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Cost Study of the Building Decarbonization Code

An analysis of the incremental first cost and life cycle cost of two common building types

April 2022

Codes for Climate™

Albany, New York

Acknowledgments

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PRIMARY NBI AUTHORS

Sean Denniston
Diana Burk
Erin Beddingfield
Kim Cheslak

CONTRIBUTORS

Sarah McDowell, Arup
Elizabeth Joyce, Arup
Lauren Urbanek, NRDC
Alejandra Mejia-Cunningham, NRDC

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Introduction and Background

New Buildings Institute's (NBI) Building Decarbonization Code is a groundbreaking tool aiming to deliver carbon neutral performance in new construction.[1] Designed to help jurisdictions mitigate carbon emissions from the built environment, the Building Decarbonization Code offers two paths to support the transition away from fossil fuel combustion in buildings: all-electric and mixed-fuel.

The efficiency gains in the International Code Council's (ICC) 2021 International Energy Conservation Code (IECC), and its subsequent publication spurring state and local code update conversations and processes created ideal circumstances to develop a "decarbonization overlay" to the model code.

This study analyzes the cost effectiveness of both the all-electric and mixed-fuel paths in the Building Decarbonization Code, as compared to a baseline of the 2021 IECC and ASHRAE 90.1-2019. Therefore, costs and savings reported in this study represent the marginal costs and savings between the Building Decarbonization Code paths and the 2021 IECC. The Decarbonization Code's path provides language to require all-electric buildings, while the mixed-fuel path requires that any fossil fuel end uses in buildings be future-proofed for future electric replacements through electric readiness, and requires greater energy efficiency to provide limited decarbonization. Both paths establish requirements for on-site renewable energy production and support both electric vehicle (EV) charging and energy storage. The Building Decarbonization Code also offers market insight into proposed rules that will determine how new buildings are designed and constructed in the future in order to reduce carbon emissions from the built environment and help avoid the worst impacts of climate change.

With each publication of the IECC, the U.S. Department of Energy (DOE) issues a determination of the expected energy and cost savings of the new version of the code compared with the previous version.[2] In order to provide the same information to jurisdictions considering adopting the Building Decarbonization Code language, NBI undertook this preliminary cost analysis. While this study looked only at a single-family home prototype and a medium office building prototype in Climate Zone 5A, we can use the same methodology and process, to look at additional building types, markets, and climate zones in support of jurisdictions considering adoption of decarbonization code provisions. It's our goal to expand this analysis to provide conclusive results for all U.S. markets.

The study examines the cost effectiveness of both the all-electric and mixed-fuel paths in the Building Decarbonization Code for Climate Zone 5A (a comparatively cold climate). New York State (a relatively expensive market) was selected in order to provide conservative estimates of expected costs and savings. The analysis includes first costs for both medium office and single-family prototype buildings and life cycle cost analysis (LCCA) for the single-family prototype.

While this study looked only at the single-family home and medium office building prototypes in Climate Zone 5A... it's our goal to expand this analysis to provide conclusive results for all U.S. markets.

1 New Buildings Institute. "Building Decarbonization Code." August 26, 2021. Available at: https://newbuildings.org/resource/building-decarbonization-code/

2 U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, Building Energy Codes Program. "Determinations." Available at: https://www.energycodes.gov/determinations

Summary and Key Findings

The study found that implementation of NBI's Decarbonization Code will lead to savings for homeowners, building owners, and society. Costs and savings related to the code provisions for typical buildings were studied for costs related to:

- First cost for single-family prototype buildings
- First cost for medium office prototype buildings,
- Life cycle cost for single-family prototype buildings.

Incremental First Cost

The incremental first cost examines the difference in expense relative to the IECC 2021 and ASHRAE 90.1-2019 baselines. Costs were estimated using multiple data sources including RS Means,[3] past project data, city cost indices, and local and national vendors. Estimates for infrastructure were calculated using standard engineering methods, and equipment costs were calculated on a per item basis.

1 The all-electric single-family home is $7,500-$8,200 cheaper to construct than the baseline code home.

- Avoided cost of installing fossil fuel infrastructure provides a substantial savings.
- Lower first costs are a critical component of the life cycle cost effectiveness of electrification. Financing a home intensifies the impact of the first cost savings as those avoided costs get translated into additional avoided financing costs such as a higher down payment and more mortgage interest paid.

2 The electric-ready single-family home has an incremental first cost of $1,000-$1,800.

- This cost is within reach of all new construction, equivalent to the expense of upgrading to an average stone kitchen countertop.
- Electric-ready construction saves the homeowner thousands of dollars compared to retrofitting to accommodate electric equipment replacements.[4] The cost of upgrading the main panel from 100A to 200A alone as a retrofit averages between $1,500 and $4,000, not including the cost of adding new electrical circuits to serve new electric equipment.[5]

3 RSMeans data from Gordian. Accessed November 2021. https://www.rsmeans.com/

4 Woody, Todd. Climate-Proofing Your Home: How to Electrify. Bloomberg, 5 Jan. 2021, www.bloomberg.com/news/articles/2021-01-05/switching-to-electric-home-appliances-for-environmental-and-economic-benefits

5 According to Fixr.com, an online remodeling resource (https://www.fixr.com/costs/install-electrical-circuit-panel-upgrade - accessed February 2022).

Residental EV charging.

PAE Living Building | Portland, OR © PORTLANDRONE

3 The all-electric medium office has an incremental cost of $0.33-0.50/sf.[6]

- An overarching electrification strategy is key to the cost effectiveness of all-electric construction. Simply swapping fossil fuel combustion equipment with equivalent electric equipment one-for-one during design may not be the most cost-effective solution. Improving the cost effectiveness of electrification may require different design solutions.

4 The electric-ready medium office has an incremental cost of $1.03-1.20/sf.[7]

- The sizing of electric infrastructure is not granular. On-site transformers, service sizes, and other infrastructure components are available in standardized size increments, making the cost impact of electrification readiness dependent on how closely the infrastructure capacity corresponds to the planned loads.

5 The largest impact on office building electrification is the cost of EV charging infrastructure (EVCI) requirements.

- 90-97% of the cost increase for application of the Building Decarbonization Code to medium offices is attributable to the EVCI requirements.
- Retrofit costs for installing EV charging equipment after the building and parking spaces are constructed are 3-4 times the cost at new construction.[8]

6 Without EVCI

7 Without EVCI

8 McEwen, Brendan, et al. Electric Vehicle Charging Infrastructure Costing Study. Clean Air Partnership, 13 Oct. 2021

Overall, electrifying new construction is far more cost effective than implementing electrification readiness. Still, electrification readiness will reduce lifecycle costs for a typical mixed-fuel building by future-proofing electrification retrofit costs as on-site fossil fuels are phased out. Adopting jurisdictions should weigh the political costs with the slight increase in construction costs when selecting between the all-electric and mixed-fuel paths of the Building Decarbonization Code.

Multi-story commercial new construction.

Figure 1: Summary of Incremental First Costs and Savings

Life Cycle Cost Analysis

Single-family new construction.

The life cycle cost analysis (LCCA) for the single-family prototype examines how energy savings and first costs or savings would impact homeowners' direct costs and the environment and economy broadly through societal cost impacts including societal cost of carbon. The decarbonization scenarios were analyzed with four utility rate schedules: typical-cost and high-cost versions of both fixed rates and time-of-use (TOU) rates.

1 The all-electric scenario reduced total energy consumption by 34%, while the mixed-fuel scenario reduced energy consumption by 9% compared to baseline.

- Heating alone accounts for approximately half the prototype home's energy use.
- Code-compliant heat pumps deliver significant space heating savings over very high-efficiency condensing furnaces, even in Climate Zone 5A.
- The reduction in energy use for the mixed-fuel prototype is due to the improved efficiency of the combustion equipment (replacing the code compliant 80% efficient furnace with a 96% efficient condensing furnace).

2 The carbon emissions impact of building electrification is six times that of the electric-ready scenarios.

- Electrification of the single family home saves 126.2 metric tons of carbon dioxide equivalent (Co2e).
- Application of the mixed-fuel scenario saves 20.05 metric tons of C02e
- To put this in perspective, the average passenger car has emissions of 4.6 metric tons/year

3 The single-family prototype shows savings between $850-$16,200 in all cases except for the all-electric scenario using fixed rate utilities in the high-cost scenario.

- Utility rates and schedules are a driving factor for life cycle cost effectiveness of the all-electric scenario.
- The all-electric home prototype uses less energy. However, it can still result in higher utility bills due to the cost of electricity compared to gas.
- Encouraging electrification would be aided by the expansion of the availability of time-of-use rates

4 **When a societal cost is attributed to carbon emissions, the results show life cycle cost savings in all scenarios.**

- Carbon emissions savings of 20-126 metric tons of CO2e.
- A savings of $5,600-$24,000 is produced from the mixed-fuel or all-electric provisions respectively.[9]

5 **Electrification readiness reduces life cycle costs for a typical mixed-fuel building by future-proofing against electrification retrofit costs as on-site fossil fuels are phased out.**

- Mixed-fuel homes built to the code baseline will face retrofit costs within the first 30-year mortgage associated with the electrification of fossil fuel loads (such as space and water heating and cooking), the addition of EVCI and renewable energy systems, and potential electrical capacity upgrades.
- These retrofit costs were not included in this life cycle cost analysis (LCCA); however, they can be substantial and would improve the life cycle cost effectiveness of both the all-electric and mixed-fuel scenarios.

6 **The life cycle cost analysis includes the first cost for EV charging infrastructure, but does not include the ongoing cost savings that generally result from EV ownership.**

- Lower fuel and maintenance costs will increase the life cycle savings of EVCI in single-family homes.
- Lower societal cost of carbon from EV ownership would likely improve the life cycle cost savings substantially.

The all-electric decarbonization scenarios yielded the highest net present value (NPV) life cycle cost savings for the homeowner and societal perspective for households with TOU utility rates and typical fixed rates. Societal NPV life cycle cost savings were still positive but lower for households under high-cost fixed rates. Consumers experiencing high-cost fixed rates could experience higher costs than the baseline scenario. Policymakers should consider ways to reduce the impact of these higher costs on households with higher energy burden.

The mixed-fuel decarbonization scenario yielded positive NPV life cycle cost savings for both the homeowner and societal perspective across all utility rate structures. However, both household and societal costs are less under the TOU and typical utility rate structures than they would under the all-electric scenario.

Still, electrifying during new construction is more cost effective than implementing electrification readiness, and notably it is significantly more cost-effective than retrofitting for electrification.

9 Using the Biden administration's social cost of carbon https://www.whitehouse.gov/wp-content/uploads/2021/02/TechnicalSupportDocument_SocialCostofCarbonMethaneNitrousOxide.pdf

Table 1: Summary of Life Cycle Costs, Single-Family Home Prototype

Scenario		Annual Total NPV Cost Impact ((Savings	NPV Life Cycle Cost (Savings) – Homeowner Perspective	NPV Life Cycle Cost (Savings) – Including societal cost of Carbon
Typical Cost TOU-Rates	Mixed-Fuel	$(68)	($870)	($5,665)
	All-Electric	$(290)	($9,451)	($23,927)
Typical Cost-Fixed Rates	Mixed-Fuel	$(62)	($850)	($5,641)
	All-Electric	$7.05	($3,779)	($17,206)
High Cost TOU-Rates	Mixed-Fuel	$(190)	($3,475)	($8,773)
	All-Electric	$(603)	($16,287)	($32,130)
High Cost Fixed Rates	Mixed-Fuel	$(182)	($3,330)	($8,602)
	All-Electric	$538	$5,531	($6,277)

Albany, New York

Recommendations

Based on the positive cost savings findings both through incremental costs and life cycle costs detailed in this study, of this study, NBI recommends the following:

- All jurisdictions in Climate Zone 5A with utility costs in the ranges presented in this study adopt all-electric single-family home provisions for new commercial construction, with the inclusion of EVCI requirements. There are currently 21 U.S. states with cities and counties in Climate Zone 5A.
- All jurisdictions in Climate Zone 5A adopt all-electric provisions for new construction, strongly considering the inclusion of EVCI requirements to mitigate future costs of electrifying the transportation sector.
- Similar cost effectiveness studies be applied to additional climate zones and building types to analyze the potential savings of these code provisions (a planned future phase of this analysis).
- All jurisdictions considering electrification provisions expand the availability of time of use rates to aid the affordability of electrification.

Because of the factors used in this study, costs in the scenarios analyzed are likely on the high end of an expected range. The favorable cost savings found in these market scenarios support the case for implementation of electrification across more temperate climate zones and less expensive utility markets. Pending additional results, NBI would therefore additionally recommend consideration of electrification requirements in all jurisdictions with climates similar to or warmer than 5A and utility costs in the range presented in this study.

How to Use this Report

This cost study is structured to provide value to both policymakers and researchers by gathering and presenting information in a way that makes the content more useful and accessible to both audiences. The following report is structured in four parts:

1. **Summary and Key Findings** summarizes the first cost and life cycle cost results and offers some key findings from the study. These focus on key information for policymakers.
2. **Methodology** details the methodology used in the study, including process, assumptions, variables and parameters, and analysis tools.
3. **First Costs Results** includes the full results for the medium office and single-family scenarios for the first cost portion of the analysis, and includes a measure-by-measure breakdown of costs.
4. **Life Cycle Cost** includes the detailed LCCA results for all scenarios from both a homeowner and societal perspective.

More detailed first cost breakdowns, including material costs and labor costs, are included in *Appendix A: Detailed First Costs.*

Glossary of Key Terms

All-Electric Decarbonization Scenario: An all-electric prototype based on the baseline code scenario that has been modified to meet the requirements of the all-electric path of the Building Decarbonization Code.

Baseline Code Scenario: A mixed-fuel building prototype with features that meet code minimums, in the case of this analysis the code minimum is considered to be the 2021 International Energy Conservation Code (IECC). It is used as the basis for comparison to the decarbonization scenarios.

Electric Vehicle Charging Infrastructure (EVCI): The electrical infrastructure and chargers, also known as Electric Vehicle Supply Equipment (EVSE), required to support electric vehicle (EV) charging.

First Costs: For the purposes of this analysis, first cost is considered to be the hard cost of construction including materials and labor.

Fossil Fuel Infrastructure: The on-site piping and other equipment required to deliver fossil fuels to fossil fuel-fired appliances and equipment in the building. For the purposes of this study, it refers to gas infrastructure.

Incremental Cost: The differential between a costing scenario and a baseline code scenario.

Life Cycle Cost Analysis (LCCA): For the purposes of this study, an analysis of cost that includes the net present value of the costs of construction, financing, taxes, utilities, maintenance and includes residual value at the end of the analysis term.

Mixed-Fuel Decarbonization Scenario: A mixed-fuel prototype based on the baseline code scenario that has been modified to meet the requirements of the mixed-fuel path of the Building Decarbonization Code.

Residual value: The value of equipment that remains at the end of the LCCA period. For the purposes of this study, fossil fuel infrastructure is considered a stranded asset without residual value.

Methodology

The study uses two building prototypes—a single-family home and a medium office building—located in Climate Zone 5A. These two prototypes were chosen for this analysis in order to provide results for both residential and commercial construction, and because these building types are two of the most common construction types and are frequently used as benchmarks for measuring building policy impacts. Climate Zone 5A was selected because of its large geographic footprint, and as representative of a colder climate, providing insight into operational energy in a heating load-dominated application.

New York State was selected as a representative location for CZ 5A in this study because it represents a potentially less favorable scenario for electrification compared to other U.S. states. New York generally has higher expenses for first costs and utility costs when compared to national averages and provides a range of costs between urban and rural locations across the state. While not the absolute worst-case scenario for electrification, results from New York State provides results that are relevant for locations with more challenging markets and for milder climates and more affordable markets.

The LCCA completed and presented in this study includes two utility rate scenarios, typical-cost and high-cost, to frame the range of potential life cycle costs. The data for the typical-cost scenario was drawn from the Buffalo market to represent a midpoint between rural and metropolitan markets. The data for the high-cost scenario were drawn from the New York City market. This overall selection and application of parameters results in a methodology that is scalable and applicable to other climate zones and locations, which the authors plan to address in subsequent studies.

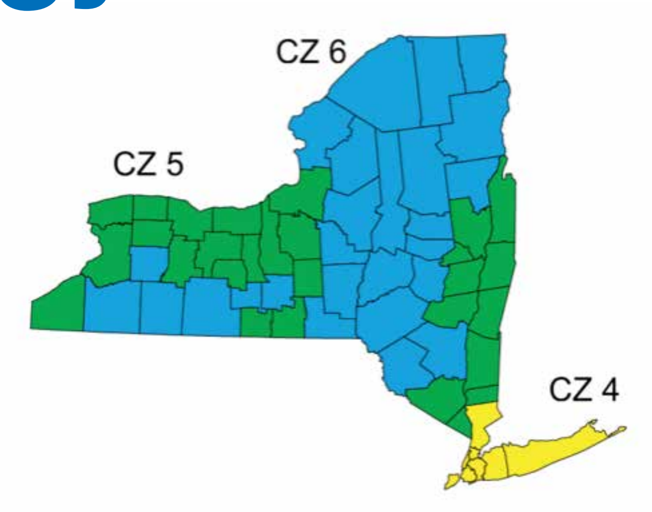
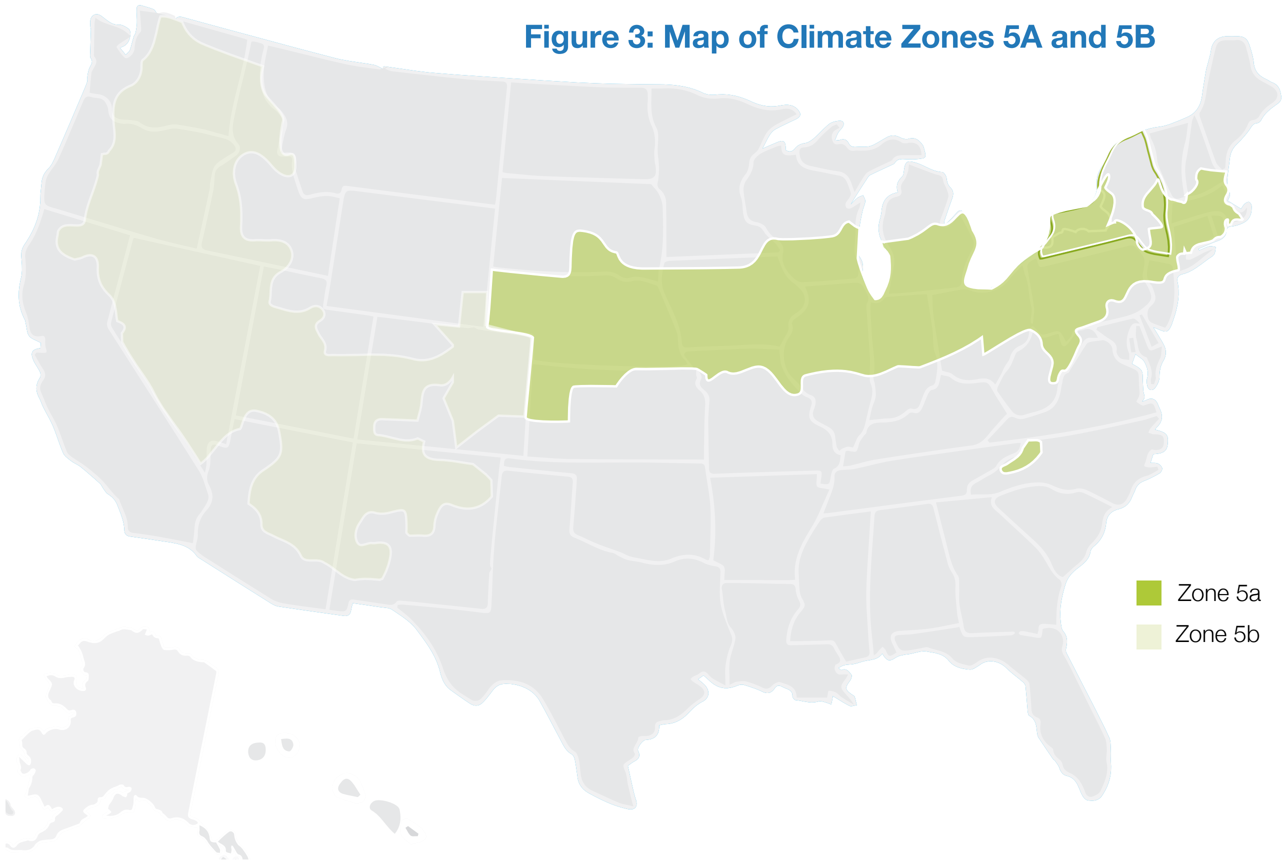


Figure 2: Climate Zones in New York State

(Source: Open Data NY)

Albany, New York

Figure 3: Map of Climate Zones 5A and 5B



Building Prototypes

The study uses prototype buildings developed by Pacific Northwest National Lab (PNNL) to evaluate the savings of updates to the model energy codes.[10] These prototypes specify building features and components including square footage and construction details, as described below. For this initial phase of the study, one residential and one commercial prototype were chosen: a single-family home and medium office building.

Prototype models were used instead of real-world project examples because they represent the average features of that building type across the country. They also create a standard comparison to other building code analyses, including analyses of model energy codes. Utilizing specific, real-world projects can create skewed results due to design conditions particular to a project. They also create a standard comparison to other building code analyses, including analyses of model energy codes.

The basis for the baseline scenario in the analysis utilizes mixed-fuel versions of the national prototypes. These prototypes were modified to create models that comply with the all-electric and mixed-fuel paths in the Building Decarbonization Code that are then compared to the baseline prototype in the first cost and life cycle cost.

10 U.S. Department of Energy. “Prototype Building Models.” Accessed January 2022 via: https://www.energycodes.gov/prototype-building-models

Bank of EV charging stations.

Figure 4: PNNL single-family prototype[12]

(Source: PNNL)

Single-family prototype

The single-family prototype[11] is based on the 2021 edition of the IECC and has the following building features that were held constant across the costing scenarios:

- Two stories above grade
- Heated basement
- Unconditioned attic
- 3,600-sf conditioned building area (2,400 plus basement)
- 13% window-to-wall ratio
- Wood frame construction
- Sloped roof

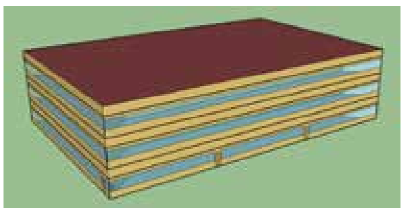


Figure 5: PNNL medium office prototype

(Source: PNNL)

Medium Office

The medium office prototype[13] is based on the 2019 ASHRAE Standard 90.1 prototype. The prototype has the following building features that were held constant in all the costing scenarios:

- Three stories
- Slab-on-grade
- 53,600-sf conditioned building area (164’ x 109’)
- 1.5 aspect ratio
- 33% window-to-wall ratio
- 13’ floor-to-floor height, 9’ floor-to-ceiling height
- Wood frame construction
- Flat built-up roof

First Cost Methodology

First cost analysis focused on incremental cost relative to the 2021 IECC baseline rather than total cost. Therefore, only the costs impacted by the provisions in the Building Decarbonization Code are included in this analysis. All other construction costs are held constant for the purposes of isolating the cost impact of the overlay provisions.

The first cost analysis was conducted by Arup under direction from NBI. Cost estimates were developed for a medium office prototype on the commercial side, and a single-family prototype house on the residential side, both in Climate Zone 5A. Direct costs were determined for both prototypes and include the cost of materials and the cost of labor.

11 The prototype files can be found at https://www.energycodes.gov/prototype-building-models#Residential. The baseline model used for this analysis is based on the 2021 IECC single-family prototype for Climate Zone 5A with a heated basement and gas space and water heating (US+SF+CZ5A+gasfurnace+heatedbsmt+IECC_2021.idf).

12 PNNL produces prototypes with multiple foundation types. This image is of the version that has a crawlspace, which is identical to the prototype used in this study except that the crawlspace is replaced with a heated basement.

13 The prototype files can be found at https://www.energycodes.gov/prototype-building-models#Commercial. The baseline model used for this analysis is based on the 2019 ASHRAE 90.1 medium office prototype for Climate Zone 5A with gas space and water heating (ASHRAE901_OfficeMedium_STD2019_Buffalo.idf).

Data Sources

Multiple data sources were used including RS Means[14], past Arup project data from projects of similar size and type, city cost indices, and local and national vendors. All costs were scaled to the average costs in New York State in 2021 dollars. Estimated lengths of infrastructure such as wiring, pipes, conduits, etc. were calculated using standard engineering methods and multiplied against cost per linear foot. Equipment costs, including meters and circuit breakers, were calculated on a per-item basis.

The PNNL prototype building simulation models were used to inform standard inputs for cost estimation. The commercial estimate referenced the ASHRAE 90.1-2019 medium office model for Climate Zone 5A. The residential estimate referenced the IECC 2021 single-family, heated basement model in Climate Zone 5A. For both prototypes, mixed-fuel and all-electric scenario cost estimates were developed independently drawing from the baseline. Mechanical equipment was sized and selected based on the PNNL prototype model equipment and load outputs, combined with engineering judgment from Arup's design experience.

Assumptions Used for Costing[15]

Electrical and Fossil Fuel Infrastructure

Residential panels and electrical service were sized based on the prototype models using a combination of loads determined from known information from the IECC added to standard miscellaneous building loads (lighting, receptacles) based on previous engineering design experience.

Commercial panels and electrical service were sized using loads determined from known information from ASHRAAE 90.1, including EVs, HVAC, and receptacles. It was assumed that the building service voltage was 480V, as that is typical for most medium sized commercial buildings. Therefore, a 480V/120V/208V transformer was also included as part of the EV scope to step the service voltage down.

This study uses the building site as the boundary condition and does not include any offsite fossil fuel infrastructure such as gas line extension costs, nor does it include utility transformers. No considerations were made for the increased utility transformer, conduit, or feeders required for the scenario study versus the base study as these are outside of the scope and boundary of the building

For the EV spaces serving the office parking lot, the number of parking spaces was calculated by assuming one parking spot/275 sf, per typical planning guidance for an office building. This resulted in 200 total parking spaces, 30 of which (15%) are EVSE spaces and 80 spaces (40%) are EV-capable. It is assumed that each EVSE would have a 1-inch underground conduit and a 40A branch circuit, and each EV-capable space would have 1-inch underground conduit.

The fossil fuel infrastructure was sized based on best practice plumbing engineering for the commercial and residential buildings of similar sizes. Pipe lengths were assumed to be 100' and 50' for the commercial and

14 RSMeans data from Gordian. Accessed November 2021 via: https://www.rsmeans.com/

15 Ibid, unless otherwise noted.

Reasonable Options

For all cases and measures, the most reasonable cost-effective option was chosen for the cost basis. This has two significant implications:

- The option chosen for this analysis may not be the option most frequently chosen by the market. Project teams have many criteria in addition to cost and code compliance when designing projects. Therefore, it is possible, and even likely, that project teams may choose an option for compliance that is costlier. For example, demand responsive functionality is provided by many “smart” thermostats that also include features such as remote user access, schedule detection, learning functionality, color LCD displays, etc. However, there are also simpler, less feature-rich demand responsive thermostats that have a much lower first cost. Since the higher cost of these smart thermostats is driven by the additional features, and not just compliance with the Building Decarbonization Code, it would not be appropriate to include that higher cost in the analysis. Therefore the lower cost option that isolates the cost of demand responsive controls from additional features the market might desire was chosen.

- It is possible to implement the Building Decarbonization Code at a lower cost using solutions that technically meet the requirements but may not be appropriate for the application. For example, inexpensive EV chargers meant for residential driveways would technically meet the EV charging requirements for the office application, but likely will not meet an owner’s project requirements for a commercial parking lot. Therefore, the lowest cost reasonable option was chosen over the absolute lowest cost option available.

Labor

The labor rate is based on actual labor expenses from Arup projects in New York State projects with related scope. As an average, it accounts for labor rates for different trades and skill levels and varying amounts of time required by those trades to complete the installation of measures. This resulted in an electrical labor rate of $130/hour, a mechanical and plumbing labor rate of $130/hour, and a construction labor rate of $100/hour.

Indirect costs

Indirect costs—such as overhead, profit, project/construction management, commissioning, etc.—were not included in the analysis. For most of the measures in the Building Decarbonization Code, it would be reasonable to assume that the indirect costs are constant between the base case and the proposed case since most measures simply involve implementing one design option instead of another. Therefore, indirect costs have not been included.

Single-family home with solar panels.

Summary of Scenario Building Features

The application of the Building Decarbonization Code on building systems varies, primarily impacting heating, water heating, and electrical systems. All building features not impacted by the Building Decarbonization Code are held constant between scenarios and are not included in the cost analysis in this study. Table 2 and Table 3 summarize the building features for both the single-family and medium office prototypes, including the baseline, all-electric and mixed-fuel scenarios.

Table 2: Summary of Building Systems for Single-Family Scenarios

Building System	Baseline Mixed-Fuel Scenario	Mixed-Fuel Decarbonization Scenario	All-Electric Decarbonization Scenario
Envelope	IECC 2021		
Lighting	IECC 2021		
DHW	35 MBH gas hot water heater		50 gallon heat pump water heater
Demand Responsive DHW	None		CTA-2045 control
HVAC	25 MBH gas furnace, 1.5-ton air conditioner		25 MBH air-source heat pump, 1.5-ton cooling
HVAC Controls	Code-compliant thermostat	Demand-responsive thermostat	
Cooking	Gas range and oven		Electric range and oven
Renewable Energy Systems	None	Renewable energy-ready	
EVCI	None	1 EV-ready space (dedicated 9.6 kVA branch circuit)	
Additional Efficiency	ERV/HRV	HRV/ERV and high-performance gas furnace	High-performance heat pump
Gas Infrastructure	250 CFH gas regulator & meter		None
Electrical Infrastructure	100A or 200A panel	200A panel	


EV charging in parking lot.


Commercial building heat pumps.

Table 3 : Summary of Building Systems for Medium Office Scenarios

Building System	Baseline Mixed-Fuel Scenario	Mixed-Fuel Decarbonization Scenario	All-Electric Decarbonization Scenario
Envelope	ASHRAE 90.1-2019		
Lighting	ASHRAE 90.1-2019		
SHW	81 MBH, code-compliant gas boiler		81 MBH central heat pump water heater system
HVAC	(3) 30 ton Packaged AC unit (3) 110 MBH gas furnace, direct fired		(3) 30 ton Packaged ASHP (3) 100 MBH heating
HVAC Controls	Standard BMS	BMS with demand responsive functionality	
Renewable Energy Systems	None	(2) 13 kW PV system (one for C405.13 and one for C406.1)	13 kW PV system
EVCI	None	30 EVSE parking spaces 80 EV-capable parking spaces	
Gas Infrastructure	720 CFH gas regulator and meter		None
Electrical Infrastructure	400A or 800A panel	800A panel	

Life Cycle Cost Analysis Methodology

NBI conducted an LCCA to evaluate the economic impact of the Building Decarbonization Code for single-family homes only.[16] The single-family prototype was chosen because residential occupancies are generally more sensitive to operational cost impacts compared to commercial occupancies and housing affordability is a critical issue. This analysis compares the costs and benefits over an established period between a baseline mixed-fuel single-family building and the same building if it met the mixed-fuel requirements or the all-electric requirements of the Building Decarbonization Code.

The LCCA utilizes the first costs combined with an analysis of the energy use of the building prototype and life cycle variables. This analysis relied primarily on the methodology and input values used by the U.S. Department of Energy (DOE) since 2015 to determine the life cycle cost of residential energy code changes with several key differences:[17]

- This analysis includes the societal cost of carbon. Although the societal cost of carbon is not included in DOE's analysis, there is growing interest among policymakers to understand the societal impact when weighing the costs and benefits of those policies.

16 The scope of this study was only able to accommodate a single prototype. An expanded LCCA addressing additional building types, climate zones and markets is planned for future phases of this study.

17 Taylor, ZT, et al. "Methodology for Evaluating the Cost Effectiveness of Residential Energy Code Changes" U.S. Department of Energy and Pacific Northwest National Laboratory. August 2015. Accessed January 2022 via: www.energycodes.gov/sites/default/files/2021-07/residential_methodology_2015.pdf.

- This analysis includes a range of higher and lower discount rates (2% or 3.6%) to give a range to the results. Discount rates are discussed in greater detail below.

- The analysis includes multiple cost scenarios based on local fixed and time of use electricity prices and local gas prices, and a combination of high and low values for future energy costs.

The addition of these factors allows the results to provide a range of outcomes rather than a single result based on fixed assumptions, making the results more applicable to a wider range of policymakers and stakeholders.

The LCCA does not include likely future retrofit costs for the mixed-fuel baseline, such as the cost of installing an EV charger, rooftop solar panels, electric space and water heating equipment, or electric appliances.[18] Furthermore, the LCCA does not include associated costs or cost savings resulting from owning an EV compared to owning a gasoline-powered vehicle. This presents a conservative estimate, as these additional cost savings would likely significantly improve the cost effectiveness of the all-electric and mixed-fuel application of the Building Decarbonization Code.

Annual Energy Use

The PNNL single-family residential prototype used for the first cost analysis was also used to determine annual energy use for the baseline single-family home and the mixed-fuel and all-electric decarbonization scenarios. Annual energy use was determined through computer simulation of energy performance with the EnergyPlus™ (Version 9.5) software, to demonstrate the energy savings that can be achieved through energy conservation measures and electrification. The prototypes used are detailed in Table 4.

Table 4 : Prototypes Used in LCCA Analysis

Scenario	Model
Baseline	US+SF+CZ5A+gasfurnace+heatedbsmt+IECC_2021.idf
Mixed-Fuel Scenario	US+SF+CZ5A+hp+heatedbsmt+IECC_2021.idf
All-Electric Scenario	US+SF+CZ5A+gasfurnace+heatedbsmt+IECC_2021_MixedFuel.idf

All systems were adjusted to match the cost estimates as described in the First Costs section, with the following omissions due to lack of data to support accurate usage profile predictions within the EnergyPlus models:

- Demand responsive controls
- EV charging

The models were simulated using the Typical Meteorological Year 3 (TMY3) weather file for Climate Zone 5A for Buffalo.

Life Cycle Cost Analysis Parameters

The LCCA was run for two cost scenarios to provide a range of results. One scenario represents an average condition that would be representative of rural and small cities and is based on costs drawn from Buffalo. The other represents typically higher costs found in dense, urban markets and is based on costs drawn from New York City.[19] These scenarios—denoted as "high cost" and "typical cost" in the study—give a perspective of the impact on the LCCA that results from variability in parameters such as utility rates, income tax rates, and property tax rates.

18 It is reasonable to assume that all mixed-fuel buildings built today will undergo full or partial electrification within the 30-year life cycle cost analysis, and the additional cost of electrification retrofits would have a significant impact on the results.

19 While the costs are drawn from New York City, the energy usage still represents Climate Zone 5A. Therefore, the "high" scenario does not, and is not meant to, represent an LCCA for new single-family construction in New York City.

The LCCA depends on a variety of inputs described in detail here. In 2020, 96% of all new homes were purchased using a loan; therefore, the LCCA assumes that the homebuyer finances the purchase through a 30-year mortgage.[20] This study, similar to DOE's analysis, analyzes costs and benefits of code changes over a span of 30 years to capture both long-term energy savings and to match the typical mortgage term. The costs of a 30-year mortgage in addition to other expenses related to making decarbonization upgrades to a home over the 30-year analysis period include the following:

- **Utility Costs:** Because the decarbonization amendments affect the energy use of the home, utility costs are also included in the analysis. Utility costs are dependent on the results of the energy model described above, as well as the utility rate. DOE's methodology uses the U.S. Energy Information Administration's (EIA) average electricity and gas rates for each state. The study includes rates for electricity and gas for customers enrolled in either standard rate structure where the price of electricity is fixed over time or a utilities' TOU program where the electricity rate changes depending on the time of day and year. This study, like DOE's analysis, assumes utility rates rise according to the reference case scenario in U.S. EIA's Annual Energy Outlook. With high- and typical-cost variations, this results in a total of four utility cost scenarios.

- **Down Payment:** The study utilizes a down payment rate of 10% of the incremental cost of the decarbonization amendments. DOE's methodology found that a 10% down payment rate was the most representative of first-time home buyers. The down payment occurs in Year 1 of the life cycle cost analysis.

- **Mortgage Fee:** The study assumes that the homebuyer would pay a mortgage fee in Year 1 of the LCCA. The mortgage fee represents the cost of obtaining credit due to the cost or savings from decarbonization amendments. The loan fee is 0.6% in line with DOE's analysis. This loan fee is based on data from Freddie Mac Weekly Primary Mortgage Market Survey.

- **Mortgage Payments:** Mortgage payments are dependent on the mortgage term (30 years), the incremental loan amount (90% of incremental cost of the decarbonization amendments), and the mortgage interest rate. Mortgage payments are paid every year throughout the analysis period and do not change over time. This study utilizes the same mortgage interest rate used by DOE, which assumes a mortgage interest rate of 5% based on the average historical interest rate for 30-year mortgage loans.

- **Property Taxes:** All homeowners must pay property taxes based on local property tax rates. Like mortgage payments, property taxes are paid every year throughout the analysis period. The analysis assumes the value of the home increases over time. The rate of increase is represented by the home price escalation rate, which is the same escalation rate of 1.6% used by DOE. This escalation is based on the inflation rate because future home prices outside of inflation are too varied and situation specific to model accurately. The analysis uses property tax rates of 1.925% (based on New York City) and 2.58% (based on Buffalo).[21]

- **Tax deductions:** Homeowners claim tax deductions annually from property tax payments and mortgage interest payments. Tax deductions depend on the value of tax and mortgage interest payments and a homeowner's income tax rate. This parameter also uses Buffalo and New York City as boundary variables instead of the DOE values (15%) The median household income is $63,998 in New York City[22] and $68,486 in Buffalo,[23] which corresponds to a combined federal and state income tax rate of 26.93% for New York City and 18.12% in Buffalo.[24]

20 U.S. Census Bureau. 2020. "Characteristics of New Single-Family Houses Sold – Financing." Accessed September 2021 via https://www.census.gov/construction/chars/sold.html

21 "New York Property Tax Calculator." SmartAsset, smartasset.com/taxes/new-york-property-tax-calculator#WM2UMKlS2I. Note that this is one case where the rate is actually lower in the high-cost scenario.

22 Quick Facts, New York City, New York, United States Census, 1 July 2019, www.census.gov/quickfacts/fact/table/newyorkcitynewyork/PST040219.

23 Quick Facts, Buffalo, New York, United States Census, 1 July 2019, https://www.census.gov/quickfacts/fact/table/buffalocitynewyork,NY/INC110219

24 "New York Income Tax Calculator." New York Income Tax Calculator, SmartAsset, Sept. 2021, smartasset.com/taxes/new-york-tax-calculator#6dRkH7ybgf.

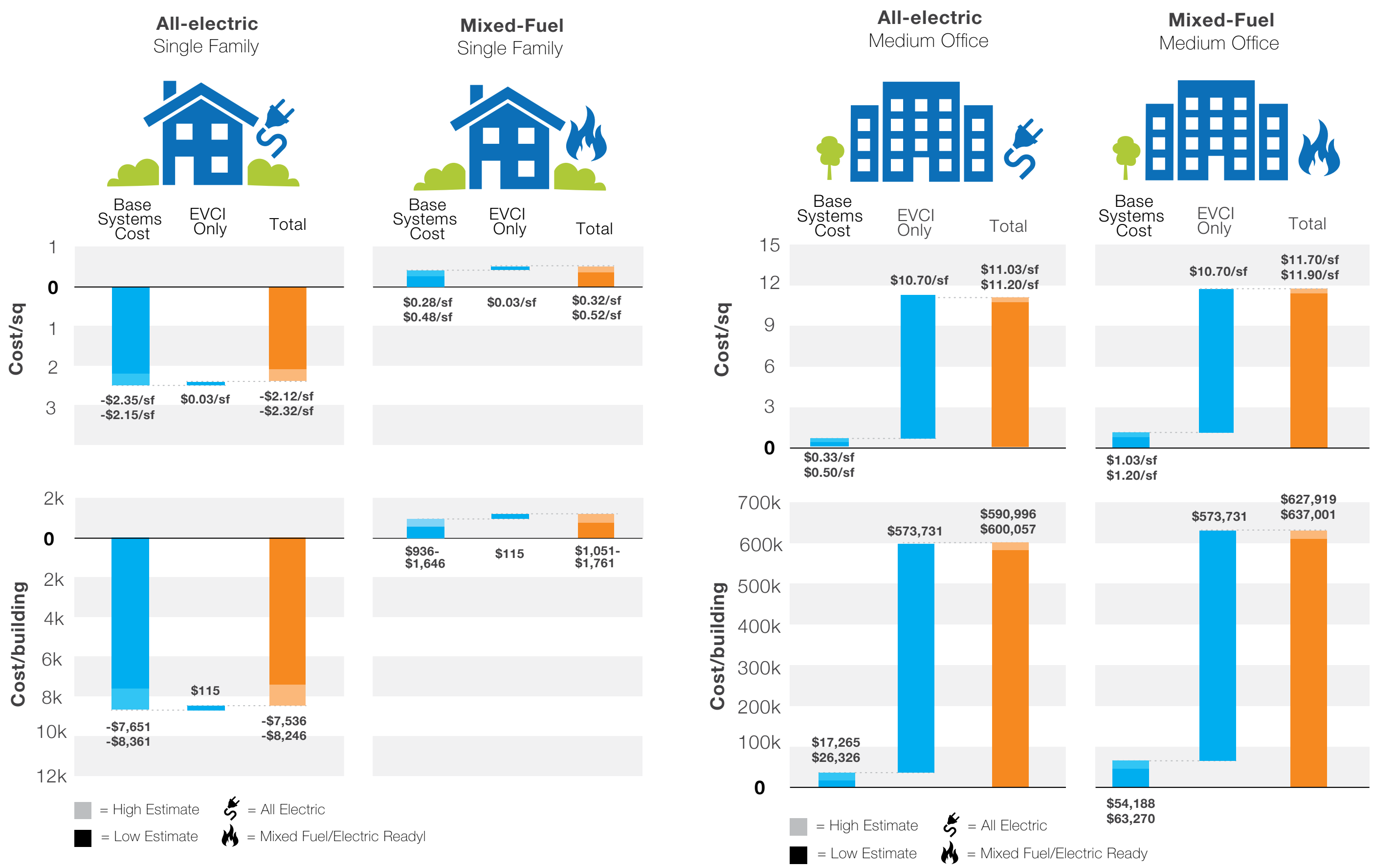
First Costs Results

Single-family: An all-electric single-family home is $7,500-$8,200 cheaper to construct than the baseline code home. This is due to the substantial savings resulting from eliminating the need for fossil fuel infrastructure at the home site. The electric-ready single-family home has an incremental cost of $1,000-$1,700.

Medium Office: The first cost for both the all-electric and mixed-fuel scenarios was higher than the baseline for the medium office prototype, with total costs ranging from approximately $600,000-$640,000 (about $11-12/sf), with 90-97% of the cost increase attributable to the EVCI requirements. Without the EVCI requirements, the two decarbonization scenarios resulted in only limited incremental cost of $0.33-1.20/sf.

Figure 1: Summary of Incremental First Costs and Savings

First referenced on p. 6



Costing for Individual Requirements

The first cost for each Building Decarbonization Code requirement is detailed in the sections below. For each code section, the baseline condition and the Building Decarbonization Code scenario are described and costed, along with the resulting incremental first cost. Any interactive impacts between measures are also identified. Whole-building incremental costs are summarized at the end of this section. Some measures are not applicable to a specific prototype, and while they have been costed as individual measures, they are not included in the whole building summary for that prototype.

Some of the measures apply to both the all-electric and mixed-fuel paths, while some are unique to one path or the other. Table 5 summarizes the measures for the two paths.

Table 5: Summary of Measures For All-Electric and Mixed-Fuel Scenarios

Code Provision	All-Electric	Mixed-Fuel
Commercial		
C401.2 Application (All-Electric Building)	X	
C403.4.1.6 Demand Responsive Controls	X	X
C404.11 Demand Responsive Water Heating	X	
C405.2 Demand Responsive Luminaire Level Lighting Controls	X	X
C405.12.2 Energy Use Categories (EV Sub-Metering)	X	X
C405.13 On-site Renewable Energy	X	X
C405.14 EV Charging Infrastructure	X	X
C405.16.2 Electrification Readiness for Water Heating equipment		X
C405.16.3 Electrification Readiness for Other Combustion Equipment		X
C406.1 Additional Energy Efficiency Credits		X
Residential		
R401.2 Application (All-electric building)	X	
R401.2.5 Additional R408 Package		X
R403.1.1 Demand Responsive Thermostats	X	X
R403.5.4 Demand Responsive Water Heating	X	
R404.4 Renewable Energy Infrastructure	X	X
R404.5 EV Charging Infrastructure	X	X
R404.6.2 Electrification Readiness for Water Heating		X
R404.6.3 Electrification Readiness for Space Heating		X
R404.6.5 Electrification Readiness for Cooking		X

Single-Family **All-Electric Scenario**

For the single-family prototype, the all-electric decarbonization scenario resulted in lower first costs than the mixed-fuel baseline, even with the inclusion of EVCI requirements. The all-electric home saves $7,651-$8,361. A complete summary of the measure-by-measure incremental first costs for the all-electric pathway of the Building Decarbonization Code is presented in Table 6, and each measure is further explained below with key assumptions.

Table 6: All-Electric Incremental First Cost Summary (Single-Family)

Code Provision	Measure	Incremental Cost/sf (Savings)	Incremental First Cost (Savings)
R401.2	Application (All-electric building)	($2.43 - $2.63)	($8,657) - ($9,367)
	- HVAC Electrification	($1.03)	($3,646)
	- Hot Water Electrification	($0.17)	($635)
	- Cooking Electrification	($0.03)	($106)
	- Fossil Fuel Infrastructure	($1.40)	($4,980)
	- Electric Infrastructure	$0.20 - $0	$710 - $0
R403.1.1	Demand Responsive Thermostats	$0.01	$21
R403.5.4	Demand Responsive Water Heating	$0.23	$828
R404.4	Renewable Energy Infrastructure	$0.04	$157
R404.5	EV Charging Infrastructure	$0.03	$115
	Total	**($2.35-$2.15)**	**($7,651) – ($8,361)**

R401.2 Application (All-Electric Building) Explanation and Assumptions

For the single-family prototype, the all-electric decarbonization scenario resulted in lower first costs than the mixed-fuel baseline, even with the inclusion of EVCI requirements. The all-electric home saves $7,651-$8,361. A complete summary of the measure-by-measure incremental first costs for the all-electric pathway of the Building Decarbonization Code is presented in Table 8, and each measure is further explained below with key assumptions.

This section requires that the building be all-electric. To determine the incremental cost of this code, the costs of providing electric space heating and water heating and cost savings from not providing fossil fuel infrastructure were included. The measures would save $2.43/sf -$2.63/sf depending on whether an electrification measure triggers an upgrade to the electrical panel.

This section requires the installation of an electric water heater, not specifically a heat pump water heater (HPWH), which is 2-3 times more efficient than electric resistance water heater. An electric resistance water heater was selected for this measure for two reasons: It was the most cost-effective way to meet the code requirement, and it allowed the costs of electrification and demand responsive controls for electric water heaters

All-electric induction cooktop

to be isolated from one other. See R403.5.4 where the electric resistance water heater is replaced with a HPWH.

This section also uses a ceramic cooktop instead of the least-cost coil range because these are rarely used in new market-rate single-family construction.

A 200A service is increasingly becoming a norm in new market-rate single-family construction. Therefore, there is an incremental cost increase for the electric infrastructure in markets where a smaller service is still common. The “electric infrastructure” line item indicates the total cost range to account for this variability.

Finally, this estimate leaves out utility connection fees and new customer connection subsidies due to the fact that they can vary widely from one utility service territory to another.

Table 7: Equipment and Electrification Infrastructure (All-Electric Scenario, Single-family)

Cost Category	Baseline	All-Electric Decarbonization Scenario	Incremental First Cost/sf (Savings)
HVAC	Code compliant gas furnace and split-system air conditioning unit with an E/HRV for R408 compliance.	High efficiency, air-source heat pump that provides cooling and meets the R408 package requirements for high efficiency HVAC.	($1.03)
	$1.93/sf	$0.90/sf	
Service Water Heating	Code compliant gas furnace and split-system air conditioning unit with an E/HRV for R408 compliance.	40 gallon electric resistance water heater with 240V/30A branch circuit.	($0.17)
	$0.53/sf	$0.36/sf	
Cooking	Gas range/oven with 120V/15A branch circuit.	Ceramic cooktop range/oven with 240V/40A branch circuit.	($0.03)
	$0.44/sf	$0.41/sf	
Fossil Fuel Infrastructure	Gas infrastructure including supply line, gas regulator, gas meeting and venting.	No gas infrastructure.	($1.40)
	$1.40/sf	--	
Electric Infrastructure	100A service, main breaker and main panel	200A service, main breaker and main panel	*$0-$0.20
	$0.16/sf	$0.36/sf	
Total	**$5.46/sf**	**$2.19-$2.39/sf**	**($2.43 - $2.63)**

R403.1.1 Demand Responsive Thermostats

This section requires that thermostatic controls have demand response functionality. These results represent only the cost of adding the demand responsive functionality and not the higher cost of more feature-rich smart thermostats (i.e., touch screen, cell phone connected, etc.) with demand responsive functionality.

Table 8: Demand Responsive Thermostats (All-Electric Scenario, Single-family)

Baseline	All-Electric Decarbonization Scenario	Incremental First Cost/sf (Savings)
Single-zone, code-compliant thermostat with schedule and setback functionality	Single-zone thermostat with schedule and set-back functionality and demand response functionality	$0.01
$0.04/sf	$0.05/sf	

R403.5.4 Demand Responsive Water Heating

This section requires that water heaters comply with the demand response requirements of Standard CTA-2045. At time of this study, only HPWH models meet this requirement, so this measure includes the cost of upgrading to a HPWH. When this measure is taken in isolation, the additional efficiency from a HPWH could be used to meet the efficiency package requirement of R408, which would provide savings to offset the cost.

Table 9: Demand Responsive Water Heating (All-Electric Scenario, Single-family)

Baseline	All-Electric Decarbonization Scenario	Incremental First Cost/sf (Savings)
40-gallon electric resistance water heater with 240V/30A branch circuit	50-gallon HPWH with 240/30A branch circuit	$0.23
$0.27/sf	$0.50/sf	

R404.4 Renewable Energy Infrastructure

This section requires that homes be provided with solar-readiness, including a solar-ready zone, reserved space in the panel and electrical interconnection.

Table 10: Renewable Energy Infrastructure (All-Electric Scenario, Single-family)

Baseline	All-Electric Decarbonization Scenario	Incremental First Cost/sf (Savings)
Nothing	Space for dual-pole breaker in main panel, ¾" conduit to solar-ready zone, junction box with 3 #10 wires	$0.04
$0.27/sf	$0.04/sf	

R404.5 EV Charging Infrastructure

This section requires that the home be provided with one EV-ready parking space. Due to the amount of electric infrastructure required under this scenario, this measure alone does not assume the need to upgrade the electrical panel. If this measure triggers an electrical panel upgrade (100A to 200A), an additional cost of $0.20/sf should be applied.

Table 11: EV Charging Infrastructure (All-Electric Scenario, Single-family)

Baseline	All-Electric Decarbonization Scenario	Incremental First Cost/sf (Savings)
No EVCI	Dedicated 240V/40A branch circuit (including breaker, wiring, junction box and outlet) installed in garage	$0.03
--	$0.03/sf*	

Measures with No Cost Impact

- R101.3 Intent: Revises the intent of the code to include GHG reductions in the scope of the code.
- R103.2.3 Information on Construction Documents: Requires the fuel source for equipment electrical pathways for renewable energy, energy storage and EV charging resources be noted on construction documents.
- R105.2.3, R105.2.5 Plumbing and Electrical Rough-in Inspection: Adds an inspection requirement for additional electrical infrastructure.
- R202 Definitions: Adds definitions that are leveraged through the code.
- R401.3 Home Certificate: Adds additional relevant items to the Home Certificate.
- R402.4.4 Rooms with fuel-burning appliances: Removes this section since it is not applicable to all-electric buildings.
- R404.11 Gas lighting: Removes this section since it is not applicable to all-electric buildings.
- R408.2 Remove fossil fuel efficiency packages: Removes language about fossil fuel options to meet the R408 requirements.

Residential all-electric heat pump.

Single-Family **Mixed-Fuel Scenario**

For the single-family prototype, the mixed-fuel decarbonization scenario resulted in marginally increased first costs. The additional first cost of the electric-ready home is $1,051-$1,761. A complete summary of the measure-by-measure incremental first costs for the mixed-fuel pathway of the Building Decarbonization Code is presented in Table 12, and each measure is further explained below with key assumptions.

Table 12 : Mixed-Fuel Incremental First Cost Summary (Single-Family)

Code Section	Measure Description	Incremental First Cost/sf (Savings)	Incremental First Cost Whole Building (Savings)
R401.2.5	Additional R408 Package	$0.09	$311
R403.1.1	Demand Responsive Thermostats	$0.01	$21
R404.4	Renewable Energy Infrastructure	$0.05	$157
R404.5	EV Charging Infrastructure	$0.04	$115
R404.6	Electric Infrastructure Upgrade	$0-$0.20	$0 - $710
R404.6.2	Electrification Readiness for Water Heating	$0.06	$204
R404.6.3	Electrification Readiness for Space Heating	*$0.06**	*$204*
R404.6.5	Electrification Readiness for Cooking	$0.07	$243
*Not included in whole-building total	**Total**	**($0.32-$0.52)**	**$1,051 - $1,761**

R401.2.5 **Additional R408 Package**

This section requires that mixed-fuel homes include an additional efficiency package from Section R408.

Table 13: Additional R408 Package (Mixed-Fuel Scenario, Single-Family)

Baseline	Mixed-Fuel Decarbonization Scenario	Incremental First Cost/sf (Savings)
Code compliant (80% efficiency) gas furnace	High Efficiency (96% efficient) furnace that meets the efficient HVAC option from Section R408	$0.09
$0.39/sf	$0.48/sf	

R403.1.1 Demand Responsive Thermostats

This section requires that thermostatic controls have demand response functionality.

Table 14 : Demand Responsive Thermostats (Mixed-Fuel Scenario, Single-Family)

Baseline	Mixed-Fuel Decarbonization Scenario	Incremental First Cost/sf (Savings)
Single-zone, code compliant thermostat with schedule and set-back functionality	Single-zone thermostat with schedule and setback functionality and demand response functionality	$0.01
$0.04/sf	$0.05/sf	

R404.4 Renewable Energy Infrastructure

This section requires that homes be provided with solar-readiness, including a physical solar-ready zone on the roof, reserved space in the electrical panel and an electrical interconnection.

Table 15: Renewable Energy Infrastructure (Mixed-Fuel Scenario, Single-Family)

Baseline	Mixed-Fuel Decarbonization Scenario	Incremental First Cost/sf (Savings)
Nothing	Space for dual-pole breaker in main panel, ¾" conduit to solar-ready zone, junction box with 3 #10 wires	$0.04
--	$0.04/sf	

R404.5 EV Charging Infrastructure

This section requires that the home be provided with one EV-ready parking space. Due to the amount of electric infrastructure required under this scenario, this measure alone does not assume the need to upgrade the electrical panel. If this measure triggers an electrical panel upgrade (100A to 200A), an additional cost of $0.20/sf should be applied as reflected in R404.6.

Table 16: EV Charging Infrastructure (Mixed-Fuel Scenario, Single-Family)

Baseline	Mixed-Fuel Decarbonization Scenario	Incremental First Cost/sf (Savings)
Nothing	Dedicated 240V/40A branch circuit (including breaker, wiring, junction box and outlet) installed in garage	$0.03
--	$0.03/sf	

R404.6 Electric Infrastructure Upgrade

The following table summarizes the cost that would result if the electrification readiness requirements of R404.6 were to trigger an electrical service upgrade. A minimum 200A service is increasingly standard in market-rate single-family new construction. In this market, the incremental cost would be $0. This line item creates the range for the total costs in the summary section of this report.

Table 17: Electric Infrastructure Upgrade (Mixed-Fuel Scenario, Single-Family)

Baseline	All-Electric Decarbonization Scenario	Incremental First Cost/sf (Savings)
100A service, main breaker and main panel	200A service, main breaker and main panel	$0-$0.20
$0.16/sf	$0.36/sf	

R404.6.2 Electrification Readiness for Water Heating

This section requires that fossil fuel water heating equipment be provided with building features—such as electrical infrastructure—to facilitate cost-effective future electrification retrofits. Due to the amount of electrical infrastructure required under this scenario, this measure alone does not assume the need to upgrade the electrical panel. If this measure triggers an electrical panel upgrade (100A to 200A), an additional cost of $0.20/sf should be applied as reflected in R404.6.

Table 18: Electrification Readiness for Water Heating (Mixed-Fuel Scenario, Single-Family)

Baseline	Mixed-Fuel Decarbonization Scenario	Incremental First Cost/sf (Savings)
Nothing	Dedicated 240V/30A branch circuit.	$0.06
--	$0.06/sf	

R404.6.3 Electrification Readiness for Space Heating

This section requires that fossil fuel space heating equipment be provided with electrical infrastructure to facilitate cost-effective future electrification retrofits. This cost is not applied to the whole-building total, as the single-family prototype has air conditioning, which provides an exception to the requirement.

Table 19: Electrification Readiness for Space Heating (Mixed-Fuel Scenario, Single-Family)

Baseline	Mixed-Fuel Decarbonization Scenario	Incremental First Cost/sf (Savings)
Nothing	Dedicated 240V/30A branch circuit.	$0.06
--	$0.06/sf	

R404.6.5 Electrification Readiness for Cooking

This section requires that fossil fuel cooking appliances be provided with electrical infrastructure to facilitate cost-effective future electrification retrofits. Due to the amount of electric infrastructure required under this scenario, this measure alone does not assume the need to upgrade the electrical panel. If this measure were to trigger an electrical panel upgrade (100A to 200A), an additional cost of $0.20/sf should be applied as reflected in R404.6.

Table 20: Electrification Readiness for Cooking (Mixed-Fuel Scenario, Single-Family)

Baseline	Mixed-Fuel Decarbonization Scenario	Incremental First Cost/sf (Savings)
Nothing	Dedicated 240V/40A branch circuit.	$0.07
--	$0.07/sf	


Albany, New York

Measures with No Cost Impact

The following measures of the mixed-fuel scenario of the Building Decarbonization Code have no or negligible incremental first cost:

- R101.3 Intent: Revises the intent of the code to include GHG reductions in the scope of the code.
- R103.2.3, R103.2.4 Information on Construction Documents: Requires that the fuel source for equipment electrical pathways for renewable energy, energy storage and EV charging resources be noted on the construction documents.
- R105.2.3, R105.2.5 Plumbing and Electrical Rough-in Inspection: Adds an inspection requirement for the additional electrical infrastructure.
- R202 Definitions: Adds definitions that are leveraged through the code.
- R401.3 Home Certificate: Adds additional relevant items to the Home Certificate.
- R403.5.4 Demand Responsive Water Heating: Adds a requirement for demand responsive controls for certain electric water heaters. Does not apply as prototype has gas water heating.
- R404.6.1 Electrification readiness for equipment serving multiple dwelling units: Adds electrification readiness requirements for equipment serving multiple dwelling units. Does not apply the single-family prototype.
- R404.6.4 Electrification readiness for clothes drying: Adds electrification readiness requirements for clothes drying. Does not apply as the prototype has electric clothes drying.

Medium Office **All-Electric Scenario**

When applied to the medium office building prototype, the all-electric decarbonization scenario results in first cost savings of $4,054-$13,115 for primary building systems (HVAC, water heating, and electrical) electrification upgrades. The single-largest impact on first cost for the all-electric medium prototype is the cost of EV infrastructure—representing 97.0%-98.5% of the first cost. A complete summary of the measure-by-measure incremental first costs for the all-electric pathway of the Building Decarbonization Code is presented in Table 21, and each measure's key assumptions are explained below.

Table 21 : All-Electric Incremental First Cost Summary (Medium Office)

Code Provision	Measure	Incremental Cost/sf (Savings)	Incremental First Cost (Savings)
C401.2	Application (All-electric building)	($0.24 - $0.07)	($8,657) - ($9,367)
	- HVAC	*($0.49)*	*($26,455)*
	- SWH	*$0.48*	*$25,530*
	- Fossil fuel Infrastructure	*($0.23)*	*($12,190)*
	- Electric Infrastructure	*$0-$0.17*	*$0-$9,061*
C403.4.1.6	Demand Responsive Controls	$0.12	$6,500
C404.11	Demand Responsive Water Heating	$0.03	$1,917
C405.2	*Demand Responsive Luminaire Level Lighting Controls*	*$0.12**	*$6,500**
Table C405.12.2	Energy Use Categories (EV Sub-Metering)	$0.01	$763
Table C405.12.2	On-site renewable energy	$0.40	$21,200
Table C405.12.2	EV Charging Infrastructure	$10.70	$573,731
	Total	**$11.03-$11.20**	**$590,996 - $600,057**

C401.2 **Application (All-Electric Building)**

This section requires that the building be all-electric. To determine the incremental first cost of this code provision, the additional cost of electrifying space heating and water heating and cost savings from not installing infrastructure for fossil fuels were included. This measure presents a savings of $0.07/sf-$0.24/sf. Total savings is dependent on whether electrification triggers an upgrade from a 400A to an 800A electrical panel.

Additionally for this measure, the baseline medium office building prototype utilizes a central gas boiler for heating water. The equivalent central HPWH system resulted in increased costs. A more cost-effective solution might have been to utilize electric storage water heaters located near the hot water loads throughout the building. The most reasonable option—the central HPWH—was chosen for this study.

Table 22: Incremental Equipment and Infrastructure Costs (All-Electric Scenario, Medium Office)

Cost Category	Baseline	All-Electric Decarbonization Scenario	Incremental First Cost/sf (Savings)
HVAC	Variable air volume (VAV) system with packaged units with both cooling and gas furnace that serve VAV terminal boxes with electric resistance reheat	VAV system with packaged air source heat pump (ASHP) units that serve VAV terminal boxes with electric resistance reheat	($0.49)/sf
	$2.53/sf	$2.04/sf	
Service Water Heating	Central gas boiler with storage tank and recirculation loop.	Central heat pump water heater with recirculation loop.	$0.48/sf
	$0.08/sf	$0.56/sf	
Fossil Fuel Infrastructure	Gas piping, valves, meter and venting.	No gas infrastructure.	($0.23)/sf
	$0.23/sf	$0/sf	
Potential Electric Infrastructure	400A main panel	800A main panel.	$0 - $0.17/sf*
	$0.18/sf	$0.35/sf	
Total	**$3.02/sf**	**$2.78 - 2.95/sf**	**($0.07 - 0.24)/sf**

* Not all buildings will require a larger electrical service, so this line item is represented as a range.

C403.4.1.6 Demand Responsive Thermostatic Controls

This section requires that thermostatic controls have demand response functionality, which is present in the hardware of building management systems (BMS), but often not included in BMS software. Including demand responsive functionality typically requires 100 hours of programming during configuration. This helps ensure the software is functional, which adds $0.12/sf to the cost of construction. It is reasonable to assume that as demand responsiveness becomes more common, this functionality will become a standard feature or option and that therefore programming costs will be lowered.

Table 23: Demand Responsive Controls (All-Electric Scenario, Medium Office)

Baseline	Decarbonization Scenario	Incremental First Cost (Savings)
Standard code-compliant seven-day thermostatic controls through a central BMS.	Programming a standard BMS to incorporate grid-flexibility functionality (100 hours of programming as per Siemens).	$0.12
--	$0.12/sf	

C404.11 **Demand Responsive Water Heating**

This section requires that storage water heaters have demand responsive controls by incorporating CTA-2045-compliance controls or the equivalent. This requirement does not apply to the large central water heater present in the medium office prototype. Rather, it has been priced for an individual water heater that might serve a set of lavatories.

The market has concentrated these controls in HPWH models. Therefore, there would be some cost savings for modeled projects that can trade off the additional efficiency elsewhere in the building design. The incremental first cost of compliance is estimated to be $0.03/sf.

Table 24: Demand Responsive Water Heating (All-Electric Scenario, Medium Office)

Baseline	Decarbonization Scenario	Incremental First Cost (Savings)
Three code-compliant electric resistance water heaters (one per floor).	Three HPWHs (one per floor) incorporating CTA-2045 grid flexibility controls.	$0.03
$0.10/sf	$0.13/sf	

C405.2 Lighting Controls

This section requires that luminaire level lighting controls (LLLC) have demand responsive functionality built in. These controls are not common in medium office buildings and are more common in large offices. As a result, the cost of the requirement is included in this study as a standalone cost for reference only; it is not included in the whole-building results. Like demand responsive thermostats, the hardware in code compliant LLLC generally supports demand responsiveness, but the LLLC would need to be programmed, adding $0.12/sf to construction costs.

Table 25: Lighting Controls (All-Electric Scenario, Medium Office)

Baseline	Decarbonization Scenario	Incremental First Cost (Savings)
Code-compliant LLLC.	Programming a standard LLLC BMS to incorporate grid-flexibility functionality (100 hours of programming as per Siemens).	$0.12
--	$0.12/sf	

C405.12.2 **Energy Use Categories**

This section requires the addition of sub-metering for EVloads. Costs assume that the load categories have been separated in the electrical system design in both the baseline and decarbonization scenario. Sub-metering for these loads is increasingly important, especially for buildings located in jurisdictions with benchmarking, disclosure and building performance standard (BPS) regulations, because it allows building owners to easily separate charging from the base building loads.

Table 26: Energy Use Categories (EV Sub-Metering) (All-Electric Scenario, Medium Office)

Baseline	Decarbonization Scenario	Incremental First Cost (Savings)
Code compliant metering system with submeters for HVAC, service water heating (SWH), Lighting and Plug Loads.	Baseline system with one additional submeter for EV loads.	$0.02
$0.09/sf	$0.11/sf	

C405.13 **On-site Renewable Energy**

This section requires the installation of an on-site renewable energy system to meet the requirement of 0.25W/sf for the first three floors of the medium office building. Because the prototype office building is a three-floor, 53,600 sf office building, meeting this requirement requires a 13kW on-site renewable energy system. Under a LCCA it is likely that this first cost would be immediately offset by the production of solar energy.

Table 27: On-site Renewable Energy (All-Electric Scenario, Medium Office)

Baseline	Decarbonization Scenario	Incremental First Cost (Savings)
No on-site renewable energy system.	13kW on-site renewable energy system, including panels, disconnect, inverter, racking, supports, meter, etc.	$0.40
--	$0.40/sf	

C405.14 **Electric Vehicle Charging Infrastructure**

This section requires the installation of EV charging infrastructure (EVCI). Costing is based on 30 EVSE spaces using a 200-space parking lot sized for the building based on typical parking requirements.

Some project teams will choose an EV charging solution that provides billing solutions in order to manage charging costs or electrical load. These EVSE are more expensive than their more basic counterparts. Due to the defined methodology looking at the most reasonable cost, the EVSE chosen for this costing exercise do not include this additional functionality as it is not required for compliance with the Building Decarbonization Code.

Table 28: Electric Vehicle Charging Infrastructure (All-Electric Scenario, Medium Office)

Baseline	Decarbonization Scenario	Incremental First Cost (Savings)
No EVCI	EVCI meeting decarbonization requirements including: • 15 dual-head EVSE with pedestals providing 30 EVSE spaces: includes earthwork, raceways, wiring, breakers, junction boxes, etc. • 80 EV Capable spaces: includes earthwork, raceways and junction boxes • Additional 800A panel board • Additional 300kVA transformer with raceways, wiring, etc.	$10.70
--	$10.70/sf	

Measures with No Cost Impact

The following nine requirements/modifications of the Building Decarbonization Code are assumed to have no or negligible incremental first cost:

- C101.3 Intent: Revises the intent of the code to include GHG reductions in the scope of the code.
- C103.2 Information on Construction Documents: Requires that the fuel source for equipment and electrical pathways for renewable energy, energy storage and EV charging resources be noted on the construction documents.
- C202 Definitions: Adds definitions that are leveraged through the code.
- C402.1.1 Low Energy Buildings: Limits the Low Energy building exemption to all-electric buildings.
- C404.9.1 Heaters: Removes a reference to pilot lights not needed in an all-electric code.
- C405.4.3 Gas lighting: Removes a reference to gas lighting not needed in an all-electric code.
- C405.13.1 Renewable energy certificate documentation: Adds a documentation requirement for renewable energy credits (RECs).
- C406.5 On-site renewable energy: Ensures that any on-site renewable energy systems used to meet the new renewable energy requirements are not also used to comply with C406.
- C405.15 Energy storage infrastructure: Requires the reservation of a limited amount of physical space in the electrical room and electrical panel.

Medium Office **Mixed-Fuel Scenario**

The single-largest impact on first cost for the mixed-fuel medium office building prototype is the cost of EV infrastructure. (The same holds true for the all-electric medium office prototype.) For this application, basic electric readiness, covering space and water heating needs, costs $0.09/sf. An upfront cost of $4,465 presents a reasonable first cost to future-proof for electric replacements in a building of this size. A summary of the measure-by-measure incremental first costs for the mixed-fuel pathway of the Building Decarbonization Code is presented in Table 29.

Table 29: Mixed-Fuel Incremental Cost Summary (Medium Office)

Code Section	Measure Description	Incremental First Cost/sf (Savings)	Incremental First Cost Whole Building (Savings)
C403.4.1.6	Demand Responsive Controls	$0.12	$6,500
C405.2	Demand Responsive Luminaire Level Lighting Controls	*$0.12**	*$6,500*
C405.12.2	Energy Use Categories (EV Sub-Metering)	$0.02	$823
C405.13	On-site renewable energy	$0.40	$21,200
C405.14	EV Charging Infrastructure	$10.70	$573,731
C405.16	Electric Infrastructure (potential capacity impact)	$0 - $0.17	$0 - $9,082
C405.16.2	Electrification Readiness for water heating equipment	$0.03	$1,361
C405.16.3	Electrification readiness for other combustion equipment (space heating)	$0.06	$3.104
C406.1	Additional energy efficiency credits	$0.40	$21,200
	Total	**$11.71 - $11.88**	**$627,919 - $637,001**

C403.4.1.6 **Demand Responsive Controls**

This section requires that thermostatic controls have demand response functionality. This functionality is present in the hardware of baseline thermostats but often not included in the BMS software. Including demand response functionality would require about 100 hours of programming to ensure the software is functional, which adds $0.12/sf to the cost of construction.

Table 30: Demand Responsive Controls (Mixed-Fuel Scenario, Medium Office)

Baseline	Decarbonization Scenario	Incremental First Cost (Savings)
Standard code-compliant seven-day thermostatic controls through a central BMS.	Programming a standard BMS to incorporate grid-flexibility functionality (100 hours of programming as per Siemens).	$0.12
--	$0.12/sf	

C405.2 Lighting Controls

This section requires that luminaire level lighting controls (LLLC) have demand response functionality built in. These controls are not common in medium office buildings (they are more common in large office buildings). As a result, the cost of the requirement is included as a standalone cost for reference only. The cost is not included in the whole-building results. Like demand responsive thermostats, the hardware in code compliant LLLC supports demand response, but the LLLC would require programming, adding $0.12/sf to construction costs.

Table 31: Lighting Controls (Mixed-Fuel Scenario, Medium Office)

Baseline	Decarbonization Scenario	Incremental First Cost (Savings)
Code-compliant LLLC	Programming a standard LLLC BMS to incorporate grid-flexibility functionality (100 hours of programming as per Siemens)	$0.12
--	$0.12/sf	

C405.12.2 Energy Use Categories

This section requires the addition of an additional sub-metering category for EV loads. Costs assume that the load categories have been separated in the electrical system design in both the baseline and decarbonization scenarios.

Table 32: Energy Use Categories (EV Sub-Metering) (Mixed-Fuel Scenario, Medium Office)

Baseline	Decarbonization Scenario	Incremental First Cost (Savings)
Code-compliant metering system with sub-meters for HVAC, SWH, lighting and plug loads	Baseline system with one additional sub-meter for EV loads	$0.02
$0.09/sf	$0.11/sf	

C405.13 On-site Renewable Energy

This section requires the installation of an on-site renewable energy system to meet the requirement of 0.25W/sf for the first three floors of the office building. Because the prototype office building is a 53,600-sf, three-story medium office building, meeting this requirement merits a 13kW on-site renewable energy system. Under an LCCA it is likely the first cost would be immediately offset by the production of solar energy.

Table 33: On-site Renewable Energy Systems (Mixed-Fuel Scenario, Medium Office)

Baseline	Decarbonization Scenario	Incremental First Cost (Savings)
No on-site renewable energy system	13kW on-site renewable energy system, including panels, disconnect, inverter, racking, supports, meter, etc.	$0.40
$0.09/sf	$0.40/sf	

C405.14 Electric Vehicle Charging Infrastructure

This section requires the installation of EVCI. Cost analysis is based on 30 EVSE spaces using a 200-space parking lot sized for the building based on typical parking requirements.

Some project teams choose an EV charging solution that includes billing services in order to manage charging costs or electrical load. Such EVSEs are more expensive than their more basic counterparts. Due to the defined methodology looking at the most reasonable cost, the EVSE chosen for this costing exercise do not include billing services, as such add-ons are not required for compliance with the Building Decarbonization Code.

Table 34: Electric Vehicle Charging Infrastructure (Mixed-Fuel Scenario, Medium Office)

Baseline	Decarbonization Scenario	Incremental First Cost (Savings)
No EVCI	EVCI meeting decarbonization requirements including: • 15 dual-head EVSE with pedestals providing 30 EVSE spaces: includes earthwork, raceways, wiring, breakers, junction boxes, etc. • 80 EV Capable spaces: includes earthwork, raceways and junction boxes • Additional 800A panel board • Additional 300kVA transformer with raceways, wiring, etc.	$10.70
--	$10.70/sf	

C405.16 Additional Electric Infrastructure

The potential first cost impact of up sizing the electrical service for the medium office building prototype is captured in this section. Electrical service sizes are not granular. Where infrastructure sizes are poorly matched to building loads (excess unused capacity), electrification of new loads is less likely to trigger an electric infrastructure capacity upgrade. Where electric infrastructure capacity is well-matched to building loads (little unused capacity), electrification of new loads is more likely to trigger an upgrade. Since up sizing the the electrical service will not be required for all buildings, it is characterized in Table 35 as a range.

Table 35: Electric Infrastructure (All-Electric Scenario, Medium Office)

Baseline	Decarbonization Scenario	Incremental First Cost (Savings)
400A main panel	800A main panel	$0.17
$0.18/sf	$0.35/sf	

C405.16.2 Electrification Readiness for Combustion Water Heating Equipment

This section requires that combustion water heaters with a capacity less than 300,000 Btuh be provided with electrical infrastructure to make a future electrification retrofit more cost-effective. By installing these features during construction, costs will be lower than the cost of retrofitting the same features in a finished building.

Table 36: Electrification Readiness for Combustion Water Heating Equipment (Mixed-Fuel Scenario, Medium Office)

Baseline	Decarbonization Scenario	Incremental First Cost (Savings)
No electrification readiness	208/240V circuit w/30 amps, 30A-2P breaker with #10 wiring upsized from standard #12, increased electrical capacity 10 kW	$0.03
--	$0.03/sf	

C405.16.3 Electrification Readiness for Other Combustion Equipment

This section requires that all other combustion equipment be provided with raceways/conduit/conductors and electrical infrastructure capacity to enable future electrification retrofits. For the medium office prototype, electrification readiness is applied to the central gas boiler providing space heating.

Table 37: Electrification Readiness for Other Combustion Equipment (Mixed-Fuel Scenario, Medium Office)

Baseline	Decarbonization Scenario	Incremental First Cost (Savings)
No electrification readiness	Increased electrical capacity (47 kW); 3 x 80A-3P circuit breakers with 100’ of 4-#3 wire and 1-#6 ground	$0.06
--	$0.06/sf	

C406.1 Additional Energy Efficiency Credits

This section requires mixed-fuel buildings to achieve an additional five credits from Section C406. For the office prototype, this is assumed to be additional on-site renewable energy capacity.

Table 38: Additional Energy Efficiency Credits (Mixed-Fuel Scenario, Medium Office)

Baseline	Decarbonization Scenario	Incremental First Cost (Savings)
No additional efficiency credits	13kW on-site renewable energy system, including panels, disconnect, inverter, racking, supports, meter, etc.	$0.40
--	$0.40/sf	

Single-family new construction.

Measures with No Cost Impact

The following requirements/modifications of the mixed-fuel scenario of the Building Decarbonization Code are assumed to have no or negligible incremental first cost:

- C101.3 Intent: Revises the intent of the code to include GHG reductions in the scope of the code.
- C103.2 Information on Construction Documents: Requires that the fuel source for equipment and electrical pathways for renewable energy, energy storage and EV charging resources be noted on the construction documents.
- C105.2.5 Electrical System: Adds an inspection requirement for the additional electrical infrastructure required by the Building Decarbonization Code.
- C202 Definitions: Adds definitions that are leveraged through the code.
- C402.1.1 Low Energy Buildings: Limits the Low Energy building exemption to all-electric buildings.
- C404.9.1 Heaters: Removes a reference to pilot lights not needed in an all-electric code.
- C404.11 Demand responsive water heaters: Demand responsive controls are only required for certain electric water heaters and the mixed-fuel scenario has gas water heating.
- C405.4.3 Gas lighting: Removes a reference to gas lighting not needed in an all-electric code.
- C405.13.1 Renewable energy certificate documentation: Adds a documentation requirement for renewable energy credits (RECs).
- C406.5 On-site renewable energy: Ensures that any on-site renewable energy systems used to meet the new renewable energy requirements are not also used to comply with C406.
- C405.15 Energy storage infrastructure: Requires the reservation of a limited amount of physical space in the electrical room and electrical panel.
- C405.16.1 Electrification Readiness for Dwelling Units: Requires electrification readiness for fossil fuel loads in dwelling units. Medium office prototype does not contain dwelling units.

Life Cycle Cost Analysis Results – Single-Family Home

Analysis of the cost effectiveness of the decarbonization code accounts for the following two perspectives:

Consumer Perspective

This perspective uses "high cost" and "typical cost" utility rates for gas and electricity in New York State. The analysis includes results for consumers that are enrolled in a TOU program and results for consumers enrolled in a typical program (where electricity rates do not depend on when the electricity is consumed). In this case, consumers in a mixed-fuel home that met the decarbonization code saved money over the analysis period using either TOU or standard electricity rates—in both high cost and typical cost utility rate structures. Consumers in all-electric homes that met the decarbonization code also saved money over the analysis period using a TOU electricity rate under both typical and high cost utility rates. The only consumer that did not experience NPV LCCA savings was the high-cost utility rate consumer in an all-electric home using fixed electricity rates.

Societal/Policy Perspective

This includes all aspects of the consumer perspective and adds to the analysis the societal cost of carbon to give policymakers an understanding of the economic impacts of the policy to society. NPV LCCA results show that societal savings occurred over the analysis period under both high cost and typical cost utility rates for both the mixed-fuel and the all-electric home that met the Building Decarbonization Code requirements using either TOU or standard electricity rates.

Energy Savings Results Summary

Considering energy use alone, the mixed-fuel scenario model reduced total prototype energy consumption by 9% compared to the baseline, while the all-electric model reduced total prototype energy consumption by 34%.

The energy savings between the all-electric and mixed-fuel home is the result of the improved efficiency of heat pump technology for the HVAC and water heating system compared to combustion equipment. The HVAC equipment in the all-electric home, which accounts for roughly half of the home's energy use, is 33% more efficient than the HVAC equipment in the mixed-fuel home. The water heating equipment, which accounts for about 10% of the baseline homes energy use, uses about 75% less energy in the all-electric home. Although much smaller, electric cooking systems also deliver energy savings compared to gas cooking systems.

The relatively small reduction in energy use between the baseline and mixed-fuel single-family home prototype is due to the improved efficiency of the combustion equipment. Heating alone accounts for approximately half the home's energy use. Replacing the code-compliant 80% efficient furnace with a 96% efficient condensing furnace (used to fulfill compliance with R408 under the mixed-fuel overlay) reduces the energy used for heating the by 10%. It is notable that code-minimum heat pumps deliver significant space heating savings over very high-efficiency condensing furnaces, even in Climate Zone 5A. Other end uses such as lighting, interior equipment, and fans remain relatively constant across all single-family home prototypes.

Detailed annual energy consumption for each end use and the total building modeled scenario are shown in Figure 6 and Table 39. Note that these energy models are representative, not predictive, of a particular building or user. These results are meant to be used for comparative purposes between scenarios only. Noteworthy is the fact that in all cases, electrification resulted in reduced energy consumption in the end-use.

Figure 6: Modeled Annual Site Energy Use Single-Family Prototype, Climate Zone 5A

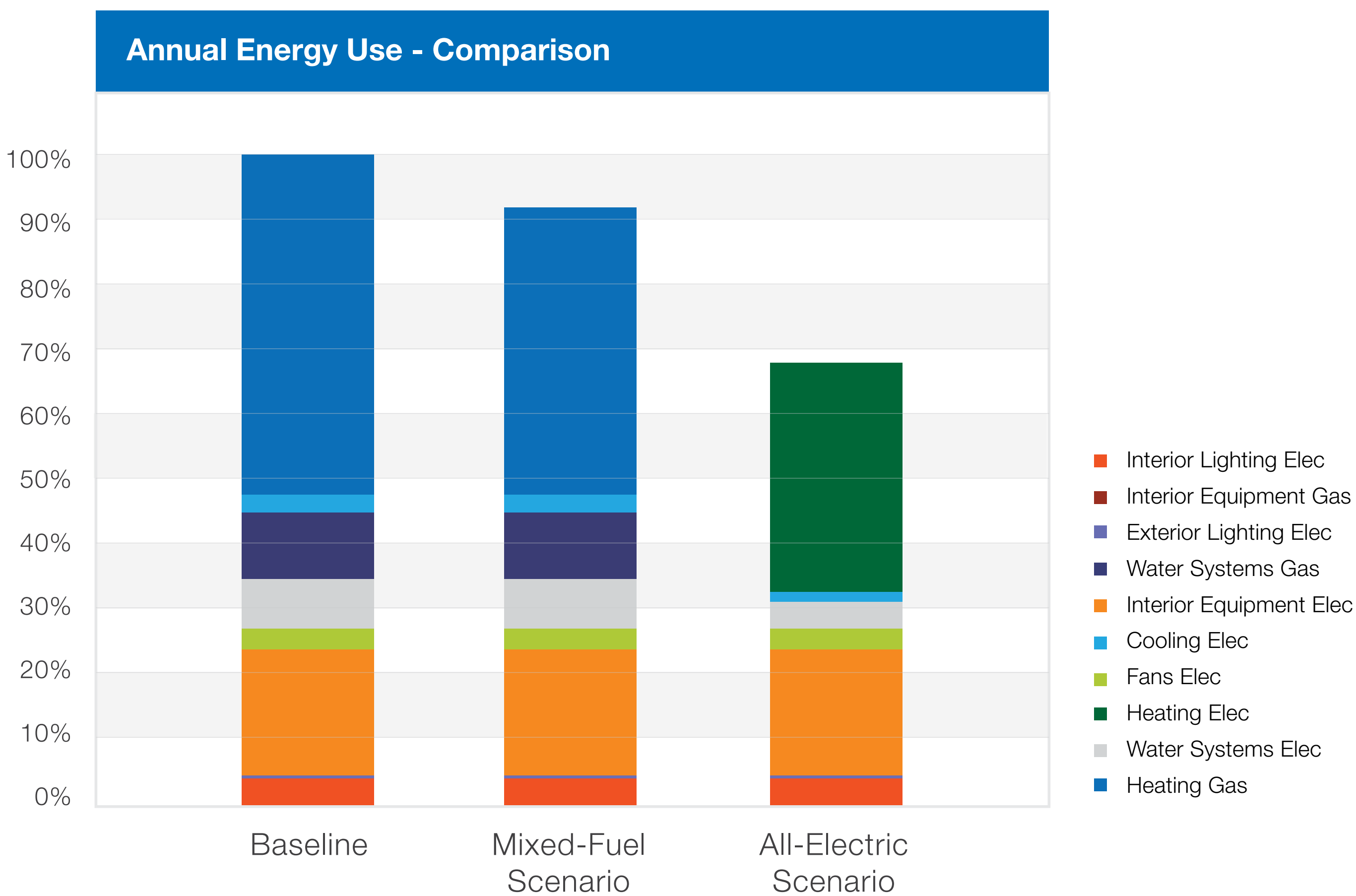
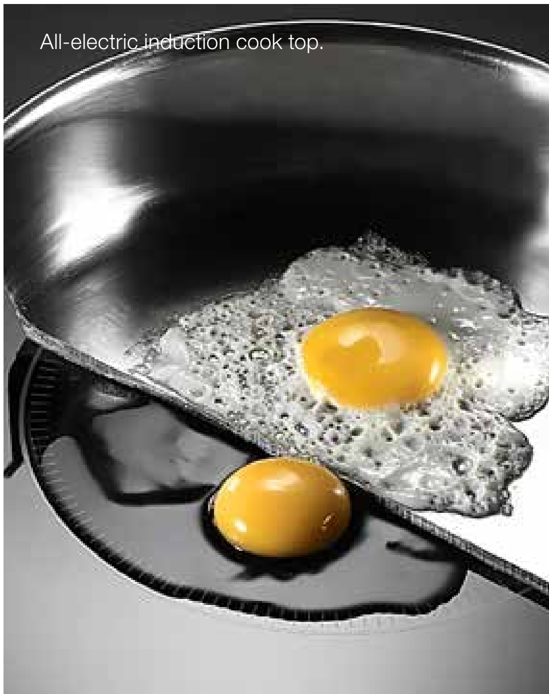


Table 39: Model Annual Energy Use – by End Use and Scenario

	Baseline		Mixed-Fuel		All-Electric	
	Electricity [kBtu]	Gas [kBtu]	Electricity [kBtu]	Gas [kBtu]	Electricity [kBtu]	Gas [kBtu]
Heating	0	71,315	0	63,202	47,984	
Cooling	3,921	0	3,578	0	2,563	0
Interior Lighting	5,314	0	5,314	0	5,314	0
Exterior Lighting	722	0	722	0	722	0
Interior Equipment	29,060	11,014	29,060	11,014	29,940	0
Exterior Equipment	0	0	0	0	0	0
Fans	4,042	0	3,940	0	3,990	0
Pumps						
Heat Rejection	0	0	0	0	0	0
Humidification	0	0	0	0	0	0
Heat Recovery	0	0	0	0	0	0
Water Systems	449	16,948	449	12,698	4,124	0
Refrigeration	0	0	0	0	0	0
Total	43,508	99,276	43,063	86,914	94,637	0


Commercial building battery storage


All-electric induction cook top.

Life Cycle Cost Analysis Results from the Homeowner Perspective

Annual Recurring Costs

The annual cost impact across four cost scenarios were considered in the analysis:

1. **Typical cost with** TOU rates
2. **Typical cost with** fixed rates
3. **High cost with** TOU rates
4. **High cost with** fixed rates

This analysis captures the impact of primary homeowner cost considerations:

Annual mortgage, property tax and tax credits
("Annual Mortgage / Property Tax / Tax Credit")

+

Direct energy costs documented by a utility bill
("Annual Utility Costs")

These two costs are combined to present a **total annual cost impact** ("Total Recuring Annual Costs") and then compared to the baseline to illustrate the difference between scenarios ("Recurring Cost Difference"). All numbers in parentheses represent cost savings rather than increased cost.

Table 40: Annual Recurring Cost Summary

Scenario		Annual Mortgage/ Property/ Tax Credit	Annual Utility Costs	Total Recurring Annual Costs	Recurring Cost Difference
Typical Cost – TOU Rates	Baseline	-	$3,133	$3,133	NA
	Mixed Fuel	$83	$2,987	$3,069	$(63)
	All-Electric	$(612)	$3,456	$2,843	$(290)
Typical Cost – Fixed Rates	Baseline	-	$3,143	$3,143	NA
	Mixed Fuel	$83	$2,998	$3,081	$(62)
	All-Electric	$(612)	$3,763	$3,150	$7.05
High Cost – TOU Rates	Baseline	-	$5,130	$5,130	NA
	Mixed Fuel	$82	$4,858	$4,940	$(190)
	All-Electric	$(591)	$5,118	$4,527	$(603)
High Cost – Fixed Rates	Baseline	-	$5,253	$5,253	NA
	Mixed Fuel	$82	$4,989	$5,071	$(182)
	All-Electric	$(591)	$6,382	$5,791	$538

The all-electric decarbonization scenarios had lower annual mortgage/tax costs due to the decreased incremental first costs, but higher annual utility costs because current gas rates make it a generally less costly energy source compared to electricity.

- With TOU utility rates, the all-electric decarbonization scenario has annual cost savings.
- With fixed utility rates, the all-electric decarbonization scenario has increased annual costs.
- In the typical cost scenario, the increased cost is minor.

The mixed-fuel decarbonization scenario has higher annual mortgage/tax costs due to the increased incremental first costs, but lower annual utility costs due to increased efficiency. When annual recurring costs are taken together, the mixed-fuel decarbonization scenario results in annual savings in every utility rate variation.

Total Life Cycle Costs

Total NPV LCCA over the 30-year analysis period are presented in Table 41, which captures the impact of homeowner cost considerations:

1. Sum of mortgage and property tax payments minus associated tax credits discounted over the analysis period **("Total NPV Mortgage/ Property/Tax credit")**
2. Sum of utility costs for both gas and electricity discounted over the analysis period **("Total NPV Utility Costs")**
3. Sum of the cost of replacing equipment over the course of the 30-year analysis period minus the residual value of equipment with life remaining at the end of the analysis discounted over the analysis period **("Total NPV Replacement Cost and Residual Value")**

The sum of these three costs illustrates the total cost of a home to the homeowner over the course of the analysis period ("Total NPV Life Cycle Cost"). Finally, that cost is compared to the cost of the baseline building ("NPV Life Cycle Cost"). All numbers in parentheses represent cost savings rather than increased cost.

Table 41: Life Cycle Cost Summary – Homeowner Perspective

Scenario		Total NPV Mortgage/ Property/Tax Credit	Total NPV Utility Costs	Total NPV Life Cycle Cost	NPV Life Cycle Cost (Savings)
Typical Cost – TOU Rates	Baseline	$-	$61,674	$7,241	N/A
	Mixed Fuel	$1,780	$58,701	$7,563	$(870)
	All-Electric	$(13,187)	$66,105	$6,546	$(9,451)
Typical Cost – Fixed Rates	Baseline	$-	$61,879	$7,241	N/A
	Mixed Fuel	$1,780	$58,927	$7,563	$(850)
	All-Electric	$(13,187)	$71,982	$65,341	($3,779)
High Cost – TOU Rates	Baseline	$-	$101,103	$108,344	N/A
	Mixed Fuel	$1,729	$95,577	$104,868	$(3,475)
	All-Electric	$(12,395)	$97,906	$92,056	$(16,287)
High Cost – Fixed Rates	Baseline	$-	$103,456	$110,697	N/A
	Mixed Fuel	$1,729	$98,075	$107,367	$(3,330)
	All-Electric	$(12,395)	$122,077	$116,228	$5,531

The LCCA shows that both of the decarbonization scenarios have a life cycle benefit to the homeowner in all cases except the high cost, fixed utility rate scenario. Additionally, unlike the simple annual costs in Table 40, the life cycle benefit of electrification generally exceeds the benefit of the increased efficiency in the mixed-fuel decarbonization scenario.

Life Cycle Cost Results from the Societal Perspective

When establishing policies, decision makers should consider both the direct impact of the policy on consumers and its on society as a whole. In the case of the Building Decarbonization Code, the societal cost of carbon is a particularly significant societal cost. To estimate this impact, this study also assesses life cycle costs including the societal cost of carbon. Table 42 shows the impact of the decarbonization amendments on the carbon emissions released by each building type through building operations over the 30-year analysis period. The first column "Total Carbon Emissions" displays that impact in total metric tons of CO2e emitted. The second column "Carbon Emission Savings" shows the metric tons of CO2e saved by each scenario compared to the baseline building over the 30-year analysis period. To put this in perspective, an average passenger car has emissions of about 4.6 MT CO2e/year.[25] As shown in Table 42, the life cycle carbon savings impact of building electrification is substantial.

Buffalo, New York

25 U.S. Environmental Protection Agency, Greenhouse Gas Emissions from a Typical Passenger Vehicle (https://www.epa.gov/greenvehicles/greenhouse-gas-emissions-typical-passenger-vehicle). Accessed January, 2021. Based on an average fuel economy of 22.0 miles per gallon of gasoline and annual mileage of 11,500 miles.

Table 42: Impact on Carbon Emissions of Operating each Scenario over Analysis Period

Scenario	Total Carbon Emissions (MT CO2e)	Carbon Emission Savings (MT CO2e)
Baseline	189.01	N/A
Mixed-Fuel	168.96	20.05
All-Electric	62.79	126.22

Table 43 shows the NPV life cycle cost impact from a societal perspective. The estimated benefit of these reduced carbon emissions was calculated by multiplying the carbon emission savings in each year by the societal cost of carbon in that year at a 2% discount rate. In all cases, NBI's decarbonization code produced life cycle cost savings to society compared with a baseline home. Life cycle cost savings for all-electric requirements yielded the largest life cycle cost savings under the high cost time of use scenarios. Life cycle cost savings were lowest for the mixed-fuel home under the typical cost fixed-rate scenario.

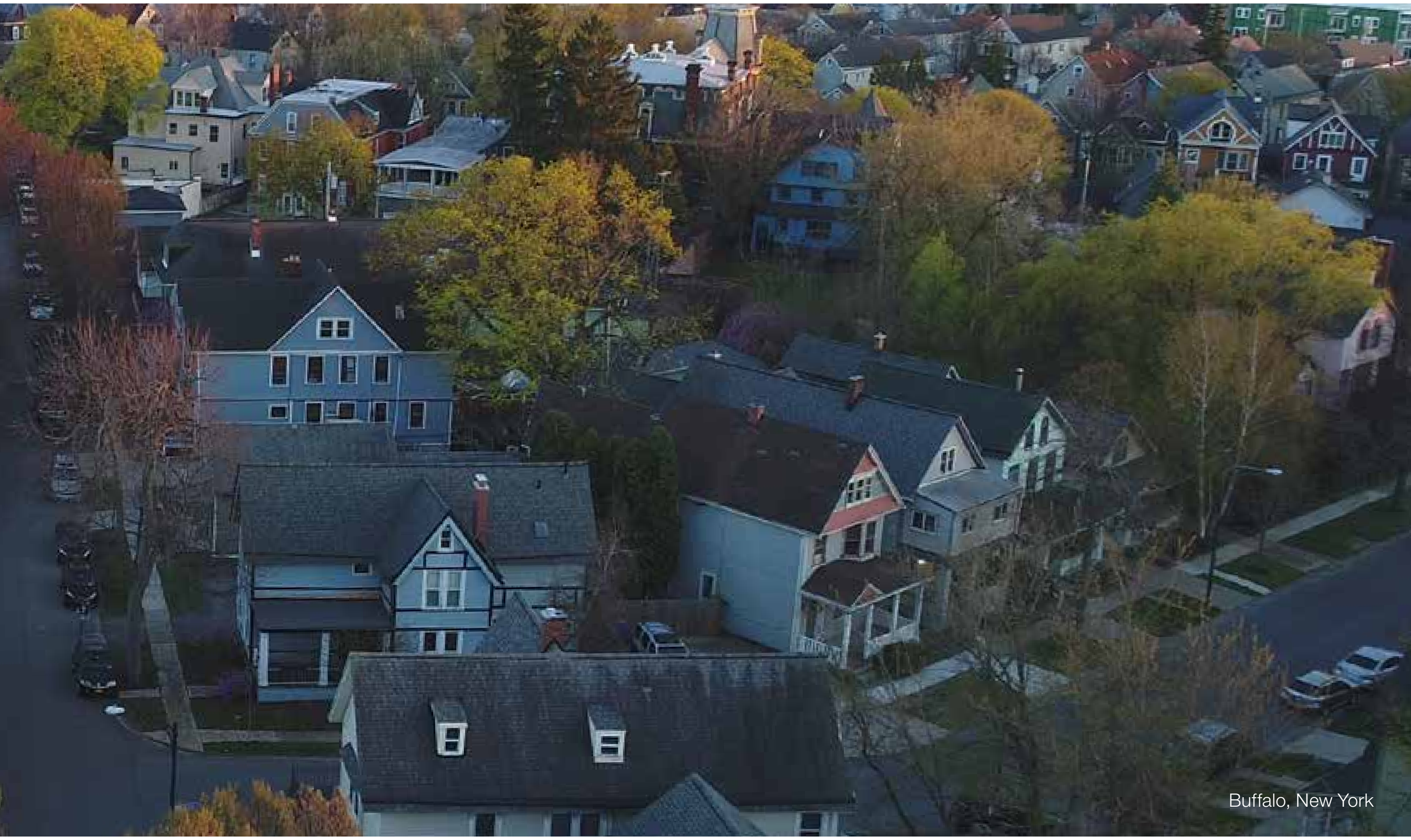

Buffalo, New York

Table 43: Life Cycle Cost Summary – Societal Perspective

Scenario		Total NPV Mortgage/ Property/Tax Credit	Total NPV Utility Costs	Total NPV Replacement Cost and Residual Value	Total NPV Societal Cost of Carbon	Total NPV Life Cycle Cost	NPV Life Cycle Cost (Savings)
Typical Cost – TOU Rates	Baseline	$-	$73,283	$8,645	$18,050	$99,978	N/A
	Mixed Fuel	$2,132	$69,741	$8,994	$13,447	$94,313	($5,665)
	All-Electric	$(15,794)	$78,329	$8,067	$5,450	$76,051	($23,927)
Typical Cost – Fixed Rates	Baseline	$-	$73,527	$8,645	$18,050	$100,221	N/A
	Mixed Fuel	$2,132	$70,008	$8,994	$13,447	$94,580	($5,641)
	All-Electric	$(15,794)	$85,292	$8,067	$5,450	$83,015	($17,206)
High Cost – TOU Rates	Baseline	$-	$120,147	$8,645	$18,050	$146,841	N/A
	Mixed Fuel	$2,066	$113,561	$8,994	$13,447	$138,068	($8,773)
	All-Electric	$(14,814)	$116,009	$8,067	$5,450	$114,712	($32,130)
High Cost – Fixed Rates	Baseline	$-	$122,936	$8,645	$18,050	$149,630	N/A
	Mixed Fuel	$2,066	$116,522	$8,994	$13,447	$141,028	($8,602)
	All-Electric	$(14,814)	$144,650	$8,067	$5,450	$143,353	($6,277)

The all-electric decarbonization scenarios yielded the highest NPV life cycle cost savings for both consumers and society for households experiencing both TOU utility rates and typical fixed-rates. Societal NPV life cycle cost savings were still positive but lower for households with high-cost fixed rates. The analysis found that consumers experiencing high-cost fixed rates could experience higher costs than the baseline scenario. Policymakers should consider ways to reduce the impact of these higher costs to households with higher energy burden.

Key factors that contribute to the cost savings from the all-electric decarbonization strategy include the avoided cost of installing fossil fuel infrastructure, the specific electrification strategy, and the electrical infrastructure costs relative to the size of the building load. This study found that electrifying during new construction is more cost effective than implementing electrification readiness, and notably that it is significantly more cost-effective than retrofitting for electrification.

The mixed-fuel decarbonization scenario yielded positive NPV life cycle cost savings for both consumers and society across all utility rate structures. However, both households and society save less money under the TOU and typical utility rate structures than they would under an all-electric decarbonization scenario. The only scenario where a mixed-fuel decarbonization scenario saved more money to both consumers and society than the all-electric decarbonization scenario was under the high cost fixed utility rate scenario.

Albany, New York

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Codes for Climate is an initiative of NBI and RMI to deliver the climate-aligned building codes and standards needed by U.S. states and cities in the face of the pressing demands of policy goals. To scale greenhouse gas reductions in the buildings sector to be in step with a 1.5ºC future, the initiative works to support policy makers at multiple levels to move codes and standards forward, making significant reductions in energy consumption and GHG emissions from buildings possible and effective. The Decarbonization Code supports the goals of the Codes for Climate Initiative. Visit **codesforclimate.org.**

151 SW 1st Ave.
Portland, OR 97204
503 761 7339

New Buildings Institute (NBI) is a nonprofit organization driving better energy performance in buildings to make them better for people and the environment. We work collaboratively with industry market players—governments, utilities, energy efficiency advocates, and building professionals—to promote advanced design practices, innovative technologies, public policies, and programs that improve energy efficiency and decarbonization of the built environment. Visit **gettingtozeroleadership.org** to learn more.