Driving Decarbonization with Codes

Sean Denniston, New Buildings Institute
Diana Burke, New Buildings Institute
Lauren Urbanek, Natural Resources Defense Council
Alejandra Mejia-Cunningham, Natural Resources Defense Council

ABSTRACT

As energy codes continue to advance, it is becoming clear that energy efficiency alone will not provide the carbon emission savings needed to reach our climate goals. Not all energy has the same carbon impact, so quantity of energy consumed alone does not provide a clear view of carbon performance. A shift from energy efficiency and performance alone to a focus on decarbonization results in different priorities and different code requirements from traditional energy codes. By combining measures that address energy efficiency, electrification, grid flexibility, and renewable energy, NBI's Building Decarbonization Code transforms traditional energy codes like the International Energy Conservation Code and ASHRAE Standard 90.1. These four foundations of decarbonization allow the code to address not just energy use in buildings, but shifts the focus to carbon emissions by focusing on what kind of energy and when that energy is used. Recognizing that not all jurisdictions are ready to transition to all-electric buildings now, the Building Decarbonization Code includes both an all-electric and a mixed-fuel version, providing multiple decarbonization code options.

This paper will provide an overview of how the Decarbonization Code was created by weaving key decarbonization elements into existing codes. The paper will also cover how the code can prepare mixed-fuel buildings today for easier, more cost-effective electrification retrofits in the future. The paper will also discuss cost effectiveness of the Building Decarbonization Code, including multiple perspectives on cost – from first cost to operational cost to lifecycle cost to social cost – and how a comprehensive approach to decarbonization can support cost effectiveness.

Introduction

Many jurisdictions have ambitious climate-related goals, and over 200 cities have made pledges to achieve 100 percent clean energy or "net zero" emissions. Ensuring that new buildings emit little – or no – carbon is an important component of meeting these goals. As a result, jurisdictions around the country have begun to realize that they cannot meet their climate goals for buildings with energy efficiency alone and have begun to look at building decarbonization policies, such as electrification, grid integration and renewable energy. As the electricity grid is powered by an increasing share of carbon-free renewable energy sources, electrifying end uses in both new and existing buildings will likewise reduce the overall carbon emissions of the building. Buildings with on-site fossil fuel combustion are "locked into" their emissions for the lifetime of the equipment, whereas electrified buildings will see reduced emissions in the same time frame as the overall electricity grid emissions decrease.

In 2019, a coalition developed building decarbonization reach/stretch provisions for California's Title 24 energy code. More than 50 California municipalities have enacted all-electric or electric-preferred requirements for new construction by adopting this language since those reach code provisions were made available. Governments outside of California soon began requesting a similar reach code that could function with their IECC base codes. To address jurisdictions' need to implement decarbonization policies, New Buildings Institute (NBI) released the Building Decarbonization Code, a "code overlay" for the International Energy Conservation Code (IECC) and ASHRAE Standard 90.1 that turns these energy codes into decarbonization codes for both commercial and residential buildings. The Building Decarbonization Code is intended for policy-makers and provides both code language and explanatory language to enable to adopt and adapt the language to the specific needs of a particular jurisdiction.

Recognizing that not every jurisdiction is ready to require all-electric construction in their next code cycle, but many are still looking to begin moving in that direction, the overlay includes both all-electric and electric ready, mixed-fuel paths. The mixed-fuel path includes increased efficiency requirements and electrification-readiness requirements to facilitate more cost-effective future electrification retrofits. For both paths, the overlay also incorporates key decarbonization strategies including solar energy production, electric vehicles charging infrastructure (EVCI), battery storage, and demand responsive controls. Together, these requirements reflect the reality that achieving building decarbonization must consider how much energy is used, how that energy is generated, and when the energy use occurs.

In order to support this overlay, New Buildings Institute undertook a cost effectiveness study for the overlay in partnership with Arup and with funding from NRDC (Natural Resource Defense Council). This project was launched in response to the growing need by state and local governments for "off the shelf" building decarbonization policies. Many cities and states are eager to take tangible steps to achieve their policy goals, but lack the resources to develop their own code language. The Building Decarbonization Code cost effectiveness study provides an incremental first-cost analysis of two building protypes (medium office and single-family buildings) in Climate Zone 5A. It also includes a lifecycle cost analysis (LCCA) for the single-family building type. The analysis will be expanded in the future to include additional building prototypes and climate zones. These two prototypes were chosen for the initial 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 building policy impacts.

The Building Decarbonization Code

The Building Decarbonization Code includes two paths: an all-electric and mixed-fuel.[1] Both paths include requirements for demand responsive controls, renewable energy and electric vehicle charging infrastructure. The all-electric path additionally supports decarbonization through requiring that all building loads be served by electric equipment. The mixed-fuel path additionally supports decarbonization through requiring higher levels of efficiency.

Methodology

There are two cost metrics targeted for the study: incremental first cost and lifecycle cost. This section summarizes the methodology that was used for analyzing both.

---

[1] For the purposes of this study, "mixed-fuel" refers to a building that has both electric and natural gas utilities. This is in contrast to dual-fuel equipment that can operate on either electricity or natural gas.

Building Prototypes

The study uses the prototype building models developed by Pacific Northwest National Lab (PNNL) for the evaluation of national model energy code changes.[2] These prototypes specify building features and components. For this initial phase of the study, one residential and one commercial prototype were chosen: a single-family home and medium office. 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 result in results that are skewed due to design conditions particular to the project. The single-family prototype[3] is based on the 2021 edition of the IECC and the medium office prototype[4] is based on the 2019 ASHRAE Standard 90.1 prototype (Figure 1).

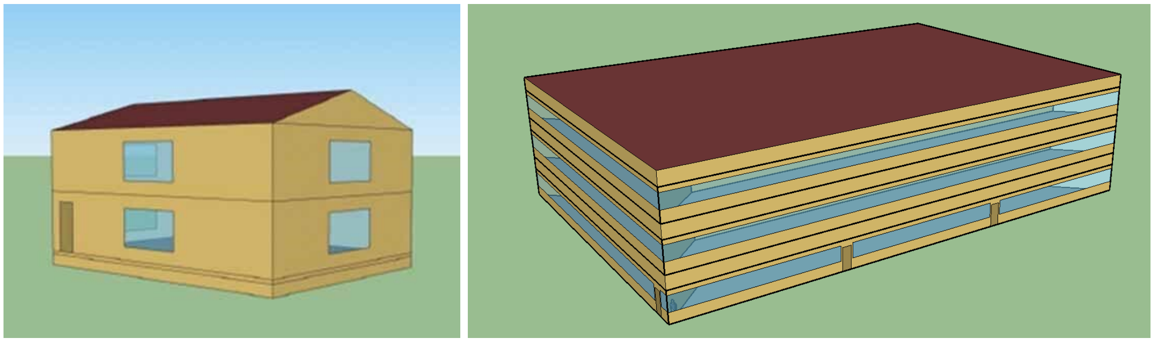

Figure 1: PNNL single-family and medium office prototypes (Source: PNNL)

Location

Climate Zone 5A was selected because of its large geographic footprint nationally, and as representative of a colder climate. This provides insight into operational energy in a heating load-dominated application. New York State was selected as a representative location for CZ 5A in the study because it represents a potentially less favorable scenario for electrification. 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, New York state provides a good test-case for building decarbonization. As such, the results are relevant for locations with milder climates and more affordable markets.

---

[2] U.S. Department of Energy. "Prototype Building Models." Accessed January 2022 via: www.energycodes.gov/prototype-building-models.

[3] The prototype files can be found at 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).

[4] 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).

First Cost Methodology

The first cost analysis assessed incremental cost relative to the 2021 IECC and included direct costs in terms of materials and the cost of labor. Only the costs impacted by the provisions in the Building Decarbonization Code were included in the analysis. All other construction costs were held constant for the purposes of isolating the cost impact of the overlay provisions. The study used the building site as the boundary condition and did not include any offsite fossil fuel infrastructure such as natural gas line extension costs. 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. These offsite impacts can also vary substantially, both in terms of the actual impacts and the costs charged by utilities to individual projects for those impacts. Requirements from the Building Decarbonization Code that simply add additional documentation or verification were assumed to not have a quantifiable cost impact. Other requirements from the Building Decarbonization Code that were not applicable to the building prototype – for example, gas clothes drying – were also excluded from the first cost analysis.

For each measure, the most cost-effective option that provided the needed functionality was chosen; this may or 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; it is this simpler version that more accurately reflects the actual cost premium of the responsiveness.

Cost data Sources

Multiple data sources were used for construction and labor costs including RS Means,[5] past Arup project data from projects of similar size and type, city cost indices, and local and national vendors. The sources are summarized by category in Table 1. All costs were scaled to the average costs in New York State in 2021 dollars.

Table 1: Cost Sources Summary

Cost Category	Sources
Gas infrastructure	RS Means, gordonelectricsupply.com, granger.com
Electric Infrastructure	RSMeans, grainger.com, homedepot.com
HVAC	RSMeans, budgeheating.com, homedepot.com, theacoutlet.com, hvacdirect.com, northerntool.com, granger.com
Water Heating	RSMeans, solutionsstores.com
Controls	RSMeans, rfwel.com, homedepot.com, supplyhouse.com
Residential EVCI	RSMeans, homedepot.com
Commercial EVCI	RSMeans, FLO Services, clippercreak.com
Energy metering	RSMeans, blackhawksupply.com
Renewable Energy	RSMeans, previous Arup project costs

---

[5] RSMeans data from Gordian. Accessed November 2021 via: www.rsmeans.com/.

Labor

The labor rates are 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/hr, a mechanical and plumbing labor rate of $130/hr, and a construction labor rate of $100/hr.

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 Decarbonization Code are held constant between scenarios and are not costed 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 the mixed-fuel scenarios.

Table 2: Summary of building systems for single-family scenarios

Building System	Baseline Mixed-Fuel Scenario	All-Electric Decarb Scenario	Mixed-Fuel Decarb Scenario
Envelope	IECC 2021	IECC 2021	IECC 2021
Lighting	IECC 2021	IECC 2021	IECC 2021
DHW	35 MBH Gas hot water heater	50 Gallon heat pump water heater	35 MBH Gas hot water heater
Demand Responsive DHW	None	CTA-2045 control	None
HVAC	25 MBH Gas furnace, 1.5-ton air conditioner	25 MBH Air source heat pump, 1.5-ton cooling	25 MBH Gas furnace, 1.5-ton air conditioner
HVAC Controls	Code Compliant Thermostat	Demand-responsive thermostat	Demand-responsive thermostat
Cooking	Gas Range & Oven	Electric range & Oven	Gas Range & Oven
Renewable Energy Systems	None	Renewable Energy Ready	Renewable Energy Ready
EVCI	None	1 EV Ready space (dedicated 9.6 kVA branch circuit)	1 EV Ready space (dedicated 9.6 kVA branch circuit)
Additional Efficiency	ERV/HRV	High Performance Heat Pump	HRV/ERV + high-performance gas furnace
Gas Infrastructure	250 CFH Gas regulator & meter	None	250 CFH Gas regulator & meter
Electrical Infrastructure	100A or 200A Panel	200A Panel	200A Panel

Table 3: Summary of building systems for medium office scenarios

Building System	Baseline Mixed-Fuel Scenario	All-Electric Decarb Scenario	Mixed-Fuel Decarb Scenario
Envelope	ASHRAE 90.1-2019	ASHRAE 90.1-2019	ASHRAE 90.1-2019
Lighting	ASHRAE 90.1-2019	ASHRAE 90.1-2019	ASHRAE 90.1-2019
SHW	81 MBH, Code Minimum Gas Boiler	81 MBH Central Heat Pump Water Heater System	81 MBH, Code Minimum Gas Boiler
HVAC	(3) 30 ton Packaged AC unit (3) 110 MBH gas furnace, direct fired	(3) 30 ton Packaged ASHP (3) 100 MBH heating	(3) 30 ton Packaged AC unit (3) 110 MBH gas furnace, direct fired

HVAC Controls	Standard BMS	BMS with Demand Responsive functionality	BMS with Demand Responsive functionality
Renewable Energy Systems	None	13 kW PV system	(2) 13 kW PV system (one for C405.13 and one for C406.1)
EVCI	None	30 EVSE Spaces 80 EV Capable Spaces	30 EVSE Spaces 80 EV Capable Spaces
Gas Infrastructure	720 CFH Gas regulator & meter	None	720 CFH Gas regulator & meter
Electrical Infrastructure	400A or 800A Panel	800A Panel	800A Panel

Life Cycle Cost Analysis Methodology (Single Family Homes)

The study included a life cycle cost analysis (LCCA) for the single-family home building type.[6] The single-family prototype was chosen because residential occupancies are generally more sensitive to operational cost impacts than commercial occupancies and housing affordability is a critical issue in the larger discussion of decarbonization and electrification. The LCCA utilized first costs from the study combined with an analysis of the energy use of the building prototype and lifecycle variables. The LCCA 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:[7]

- The analysis included the social cost of carbon. Although the social 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.
- This analysis included 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 included multiple utility cost scenarios, including both typical-cost and high-cost scenarios for both fixed and time of use electricity prices.

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.

Importantly, the LCCA did not include future retrofit costs for the mixed-fuel baseline, such as an EV-charger, rooftop solar panels, and equipment and wiring for space heating electrification, water heating electrification or appliance electrification.[8] The LCCA also does not include any associated costs or cost savings from EV ownership instead of a gasoline-powered vehicle. As such, this analysis presents an extremely conservative approach, as these cost savings would likely significantly improve the cost effectiveness of the all-electric and mixed-fuel application of the Building Decarbonization Code.

---

[6] The scope of the 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 the study.

[7] "Methodology for Evaluating the Cost Effectiveness of Residential Energy Code Changes"

[8] 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.

Annual Energy Use

The PNNL single-family residential prototype used for the first cost analysis was also used to determine annual energy usage 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^{TM} (Version 9.5) software, to demonstrate the energy savings that can be achieved through energy conservation measures and electrification. The models were simulated using the Typical Meteorological Year 3 (TMY3) weather file for Climate Zone 5A for Buffalo, NY.

Annual Carbon Emissions

Carbon emissions from electricity were calculated by multiplying the hourly profile of the building's electricity use over the course of a year by the estimated hourly profile of carbon emissions from electricity estimated for New York State using the National Renewable Energy Laboratory Cambium data set.[9] The reduction in carbon emissions was based on New York State's current target to generate 70% of electricity from renewable energy by 2030 and for 100% to be carbon free by 2040.[10] NBI estimated carbon emissions from natural gas consumption in the home using EPA's published emission factor from natural gas.

Life Cycle Cost Analysis Parameters

The DOE LCCA methodology was used for most of the LCCA parameters, including the term, escalation rate, and mortgage terms. The LCCA was run for two utility cost scenarios to give a range to the results. These scenarios – denoted as "typical" and "high" 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. The costs for the typical-cost scenario were drawn from the Buffalo market to represent a midpoint between rural and metropolitan markets in New York state. The costs for the high-cost scenario were drawn from the New York City market.[11]

The study includes rates for electricity for customers enrolled in either standard rate structure where the price of electricity is fixed over time or a utilities' time-of-use program where the electricity rate changes depending on the time of day and year. The study assumes electricity and gas rates rise according to the reference case scenario in U.S. EIA's Annual Energy Outlook.

These variables resulted in four cost scenarios for each decarbonization path in the Building Decarbonization Code which serve to frame the range of potential life-cycle costs. 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.

---

[9] Standard scenario, mid-case hourly carbon emissions for New York state.

[10] *Amendment to the 2015 State Energy Plan.*

[11] 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.

First Costs Results (Single Family and Medium Office)[12]

Table 4 includes a whole-building summary of the first cost impacts from the study with detailed results in Table 5, Table 6, Table 7 and Table 8. Infrastructure impacts create a range in the results. The standard capacities for electric infrastructure – utility service, wiring, switchgear, panels, transformers, etc. – are often not very granular, and there can be large jumps between typical sizes. As a result, some buildings could have substantial unused electrical capacity and can tolerate additional electrical loads without any impact on infrastructure sizing while other buildings will have little unused capacity and can incur costs for upsizing infrastructure as a result of even minor additional loads. To address this variability, first costs are presented as a range both with and without onsite electrical infrastructure upsizing costs.

Table 4: Summary of Incremental First Costs (Savings)

Scenario		Building System Costs		EVCI Costs		Total	
		Cost / ft^2	Cost / building	Cost / ft^2	Cost / building	Cost / ft^2	Cost / building
Single-family	All-electric	**($2.35) – ($2.15)**	**($7,651) – ($8,361)**	$0.03	$115	**($2.12) - ($2.32)**	**($7,536) – ($8,246)**
	Mixed-fuel	$0.28 - $0.48	$936 - $1,646	$0.03	$115	$0.32 - $0.52	$1,051 - $1,761
Medium Office	All-electric	$0.33 - $0.50	$17,265 - $26,326	$10.70	$573,731	$11.03 - $11.20	$590,996 - $600,057
	Mixed-fuel	$1.03 - $1.20	$54,188 - $63,270	$10.70	$573,731	$11.73 - $11.90	$627,919 - $637,001

An all-electric single-family home is $7,500 to $8,200 cheaper to construct than the baseline code home. This is due to the substantial savings from eliminating the need for fossil fuel infrastructure in the building and on the site. For jurisdictions not ready to require electrification, the electric-ready, mixed-fuel single-family home has an incremental cost of $1,000 to $1,700. This would be equivalent to the cost of upgrading to a typical stone kitchen countertop.

For the medium office prototype, the first cost for both the all-electric and mixed-fuel scenarios was higher than the baseline, with total costs ranging from approximately $600,000 to $640,000 (about $11-12/ ft^2), 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/ ft^2.

---

[12] At the time of writing this paper in 2022, the US is experiencing significant supply issues for building materials, including the kinds of equipment that is critical to this study. The costs in the study were based on pricing from before those issues fully emerged and may not reflect current construction and material costs.

Table 5: All-Electric Incremental First Cost Summary (Single-family)

Code Provision	Measure	Incremental First Cost/ ft^2 (Savings)	Incremental First Cost (Savings)
R401.2	Application (All-electric building)	**($2.63 - $2.43)**	**($9,367) - ($8,657)**
	- *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 - $0.20*	*$0 - $710*
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)**	**($8,361) – ($7,651)**
Italicized line items represent a breakdown of the costs of the line item above.			

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. There are several key observations from these results:

- The all-electric home results in first-cost savings for equipment alone and the cost savings are not just due to the elimination of the natural gas infrastructure. One frequent response to the concept of all-electric construction is that electric equipment costs more than its gas counterparts. However, the all-electric home saw first cost savings for space conditioning, water heating and cooking. It is likely that the safety features that have been mandated for natural gas equipment and appliances have eliminated any cost advantage that may have previously existed.
- The cost of a potential upgrade to the electric infrastructure reflects the cost of moving from a 100A to a 200A service and panel. In many markets, a 200A panel is becoming standard for a single-family home, making this cost less likely to be incurred. It is also important to note that a 3,600 ft^2 all-electric home with EV charging in New York's climate can be served by a 200A panel. This is a result of the efficiency of the 2021-IECC baseline home.
- The cost for demand responsive water heating includes the cost of upgrading to a heat pump water heater (HPWH). At the time of the study, the only water heaters that implement built-in demand responsive controls are HPWHs. This explains the higher cost for this measure; however, this also means that the measure has the potential to contribute energy savings to lifecycle cost-effectiveness.
- Although EVVCI is a significant cost for the medium office prototype, it is a minor cost for the single-family home.

Table 6: Mixed-Fuel Incremental First Cost Summary (Single-family)

Code Section	Measure Description	Incremental First Cost/ ft^2 (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**
	Total	**$0.32 - $0.52**	**$1,051 - $1,761**

*Not included in whole-building total as the Building Decarbonization Code does not require electrification readiness for heating when cooling is provided.

For the single-family prototype, the mixed-fuel decarbonization scenario resulted in marginally increased first costs between $1,051 and $1,761. There are several key observations from these results:

- In most cases, electrification-readiness requires only the addition of a simple 240V branch circuit. During new construction, when an electrician is already onsite and the walls are open, this is not a significant cost.
- The total electric demand of the mixed-fuel and all-electric scenarios is the same, so the observations about service size from the all-electric scenario apply to the mixed-fuel as well.
- The demand responsive water heating requirement only applies to electric water heaters, so there is no cost for that measure in the mixed-fuel scenario.
- The scenario is assumed to have space cooling. The Building Decarbonization Code does not require space heating electrification-readiness when space cooling equipment is provided since it assumes that a future electrification retrofit would just replace the air conditioning equipment with a heat pump that can handle space heating and cooling. Therefore, the cost of space heating electrification is not included in the whole-building total.

Table 7: All-Electric Incremental First Cost Summary (Medium Office)

Code Provision	**Measure**	**Incremental First Cost/ ft^2 (Savings)**	**Incremental First Cost Whole Building (Savings)**
C401.2	Application (All-electric building)	($0.07 - $0.24)	($13,115) – ($4,054)
	- *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
C405.13	On-site renewable energy	$0.40	$21,200
C405.14	EV Charging Infrastructure	$10.70	$573,731
	Total	**$11.03-$11.20**	**$590,996 - $600,057**

Italicized line items represent a breakdown of the costs of the line item above.
*Not included in whole building total since LLLC is not part of the prototype.

While the whole-building impact of the all-electric scenario results in an incremental first cost of just over \$11/ ft^2, it results in cost savings for the primary building systems (HVAC, water heating, and electrical). There are several key observations from these results:

- The single largest impact on first cost for the all-electric medium office building is the cost of EV infrastructure – representing 97.0% to 98.5% of the incremental first cost. This is driven largely by the cost of bringing this infrastructure to a parking lot. The scenario for EV infrastructure was intended to represent a high level of penetration for EV use and EV charging in a parking lot at 15% EVSE spaces and 40% EV Capable spaces. Most jurisdictions are likely to consider more modest requirements with lower levels of cost.
- The first cost increase for service water heating was driven primarily by the system selected in the scenario and highlights an important lesson about building electrification. The mixed-fuel prototype includes a central gas boiler for water heating as that is a cost-effective solution. The all-electric scenario just replaced that boiler with a central HPWH system. However, the medium office likely could have been more cost-effectively electrified by replacing the central boiler with electric storage water heaters distributed around the building for lavatories and kitchenettes. This highlights the reality that cost-effective electrification will often require fundamental changes to design choices. Simply swapping natural gas equipment for electric equipment, as was done in the case of SWH, can lead to unnecessary cost increases.
- The Building Decarbonization Code only requires demand response lighting controls when LLLCs are installed. LLLCs are not required by the underlying code and a medium office is unlikely to have LLLC. Therefore, the cost of demand responsive LCCC is not included in the whole-building total.

Table 8: Mixed-Fuel Incremental Cost Summary (Medium? Office)

Code Provision	**Measure**	**Incremental First Cost / ft^2 (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**
*Not included in the whole-building total.			

Similar to the all-electric office, the single largest impact on first cost for the mixed-fuel medium office building is the cost of EV infrastructure.

- For this application, basic electric-readiness, covering space and water heating needs, costs only $0.09/square foot. This upfront cost of $4,465 presents a reasonable first cost to future proof for electric replacements in a building of this size.
- The additional energy efficient credit requirement was met with additional onsite renewable energy production; therefore, the incremental cost is the same as the on-site renewable energy requirement.

Life Cycle Cost Analysis Results (Single Family)

Annual Energy Use

The LCCA, performed only for the single-family building scenario, begins with the energy impact of the Building Decarbonization Code's all-electric and mixed-fuel paths (Figure 2). The mixed-fuel scenario model reduced total prototype site energy consumption by 9% compared to the baseline. This is driven primarily by the Building Decarbonization Code's requirement to adopt an additional R408 package of increased efficiency measures in the mixed-fuel scenario. The all-electric model reduced total prototype energy consumption by 34%. The energy savings for the all-electric scenario is the result of the improved efficiency of heat pump technology for the HVAC and water heating system compared to combustion equipment.

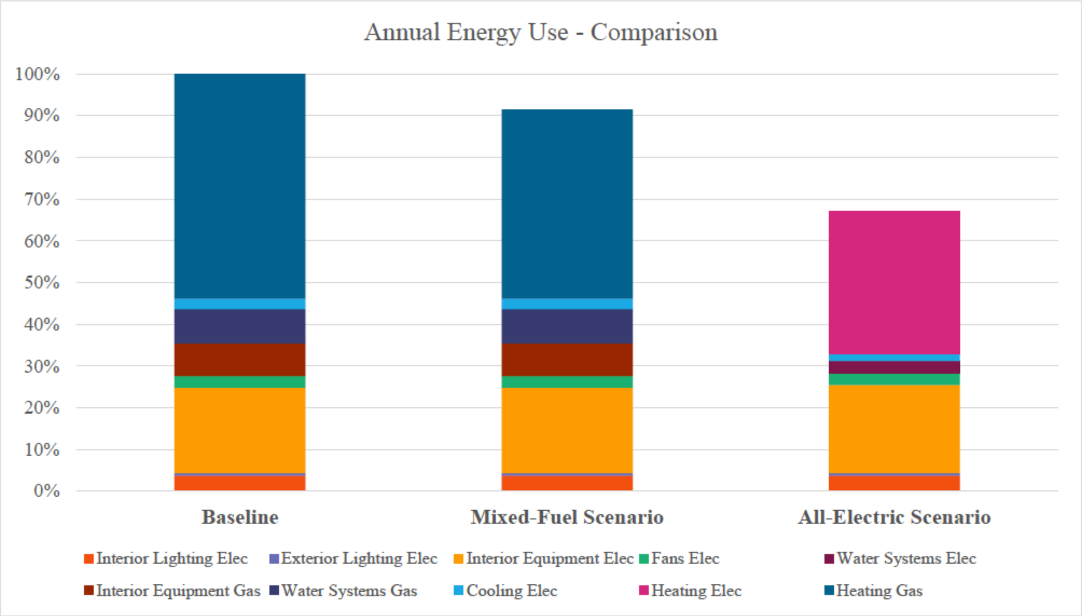

Figure 2: Modeled Annual Site Energy Use for the Single-Family Prototype, CZ 5A

The annual energy use was converted into utility costs using the four utility scenarios described above: high and typical TOU rates and high and typical fixed rates. These costs were then used together with the other LCCA parameters as described in the Life Cycle Cost Analysis Methodology section above. The annual cost impact is summarized in Table 9 and reveal some important takeaways:

- The all-electric decarbonization scenarios had lower annual mortgage/tax costs due to the decreased incremental first costs, but higher annual utility costs due to gas rates make it a generally less costly energy source than 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, but in the typical cost scenario that increased cost is very 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 all annual recurring costs are taken together, the mixed-fuel decarbonization scenario results in annual savings in every utility rate variation.

Total Lifecycle Costs

Total net present value lifecycle impacts over the 30-year analysis period from the homeowner perspective are presented in Table 9. The life cycle analysis shows that both of the decarbonization scenarios have a lifecycle benefit to the homeowner in all cases except the high cost, fixed utility rate scenario. Additionally, unlike the simple annual costs, the lifecycle benefit of electrification generally exceeds the benefit of the increased efficiency in the mixed-fuel decarbonization scenario. This reveals a critical issue for electrification policy. Rate structure has a significant influence on the utility cost impact of electrification for single-family residences. The time of day that corresponds to lower TOU rates has a relatively high level of correlation to the times that buildings will need space heating. This is the source of the advantage of TOU rates for electrification.

Table 9: Annual and Lifecycle Cost Summary (Single Family)

Scenario		Annual Mortgage/ Property/ Tax Credit Impact (Savings)	Total Annual Utility Costs	Recurring Cost Impact (Savings)	Total NPV Life Cycle Cost	NPV Life Cycle Cost (Savings)
Typical Cost – TOU Rates	Baseline	-	$3,133	NA	$68,915	N/A
	Mixed-Fuel	$83	$2,987	$(63)	$68,045	($870)
	All-Electric	$(612)	$3,456	$(290)	$59,464	($9,451)
Typical Cost – Fixed Rates	Baseline	-	$3,143	NA	$69,120	N/A
	Mixed -Fuel	$83	$2,998	$(62)	$68,270	($850)
	All-Electric	$(612)	$3,763	$7	$65,341	($3,779)
High Cost – TOU Rates	Baseline	-	$5,130	NA	$108,344	N/A
	Mixed-Fuel	$82	$4,858	$(190)	$104,868	($3,475)
	All-Electric	$(591)	$5,118	$(603)	$92,056	($16,287)
High Cost – Fixed Rates	Baseline	-	$5,253	NA	$110,697	N/A
	Mixed-Fuel	$82	$4,989	$(182)	$107,367	($3,330)
	All-Electric	$(591)	$6,382	$538	$116,228	$5,531

When establishing policies, policymakers consider both the direct impact of the policy on consumers and the impact of the policy on society as a whole. In the case of the Building Decarbonization Code, the social cost of carbon is a particularly significant societal cost. Table 10 shows the impact of the Building Decarbonization Code on the carbon emissions released by each building type through building operations over the 30-year analysis period. As can be seen in the table, the lifecycle carbon savings impact of building electrification is substantial. To put this in perspective, an average passenger car has annual emissions of about 4.6 MT CO_2e.[13]

Table 10: Lifecycle impact on Carbon Emissions of Operating each Single-Family Scenario

Scenario	Total Carbon Emissions (MT CO_2e)	Carbon Emission Savings (MT CO_2e)
Baseline	189.01	N/A
Mixed-Fuel	168.96	20.05
All-Electric	62.79	126.22

Table 11 shows the NPV life cycle cost impact from a societal perspective when including the social cost of carbon.[14] In all cases, the Building Decarbonization Code produced life cycle cost savings compared with a baseline home from a societal perspective. 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.

Table 11: 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 Social 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)

Conclusion and Key Findings

The results of this study strongly support the decarbonization of buildings through either the Building Decarbonization Code's mixed-fuel or all-electric paths. On a lifecycle basis, all of the scenarios were cost effective, with the exception of the high-cost, fixed-rate all-electric scenario. New York state's cold climate, relatively high utility costs and relatively expensive labor make New York a very conservative test case for demonstrating cost effectiveness of

---

[13] *Greenhouse Gas Emissions from a Typical Passenger Vehicle*. Based on an average fuel economy of 22.0 miles per gallon of gasoline and annual mileage of 11,500 miles.

[14] The social cost of carbon was based on the standard set by the Biden Administration in 2021. *Technical Support Document: Social Cost of Carbon, Methane, and Nitrous Oxide: Interim Estimates under Executive Order 13990*.

building decarbonization as a whole. It is reasonable to conclude that milder climates and markets with less costly electricity and labor costs will see an improvement for the cost-effectiveness of electrification. In addition, the study also revealed other key findings and recommendations for policy-makers pursuing building decarbonization in codes:

- The avoided costs from not installing fossil fuel infrastructure are a key component to the cost effectiveness of the all-electric decarbonization scenario. Partial electrification is therefore less cost-effective since it lacks those cost savings.
- Wholistic electrification is key to the cost effectiveness of all-electric construction. Simply swapping a piece of fossil fuel equipment with an equivalent piece of 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 (see discussion in the all-electric medium office results above).
- Electric infrastructure sizes are not granular, making the cost impact of electrification and electrification readiness dependent on how closely the infrastructure capacity of a particular project corresponds to the planned loads of that project.
- The all-electric home uses less energy, but can still result in higher utility bills today due to the fact that electricity is currently more expensive than natural gas. Utility rates and schedules are a driving factor for lifecycle cost-effectiveness of the all-electric scenario. While lower electricity rates make a difference, the expansion of the availability to take advantage of TOU and other rates that are closer to real marginal costs would encourage electrification as well.
- The retail market for natural gas is more volatile than the retail market for electricity. Therefore, the all-electric scenario has the additional benefit of better insulating building occupants from utility cost volatility.
- The cost savings from the elimination of on-site natural gas infrastructure are a critical component of the lifecycle cost effectiveness of electrification in the single-family scenario and would likely be critical in other building types as well.
- Financing a home intensifies the impact of the first cost savings since those avoided construction costs get translated into avoided financing costs.
- The single family LCCA includes the first cost for EVCI, but does not include the ongoing cost savings that generally result from electric vehicle ownership (lower fuel and maintenance costs in particular). The LCCA also does not include the cost savings due to the lower social cost of carbon of electric vehicle ownership. Including these factors would substantially improve the LCCA.
- Mixed-fuel homes built to the code baseline will face electrification retrofit costs within the 30-year analysis period. These retrofit costs were not included in the single family LCCA; however, they can be substantial and would improve the lifecycle cost effectiveness of both the all-electric and mixed-fuel scenarios.

Next Steps

The cost study described in this paper is only a proof of concept and blueprint for how to analyze cost effectiveness for decarbonization policies built on requirements like those in the Building Decarbonization Code. It only addresses one climate zone and the lifecycle analysis is only for a single-family prototype. Additionally, it does not include future electrification retrofit costs in the mixed-fuel scenarios, which would have a significant impact on the lifecycle cost analysis. The ultimate goal is to create a simple tool where policy-makers could enter their own climate zone and specific utility data and the tool could return cost effectiveness data for the Building Decarbonization Code that is specific to their jurisdiction. The key next step is to broaden the study with additional building types and climate zones.

References

American Society of Heating, Refrigerating and Air-Conditioning Engineers. 2019. *ANSI/ASHRAE/IES Standard 90.1-2019 -- Energy Standard for Buildings Except Low-Rise Residential Buildings.* New York: The Society.

Interagency Working Group on Social Cost of Greenhouse Gases, United States Government. 2021. *Technical Support Document: Social Cost of Carbon, Methane, and Nitrous Oxide: Interim Estimates under Executive Order 13990.* (www.whitehouse.gov/wp-content/uploads/2021/02/TechnicalSupportDocument_SocialCostofCarbonMethaneNitrousOxide.pdf) Accessed January 2022.

International Code Council. 2021. *International Energy Conservation Code.* Washington DC: ICC.

National Renewable Energy Laboratory. 2021. *Energy Analysis: Cambium.* (www.nrel.gov/analysis/cambium.html). Accessed September 2021.

New Buildings Institute. 2021. *Building Decarbonization Code.* Portland: NBI. (newbuildings.org/resource/building-decarbonization-code/)

New York State Energy Planning Board. 2019. *Amendment to the 2015 State Energy Plan.*

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

U.S Energy Information Administration. 2019. *New York Electricity Profile*. (www.eia.gov/electricity/state/newyork/) Accessed September, 2021.

U.S. Environmental Protection Agency. *Greenhouse Gas Emissions from a Typical Passenger Vehicle*. (www.epa.gov/greenvehicles/greenhouse-gas-emissions-typical-passenger-vehicle). Accessed January, 2021.

---. *Greenhouse Gases Equivalencies Calculator - Calculations and References*. www.epa.gov/energy/greenhouse-gases-equivalencies-calculator-calculations-and-references. Accessed September 2021.