducing fan to force combustion exhaust through a secondary heat exchanger. In addition, the acidic water must be treated from a condensing boiler prior to flushing.
- Indirect water heaters use a storage tank that is heated by excess heat from an adjacent main boiler. The water tank both eliminates the need for a burner, and balances the boiler temperature variance, saving energy and potentially extending its useful life by limiting the need to cycle as often.
- Tankless water heaters circulate water through a heat exchanger to be heated for immediate use, eliminating the standby heat loss associated with a storage tank.

The sizing of the water heater depends on the flow rate and temperature rise needed for its application, which could be supplying a whole building or a remote space (e.g., bathrooms). Secondary NEIs could be potentially assigned depending on the end-use application, as condensing water heaters are able to heat water much faster. Tankless heaters have no standby losses and are not powered on under low-flow conditions, but typically have a low thermal efficiency. Tankless heaters also are limited to certain minimum and maximum flow rates. An indirect water heater is essentially just a tank with coils, with the performance tied to that of the supply boiler. They can also force the supply boiler to run in months it would typically be shut down.

The calculations and estimates shown here are based primarily on CostLab projected maintenance and repair costs, DNV GL internal expertise, and expert interviews. The measure calculations were dependent on baseline heating as defined by the Massachusetts TRM 2013. The following table shows the characteristics of the baseline and efficient options for this measure.

Table 121. Summary of Baseline and Efficient Options for Water Heaters

Charac-teristic	Baseline	Efficient	NEIs (relative to Baseline)	Analysis Period
Type	Per Code Hot Water Heater <75 MBH EF = 0.59	ENERGY STAR Certified Freestanding <75 MBH EF > 0.67	**Maintenance**: Requires periodic vent clearing service. **Repairs**: Requires a system flush once during lifetime.	13 years
		Indirect Water Heater CAE > 85%	**Maintenance**: Requires heat exchanger flushes.	15 years
		Tankless (electronic ignition) 50 to 200 MBH EF > 0.82	**Maintenance**: Additional labor for heat exchange elements to be descaled with a vinegar flush (often vinegar based) and filters cleaned.	20 years
	Per Code Hot Water Heater 75 to 300 MBH E_{th} = 80%	Condensing Stand-alone Water Heater 75 to 300 MBH E_{th} > 95%	**Maintenance**: Water must be chemically treated before release to reduce acidity	13 Years

NEIs associated with this measure are as follows:

- *Maintenance* – All hot water heaters require periodic maintenance for safety and performance.
  - Baseline: Tank systems require a cleaning and a flush-out after seven years in order to avoid a reduction in equipment lifetime. The vent connections and flue must be cleared of obstructions every three years. There are few electrical components, while parts and service providers are common. Models with larger heating elements have a much better resistance to mineral build-up.
  - ENERGY STAR® Freestanding: Similar to baseline.
  - Indirect: Indirect heaters require heat exchanger flushes every three years.
  - Condensing Freestanding: The use of a secondary heat transfer process encourages the formation of corrosive condensate on the tubing coils. The water must be chemically treated before release for being too acidic.
  - Tankless: Dependent on the hardness of the water, heat exchange elements must be descaled with a flush (often vinegar based) and filters must be cleaned. There is typically more maintenance than the baseline, but fewer repairs and a longer lifespan.
- *Repair* – All hot water heaters require parts replacement during their useful life, requiring labor and materials. Control boards may fail, leaks will form around seals, and heat exchangers may corrode. Air infiltration and scale build-up often are the cause of repairs. Larger systems require lifts or cranes for extensive repairs.
  - Baseline: Tank systems may have the heating element or the gas control valve fail well before the system must be replaced. Temperature controls may fail; the pressure relief valve may become jammed. A sacrificial anode replacement will extend the tank lifespan. Tank failure is the only reason to replace a unit.

- ENERGY STAR Freestanding: Similar to conventional units.
  - Indirect: The likely components to fail are the temperature control and circulator pump, or leaks due to corrosion. Replacement depends on the associated boiler lifespan.
  - Condensing Freestanding: The use of a secondary heat transfer process precipitates the formation of condensate on the tubing coils. Colder water in the coils increases the potential for condensate formation. The water must be chemically treated before release for being too acidic.
  - Tankless: Most tankless water heaters have a life expectancy of more than 20 years, and easily replaceable parts.

- *Replacement*: High-efficiency condensing units have been found to require additional repair/replacement concerns. However, considerable uncertainty exists in the area of lifetime assumptions for condensing units resulting from the acidic condensate. Because of this uncertainty, we did not consider lifetime differences resulting from condensing heat exchangers.

The measure calculations were dependent on baseline heating as defined by the Massachusetts TRM 2013. This measure category compared size-comparable hot water heater measures. The following table shows the schedule of costs associated with the baseline and efficient options for this measure.

Table 122. Cost Schedule for Water Heaters

Year	Baseline	Indirect	Tankless	ENERGY STAR Freestanding	Condensing Freestanding (75–300 MBH)
1			M		
2			M		
3	M	M	M	M	M
4			M		
5			M		R
6	M	M	M	M	M
7	R		M	R	
8			M		
9	M	M	M	M	M
10			M, R		R
11			M		
12	M	M	M	M	M
13	P		M	P	P
14			M		
15		M	M		
16	M		M	M	M
17			M		
18		M	M		
19	M		M	M	M

M=Maintenance R=Repair P=Replacement

The following table shows the prices associate with each cost listed above. Each value in the table represents a single letter above.

Table 123. Cost Breakdown for Water Heaters (Price for Each Occurrence Shown Above)

<table>
<tr><th rowspan="2">Measure</th><th colspan="3">Baseline</th><th colspan="3">Efficient</th></tr>
<tr><th>Maintain</th><th>Repair</th><th>Replace</th><th>Maintain</th><th>Repair</th><th>Replace *</th></tr>
<tr><td>ENERGY STAR Freestanding</td><td rowspan="6">$38</td><td rowspan="6">$500</td><td rowspan="3">$2,796</td><td rowspan="4">$38</td><td>$465</td><td rowspan="6">-</td></tr>
<tr><td>Indirect</td><td>-</td></tr>
<tr><td>Tankless (75–155 MBH)</td><td rowspan="2">$620</td></tr>
<tr><td>Tankless (155–200 MBH)</td><td>$6,360</td></tr>
<tr><td>Condensing Freestanding (75–155 MBH)</td><td>$2,796</td><td rowspan="2">$310</td><td rowspan="2">$240</td></tr>
<tr><td>Condensing Freestanding (155–300 MBH)</td><td>$11,710</td></tr>
</table>

* In no case is the efficient version of the equipment replaced during the analysis period, so the cost of replacement is not applicable.

The following table shows these costs totaled across the analysis period on an NPV basis, as well as the cost differences (NEIs) between baseline and efficient, both on an NPV and annualized basis.

Table 124. Lifetime and Annualized Costs for Water Heaters

Category	Baseline Costs* (Analysis Period—$2015)				Efficient Option Costs* (Analysis Period—$2015)				Efficient Option NEIs (relative to baseline)	
	Maintain	Repair	Replace	Total	Maintain	Repair	Replace	Total	Total NPV	Amortized per year
ENERGY STAR Freestanding	$ 148	$ 485	$ -	$ 633	$ 125	$ 450	$ -	$ 575	$ 58	$ 5
Indirect	$ 148	$ 955	$ 626	$ 1,729	$ 155	$ -	$ -	$ 155	$ 1,574	$ 109
Tankless (75–155 MBH)	$ 220	$ 955	$ 1,650	$ 2,825	$ 732	$ 598	$ -	$ 1,330	$ 1,495	$ 78
Tankless (155–200 MBH)	$ 220	$ 955	$ 1,650	$ 2,825	$ 732	$ 598	$ -	$ 1,330	$ 1,495	$ 78
Condensing Freestanding (75–155 MBH)	$ 148	$ 955	$ -	$ 1,103	$ 4,491	$ 464	$ -	$ 4,955	$ (3,852)	$ (266)
Condensing Freestanding (155–300 MBH)	$ 148	$ 955	$ -	$ 1,103	$ 4,491	$ 464	$ -	$ 4,955	$ (3,852)	$ (266)

* Reflects the total NPV cost that would be incurred in accordance to the schedule shown in the previous two tables.

** In no case is the efficient version of the equipment replaced during the analysis period, so the cost of replacement is not applicable.

Heat recovery

When comparing an air handler with heat recovery verses a baseline with no heat recovery, it is possible additional maintenance will be required. However, a heat pipe requires little maintenance, a plate heat wheel requires motor maintenance, and a heat recovery wheel with a silica gel descant requires motor maintenance and occasional cleaning.

DNV GL opted to exclude the potential additional maintenance time necessary for a heat wheel because the addition of the heat wheel means a reduction of the size of the AHU, thereby slightly reducing the maintenance of the total unit; and, due to the reduction on the coils and motors, heat recovery may extend the lifespan of the equipment. Further study of each specific building would be needed to know if a heat wheel is adding to or reducing the NEIs of the specific sample.

Gas – HVAC/heat recovery summary

The following tables summarize the NEIs we calculated for the Gas HVAC/heat recovery sample categories, as well as the total population of gas HVAC/heat recovery measures installed in 2013.

Table 125. NEI Estimates for Measures in Gas HVAC/Heat Recovery Sample Categories

Measure Type/ Technology	Custom			Prescriptive		
	Average Annual NEI	Total Weighted Annual NEI	Sampled Measures	Average Annual NEI	Total Weighted Annual NEI	Sampled Measures
Compressor Heat Recovery	$ -	$ -	1			
Custom Chiller	$ 10	$ 49	3			
Efficient - Condensing, Standalone, Gas, 75kBTU/h < X < 155kBTU/h				$ (266)	$ (1,105)	2
Efficient - Indirect Water Heater				$ 109	$ 1,354	6
HVAC Controls	$ -	$ -	3			
Tankless (electronic ignition) >200k BTU/h				$ 78	$ 813	5
Overall	**$ 4**	**$ 49**	**7**	**$ 39**	**$ 1,062**	**13**

Table 126. Overall NEI Estimates for Gas HVAC/Heat Recovery Sample Categories

	Custom	Prescriptive
Sampled Measures (a)	7	13
Average NEI per Sample Measure	$ 4	$ 39
Sample Total NEIs (b)	$ 29	$ 511
Sample Total Therms Savings (c)	125,352	2,115
NEI/kWH (d = b / c)	$ 0.000	$ 0.242
90% CI Low	$ (0.000)	$ (0.174)
90% CI High	$ 0.001	$ 0.657
p-value	0.41	0.34
Population Measures (2013) (e)	12	27
Weighted Population Savings Therms (2013) (f = c * (e / a))	214,889	4,393
Total Estimated Population NEI (g = d * f)	$ 49	$ 1,062

A.2.17 Gas – Other

As shown in Table 5, from the population of gas “other” measures (7 custom and zero prescriptive) installed in 2013, we drew a sample of 5 custom measures to characterize the types of technologies deployed in NC and their associated NEIs. None of the eight custom CDA projects we sampled included the installation of at least one gas “other” measure.

Based on our review of the PA tracking data for these sampled measures, the information obtained in our interviews, and the supporting documentation provided by the PAs for the projects we sampled, we identified at least three types of gas “other” measures or technologies. Upon further review of the available data and information with which we can characterize and estimate NEIs, the following three types of gas “other” measures or technologies are considered further in our NEI analysis:

- Boilers
- Furnaces
- Water Heaters.

Despite being categorized as gas “other,” these measures actually fit well under other categories and are analyzed under their own sections. Please see the appropriate sections for NEI estimates for each of these measures.

Gas – other summary

The following tables summarize the NEIs we calculated for the gas “other” sample categories, as well as the total population of gas “other” measures installed in 2013.

Table 127. NEI Estimates for Measures in Gas Other Sample Categories

	Custom		
Measure Type/ Technology	Average Annual NEI	Total Weighted Annual NEI	Sampled Measures
Custom Other	$ (277)	$ (1,938)	5
Overall	**$ (277)**	**$ (1,938)**	**5**

Table 128. Overall NEI Estimates for Gas Other Sample Categories

	Custom
Sampled Measures (a)	5
Average NEI per Sample Measure	$ (277)
Sample Total NEIs (b)	$ (1,385)
Sample Total Therms Savings (c)	43,860
NEI/kWH (d = b / c)	$ (0.032)
90% CI Low	$ (0.092)
90% CI High	$ 0.029
p-value	0.39
Population Measures (2013) (e)	7
Weighted Population Savings Therms (2013) (f = c * (e / a))	61,404
Total Estimated Population NEI (g = d * f)	$ (1,938)

A.2.18 Gas – Industrial Process

As shown in Table 5, from the population of gas industrial process measures, 2 custom and zero prescriptive were installed in 2013. We drew a sample of 2 custom measure to characterize the types of technologies deployed in NC and their associated NEIs. None of the eight custom CDA projects we sampled included the installation of at least one gas industrial process measure.

Based on our review of the PA tracking data for these sampled measures, the information obtained in our interviews, and the supporting documentation provided by the PAs for the projects we sampled, we identified at least one type of gas industrial process measures or technologies. Upon further review of the available data and information with which we can characterize and estimate NEIs, the following type of gas industrial process measure or technology is considered further in our NEI analysis:

- Infrared Heating.

For the analysis of NEIs associated with infrared heating, see Section A.2.19, other gas heating.

Gas – Industrial process summary

The following tables summarize the NEIs we calculated for the gas industrial process sample categories, as well as the total population of gas industrial process measures installed in 2013.

Table 129. NEI Estimates for Measures in Gas Industrial Process Sample Categories

	Custom		
Measure Type/ Technology	Average Annual NEI	Total Weighted Annual NEI	Sampled Measures
Custom Industrial Process	$ 72	$ 144	2
Overall	**$ 72**	**$ 144**	**2**

Table 130. Overall NEI Estimates for Gas Industrial Process Sample Categories

	Custom
Sampled Measures (a)	2
Average NEI per Sample Measure	$ 72
Sample Total NEIs (b)	$ 144
Sample Total Therms Savings (c)	20,608
NEI/kWH (d = b / c)	$ 0.007
90% CI Low	$ (0.011)
90% CI High	$ 0.025
p-value	0.51
Population Measures (2013) (e)	2
Weighted Population Savings Therms (2013) (f = c * (e / a))	20,608
Total Estimated Population NEI (g = d * f)	$ 144

A.2.19 Gas – Other Gas Heating

As shown in Table 5, from the population of other gas heating measures (2 custom and 7 prescriptive) installed in 2013, we drew a sample of two custom and five prescriptive measures to characterize the types of technologies deployed in NC and their associated NEIs. In addition, none of the eight custom CDA projects we sampled included the installation of at least one other gas heating measure.

Based on our review of the PA tracking data for these sampled measures, the information obtained in our interviews, and the supporting documentation provided by the PAs for the projects we sampled, we identified at least two types of other gas heating measures or technologies. Upon further review of the available data and information with which we can characterize and estimate NEIs, the following two types of other gas heating measures or technologies are considered further in our NEI analysis:

- Furnaces
- Infrared Heaters.

The following sections summarize the NEI estimates for each measure type.

Furnaces

Furnaces heat air and distribute the heated air through the building using ducts. Older furnace systems had efficiencies in the range of 56% to 70%, and most manufacturers still produce non-condensing models with only one heat exchanger. These units have a minimum code-mandated efficiency of 80%, and are sometimes referred to as mid-efficiency units. These units use metal pipe for the hot combustion exhaust.

Modern heating systems utilize a condensing system with a secondary heat exchanger to bring the efficiency up to over 90%. With the addition of a variable speed blower motor, furnaces achieve efficiencies as high as 98.5%. Two-stage furnaces are also used to reduce the fuel burned and limit the firing rate. The most expensive and efficient units use a modulating multi-stage firing configuration.

A condensing furnace utilizes the water vapor produced in the combustion process and transfers the heat from this condensation. High efficiency furnaces are better at converting fuel into direct heat and better insulated to reduce heat loss. The higher efficiencies are achieved by sending flue gasses through a secondary heat exchanger that extracts heat from the exhaust gasses.

If the building is constructed to be exceptionally air tight, an additional heat recovery ventilator (HRV) or energy recovery ventilator (ERV) is added to provide fresh air (with an ERV also adding humidity). Often these units are dedicated outdoor air units and require small furnaces to heat the air to 55°F-65°F to avoid distributing sub-freezing air into the space.

The calculations and estimates shown here are based primarily on CostLab projected maintenance and repair costs, DNV GL internal expertise, and expert interviews. The following table shows the characteristics of the baseline and efficient options for this measure.

Table 131. Summary of Efficient and Baseline Options for Furnaces

Characteristic	Baseline	Efficient	NEIs (relative to Baseline)
Type	Massachusetts State Building Code Compliant Furnace	High-efficiency Furnace w/ electronically commutated motor (ECM)	**Maintenance**: A condensing furnace requires minimal extra labor. **Repair**: Higher efficiency units incorporate corrosive condensates, reducing durability.
Efficiency	90% AFUE	AFUE > 95%	
Equipment Life	18 years	18 years	

NEIs associated with this measure are as follows:

- *Maintenance* – All furnaces have a common process of using cold air from a return, drawing it through a filtering system, heating the air using a gas burner with electronic ignition and heat exchanger, and expelling the hot air to the distribution system using circulation fans. Air filters must be replaced in equal frequency monthly or quarterly. Annual maintenance typically only involves inspection, motor oiling, belt checks, and dust/soot cleanout of the grill, heat exchanger, and duct fan. A condensing furnace requires minimal extra attention, as it has two heat exchangers, one for primary heat exchange and a secondary heat exchanger to handle the corrosive condensed exhaust gases. There is also carbonic acid condensate resulting from the gases going through the secondary heat exchanger, which must be drained, and requires a clean-out of a PVC discharge pipe.
- *Repair* – Furnace systems are generally low maintenance. The main sources of repair are burners, distribution fans, controls, and thermostat. Mechanical failures, clogged filters, and thermostat malfunctions all require minimal replacement parts to bring the furnace back to working order. Estimates for repair between baseline and efficient units, however, remain comparable.
- *Replacement* – Although presently estimated to have similar lifespans, higher efficiency technology units must contend with corrosive condensates. While this may shorten the lifespan of the equipment, we did not find sufficient evidence to justify an NEI claim.

Infrared heaters

Task heating equipment is becoming popular in areas with difficult environmental control situations. These include warehouses, hangars, garages, and loading docks where—due to door opening—it is difficult to maintain a comfortable condition. Gas-fired, low intensity infrared heating systems are a more efficient measure than unit heaters, furnaces, or other types of air heating equipment. Low-intensity infrared heaters provide on-demand heat; the burner control box ignites a gas/air mixture and hot gases are pushed through steel radiant tubing by an internal fan. As these gases pass through the assembly, the tubing is heated and emits infrared energy, which is then directed toward the floor by highly polished reflectors. This energy is absorbed by objects in its path, such as the floor, machinery, and people. Objects in the path of the infrared energy in turn re-radiate this heat to create a comfort zone at the floor level.

The true advantage of infrared heaters is the direct comfort factor encountered with the use of radiant heat rather than the inefficiency of conventional heaters working to heat large quantities of air surrounding a person or object within a large conditioned space. Proper equipment selection and layout of the IR heaters are critical to ensure proper heating.

The calculations and estimates shown here are based primarily on CostLab projected maintenance and repair costs, DNV GL internal expertise, and expert interviews. The following table shows the characteristics of the baseline and efficient options for this measure.

Table 132. Summary of Efficient and Baseline Options for Infrared Heaters

Characteristic	Baseline	Efficient	NEIs (relative to Baseline)
Type	Gas-fired Unit Heater (80%)	Gas-Fired Low-Intensity Infrared Heating Unit	**Maintenance**: The fan and motor for a unit heater is larger, and requires additional maintenance. The reflector shield on the IR heater may require polishing. The tube of the IR heater also serves as the exhaust, therefore a cleaning of the long run is necessary. **Repair**: The larger fan on the unit heater is more costly to replace.
Equipment Life	17 Years	17 Years	

NEIs associated with this measure are as follows:

- *Maintenance* – Some of the components are similar, and should only require maintenance periodically on the burner assembly, controls, and exhaust. The fan and motor for a unit heater is larger, and requires additional attention. The reflector shield on the IR heater may require polishing. The tube of the IR heater also serves as the exhaust; therefore a cleaning of the long run is necessary over time.
- *Repair* – Neither the unit heater nor the IR heater is susceptible to breakdowns, and both have lengthy lifespans. The larger fan on the unit heater is more costly to replace.

The following table shows the schedule of costs associated with the baseline and efficient options for this measure.

Table 133. Cost Schedule for Infrared Heaters

Year	Baseline	Efficient
1	M	M
2	M	M
3	M	M
4	M	M
5	M	M
6	M	M
7	M	M
8	M,R	M,R
9	M	M
10	M	M
11	M	M
12	M	M
13	M	M
14	M	M
15	M	M
16	M,R	M,R
17	M	M

M=Maintenance
R=Repair
P=Replacement

The following table shows the prices associate with each cost listed above. Each value in the table represents a single letter above.

Table 134. Cost Breakdown for Infrared Heaters (Price for Each Occurrence Shown Above)

Baseline		Efficient	
Maintain	Repair	Maintain	Repair
$3,290	$620	$2,820	$380

The following table shows these costs totaled across the analysis period on an NPV basis, as well as the cost differences (NEIs) between baseline and efficient, both on an NPV and annualized basis.

Table 135. Lifetime and Annualized Costs for Infrared Heaters

Baseline Costs* (Analysis Period—$2015)				Efficient Option Costs* (Analysis Period—$2015)				Efficient Option NEIs (relative to baseline)	
Maintain	Repair	Replace	Total	Maintain	Repair	Replace	Total	Total NPV	Amortized per year
$ 2,500	$ 1,185	$ -	$ 3,685	$ 2,500	$ 714	$ -	$ 3,214	$ 471	$ 29

* Reflects the total NPV cost that would be incurred in accordance to the schedule shown in the previous two tables.

Gas – other gas heating summary

The following tables summarize the NEIs we calculated for the other gas heating sample categories, as well as the total population of other gas heating measures installed in 2013.

Table 136. NEI Estimates for Measures in Gas Other Gas Heating Sample Categories

Measure Type/ Technology	Custom			Prescriptive		
	Average Annual NEI	Total Weighted Annual NEI	Sampled Measures	Average Annual NEI	Total Weighted Annual NEI	Sampled Measures
Gas Heating - Other				$ -	$ -	2
Infrared Heater Low-Intensity IR Heater				$ 29	$ 121	3
Other	$ -	$ -	2			
Overall	**$ -**	**$ -**	**2**	**$ 17**	**$ 121**	**5**

Table 137. Overall NEI Estimates for Gas Other Gas Heating Sample Categories

	Custom	Prescriptive
Sampled Measures (a)	2	5
Average NEI per Sample Measure	$ -	$ 17
Sample Total NEIs (b)	$ -	$ 86
Sample Total Therms Savings (c)	46,466	1,634
NEI/kWH (d = b / c)	$ -	$ 0.053
90% CI Low	$ -	$ 0.043
90% CI High	$ -	$ 0.063
p-value	0.00	0.00
Population Measures (2013) (e)	2	7
Weighted Population Savings Therms (2013) (f = c * (e / a))	46,466	2,288
Total Estimated Population NEI (g = d * f)	$ -	$ 121

A.2.20 Gas – Overall

The following table shows the overall population NEI estimates for custom and prescriptive gas.[58]

Table 138. Overall Gas NEI Results

	Custom Gas		Prescriptive Gas	
Measure Type/ Technology	Total Annual NEI	Sampled Measures	Total Annual NEI	Sampled Measures
Gas Boilers	$ (730.84)	5	$ (9,282.62)	34
Gas Building Shell	$ -	1	$ -	0
Gas Commercial Kitchen			$ 38,250.28	9
Gas Comprehensive Design	$ (1,166.93)	8	$ -	0
Gas HVAC/ Heat Recovery	$ 49.40	7	$ 1,061.91	13
Gas Industrial Process	$ 144.08	2		
Gas Other	$ (1,938.45)	5		
Gas Other Gas Heating	$ -	2	$ 121.03	5
Gas Overall	**$ (3,642.75)**	**30**	**$ 30,150.60**	**61**

[58] The estimates shown in Table 138 are intended to illustrate the estimated magnitude of the total annual NEIs realized for true NC projects in 2013 because they include NEIs for some measure categories that did not meet the test for statistical significance.

APPENDIX B: BACKGROUND AND PRELIMINARY RESEARCH

This appendix describes the preliminary and Stage 1 research conducted by the Evaluation Team. This research determined the direction for the Stage 2 research, which is described in Section 2.3.

Estimating NEIs requires information concerning changes to the participant's costs (e.g., operations and maintenance, waste management, or administration costs), production output, or revenues resulting from the installed measure.

In the 2012 C&I NEI Retrofit study, the baseline conditions for natural replacement measures were determined by identifying the costs and revenues prior to the replacement of the non-energy efficient equipment. Interviewed respondents were able to use their experience prior to the installation of the incentivized measure as a frame of reference for cost or revenue changes to assess the NEIs. However, only cost and revenue changes associated with equipment being energy efficient (not being new) were relevant. Thus, the NEI value should reflect the incremental difference in costs or benefits of the new energy-efficient equipment relative to new standard-efficiency equipment; this can be difficult for participants to conceptualize and self-report for a number of reasons.

First, in the case of a new facility, there was not a pre-existing structure that participants could use as a reference point to compare cost and revenue changes. While some of the existing literature suggested using experience at a different facility as a point of comparison, there may be many dissimilarities between operations at the new facility and other facilities for which respondents do not account. In the case of a major retrofit, it is not appropriate to compare current operations to the previous facility because the renovated facilities are often so drastically altered that the pre-renovated facility does not offer a valid point of comparison. For natural replacement measures, participants may have similar difficulty identifying an appropriate comparison point that only accounts for the NEIs associated with the equipment being energy efficient (not simply "new").

Therefore, for all types of NC projects—natural replacement, major renovation, and new construction—a key challenge for deriving NEI estimates is the ability of end-users to conceptualize changes relative to the counterfactual baseline if asked in an interview. Determining how best to overcome this challenge was the primary focus of the Stage 1 research.

As a preliminary research activity, the Evaluation Team conducted a literature review to determine if existing NEI research could provide a suitable approach to estimate baseline conditions to isolate NEIs. The studies reviewed by the Evaluation Team are listed below. These studies employed a range of survey techniques that included direct query, conjoint analysis, market actor interviews, and on-site visits. They also used a range of techniques to establish the baseline conditions, which included comparing the installed technology to building codes, standard efficiency measures, or the respondent's previous experience in other facilities with standard efficiency measures.

NYSERDA 2004[59]

- Approach – Used the direct query method (asked program participants, contractors, architects, and engineers to assign a value to each NEI in terms of percentage of the project's estimated energy savings), and collected data to estimate NEIs through in-person interviews, focus groups, mail and telephone surveys, field observations, and site visits
- NEI categories – Maintenance costs, equipment performance, tenant satisfaction, tenant comfort, building aesthetics/appearance, noise levels, lighting/quality of light, building safety, environmental effects, equipment lifetime, ability of tenants to stay in their units
- Baseline for NEIs – On-site interviews with building owners. For the Small Commercial Lighting Program (SCLP), the study also used the ASHRAE 90.1 1989 standard and minimum efficiency levels required by the National Appliance Energy Conservation Act (NAECA)

Barkett et al. 2006[60]

- Approach – Combination of (1) the direct query method of C&I program participants and non-participants and (2) a conjoint analysis approach, which gave respondents hypothetical situations of products from which to choose
- NEI categories – Lighting quality, thermal comfort and HVAC effectiveness, occupant productivity, noise levels, doing good for the environment, O&M costs, indoor air quality, ease of selling/leasing
- Baseline for NEIs – Asked the respondent to compare their old and new buildings and/or similar buildings in the area just meeting levels required by the State Energy Code

Bemont and Skumatz 2007[61]

- Approach – Interviews with a random sample of developers, owners, architects, engineers, vendors, participants, and non-participants. Asked participants whether they were aware of NEIs that were read from a list of pre-defined NEI choices
- NEI categories – Equipment performance, productivity, tenant satisfaction, comfort, appearance, quality of light, building safety, noise, equipment lifetime, sick days

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[59] New York Energy Smart Program Evaluation and Status Report. 2004. *New York Energy Smart Program Evaluation and Status Report, Volume 2.* Report to the Systems Benefit Charge Advisory Group.

[60] Brent Barkett, Nicole Wobus, Rachel Freeman, Daniel Violette, Scott Dimetrosky. 2006. *Non-Energy Impacts (NEI) Evaluation.* Prepared for the New York State Energy Research and Development Authority. Prepared by Smith Blue Consulting & Quantec, LLC.

[61] Dawn Bemont & Lisa Skumatz. 2007. *New Non-Energy Benefits (NEBs) results in the commercial / industrial sectors: Findings from incentive, retrofit, and technical assistance /new construction programs.* ECEEE 2007 Summer Study, *Skumatz Economic Research Association.*

- Baselines for NEIs – Standard efficiency equipment

Bicknell and Skumatz 2004[62]

- Approach – Computer-assisted telephone interviewing (CATI) surveys and in-depth interviews with owners, developers, architects, and engineers. The owners/occupants and facility managers were asked about NEI valuations based on their experience, whereas specifiers/decision-makers were asked about their perceptions of the NEIs and perceptions of the value to owners
- NEI categories – Maintenance costs, equipment performance, tenant satisfaction, tenant comfort, building aesthetics/appearance, noise levels, lighting/quality of light, building safety, environmental effects/benefits, equipment lifetime, ability of tenants to stay in unit
- Baseline for NEIs – Not specifically stated

Mills et al. 2005[63]

- Approach – Compared NEIs on new construction commissioning to existing building commissioning, and reviewed Lawrence Berkeley National Laboratory (LBNL) publications and project files
- NEI categories – Reduced change orders, safety impacts, O&M costs
- Baseline for NEIs – Review of literature

Our review of these studies provided limited methodological guidance in developing baseline conditions for the present study beyond those used in the 2012 C&I NEI Retrofit study. While each study used various techniques to address baseline conditions, the Evaluation Team did not find that any of them convincingly overcame the challenge of establishing baseline conditions.

Our concerns with the reviewed studies include the following:

- The research pointed to the need to contrast the installed measures to standard efficiency equipment; however, a number of studies used ASHRAE or local building codes to establish baseline conditions, not standard equipment.
- The studies did not necessarily capture the full range of cost and revenue changes that may result from the efficient measures.

[62] Charles Bicknell & Lisa Skumatz. 2004. *Non-Energy Benefits (NEBs) in the Commercial Sector: Results from Hundreds of Buildings.* ACEEE Proceedings 2004, Skumatz Economic Research Association.

[63] Evan Mills, Norman Bourassa, Mary Ann Piette, Hannah Friedman, Tudi Haasl, Tehesia Powell, and David Claridge. 2005. *The Cost-Effectiveness of Commissioning New and Existing Commercial Buildings.* National Conference on Building Commissioning: May 4-6, 2005. Prepared by the Lawrence Berkeley National Laboratory, Portland Energy Conservation Inc., and Texas A&M University.

- Barkett et al. (2006) separated projects into types based on whether or not the new construction replaced a similar building at a different location. It did not distinguish NC measures at a more refined level. The Evaluation Team believed measures should be further separated into the following categories based on distinctions made by the PAs in administering their NC programs: new building, major retrofit, and natural replacement.

We concluded that none of the previous studies offered a single approach that would be appropriate for estimating NEIs associated with the variety of measures covered by the Massachusetts NC program. As such, we proceeded with the Stage 1 research to identify one or more approaches for estimating NEIs associated with the 2013 NC program. The Stage 1 research included two key components to assess the most appropriate means of estimating NEIs for NC measures:

- *Data mining* – DNV GL analyzed the 2013 program tracking data and the 2012 C&I NEI Retrofit study results to support the remaining tasks in the Stage 1 research.
- *In-depth interviews* – We used information from the data mining task to identify a sample of interviewees from four groups: 1) PA staff who market the NC programs; 2) Design firms (engineers and architects); 3) Manufacturers and suppliers of energy efficient technologies; and 4) Energy managers and operations groups of large institutional participants (e.g., large customers with multiple facilities such as college campuses, government offices, or manufacturing facilities). We then completed 54 interviews to determine the appropriate means of establishing baseline conditions for new construction measures.

The result of this effort was a detailed work plan for Stage 2.

APPENDIX C: COMPARISON OF NC NEI RESULTS TO 2012 C&I RETROFIT NEI RESULTS

As part of our analysis, we compared the current results to the results calculated as part of the 2012 C&I Retrofit study. In some cases, results for the same technology types were vastly different. Comparing the sources of NEIs from both studies, these differences are explained by the following:

- The mix of measures within each measure category was different during the 2012 C&I Retrofit NEI study compared to the NC NEI study.
- Respondents to our survey during the 2012 C&I Retrofit study focused on O&M cost differences over the period of time they had owned the equipment (1–2 years), versus expected lifetime O&M differences between baseline and efficient technologies, as considered in the NC engineering analysis.
- The NC engineering analysis could not account for some NEIs captured by the C&I Retrofit study survey, such as increased sales, productivity, and rent revenue related to installing efficient measures.

Table 139 provides a qualitative comparison of some of the measures studied as part of the NC and Retrofit studies.

Table 139. New Construction versus Retrofit NEIs

Technology	Retrofit NEI Sources	New Construction NEI Sources	Retrofit vs. New Construction NEI Comparison
Boilers	•Boiler requires 120 fewer internal maintenance hours each year. •Customer reduced external HVAC contractor visits. •Customer saved dozens of hours in avoided administrative costs processing and paying for maintenance work. •Property value increased several hundred thousand dollars due to boiler system. •Utility cost reduction related to efficient equipment allowed building owners to reduce rental rates and more competitively attract tenants.	•Efficient boilers require more maintenance over their lifetime. Costs vary by boiler size.	•Boilers were not a separate category from HVAC in the Retrofit NEI study •The Retrofit NEI study showed positive NEIs for gas HVAC, while the NC NEI study showed negative NEIs for gas Boilers. •The difference is explained by the type of information capture by each study. •The NC NEI study considered operations and maintenance (O&M) costs over the life of each system, which were higher for efficient measures, while the Retrofit NEI study considered O&M costs over the one or two years that the systems had been installed prior to our interviews. •The Retrofit NEI study also assigned NEI values to increased rents, increased property values, and decreased administrative costs that the NC NEI study could not quantify for new buildings.
Comprehensive Design	•No comprehensive design measures.	•NEIs sources related to the technologies that comprised each comprehensive design measures.	•N/A
Compressed Air	•Equipment requires less frequent oil changes. •Avoided annual product loss due to compressor failures.	•Efficient equipment requires rebuilding and replacement of parts every 6-7 years versus every 3 years for baseline. •Equipment requires less frequent oil changes. •Zero-loss condensate drains avoid frequent filter replacements and treatment of oily condensate.	•Sources of NEIs are very similar between the NC NEI and Retrofit NEI studies. •NEIs were not calculated for compressed air in the Retrofit NEI study due to small sample sizes.
Food Service	•No food service measures.	•Reduced water usage. Decreased water and wastewater costs. •De-liming maintenance required less frequently. •Ovens and fryers have increased production capacity, steamers have decreased production capacity. •Efficient fryers require less maintenance, decreased oil replacement, less frequent oil filtration.	•N/A

New Construction versus Retrofit NEIs (Continued)

Technology	Retrofit NEI Sources	New Construction NEI Sources	Retrofit vs. New Construction NEI Comparison
Hot Water	•Switch to tankless water heater saved costs of EPA inspection for tank heater. •Fewer repairs needed after installation of efficient system. •Reduced labor costs after switch to instant hot water heater. Employees did not have to wait for hot water.	•Additional labor costs related to heat exchanger descaling and filter cleaning. •Fewer repairs required compared to baseline system.	•Hot water NEIs are positive for both the NC and Retrofit study •The NC NEI study calculated higher NEIs for hot water than the Retrofit NEI study, explained by differences in the size of repair and maintenance costs recorded by self-report interviews vs. the new construction engineering model.
Industrial Process	•Excess heat from water cooled manufacturing compressor used to eliminate other space heating.	•Electric injection molding machine does not require oil servicing.	•NEIs were not calculated for industrial process in the Retrofit NEI study due to small sample sizes.
Lighting	•Avoided light bulb and ballast changes. •Efficient lighting decreased staff time identifying burnt out bulbs. •Occupancy sensors eliminated twice daily building checks to make sure all lights are turned on and turned off. •Decreased electrical service contract price and number of contractor visits in buildings that rely on external instead of internal service. •Administrative hours saved processing contractor invoices, ordering bulbs, etc... •In warehouses, eliminated one stockroom FTE due to decreased bulb changes. •Savings related to disposing of fewer light bulbs.	•T5 bulbs are brighter than T8 bulbs, and can light a 20% larger space using the same number of fixtures. T5s results in fewer bulbs and fewer bulb changes. •LED fixtures require no maintenance in most cases, significantly reducing maintenance costs.	•Lighting NEIs were higher in the NC NEI study compared to the Retrofit NEI study. •Most of the bulbs installed during the NC study period were LEDs and T5s, which had very high maintenance savings, versus the T8 and T5 bulbs installed during the Retrofit study period, which had comparatively smaller maintenance savings.

New Construction versus Retrofit NEIs (Continued)

Technology	Retrofit NEI Sources	New Construction NEI Sources	Retrofit vs. New Construction NEI Comparison
Motors	•One respondent indicated that VFDs decreased frequency of needed system inspections.	•None	•Motors and Drives had slight positive NEIs under the Retrofit NEI study, but were not statistically significant.
Other Gas Heating	•All heating recorded under HVAC	•Infrared unit heaters are more costly to repair, and may require polishing reflector shield.	N/A
Refrigeration	•Systems require less maintenance. •Avoided significant food spoilage in food sales facilities.	•Efficient systems have longer useful life. •Systems require less maintenance. Compressor replacements are reduced from 2 to 4 years of the measure life. •Condenser lifetimes extended from 20 to 50 years.	•Refrigeration NEIs were very similar between the New Construction and Retrofit studies.
HVAC	•Systems require less maintenance. •Saved administrator hours overseeing contractor visits and repairs. •Utility cost reduction related to efficient equipment allowed building owners to reduce rental rates and more competitively attract tenants. •Equipment maintained building at more comfortable temperature, decreased tenant turnover. •Reduced product spoilage in food sales and food service facilities.	•Condensing furnaces require extra maintenance labor. •High efficiency units produce corrosive condensates, which may reduce durability. •Magnetic bearing chiller compressors require less frequent maintenance/oil changes. •Water cooled chillers last longer. •Chilled beams require less maintenance than fan coil boxes.	•HVAC NEIs were higher under the Retrofit NEI study compared to the NC NEI study. •The difference is explained by the type of information capture by each study. •The NC NEI study considered operations and maintenance (O&M) costs over the life of each system, which were higher for efficient measures, while the Retrofit NEI study considered O&M costs over the one or two years that the systems had been installed prior to our interviews. •The Retrofit NEI study also assigned NEI values to increased rents, increased property values, increased tenant comfort leading to decreased tenant turnover, reduced product spoilage in food sales buildings, and decreased administrative costs that the NC NEI study could not quantify for new buildings.