BUILDING ELECTRIFICATION:
EXPLORING AND ADDRESSING AFFORDABILITY CHALLENGES

ABSTRACT

Buildings account for nearly 70% of greenhouse gas emissions in New York City, thus decarbonizing the building stock is critical to reaching NYC climate goals. Energy efficiency and electrification of space and water heating are the two key pathways to reducing buildings' GHG footprint. These strategies not only mitigate carbon emissions due to reduced fossil fuel demands, but also improve resident comfort and health. However, building energy efficiency and electrification come with high price tags, and for affordable housing in NYC, these costs are often higher than market rate housing due to older, inefficient building envelopes and deferred health and safety hazards that pose barriers to energy retrofits. These disparities in access to building decarbonization must be addressed; it is critical that all New Yorkers have access to safe, healthy, efficient, and electrified homes and that low-income renters are not left behind in NYC's transition to a clean energy future. This study was conducted to analyze the missing funding that is required to electrify NYC's rent-stabilized unsubsidized building stock, as well as the analyze the impacts of building electrification on tenant energy bills. Rent-stabilized units make up 44% of all rental units in NYC. These are generally buildings built between 1947 and 1974 and have rent increases set by the Rent Guidelines Board.[i] The study team chose to focus on the rent-stabilized building stock because despite constituting nearly half of all rental units in New York City, very few studies examining building electrification in this sector exist. Study findings show that missing funding for building electrification ranges from ~$30,000-$40,000/unit depending on partial vs. full electrification and whether a building shell upgrade is included. Additional findings reveal that metering configuration significantly influences electrification's impact on tenant energy bills; when heating costs are covered by the landlord, building electrification reduces tenant energy bills, but when the tenant is responsible for heating bills after electrification, tenant bills increase drastically.

RESEARCH AREA OVERVIEW AND OBJECTIVE

Reaching NYC's climate goals will require many buildings to switch their heating and hot water systems from fossil fuels to clean electricity. This widespread electrification of space and water heating loads with heat pumps is regarded to be a central pillar in reducing building greenhouse gas (GHG) emissions. Heat pumps are favored due to their superior efficiency, ability to serve heating and cooling loads, and decreased local emissions from on-site combustion. However, outfitting low-income housing in NYC with electric heat will be expensive: older, inefficient building envelopes translate to higher heating and cooling energy intensity, and extensive health and safety costs. Building electrification must also be carefully coordinated with efficiency and housing quality measures to ensure affordability and positive health outcomes.

Based on the current economics for many low- and moderate-income (LMI) housing typologies, there is a significant cost burden incurred by the building owner to complete an electrification retrofit, especially in the rent-stabilized unsubsidized housing sector. This portion of the LMI housing stock is unique in that owners cannot make up for losses in building electrification costs through increased rent. In addition, even for non-gas sites with better operating cost economics, if tenants pay utility bills, there is still no opportunity for building owners to recover incremental upfront capex through bill savings over the system lifetime.

It is imperative that the building electrification transition be planned appropriately to ensure it is affordable for all New Yorkers. A transition in which electrification of low-income housing trails other market segments will only deepen the existing inequity in local emissions, access to comfortable and safe living conditions, and affordable energy costs. In 2019, over 480,000 low-income families in NYC–amounting to over 1 million residents–were energy-cost burdened2. In addition, more than 80,000 residents reported problems with lack of heat and/or hot water this past winter. Without regulatory and other financial intervention, customers transitioning away from natural gas later than others may be subject to increasing gas rates as local distribution companies recover fixed costs from a shrinking number of customers. Yet customers using electricity to heat their homes could see price spikes if little is done to mitigate the growth of electricity system winter peaks. For residents living with mold, mildew, pests, lead, or failing envelopes, housing quality must be addressed before or alongside efficiency and electrification. The building electrification transition should be a platform for advancing energy equity, not a reason we move further from it.

Under this research topic, this study:

- Created a collection of building typologies representative of New York City's population of rent-stabilized unsubsidized housing
- Utilized previous studies to understand common barriers to building decarbonization and the technology and logistical solutions best suited to overcome these barriers;
- Analyzed the prevalence and extent of anticipated energy bills increases after retrofit for different rent-stabilized unsubsidized housing typologies, and opportunities to mitigate this outcome;
- Quantified the "missing money" required to provide rent-regulated unsubsidized housing buildings with an appropriate payback upon heat pump adoption, along with the extent to which existing and anticipated federal and state programs can be leveraged to reduce the "missing money" amount;
- Provides a discussion on how the City's actions could fill the gap remaining after federal and state resources have been exhausted (e.g., consideration of electricity rate equity, strategies for underwriting risk, tax abatement and incentive programs).

METHODOLOGY

Modeling Approach

To begin tackling the objectives listed above, the team first developed an understanding of the current landscape of rent-regulated unsubsidized housing in New York City. This entailed collecting the following data from NYC Housing & Vacancy Survey (NYCHVS), PLUTO database, and Local Law 87 database:

- Quantity and types of rent-regulated unsubsidized housing across the city
- Building stock characteristics
- Differing requirements between affordable housing and market rate housing
- Quantity and types of health & safety problems reported by residents
- Number of homes that are ineligible for electrification due to health & safety problems

Figure 1: Building Typology Categories and Sample Building Typology

Category	Typology Options
Gas Service Utility	Con Edison National Grid
Building Size	Multifamily <= 7 stories Multifamily > 7 stories
Vintage	Pre-war Post-War
Energy Usage	Low Medium High
Existing Heating System	Gas Fuel Oil Steam Electric Resistance
Health & Safety Issue(s)	Asbestos Lead Mold Structural Issue

Category	Typology Options
Gas Service Utility	National Grid
Building Size	Multifamily <= 7 stories
Vintage	Pre-war
Energy Usage	Medium
Existing Heating System	Gas
Health & Safety Issue(s)	Asbestos Structural Issues

Once this initial data review was complete, the next step was to develop a set of housing building typologies based on size, jurisdiction, vintage, energy usage, existing systems, and state of repairs that would be representative of the rent-regulated unsubsidized building stock. With the calculated costs and emissions for each typology, results were aggregated up the full building stock level. Figure 1 shows the typology categories that were selected for this study:

After all building typologies were selected, the team conducted energy benchmarking using Local Law 84 and Department of Housing Preservation and Development (HPD) data. For this benchmarking, median energy consumption was calculated for each building typology by end-use (heating, cooling, and water heating). Subsequently, end-use load shapes were developed for each building typology using the NREL ResStock database and system performance criteria, including efficiency curves and system lifetime, was collected from NYSERDA's Building Efficiency & Electrification Model (BEEM) and EIA National Energy Modeling System (NEMS). Figure 2 shows the electrification scenarios evaluated for this study:

Figure 2: Electrification Scenario Options and Sample Electrification Scenario

Category	Scenario Options
Electrification Level	Full Electrification: Cold Climate Air-Source Heat Pump sized to 20°F with electric resistance backup
	Partial Electrification: Cold Climate Air-Source Heat Pump sized to 30°F with existing fuel backup
Shell Upgrade	With Shell Upgrade
	Without Shell Upgrade
Electric Technologies	Cold Climate Air Source Heat Pump (sized according to full vs partial electrification)
	Heat Pump Water heater
	Electric Cooktop

Category	Scenario Options
Electrification Level	Full Electrification
Shell Upgrade	With Shell Upgrade
Electric Technologies	ccASHP sized to 20°F with electric resistance backup
	Heat Pump Water heater
	Electric Cooktop

Using a combination of energy benchmark data, ResStock load shapes, and system performance data, a set of 8760 hourly energy consumption profiles and system sizes was generated for each relevant technology for each building typology.

Once energy profiles and systems sizes were created, the team did an extensive literature review and data collection for relevant cost data and emissions data including the following:

- Appliance capital costs, broken out by equipment costs and labor costs, acquired from NYSERDA BEEM.
- Health & safety costs, acquired from the American Housing Survey (AHS).
- Available funding sources for NYC low-income building stock including federal, state, and city incentives, rebates, tax credits, bill-assistance programs, and loans. For each funding source, the team identified program caps per home for each technology and total program caps. The team also factored in which incentives could and could not be stacked.
- Electricity, gas, fuel oil, and steam utility rates for master-metered and individually metered customers with Con Edison and National Grid, including Con Edison's rate for all-electric customers.
- Forecasted rate escalation factors, acquired from NYSERDA BEEM.
- Forecasted grid emissions factor, acquired from NYSERDA BEEM and Cambium.
- Local Law 97 emissions limits and fine requirements.

Citywide Funding Gap Analysis Approach

Using the abovementioned cost and emissions data, along with the energy consumption profiles, the team calculated total lifetime costs for each building typology for an electrification retrofit vs a like-for-like replacement. To calculate these lifecycle costs, an annual inflation rate of 2% was used, and an annual discount rate of 4% was used, which reflects the average prime lending rate over the last 5 years. For the purposes of calculating the citywide funding gap, it was assumed that 100% of costs and benefits in this lifecycle analysis fall on the building owner, and that all heating and hot water is master-metered and provided through central equipment (tenant energy burden analysis was conducted separately). Lifecycle cost and benefits incorporated in this analysis include:

- Incremental Equipment costs
- Health & safety costs
- Incremental operation & maintenance (O&M) costs
- Incremental electricity bills

- Avoided fuel bills
- Local law 97 penalty reduction
- Incentives & tax credits

Using the net-present valued incremental lifecycle costs, the team quantified the "missing money" for each electrification retrofit scenarios vs a like-for-like replacement. For scenarios with a shell upgrade, the additional upfront cost of shell retrofits, reduced system size, reduced energy bill, and additional efficiency incentives and tax credits were all incorporated. For scenarios with partial electrification, the counterfactual capital costs are zero, representing continued use of existing systems, while the proposed capital costs represent the cost of a smaller air-source heat pump sized to 30^0F.

Finally, the team scaled up the "missing money" for each building typology to determine the citywide funding gap for each electrification scenario. In the scaling process, existing state and federal program spending caps were incorporated. Therefore, this analysis specially identified how much money would be covered by existing federal and state programs, and what fraction was remaining.

To conclude this analysis, the team used the citywide funding gap results for different electrification scenarios, in addition to lessons learned throughout the research, to determine potential city actions that can most cost-effectively reduce the funding gap while increasing citywide adoption of electrification.

Tenant Energy Burden Analysis Approach

Using the abovementioned cost and emissions data, along with the energy consumption profiles, the team calculated tenant utility bills for each building typology before and after an electrification retrofit, for all electrification scenarios. It has been assumed that all buildings start with central heating and hot water, paid for by the owner. Tenant utility bills have been calculated using direct-metered electric rates and are broken out by end-use (heating, cooling, fans, water heating, cooking, plug loads, lighting). For the purposes of this analysis, tenant utility bills have been calculated for first year of installation (2023) and levelized net-present value lifetime utility bills over the equipment lifetime. To calculate lifetime utility bills, an annual inflation rate of 2% was used, and an annual discount rate of 4% was used.

In addition to utility bills, tenant energy burden has also been calculated using annual utility bill divided by annual income. An annual income of $47,000, determined using NYCHVS 2021, was used in this study to represent a typical tenant of a rent stabilized household. Energy burden for each typology and electrification scenario was also compared to the NY state energy affordability threshold of 6% tenant energy burden, set by the state in 2016 for all buildings with central heating.

As a sensitivity study, the following parameters were adjusted to identify their impact on tenant utility bills and energy burden:

- Final metering configuration. Because it is still a big unknown if the owner or tenant is responsible for paying post-electrification heating, cooling, and water heating utility bills, the impact of final metering configuration has large implications.
- Bill assistance. Existing bill assistance programs have been incorporated to show how much these programs can reduce energy burden, and how much gap remains.

To conclude this analysis, the team used the energy burden results for different electrification scenarios to determine potential city actions that can help minimize tenant energy burden while increasing citywide adoption of electrification.

General Assumptions

Building and technology assumptions

- All heat pumps are cold-climate HPs
- Pre-war vintage requires panel upgrade

Citywide funding gap assumptions

- Structural deficiencies (such as cracks/holes in the walls), asbestos, lead, and mold are most frequent health & safety barriers to electrification, and are distributed equally amongst the building stock
- Owner incurs all capital & operating costs for calculating citywide financing gap
- All master-metered buildings use the all-electric rate after electrification
- All capital projects fall within the per-building cap for financing
- All customers who pursue shell upgrades are eligible for weatherization assistance programs
- Where applicable, customers will receive the maximum allowable program benefit for each program or an average of the maximum allowable program benefit if multiple pathways exist (e.g., Affordable Multifamily Energy Efficiency Program Tier 1 and Tier 2; IRA 45L Tax Credit Basic, Deep, and Bonuses)
- All buildings have >35% rent-regulated units, therefore the buildings are required to follow the LL97 Prescriptive Pathway (Article 321)

Energy burden assumptions

- All buildings start with central heating and hot water. This starting configuration would be the least costly for tenants, so the electrification analysis showcases a conservative bill impact comparison.
- No customers are on utility allowance.
- The median rent stabilized household income in NYC in 2021 is $47,000.

Key Inputs

See Appendix for details on the following inputs:

- Technology efficiencies and lifetimes
- System sizes
- Panel upgrade costs
- Avoided gas connection costs
- Utility rates and utility escalation factors
- Health & safety costs and occurrence rates
- LL97 penalty thresholds and costs
- Emissions factors
- Modeled program benefit amounts and caps

Also found in the Appendix:

- Detailed list of data sources
- Resources reviewed for literature review

KEY FINDINGS

Individual Building Funding Gap Results

Electrification retrofits of rent-regulated unsubsidized housing currently on gas or steam incur more lifetime costs than lifetime benefits for building owners (Figure 3 and 4)

- Current federal and state programs do not provide adequate funding to close the gap between counterfactual and heat pump upfront costs

Figure 3: Individual Building Cost Gap Analysis (MF <7 Stories, Gas Furnace)

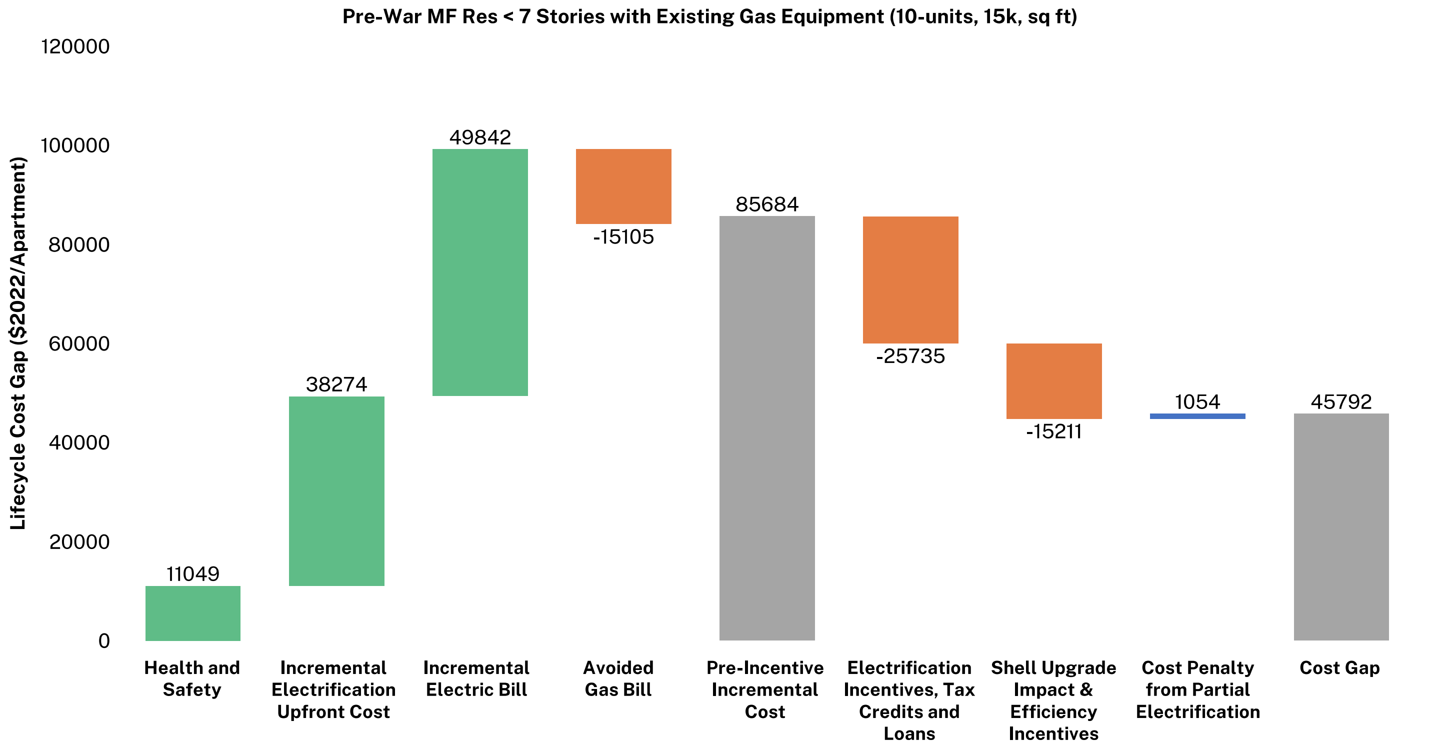
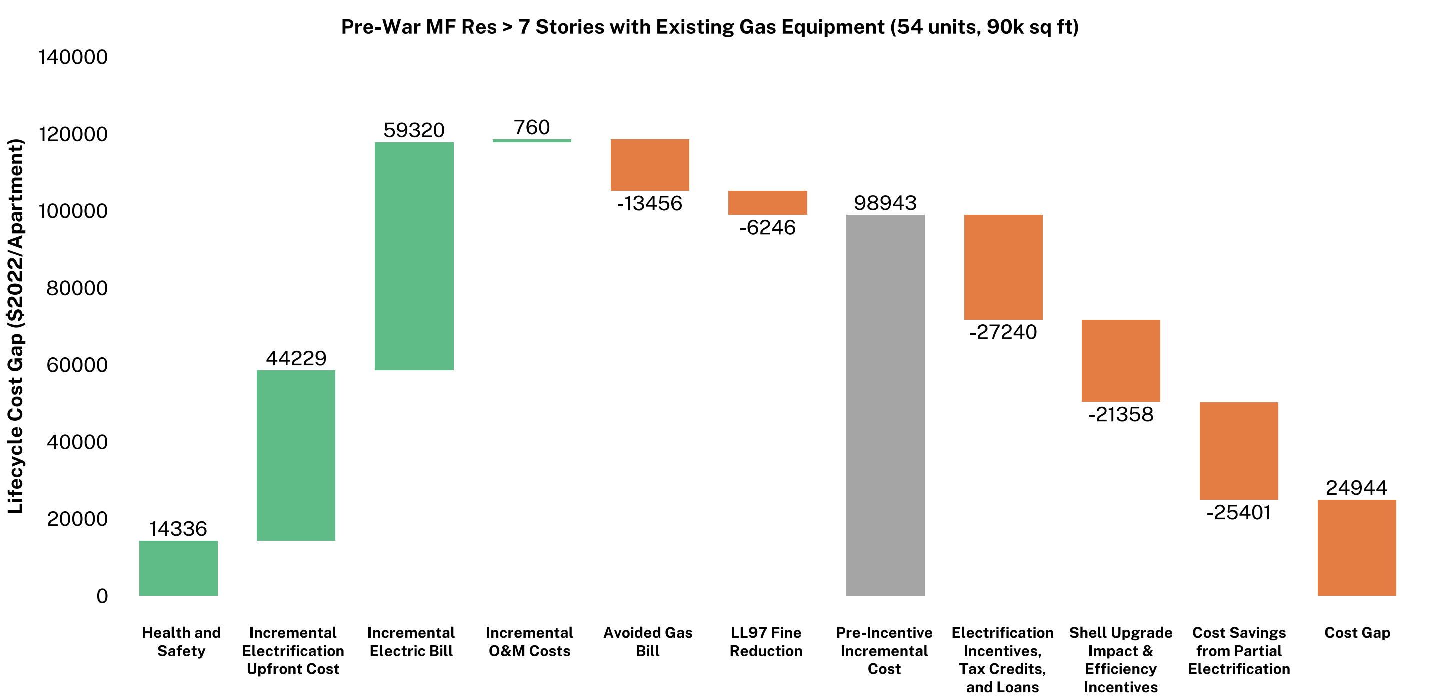
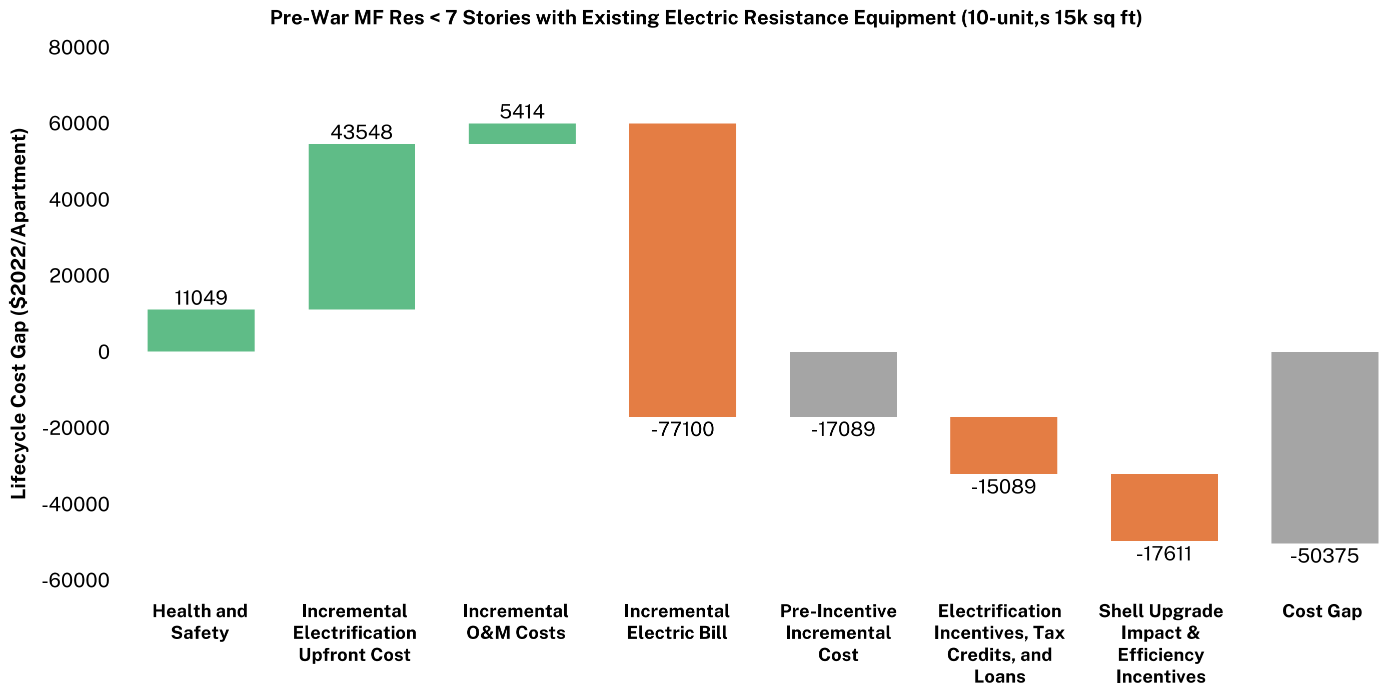


Figure 4: Individual Building Cost Gap Analysis (MF >7 Stories, Gas, Furnace)



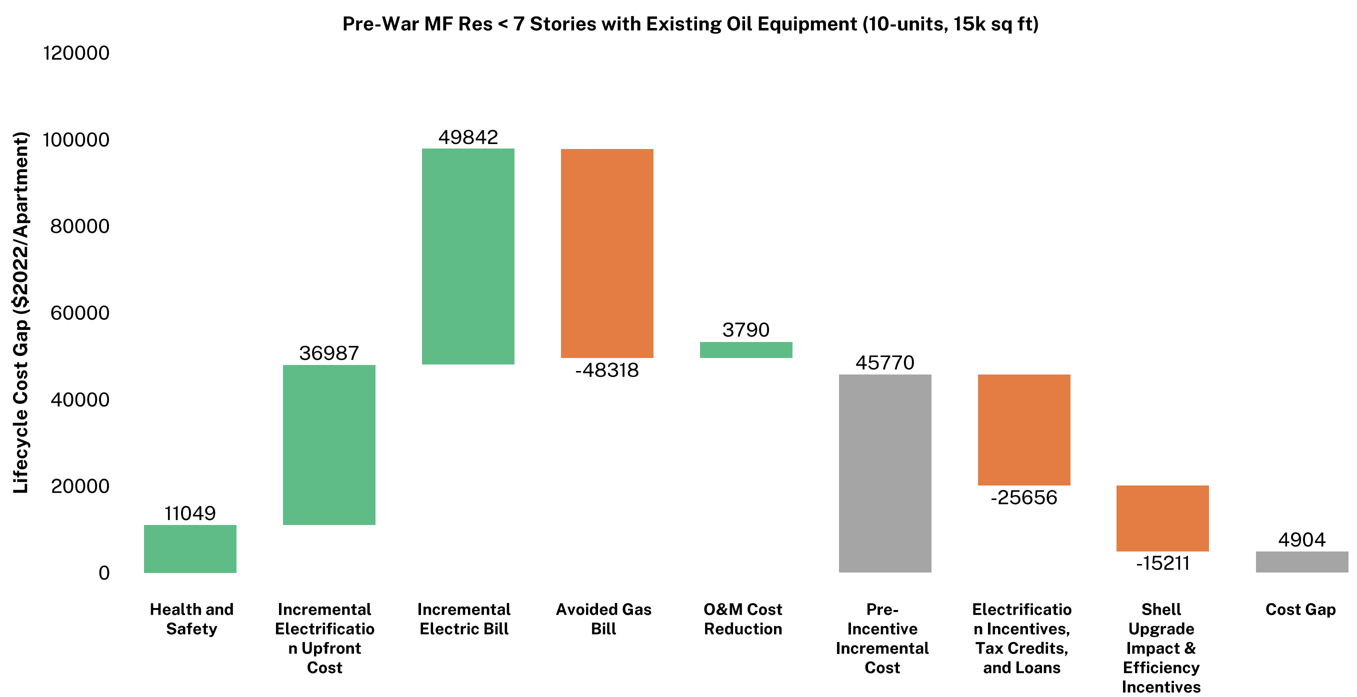
- Electrification retrofits of rent-regulated unsubsidized housing currently using electric resistance technologies incur more lifetime benefits than lifetime costs for building owners; therefore, it is cost-effective for buildings with electric resistance technologies to convert to heat pumps (Figure 5)

Figure 5: Individual Building Cost Gap Analysis (MF <7 Stories, Electric Resistance)



- Electrification retrofits of rent-regulated unsubsidized housing currently on fuel oil incur slightly more lifetime costs than lifetime benefits for building owners (Figure 6)

Figure 6: Individual Building Cost Gap Analysis (MF <7 Stories, Fuel Oil)



- Health and safety issues, such as asbestos and lead abatement, often must be addressed before building electrification is possible in affordable housing

- Health and safety hazards in affordable housing pose disparate risks to residents and lead to inequitable barriers to building electrification
- Households that pair building shell upgrades with electrification measures incur fewer lifetime costs due to energy savings from improved building efficiency as well as access to additional incentive dollars, such as the Weatherization Assistance Program (WAP)
- Partial electrification, meaning the installation of a ccASHP that is used to meet all heating loads except on the coldest days of the year (on those days the counterfactual heating system meets the heating load) incurs fewer costs for individual buildings than full electrification due to reduced system sizing for heat pumps
- Due to smaller unit size in larger buildings (and thus smaller heating system size), the cost gap per unit for multifamily buildings >7 stories is smaller than the cost gap per unit for multifamily buildings <= 7 stories

CITYWIDE FUNDING GAP RESULTS

- Program funding for electrification upgrades is currently not sufficient to cover the missing money gap, primarily due to caps on program spending for many programs
- Partial electrification, meaning the installation of a ccASHP that is used to meet all heating loads except on the coldest days of the year (on those days the counterfactual heating system would meet the load), incurs fewer costs citywide than full electrification due to reduced system sizing for heat pumps

Figure 7: Citywide Funding Gap (NPV 2022$/unit)

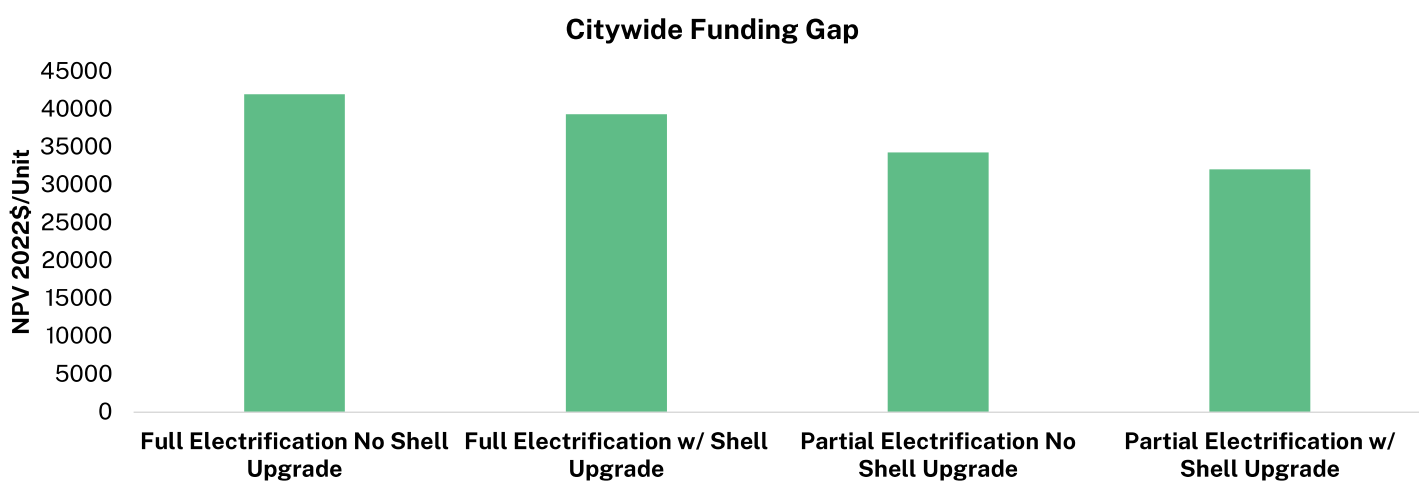
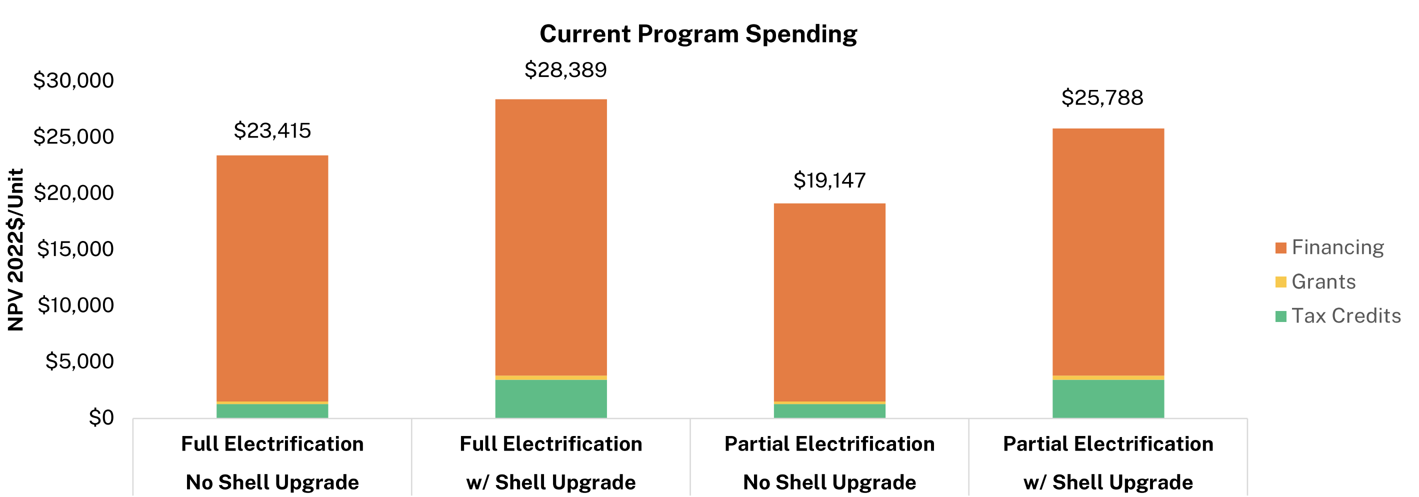


Figure 8: Current Citywide Program Spending (NPV $2022/unit)



BILL IMPACTS AND TENANT ENERGY BURDEN RESULTS

Residents of affordable housing units are likely to experience increased energy burden due to building electrification (Figure 9 and 10)

- Current bill assistance programs are not sufficient to offset the increased bills from electrification

Figure 9: Tenant First Year Utility Bill Analysis, Gas to Electric Heat Pumps (MF <7 Stories). Tenant costs decrease for central heating/cooling and hot water, but increase when heating/cooling costs are billed individually.

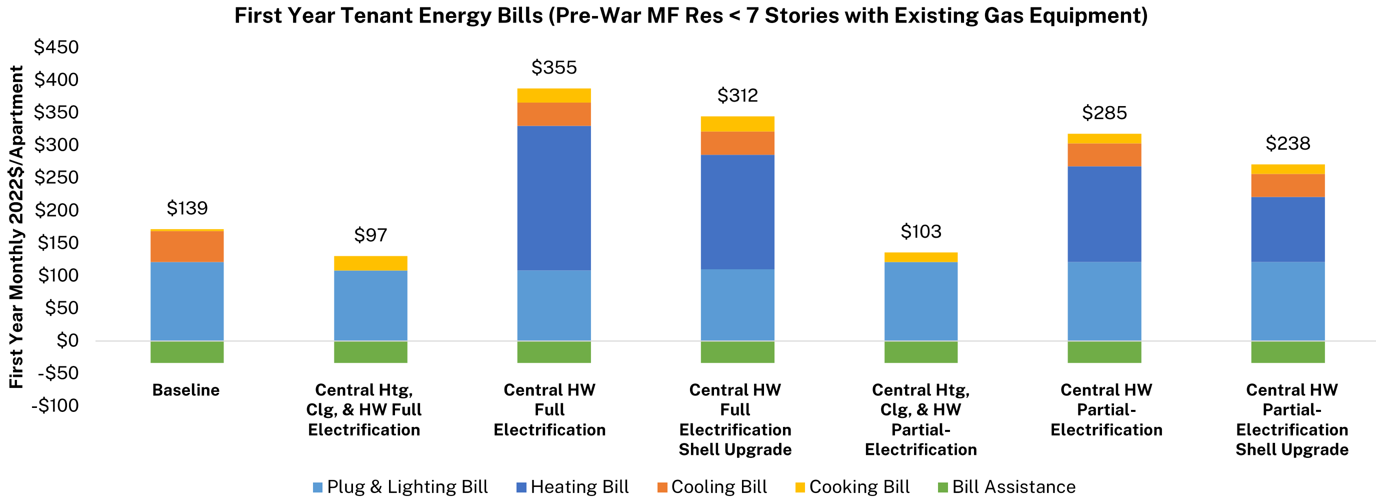
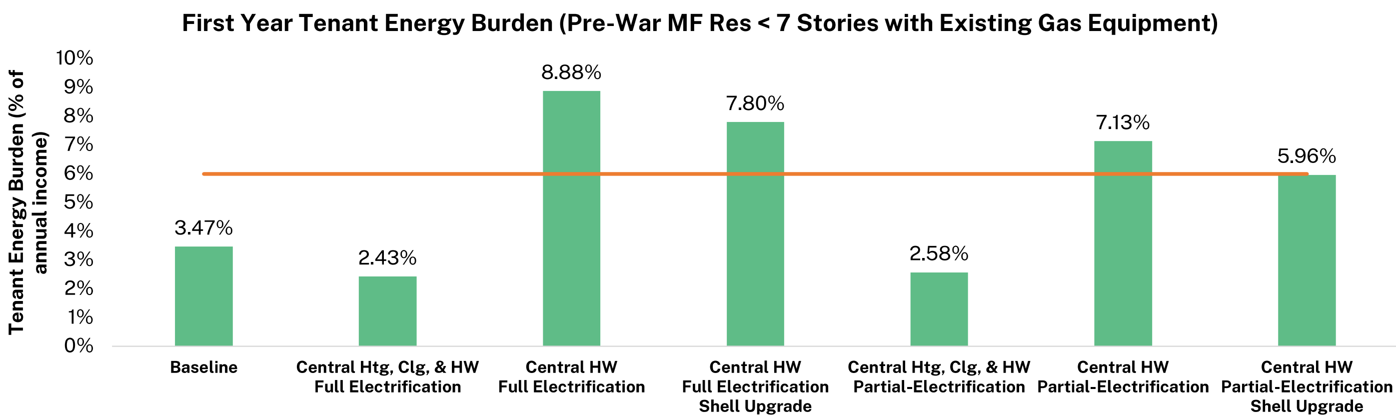


Figure 10: Tenant First Year Energy Burden Analysis, Gas to Electric Heat Pumps (MF <7 Stories). Tenants with individually billed heating/cooling become energy cost burdened. Those with central heating/cooling and hot water see reduced burdens.



Starting and ending metering configuration has significant implications on tenant energy burden

- There is a lot of confusion about whether the tenant or owner bears the operating costs of electrification due to the change in metering configuration and NYC requirements to provide heating. Situations where master-metered heating bills become direct-metered after electrification are very likely to cause significant energy burden on LMI tenants

- Tenant energy burdens are kept beneath the 6% energy affordability threshold (set by the State in 2016) in all scenarios that end in central heating metering configurations
- Energy burdens increase drastically when the tenant is responsible for heating bills
- However, when tenants are responsible for heating bills after electrification, building owner costs decrease significantly (Figure 11)

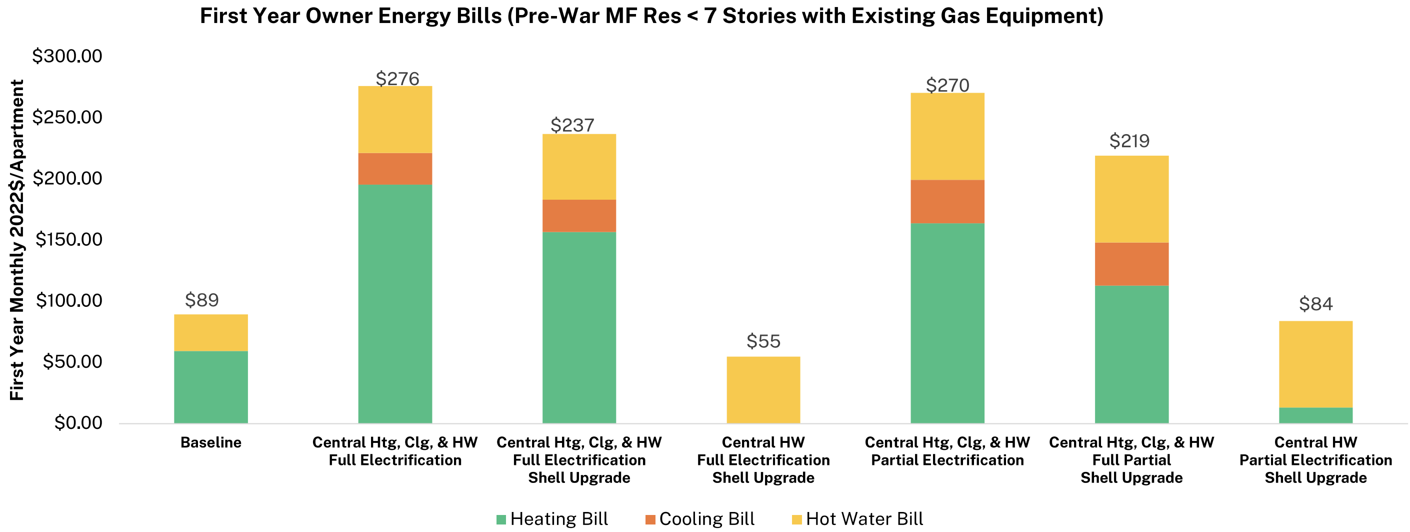


Figure 11: Owner First Year Utility Bill Analysis (MF <7 Stories). Owners see incerased costs with central heating/cooling and hot water. Costs decrease if shifted to tenants.

Partial electrification and shell upgrades can help reduce tenant energy burden and building owner costs

- Tenant energy burden can be reduced in buildings that undergo partial electrification where the owner continues to pay the bill for central equipment. This is essentially because during the coldest hours of the year, the heat is still provided for free by the landlord
- Shell upgrades can help reduce tenant energy burden and building owner bills by reducing heating and cooling load
- Combination of partial electrification and shell upgrade can help buildings get close to, or in some cases even below, the 6% tenant energy burden threshold

Current utility allowances for electric heating are designed with electric resistance heating rather than heat pump, which disincentivizes electrification for tenants

Electric rate structure has huge implications on tenant energy burden

- Electric-friendly rates can mitigate negative bill impacts after building electrification

BUILDING ELECTRIFICATION: ASSESSING THE FEASIBILITY AND COST OF HEAT PUMPS

ABSTRACT

In 2021, NYC passed Local Law 154 (LL154) – legislation that establishes strict emissions limits for new buildings, effectively phasing out fossil fuels in new construction beginning in 2024. New construction will need to be equipped with heat pumps for space and water heating to comply with LL154, thus the law requires this study to understand the feasibility, costs, and environmental impact of heat pumps in new buildings. Study findings show that all-electric HVAC systems can result in up to 75% emissions reductions compared to the standard gas heating technology and are cost-effective in all new residential and commercial buildings. Findings also show that all-electric water heating systems can result in 90% emissions reductions compared to standard gas tank water heaters and are cost-effective in new single-family residential and commercial buildings, while the costs outweigh the benefits for new multifamily buildings.

RESEARCH AREA OVERVIEW AND OBJECTIVE

Local Law 154 of 2021 establishes emissions limits for new buildings in New York City by prohibiting on-site combustion of any substance that emits 25 (twenty-five) kilograms or more of carbon dioxide per MMBtu of energy. Noting the importance of heat pump technologies for compliance, the law requires a study of four HVAC and DHW solutions for new construction: Central ASHP with a storage tank; GSHP and multisource HP; solar thermal with storage tank and ASHP; and on-demand electric water heaters. The goal of the study is to understand feasibility, capital costs, costs of usage, and environmental impact of each technology relative to code before the Local Law takes effect. With this information, the City would fully understand the implications of LL154 compliance in time to create mitigation strategies prior to the Law's start date.

The research team first drew from existing studies that have examined the ability of heat pumps to cost-effectively serve load for new construction in cold climates. To supplement extant literature, the team conducted building simulations of each technology in a number of new construction typologies, differentiating among building type, size, and other chosen characteristics. These simulations use the best available cost data specific to New York City and considered environmental impacts including refrigerant leakage.

METHODOLOGY

Approach

To begin tackling the objectives listed above, the team first developed a set of building typologies based on primary building program and size, to represent the major types of new construction across the city. The following typology categories were selected for this study, in alignment with NYSERDA's Building Efficiency & Electrification Model (BEEM):

- Single Family Residential (1 unit)
- Single Family Residential (2 to 4 units)
- Multifamily Residential <= 7 Stories
- Multifamily Residential > 7 Stories
- Education
- Grocery/Convenience
- Health Services
- Lodging/Hospitality
- Office/Government

After all building typologies were selected, the team utilized NYSERDA BEEM data to determine typical new construction annual energy consumption by end-use (heating, cooling, and water heating). Subsequently, end-use load shapes were developed for each building typology using the NREL ResStock and ComStock databases and system performance criteria, including efficiency curves and system lifetime, was collected from NYSERDA BEEM and EIA National Energy Modeling System (NEMS). To ensure that load shapes accurately reflected new construction, building envelope parameters in all energy simulations were adjusted to match the prescriptive requirements in the latest New York energy code.

For this study, all building typologies were modeled with a baseline gas heating and hot water system, for easy comparison. Due to the low cost of natural gas heating, the operating cost increase resulting from electrification in this analysis is particularly conservative; the cost increases after electrification would be lower for buildings with oil as the standard heating fuel. The following technologies were evaluated under the scope of this study using the methods listed below:

- Centralized air source heat pumps with storage tanks
    - Applied efficiency and capacity curves to calculate hourly heat pump efficiency and capacity based on hourly outdoor air temperature
    - For load below heat pump capacity, assigned 100% efficient electric resistance backup
    - For load above heat pump capacity, applied temperature-adjusted efficiency
- Ground source heat pumps and multi-source heat pumps

    - For simultaneous heating and cooling load, applied simultaneous seasonal COPs
    - For non-simultaneous heating and cooling load, applied non-simultaneous seasonal COPs
- Solar thermal with storage tanks and air source heat pumps
    - Ran simulations with tank WH to incorporate time delay and losses
    - Calculated water heating load covered by solar thermal (depending on roof size) and remaining load met by heat pump
    - Applied efficiency and capacity curves to calculate hourly heat pump efficiency and capacity based on hourly outdoor air temperature
    - For load below heat pump capacity, assigned 100% efficient electric resistance backup
    - For load above heat pump capacity, applied temperature-adjusted efficiency
- On-demand electric water heaters, both with tank and tankless
    - Ran simulations with tank and tankless water heaters to get two sets of hourly load (tank simulation incorporates time delay and losses)
    - Applied 100% efficiency to load

Using a combination of BEEM energy consumption data, ResStock and ComStock load shapes, and system performance data, a set of 8760 hourly energy consumption profiles and system sizes was generated for each relevant technology for each building typology.

Once energy profiles and systems sizes were created, the team did an extensive literature review and data collection for relevant cost data and emissions data including the following:

- Appliance capital costs, broken out by equipment costs and labor costs, acquired from NYSERDA BEEM.
- Available funding sources for new construction in NYC including federal, state, and city incentives, rebates, tax credits, and loans. For each funding source, the team identified program caps per home for each technology and total program caps. The team also factored in which incentives could and could not be stacked.
- Electricity and gas utility rates for customers with Con Edison and National Grid, including Con Edison's rate for all-electric customers.
- Forecasted rate escalation factors, acquired from NYSERDA BEEM.
- Forecasted grid emissions factor, acquired from NYSERDA BEEM and Cambium.
- Local Law 97 emissions limits and fine requirements.

Using the abovementioned cost and emissions data, along with the energy consumption profiles, the team calculated total lifetime energy consumption, lifetime emissions, and lifetime costs. For each building typology, these metrics were calculated for a baseline system (gas boiler or gas furnace for HVAC, gas tank water heater for water heating) and the 4 all-electric system options. To calculate these lifecycle costs, an annual inflation rate of 2% was used, and an annual discount rate of 4% was used, which reflects the average prime lending rate over the last 5 years. Lifecycle cost and benefits incorporated in this analysis include:

- Incremental equipment costs
- Incremental operation & maintenance (O&M) costs
- Incremental electricity bills
- Avoided fuel bills
- Local law 97 penalty reduction
- Incentives & tax credits

Key Inputs

See Appendix for details on the following inputs:

- Technology efficiencies and lifetimes
- System sizes
- Panel upgrade costs
- Avoided gas connection costs

- Utility rates and utility escalation factors
- Health & safety costs and occurrence rates
- LL97 penalty thresholds and costs
- Emissions factors
- Modeled program benefit amounts and caps

Also found in the Appendix:

- Detailed list of data sources
- Resources reviewed for literature review

KEY FINDINGS

Emissions Results

- Compared to the counterfactual gas heating technologies, all-electric HVAC technologies produce far lower levels of emissions, leading to significant emissions reductions after space heating electrification (Figure 12)
    - Emissions reductions after ASHP installation range from 50-61% for residential and 11-23% for commercial (Table 1 and 2)
    - Emissions reductions after GSHP installation range from 64-75% for residential and 30-36% for commercial (Table 1 and 2)

Figure 12: Lifetime Emissions for All-Electric HVAC Compared to Gas in New Construction

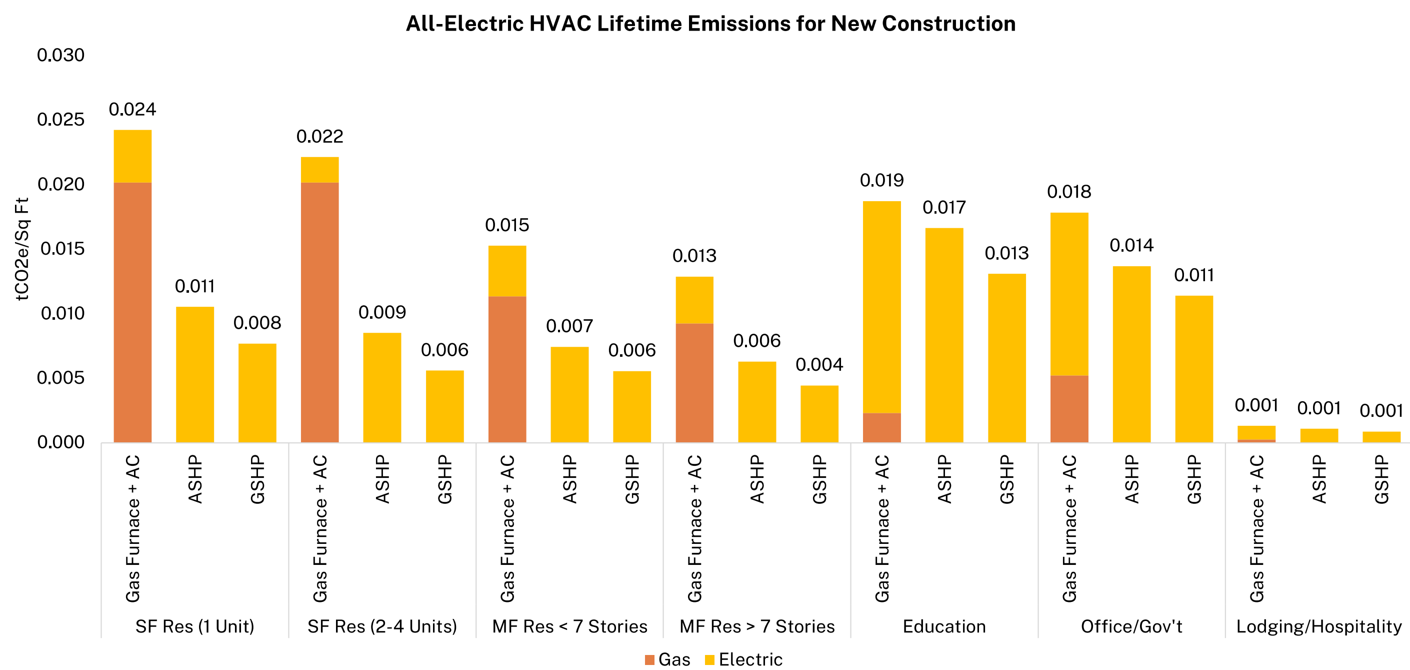


Table 1: Residential All-Electric HVAC Emissions Reductions Compared to Gas + AC

Building Typology	SF Res (1 Unit)		SF Res (2-4 Units)		MF Res < 7 Stories		MF Res > 7 Stories	
Electrification Technology	ASHP	GSHP	ASHP	GSHP	ASHP	GSHP	ASHP	GSHP
Emissions Reductions	-56%	-68%	-62%	-75%	-51%	-64%	-51%	-65%

Table 2: Commercial All-Electric HVAC Emissions Reductions Compared to Gas + AC

Building Typology	Education	Office/Gov't	Lodging/Hospitality

Electrification Technology	ASHP	GSHP	ASHP	GSHP	ASHP	GSHP
Emissions Reductions	-11%	-30%	-23%	-36%	-17%	-33%

Compared to the counterfactual gas water heating technologies, all-electric water heating technologies produce far lower levels of emissions, leading to significant emissions reductions (Figure 13)

- When paired with solar thermal, heat pump water heaters result in even greater emissions reductions
- Emissions reductions after HPWH installation range from 70-75% for residential and are about 75% for commercial (Table 3 and 4)
- Emissions reductions after HPWH + Solar Thermal installation range from 85-88% for residential and 86-89% for commercial (Table 3 and 4)

Figure 13: Lifetime Emissions for All-Electric Water Heating Compared to Gas in New Construction

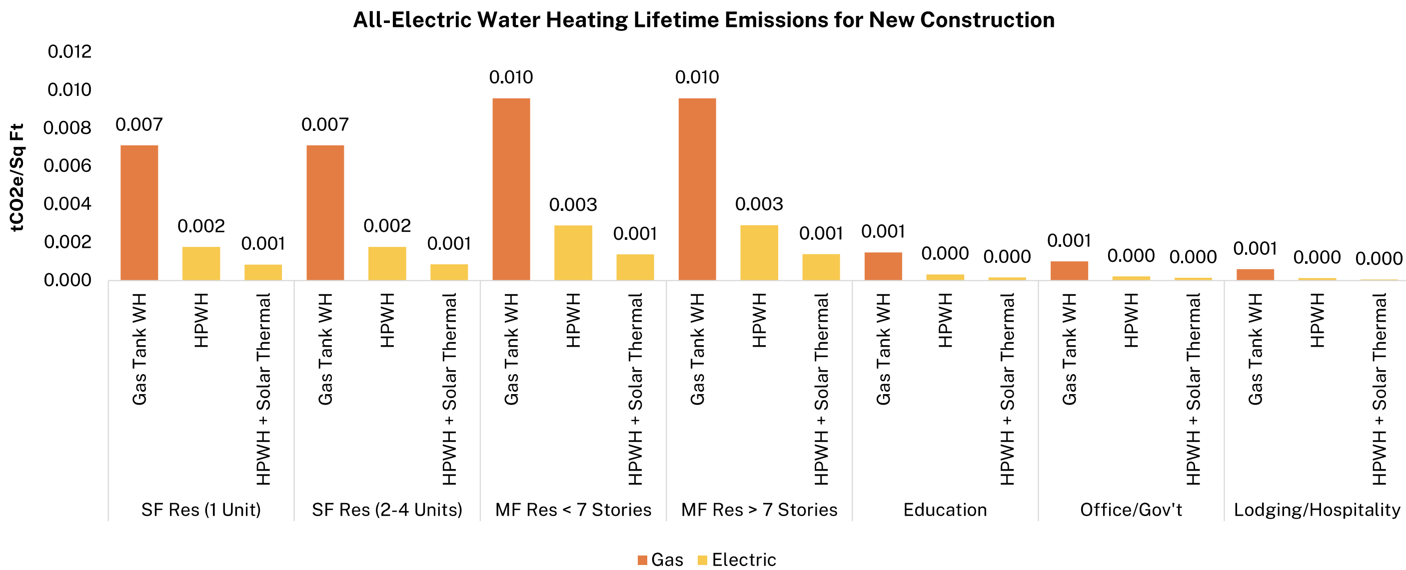


Table 3: Residential All-Electric Water Heating Emissions Reductions Compared to Gas Tank

Building Typology	SF Res (1 Unit)		SF Res (2-4 Units)		MF Res < 7 Stories		MF Res > 7 Stories	
Electrification Technology	HPWH	HPWH + Solar Thermal	HPWH	HPWH + Solar Thermal	HPWH	HPWH + Solar Thermal	HPWH	HPWH + Solar Thermal
Emissions Reductions	-75%	-88%	-75%	-88%	-70%	-86%	-70%	-85%

Table 4: Commercial All-Electric Water Heating Emissions Reductions Compared to Gas Tank

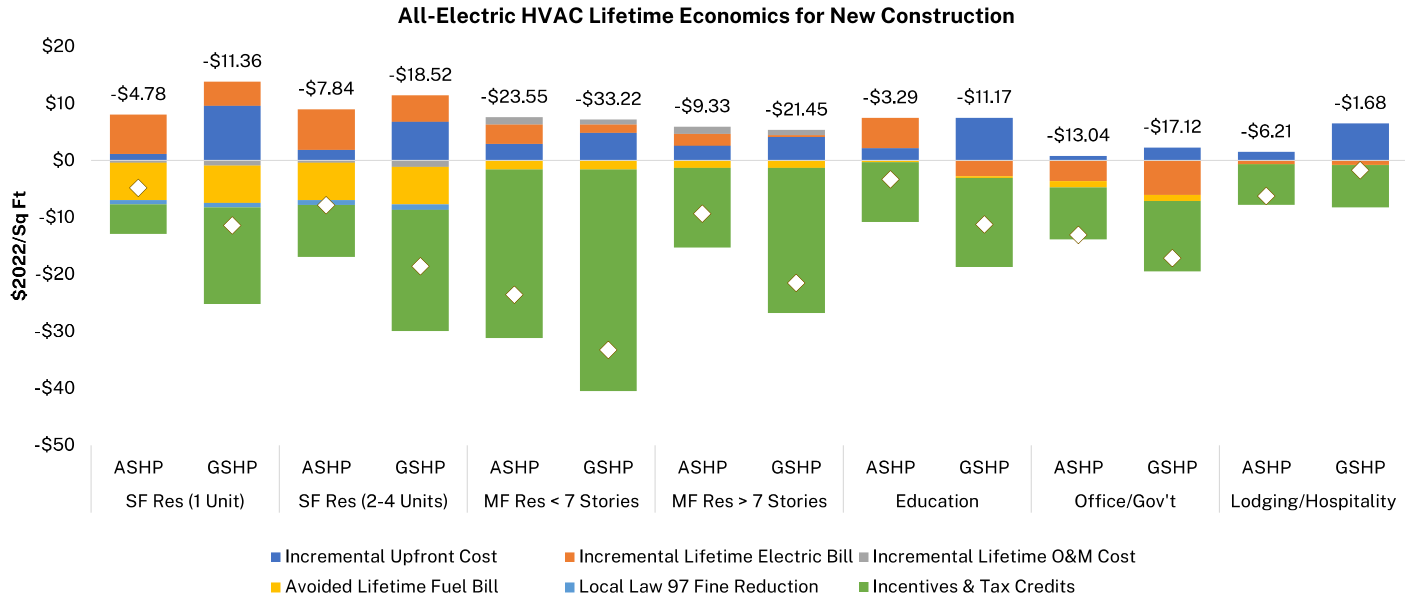
Building Typology	Education		Office/Gov't		Lodging/Hospitality	
Electrification Technology	HPWH	HPWH + Solar Thermal	HPWH	HPWH + Solar Thermal	HPWH	HPWH + Solar Thermal
Emissions Reductions	-78%	-88%	-78%	-86%	-78%	-89%

Lifetime Economics Results

For all residential and commercial building types, all-electric HVAC technologies are more cost-effective than counterfactual gas space heating technologies (Figure 14)

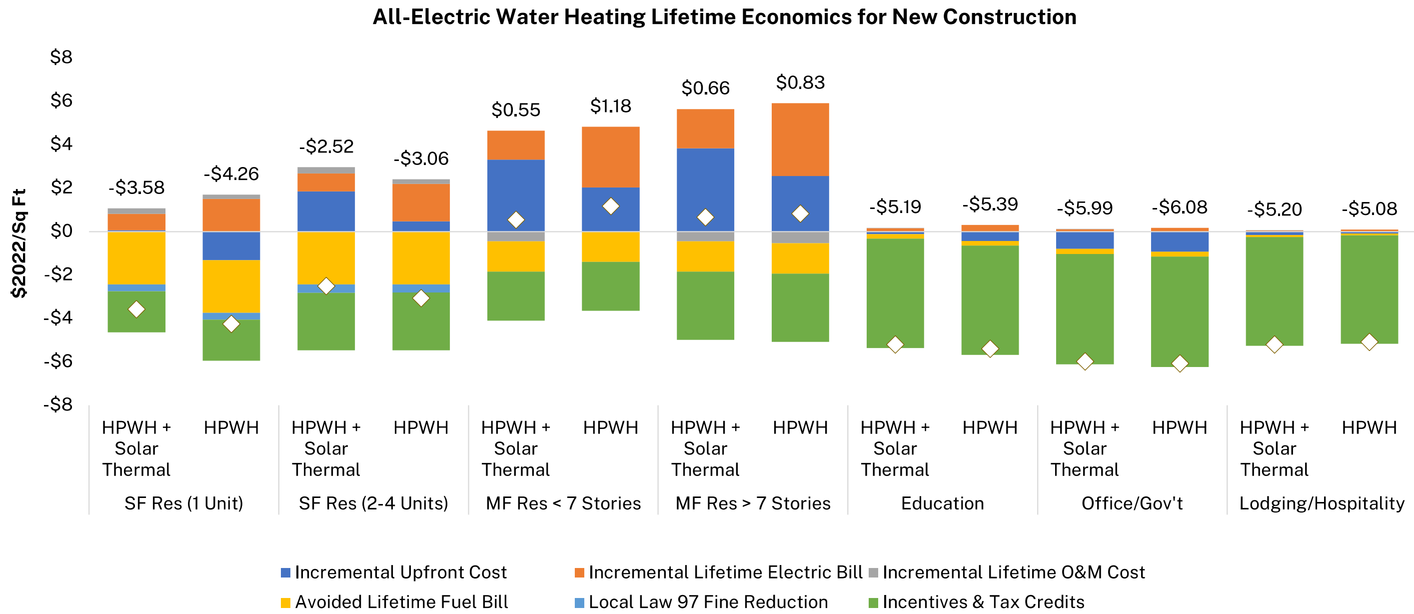
- For almost all building typologies, ground source heat pumps are the most cost-effective space heating technology
- Cost benefits come primarily from avoided fuel costs and available incentive dollars

Figure 14: Lifetime Economics for All-Electric HVAC in New Construction



- For residential multifamily buildings, the lifetime costs of heat pump water heaters outweigh the lifetime benefits (Figure 15)
    - The increased costs are primarily driven by higher incremental electric bills. For this reason, electric resistance water heaters are even less cost-effective than heat pump water heaters, and the results are not shown here
- Heat pump water heaters are cost-effective in commercial buildings and single-family buildings
- Because HPWHs are cost-effective for single-family and commercial buildings, it is logical that building owners should install heat pumps for water heating rather than electric resistance water heaters. Because the cost-ineffectiveness for HPWHs in multifamily buildings is driven by higher electric bills, electric resistance water heating technologies will be even less cost effective than heat pumps

Figure 15: Lifetime Economics for All-Electric Water Heating in New Construction



1.2 BUILDING ELECTRIFICATION RESEARCH TOPIC APPENDIX

1.2.1 GENERAL INPUTS

Input Type	Details (as applicable)
Installation Year	2023
Inflation Rate	2%
Discount Rate	4% (based on 5-year historical prime lending rate)
Tenant median annual income	$47,000 (for rent stabilized households in 2021)
Equipment costs	Varies by technology (variable global, variable local, fixed capex, O&M)

TECHNOLOGY INPUTS

Building Type	End Use	Technology	Efficiency (kBtu/kBtu)	Lifetime (years)
Multifamily	Space Heating	ASHP – Cold Climate	2.62	18
Multifamily	Space Heating	Electric Resistance + AC	1.00	18
Multifamily	Space Heating	Gas Boiler + AC	0.86	18
Multifamily	Space Heating	Oil Boiler + AC	0.82	18
Multifamily	Space Heating	Steam + AC	0.94	18
Multifamily	Space Cooling	ASHP – Cold Climate	5.82	18
Multifamily	Space Cooling	Electric Resistance + AC	3.50	18
Multifamily	Space Cooling	Gas Boiler + AC	3.50	18
Multifamily	Space Cooling	Oil Boiler + AC	3.50	18
Multifamily	Space Cooling	Steam + AC	3.86	18
Multifamily	Water Heating	HPWH	2.10	13
Multifamily	Water Heating	Electric Resistance WH	0.92	13
Multifamily	Water Heating	Gas Tank WH	0.59	13

Building Type	End Use	Technology	Efficiency (kBtu/kBtu)	Lifetime (years)
Multifamily	Water Heating	Gas Tankless WH	0.83	13
Multifamily	Water Heating	Oil Tank WH	0.60	13
Multifamily	Water Heating	Oil Tankless WH	0.85	13
Multifamily	Water Heating	Steam WH	0.75	13
Multifamily	Cooking	Electric Cooktop	0.74	13
Multifamily	Cooking	Gas Cooktop	0.40	13
Single Family	Space Heating	ASHP – Cold Climate	2.51	18
Single Family	Space Heating	GSHP	3.55	18
Single Family	Space Heating	Electric Resistance + AC	1.00	18
Single Family	Space Heating	Gas Furnace + AC	0.77	18
Single Family	Space Heating	Oil Furnace + AC	0.78	18
Single Family	Space Cooling	ASHP – Cold Climate	5.48	18
Single Family	Space Cooling	GSHP	6.34	18
Single Family	Space Cooling	Electric Resistance + AC	3.86	18
Single Family	Space Cooling	Gas Furnace + AC	0.77	18
Single Family	Space Cooling	Oil Furnace + AC	0.78	18
Single Family	Water Heating	HPWH	0.58	13
Single Family	Water Heating	Electric Resistance WH	0.92	13
Single Family	Water Heating	Gas Tank WH	0.58	13
Single Family	Water Heating	Gas Tankless WH	0.82	13
Single Family	Water Heating	Oil Tank WH	0.58	13
Single Family	Water Heating	Oil Tankless WH	0.82	13
Single Family	Water Heating	Steam WH	0.75	13
Single Family	Cooking	Electric Cooktop	0.74	13
Single Family	Cooking	Gas Cooktop	0.40	13
Commercial	Space Heating	ASHP – Cold Climate	3.79	18
Commercial	Space Heating	GSHP	3.50	18
Commercial	Space Heating	Electric Resistance + AC	1.00	18
Commercial	Space Heating	Gas Furnace + AC	0.80	18
Commercial	Space Heating	Gas Boiler + AC	0.81	18
Commercial	Space Heating	Gas Boiler + Chiller	0.81	18
Commercial	Space Cooling	ASHP – Cold Climate	4.47	18
Commercial	Space Cooling	GSHP	6.50	18
Commercial	Space Cooling	Electric Resistance + AC	3.66	18
Commercial	Space Cooling	Gas Furnace + AC	3.66	18
Commercial	Space Cooling	Gas Boiler + AC	3.66	18
Commercial	Space Cooling	Gas Boiler + Chiller	6.28	18
Commercial	Water Heating	HPWH	3.90	13
Commercial	Water Heating	Electric Resistance WH	0.98	13
Commercial	Water Heating	Gas Tank WH	0.82	13
Commercial	Water Heating	Gas Tankless WH	0.92	13
Commercial	Cooking	Electric Cooktop	0.74	13
Commercial	Cooking	Gas Cooktop	0.40	13

SYSTEM SIZES

Multifamily									
Housing Type	**Vintage**	**Energy Use Level**	**Gas Furnace**	**Oil Furnace**	**Steam**	**Electric Res**	**AC**	**ccASHP**	**Dual-Fuel HP**
MF <= 7 stories	Pre-War	Low	4.8	4.8	4.8	4.8	.5	3.5	2.3
MF <= 7 stories	Pre-War	Medium	5.1	5.1	5.1	5.1	.6	4.6	3.1
MF <= 7 stories	Pre-War	High	6.5	6.5	6.5	6.5	1	6.2	4.1
MF > 7 stories	Pre-War	Low	5.5	5.5	5.5	5.5	.8	3.9	2.6
MF > 7 stories	Pre-War	Medium	5.9	5.9	5.9	5.9	.9	5.1	3.4
MF > 7 stories	Pre-War	High	7.6	7.6	7.6	7.6	1.2	6.9	4.6
MF <= 7 stories	Post-War	Low	2.9	2.9	2.9	2.9	.3	2.1	1.4
MF <= 7 stories	Post-War	Medium	3.1	3.1	3.1	3.1	.4	2.8	1.9
MF <= 7 stories	Post-War	High	4.0	4.0	4.0	4.0	.6	3.7	2.5
MF > 7 stories	Post-War	Low	3.8	3.8	3.8	3.8	.6	3.5	2.3
MF > 7 stories	Post-War	Medium	4.0	4.0	4.0	4.0	.6	3.5	2.3
MF > 7 stories	Post-War	High	5.2	5.2	5.2	5.2	.8	4.7	3.1

Single Family							
Building Type	Vintage	Energy Use Level	Gas Furnace	Oil Furnace	AC	ccASHP	Dual-Fuel HP
Single Family (1 unit)	New Construction	Medium	2.5	2.5	1.0	2.5	2.5
Single Family (2-4 Unit)	New Construction	Medium	1.7	1.7	0.6	1.6	1.4

Commercial					
Building Type	Vintage	Energy Use Level	Total Counterfactual	ccASHP	Dual-Fuel HP
Education	New Construction	Medium	37.0	37.0	37.0
Grocery /Convenience	New Construction	Medium	3.0	3.0	3.0
Office /Government	New Construction	Medium	10.5	10.5	10.5
Lodging /Hospitality	New Construction	Medium	32.0	32.0	32.0

1.3.4 PANEL UPGRADE AND AVOIDED GAS COSTS

Housing Type	Avoided Gas Cost ($)	Panel Upgrade Cost ($)
Multifamily	$(20,269)	$2,744
Single Family (1 unit)	$(5,147)	N/A

Single Family (2-4 units)	$(4,554)	N/A
Commercial	$(10,164)	N/A

1.3.5 UTILITY RATES

Fuel Type	Utility	Tier	Season	Building Type	Rate Unit >>	Rate and Year	Energy Charge ($/kWh)	Demand Charge ($/kW)
Gas	Con Edison	1	All	Multifamily	Nominal $/therm	$11.96 (2022)	N/A	N/A
Gas	Con Edison	2	All	Multifamily	Nominal $/therm	$1.37 (2022)	N/A	N/A
Gas	Con Edison	3	All	Multifamily	Nominal $/therm	$0.88 (2022)	N/A	N/A
Gas	Con Edison	4	All	Multifamily	Nominal $/therm	$.70 (2022)	N/A	N/A
Gas	Con Edison	5	All	Multifamily	Nominal $/therm	$.5396 (2022)	N/A	N/A
Gas	National Grid	1	All	Multifamily	Nominal $/therm	$11.96 (2022)	N/A	N/A
Gas	National Grid	2	All	Multifamily	Nominal $/therm	$1.37 (2022)	N/A	N/A
Gas	National Grid	3	All	Multifamily	Nominal $/therm	$1.12 (2022)	N/A	N/A
Gas	National Grid	4	All	Multifamily	Nominal $/therm	$.88 (2022)	N/A	N/A
Gas	National Grid	5	All	Multifamily	Nominal $/therm	N/A	N/A	N/A
Electricity	Con Edison	1	Summer	Multifamily	$/kWh	$.2244 (2020)	$.2244 (2020)	None
Electricity	Con Edison	1	Winter	Multifamily	$/kWh	$.2029 (2020)	$.2029 (2020)	None
Electricity All-Electric	Con Edison	1	Summer	Multifamily – Master Meter	$/kWh	$.0710 (2020)	$.0710 (2020)	$36.23 (2020)
Electricity All-Electric	Con Edison	1	Winter	Multifamily – Master Meter	$/kWh	$.0840 (2020)	$.0840 (2020)	$18.15 (2020)
Electricity All-Electric	Con Edison	1	Summer	Multifamily – Direct Meter	$/kWh	$.1468 (2020)	$.1468 (2020)	$19.80 (2020)
Electricity All-Electric	Con Edison	1	Winter	Multifamily – Direct Meter	$/kWh	$.1071 (2020)	$.1071 (2020)	$15.85 (2020)
Steam	Con Edison	N/A	All	Multifamily	Nominal $/therm	$3.76 (2020)	N/A	N/A
Fuel Oil	State average	N/A	All	Multifamily	Nominal $/therm	$2.30 (2020)	N/A	N/A
Gas	Con Edison	1	All	Single Family	Nominal $/therm	$9.59 (2022)	N/A	N/A
Gas	Con Edison	2	All	Single Family	Nominal $/therm	$2.07 (2022)	N/A	N/A
Gas	National Grid	1	All	Single Family	Nominal $/therm	$7.54 (2022)	N/A	N/A
Gas	National Grid	2	All	Single Family	Nominal $/therm	$1.57 (2022)	N/A	N/A
Gas	National Grid	3	All	Single Family	Nominal $/therm	$0.81 (2022)	N/A	N/A
Gas	Con Edison	1	All	Commercial	Nominal $/therm	$11.96 (2022)	N/A	N/A

Fuel Type	Utility	Tier	Season	Building Type	Rate Unit >>	Rate and Year	Energy Charge ($/kWh)	Demand Charge ($/kW)
Gas	Con Edison	2	All	Commercial	Nominal $/therm	$1.37 (2022)	N/A	N/A
Gas	Con Edison	3	All	Commercial	Nominal $/therm	$0.88 (2022)	N/A	N/A
Gas	Con Edison	4	All	Commercial	Nominal $/therm	$0.70 (2022)	N/A	N/A
Gas	Con Edison	5	All	Commercial	Nominal $/therm	$0.54 (2022)	N/A	N/A
Gas	National Grid	1	All	Commercial	Nominal $/therm	$11.96 (2022)	N/A	N/A
Gas	National Grid	2	All	Commercial	Nominal $/therm	$1.37 (2022)	N/A	N/A
Gas	National Grid	3	All	Commercial	Nominal $/therm	$1.12 (2022)	N/A	N/A
Gas	National Grid	4	All	Commercial	Nominal $/therm	$0.88 (2022)	N/A	N/A
Electricity	Con Edison	1	Summer	Single Family	$/kWh	$.2102 (2020)	$.2102 (2020)	None
Electricity	Con Edison	1	Winter	Single Family	$/kWh	$.2102 (2020)	$.2102 (2020)	None
Electricity	Con Edison	2	Summer	Single Family	$/kWh	$.2268 (2020)	$.2268 (2020)	None
Electricity	Con Edison	2	Winter	Single Family	$/kWh	$.2102 (2020)	$.2102 (2020)	None
Electricity	Con Edison	1	Summer	Commercial	$/kWh	$.2244 (2020)	$.2244 (2020)	None
Electricity	Con Edison	1	Winter	Commercial	$/kWh	$.2029 (2020)	$.2029 (2020)	None
Electricity All-Electric	Con Edison	1	Summer	Single Family	$/kWh	$.1470 (2020)	$.1470 (2020)	$19.50 (2020)
Electricity All-Electric	Con Edison	1	Winter	Single Family	$/kWh	$.1060 (2020)	$.1060 (2020)	$15.82 (2020)
Electricity All-Electric	Con Edison	1	Summer	Commercial	$/kWh	$.0710 (2020)	$.0710 (2020)	$38.14 (2020)
Electricity All-Electric	Con Edison	1	Winter	Commercial	$/kWh	$.0840 (2020)	$.0840 (2020)	$20.24 (2020)
Steam	Con Edison	N/A	All	Single Family	Nominal $/therm	$3.76 (2020)	N/A	N/A
Steam	Con Edison	N/A	All	Commercial	Nominal $/therm	$3.76 (2020)	N/A	N/A
Fuel Oil	State average	N/A	All	Single Family	Nominal $/therm	$2.29 (2020)	N/A	N/A
Fuel Oil	State average	N/A	All	Commercial	Nominal $/therm	$2.30 (2020)	N/A	N/A

1.3.6 UTILITY RATE ESCALATION FACTORS

Fuel	Rate Escalation Factor	
	Residential	Commercial
Gas	2%	2%
Fuel Oil	2%	2%
Steam	2%	2%

Electricity	5.3% (average over next 30 years)	5.2% (average over next 30 years)

1.3.7 HEALTH & SAFETY COSTS AND OCCURRENCE RATE

Housing Type	Deficiency Type	Estimated Cost ($/sqft)	Estimated Occurrence Rate (% of study sector)
MF <= 7 Stories	Asbestos	$4.10	1.5%
MF <= 7 Stories	Lead	$1.43	2.2%
MF <= 7 Stories	Structural Deficiencies	$1.66	23%
MF <= 7 Stories	Mold	$0.40	14%
MF > 7 Stories	Asbestos	$4.10	1.5%
MF > 7 Stories	Lead	$0.67	2.2%
MF > 7 Stories	Structural Deficiencies	$3.80	23%
MF > 7 Stories	Mold	$0.28	14%

1.3.8 LL97 PENALTY AND EMISSIONS INPUTS

Building Type	Year	Emissions Limit (tCo2e/sqft)	Penalty ($nominal/tonne)
Multifamily	2024-2029	.00675	$268
Multifamily	2030-2034	.003347	$268
Multifamily	2035-2039	.002692	$268
Multifamily	After 2040	.002053	$268
Single Family	2024-2029	.00758	$268
Single Family	2030-2034	.001902	$268
Single Family	2035-2039	.001329	$268
Single Family	After 2040	.000762	$268
Education	2024-2029	.00675	$268
Education	2030-2034	.002231	$268
Education	2035-2039	.001488	$268
Education	After 2040	.00081	$268
Grocery/convenience	2024-2029	.02381	$268
Grocery/convenience	2030-2034	.006755	$268
Grocery/convenience	2035-2039	.004256	$268
Grocery/convenience	After 2040	.00203	$268
Lodging/hospitality	2024-2029	.00987	$268
Lodging/hospitality	2030-2034	.003851	$268
Lodging/hospitality	2035-2039	.00264	$268
Lodging/hospitality	After 2040	.001466	$268
Office/government	2024-2029	.00758	$268
Office/government	2030-2034	.002691	$268
Office/government	2035-2039	.001652	$268
Office/government	After 2040	.000582	$268

Fuel	Emission Factor (tCO2e/therm)
Gas	.0053
Fuel Oil	.0074
Steam	.0053
RNG	.0000

1.3.9 MODELED EXISTING PROGRAMS AND ESTIMATED CAP

Program Type	Name	Estimated Program Cap
Electrification Incentive	HEEHRA	$50,693,072
Electrification Incentive	NYS Clean Heat	$184,000,000
Electrification Incentive	Low-Carbon Capital Pathways	$3,120,000
Electrification Incentive	Commercial – NC Program	$5,654,376
Efficiency Incentive	Weatherization Assistance Program	$78,290,863
Efficiency Incentive	AMEEP	Unknown
Efficiency Incentive	Low-Carbon Capital Pathways	$3,120,000
Efficiency Incentive	HOMES	$50,988,282
Efficiency Incentive	HEEHRA	$50,693,072
Tax Credit	25C	No cap
Tax Credit	45L	No cap
Tax Credit	179D	No cap
Tax Credit	25D	No cap
Bill Assistance	HEAP	$200,000,000
Loan	Catalyst	Unknown
Loan	GHPP	Unknown
Loan	HRP	Unknown
Loan	On-Bill Recovery	Unknown
Loan	Smart Energy	Unknown
Loan	Companion Loan	Unknown
Loan	Climate Friendly Homes	$100,000,000
Loan	PACE	Unknown

1.3.9.1 ELECTRIFICATION PROGRAM BENEFIT AMOUNTS

Program	Building Type	Utility	Technology (assumed maximum or average benefit amount)						
			Unit >>	ccASHP	GSHP	Unit >>	Dual-Fuel HP	HPWH	Electric Cookstove
NYS Clean Heat	Multifamily	Con Edison	$/10,000 Btu	$2,000	N/A	$/unit	$500	$1,000	N/A
NYS Clean Heat	Multifamily	National Grid	$/10,000 Btu	$1,000	N/A	$/unit	$500	$700	N/A
NYS Clean Heat	Single Family	Con Edison	$/10,000 Btu	$500	$5,000	$/unit	$100	$1,000	N/A

NYS Clean Heat	Single Family	National Grid	$/10,000 Btu	$1,000	$1,500	$/unit	$500	$700	N/A
NYS Clean Heat	Commercial	Con Edison	$/10,000 Btu	$2,000	$5,000	$/unit	$500	$1,000	N/A
NYS Clean Heat	Commercial	National Grid	$/10,000 Btu	$1,000	$1,500	$/unit	$500	$700	N/A
HEEHRA	Multifamily	Con Edison	$/unit	$8,000	N/A	$/unit	$8,000	$1,750	$840
HEEHRA	Multifamily	National Grid	$/unit	$8,000	N/A	$/unit	$8,000	$1,750	$840
Low Carbon Capital Pathways	Multifamily	Con Edison	$/unit	$750	N/A	$/unit	$750	$750	N/A
Low Carbon Capital Pathways	Multifamily	National Grid	$/unit	$750	N/A	$/unit	$750	$750	N/A

1.3.9.2 EFFICIENCY PROGRAM BENEFIT AMOUNTS

Name	Unit >>	Estimated Benefit Amount
Weatherization Assistance Program	$/unit	$7,600
Affordable Multifamily Energy Efficiency Program	$/unit	$1,750
Low-Carbon Capital Pathways	$/unit	$3,750
HOMES	$/unit	$4,000
HEEHRA	$/unit	$1,600
Commercial – NC Program	$/sqft	$2.00

1.3.9.3 BILL ASSISTANCE BENEFIT AMOUNTS

Name	Estimated Benefit Amount (annual $/unit)
HEAP	$400

1.3.9.4 TAX CREDIT BENEFIT AMOUNTS

Name	Building Type	Retrofit Type	Unit >>	Amount	Average Amount
45L	Multifamily	Basic Base	$/unit	$500	$2,250
	Multifamily	Basic Bonus	$/unit	$2,500	
	Multifamily	Deep Base	$/unit	$1,000	
	Multifamily	Deep Bonus	$/unit	$5,000	
	Single Family	Basic	$/unit	$2,500	$3,750
	Single Family	Deep	$/unit	$5,000	
179D	Commercial	Efficiency	$/sqft	$5.00	$5.00
25D	Single Family	GSHP	$/unit	30% project	$10,000
25C	Multifamily	ccASHP	$/unit	$2,000	$2,000
	Multifamily	Dual-Fuel HP	$/unit	$2,000	$2,000

1.3.9.5 LOAN BENEFIT AMOUNTS

Name	Estimated Interest Rate
Catalyst	6%
GHPP	3%
On-Bill Recovery	3.49%
Smart Energy	3.49%
Climate Friendly Homes	3%
Companion Loan	6.49%
HRP	3%
PACE	6%

1.3.10 DATA SOURCES

Research Area	Data Source
Cost Data	
Equipment Capital costs	NYSERDA Building Electrification and Efficiency Modeling (BEEM)
Heat pump cost reduction curve	NREL Electrification Futures Study
Panel upgrade costs and avoided gas costs	E3 2019 Residential Building Electrification in CA Report
Emissions penalties	Local Law 97
System Performance Data	
Equipment rated efficiencies, efficiency curves, and capacity curves	NYSERDA Building Electrification and Efficiency Modeling (BEEM)
Equipment rated efficiencies, efficiency curves, and capacity curves	EIA National Energy Modeling System
Equipment rated efficiencies, efficiency curves, and capacity curves	Manufacturer heat pump data
System lifetime	E3 2019 Residential Building Electrification in CA Report
LL97 Penalty and Emissions Data	
Emissions factors	NYSERDA Building Electrification and Efficiency Modeling (BEEM)
Emissions factors	Cambium hourly grid emissions database, developed by NREL
Penalty amounts and emissions limits	LL97 policy documentation
Energy Consumption and Service Demand	
Service demand shapes	ResStock and ComStock databases
Energy consumption data (buildings >25 sqft)	Local Law 84
Energy consumption data (buildings <25 sqft)	Department of Housing Preservation and Development dataset

Research Area	Data Source
Energy benchmarking	Residential Energy Consumption Survey and Commercial Building Energy Consumption Survey
Energy benchmarking	One City Built to Last, City of New York Technical Working Group
Energy benchmarking	Pathways to Carbon-Neutral NYC, City of New York
Energy benchmarking	Grid Ready: Powering NYC's All-Electric Buildings, Urban Green
Energy benchmarking	Turning Data into Action, Building Energy Exchange
Energy benchmarking	Minnesota Decarbonization Scenarios, E3
Energy benchmarking	Local Law 97 Implementation Plan, NYC Administrative Services
Energy benchmarking	NYC DCAS project data
Energy benchmarking and service demand shapes	CO GHG Pollution Reduction Roadmap
Energy benchmarking	NYSERDA BEEM building characterization data
Utility Rates	
Gas rates	NYSERDA Building Electrification and Efficiency Modeling (BEEM)
Fuel oil rates	NYSERDA Building Electrification and Efficiency Modeling (BEEM)
Electricity rates (standard)	NYSERDA Building Electrification and Efficiency Modeling (BEEM)
Steam rates	ConEd utility tariff leaves
All-electric rates (ConEd)	Genability
Rent-Stabilized Unsubsidized Housing Building Characteristics	
Housing type breakdown in NYC	NYC Housing and Vacancy Survey 2021
Housing types, size, and ownership	PLUTO
Heating technologies	Local Law 87
Deferred maintenance/health and safety data	
Housing quality upgrade costs	American Housing Survey 2021 (NYC Metro Area)
Mold and structural deficiencies occurrence rate	NYC Housing and Vacancy Survey 2021
Lead occurrence rate	Estimate based on NYC City Council website
Asbestos occurrence rate	Estimate based on Asbestos Control Program data from 2017-2022 (ACP7)
Energy Code Requirements	
Energy Code Requirements	ASHRAE 90.1
Energy Code Requirements	International Energy Conservation Code
Energy Code Requirements	NYC Energy Code

1.3.11 LITERATURE REVIEW

Source Name	Author
Building Electrification Frameworks and Best Practices	
Equitable Electrification Report	Greenlining Institute
Building Electrification Equity Project	Emerald Cities Collaborative
City Playbooks for Equitable Electrification of Multifamily Buildings	Building Electrification Institute
Building Decarbonization Solutions for the Affordable Housing Sector	American Council for an Energy Efficient Economy

Source Name	Author
Decarbonizing Homes: Improving Health in Low-Income Communities Through Beneficial Electrification	RMI
Leading with Equity and Justice in the Clean Energy Transition: Getting to the Starting Line for Residential Building Electrification	Green & Healthy Homes Initiative
NYS-Specific Studies	
Performance Standards for Existing Buildings	Steven Winters
Multifamily Retrofit Playbooks	Steven Winters
New Efficiency New York	NYSERDA
Sustainable Affordable Housing	Federal Research Bank of NY
NYC-Specific Studies	
One City Built to Last	Mayor's Office of Long-Term Planning and Sustainability
Pathways to Carbon-Neutral NYC	New York City Mayor's Office of Sustainability
Going Electric – Retrofitting NYC's Multifamily Housing	Urban Green
Grid Ready: Powering NYC's All-Electric Buildings	Urban Green
NYC All-Electric New Construction Playbooks	Steven Winter Associates
LL154 Program Documentation	City of New York
Energy and Cost Burden	
NYCHVS 2021 Findings	NYC Department of Housing Preservation & Development
Understanding and Alleviating Energy Cost Burden in New York City	NYC's Mayor's Office
How High are Household Energy Burdens?	American Council for an Energy Efficient Economy
Energy Cost Burdens for Low-Income and Minority Households	Journal of the American Planning Association

[i] Source: "2021 New York City Housing and Vacancy Survey Selected Initial Findings." New York City Department of Housing Preservation and Development