RNC NEI Quick Hit Assessment

(MA20X14-B-RNCNEI)

Final Report

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SUBMITTED TO:
The Massachusetts Electric and Gas Program Administrators

SUBMITTED BY:
NMR Group, Inc.
Three[3], Inc.

Table of Contents

Tables

Acronyms

Acronym	Definition
AESC	Avoided Energy Supply Component
BLS	Bureau of Labor Statistics
CDC	Centers for Disease Control and Prevention
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CPI	Consumer Price Index
ED	Emergency Department
EEAC	Energy Efficiency Advisory Council
ERV	Energy Recovery Ventilation
HRV	Heat Recovery Ventilation
HVAC	Heating, Ventilation, and Air Conditioning
IAQ	Indoor Air Quality
IEQ	Indoor Environmental Quality
LEED	Leadership in Energy and Environmental Design
MA TRM	Massachusetts Technical Reference Manual
MEPS	Medical Expenditures Panel Survey
MFHR	Multifamily High-Rise
MFLR	Multifamily Low-Rise
MMBtu	Metric Million British Thermal Unit
NEI	Non-Energy Impact
NO_2	Nitrogen Dioxide
PA	Program Administrator
PH	Passive House
PM	Particulate Matter
PNNL	Pacific Northwest National Laboratory
R&A	Renovations and Additions
RNC	Residential New Construction
SBS	Sick Building Syndrome
SF	Single-Family
TVOC	Total Volatile Organic Compounds
VOC	Volatile Organic Compound

Executive Summary

This report presents final results from the *Residential New Construction Non-Energy Impact Assessment* (study number MA20X14-RNCNEI). The Cross-Cutting Non-Energy Impacts evaluation team, led by NMR Group, Inc., with the support of Three[3], prepared this report for the Massachusetts Program Administrators (PAs).[1] The study updates non-energy impact (NEI) values for the PAs' Residential New Homes and Renovations Initiative (referred to as "RNC program" throughout this report).

STUDY OVERVIEW

Study Objectives

The primary goal of this study was to use secondary data to identify and propose updates to the monetized NEI values associated with the PAs' Residential New Homes and Renovations initiative, where possible. A secondary goal was to identify potential health-related NEIs that the PAs do not currently claim, and either use academic research and secondary data to monetize them where possible or develop approaches for conducting primary research to monetize them.

Research Questions

The evaluation team looked to answer the following research questions:

1. What secondary data are available that address NEIs related to the Residential New Construction (RNC) market since 2009?[2]
2. What NEIs are other jurisdictions claiming for their RNC programs?
3. Are there additional NEIs for the RNC market that can be monetized with available secondary data?
4. How can potential NEIs be monetized for the RNC program if sufficient secondary data are not available?

[1] The PAs comprise Berkshire Gas, Cape Light Compact, Eversource, Eversource Gas of Massachusetts, Liberty Utilities, National Grid, and Until.
[2] The RNC NEIs currently claimed by the PAs are based on NEI research from the 2009 Evaluation of the Massachusetts New Homes with ENERGY STAR® Program (NMR and Conant, 2009) and adjusted in the 2011 NEI report (https://ma-eeac.org/wp-content/uploads/Residential-and-Low-Income-Non-Energy-Impacts-Evaluation-1.pdf).

Methodology

This section provides a summary of the methods used in this study. For more details, see Section 2 in the main body of the report.

Literature review. The evaluation team conducted a broad review of available literature, comprising 41 studies, to identify potential secondary data sources with which to update NEI values, monetize additional NEIs, and understand potential NEIs related to RNC. To the extent possible, the team considered differences in potential NEIs or valuation approaches between the RNC market segments:[3]

- Single-family (SF)
- Multifamily low-rise (MFLR)
- Multifamily high-rise (MFHR)
- Passive House offering, currently only multifamily (PH)
- Renovations and Additions (R&A)

Scan of jurisdictions. The team also conducted a jurisdictional scan of ten jurisdictions outside Massachusetts, reviewing 14 public planning documents, Technical Reference Manuals (TRMs), cost-effectiveness testing documents, and other public documents. The purpose of the scan was to obtain details on how other jurisdictions claim NEIs, specifically those attributed to RNC programs.

Updates to NEIs the RNC program currently claims. The evaluation team originally hoped to find sufficient relevant data from the literature review with which to update the values of the thermal comfort and noise reduction NEIs that the PAs currently claim for the RNC program. The plan was to develop a method by which to scale more recent NEI values from the literature review to the PAs' outdated values. If the team did not find that sufficient relevant data was available, the fallback plan was to develop analytical approaches with which to temporarily update these NEIs until primary data could be collected.

Monetization of new asthma-related NEIs using reviewed literature and secondary data. The team relied primarily on the academic research to identify new NEIs that the PAs could potentially claim as outcomes from the RNC program. Several of the NEIs the team identified could be monetized without collecting primary data. The selection criteria for NEIs that could be monetized without collecting primary data was the level of evidence in the literature, the availability of additional information with which to monetize the impacts, and the ability to link the impacts to the RNC program. The evaluation team focused on monetizing additional NEIs that met the following conditions:

1. Studies presented data that provided evidence of an NEI attributable to components, equipment, and design commonly found in energy-efficient new construction (such as

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[3] Note that this research did not attempt to monetize differences that may exist between market rate and low-income market segments.

exposure to gas stoves, inclusion of Energy Recovery Ventilation [ERV] / Heat Recovery Ventilation [HRV] systems)[4]

2. The measured data had strong evidence of association with a monetizable health outcome.

Identify future RNC NEI research needs. The team used findings from the literature review to identify NEIs that could potentially result from the RNC program activities and be monetized, and scoped the data collection needs and valuation methodology for each proposed NEI. The team focused on NEIs for which there is a greater amount of evidence in the secondary literature.

Key Findings

- The evaluation team reviewed 41 studies to inform this research. The team found multiple papers that measured indoor environmental quality (IEQ) in passive homes, but found much less information for general high-efficiency RNC. As a short-term solution, the team adjusted for inflation the NEIs that the RNC program currently claims. The adjustment increased the thermal comfort and noise reduction NEIs from a total value of $117 to $139 per home per year.
- Two studies met the team's criteria for developing monetization algorithms: one meta-analysis on the asthma impacts of exposure to gas stoves in the home, and one randomized controlled trial investigating the impact of heat and ERV on formaldehyde levels in study homes and the resulting change in asthma-related emergency department visits. Based on these two studies, the team monetized additional NEIs totaling $3.30. The additional monetized NEIs accounted for gas stove impacts on asthma ($3.28 per home per year)[5] and for the impact of reduced formaldehyde due to mechanical ventilation with heat or energy recovery (ERV or HRV), which leads to fewer asthma-related emergency room visits ($0.02 per home per year).
- The additional monetized NEI values can be recalculated on an annual basis if there is a change in the program saturation compared to baseline saturations of homes with gas stoves and homes with ERVs or HRVs. In addition, updated program requirements or pathways, such as an all-electric pathway, are potential avenues to increase monetized NEIs for asthma-related impacts due to reduced exposure to gas stoves. (Gas stoves have negative health impacts due to releasing combustion byproducts, such as NO_2 and CO into the home.) If all-electric program homes increase in saturation relative to non-program

[4] ERVs and HRVs are balanced ventilation systems with heat recovery. The difference between an ERV and a HRV is that in an ERV, the heat exchanger transmits some amount of water vapor along with the heat energy, whereas only heat is transferred in a HRV.

[5] Proper ventilation appears to mitigate but not eliminate the risks of cooking with gas stoves. However, the team was not able to quantify and in turn monetize the impacts of proper ventilation or installation of ERVs or HRVs in homes with gas stoves from the reviewed literature. Additional secondary research or primary research on the impacts of proper ventilation on IAQ of program homes with gas stoves may be able to determine the degree to which combustion byproducts are removed from the home through proper ventilation.

homes, the PAs should also reconsider adding the CO-poisoning NEI to future research considerations, especially if there is a dedicated all-electric track.

- The evaluation team found potential NEIs for future research in the literature, such as reduced sick building syndrome (SBS), lower operations and maintenance costs, and increased productivity. The level of evidence varied by NEI. The team used these potential NEIs to inform considerations for future research priorities.
- The literature review did not yield any new energy-efficiency program evaluations that included primary research for RNC-related NEIs, nor did it yield any evaluations that attempted to monetize RNC NEIs using primary or secondary data.[6]
- Only one out of ten jurisdictions reviewed claim RNC-specific NEIs: Rhode Island, which leverages the 2011 Massachusetts NEI study. [7]

Conclusions

The evaluation team leveraged the existing literature and secondary data sources to monetize new asthma-related NEIs. The team was able to monetize and recommend three asthma-related NEIs using existing literature and secondary data. To monetize the new NEIs, the evaluation team triangulated evidence and data from various studies and secondary data sources (see Section 3.3 for methodology details and Section 3.4 for results).

Available literature indicates potential for future NEI research in the RNC market. Based on the literature reviewed, the evaluation team identified potential new RNC-related NEIs for the PAs to consider monetizing in the future and approaches for updating existing NEIs with new primary research, such as reduced SBS, lower operations and maintenance costs, and increased productivity (a complete list of the potential NEIs found in the literature is discussed in Section 4). The team looked at potential NEIs found in the literature and focused on those that had more evidence to support monetization in the future. It should be noted that the potential and additional NEIs monetized in this report are not exhaustive.

Review of additional secondary data, and new primary research, could lead to a more substantial adjustment to the NEIs the RNC program currently claims (i.e., thermal comfort and noise reduction). The literature review found studies that addressed thermal comfort and noise reduction, but the results were mixed – both positive and negative. For example, some studies reported overheating in energy-efficient buildings and occupant complaints related to noise. These mixed results created uncertainty in updating the thermal comfort or noise reduction NEIs. In addition, the team was not able to link studies documenting noise impacts to monetization algorithms. Ultimately, the evaluation team defaulted to exploring analytical approaches to update the NEIs the RNC program currently claims. (See Section 2.2 for methodology details and Section 3.3 for results.)

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[6] Note that the team reviewed a 2017 white paper of ENERGY STAR® Homes in Maryland that quantified the impact of ENERGY STAR certification on home prices. However, the results are not used for EmPOWER Maryland cost-effectiveness testing. (https://www.icf.com/-/media/files/icf/white-paper/2017/energy-energy-star-new-homes-impact-certification-on-maryland-home-prices_web.pdf)

[7] https://library.cee1.org/system/files/library/12163/Mass_Crosscutting_NEIs_Final_Report_081511_2.pdf

The literature review did not yield any new energy-efficiency program evaluations that included primary research for RNC-related NEIs, nor did it yield any evaluations that attempted to monetize RNC NEIs using primary or secondary data. The most recent evaluation of the kind the team sought was an NEI evaluation that was conducted for the Massachusetts PAs in 2011 by NMR.[8]

Research challenges, limitations, and sources of uncertainty. The literature clearly identified impacts from gas stoves and formaldehyde on asthma incidence, symptoms, and healthcare utilization and these have been monetized in the report below. However, there were a number of challenges, limitations, and sources of uncertainty in the studies reviewed for other potential NEIs. For example, while the literature review included studies that conducted data collection on various parameters related to IEQ, a number were conducted outside the U.S, making it difficult to compare potential program impacts in relation to baseline, non-program homes. Other factors included the following: a mix of both positive and negative findings; studies that measured changes or differences in general health symptoms, such as coughing, wheezing during exercise, or runny nose, but did not directly link energy-efficient new construction to specific healthcare utilization outcomes; small sample sizes; and limited ability to determine which energy-efficiency component led to an observed difference in IEQ. In summary, quantifying additional NEIs from the literature was hampered by the following:

1. A mix of results in the reviewed literature indicating positive effects, negative effects and / or no effects, preventing the team from making a determination of RNC impacts for some NEIs.
2. A lack of sufficient data quantifying how measures and building practices implemented by the RNC program impact specific IEQ parameters, and more specifically, to what degree program homes differ from non-program homes on IEQ parameters that influence health.
3. Differences in measuring IEQ between the energy-efficiency and healthcare sectors, making it difficult to link the findings from the energy-efficiency and health literature. For example, the reviewed literature used different metrics for mold and moisture issues.
4. Applicability of findings from studies of SF PH to traditional RNC.
5. Studies that looked at extremely high-performance construction, such as PH, were mostly for SF homes, attached homes, and smaller apartment complexes. This adds another layer of complexity given that the PH offering primarily encompasses mid- and high-rise multifamily buildings.
6. Time constraints on the literature review due to needing final, monetized NEI values for PA planning purposes. Follow-up research may be able to explore other potential NEIs

[8] Note that the team reviewed a 2017 white paper of ENERGY STAR Homes in Maryland that quantified the impact of ENERGY STAR certification on home prices. However, the results are not used for EmPOWER Maryland cost-effectiveness testing. (https://www.icf.com/-/media/files/icf/white-paper/2017/energy-energy-star-new-homes-impact-certification-on-maryland-home-prices_web.pdf)

identified in the literature that could potentially be linked with other literature to triangulate and develop monetized values.

In addition, most studies only looked at the post-treatment period, without pre-treatment observations or random assignment of subjects to treatment and control groups. The evaluation team selected the most appropriate literature available for each NEI. However, given remaining uncertainties, the evaluation team applied conservative assumptions in developing the algorithms and inputs whenever the data required interpretation.

Recommendations

Overall Recommendation. The evaluation team recommends the NEI values presented in Table 1 be applied to the RNC program. The recommended NEI values include the update to the NEIs the program currently claims (thermal comfort and noise) and the new NEIs that were monetized as part of this study. Additional context for each recommendation is presented below.

Table 1: Summary of Recommended NEI values for RNC Program

Measure	NEI	Recommended Value
Thermal comfort	Inflation-based update of 2011 value	$91.50 per household per year
Noise	Inflation-based update of 2011 value	$47.53 per household per year
Electric Stoves (elimination of exposure to gas stove combustion byproducts)	Childhood asthma prevention, occupant lifetime	$0.65 per household per year
	Adult asthma symptom reduction	$2.21 per household per year
	Childhood asthma symptom reduction	$0.42 per household per year
ERV/HRV (formaldehyde)	Reduced asthma ED visits	$0.02 per household per year
Total Recommended NEIs		**$142.30 per household per year**

Recommendation. In the short term, the evaluation team recommends using the inflation adjustment approach to update the RNC NEI values currently claimed by the PAs from $117 to $139. The RNC NEIs that are currently claimed by the PAs are from the 2011 Residential and Low-income NEI study.[9]

The team ultimately recommended the inflation adjustment approach to update the RNC NEI values in the short term. The inflation adjustment is a simple approach to adjusting the current NEI values given the mixture of positive and negative results for thermal comfort and a mix of positive and inconclusive results for noise that the team found in the literature.[10] This approach can be updated on an annual basis until new secondary or primary research is available to develop updated NEI values. In addition, this approach can be applied to future updates to RNC NEIs between evaluation cycles. The inflation adjustment approach does not eliminate the need for conducting new primary research on the NEIs currently claimed by the RNC program and on any potential NEIs identified as a part of this research.

Table 2: Recommended Update to RNC NEI Values in the Short Term

	Date	Value
2011 RNC NEI Study Value[1]	August 2011	$117
2021 Inflation Adjustment	May 2021	$139

[1] The current RNC NEI study value comprises thermal comfort ($77) and noise ($40). The recommended RNC NEI values due to the inflation adjustment are $91.50 for thermal comfort and $47.53 for reduced noise.

[9] The PAs currently claim RNC NEI values for Thermal Comfort ($77 annually per participant) and Noise Reduction ($40 annually per participant). See https://ma-eeac.org/wp-content/uploads/Residential-and-Low-Income-Non-Energy-Impacts-Evaluation-1.pdf

[10] The evaluation team conducted a literature review of 41 studies and reports and did not find any NEI evaluations of RNC programs.

Recommendation: In the short term, the PAs should adopt an asthma-related RNC NEI of $3.30 per household per year (Table 3). This is the total value of asthma-related NEIs attributable to improved IAQ in new program homes over new baseline homes. The value of the NEI reflects the current difference between program and baseline saturations for both stoves and ventilation. These NEI values can be updated on an annual basis based on program saturation rates for these measures to reflect differences from baseline practices.[11] In addition, the baseline saturation values used in the algorithms can be updated with new baseline study results as they become available. Each of the NEIs, including the algorithm, sources, and caveats, are detailed in the subsections below.

Table 3: Summary of Recommended Asthma Related RNC NEIs

Measure	NEI	Recommended Value
Electric Stoves (elimination of exposure to gas stove combustion byproducts)	Childhood asthma prevention, occupant lifetime	$0.65 per household per year
	Adult asthma symptom reduction	$2.21per household per year
	Childhood asthma symptom reductio	$0.42 per household per year
ERV/HRV (formaldehyde)	Reduced asthma ED visits	$0.02 per household per year

Considerations

Consideration. In the long-term, the PAs should strongly consider conducting research on NEIs the team has identified as having sufficient evidence in the literature. Based on existing research, the NEIs in Table 4 are likely to exist for the RNC program and could be quantified and monetized through a combination of targeted secondary research and primary research. Primary research could be combined with the literature review findings from this study and additional research targeted specifically at potential NEIs identified in this study to monetize NEIs, if they exist.

The update to the 2019 RNC Baseline I/Compliance Study that is proposed to begin in the summer of 2022 could present an opportunity to streamline data collection efforts and reduce research costs by collecting data for both the baseline and the NEI studies simultaneously. Another option is to use the RNC Baseline I / Compliance Study data as a source for developing a non-program sample at a later date.

Note that a targeted review of secondary literature for all potential NEIs slated for future research could be conducted prior to primary data collection. This targeted secondary research would identify any new literature published since this report or that was not identified and reviewed as a part of this research due to time constraints, and determine whether such literature could be used

[11] The algorithms to monetize the NEIs include program and baseline saturation values for the measure. These inputs can be updated in the algorithm to adjust the monetized NEI value in the future, as shown in the considerations section below.

to monetize the NEI or confirm if primary data collection would be required. This process could help avoid costs associated with conducting primary research.

Other ways to minimize the cost of primary data collection include selecting the most comprehensive loggers and leveraging upcoming site visits, such as those that are likely to occur with the update to the 2019 RNC Baseline I / Compliance Study. To capture these efficiencies, the targeted secondary research would need to occur before the on-site visits for the next baseline update (Section 4.3).

Table 4: Summary of Research Considerations for Future RNC NEI Research

NEI Category	Summary of Research Considerations
Thermal Comfort	Update the 2011 Thermal Comfort NEI with new field research and occupant surveys rather than simply adjusting for inflation.
Summer Overheating and Winter Underheating	Account for the potential that PH construction in particular can lead to uncomfortable indoor temperatures in summer and winter.
Noise	Update the 2011 Noise NEI with new field research and occupant surveys rather than simply adjusting for inflation.
Respiratory Health and SBS	Measure additional respiratory and SBS symptom impacts from air pollutants, including updates or additions to asthma algorithms.
Operations and Maintenance	Document the amount of maintenance and operational costs required for high-performance compared to baseline homes.
Productivity	Survey occupants and incorporate secondary literature on the impacts of improved air quality on productivity for occupants who work from home.
Avoided Deaths due to Air Pollution	Measure indoor and outdoor particulate matter and infiltration rates to quantify reductions in exposure and excess mortality.

The evaluation team examined how the NEIs would be affected if the RNC program were to evolve to an all-electric pathway, which would require electric-fueled cooking. This was to show the potential magnitude of NEIs from eliminating occupant exposure to gas combustion stove byproducts due to the program. The NEI estimates are solely based on the elimination of combustion stoves. They do not include potential additional impacts on health outcomes that could result from reductions in nitrogen oxide (NO_2) and other IAQ parameters, such as Particulate Matter ($PM_{2.5}$) and Carbon Monoxide (CO) concentrations, subsequent to eliminating combustion heating and water heating equipment completely from the home.

Consideration: Table 5 **estimates the value of additional monetized NEIs if none[12] of the new RNC program homes were to have combustion stoves, while baseline homes continue to have combustion stoves at the current rate.[13] The table suggests the grand total of additional health related NEIs resulting from this change to be $40.48 per home per year.** The team based these values on the algorithms derived in Section 3.4, with combustion stoves completely removed from program participants' homes. (See Appendix B.1 for supplemental algorithms.)

Table 5: RNC Asthma-Related NEIs from Eliminating Combustion Stoves

Non-Energy Impact	Value Suggested
Childhood asthma prevention, occupant lifetime	$8.00 per all-electric home per year
Adult asthma symptom reduction	$27.36 per all-electric home per year
Childhood asthma symptom reduction	$5.13 per all-electric home per year
Total	**$40.48 per all-electric home per year**

The evaluation team also examined how the NEIs would be affected if the RNC program homes all had balanced mechanical ventilation systems (i.e., ERVs or HRVs). This programmatic shift may be reflected in a scenario in which all program participants build to or near PH levels of efficiency.

Consideration: Table 6 **shows the estimated value from reductions in formaldehyde due to the use of mechanical ventilation with heat recovery (i.e., heat recovery ventilator [HRV] or energy recovery ventilator [ERV]) in all program homes ($0.33 per ERV/HRV home per year).** One program scenario that could result in increased saturation of ERV or HRV installations is if program participants were required to build at or near PH levels of efficiency. (See Appendix B.2 for supplemental algorithms.) However, the scenario the team based Table 6 on is one in which program participants install ERVs or HRVs exclusively as ventilation strategies.

Table 6: RNC Asthma-Related NEI – Homes with ERV/HRV Only

NEI	Value Suggested
Reduced Asthma ED Visits	$0.33 per ERV/HRV home per year

In addition, the team identified some potential NEIs to consider for follow-up research. These NEIs were identified in the MA19R05 PA Assessment study, which interviewed market actors and noted potential benefits associated with PH construction. These NEIs may be relevant to projects that achieve PH levels of efficiency.

12 As would be seen from an all-electric program or one that required installation of non-combustion stoves.

13 This illustrates the scenario where the difference in presence of combustion stoves between program and baseline homes is maximized based on current baseline home characteristics. The NEI values per RNC home would be lower if the presence of combustion stoves in baseline homes decreases from current levels.

Consideration. **The team identified the following new NEIs related to PH new construction: water savings, increased thermal performance during extreme weather events, increased lifetimes for mechanical equipment and building shell, carbon emission reductions from fossil fuel free construction (including embodied carbon in construction materials),[14] and reductions in fire risk.** These NEIs were mentioned by market actors and others interviewed for the PA Assessment[15] study, but the evaluation team found limited or no research about them in the literature review (see Section 4.1.2.1). The PAs may wish to consider examining some of these NEIs as part of the next RNC NEI evaluation that involves primary data collection.

The team is aware of several recent studies on the embodied carbon of construction materials. This body of literature include studies on the carbon impacts of materials in low-rise residential buildings and highlights potential opportunities to contribute to decarbonization and sequestration.[16,17,18] While the team did not include embodied carbon studies in this literature review, including them in future research could lead to a deeper understanding of how to monetize potential benefits from using building materials with lower embodied carbon in new construction. Some examples of such benefits are carbon reduction, health-related impacts from material choices, and localized supply chains. In addition, including embodied carbon in future research could improve PA understanding of the opportunities for, and potential barriers to, incorporating embodied carbon into program design and evaluation.[19]

[14] If carbon emission reductions from energy savings and fossil-fuel free constructions are captured by the avoided cost study than they should not be considered an NEI. However, embodied carbon in construction materials might be considered an NEI if it is incorporated into program design.
[15] https://ma-eeac.org/wp-content/uploads/MA19R05_PassiveHouse_OverallReport_Final_2020.01.06.pdf
[16] https://www.greenbuildingadvisor.com/app/uploads/2021/09/EnerCan.pdf
[17]https://www.efficiencyvermont.com/news-blog/whitepapers/embodied-carbon-in-vermont-residential-retrofits
[18]https://www.efficiencyvermont.com/news-blog/whitepapers/the-high-greenhouse-as-price-tag-on-residential-building-materials
[19] The RNC program currently captures a significant amount of data (such as materials, volume, area) that overlaps with what would be required to calculate embodied carbon in materials, through HERS ratings, and within energy models.

Section 1 Introduction

This report presents final results from the *Residential New Construction Non-Energy Impact Assessment* (study number MA20X14-RNCNEI). The Cross-Cutting Non-Energy Impacts evaluation team, led by NMR Group, Inc., with the support of Three[3], prepared this report for the Massachusetts Program Administrators (PAs).[20] The study updates non-energy impact (NEI) values for the PAs' Residential New Homes and Renovations Initiative (referred to as "RNC program" throughout this report).

1.1 Goals, Research Questions, and Outcomes

The primary goal of this study was to use secondary data to identify and propose updates to the monetized NEI values associated with the PAs' Residential New Homes and Renovations initiative, where possible. A secondary goal was to identify potential health-related NEIs that the PAs do not currently claim, and either use academic research and secondary data to monetize them where possible or develop approaches for conducting primary research to monetize them.

The evaluation team looked to answer the following research questions:

1. What secondary data are available that address NEIs related to the Residential New Construction (RNC) market since 2009?[21]
2. What NEIs are other jurisdictions claiming for their RNC programs?
3. Are there additional NEIs for the RNC market that can be monetized with available secondary data?
4. How can potential NEIs be monetized for the RNC program if sufficient secondary data are not available?

[20] The PAs comprise Berkshire Gas, Cape Light Compact, Eversource, Eversource Gas of Massachusetts, Liberty Utilities, National Grid, and Until.

[21] While the previous RNC NEI study was published in 2011, research activities began in 2009. This study aimed to understand what literature and secondary data has become available since the last evaluation's research activities were conducted.

The outcomes of this research are as follows:

1. A literature review that summarizes residential new construction (RNC) NEI research and values from jurisdictions other than Massachusetts. The review includes literature published since 2009 and identifies RNC NEIs that could be updated for Massachusetts with the findings.
2. Short-term updates to NEIs that are currently claimed by the RNC program (i.e., thermal comfort and noise).
3. Monetized values for two NEIs not currently claimed by the PAs: asthma impacts from reductions in formaldehyde and reduced exposure to gas stoves. These values were developed using academic research and secondary data.
4. A prioritized listing of NEIs that could potentially be monetized using primary research, and research approaches for monetizing them.

Section 2 describes the research approach. Section 3 presents the results of the literature review, updated values for the NEIs the PAs currently claim, and proposed values for new NEIs based on academic literature and secondary data. Section 4 describes research approaches for monetizing potential new NEIs identified through the literature review and updating existing NEIs with new primary research. Appendix A presents a comprehensive list of the literature reviewed. Appendix B shows how the monetization approaches for the new NEI values proposed in Section 3 would need to change if the RNC program were to provide an all-electric program pathway, with program participants installing only Energy Recovery Ventilation (ERV) or Heat Recovery Ventilation (HRV) mechanical ventilation systems. Appendix C provides references.

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Section 2 Research Methodology

2.1 Reviewing Existing Literature

The evaluation team conducted a broad review of available literature, comprising 41 studies, to identify potential secondary data sources with which to update NEI values, monetize additional NEIs, and understand potential NEIs related to RNC. The team detailed key findings, data collection methods, and any analytical methods used in the one study that quantified and monetized RNC NEIs.

While the research initially looked at NEIs the PAs' currently claim for their RNC programs, the team also documented additional RNC NEIs found in the literature.[22]

Categories of literature reviewed. The review focused on research produced since 2009, the year in which research for the last RNC NEI evaluation conducted for the Massachusetts PAs began.[23] The review covered three main categories of research:

1. Utility and state program-evaluation-based NEI research.
2. Public planning documents, Technical Reference Manuals (TRMs), cost-effectiveness testing documents, and other public documents outlining NEIs claimed for RNC programs in jurisdictions outside of Massachusetts.
3. Academic studies and journals, including both international and U.S. research. The studies in this category included those that measured indoor air quality (IAQ), health-related impacts on occupants, and various other potential NEIs.

In this process, the team considered differences in RNC market segments (i.e., single-family [SF], multifamily low-rise [MFLR], multifamily high-rise [MFHR], renovations and additions [R&A], Passive House [PH]) to the extent possible given the available data.[24] The team primarily focused on reviewing literature that included the RNC market, whether for SF or multifamily housing. The team also reviewed studies that focused on residential retrofits and, in some cases, commercial buildings to better understand how potential NEIs might differ between R&A projects and MFHR construction.

The team also conducted a jurisdictional scan of ten jurisdictions outside Massachusetts. The team reviewed 14 public planning documents, TRMs, cost-effectiveness testing documents, and other public documents. The purpose of the scan was to obtain details on how other jurisdictions claim NEIs, specifically those attributed to RNC programs.

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[22] The RNC programs currently claim the following NEIs: thermal comfort, noise reduction, and lighting quality.
[23] https://library.cee1.org/system/files/library/12163/Mass_Crosscutting_NEIs_Final_Report_081511_2.pdf
[24] Affordable housing and market rate were not a defined market segment as a part of this research.

2.2 Updating Existing RNC NEI Values

The evaluation team originally hoped to find sufficient relevant data from the literature review with which to update the values of the thermal comfort and noise reduction NEIs that the PAs currently claim for the RNC program. The plan was to develop a method by which to scale more recent NEI values from the literature review to the PAs' outdated values. If the evaluation team did not find that sufficient relevant data was available, the fallback plan was to develop analytical approaches with which to temporarily update these NEIs until primary data could be collected.

While the literature review found studies that covered thermal comfort and noise reduction, the results were mixed – both positive and negative – and were not particularly useful for updating the thermal comfort or noise reduction NEIs. Ultimately, the evaluation team defaulted to exploring analytical approaches to update these values. (These approaches are detailed in Section 3.3). The team recommended that, until the PAs could conduct the additional research needed to update the thermal comfort and noise reduction NEIs, they adjust the out-of-date values for inflation. The inflation adjusted values are presented in Section 3.3.1.

2.3 Monetizing Additional RNC NEIs for Short-Term Use

The team primarily relied on the academic research to identify new NEIs that the PAs could potentially claim as outcomes from the RNC program. Several of the NEIs the team identified could be monetized without collecting primary data. The selection criteria for NEIs that could be monetized without collecting primary data was as follows: the level of evidence in the literature, the availability of additional information with which to monetize the impacts, and the ability to link the impacts to the RNC program. The evaluation team focused on monetizing additional NEIs that met the following conditions:

- Studies presented data that provided evidence of an NEI attributable to components, equipment, and design commonly found in energy-efficient new construction (such as exposure to gas stoves, inclusion of ERV / HRV systems).
- The measured data had strong evidence of association with a monetizable health outcome.

While estimating monetized values for the new NEIs, the evaluation team attempted to triangulate evidence and data from various studies and secondary data sources. Note that the potential and additional NEIs monetized in this report are not exhaustive. The literature review uncovered several more potential new NEIs than the evaluation team monetized, as Section 4 describes; however, the available literature did not always have strong evidence of the NEI or pathways for monetization.

2.3.1 Research Challenges, Limitations, and Sources of Uncertainty

The team did not find any energy-efficiency program evaluations that included new primary research for NEIs in the RNC market, nor any evaluations that attempted to monetize RNC NEIs using primary or secondary data.[25]

The literature clearly identified impacts from gas stoves and formaldehyde on asthma incidence, symptoms, and healthcare utilization. These NEIs are monetized in this report. However, studies of other potential NEIs presented a number of challenges, limitations, and sources of uncertainty. For example, while the literature review included studies that conducted data collection on various parameters related to indoor environmental quality (IEQ), most were conducted outside the U.S, making it difficult to compare potential program impacts in relation to baseline, non-program homes. Other factors included the following: a mix of both positive and negative findings; studies that measured changes or differences in general health symptoms, such as coughing, wheezing during exercise, or runny nose, but did not directly link energy-efficient new construction to specific healthcare utilization outcomes; small sample sizes; and limited ability to determine which energy-efficiency component led to an observed difference in IEQ. In summary, quantifying additional NEIs from the literature was hampered by the following:

1. A mix of results in the reviewed literature indicating positive effects, negative effects and / or no effects, preventing the team from making a determination of RNC impacts for some NEIs.
2. A lack of sufficient data quantifying how measures and building practices implemented by the RNC program impact specific IEQ parameters, and more specifically, to what degree program homes differ from non-program homes on IEQ parameters that influence health.
3. Differences in measuring IEQ between the energy-efficiency and healthcare sectors, making it difficult to link the findings from the energy-efficiency and health literature. For example, the reviewed literature used different metrics for mold and moisture issues.
4. Applicability of findings from studies of SF PH to traditional RNC
5. Studies that looked at extremely high-performance construction, such as PH, were mostly for SF homes, attached homes, and smaller apartment complexes. This adds another layer of complexity given that the PH offering primarily encompasses mid- and high-rise multifamily buildings.
6. Time constraints on the literature review due to needing final, monetized NEI values for PA planning purposes. Follow-up research may be able to explore other potential NEIs identified in the literature that could potentially be linked with other literature to triangulate and develop monetized values.

[25] Note that the team reviewed a 2017 white paper of ENERGY STAR® Homes in Maryland that quantified the impact of ENERGY STAR certification on home prices. However, the results are not used for EmPOWER Maryland cost-effectiveness testing.

In addition, most studies only looked at the post-treatment period, without pre-treatment observations or random assignment of subjects to treatment and control groups. The evaluation team selected the most appropriate literature available for each NEI. However, given remaining uncertainties, the evaluation team applied conservative assumptions in developing the algorithms and inputs whenever the data required interpretation.

2.4 Identifying Potential New NEIs for Adoption and Approaches to Monetizing Them

The team used findings from the literature review to identify NEIs that could potentially result from the RNC program activities and be monetized to scope the data collection needs and valuation methodology for each. The team focused on NEIs for which there is a greater amount of evidence in the secondary literature.

To the extent possible, the team considered differences in potential NEIs or valuation approaches between the RNC market segments (SF, MFLR, MFHR, R&A, PH). The available research covered both SF and multifamily buildings, but the differences in NEIs was not always easy or possible to distinguish between the two segments. The literature did identify some general differences between SF and multifamily homes that could be associated with NEIs. For example, multifamily buildings built to PH specifications may experience overheating more frequently than SF homes built to these specifications.[26]

[26] Note that this observation may likely be due to higher occupant-density within the multifamily building that result in higher internal heat gains.

Section 3 NEI Monetization Updates

This section summarizes the results from the jurisdiction scan and literature review, the subsequent updates to current RNC NEI values, and the monetization of three additional NEIs from secondary data.

Key Findings

- The RNC program currently claims NEIs for thermal comfort and noise reduction. The team adjusted these NEIs for inflation as a short-term solution to the lack of new research monetizing these NEIs in new residential buildings. The adjustment increased the thermal comfort and noise reduction NEIs from a total value of $117 to $139 per year.
- The literature review found multiple papers that measured IEQ in passive homes in particular, but found much less information for general high-efficiency RNC. Two studies met the team's criteria for developing monetization algorithms: one meta-analysis on the asthma impacts of exposure to gas stoves in the home, and one randomized controlled trial investigating the impact of heat and ERV on formaldehyde levels in study homes and the resulting change in asthma-related emergency department visits
- Based on these two studies, the team monetized additional NEIs to account for gas stove impacts on asthma, totaling $3.28.
- The team monetized an additional NEI for the impact of reduced formaldehyde due to mechanical ventilation with heat or energy recovery (ERV or HRV), which leads to fewer asthma-related emergency room visits, totaling $0.02.
- Updated program requirements or pathways, such as eliminating combustion stoves (which would result from an all-electric pathway), are potential avenues to increase monetized NEIs for asthma-related impacts. The monetized NEIs described in this section are impacted by small differences observed in program and baseline homes for the key building components.
- The saturation of gas stoves is 84% in baseline homes and 77% in program homes – only an 8% reduction compared to the baseline. The saturation of homes without ERV or HRVs is 85% of baseline homes and 81% of program homes – only a 5% reduction compared to the baseline. The differences between program and baseline homes for the measures used in the NEI monetization algorithms are modest, but indicate potential for the program to achieve deeper NEI savings with new program pathways, with new program requirements, or by shifting general practice.
- The literature review for thermal comfort and noise, which included RNC and existing programs treatment of these NEIs, did not yield any new energy-efficiency program evaluations that included primary research for RNC-related NEIs, nor did it yield any evaluations that attempted to monetize RNC NEIs using primary or secondary data. In addition, the other literature reviewed included a mixture of positive and negative results.

- The literature review yielded just one RNC study that attempted to monetize the benefits from program homes compared to non-program homes since the last RNC NEI study conducted in Massachusetts. This study, *ENERGY STAR New Homes and the Impact of Certification on Maryland Home Prices*, did not distinguish between energy and non-energy benefits. The evaluation team developed an approach to estimate the non-energy portion of the premium from this study in order to compare it to the value of NEIs currently claimed by the Massachusetts PAs (adjusted for inflation) and to use as a benchmark against any additional NEI quantification approaches developed by the team. This analysis estimates that the annualized price premium net of energy savings is $196, and when adjusted for inflation, $226 (see Appendix A.3 for details).

3.1 Review of Other Jurisdictions' NEIs

The jurisdictional scan provided details on how ten jurisdictions outside Massachusetts claim NEIs, specifically those attributed to the RNC market. Overall, the scan found that nine of the jurisdictions did not claim NEIs specific to RNC programs. Rhode Island is the only jurisdiction included in this scan that claims RNC-specific NEIs. However, the Rhode Island RNC NEIs are based on the 2011 Massachusetts NEI evaluation. For a details of the jurisdiction scan, see Appendix A.2.

3.2 Literature Review

3.2.1 Overall Findings

The literature review did not yield any new energy-efficiency program evaluations that included primary research for RNC-related NEIs, nor did it yield any evaluations that attempted to monetize RNC NEIs using primary or secondary data. The most recent evaluation of the kind the team sought was an NEI evaluation that was conducted for the Massachusetts PAs in 2011 by NMR. The team searched the IEPEC Evaluation Library, ESource DSM evaluation library, Google, and databases available through the University of Tennessee's OneSearch, which includes Academic Search Complete, PubMed, Scopus, and ERIC by EBSCO. Keywords and search terms included, but were not limited to, "health impacts," "energy efficient," "new homes," "indoor air quality" (or "IAQ"), "passive house," "heat recovery ventilation" (or "energy recovery ventilation"), and "ENERGY STAR," in various combinations.

The team reviewed a few studies that included monetized values, but none provided information that could be used to update existing NEI values or as a basis for monetizing new RNC-related NEIs.

The literature review yielded just one RNC program white paper that attempted to monetize the benefits from program homes compared to non-program homes since the last RNC NEI study conducted in Massachusetts (in 2011). This study, *ENERGY STAR New Homes and the Impact of Certification on Maryland Home Prices*,[27] did not distinguish between energy and non-energy

[27] https://www.icf.com/-/media/files/icf/white-paper/2017/energy-energy-star-new-homes-impact-certification-on-maryland-home-prices_web.pdf

benefits. The evaluation team developed an approach to estimate the non-energy portion of the premium from this study in order to compare it to the value of NEIs currently claimed by the Massachusetts PAs, adjusted for inflation, and to use as a benchmark against any additional NEI quantification approaches developed by the team.

Based on the analysis of results from the Maryland price premium, the evaluation team estimates that the annualized price premium net of energy savings is $196 and, when adjusted for inflation, it is $226. The Maryland price premium is the same order of magnitude as the PAs inflation adjusted NEI values, providing further support for the PAs' RNC NEI values. However, the evaluation team does not recommend the PAs use this information to update the NEIs because applying the results from a home price premium study with different geographic, housing characteristics, and RNC program thresholds could lead to overstating or understating NEIs in Massachusetts.

Appendix A.3 summarizes the study as a potential benchmark against which to assess the NEI values and presents the premium analysis approach on which the results above are based.

3.2.2 Current and Potential New NEIs

Table 7 summarizes the literature found for each current and potential NEI based on geography and climate, level of evidence (number of studies and literature reviews), and research methodologies employed. The NEIs are divided into three tiers based on the level of evidence: high, moderate, and low. High-evidence NEIs appear in at least five studies or literature reviews, moderate-evidence NEIs appear in two to four studies, and low-evidence NEIs only appeared in one study. Three of the four NEIs in the top tier have at least one study that was conducted in the U.S. in a cold or very cold climate.

Table 7: Summary of the Literature by NEI Category, Geography, Climate, Level of Evidence, and Methodology

Evidence Tier	NEI	No. of Studies by Geography					Total Papers	Methodologies			
		U.S. - Cold or Very Cold	U.S. - Moderate or Hot	Canada	Europe	Australia	Individual studies and Literature Reviews*	Self-Report	Monitor Devices	Home Visit	Building/Utility Records
1	Respiratory health**	5	0	2	5	0	21	•	•	•	•
	Thermal comfort**	1	0	0	10	0	12	•	•	•	
	General health & safety**	1	0	0	2	0	5	•	•	•	
	Noise**	0	0	0	5	0	5	•	•		
2	Sick building syndrome (SBS)**	2	0	0	2	0	4	•	•	•	
	Operations & maintenance	1	0	0	2	0	3	•	•		
	CO poisoning	1	0	0	1	0	3	•	•		
	Summer overheating / winter underheating**	0	0	0	3	0	3	•	•		
	Environmental benefits / reduced carbon emissions	0	0	0	1	0	2	•	•		
	Mental well-being	0	0	0	1	0	2	•			
	Home price	1	0	0	1	0	2	•			•
3	Productivity (remote work and home productivity)	0	0	0	0	0	1	•	•		
	Excess mortality from air pollution	1	0	0	0	0	1		•		•
	Trips/falls	0	0	0	0	0	1				

*Total includes literature reviews, which this team did not include under the "No. of Studies by Geography" column due to the geographic diversity of the studies contained within these literature reviews.
**Literature included both positive and negative results.

Respiratory health. Twenty-one articles, including nine literature reviews, addressed respiratory health and/or the indoor environmental factors that influence respiratory health. Overall, the literature suggests that energy-efficient new construction results in better respiratory health outcomes or improved IEQ. However, it is important to note that there are several studies that found negative effects of energy-efficient new construction. Nine of the articles included direct measurements of respiratory health, such as number of respiratory infections and instances of bronchitis, number of hospitalizations due to asthma, and number of asthma attacks; eight indicated improvements in respiratory health could result from living in a passive, high energy-efficiency or green home; and one found modest to no change in respiratory symptoms after remediating mold (high-performance homes tend to be drier and less prone to mold). The remaining 11 studies measured IEQ factors that have impacts on respiratory health that are well-documented in health literature; IEQ is an umbrella term that includes both IAQ (i.e., the quality of the air we breathe in) and other physical factors in the home, such as mold and presence of pests. The majority (ten) measured IAQ and presented a mix of results: five papers showed better IAQ in passive and high energy-efficiency homes compared to conventional homes, one paper showed worse IAQ than conventional homes, and four papers found no difference between the housing types or mixed results (some pollutants decreased, while others increased or did not change). Two of the 21 studies assessed extensive retrofits resembling renovation, while one retrofit study only installed Mechanical Ventilation with Heat Recovery (MVHR), which is common in PH and very low-energy construction.

The specific types of air pollution being measured varied among the papers but typically included particulate matter (typically in $PM_{2.5}$),[28] CO_2, nitrogen oxide (NO_2), formaldehyde and/or volatile organic compound (VOCs); notably, NO_2 and particulate matter were found to improve in every study that measured them. Six papers measured other IEQ factors (e.g., pest infestation, mold, moisture, ventilation) and found improvements in these conditions in the passive, green and high energy-efficiency homes. There was some overlap between papers that measured direct asthma indicators, IAQ, and IEQ.

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[28] $PM_{2.5}$ refers to the mass of particulate matter that is below 2.5 micrometers in diameter. $PM_{2.5}$ has been shown to penetrate into the alveoli and lodge deeply into the lungs and even enter the blood stream. While $PM_{2.5}$ is typically more of a concern with outdoor air quality, indoor sources of $PM_{2.5}$ are also a health concern and include smoking, cooking (this occurs to some extent regardless of fuel type), and burning incense and candles. Reference: https://www.osti.gov/servlets/purl/1172959.

Table 8: Summary of Respiratory Health and IEQ Studies

Respiratory Health or IEQ Metric	Positive NEI (# of studies)	Negative NEI (# of studies)	Mixed Results (# of studies)
Respiratory health	8	0	1
Particulate matter	6	0	0
CO_2	1	1	6[1]
NO_2	3	0	0
Formaldehyde	3	1	2
VOCs	2	0	1
Pest infestation, mold, moisture, ventilation	6	0	0

[1] For CO_2 concentration, six papers found either no difference in CO_2 concentrations between high-efficiency and standard new homes, or the results were mixed and inconsistent.

Thermal comfort. Twelve studies examined thermal comfort in high-performance homes: three took place in the UK, two in Sweden, five in continental Europe, one in the U.S. (Ohio), and one was a literature review. Five studies showed improved thermal comfort in passive and low-energy homes, three reported issues with overheating in summer, one reported general lack of thermal comfort, and three studies had mixed results or showed no difference compared to conventional homes. Studies of SF homes were more likely to have positive thermal comfort outcomes than multifamily or semi-detached homes. Summer overheating was primarily associated with passive homes and was particularly common when residents attempted to cook with the stove or oven.

General health and safety. Five articles, including two literature reviews, reported general measures of health or asked residents in high-performance homes to report on their perception of their health overall. All five showed modest to moderate positive results, though one study assessed a retrofit program that was not defined clearly enough to determine if it constituted a renovation. These studies were distinct from research on SBS, which is addressed below. Health indicators ranged from simple ordinal measure of self-reported health to estimates of reductions in doctor's visits. One literature review also notes improvements in overall mental health, which will be addressed separately. The second literature review notes that NO_2 exposure can increase the risk of cardiovascular effects, diabetes, cancer, and reproductive effects.

Noise. Five studies measured noise in high-performance homes. Three studies had positive noise-related findings, while two did not find any differences between the efficient homes and standard homes. One study measured noise in five passive homes and two BBC-Energie homes in France (Derbez, 2014); all homes were SF detached with MVHR. Residents generally rated noise levels positively, indicating noise levels were "quite pleasant" to "extremely pleasant." Noise levels in the living room, bedrooms, and bathrooms rarely exceeded 40 decibels (dB) and were often below 30 dB, which was the minimum threshold for what the measurement device could detect. A study from Sweden (Rhodin, 2014) that studied a group of 39 terraced homes – nine passive home certified and 30 simply built to the Swedish building standard – found no significant difference in noise levels. A study from Austria (Walner, 2015) found that all 14 high-performing homes had ventilation systems with noise levels below the recommended threshold when operating at normal capacity; 21% of homes exceeded the limit when turned to maximum ventilation. A second study from Austria (Walner, 2017) included 123 high-performance homes and a control group of 170 homes. The researchers found no significant difference in noise levels. Lastly, a team in Romania (Bailescu, 2019) simulated noise levels in passive homes under various parameters and found noise to be within the recommended parameters when equipment is operating normally.

Sick building syndrome. Four studies discussed the impacts of high-performance homes as they relate to SBS symptoms and potential sources. One study out of the UK (McGill, 2014) monitored IAQ in six newly constructed attached homes constructed to very efficient standards. The study found an occurrence of SBS symptoms in participants, including symptoms that became better when away from the house (such as dry throat, itchy eyes, and stuffy nose). Another study in the UK (McGill, 2015) compared newly constructed PH homes with Code for Sustainable Homes (CSH). Results of the indoor air measurements suggested that the CSH homes exceeded the maximum level of 1,000 ppm of CO_2, while CO_2 was slightly under that threshold in the PH homes. One study, based out of Boston (Colten, 2014), compared the IAQ of a green renovated multifamily building to a conventional building and found a 47% decrease in SBS symptoms for participants that lived in the renovated building.[29] Note that this comparison is based on a newly renovated building compared to an existing building. An additional study based out of Boston (Colten, 2015), which compared IAQ of newly constructed and renovated green multifamily buildings to existing buildings, found that participants reported an average of 2.9 SBS symptoms compared to 4.2 SBS symptom for residents of existing buildings.

Additionally, some common conclusions were drawn from the SBS studies that determined additional factors that were likely contributors to SBS symptoms. SBS symptoms are due to a variety of factors, including inadequate IAQ; thermal comfort issues; and lack of occupant knowledge for operating ERV or HRV systems, such as insufficient use of boost ventilation , noise complaints regarding ventilation, lack of occupant awareness to change air filters, adjusting or closing ventilation supply vents during winter months, lack of natural ventilation; presence of mold;[30] and significant variance in heating patterns (likely due to internal gains, such as from cooking). In some cases, one or multiple of these issues led the occupant to completely shut off the ventilation system.

[29] The study observed lower concentrations in $PM_{2.5}$ (57%), NO_2 (65%), and nicotine (93%) in green homes vs. the control homes. Occupants in green homes reported reduced instances of mold, pests, inadequate ventilation, and stuffiness.

[30] Interestingly, five of six of the households dried their clothes without dryers, which suggests that mechanical ventilation systems may need to account for additional moisture to prevent mold growth when occupants passively dry clothes indoors.

Operations and maintenance. There were three studies that discussed the impacts on building operations and maintenance costs for a higher-performance home or multifamily building. Overall, the studies suggested potential for reduced operational and maintenance costs in higher-performance homes, including those built to PH specifications. The first study, based in Sweden (Langer, 2015), compared 20 new homes built to PH specifications and 21 newly constructed homes built to standard Swedish practices. This study monitored indoor conditions, including temperature; relative humidity; concentrations of CO_2, NO_2, Ozone, formaldehyde, VOCs, and viable microbiological flora; and air infiltration levels. There was evidence of mold and moisture issues in 29% of the homes built to standard practices, while the absence of microbiological flora related to mold growth or water damage was observed in the PHs, suggesting higher-performing homes can have a more durable building envelope. The second study (Mahdavi, 2010) compared 27 PH apartments with 111 low-energy apartments in Vienna.[31] The study monitored the indoor environmental conditions, conducted occupant evaluations, metered energy usage, calculated embodied energy and CO_2 emissions, and included construction cost estimates. The results suggested that the PH apartments consumed 65% less heating energy and 35% less electrical energy, CO_2 emissions were 25%-40% lower, and construction costs were 5% higher than the low-energy apartments. The IAQ monitoring in the study suggested slightly better levels of air quality in the Passive Homes, with the mechanical ventilation contributing to lower levels of CO_2 concentrations, particularly during cold periods and in multiple occupancy apartments. The reduced heating energy consumption is an indicator that smaller capacity equipment can be used at potentially reduced mechanical equipment runtimes. Another study (Brod, 2020) that potentially provides insights for the R&A program component looked at the pre- and post-renovation of two Boston multifamily public housing developments and quantified over a 50% reduction in work orders associated with mold, pests, and window and plumbing issues. The renovated sites had reductions in consumption for electricity (30%-46%), gas (72%-75%), and water (29%-56%).[32]

Carbon Monoxide (CO) poisoning. Three of the reviewed studies, one of which was a literature review, discussed CO measurements. One study (Derbez, 2014), which measured air quality of seven passive homes in France, found very low concentrations of CO but only measured this in homes without combustion heating equipment (wood stoves). An all-electric homes study from Colorado (SWEEP, 2021) found that eliminating natural gas pipes from furnaces, water heaters, and stoves, eliminated risks of CO poisoning or explosions. [33] The literature review (Seals, 2020) compiled information from various studies that measured the CO levels in homes. The CO levels were as follows:

- Between 0.5 and 5 ppm in homes with electric stoves
- Between 5 and 15 ppm in homes with gas stoves with properly adjusted ventilation
- Over 30 ppm in homes with gas stoves and unadjusted ventilation

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[31] There was one PH multifamily building and four low-energy multifamily buildings.
[32] The study quantified annual per-unit utility savings of $5,033 and $2,177 annually (for gas, electric, and water) for the two developments.
[33] The team notes that there may be opportunities for CO to enter into the homes with attached garages in the absence of combustion appliances.

Summer overheating and winter underheating. Three of the reviewed studies discussed the potential for overheating or underheating in higher-efficiency homes, including those built to PH specifications. Potential for overheating in the summer can be due to airtight construction, high levels of insulation, and window placement that is optimized to capture solar gains.[34] One study (Masoud, 2015) monitored temperature in 25 apartment *flats* in the United Kingdom over three cooling seasons. The study found that overheating did occur, but the primary drivers to overheating were occupant behaviors, such as not using windows for ventilation and drawing shades, combined with activities that generate internal heat gains, such as cooking. In addition, the study noted that external shading devices were not present and there were additional strategies to reduce potential for overheating, such as window orientation and thermal massing to help reduce overheating from solar irradiance. Another study (Rhodin, 2014), based out of Sweden, covered 39 newly constructed homes, nine of which were built to PH standards. This study found that thermal comfort for the passive homes was well within the limits of local codes. However, energy modeling and post-occupancy surveys found that PH occupants experienced cold floors to a greater degree in the passive subset. In addition, the PH sample had a higher number of complaints associated with high temperatures during the summer. The authors noted that external shading was not present, and that variation in the monitored temperatures were also impacted due to cooking and other heat-generating activities to a greater degree than the conventional homes. The third study (Derbez, 2014) monitored thermal and other indoor parameters of seven PHs in France and found that occupants were generally comfortable during the warmer months but found that occupants experienced some discomfort during the cooler months.

Environmental benefits / reduced carbon emissions. One study (Osso et al., 2016) discussed the potential for avoided environmental externalities, such as avoided carbon emissions and avoided electricity use. The study provides interesting insights into potential monetization of various NEIs from a societal and utility perspective, such as participant reinvestments into the economy from bill savings; creation of jobs; avoided CO_2; and impacts on the electric system, electric suppliers, and electric distribution and transmission.[35]

Mental wellbeing. One literature review (Wilson et al., 2016) found two studies that showed improvements in mental health and well-being associated with green and high-performance homes. A separate study (Wallner et al., 2017) found no difference in mental health and well-being between occupants of high-performance and conventional housing when they asked about four specific topics: anxiety, nervousness, mood change, and tiredness.

Home price. Two of the reviewed studies discussed home price. One of which is the Maryland ENERGY Star New Homes Price study, which is detailed in Appendix A.3. The Maryland study isolated newly constructed homes, which was unique among studies that looked at price premiums of higher performance homes than standard practice or homes built to code. The

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[34] Note that optimized solar gains are intended to capture heat in the winter but often require exterior shading strategies to limit solar gains in the summer.

[35] In this study, they explored avoided electricity usage due to fuel switching to wood. Note that fuel switching from gas to another system would also have an impact on natural gas pipe infrastructure and leakage associated with those pipelines.

second study (Osso et al., 2016) is set in France and focuses on renovations and replacing electric heating systems with wood-fired heating systems, which has not been observed in great prevalence in the last several RNC baseline studies.

Productivity. Researchers at the Pacific Northwest National Laboratory (PNNL) (Wang, 2020) have reviewed existing literature on the impacts of air quality on productivity, retention, and wellness in office buildings. Given the dramatic rise in the number of people working from home, these benefits may increasingly apply to the RNC sector. Sources identified in the PNNL report indicated an annual benefit of $17.14 per square foot[36] from implementing retrofits in a typical office building, while another study estimated an annual benefit of $6.83 per square foot[37] from obtaining WELL healthy building certification.[38] This work focuses on commercial spaces, particularly office buildings, but the evaluation team includes it here in light of increasing prevalence of remote work brought about by technological changes and the COVID-19 pandemic. As more employees work from home, indoor air and environmental quality in the home will become more vital to worker productivity and may be improved by building high-performance homes with attention to IAQ and proper ventilation.

Excess avoided death due to air pollution. The link between air pollution, particularly $PM_{2.5}$, and premature or excess mortality is well-established, but researchers continue to work on separating the influence of localized, indoor pollution from ambient air pollution in a region. One study (Zhao et al. 2015) used modelling to estimate reductions in premature mortality and increases in life expectancy that would result from using varying levels of HEPA and MERV filters in homes to reduce indoor $PM_{2.5}$ concentrations. The study also modeled the amount of infiltration in different home vintages and the resulting amount of indoor $PM_{2.5}$ of outdoor origin.

Trips/falls. One literature review (Wilson, 2016) that explored the health benefits of home performance found that elderly, low-income occupants in newly renovated green buildings reported improved mental health conditions and a 16% reduction in occupant falls compared to before the renovation.

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[36] The team converted the annual value from $115 per square foot (ten-year net present value) using an 8% discount rate.
[37] The team converted the annual value from $28 per square foot (five-year net present value) using a 7% discount rate.
[38] The WELL building standard is a certification standard that is designed to help building designers deliver more thoughtful and intentional spaces that enhance human health and well-being. The WELL building standard incorporates ten concepts as a part of its certification: air, water, nourishment, light, movement, thermal comfort, sound, materials, mind, and community. The WELL certification requires projects to meet certain criteria to earn specific certification levels, such as WELL Bronze, WELL Gold, and WELL Platinum. https://v2.wellcertified.com/wellv2/en/overview

3.3 Short-Term Approaches to Updating Values of NEIs Claimed for RNC

The mixed results stemming from the new research on thermal comfort and noise reduction in new residential buildings limited what approaches the evaluation team could explore to monetize or update these NEIs. Ultimately, the team relied on two approaches: (1) inflation adjustment and (2) historic RNC program performance.[39] Note that these approaches are limited due to lack of existing research that monetize NEIs in the RNC market. In absence of conducting primary research or researching additional secondary literature, these adjustments are only short-term solutions to monetizing NEIs related to thermal comfort and noise reduction.

3.3.1 Inflation Adjustment

To update the RNC NEI values to current dollars, the evaluation team applied the BLS CPI Inflation Calculator[40] to the thermal comfort and noise reduction NEI values from the 2011 RNC NEI study. Table 9 presents original and updated values. The team explored an additional method to update the NEI values using historic RNC program performance, but ultimately did not recommend this approach. The details of the historic performance approach are included in Appendix A.5.

3.3.1.1 Recommendation

Recommendation: Adopt the inflation-updated RNC NEI value of $139 per year for thermal comfort and noise, combined. This is meant as a short-term solution, to be used only until further primary research has been conducted or additional secondary data becomes available to update these values. The inflation adjustment method could be leveraged generally as an interim update to RNC NEI values between evaluation studies.

Table 9: Inflation Adjustment Method Results

	Date	Annual Value
2011 RNC NEI Study Value[1]	August 2011	$117
2021 Inflation Adjustment	May 2021	$139

[1] The 2011 RNC NEI study value was $77 for thermal comfort and $40 for noise reduction. After the 2021 inflation adjustment, the values for thermal comfort and noise reduction are $91.50 and $47.53, respectively.

3.4 Monetization of Additional RNC NEIs

This subsection details the approaches the team developed to monetize each of three additional health-related NEIs associated with high-efficiency new construction practices that the RNC program does not currently claim. These approaches are based on academic research and other secondary data.

The new NEIs are associated with reducing the risks to asthma patients posed by gas combustion stoves and formaldehyde from poor ventilation. The NEIs are due in large part from improving

[39] The team presented both approaches to the RNC NEI study working group and ultimately decided to recommend the inflation adjustment method for current RNC program NEI values.

[40] https://www.bls.gov/data/inflation_calculator.htm

IAQ by eliminating byproducts of combustion from stoves. These byproducts include NO_2, $PM_{2.5}$, CO, and others. The NEIs are also due to reducing formaldehyde concentrations that build up in the home due to limited or poor ventilation.[41] Increased levels of $PM_{2.5}$ and CO from combustion stoves are associated with negative health outcomes, such as damage to respiratory systems.[42,43] IAQ can also be improved by removing similar emissions by eliminating other gas combustion appliances, such as heating and water heating, but the literature did not specify the asthma impact from these additional end-uses. Formaldehyde can be reduced in the home through high-efficiency ventilation, such as HRV or ERV. [44]

It should be noted that the values of these new NEIs are impacted by observed differences in the program and baseline saturation levels. For example, if the program saturation of homes without gas stoves increases relative to baseline, the NEIs will increase in value, but if the baseline saturation increases relative to program homes, the NEI decreases.

3.4.1 Recommendation

Recommendation: In the short term, the PAs should adopt an asthma-related RNC NEI of $3.30 per household per year (Table 10). This is the total value of asthma-related NEIs attributable to improved IAQ in program new homes over baseline new homes. The value of the NEI reflects the current difference between program and baseline saturation for both stoves and ventilation systems. These NEI values can be updated on an annual basis based on program saturation rates for these measures to reflect differences from baseline practices. In addition, the baseline saturation values used in the algorithms can be updated with new baseline study results as they become available. Each of the NEIs, including the algorithm, sources, and caveats, are detailed in the subsections below.

Table 10: Summary of Recommended Asthma Related RNC NEIs

Measure	NEI	Value Suggested
Electric Stoves (NO_2)	Childhood asthma prevention, occupant lifetime	$0.65 per household per year
	Adult asthma symptom reduction	$2.21per household per year
	Childhood asthma symptom reduction	$0.42 per household per year
ERV/HRV (formaldehyde)	Reduced asthma ED visits	$0.02 per household per year

[41] Formaldehyde is a VOC with negative health effects and is a known carcinogen. It can be released by many products and materials used in energy-efficiency measures and other applications. The NEI focuses on outcomes associated with removing formaldehyde concentrations through ventilation strategies. It does not address outcomes from using materials that may emit lower levels of formaldehyde or other VOCs.

[42] https://rmi.org/insight/gas-stoves-pollution-health

[43] https://www.osti.gov/servlets/purl/1172959

[44] https://pubmed.ncbi.nlm.nih.gov/25603837/

3.4.2 Electric Stoves: Childhood Asthma Prevention

The use of combustion appliances, such as gas stoves, produces multiple byproducts, including nitrogen dioxide (NO_2). Medical research has increasingly indicated that the elevated levels of NO_2 resulting from cooking with a gas stove can increase the risk of developing asthma and exacerbate asthma symptoms.[45,46,47,48] The Massachusetts Medical Society issued an official resolution in December 2019, stating that it "recognizes the association between the use of gas stoves, indoor NO_2 levels, and asthma."[49] Proper ventilation appears to mitigate, but not eliminate, the risks of cooking on gas stoves.[50, 51]

A meta-analysis on the effects of indoor NO_2 and gas cooking on asthma and wheeze in children identified an odds ratio of 1.36 for North America asthma incidence in children living in homes with gas stoves. Incidence is defined as the *number of new asthma cases in a group in a given year,* or in this specific case, the number of Massachusetts children who develop asthma in a given year.[52] This is in contrast to *prevalence,* which measures how many people *in total* have asthma at any given point in time; as a result, prevalence will generally be higher than incidence. The odds ratio of 1.36 indicates a higher risk of asthma incidence, or developing asthma, in homes with gas stoves than in homes without gas stoves. Preventing the development of asthma would lead to reductions in healthcare costs across the lifetime and fewer missed days of school for children and missed days of work for adults.

Extrapolating from the meta-analysis, the monetization detailed below calculates the household healthcare cost savings that would be expected as a result of having fewer gas stoves among program homes than non-program homes, based on data indicating that removing gas stoves is associated with lower rates of children developing asthma each year. Table 11 presents the recommended occupant lifetime cost reduction approach, annualized by the RNC home measure life of 25 years. The evaluation team developed the value being recommended for this NEI based on the assumption that the benefits of preventing a child from developing asthma extend beyond the useful life of the program measures given that it would prevent a lifetime of asthma-related medical costs for those children who do not go into remission. While it is possible that gas cooking

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[45] Belanger, K., Holford, T. R., Gent, J. F., Hill, M. E., Kezik, J. M., & Leaderer, B. P. (2013). Household levels of nitrogen dioxide and pediatric asthma severity. *Epidemiology (Cambridge, Mass.)*, *24*(2), 320–330. https://doi.org/10.1097/EDE.0b013e318280e2ac

[46] U.S. EPA. Integrated Science Assessment (ISA) for Oxides of Nitrogen – Health Criteria (Final Report, Jan 2016). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-15/068, 2016.

[47] Lin, W., Brunekreef, B., Gehring, U. Meta-analysis of the effects of indoor nitrogen dioxide and gas cooking on asthma and wheeze in children, *International Journal of Epidemiology*, Volume 42, Issue 6, December 2013, Pages 1724–1737, https://doi.org/10.1093/ije/dyt150

[48] Luke D Knibbs, Solomon Woldeyohannes, Guy B Marks and Christine T Cowie
Med J Aust 2018; 208 (7): 299-302. || doi: 10.5694/mja17.00469
Published online: 16 April 2018

[49] Informing Physicians, Health Care Providers, and the Public That Cooking with a Gas Stove Increases Household Air Pollution and the Risk of Childhood Asthma, Massachusetts Medical Society, December 2019. https://gbpsr.org/wp-content/uploads/sites/11/2020/01/gas-cooking-and-asthma-2019-mms.pdf

[50] Ibid.

[51] Luke D Knibbs, Solomon Woldeyohannes, Guy B Marks and Christine T Cowie
Med J Aust 2018; 208 (7): 299-302. || doi: 10.5694/mja17.00469
Published online: 16 April 2018

[52] Lin W, Brunekreef B, Gehring U. Meta-analysis of the effects of indoor nitrogen dioxide and gas cooking on asthma and wheeze in children. Int J Epidemiol. 2013 Dec;42(6):1724-37. doi: 10.1093/ije/dyt150. Epub 2013 Aug 20. PMID: 23962958.

could also increase asthma incidence in adults, the foundational literature for this NEI focused on the risk of childhood asthma incidence and therefore a corresponding NEI was not monetized for adults. The team determined that monetizing an NEI for the impact of gas stoves on adulthood asthma incidence would require reviewing additional literature.

Table 11: Electric / Non-Combustion Stove – Childhood Asthma Prevention, Annualized Occupant Lifetime Benefit

Input		Value	Source
a	MA average lifespan	80	Centers for Disease Control and Prevention (CDC)[1]
b	Number of years as a child	18	Constant
c	Average age of asthma onset	5	MA Department of Public Health[2]
d	Number of years with childhood asthma	13	b - c
e	Number of years with asthma as an adult	62	a - b
f	Childhood asthma prevalence rate, MA	12.9%	Massachusetts Government Asthma Statistics[3]
g	Adulthood asthma prevalence rate, MA	10.2%	
h	Percent reduction in asthma from childhood to adulthood	21%	(f - g) / g
i	Incremental annual medical cost associated with childhood asthma, adj. for MA (2019 $)	$2,139	Nurmagambetov et al.
j	Incremental annual medical cost associated with adult asthma, adj. for MA (2019 $)	$4,022	Ibid.
k	Out-of-pocket (OOP) medical costs	11%	MEPS[53]
l	Incremental annual cost associated with missed days of school, adj. for MA (2019 $)	$252	Nurmagambetov et al.
m	Incremental annual cost associated with missed days of work, adj. for MA (2019 $)	$266	Ibid.
n	OOP incremental costs associated with gas stove exposure - childhood	$6,235	d * (i * k + l)
o	OOP incremental costs associated with gas stove exposure - adulthood	$34,014	(1 - h) * (e * (j * k + m)
p	Increased risk of Asthma due to gas combustion stove	1.36	Lin et al.[4]
q	MA incidence of asthma, ages 0-18	43,329	Global Health Data Exchange[5]

[53] https://meps.ahrq.gov/mepstrends/hc_use/

Input		Value	Source
r	MA asthma eligible population, ages 0-18	1,200,119	Massachusetts under 18 population, U.S. Census[6] * (1 – **f**)
s	MA asthma incidence rate, ages 0-18	3.6%	**q** / **r**
t	Estimated asthma incidence rate, gas stoves	4.9%	**p** * **s**
u	Estimated asthma incidence rate of children based on gas stove rate, annual	58,927	**r** * **t**
v	Estimated increase in asthma incidence due to gas stoves	26.5%	(**u** – **q**) / **u**
w	MA average number of children per home	0.52	Extrapolated from MA-specific U.S. Census population and occupied housing data
x	Percent of non-program homes with combustion ranges	84%	2019 Massachusetts Baseline Study[7]
y	Percent of program homes with combustion ranges	77%	RNC Program Data provided for the 2019 baseline study[8]
z	Percent reduction in homes with combustion ranges	8%	(**x** – **y**) / **x**
AA	RNC program home measure life	25 years	MA TRM[9]
NEI Value			
AB	Value of avoided all-setting healthcare costs of asthma due to prevented cases of childhood asthma, MA, annualized lifetime benefit	**$0.65**	((**n** + **o**) * **s** * **v** * **w** * **z**) / **AA**

[1] Arias E, Bastian B, Xu JQ, Tejada-Vera B. U.S. state life tables, 2018. National Vital Statistics Reports; vol 70 no 1. Hyattsville, MD: National Center for Health Statistics. 2021. DOI: https://doi.org/10.15620/cdc:101128.
[2] Asthma Among Children in Massachusetts, Commonwealth of Massachusetts Department of Public Health, January 2017. Retrieved from https://www.mass.gov/doc/pediatric-asthma-data-bulletin-0/download
[3] https://www.mass.gov/service-details/statistics-about-asthma
[4] Lin W, Brunekreef B, Gehring U. Meta-analysis of the effects of indoor nitrogen dioxide and gas cooking on asthma and wheeze in children. Int J Epidemiol. 2013 Dec;42(6):1724-37. doi: 10.1093/ije/dyt150. Epub 2013 Aug 20. PMID: 23962958.
[5] http://ghdx.healthdata.org/gbd-results-tool
[6] https://www.census.gov/programs-surveys/acs
[7] NMR Group, 2019. Residential New Construction Baseline/Compliance Study (MA19X02-B-RNCBL), April 1, 2020.
[8] RNC program tracking data was provided for the MA19X02 study. These data were used to calculate the percent of program homes with electric stoves/ranges.
[9] https://fileservice.eea.comacloud.net/FileService.Api/file/FileRoom/12190505

3.4.3 Electric Stoves: Reduced Asthma Symptoms

In addition to increasing the risk of developing childhood asthma, gas stoves can exacerbate symptoms for those who already have asthma. A meta-analysis on the association between exposure to gas cooking and asthma estimated that the risk of having asthma symptoms increases by 42% (due to combustion byproducts such as NO_2) for children living in a home with gas cooking over those without gas cooking.[54] Evidence indicates that asthma is less sensitive to NO_2 in adults than children, but adults may experience exacerbations as well.[55] Table 12 shows the approach to monetizing the reduction in asthma symptoms in children due to removal of gas combustion stoves.

[54] Lin, W., Brunekreef, B., Gehring, U. Meta-analysis of the effects of indoor nitrogen dioxide and gas cooking on asthma and wheeze in children, *International Journal of Epidemiology*, Volume 42, Issue 6, December 2013, Pages 1724–1737, https://doi.org/10.1093/ije/dyt150

[55] Seals, B. and Krasner, A. (2020). Health Effects from Gas Stove Pollution. Rocky Mountain Institute, Physicians for Social Responsibility, Mothers Out Front, and Sierra Club, 2020, https://rmi.org/insight/gas-stoves-pollution-health.

Table 12: Electric Stove – Reduced Childhood Asthma Symptoms

Input		Value	Source
a	Increase in childhood asthma symptoms attributable to gas stoves	42%	Lin et al.[1]
b	Discount factor, ratio of healthcare costs to symptoms	80%	Evaluation team estimate[2]
c	Incremental annual medical cost associated with childhood asthma, adj. for MA (2019 $)	$2,139	Nurmagambetov et al.[3]
d	Estimated annual incremental medical cost with exposure to gas stove in home, MA (2019 $)	$3,038	c * (1 + a)
e	OOP medical costs	11%	MEPS
f	Estimated OOP cost associated with exposure to gas stove	$96	(d – c) * e
g	MA childhood current asthma rate	12.9%	Massachusetts Government Asthma Statistics[4]
h	MA average number of children under 18 per home	0.52	Massachusetts under 18 population in occupied homes, U.S. Census[5]
i	Percent of non-program homes with combustion ranges	84%	2019 Massachusetts Baseline Study[5]
j	Percent of program homes with combustion ranges	77%	RNC Program Data provided for the 2019 baseline study[6]
k	Percent reduction in homes with combustion ranges	8%	(i – j) / i
NEI Value			
n	Value of avoided all-setting healthcare costs of adult asthma due to reduced symptoms, MA, annual	**$0.42**	b * f * g * h * k

[1] Lin, W., Brunekreef, B., Gehring, U. (2013). Meta-analysis of the effects of indoor nitrogen dioxide and gas cooking on asthma and wheeze in children. International Journal of Epidemiology, 42(6), 1724-1737.
[2] The evaluation team applied a discount factor to the NEI. The team assumed that reductions in symptoms do not translate to an equivalent reductions in medical costs. The reviewed studies did not include data on the relationship between changes in symptoms and changes in medical costs so the team applied the discount factor in order to take a conservative approach to the NEI estimate. The team suggests updating this discount factor if future literature reviews find studies documenting the relationship between changes in symptoms and changes in medical costs.
[3] Nurmagambetov, T., Kuwahara, R., & Garbe, P. (2018). The Economic Burden of Asthma in the United States, 2008-2013. Annals of the American Thoracic Society, 15(3), 348–356.
[4] https://www.mass.gov/service-details/statistics-about-asthma
[5] https://www.census.gov/programs-surveys/acs
[5] NMR Group (2019). Residential New Construction Baseline/Compliance Study (MA19X02-B-RNCBL), April 1, 2020.
[6] The team used RNC program tracking data that was provided for the MA19X02 study to calculate the percent of program homes with electric stoves/ranges.

Table 13 details the approach to monetizing the reduction in asthma symptoms experienced by adults from reductions in combustion byproducts when electric stoves are used rather than gas stoves. The evaluation team discounted the impacts by 70% rather than 80% for children due to evidence that asthma is less responsive to the combustion stove byproduct NO_2 among adults than children.

Table 13: Electric Stove – Reduced Adult Asthma Symptoms

Input		Value	Source
a	Increase in childhood asthma symptoms attributable to gas stoves	42%	Lin et al.[1]
b	Adjustment factor, ratio of healthcare costs to symptoms (adults less sensitive to combustion byproducts than children)	70%	Evaluation team estimate[2]
c	Incremental annual medical cost associated with adult asthma, adj. for MA (2019 $)	$4,022	Nurmagambetov et al.[3]
d	Estimated annual incremental medical cost with exposure to gas stove in home, MA (2019 $)	$5,712	c * (1 + a)
e	OOP medical costs	11%	MEPS
f	Estimated OOP cost associated with exposure to gas stove	$180	(d – c) * e
g	MA adult current asthma rate	10.2%	Massachusetts Government Asthma Statistics[4]
h	MA average number of adults per home	2.1	Massachusetts over 18 population in occupied homes, U.S. Census
i	Percent of non-program homes with combustion ranges	84%	2019 Massachusetts Baseline Study[5]
j	Percent of program homes with combustion ranges	77%	RNC Program Data provided for the 2019 baseline study[6]
k	Percent reduction in homes with combustion ranges	8%	(i – j) / i
NEI Value			
l	Value of avoided all-setting healthcare costs of adult asthma due to reduced symptoms, MA, annual	**$2.21**	b * f * g * h * k

[1] Lin, W., Brunekreef, B., Gehring, U. (2013). Meta-analysis of the effects of indoor nitrogen dioxide and gas cooking on asthma and wheeze in children. International Journal of Epidemiology, 42(6), 1724-1737.
[2] The evaluation team applied a discount factor to the NEI. The team assumed that reductions in symptoms do not translate to an equivalent reductions in medical costs. The reviewed studies did not include data on the relationship between changes in symptoms and changes in medical costs so the team applied the discount factor in order to take a conservative approach to the NEI estimate. The team applied an additional discount to adults as evidence suggested they are less sensitive than children (see Seals, B. and Krasner, A. (2020)). The team suggests updating this discount factor if future literature reviews find studies documenting the relationship between changes in symptoms and changes in medical costs.
[3] Nurmagambetov, T., Kuwahara, R., & Garbe, P. (2018). The Economic Burden of Asthma in the United States, 2008-2013. Annals of the American Thoracic Society, 15(3), 348–356.

Input	Value	Source

[4] https://www.mass.gov/service-details/statistics-about-asthma
[5] NMR Group, 2019. Residential New Construction Baseline/Compliance Study (MA19X02-B-RNCBL), April 1, 2020.
[6] The team used RNC program tracking data that was provided for the MA19X02 study to calculate the percent of program homes with electric stoves/ranges.

3.4.4 Energy and Heat Recovery Ventilation: Reduced Emergency Department Visits for Asthma

The monetization of the Formaldehyde-Related Asthma Exacerbation NEI shown in Table 14 is derived from one study that focused on the impact of Mechanical Ventilation and Heat Recovery (MVHR) for children with asthma. The study observed a 16% reduction in ED visits in homes after a 50% reduction in formaldehyde.[56] Reductions in formaldehyde were observed in various studies that measured IAQ in energy-efficient homes.[57,58,59,60,61,62] While it was not possible to apply these measured reductions in concentrations of formaldehyde to the monetization, these studies provide additional evidence that energy-efficient homes with ERV and HRV systems can reduce formaldehyde concentrations substantially (between 29% and 78%). As a result, this NEI focuses on the presence of ERV or HRV systems.

As homes are constructed to more stringent air infiltration standards, the importance of a properly balanced, efficient mechanical ventilation system increases. ERV and HRV systems can efficiently bring in supply air to tighter homes to promote better filtration and a higher air exchange rate. This can improve IAQ by removing stale and potentially contaminated air. While there are energy savings benefits to an ERV or HRV compared to a mechanical system without heat recovery, there is concern about the IAQ of extremely airtight homes and whether lack of air exchanges or poor ventilation strategies could lead to negative health outcomes due to factors such as increased concentrations of formaldehyde.

Various materials and products within a home can contribute to increased levels of formaldehyde, a known carcinogen that is linked to negative health outcomes in asthma patients. The concentration of formaldehyde in materials associated with both construction and interior finishes

[56] https://pubmed.ncbi.nlm.nih.gov/25603837/
[57] Langer, S., Bekö, G., Bloom, E., Widheden, A., & Ekberg, L. (2015). Indoor air quality in passive and conventional new houses in Sweden. Building and Environment, 93(P1), 92–100. https://doi.org/10.1016/j.buildenv.2015.02.004
[58] Colton, M. D., MacNaughton, P., Vallarino, J., Kane, J., Bennett-Fripp, M., Spengler, J. D., & Adamkiewicz, G. (2014). Indoor Air Quality in Green Vs Conventional Multifamily Low-Income Housing. Environmental Science & Technology, 48(14), 7833–7841. https://doi.org/10.1021/es501489u
[59] McGill, G., Oyedele, L. O., & Keeffe, G. (2015). Indoor air-quality investigation in code for sustainable homes and passivhaus dwellings: A case study. World Journal of Science, Technology and Sustainable Development, 12(1), 39–60. https://doi.org/10.1108/WJSTSD-08-2014-0021
[60] Grainne McGill, Lukumon O Oyedele, & Keith McAllister. (2015). An investigation of indoor air quality, thermal comfort and sick building syndrome symptoms in UK energy efficient homes. Smart and Sustainable Built Environment, 4(3), 329–348. https://doi.org/10.1108/SASBE-10-2014-0054
[61] Derbez, M., Berthineau, B., Cochet, V., Lethrosne, M., Pignon, C., Riberon, J., & Kirchner, S. (2014). Indoor air quality and comfort in seven newly built, energy-efficient houses in France. Building and Environment, 72, 173–187. https://doi.org/10.1016/j.buildenv.2013.10.017
[62] Wallner, P., Munoz, U., Tappler, P., Wanka, A., Kundi, M., Shelton, J. F., & Hutter, H.-P. (2015). Indoor Environmental Quality in Mechanically Ventilated, Energy-Efficient Buildings vs. Conventional Buildings. International Journal of Environmental Research and Public Health, 12(11), 14132–14147. https://doi.org/10.3390/ijerph121114132

varies greatly. Using MVHR, specifically ERVs or HRVs, is a strategy that has been observed to reduce concentrations of formaldehyde in homes.

Table 14: HRV/ERV – Reduced Asthma ED Visits for Children

Input		Value	Source
a	Average annual ED visits per person with at least one asthma related visit	1.4	MEPS[1]
b	Adjustment factor for higher ED rates among children than adults	2	CDC[2]
c	Reduction in children with >=1 ED visits following a 50% reduction in formaldehyde	16%	Lajoie et al.[3]
d	Baseline rate of >=1 ED visits for asthmatic children in the study	76%	Ibid.
e	Baseline rate of >=1 ED visits for asthmatic children in MA, general population	19%	MA Department of Public Health[4]
f	Estimated reduction in children with >=1 ED visits following a 50% reduction in formaldehyde, MA, general population	4%	**c** / **d** * **e**
g	Percent of homes that achieve a 50% reduction in formaldehyde with HRV	25.6%	Lajoie et al.[3]
h	MA cost for an asthma ED visit (2019 $)	$1,671	MA Department of Public Health[5]
j	OOP Costs	11%	MEPS
k	MA average number of children per home	0.52	Extrapolated from U.S. Census population and housing data
l	MA childhood current asthma	12.9%	Massachusetts Government Asthma Statistics[6]
m	Percent of non-program homes without HRV	85%	2019 Massachusetts Baseline Study[7]
n	Percent of program homes without HRV	81%	RNC Program Data provided for the 2019 baseline study[8]
o	Percent reduction in homes without HRV	5%	(**m** – **n**) / **m**
NEI Value			
L	Value of avoided ED healthcare costs of childhood asthma due to reduced formaldehyde, MA, annual	**$0.02**	**a * b * f * g * h * j * k * l * o**

[1] Agency for Healthcare Research and Quality. Number of people with care and number of events in thousands by condition, United States, 2018. Medical Expenditure Panel Survey.
[2] Asthma Emergency Department (ED) Visits 2010-2018, Centers for Disease Control and Prevention, Last reviewed on April 9, 2021.
[3] Lajoie, P., Aubin, D., Gingras, V., Daigneault, P., Ducharme, F., Gauvin, D., Fugler, D., Leclerc, J.-M., Won, D., Courteau, M., Gingras, S., Héroux, M.-È., Yang, W., & Schleibinger, H. (2015). The IVAIRE project - a randomized controlled study of the impact of ventilation on IAQ and the respiratory symptoms of asthmatic children in single family homes. Indoor Air, 25(6), 582–597. https://doi.org/10.1111/ina.12181
[4] Asthma Among Children in Massachusetts, Commonwealth of Massachusetts Department of Public Health, January 2017. Retrieved from https://www.mass.gov/doc/pediatric-asthma-data-bulletin-0/download
[5] Asthma Among Children in Massachusetts, Commonwealth of Massachusetts Department of Public Health, January 2017. Retrieved from https://www.mass.gov/doc/pediatric-asthma-data-bulletin-0/download
[6] https://www.mass.gov/service-details/statistics-about-asthma

[7] NMR Group, 2019. Residential New Construction Baseline/Compliance Study (MA19X02-B-RNCBL), April 1, 2020.
[8] The team used RNC program tracking data that was provided for the MA19X02 study to calculate the percent of program homes with ERVs and HRVs.

Section 4 Research Approaches for Monetizing Potential RNC NEIs

Based on the literature reviewed, the evaluation team identified potential new RNC-related NEIs for the PAs to consider monetizing in the future through a combination of primary and targeted secondary research. The team also identified approaches for updating existing NEIs with new primary research. This section provides NEIs to consider for research, details how these NEIs could be monetized in a future study, and presents related considerations. While the information presented here is not a workplan, it can be used to guide the development of future research. This section covers the following:

- Potential NEIs identified in the literature review that should be considered for future research, including data collection methods specific to each category of NEIs (Section 4.1)
- Potential NEIs identified in the literature review that are not currently considered for future research but could be if there were programmatic or policy changes (Section 4.2)
- Additional methods and considerations for future research, including study methods and strategies, sample size considerations, sub-program considerations, data collection monitors and loggers, and cost considerations (Section 4.3)

To the extent possible, the team considered differences in potential NEIs or valuation approaches between the RNC market segments:

- SF
- MFLR
- MFHR
- PH offering, currently only multifamily
- R&A
- While currently not considered in this research, future research may consider differences in NEIs for market rate and low-income market segments.

4.1 New NEIs for Future Research

Table 7 in Section 3.2.2 included several potential new RNC NEIs, in addition to thermal comfort and noise reduction, that were identified in the literature review. The new NEIs not currently claimed by the PAs are listed below:

- Respiratory health
- General health & safety
- SBS
- Operations & maintenance
- CO poisoning
- Summer overheating / winter underheating
- Environmental benefits / reduced carbon emissions including embodied carbon
- Mental well-being
- Home price
- Productivity (remote work and home productivity)
- Excess mortality from air pollution
- Trips/falls

4.1.1 Consideration

Consideration: Of the existing and potential new NEIs identified in this study, the team suggests conducting research on the following NEIs associated with RNC: thermal comfort, summer overheating and winter underheating, noise, respiratory health and SBS, operations and maintenance, productivity, and avoided deaths due to air pollution. Table 23 summarizes potential data-collection technologies and their costs.

Research into these NEIs should start with a review of secondary literature that focuses specifically on these potential new NEIs. The review should be conducted prior to collecting any primary data. The evaluation team would expect such a review to identify any new literature about these NEIs published since this report. Because the literature review conducted for this study was general in scope, a more-targeted literature review might unearth relevant research that was not encountered as part of this study. It is possible that a more-targeted literature review could yield data that can be used to monetize one or more of the NEIs without collecting primary data, or confirm if primary data collection would be needed to monetize any of them. By starting with a targeted literature review, it may be possible to avoid conducting much, or any, primary research.

If primary data must be collected, some ways to mitigate the costs include selecting more-comprehensive loggers and leveraging upcoming site visits, such as those that are like to occur with the update to the 2019 RNC Baseline I / Compliance Study. If these efficiencies are to be captured, the targeted secondary research would need to occur before the on-site visits for the baseline update (Section 4.3).

4.1.1.1 Rationale and Data Collection Considerations for Potential New NEIs

Thermal comfort. Due to the amount of secondary literature and advances in the RNC market, the team suggests updating the thermal comfort NEI with new research conducted in the field and through occupant surveys to understand what, if any, differences between program and non-program participants exist. Direct measurements of average temperature, temperature fluctuations, and relative humidity in key living spaces would provide additional data for a contingent valuation approach and allow the team to triangulate a monetization for thermal comfort.

Summer overheating and winter underheating. Three of the studies reviewed discussed the potential for overheating or underheating in higher-efficiency homes, including those built to PH specifications. Potential for overheating in the summer can be due to airtight construction, high levels of insulation, and window placement that is optimized to capture solar gains.[63] In-field measurements intended to capture thermal comfort in a subset of PH homes might also reveal issues with over- and underheating that would need to be either remediated in the program design or discounted from the thermal comfort benefit.

Table 15 summarizes considerations for collecting data to monetize thermal comfort, summer overheating, and winter underheating NEIs. The data described in the table may also aid in understanding whether certain program types, such as PH, have increased thermal performance during extreme weather events and events such as power outages. However, monetizing these NEIs would likely require an additional building simulation component.

Table 15: Thermal Comfort Data Collection Methods

Data Collection Activity	Data Types Collected	Sub-Programs
Indoor monitoring	Time series measurement of temperature in primary living spaces; consideration of capturing data in multiple seasons to account for seasonal variation	SF, MFLR, MFHR, PH, R&A
Occupant survey	Occupant perception of temperature and comfort; consideration to administer multiple surveys to account for seasonal differences	SF, MFLR, MFHR, PH, R&A
Maintenance records	Reports of overheating and underheating, temperature complaints	MFHR, PH
Interviews or surveys with building or property managers	In-depth interviews or surveys for broad perspective on occupant comfort in the building	MFHR, PH

[63] Note that optimized solar gains are intended to capture heat in the winter but often require exterior shading strategies to limit solar gains in the summer.

Noise. Five studies measured or modelled noise in high-performance homes. Three of these studies had positive noise-related findings, while two did not find any differences in levels of noise between the efficient and standard homes. In addition to the mixed results, all five studies took place in Europe. Some anecdotal findings were included in studies that monitored IAQ regarding occupant complaints about noise, such as with ERV or HRVs.[64] Therefore, the team suggests in-field monitoring of indoor noise levels in program and non-program homes, given the program currently claims noise reduction and the additional evidence of a benefit. Differences in exposure to outdoor noise can be controlled for either through monitoring outdoor noise directly or through approximation methods, such as measuring the distance from major roads and highways as a proxy for noise levels, as in Bailescu et al. (2019). Table 16 details data collection methods to support new or updated monetization of noise reductions.

Table 16: Noise Reduction Data Collection Methods

Data Collection Activity	Data Types Collected	Sub-Programs
Indoor monitoring	Time series measurement of noise levels in primary living spaces	SF, MFLR, MFHR, PH, R&A
Occupant survey	Occupant perception of noise and disturbance	SF, MFLR, MFHR, PH, R&A
Maintenance records	Reports of noise complaints	MFHR, PH
Interviews or surveys with building or property managers	In-depth interviews or surveys for broad perspective on occupant comfort in the building	MFHR, PH

Respiratory health and SBS. Twenty-one articles, including nine literature reviews, addressed respiratory health and/or the indoor environmental factors that influence respiratory health. Overall, the literature suggests that energy-efficient new construction results in improved IEQ and better respiratory health outcomes, such as number of respiratory infections and instances of bronchitis, number of hospitalizations due to asthma, and number of asthma attacks. In addition, four studies discussed the impacts of high-performance homes on symptoms of SBS, with an even split of two negative findings and two positive findings. The positive findings were both for renovated buildings that used green building practices, while the two studies with negative results focused on high-efficiency and standard energy-efficient building in newly constructed homes. This has raised concerns in the literature that high-performance buildings could create IAQ issues that lead to SBS. The topic should be investigated further to examine potential positive effects on respiratory health and ensure the program does not create health problems (Table 17).

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[64] One consideration for primary research would be to understand whether any energy-efficiency measures are leading to increased levels of noise, and, if so, whether it has been or could be mitigated through design.

Table 17: Respiratory Health and SBS Data Collection Methods

Data Collection Activity	Data Types Collected	Sub-Programs
Indoor monitoring	Levels of VOCs, $PM_{2.5}$, NO_2. Air exchange rates and CO_2 levels	SF, MFLR, MFHR, PH, R&A
Biological sampling or visual inspection	Amount/severity of mold	SF, MFLR, MFHR, PH, R&A
Occupant survey	Self-report of respiratory health, SBS symptoms, Quality of Life indicators, productivity, and costs associated with treating or mitigating symptoms and healthcare outcomes	SF, MFLR, MFHR, PH, R&A
Maintenance records	Reports of mold	MFHR, PH

Operations and maintenance. There were three studies that discussed the impacts on building operations and maintenance costs for a higher-performance home or multifamily building. Overall, the studies suggested potential for reduced operational and maintenance costs and longer equipment life in higher-performance homes, including those built to PH specifications. Such reductions would lead to direct savings for the households that could be counted as a program benefit.

Table 18: Operations & Maintenance Data Collection Methods

Data Collection Activity	Data Types Collected	Sub-Programs
Occupant Survey	Self-report of home maintenance needs and costs	SF, MFLR, MFHR, PH, R&A
Maintenance Staff Survey	Self-report of building maintenance needs and costs: expected life of heating and cooling equipment, shell measures	MFHR, PH
Maintenance Records	Number, type, and cost of maintenance orders	MFHR, PH
Maintenance Records	Comparison of maintenance & operation costs from before to after renovation	R&A

Productivity. Researchers at the PNNL have extensively studied the relationship between building energy efficiency, IAQ, and occupant health and productivity. This work focuses on commercial spaces, particularly office buildings, but the team includes this study in light of the increasing prevalence of remote work brought about by technological innovations and the COVID-19 pandemic. As more employees work from home, indoor air and environmental quality in the home will become more vital to worker productivity. These factors may be improved by building high-performance homes. The team has already developed algorithms to monetize productivity in the low-income energy retrofit sector, and the information used in these algorithms could readily be used in combination with occupant survey data for the RNC program.

Table 19: Data Collection Methods on Productivity

Data Collection Activity	Data Types Collected	Sub-Programs
Occupant Survey	Self-report of productivity levels, interruptions to normal activities; saturation and frequency of working from home	SF, MFLR, MFHR, PH, R&A
Secondary Data Review	Leverage secondary data from office-based commercial studies	SF, MFLR, MFHR, PH, R&A

Avoided deaths due to air pollution. The link between air pollution, particularly $PM_{2.5}$, and premature or excess mortality is well-established, but researchers continue to work on distinguishing the influence of localized indoor pollution from ambient outdoor air pollution in a region. However, given the potential role that $PM_{2.5}$ has on premature death, the team suggests considering measuring indoor $PM_{2.5}$ as a part of the IAQ data collection efforts (Table 20).[65]

Table 20: Data Collection Methods on Excess Mortality Due to Air Pollution

Data Collection Activity	Data Types Collected	Sub-Programs
Indoor Monitoring	Indoor $PM_{2.5}$ levels	SF, MFLR, MFHR, PH, R&A
Access Secondary Outdoor Air Quality Data	Outdoor $PM_{2.5}$ concentrations (to control for different exposure levels at different locations)	SF, MFLR, MFHR, PH, R&A

[65] Premature death due to air pollution is distinct from air pollution's impact on asthma. While air pollution can exacerbate asthma symptoms, which could lead to an increase in risk of premature death, air pollution also increases the risk of other respiratory diseases that are more deadly (e.g. Chronic Obstructive Pulmonary Disease [COPD]), as well as the risk of heart attack, stroke, diabetes, cancer, lung disease and more. Asthma itself is associated with relatively low Years of Life Lost in the U.S. and likely has a small impact on premature death compared to the other health conditions that can be caused by air pollution.

4.1.2 Consideration

Consideration. The literature review identified the following new NEIs related to PH new construction: water savings, increased thermal performance during extreme weather events, increased lifetimes for mechanical equipment and building shell, carbon emission reductions from fossil fuel free construction, and reductions in fire risk. These NEIs were mentioned by market actors and others interviewed for the PH Assessment[66] study, but there was limited or no research available on them. The PAs may wish to consider examining some of these NEIs as part of the next RNC NEI evaluation that involves primary data collection.

4.1.2.1 Rationale and Data Collection Considerations for Additional Potential New NEIs from New Passive Homes

Water savings. Water savings may come directly from the design and placement of the water heating equipment, as well as from conservation measures, including low-flow shower heads or aerators. For example, PH design advocates for a centralized placement that reduces pipe lengths, with the aim of reducing long runs of hot water and associated cooling of the water. In addition to saving energy, this would effectively reduce the amount of water wasted because users would have less cooled water to discard before the hot water arrives. In order to assess the feasibility of pursuing a water savings NEI, the team could estimate a range of likely water savings values for program compared to non-program homes and determine if the potential benefit is large enough to justify pursuit. One option would be to review differences between program and baseline hot water pipe lengths.[67] If so, the team would collect water bills and survey residents from a statistically valid sample of both program and non-program new homes and compare water savings, adjusting for confounding factors, such as the size of the home and number of occupants. (It should be noted that water consumption is highly influenced by occupant behavior.)

Increased thermal performance during extreme weather events. Given the infrequent – though increasing – occurrence of extreme weather events, a thermal performance NEI would rely on direct temperature measurements and surveys and in-depth interviews with manufacturers, architects, engineers, maintenance personnel, and homeowners. This NEI could leverage the temperature monitoring taking place for thermal comfort and summer overheating NEIs. In addition, the research team could use climate data to time the monitoring during periods expected to see extreme weather based on historic patterns and climate change predictions. This information may be used in conjunction with building energy simulations to understand thermal performance in extreme weather conditions, including loss-of-power scenarios.

Increased lifetimes for mechanical equipment and building shell. Reduced heating and cooling loads that are associated with efficient construction, specifically PH levels of efficiency, may increase the lifetime of the mechanical equipment in the building due to less frequent use. Increased mechanical lifetimes, especially for heating and cooling equipment, reduce the frequency at which equipment replacements occur and save the occupant money. In addition, the durability of the building shell may increase due to reduced gaps and penetrations in the building

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[66] https://ma-eeac.org/wp-content/uploads/MA19R05_PassiveHouse_OverallReport_Final_2020.01.06.pdf

[67] For the SF, MFLR, and potentially R&A sub-programs, hot water pipe length is recorded for modeling purposes. This data is also estimated during the baseline on-site visits. For MFHR and PH projects, this would likely require a review of the plumbing schematics.

where bulk water and water vapor may enter and cause damage. (The reduced gaps and penetrations would be due to increased airtightness.) In addition, the increased levels of insulation associated with PH design and construction principles (i.e., continuous insulation and reduced or eliminated thermal bridging) aim to reduce or eliminate condensation layers that can form within the building assembly or on the interior walls and can also lead to potential future durability issues.

Carbon emission reductions from fossil-fuel-free construction. The PH Assessment included the following positive outcomes that result from PH construction: fossil-fuel-free equipment, material consideration (both health and embodied carbon), [68,69] and efficient building design. Once estimated, reductions in carbon emissions can be readily monetized using an agreed-upon carbon value. For example, a 2021 Avoided Energy Supply Component (AESC) study estimated the social price of one ton of carbon emissions to be $128.[70] Further research would allow the team to establish a predictable relationship between specific RNC interventions and carbon emission reductions by comparing energy consumption, prevalence of combustion appliances, and amount of embodied carbon between program and comparable non-program new homes. The team could draw on methods presented in a 2016 International Energy Agency (IEA) literature review of studies on embodied energy in existing buildings and new construction,[71] and on multiple studies on embodied carbon in buildings that have been published since.[72, 73, 74, 75]

Reductions in fire risk. Given the challenges associated with capturing rare occurrences within a population sample, such as house fires, reductions in fire risk have traditionally relied exclusively on secondary data.[76] Direct measurements and surveys cannot adequately measure the likelihood of fires in the course of a one-to-two-year study, particularly in new homes that were only built in the last decade. Existing research on what factors in the home tend to increase or suppress fire risks and data about typical measures and building materials in program and non-program homes can be leveraged to estimate whether the program is lowering fire risks for residents. Any specific fire safety-related requirements of the program may also be considered.

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[68] Some constructions materials can contribute to poor IAQ through processes such as off-gassing VOCs; however, there are often low-VOC alternatives or strategies to avoid use of certain materials.
[69] Industry actors noted that some emissions reductions due to reduced energy usage in high-efficiency construction can be offset through the use of high-embodied carbon materials.
[70] Synapse Energy Economics, Resource Insight, Les Deman Consulting, North Side Energy, Sustainable Energy Advantage. (2021). Avoided Energy Supply Components in New England: 2021 Report. Prepared for AESC 2021 Study Group. Retrieved from: https://www.synapse-energy.com/sites/default/files/AESC_2021_.pdf
[71] Chae, C. and Kim, S. (2016). Evaluation of Embodied Energy and $CO2_{eq}$ for Building Construction (Annex 57). International Energy Agency. Retrieved from: http://www.iea-ebc.org/Data/publications/EBC_Annex_57_ST2_Literature_Review.pdf
[72] Struhala, K.; Ostrý, M. Life-Cycle Assessment of a Rural Terraced House: A Struggle with Sustainability of Building Renovations. Energies 2021, 14, 2472. https://doi.org/10.3390/en14092472
[73] A. Koezjakov, D. Urge-Vorsatz, W. Crijns-Graus, M. van den Broek, The relationship between operational energy demand and embodied energy in Dutch residential buildings, Energy and Buildings, Volume 165, 2018, Pages 233-245, ISSN 0378-7788, https://doi.org/10.1016/j.enbuild.2018.01.036.
[74] C. Piccardo, A. Dodoo, L. Gustavsson, Retrofitting a building to PH level: A life cycle carbon balance, Energy and Buildings, Volume 223, 2020, 110-135, ISSN 0378-7788, https://doi.org/10.1016/j.enbuild.2020.110135.
[75] In addition to studies, the Northeast Home Energy Rating System Alliance (NEHERS), a training platform used by some of the HERs rater participants of the RNC Program, has conducted training presentations that explore the impact of embodied carbon in the built environment.
[76] Such as the Low-Income Multifamily Health- and Safety-Related NEIs Study (study number TXC50).

4.2 Potential NEIs Identified and Not Currently Considered for Future Research

At this time, the team is not presenting for consideration future research on the following categories of NEIs identified in the literature review and listed in Table 21: general health, well-being, and safety; home price premium; trips/falls; and CO poisoning. If programmatic changes or the available secondary data expands in future, the potential for monetization should be revisited. For example, if state policies direct PA programs to consider societal or environmental impacts to a greater degree before the next RNC NEI evaluation, this NEI category should be explored.

Table 21: Potential NEIs Not Currently Considered for Additional Research

NEI category	Summary
General health, well-being, and safety	While there was evidence for modest to moderate improvements in measures of general health, there is no clear pathway to monetize general health. Given the evidence for specific diseases with quantifiable healthcare costs, such as asthma, the team recommends a focus on individual health issues. This approach avoids potential double-counting with thermal comfort and noise, which can also impact general health. The evidence for improvements in mental health and well-being was less conclusive. The team does not recommend monetization due to the lack of evidence and for the same reasons as general health.
Home price premium	Given that a home price premium is predicated on many of the other NEIs outlined above, including the price premium would lead to double counting.
Trips/falls	One literature review that explored the health benefits of home performance identified that low-income, elderly occupants in newly renovated green buildings reported a 16% reduction in occupant falls. Given that the only study on the topic took place in a green renovation of a multifamily building for the elderly, which is not representative of the majority of the program population, the team does not recommend this NEI.
CO poisoning	Three of the studies reviewed, one of which was a literature review, discussed CO measurements. While all-electric new homes largely eliminate the risk of CO poisoning, there was not sufficient evidence that the average program home with combustion appliances would pose a lower risk than a standard non-program home, or that the difference between the program and baseline in all-electric homes is substantial enough to warrant monetization. However, if all-electric homes increase in saturation for the program relative to non-program homes, the PAs should also reconsider adding a CO poisoning NEI, especially for a dedicated all-electric track.

4.3 Additional Methods and Considerations for Researching Potential New NEIs

The additional data needed to monetize the potential new NEIs to consider (presented in Section 4.1) could be collected with in-home sensors and monitoring, alongside a standardized occupant survey that could cover multiple NEIs. Below, are simplified descriptions of the types of potential approaches, methodologies, and analysis that could be considered:

- Installing data collection loggers in both program and non-program homes to measure temperature and relative humidity. Loggers would record data points at a frequency sufficient enough to capture fluctuations that could indicate drafts or other indicators of thermal comfort/discomfort. Relative humidity data would measure a separate dimension of comfort and provide an indicator of homes with potential moisture issues.
- Installing IAQ loggers in program and non-program homes to measure key pollutants of concern for health outcomes, namely $PM_{2.5}$, formaldehyde, and NO_2. Ideally, these loggers would also measure CO_2, which can be used as an indicator of ventilation rates. Data analysis would control for proximity to major roads and highways as major pollution sources. Ideally, the research team would either access existing data on outdoor air pollution or take direct measurements and calculate the ratio of indoor-to-outdoor air pollution.
- Installing noise monitors in program and non-program homes to measure the level of noise infiltration from the outdoors, as well as noise generated by HVAC and other energy-efficient equipment and appliances installed as part of the program. Data analysis would control for proximity to major roads and highways as major sources of noise.
- Conducting an occupant survey with program and non-program residents to capture their metrics of comfort, noise, respiratory health (using validated measures, such as the Asthma Control Test), and SBS symptoms. The survey would be instrumental for monetizing operations and maintenance, for which occupants of SF homes might not have records readily available.
- For multifamily buildings, the team would access maintenance and tenant complaint records and conduct interviews or surveys with building managers in order to assess maintenance and operations costs and look for signs of noise, comfort, or IAQ complaints. This data collection effort would be in addition to the direct measurements outlined above.

Sample sizes. Research would aim to compile sample frames representative of the RNC program and of newly built homes not enrolled in the program, including a mix of low-rise (both SF and MFLR), MFHR, and R&A sub-programs. Within the program home sample pool, the team would seek to include passive, all-electric, and regular high-performance homes in proportion to their representation in the program.[77] The non-program or control group may be limited to a non-stratified simple random sample, particularly for MFHR due to the limited population and lack of

[77] Oversampling in newer initiatives, such as the PH offering and the upcoming all-electric pathway, may provide insights into the future direction of the program.

readily available data. As noted above, the update to the RNC baseline study presents a ready control group for the SF sector.

The team anticipates a minimum sample of 70 program and 70 non-program homes to ensure there is enough statistical power to detect statistically significant differences. However, sample size needs will vary by NEI and research method. Given the high precision and frequency of measurements, most IAQ and IEQ parameters may not require sample sizes above 50 homes to achieve sufficient statistical power; most existing literature reports only small case studies of ten or fewer homes. A study of green versus conventional low-income multifamily buildings in Massachusetts reported statistically significant results for both differences in work order quantity and IAQ/IEQ measurements using 18 green and 43 conventional buildings. If an NEI relies on survey and interview data alone, the team may wish to increase the sample sizes to account for the lower precision of these methods.

Research design. The research team would seek to conduct controlled and ideally matched pairs studies involving data collection from a statistically valid sample of RNC homes to compare with new code-compliant homes. In cases where matched pairs may not be achievable due to small sample pools (e.g., PH) or recruitment challenges (e.g., MFHR – "Special considerations for individual sub-programs," below), the team would develop regression models to better control for differences in demographics and housing characteristics between the two groups.

Special considerations for individual sub-programs. While most of the potential NEIs for consideration will apply to all four segments of the RNC program – Low-Rise, MFHR, PH, and Renovations & Additions – the different building types may require adaptations to the research methodologies and monetization approaches. The team expects that the NEIs may have different magnitudes across the sub-programs and should be considered according to sub-program, where possible, and across the RNC program. For example, summer overheating was primarily associated with multifamily PH construction in the literature, in large part due to the tightness of the buildings, combined with a larger number of occupants generating heat through cooking and other activities. As the share of PH construction increases within the RNC program, it may affect the magnitude of a potential overheating NEI. Other NEIs might only apply to homes with certain measures, like ERVs/HRVs or non-combustion stoves, which may differ in prevalence across sub-programs.

The different sub-programs will also present different research challenges for recruitment and data collection. While MFHR buildings may have better documentation for operations and maintenance costs than SF homes, they also present the challenge of a two-step recruitment effort: first to recruit landlords or building owners and second to recruit occupants of individual units after receiving permission to enter the premises or otherwise contact residents. Additionally, while the program will have client records, some MFHR clients will be developers that have since sold the building to a management company that would not be on record with the program. Identifying non-program homes for a control group also presents challenges and may require accessing databases, such as Dodge Data,[78] or city permitting records and then working to distinguish SF and MFLR from MFHR buildings. These methods may not work for identifying PH

[78] https://www.construction.com/

or R&A projects. An alternative recruitment method would involve contacting implementers and contractors who perform energy-efficient or PH construction to obtain records of their clients or referrals to interested property owners. This also presents an opportunity to learn if architecture firms or developers are already monitoring IAQ or IEQ in their energy-efficient buildings to measure and validate performance.

Data collection monitors and loggers. The evaluation team identified data monitoring devices and loggers for potential use with various IEQ and IAQ parameters (Table 22). The price per device ranges from $20-$650 depending on the number of IEQ parameters monitored and the method of storing or transmitting data. The evaluation team notes that the technology for these devices may advance between now and future primary research, so additional verification of loggers and monitors should be considered before selecting the equipment to be used for data collection.

Table 22: IEQ Monitoring Devices for Potential Use in Data Collection

Device Name	IEQ Parameters Measured	Price per Device
AWAIR Omni	Temperature, Relative Humidity, CO_2, TVOCs, $PM_{2.5}$, Noise Level (dBA), Light	$449
AWAIR Element	Temperature, Relative Humidity, CO_2, VOCs, $PM_{2.5}$	$149
HOBO MX1102A	Temperature, Relative Humidity, CO_2	$595
HOBO MX1104	Temperature, Relative Humidity, Light	$185
HOBO MX1104 w/ TEL-7001 add-on	Temperature, Relative Humidity, CO_2, Light	$650
EMSL Analytical[1]	Formaldehyde	$20/sensor + $150 laboratory fee
Assay Technology[1]	Formaldehyde, Other Aldehydes	$46.40/sensor (laboratory fee included)
Assay Technology[1]	NO_2	$53.40/sensor (laboratory fee included)

[1] Requires taking samples in-home and then sending them to the company's laboratory for analysis.

Cost-effective data collection considerations. The most cost-effective study would likely be to leverage a device like the AWAIR Omni, which is capable of monitoring and recording most, if not all, IEQ parameters of interest for the NEIs considered. Not only would this be less expensive than buying separate devices to collect disparate data, it would also reduce labor time for installing and extracting devices, and ultimately minimize data collection errors.

The update to the 2019 RNC Baseline I / Compliance Study that is proposed to begin in the summer of 2022 could present an opportunity to streamline data collection efforts and reduce research costs by collecting data for both the baseline and the NEI studies simultaneously, or be used as a source of non-program sample at a later date. This would provide the NEI research with specific energy-efficiency characteristics captured during the baseline assessment.

A

Appendix A Literature Review Summary

A.1 Comprehensive Summary of Literature Review

Table 23 is a comprehensive list of literature reviewed in this study. Brief summaries of these studies are presented in an accompanying spreadsheet.

Table 23: Summary of Literature Reviewed

Category	Journal / Publisher	Article Title	Authors	Home Type	Efficiency Standard
Baseline Studies	CARB & CEC	Ventilation And Indoor Air Quality In New Homes	F. J. Offerman et al. 2009	SF	N/A
Baseline Studies	LBNL	Ventilation and Indoor Air Quality in New California Homes with Gas Appliances and Mechanical Ventilation	Y. Kim et al. 2019	SF	N/A
Baseline Studies	NMR	2019 RNC Baseline / Compliance Study	NMR 2020	SF	N/A
Baseline Studies	IEPEC	Watch Your Next Step – Continuing Change in the Northwest New Homes Market	J. Boroski, T. Helvoigt, A. Teja, C. Frye 2015	SF	N/A
H&S, Home Price	IEPEC	Regional efficiency programme valuating energy and multiple benefits: a balance between bill and comfort and far beyond	D.Osso, S. Nösperger, M. Raynaud 2016	SF	EE Renovation
H&S, IEQ	Atmosphere	Greener and Leaner - Lower Energy and Water Consumption, and Reduced Work Orders, in Newly Constructed Boston Public Housing	M. Brod, J. Guillermo C. Laurent et al. 2020	MF	LEED Platinum
Home Price	ICF	ENERGY STAR New Homes and the Impact of Certification on Maryland Home Prices	M. Yuan and J. Cohen 2017	SF	ENERGY STAR
IAQ	Emerald	Indoor air-quality investigation in CSH and	G. McGill, L. O. Oyedele, G. Keefe 2015	SF	PH and CSH

Category	Journal / Publisher	Article Title	Authors	Home Type	Efficiency Standard
		passivhaus dwellings - A case study			
IAQ	PNNL	Energy and Health Nexus: Making The Case For Building Energy-efficiency Considerations Of Occupant Health And Productivity	N. Wang and J. A. Rotondo 2020	Office Buildings	High EE; WELL healthy building
IAQ	Int. J. Environ. Res. Public Health	Indoor Air Quality in Passivhaus Dwellings: A Literature Review	A. Moreno-Rangel, T. Sharpe, G. McGill, F. Musau 2020	Unspecified	PH
IAQ	RMI	Health Effects from Gas Stove Pollution	B. Seals and A. Krasner 2020	SF and MF	All Electric
IAQ	Int. J. Environ. Res. Public Health	Indoor Exposure to Selected Air Pollutants in the Home Environment: A Systematic Review	S. Vardoulakis et al. 2020	SF and MF	N/A
IAQ	Southwest Energy Efficiency Project	All-Electric New Homes & Buildings In Colorado	Southwest Energy Efficiency Project 2021	SF	All-Electric
IAQ	Building and Environment	Indoor air quality in passive and conventional new houses in Sweden	S. Langer, G. Beko, E. Bloom et al. 2015	SF	PH
IAQ	Building and Environment	Indoor air quality and comfort in seven newly built, energy-efficient houses in France	M. Derbez, B. Berthineau, V. Cochet et al. 2014	SF	High EE and PH
IAQ	Nature Research Scientific Reports	Radon concentration in conventional and new energy-efficient multi-story apartment houses – results of survey in four Russian cities	I. V. Yarmoshenko, A. D. Onishchenko, G. P. Malinovsky et al. 2020	HRMF	EE RNC
IAQ	Environment International	Chemical exposures in recently renovated low-income housing - Influence of building materials and occupant activities	R. E. Dodsona, J. O. Udeskya, M. D. Colton et al. 2017	MF	LEED; HERS tier II rating of 65
IAQ	Aerosol and Air Quality Research	Airborne Particulate Matter - An Investigation of Buildings with PH Technology in Hungary	K. Szirtesi, A. Angyal, Z. Szoboszlai et al. 2018	SF	PH

Category	Journal / Publisher	Article Title	Authors	Home Type	Efficiency Standard
IAQ, IEQ, H&S	Environ Sci Technol	Indoor Air Quality in Green Vs Conventional Multifamily Low-Income Housing	M. D. Colton et al. 2014	MF	Green Homes
IAQ, IEQ, H&S	Harvard TH Chan School of Public Health (Webinar)	Creating Evidence-based Healthy and Energy-Efficient Housing	G. Adamkiewicz and J. Spengler 2015	SF and MF	High EE
IAQ, IEQ, Respiratory Health, H&S	DOE EERE	Home Rx: The Health Benefits of Home Performance - A Review of the Current Evidence	J. Wilson et al. 2016	SF and MF	High EE
IAQ, IEQ, Thermal Comfort	Emerald	An investigation of indoor air quality, thermal comfort and SBS symptoms in UK energy-efficient homes	G. McGill, L. O. Oyedele, K. McAllister 2014	Row homes	High EE with MVHR
IAQ, Respiratory Health	Indoor Air	Ventilation rates and health: multidisciplinary review of the scientific literature	J. Sundell et al. 2010	SF (and office buildings)	High Ventilation
IAQ, Respiratory Health	Indoor Air	The IVAIRE project – a randomized controlled study of the impact of ventilation on indoor air quality and the respiratory symptoms of asthmatic children in SF homes	P. Lajoie et al. 2014	SF	High Ventilation
IAQ, Thermal Comfort	Building and Environment	Indoor air quality and occupant comfort in homes with deep versus conventional energy-efficiency renovations	E. M. Wells, M. Berges, M. Metcalf et al. 2015	SF	EE Renovations
IAQ, Thermal Comfort	Energy and Buildings	A performance comparison of passive and low-energy buildings	A. Mahdavi, E. Doppelbauer 2010	MF	PH and Low-Energy Homes
IAQ, Thermal Comfort	Int. J. Environ. Res. Public Health	IEQ in Mechanically Ventilated, Energy-Efficient Buildings vs. Conventional Buildings	P. Wallner, U. Munoz, P. Tappler et al. 2015	SF and MF	High EE

Category	Journal / Publisher	Article Title	Authors	Home Type	Efficiency Standard
IAQ, Thermal Comfort, H&S	Int. J. Environ. Res. Public Health	Health and Wellbeing of Occupants in Highly Energy Efficient Buildings - A Field Study	P. Wallner, P. Tappler, U. Munoz et al. 2017	SF and MF	Not Specified
IEQ	Renewable and Sustainable Energy Reviews	A state of art review on interactions between energy performance and indoor environment quality in PH buildings	Y. Wang, J. Kuckelkorn, F. Zhao, H. Spliethoff 2017	SF and MF	PH
IEQ, Respiratory Health	Science of the Total Environment	Investigation of different approaches to reduce allergens in asthmatic children's homes – The Breath of Fresh Air Project, Cornwall, United Kingdom	S. A. Eick, G. Richardson 2011	SF, Terraced, and MF	Mechanical Ventilation And Heat Recovery (MVHR) Systems Retrofit
IEQ, Respiratory Health	Environmental Health Perspectives	Respiratory and Allergic Health Effects of Dampness, Mold, and Dampness-Related Agents – A Review of the Epidemiologic Evidence	M. J. Mendell et al. 2010	Unspecified	No Mold/ Moisture
IEQ, Respiratory Health	Curr Allergy Asthma Rep	Indoor Water and Dampness and the Health Effects on Children: A Review	K. Kennedy & C. Grimes 2013	Unspecified	No Mold/ Moisture
Noise	CLIMA	Studies on acoustic comfort in a PH	C. Bailescu, T. Catalina, V. Iordache 2019	SF	PH
Respiratory Health	AJPH	Health Benefits of Green Public Housing - Associations With Asthma Morbidity and Building-Related Symptoms	M. D. Colton et al. 2015	MF	Green Homes
Respiratory Health	Environmental Health	Association of residential dampness and mold with respiratory tract infections and bronchitis: a meta-analysis	W. J. Fisk, E. A. Eliseeva, M. J. Mendell 2010	SF and MF	No Mold/ Moisture
Respiratory Health	Indoor Air	Health in occupants of energy-efficient new homes.	J. A. Leech, M. Raizenne, J. Gusdorf 2004	SF	High EE
Thermal Comfort	Building and Environment	Overheating investigation in UK social	S. Masoud, T. Sameni, M. Gaterell et al. 2015	MF	PH

Category	Journal / Publisher	Article Title	Authors	Home Type	Efficiency Standard
		housing flats built to the Passivhaus standard			
Thermal Comfort	Sustainability	Scottish PH - Insights into Environmental Conditions in Monitored PHs	J. Foster, T. Sharpe, A. Poston et al. 2016	Semi-detached	PH
Thermal Comfort	Building and Environment	Experiences from nine PHs in Sweden - Indoor thermal environment and energy use	P. Rohdin, A. Molin, B. Moshfegh 2014	Terraced	PH
Respiratory Health	International Journal of Epidemiology	Meta-analysis of the effects of indoor nitrogen dioxide and gas cooking on asthma and wheeze in children	W. Lin et al. 2013	N/A	All-Electric

A.2 Detail of Other Jurisdictions' NEIs

Table 24 presents detailed results of the team's review of other jurisdictions' NEIs, which included reviewing 14 public planning documents, TRMs, cost-effectiveness testing documents, and other public documents.

Table 24: Jurisdiction Scan of NEIs in other RNC Programs

Jurisdiction	Monetized RNC NEIs Used for Cost-Effectiveness	Summary of NEIs for Energy-Efficiency Programs	Source
New York[1]	No	Social cost of carbon	NEEP 2017;
Illinois	No	Water savings and greenhouse gas (GHG) adder for avoided electricity production. Ongoing research to quantify additional NEIs (economic impacts; societal and utility NEIs of income qualified programs; participant NEIs on selected income eligible and non-income eligible programs).	NEEP 2017; Guidehouse 2020; Illinois Stakeholder Advisory Group (SAG) 2020
New Hampshire[2]	No	The Primary Granite State Test incorporates low-income participant NEIs that include increased comfort, decreased noise, and health-related NEIs. The Secondary Granite State Test incorporates sector-level percentage adders for participant NEIs for the Residential (non-low-income) and C&I sectors. The adder is derived from a secondary research database, adjusted for New Hampshire-specific factors, such as economic factors, and matched to New Hampshire's programs and measures.	2021-2023 New Hampshire Statewide Energy Efficiency Plan
Connecticut	No	The Companies currently quantify and count several NEIs in the Total Resource Cost Test, including water, non-embedded emissions, and several participant	2020 Program Savings Document (PSD)

		NEIs for their income-eligible Home Energy Services (HES-IE) program (including comfort and noise).	
Washington DC	No	The DC Sustainable Energy Utility (SEU) Program uses a societal cost test (SCT) that includes a 5% adder for several NEIs, as well as a 15% adder for low-income solar and a $100 per short ton benefit for all avoided CO_2 emissions. The individual NEIs in the adder include comfort, noise reduction, aesthetics, health and safety, ease of selling/leasing home or building, improved occupant productivity, reduced work absences due to illness, ability to stay in home/avoided moves, and macroeconomic benefits.	DCSEU FY2019 Performance Benchmarks Report
Vermont	No	Vermont uses a SCT that includes a 15% NEI adder to the energy benefits in cost-effectiveness screening. In addition, water and O&M savings are directly quantified.	Brown, 2017 Efficiency Vermont, 2020 NEEP 2017;
Rhode Island	Yes	The RI cost-effectiveness test includes a number of NEIs, including NEIs for the RNC program. The RNC NEIs are based on the Massachusetts RNC NEIs.	2021-2023 Energy Efficiency Program Plan 2020 Rhode Island TRM
Maryland	No	The EmPOWER Maryland programs currently claim water savings benefits, an NEI of enhanced comfort for the Home Performance with ENERGY STAR and (HPwES), and limited income program installations of insulation or air sealing measures and early replacement HVAC systems. Comfort benefits are escalated annually for inflation. In addition, the SCT includes air emissions benefits.	Itron 2015 EmPOWER Energy Efficiency Programs Strategic Evaluation Guidance Version 6 (2020)
Pennsylvania	No	The Pennsylvania PAs can include “reasonably quantifiable” fossil fuel (natural gas) and water benefits in the TRC test for cost-effectiveness.	2021 TRC Test Order
Delaware	No	The Delaware Energy Efficiency Advisory Council approved a limited number of NEIs for low-income weatherization programs, non-low-income HPwES programs, water savings, and avoided air emissions.	Delaware Energy Efficiency Advisory Council Meeting Approved DE EEAC NEIs

[1] NY has supported NEI research, including research of RNC NEIs, but has not used the quantified results in cost-effectiveness testing (see, for example, Malmgren and Skumatz 2014, Fuchs et. al., 2004, Summit Blue & Quantec 2006.

[2] The NH NEI database that is the basis for the NEI adder in the Secondary Granite Test includes RNC-specific NEI values that were derived from a 2006 study of NYSERDA’s ENERGY STAR Homes program (Summit Blue & Quantec 2006).

A.3 MARYLAND ENERGY STAR NEW HOMES PRICE PREMIUM RESEARCH AND NEIS

Maryland ENERGY STAR price premium study background. The evaluation team reviewed a 2017 study that explored the impact of the ENERGY STAR homes certification program on new home sale prices in Maryland.[79] The study looked at newly constructed homes and compared the sale prices of ENERGY STAR certified and non-ENERGY STAR certified homes to determine whether there was evidence of a price premium for homes that went through the ENERGY STAR New Homes programs in Maryland.[80] At the date the study was published, the Maryland ENERGY STAR New Homes programs had incentivized more than 21,000 homes since it began in 2009.

The Maryland price premium study evaluated home prices and sales for over 2,700 ENERGY STAR certified homes and over 13,000 non-certified homes that were sold between 2010 and 2016. The Maryland price premium study developed a regression model to isolate impacts of ENERGY STAR certification on the home value, taking into account other home characteristics, such as location, home type, and year built. In addition to price differences, the study found that ENERGY STAR certified homes had fewer days on the market before selling compared to non-ENERGY STAR certified homes.

Maryland price premium study results. The results of the study estimated that ENERGY STAR certified homes sold at a price premium between 2.1% and 5.2% from 2011 to 2016. Table 25 displays the estimated price premium for ENERGY STAR certified homes in Maryland for 2012 through 2016.

Table 25: Maryland ENERGY STAR New Homes Price Premium Results

Year	Price Premium
2012	$ 24,953
2013	$ 15,645
2014	$ 12,978
2015	$ 10,077

Rationale for using the Maryland price premium study as a benchmark for updates to existing and additional monetization of NEI values. The Maryland price premium study was one study that attempted to monetize the NEIs of an energy-efficient RNC program since the last RNC NEI study conducted in Massachusetts (in 2011). Overall, there was a lack of RNC NEI research and evaluations specific to RNC energy-efficiency programs, which limited the ability to leverage secondary literature to monetize NEIs.

79 https://www.icf.com/-/media/files/icf/white-paper/2017/energy-energy-star-new-homes-impact-certification-on-maryland-home-prices_web.pdf

80 Maryland's ENERGY STAR New Homes Program encompasses the new homes programs for BGE, SMECO, Delmarva Power, Pepco, and Potomac Edison.

Approach and monetization of RNC NEI values using the Maryland price premium study results. The evaluation team applied an analytical approach to triangulate a monetized NEI value to use as a benchmark for the Massachusetts RNC programs. Table 26 provides the inputs and the sources used in the quantification analysis.

Note that there are inherent limitations with this approach, including the geographic location of the study, the timeframe, the differing baselines, and the difference in RNC programmatic requirements.

Table 26: Approach to Monetize NEIs using Maryland Price Premium Study Results

Variable	Description	Input	Source
a	Annual kWh savings per home	1,719	Maryland price premium study
b	Average annual electricity consumption per home (in kWh) in Mid-Atlantic states	8,465	2015 RECS[1]
c	Average percent energy savings per ENERGY STAR home	20.31%	**b / c**
d	Average annual energy expenditures per home in Mid-Atlantic states	$2,169	2015 RECS[2]
e	Average energy cost savings per ENERGY STAR home	$441	**c * d**
f	Average price premium of ENERGY STAR new home (2012-2015)	$15,913	Maryland price premium study
g	Measure life	25	Massachusetts TRM[3]
h	Annualized price premium per ENERGY STAR home	$637	**f / g**
j	Annualized price premium per ENERGY STAR home net of energy savings (January 2014)	$196	**h – e**
k	May 2021 value of annualized price premium per ENERGY STAR home net of energy savings	$226	Inflation adjustment[4]
l	Lifetime price premium per ENERGY STAR home net of energy savings	$5,650	**k * g**

[1] https://www.eia.gov/consumption/residential/data/2015/c&e/pdf/ce2.2.pdf
[2] https://www.eia.gov/consumption/residential/data/2015/c&e/pdf/ce1.2.pdf
[3] Measure life is based on the HVAC effective useful life (EUL) described in Section 1.60 Whole Home - New Construction of the MA TRM https://fileservice.eea.comacloud.net/FileService.Api/file/FileRoom/12190505
[4] Adjusted for inflation from the midpoint of the study (January 2014) to May 2021 using the BLS CPI inflation calculator https://www.bls.gov/data/inflation_calculator.htm

A.4 OTHER MONETIZED NEIS IN THE SECONDARY LITERATURE

The team identified two other studies that monetized NEIs, but one study focused on the retrofit market and one focused on commercial office buildings. Outside of potential methodological guidance for future NEI monetization efforts, the information in these studies were not particularly useful for monetization of NEIs for the RNC program.

In 2016, D.Osso, S.Nösperger, and M.Raynaud evaluated a French energy-efficiency retrofit program that focused on replacing electric space heating with wood stoves and offered incentives for additional energy-saving measures. They calculated a thermal comfort NEI of €110 annually or €1,100 over the lifetime of the equipment (approximately $122 USD and $1,221 USD, respectively, in 2015); €103 ($114 USD) for reduced medical costs over the lifetime of the equipment; and €3,489 ($3,873 USD) for a *Green Value*, which is conceptually similar to the price premium found for ENERGY STAR homes in Maryland, although the study did not indicate whether the green value was exclusive of all other NEIs. The researchers also calculated utility and societal benefits of electricity not produced at €24 per household[81] and avoided carbon emissions at €649 per household ($27 USD and $720 USD, respectively).

A.5 HISTORIC RNC PROGRAM PERFORMANCE ADJUSTMENT

The team also explored adjusting the thermal comfort and noise reduction RNC NEI values based on the historic performance of the RNC program relative to the energy savings achieved. The theory behind this approach is from the 2011 RNC NEI study, which found that increased energy savings was a likely indicator of increased NEIs.

The team compiled savings data from 2010 to 2020 using the Mass Save data portal.[82] The team converted both the electric and gas savings to MMBtus to provide a common metric. The team calculated the MMBtu savings on a per-participant basis (Table 27).

[81] This is a lifetime benefit and is estimated using wholesale electric prices.
[82] https://www.masssavedata.com/Public/PerformanceDetails

Table 27: Total Per-Participant Annual Savings (in MMBtu/year)

Year	Total Participants (Electric and Gas Combined)[1]	Total MMBtu Savings (Electric and Gas Combined)	Total MMBtu per Participant
2010	3,517	45,015	12.80
2011	3,203	50,827	15.87
2012	4,807	63,734	13.26
2013	6,971	132,864	19.06
2014	10,531	141,049	13.39
2015	9,278	164,306	17.71
2016	13,705	150,785	11.00
2017	15,210	196,864	12.94
2018	11,883	214,133	18.02
2019	16,763	132,727	7.92
2020	14,046	150,657	10.73

[1] It was unclear in the data whether the participant count for electric and gas participants only included unique participants only or if there was overlap in the gas and electric participant counts. The team assumed an aggregated electric and gas participant count.

The team calculated weighted three-year averages of per-home MMBtu savings for 2010-2012 (13.84 MMBtu) and 2018-2020 (11.65 MMBtu) to reduce the impacts of variation from a specific program year. The team developed an adjustment factor of 0.84 by dividing the 2018-2020 per-home savings average by the 2010-2012 per-home savings average. The team applied this savings-based adjustment factor to the current RNC NEI values, resulting in an adjusted value of $98 (Table 28). There are inherent limitations to this approach and *therefore it is not recommended for usage*. These limitations include the following:

- Mass Save data reports evaluated net savings rather than gross savings.
- Savings are aggregated for the RNC program and are not separated by building or sub-program (i.e., SF vs. MFLR vs. MFHR unit types).
- The later program years include savings from the R&A program.
- There is uncertainty with the unique participant count and whether there is overlap considered in both the electric and gas participant counts. Calculating the adjustment factor using electric-only participant counts, assuming all homes in the program had to have at least some electric, would change the adjustment factor to 0.68.

Table 28: Program Performance Savings Adjustment Method (Not Recommended)

Approach	2010-2012 Weighted Average MMBtu	2018-2020 Weighted Average MMBtu	Adjustment Factor	Adjusted NEI Value
Program performance savings adjustment	13.84	11.65	0.84	**$98**

Appendix B Supplemental Algorithms

If the RNC program provides an all-electric program pathway in the future, and program participants only install ERV or HRV mechanical ventilation systems – a likely result from building to PH levels of efficiency – the monetization approaches for the new NEI values proposed in Section 3 would need to change. As noted in Section 3.4, as changes occur within the program or baseline, the NEI monetization approach can be updated. This section describes the changes that would be needed.

Please note that the only variables that differ between the equations below and those in Section 3.4.2 and Section 3.4.3 are that the percent of program homes with combustion stoves and of program homes without ERV/HRV each drop to 0%. This change is shown in boldface below.

Table 29 summarizes the impact of the potential program changes or potential changes in program homes on the monetization of the new health-related NEIs.

Table 29: Summary of Impacts on NEIs from Potential Program Changes

NEI	Value Suggested
Childhood asthma prevention, occupant lifetime	$8.00 per all-electric home per year
Adult asthma symptom reduction	$27.36 per all-electric home per year
Childhood asthma symptom reduction	$5.13 per all-electric home per year
Reduced Asthma ED visits	$0.33 per ERV/HRV home per year
Total	**$40.81 total adjusted value**

B.1 All-Electric Home Adjustments

The algorithms presented below show a program participant mix with no combustion stove tops.

Due to limitations of the secondary data, these monetized NEI values are based only on the removal of combustion stoves. They do not consider the additional impact on health outcomes that may result from reductions in concentrations of NO_2 and other byproducts, such as increased levels of $PM_{2.5}$ from also removing combustion heating and water heating equipment.

Table 30: All Electric Stove – Childhood Asthma Prevention, Annualized Occupant Lifetime Benefit

Input		Value	Source
a	MA average lifespan	80	CDC[1]
b	Number of years as a child	18	Constant
c	Average age of asthma onset	5	MA Department of Public Health[2]
d	Number of years with childhood asthma	13	b – c
e	Number of years with adult asthma	62	a – b
f	Childhood asthma prevalence rate, MA	12.9%	Massachusetts Government Asthma Statistics[3]
g	Adulthood asthma prevalence rate, MA	10.2%	
h	Percent reduction in asthma from childhood to adulthood	21%	(f - g) / g
i	Incremental annual medical cost associated with childhood asthma, adj. for MA (2019 $)	$2,139	Nurmagambetov et al.
j	Incremental annual medical cost associated with adult asthma, adj. for MA (2019 $)	$4,022	Ibid.
k	OOP medical costs	11%	MEPS
l	Incremental annual cost associated with missed days of school, adj. for MA (2019 $)	$252	Nurmagambetov et al.
m	Incremental annual cost associated with missed days of work, adj. for MA (2019 $)	$266	Ibid.
n	OOP incremental costs - childhood	$6,235	**d** * (**i** * **k** + **l**)
o	OOP incremental costs - adulthood	$34,014	(1 - h) * (e * (j * k + m)
p	Increased risk of Asthma due to gas combustion stove	1.36	Lin et al.[4]

Input		Value	Source
q	MA incidence of asthma, ages 0-18	43,329	Global Health Data Exchange[5]
r	MA asthma eligible population, ages 0-18	1,200,119	Massachusetts under 18 population, U.S. Census[6] * (1 – f)
s	MA asthma incidence rate, ages 0-18	3.6%	q / r
t	Estimated asthma incidence rate, gas stoves	4.9%	p * s
u	Estimated asthma incidence rate of children based on gas stove rate, annual	58,927	r * t
v	Estimated increase in asthma incidence due to gas stoves	26.5%	(u – q) / u
w	MA average number of children per home	0.52	Extrapolated from MA-specific U.S. Census population and occupied housing data
x	Percent of non-program homes with combustion ranges	84%	2019 Massachusetts Baseline Study[7]
y	**Percent of program homes with combustion ranges**	**0%**	**All-electric stove assumption**
z	Percent reduction in homes with combustion ranges	100%	(x – y) / x
AA	RNC program home measure life	25 years	MA TRM[8]
NEI Value			
AB	Value of avoided all-setting healthcare costs of asthma due to prevented cases of childhood asthma, MA, annualized lifetime benefit	**$8.00**	((n + o) * s * v * w * z) / AA

[1] Arias E, Bastian B, Xu JQ, Tejada-Vera B. U.S. state life tables, 2018. National Vital Statistics Reports; vol 70 no 1. Hyattsville, MD: National Center for Health Statistics. 2021. DOI: https://doi.org/10.15620/cdc:101128.
[2] Asthma Among Children in Massachusetts, Commonwealth of Massachusetts Department of Public Health, January 2017. Retrieved from https://www.mass.gov/doc/pediatric-asthma-data-bulletin-0/download
[3] https://www.mass.gov/service-details/statistics-about-asthma
[4] Lin W, Brunekreef B, Gehring U. Meta-analysis of the effects of indoor nitrogen dioxide and gas cooking on asthma and wheeze in children. Int J Epidemiol. 2013 Dec;42(6):1724-37. doi: 10.1093/ije/dyt150. Epub 2013 Aug 20. PMID: 23962958.
[5] http://ghdx.healthdata.org/gbd-results-tool
[6] https://www.census.gov/programs-surveys/acs
[7] NMR Group, 2019. Residential New Construction Baseline/Compliance Study (MA19X02-B-RNCBL), April 1, 2020.
[8] https://fileservice.eea.comacloud.net/FileService.Api/file/FileRoom/12190505

Table 31: All Electric Stove – Reduced Childhood Asthma Symptoms

Input		Value	Source
a	Increase in childhood asthma symptoms attributable to gas stoves	42%	Lin et al.[1]
b	Discount factor, ratio of healthcare costs to symptoms	80%	Evaluation team estimate[2]
c	Incremental annual medical cost associated with childhood asthma, adj. for MA (2019 $)	$2,139	Nurmagambetov et al.[3]
d	Estimated annual incremental medical cost with exposure to gas stove in home, MA (2019 $)	$3,038	c * (1 + a)
e	OOP medical costs	11%	MEPS
f	Estimated OOP cost associated with exposure to gas stove	$96	(d – c) * e
g	MA childhood current asthma rate	12.9%	Massachusetts Government Asthma Statistics[4]
h	MA average number of children under 18 per home	0.52	Massachusetts under 18 population in occupied homes, U.S. Census[5]
i	Percent of non-program homes with combustion ranges	84%	2019 Massachusetts Baseline Study[5]
j	**Percent of program homes with combustion ranges**	**0%**	**All-electric stove assumption**
k	Percent reduction in homes with combustion ranges	100%	(i – j) / i
NEI Value			
n	Value of avoided all-setting healthcare costs of adult asthma due to reduced symptoms, MA, annual	**$5.13**	b * f * g * h * k

[1] Lin, W., Brunekreef, B., Gehring, U. (2013). Meta-analysis of the effects of indoor nitrogen dioxide and gas cooking on asthma and wheeze in children. International Journal of Epidemiology, 42(6), 1724-1737.
[2] The evaluation team applied a discount factor to the NEI. The team assumed that reductions in symptoms do not translate to an equivalent reductions in medical costs. The reviewed studies did not include data on the relationship between changes in symptoms and changes in medical costs so the team applied the discount factor in order to take a conservative approach to the NEI estimate. The team suggests updating this discount factor if future literature reviews find studies documenting the relationship between changes in symptoms and changes in medical costs.
[3] Nurmagambetov, T., Kuwahara, R., & Garbe, P. (2018). The Economic Burden of Asthma in the United States, 2008-2013. Annals of the American Thoracic Society, 15(3), 348–356.
[4] https://www.mass.gov/service-details/statistics-about-asthma
[5] https://www.census.gov/programs-surveys/acs
[5] NMR Group, 2019. Residential New Construction Baseline/Compliance Study (MA19X02-B-RNCBL), April 1, 2020.

Table 32: All Electric Stove – Reduced Adult Asthma Symptoms

Input		Value	Source
a	Increase in childhood asthma symptoms attributable to gas stoves	42%	Lin et al.[1]
b	Adjustment factor, ratio of healthcare costs to symptoms (adults less sensitive to combustion byproducts than children)	70%	Evaluation team estimate[2]
c	Incremental annual medical cost associated with adult asthma, adj. for MA (2019 $)	$4,022	Nurmagambetov et al.[3]
d	Estimated annual incremental medical cost with exposure to gas stove in home, MA (2019 $)	$5,712	c * (1 + a)
e	OOP medical costs	11%	MEPS
f	Estimated OOP cost associated with exposure to gas stove	$180	(d – c) * e
g	MA adult current asthma rate	10.2%	Massachusetts Government Asthma Statistics[4]
h	MA average number of adults per home	2.1	Massachusetts over 18 population in occupied homes, U.S. Census
i	Percent of non-program homes with combustion ranges	84%	2019 Massachusetts Baseline Study[5]
j	**Percent of program homes with combustion ranges**	**0%**	**All-electric stove assumption**
k	Percent reduction in homes with combustion ranges	100%	(i – j) / i
NEI Value			
l	Value of avoided all-setting healthcare costs of adult asthma due to reduced symptoms, MA, annual	**$27.36**	b * f * g * h * k

[1] Lin, W., Brunekreef, B., Gehring, U. (2013). Meta-analysis of the effects of indoor nitrogen dioxide and gas cooking on asthma and wheeze in children. International Journal of Epidemiology, 42(6), 1724-1737.

[2] The evaluation team applied a discount factor to the NEI. The team assumed that reductions in symptoms do not translate to an equivalent reductions in medical costs. The reviewed studies did not include data on the relationship between changes in symptoms and changes in medical costs so the team applied the discount factor in order to take a conservative approach to the NEI estimate. The team applied an additional discount to adults as evidence suggested they are less sensitive than children (see Seals, B. and Krasner, A. (2020)). The team suggests updating this discount factor if future literature reviews find studies documenting the relationship between changes in symptoms and changes in medical costs.

[3] Nurmagambetov, T., Kuwahara, R., & Garbe, P. (2018). The Economic Burden of Asthma in the United States, 2008-2013. Annals of the American Thoracic Society, 15(3), 348–356.

[4] https://www.mass.gov/service-details/statistics-about-asthma

[5] NMR Group, (2019). Residential New Construction Baseline/Compliance Study (MA19X02-B-RNCBL), April 1, 2020.

B.2 All ERV and HRV Adjustments

Table 33 corresponds with Section 3.4.4, but has been adjusted to reflect a program offering that requires ERV or HRV systems, as would be expected from program participants that build exclusively to or near passive-house levels of efficiency.

Table 33: All Program Homes with ERV or HRV

Input		Value	Source
a	Average annual ED visits per person with at least one asthma related visit	1.4	MEPS[1]
b	Adjustment factor for higher ED rates among children than adults	2	CDC[2]
c	Reduction in children with >=1 ED visits following a 50% reduction in formaldehyde	16%	Lajoie et al.[3]
d	Baseline rate of >=1 ED visits for asthmatic children in the study	76%	Ibid.
e	Baseline rate of >=1 ED visits for asthmatic children in MA, general population	19%	MA Department of Public Health[4]
f	Estimated reduction in children with >=1 ED visits following a 50% reduction in formaldehyde, MA, general population	4%	**c** / **d** * **e**
g	Percent of homes that achieve a 50% reduction in formaldehyde with HRV	25.6%	Lajoie et al.[3]
h	MA cost for an asthma ED visit (2019 $)	$1,671	MA Department of Public Health[5]
j	OOP Costs	11%	MEPS
k	MA average number of children per home	0.52	Extrapolated from U.S. Census population and housing data
l	MA childhood current asthma	12.9%	Massachusetts Government Asthma Statistics[6]
m	Percent of non-program homes without HRV	85%	2019 Massachusetts Baseline Study[7]
n	Percent of program homes without HRV	0%	All ERV or HRV assumption
o	Percent reduction in homes without HRV	100%	(**m** – **n**) / **m**
NEI Value			
L	Value of avoided ED healthcare costs of childhood asthma due to reduced formaldehyde, MA, annual	**$0.33**	**a * b * f * g * h * j * k * l * o**

[1] Agency for Healthcare Research and Quality. Number of people with care and number of events in thousands by condition, United States, 2018. Medical Expenditure Panel Survey.
[2] Asthma Emergency Department (ED) Visits 2010-2018, Centers for Disease Control and Prevention, Last reviewed on April 9, 2021.
[3] Lajoie, P., Aubin, D., Gingras, V., Daigneault, P., Ducharme, F., Gauvin, D., Fugler, D., Leclerc, J.-M., Won, D., Courteau, M., Gingras, S., Héroux, M.-È., Yang, W., & Schleibinger, H. (2015). The IVAIRE project - a randomized controlled study of the impact of ventilation on indoor air quality and the respiratory symptoms of asthmatic children in SF homes. Indoor Air, 25(6), 582–597. https://doi.org/10.1111/ina.12181
[4] Asthma Among Children in Massachusetts, Commonwealth of Massachusetts Department of Public Health, January 2017. Retrieved from https://www.mass.gov/doc/pediatric-asthma-data-bulletin-0/download
[5] Asthma Among Children in Massachusetts, Commonwealth of Massachusetts Department of Public Health, January 2017. Retrieved from https://www.mass.gov/doc/pediatric-asthma-data-bulletin-0/download
[6] https://www.mass.gov/service-details/statistics-about-asthma
[7] NMR Group, 2019. Residential New Construction Baseline/Compliance Study (MA19X02-B-RNCBL), April 1, 2020.

Appendix C References

This Appendix lists the references to studies discussed in the main body of the report. See Appendix A for the summary of all the available literature that was reviewed during this evaluation.

C.1 Jurisdictional Scan References

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