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CNCA

CARBON NEUTRAL CITIES ALLIANCE

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Performance Standards for Existing Buildings

Performance Targets and Metrics

Final Report

Carbon Neutral Cities Alliance

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PROJECT EXECUTIVE SUMMARY

Two basic changes are required of buildings to reach long-term citywide climate action goals:

a) All buildings achieve a high level of energy efficiency, minimizing the required input energy to meet necessary end use energy demands
b) The source of input energy needs to emit as little greenhouse gas (GHG) as possible, which means a clean electric grid and eliminating as much on-site combustion as possible.

This analysis attempts to assess all building energy use in the participant cities in the context of these requirements. The first requirement drives an analysis of optimized energy efficiency, identifying the performance that can be required for all building energy end uses. This performance target is important but does not achieve the long-term climate action goals by itself. The transition to clean energy is the second key component. Therefore, optimized energy efficiency is only an interim target.

Some level of electricity end use efficiency and performance improvement can be modeled based on expected equipment trends. An unknown addressed in this study is to develop broadly applicable assumptions on the performance potential of building energy end uses that burn on-site fossil fuels. For most buildings, the on-site fuel-burning end uses are space heating, water heating, laundry, and food cooking. A small portion of buildings in some cities also burn fuel on-site for cooling using absorption chillers; it is assumed that these will be converted to electricity-sourced cooling equipment.

From a site energy use perspective, a given end use is expected to be similar whether the fuel source is natural gas, fuel oil, or district steam. A certain percentage of buildings in some cities serve these end uses with district steam or heating oil, and the performance targets developed here assume the same site energy use performance is possible across gas, district steam, and heating oil input fuels. To simplify text, all these end uses are referred to in this analysis as “gas” since natural gas makes up the majority of non-electricity energy use in commercial buildings around the country. The word “fuel” signifies any energy type, whether electricity, on-site combustion, or delivered steam.

OVERALL PROJECT GOALS

Goal 1: Develop Appropriate Performance Metrics

- **Task 1:** Compile relevant data sources and create analysis methodology
- **Task 2:** Develop energy use, fuel splits and carbon intensities, by building type and/or space use, necessary to meet building sector GHG reduction goals by 2050, for each of the four cities.
- **Task 3:** Identify the potential energy and emissions standards and metrics relevant to achieving the identified targets, with variations by building type as needed, and evaluation of applicability (e.g. pros and cons).

Goal 2: Simplify the required inputs and outputs so other cities can use results to develop performance standards for their building stock

- **Tasks 4 & 5:** Target Development Tool for Nationwide City Use - any city that can compile the input information could then adapt the tool to apply to their targets

EXISTING BUILDING PERFORMANCE TARGETS

OBJECTIVE

Task 1: Compile relevant data sources and create analysis methodology

Task 2: Develop energy use, fuel splits and carbon intensities, by building type and/or space use, necessary to meet building sector GHG reduction goals by 2050, for each of the four cities

- Identify preliminary, energy use intensity ranges, and fuel split targets for total building sector, and by building type and/or space type.
- Preliminary engineering assessment, with energy modeling of established building prototypes, to determine anticipated achievable performance by building type.
- Preliminary rough order of magnitude (e.g. per sq. ft or energy unit) cost estimates of upgrades required to reach anticipated achievable performance, by building type as relevant. Provide as range with associated criteria for low to high estimates.

APPROACH – DEFINING PATHS AND TARGETS

The carbon emissions targets that can be established for buildings are not useful unless there is a feasible way for buildings to achieve the required performance. Citywide targets, when distributed to each individual building, need to consider what is technically feasible via a known pathway to each target.

A path is a package of retrofits that are implemented at a building between now and a future date when a target performance is required. Paths need to be technically appropriate for each building typology – that means that each retrofit needs to be technically feasible using today's technology offerings.

Targets are each building's resulting performance after the potential paths are followed. The targets are a performance requirement that can be enforced through legislation. There are many metrics that can be used to convey and promote work toward targets, described in the Performance Metrics section of this report.

The energy efficiency targets are approachable through the optimization of existing systems in the near term, while the more aggressive targets likely necessitate higher efficiency electrical equipment and the elimination of on-site combustion systems. Earlier electrification of building systems may be used to reach energy efficiency targets, but energy efficiency improvements alone will not get energy or emissions low enough to reach long term zero net carbon (ZNC) targets. Table 1 shows how each building performance target requires different retrofit paths.

Table 1. An illustration of the intent of performance standards to promote certain retrofit pathways

Path / Package	Interim Target	Zero Net Carbon (ZNC) Target	ZNC Target – Reduced Consumption
Energy Efficiency Path *Optimized Systems*	Target is achievable	Target not achievable	Target not achievable
EE + Electrification Path *Gas Using Systems are electrified*	Target is achievable	Target is achievable	Target not achievable
EE + Electrification + Envelope Path *Space conditioning load reduction*	Target is achievable	Target is achievable	Target is achievable

APPROACH – USING SITE ENERGY USE INTENSITY BY FUEL TYPE

Throughout this report, the performance standards and targets are presented in the form of site energy use intensity (Site EUI), with units of thousand British thermal units per square foot of building floor area per year (kBTU/SF). See the Performance Metrics for Existing Buildings section for more discussion on the relative advantages of a site energy metric for comparing performance between buildings. The following is a brief justification on why site EUI is used for this report, though some of these points may be more widely applicable to long term planning for buildings.

Site Energy

Site energy is an empirical data point from energy metering in each building. It is not a modeled number using equipment information or design conditions, or any other prediction or estimate.

Site energy reflects the form of energy used at the building. Some end uses have energy delivered through wires – electricity. Some end uses have energy delivered through fluid in pipes – gas, oil, district steam/hot water. The implications of the use of these fuels, which can be environmental, economic, social, or health related, differ from each other, and cities will want to differentiate energy types and the implications of reducing their use in different ways. Site energy total by fuel type totals these numbers without obscuring what types of energy are used.

Site energy draws the boundary of building energy use measurement at the boundary of the building, which aligns with building performance requirements imposed on building owners and operators and allows for a consistent framework for comparing building performance across cities. Building owners held to a performance requirement would be responsible for in-building systems, regardless of how the energy is delivered to the building systems. Because of the difference in equipment efficiency from gas to electricity, a site energy intensity metric also provides a reasonably strong signal for the efficient electrification of end uses that will be essential to meeting carbon neutral goals.

Source energy, a metric used by the ENERGY STAR® Portfolio Manager® (ESPM)[1] program to compare buildings, is highly sensitive to where and how electricity and fuel energy is produced and delivered across the country. The only common source energy metric is administered by ESPM, and uses a national average for conversion factors, which simply divides all energy use input at power plants and extraction facilities over output energy from all plants and extraction facilities for purchase by consumers. Using this metric for localities which may be very different than the average, especially with different rates of renewable energy adoption going forward, is not an appropriate way to assess energy use by buildings. Source energy also provides both a very weak signal for electrification and a strong signal for increasing natural gas infrastructure through on-site gas use, including gas-powered cogeneration of electricity and heat. The flaws of source EUI as a long-term signal for deep decarbonization should be understood by policymakers and industry professionals.[2] An appropriate use for the ESPM source energy metric is for totaling all site energy use nationally and comparing to input energy use.

While greenhouse gas emissions (GHG) is the metric for cities as a whole, GHG emissions intensity from grid-supplied electricity is highly variable between cities and introduces a layer of mathematical conversion that can create a different apparent performance for two buildings with the same energy signature in different cities. There may however be communication benefits associated with educating building owners on the direct carbon

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[1] ENERGY STAR Portfolio Manager Technical Reference: Source Energy. Last updated 8-26-2019. Accessed Nov 2019. https://www.energystar.gov/buildings/tools-and-resources/portfolio-manager-technical-reference-source-energy

[2] The flaws with the source energy metric are well-documented in Keith Dennis' 2015 article "Environmentally Beneficial Electrification: Electricity as the End-Use Option". Section IV – "A. Revisiting the 'source' energy metric" https://www.sciencedirect.com/science/article/pii/S104061901500202X

impact of their building's fuel use. In addition, GHG emissions intensity of the electric grid (based on average annual carbon intensity) can provide a reasonably strong signal for electrification today in many cities.

Scaling with Floor Area

While other scaling factors may be useful to adjust building energy use, a unifying way to scale energy use across building types and locations is to divide energy use by floor area. In theory, space conditioning and small appliance end uses scale with floor area within a building typology, as it usually correlates with exterior wall and roof area as well as internal volume and number of people. For scaling to the city level, energy use per floor area is easily converted to citywide meaning using property records that include floor areas.

Not all end uses scale well with floor area. For example, the table shows the median and 90th percentile site EUI across building types in Seattle. Some building types have a wider range between the median building and more energy intensive buildings. These building types may have more difficulty achieving high compliance rates with performance standards due to the assumed diversity of energy use characteristics within the typology. For these building types, some provisions or adjustment factors may need to be taken into consideration.

Table 2. Seattle 2017 benchmarking data, for buildings 20,000+ SF, showing the difference in site EUI between the median and 90th percentile building of each space use type.

Total Site EUI [kBTU/SF]	Property Count	Median	90th PCT	90th/Median
MF-New-Tall	305	30	48	161%
MF-Old-Tall	106	33	66	199%
MF-Short	104	32	69	214%
Education	157	44	91	206%
Food Sales	27	217	408	188%
Food Service	12	138	466	337%
Health care Inpatient	5	254	294	115%
Health care Outpatient	27	75	473	630%
Lodging	108	68	110	161%
Mercantile Enclosed and strip malls	11	64	165	257%
Mercantile Retail (other than mall)	67	58	126	216%
Office	324	52	88	171%
Other	95	62	246	395%
Public Assembly	46	85	239	281%
Public order and safety	3	82	93	113%
Religious Worship	51	38	57	151%
Service	11	99	118	119%
Warehouse and storage	236	31	80	261%
Citywide Average	1,695	49	108	220%

APPROACH – PATHS ACHIEVING PERFORMANCE TARGETS OVER TIME

To achieve GHG reduction goals at the community level, most buildings in cities will need to approach the technical performance limits. However, these aggressive targets may not be achievable in the next 10-20 years because of equipment life, capital planning, and retrofit mobilization.

The interim targets that a city can set need to take a rate of change perspective to understand where buildings need to be in 2030 or 2040 so that the 2050 goals are achievable.

The Energy Efficiency Component

Performance standards for existing buildings include consideration for a high level of energy efficiency.

The NYC Technical Working Group[3] analysis found that it is technically feasible to significantly reduce energy loads in buildings through energy efficiency measures that do not require electrification of space heating. The resulting target end use performance is represented as the “Interim Target”.

The interim target is a performance level that maximizes the efficiency of gas-based central heating systems before electrification retrofits are applied. All other energy end uses are improved to more efficient appliances to reduce gas and electricity loads without major system replacement.

Within a building, centrally-produced end use energy introduces distribution inefficiency. For example, a centrally located water heating plant loses energy while distributing the hot water around the building. A water heater located near the point of use would not have these distribution losses and would use less input energy to serve a given end use demand, even with the same water heat efficiency rating.

Water Heating Example

- Example water heating demand = 1 pound of hot water raised one degree Fahrenheit at the faucet
- Energy required at the faucet = 1 British thermal unit (BTU)
- Water heater efficiency = 80%
- If central plant, distribution efficiency = 80% (note this is an assumption that is difficult to verify)
- Central plant required fuel = 1 / (80% * 80%) = 1.56 BTU
- Point of use water heater required fuel = 1 / 80% = 1.25 BTU

Without changing the water heater, the distribution losses should be accounted for and minimized. A viable energy efficiency target for this load could be equivalent of a distribution efficiency of 100%, or 1.25BTU required per 1BTU demand.

[3] Infra note 20.

APPROACH - TYPOLOGY ASSIGNMENT

Among the population of “large” buildings – defined here as all residential buildings with five or more dwelling units and all non-residential buildings – the target-setting methodology is separated in two parts. Multifamily buildings, offices, and hotels have previously been analyzed through energy modeling studies for performance potential of heating, cooling, and hot water systems. These types of buildings thus have a basis of analysis which is used in this target setting study. That prior work[4,5,6] has been leveraged to indicate potential performance standards and targets.

Other types of buildings, which make up a minority of floor area but can make up the majority of baseline carbon emissions, do not have a basis of analysis where energy modeling studies were done to assess the performance potential of the different end uses in a unified way. For these types of buildings, the city’s building population is mapped to the Commercial Building Energy Consumption Survey (CBECS) “Principal Building Activity” types. Where benchmarking data is used for this mapping, the Portfolio Manager space types have been mapped using the EPA’s Technical Reference: U.S. Energy Use Intensity by Property Type.

Major Typologies (Hotels, Multifamily, Office) – assign based on type, age, and size	All Others – CBECS Primary Building Activity
MF-Tall-New: built after 1979 and taller than three stories (4+)	Education
MF-Tall-Old: built before 1980 and taller than three stories (4+)	Food sales
MF-Short: any age and shorter than four stories (1-3)	Food service
Hotel-Dorm-Lodging: hotels, hospitality, and temp. lodging	Health care Inpatient
Office: commercial office spaces	Health care Outpatient
	Mercantile Retail (other than mall)
	Mercantile Enclosed and strip malls
	Public assembly
	Public order and safety
	Religious worship
	Service
	Warehouse and storage
	Other
	Vacant

An estimate of the division in floor area across these groupings is shown in Table 3, sourced from each city’s property tax database. The energy data used to make the baselines for each building type uses available benchmarking data, which only covers larger buildings.

Table 3. Performance target analysis methods - percentage of city floor area in each typology category. Smaller residential 1-4 family homes are shown for context but are not addressed in this study.

Analysis Method	Multifamily, Hotel, and Office	All Others	1-4 Family (outside study scope)
Percent of City Floor Area in Core Cities (estimate from tax data for each city)	35% Seattle 54% DC 54% NYC 43% Santa Monica	17% Seattle 15% DC 21% NYC 18% Santa Monica	47% Seattle 30% DC 26% NYC 39% Santa Monica

[4] Supra note 3.
[5] RMI. “How-To Guide: Net Zero Retrofit Technical and Cost Benchmark Studies”. 2017. https://rmi.org/wp-content/uploads/2017/09/RMI_Techno_Economic_Study_How_To_Guide.pdf
[6] Hannas, B. Storm, P., Baylon, D. “Final Report: Building Energy Use Intensity Targets”. Ecotope, Inc. 2017. http://www.seattle.gov/Documents/Departments/OSE/BldgEngy_Targets_2017-03-30_FINAL.pdf

BUILDING TYPES ANALYZED USING PREVIOUS STUDIES AND ENERGY MODELS

The whole-building types leverage prior work on retrofit modeling and empirical information. Space heating for these building types includes a level of baseline waste due to poor control of centralized plants and distribution systems. As a result, the baseline heating and cooling loads are artificially inflated because of overheating and overcooling. If done well, the electrification of space conditioning systems brings better control so that the right amount of space conditioning is delivered to the right space at the right time. Waste is decreased, which reduces the end user loads in addition to improving delivery efficiency. This analysis is applied to:

- MF-Old-Tall *(pre-1980 construction, taller than 3 stories)*
- MF-New-Tall *(post-1979 construction, taller than 3 stories)*
- MF-Short *(all ages, shorter than 4 stories)*
- Hotel-Dorm-Lodging
- Office

End uses are aggregated into the following:

- Space heating – heating energy used by the main space heating equipment. The baseline is assumed to use gas for space heating. Buildings that use electricity for space heating tend to have overall site energy use.
- Space cooling – cooling energy used by the main space cooling equipment
- Domestic hot water – heating energy used by the main water heating equipment to produce hot water at 120-180 F for personal use. This end use does not include laundry or steam cleaning energy end uses
- Electric loads – plug loads including cooking and dryers, process equipment, lighting, fans and pumps, elevators
- Cooking and laundry gas loads – other process loads that use gas, such as gas cooking, laundry/dryers, and other process heating

ALL OTHER BUILDING TYPES

Achieving carbon neutrality requires action from nearly all buildings and building types, which necessitates a second type of analysis and target setting. The analysis described in this section is one method of a unified approach to developing performance standards for the remaining building types, which vary greatly in usage type and occupancy patterns.

Included in this analysis are two approaches. One uses a city's building energy use data, available through city benchmarking ordinances or utility data, and applies typical end use proportions to each building type's median energy use. The second approach is defaulted to when a city does not have widely available building energy use data. In this case, the Commercial Building Energy Consumption Survey (CBECS)[7] typical energy use is used to develop building performance standards for each building type.

TYPOLOGY ANALYSIS

Calculating the Baseline Fuel Splits Across Typologies

The baseline energy use intensity for each typology is selected by aggregating the benchmarked energy use for a single year. At the time of the analysis, the data used was the most recently available. For each typology, the median site EUI was calculated and split into electricity and gas portions based on the typical fuel split. In

[7] https://www.eia.gov/consumption/commercial/data/2012/index.php?view=consumption

earlier iterations of this analysis, the median electricity EUI and the median gas EUI were calculated separately and added together to make the baseline total. However, for many typologies, the addition of these two components did not result in the same median site EUI as if it was directly calculated. For example, multifamily buildings in Seattle exhibit the following site energy and fuel split intensities:

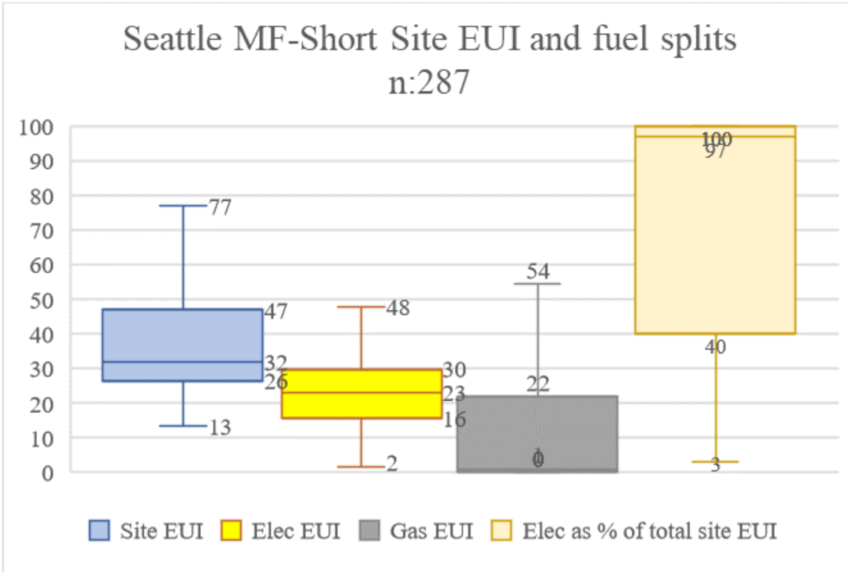


Figure 1. Energy Use Intensity of a single typology in terms of whole Site EUI, Electricity EUI, and Gas EUI. Also shown is the distribution of how much of site EUI is electricity.

To more accurately represent the overall site energy use median, the median site EUI is calculated directly, and the median % electricity is used to split it into electricity and gas EUIs. For the Seattle MF-Short typology, the median site EUI is 32 kBTU/SF with a median electricity proportion of 97%. The calculated electricity EUI and gas EUI are 31 and 1 kBTU/SF, respectively. Compare this to the median electricity and gas EUIs directly from the data, which are 23 and 1 kBTU/SF, respectively. Adding these up results in a calculated site EUI of 24, a significant underestimate of the actual median site EUI (32 kBTU/SF) for this typology. It is important to not underestimate the baseline site EUI, as the targets are calculated based on this baseline, and an underestimate of the baseline results in more aggressive targets that may be too low for most buildings to achieve. Using the site EUI median directly is a better choice for technically achievable target setting.

Notes on customizing fuel split variations and end uses within a typology:

To account for typologies with fuel splits that can vary, likely as a result of end uses being gas-based or not, the analysis tool can account for typologies' assumed end use fuels. For example, in the above example of the median MF-Short with a gas EUI of 1kBTU/ SF, the assumption is that the EUI is too low to be used for space and water heating, as that amount of gas is likely just cooking and/ or laundry. For that typology, the analysis tool can be set up to not assign a portion of that gas use to space or water heating, and the downstream target-setting calculations reflect that.

Estimating Baseline Energy Use and End Use Proportions

CBECS national average electricity use intensity data[8] is used as a default if enough building energy data is not available for any particular building type in a city, shown in Table 4. The percent of the total electricity EUI

[8] Adapted from 2012 CBECS, Table E4.

typically used for space cooling is also shown in this table. Note that space cooling does not include refrigeration. For brevity all other electricity end uses are summarized across building types in Table 5.

Similarly, national average gas use intensity data[9] is used as a default if not enough building energy data is available for any particular building type in a city.

The total gas use by a building is a sum of the different end uses using gas. The energy data in CBECS gives an indication of the relative energy use for each end use for each building type. Using this data, an estimate of where the gas is used in each building type can be made.

Table 4. CBECS 2012 National Average[10] Site Energy Use Intensity (EUI) [kBTU/SF] organized by Principal Building Activity. Average total gas EUI does not equal the sum of each end use in a given row. The "Total Gas" column is the national average EUI for all buildings that report using natural gas for any end use. Each end use is the average EUI for the buildings that use gas for that end use, i.e., the "Conditional EUI".

CBECS Principal Building Activity Site EUI [kBTU/SF]	Average Total Electricity	Cooling Portion of Electricity EUI	Average Total Gas	Space Heating Portion of Gas EUI
Education	34	24%	**31**	65%
Food sales	149	4%	**63**	54%
Food service	90	20%	**163**	18%
Health care Inpatient	97	27%	**104**	49%
Health care Outpatient	59	11%	**39**	91%
Merc Retail (other than mall)	48	16%	**22**	71%
Merc Enclosed and strip malls	68	13%	**42**	38%
Public assembly	44	40%	**35**	73%
Public order and safety	45	25%	**40**	51%
Religious worship	16	23%	**29**	82%
Service	26	17%	**44**	70%
Warehouse and storage	22	16%	**20**	63%
Other	0	15%	**59**	95%
Vacant	0	15%	**14**	91%

[9] Adapted from "Natural gas energy intensity" column of 2012 CBECS, Table E7. "Natural gas consumption and conditional energy intensities (Btu) by end use, 2012". *Released May 2016.*
[10] 2012 CBECS Table E7, footnote 1: *"The natural gas intensity calculation (total natural gas use for the end use divided by the floorspace in buildings that use natural gas for the particular end use) differs from the calculation used in the 2003 CBECS tables, in which the intensities were not conditional on the presence of the end use; the 2003 CBECS denominator was total floorspace in all buildings that use natural gas. In this table, the intensities for each end use do not sum to the total natural gas intensity, whereas they did in the 2003 CBECS table."*
https://www.eia.gov/consumption/commercial/data/2012/c&e/cfm/e7.php

Table 5. Average proportions of electricity energy use[11].

End Use	Estimated portion of national average Site EUI
Cooling	16%
Ventilation	16%
Lighting	17%
Refrigeration	18%
Office Equipment	4%
Computing	10%
Other Electric	18%

Regional Adjustments to Space Conditioning End Uses

The typical space heating share of gas use and space cooling share of electricity use is dependent on region and climate and can be adjusted for using the outputs of the CBECS methodology. The table below shows the relative space heating and cooling use across the different Building America Climate Zones[12] for all building types.

Table 6. Regional climate adjustments for heating use according to CBECS averages[13].

Relative Space Heating Gas Use Intensity Across BA Climates Zones	Space Heating Ratio [CZ average EUI / national average EUI]	Space Cooling Ratio [CZ average EUI / national average EUI]	Core Cities
Very cold/Cold	1.32	0.58	
Mixed-humid	0.84	1.05	DC, NYC
Mixed-dry/Hot-dry	0.52	0.88	Santa Monica
Hot-humid	0.54	2.20	
Marine	0.86	0.39	Seattle

The adjustment factors are applied to each city's space heating and cooling use to develop city-specific estimates of end use proportions. Space heating EUI adjustments impact the relative proportion of all other end uses, so all percentages are updated from the national average.

When the above space heating ratios are applied to multifamily buildings, the resulting "climate-normalized" space heating use does not align with Seattle and NYC audit / regional assessments done previously. In theory, if the climate adjustment above - derived from commercial building types - was fully applicable to multifamily buildings in the same regions, the averages in Table 7 would be very similar across cities. Namely because of NYC's high baseline for gas-based space heating systems, an additional adjustment was needed.

[11] Supra note 8.

[12] Reference to determine Building America Climate Zone by county: https://www.energy.gov/sites/prod/files/2015/10/f27/ba_climate_region_guide_7.3.pdf

[13] Adapted from 2012 CBECS, Table E7. "Natural gas energy intensity – Space heating" column differences per Building America Climate Zone. https://www.eia.gov/consumption/commercial/data/2012/c&e/cfm/e7.php

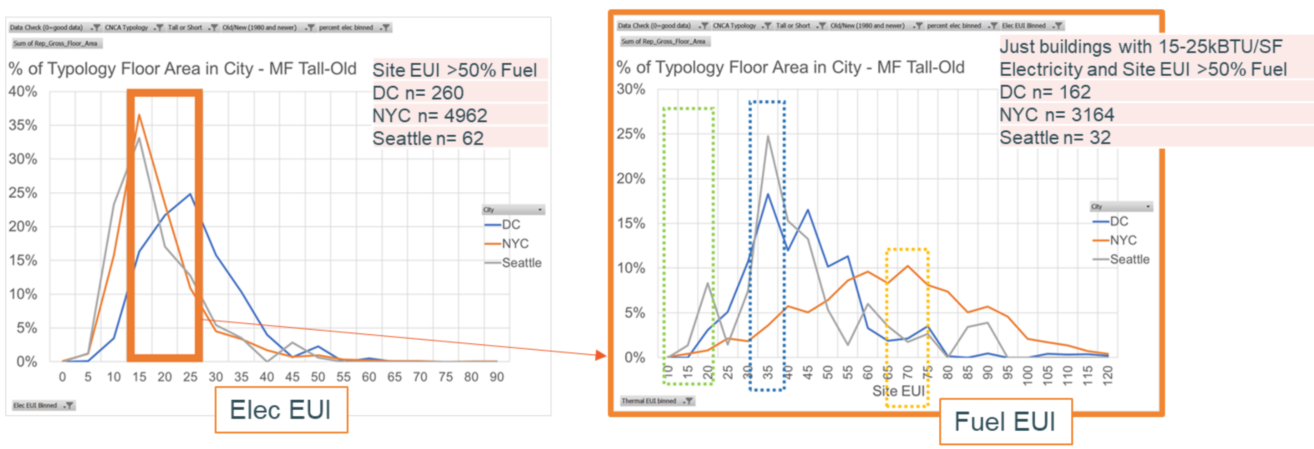
Table 7. Multifamily typologies' gas space heating use comparison.

MF Gas Space Heating EUIs from baseline analysis [kBTU/SF]	MF-New-Tall	MF-Old-Tall	MF-Short	Average / CBECS adjustment factor for respective climate in Table 6
Seattle	10	15	10	14
DC	10	15	10	14
NYC	40	48	37	32
Santa Monica	10	10	10	19

A visual comparison of the cities is shown in Figure 2 for the MF-Old-Tall typology. The benchmarking data was filtered for buildings with similar electricity EUI, which was assumed to mean similar end uses that use electricity. Using that sub-set of buildings, the gas EUI was compared between cities. As can be seen on the right chart, the Seattle and DC buildings have a similar distribution of gas EUI with a median between 35 and 45 kBTU/SF, while the NYC population is centered around a much higher median gas EUI, closer to 70kBTU/SF. Considering that central DHW systems would be similar across cities, the remaining gas use is mostly space heating, and the difference between cities was derived using this difference. The same was done, and a similar pattern appeared for the other multifamily typologies.

MF-Tall-Old Target Development:

Regional Considerations: Fuel-dominated building fuel optimization targets



Using empirical data to understand city-specific energy end uses
Older MF buildings commonly use fuel for space and water heating. Annual energy data split by fuel shows that buildings with more than half of the energy use as fuel (an indicator that heat and hot water are produced with fuel-based systems) have a tight distribution of electricity EUI. The electricity using systems in these buildings are mostly plug loads and cooling.
Seattle and NYC overlap almost completely, while DC buildings use more electricity, likely due to higher cooling loads.
Looking only at the center of the Elec EUI distribution – an electricity EUI of 15-25 kBTU/SF, the fuel distributions represent the isolation of the space heating and DHW loads.

End Use Category	EUI [kBTU/SF]	Source
Central Gas DHW + Cooking = 20kBTU/SF	20	RECS End Uses
Seattle and DC Heating = 35 - 20 = 15 kBTU/SF	15	From chart above
NYC Heating = 68 - 20 = 48 kBTU/SF	48	From chart above
Electric DHW (assuming electric resistance)	11	RECS End Uses
Electric Cooking	1	RECS End Uses

Figure 2. Comparison of core city gas EUI for multifamily buildings with similar electricity use profiles.

For the multifamily typologies - where CBECS data is not available - a different adjustment factor was used to establish the baselines. Instead, the baselines, fuel splits, and end use approximations use benchmarking data from the core cities combined with Seattle and NYC audit / regional assessments done previously. The benchmarking baselines for the core cities were used to create the multifamily-specific space heating ratios, which are used to calculate the proportion of gas EUI used for space heating. For the purposes of this component, the NYC baseline is used for the Cold/Very cold climate zone because of the similarity of system type (central steam and hot water systems) to other cold regions.

Table 8. Additional regional climate adjustments for multifamily gas space heating use according to differences in population energy use between core cities.

BA Climate Zone	Climate-analogous core city for additional cities	MF Heating Adjustment
Very cold/Cold	NYC	1.62
Mixed-humid	DC	0.71
Mixed-dry/Hot-dry	Santa Mon	0.98
Hot-humid	DC	0.71
Marine	Seattle	0.69

Energy Efficiency Performance Standard - Assumptions and Incremental Upgrades

To enable carbon neutrality in the long term, energy efficiency improvements are needed and can be promoted through interim target setting while not specifically requiring electrification. The results of the following retrofits indicate the Energy Efficiency (EE) target:

1. Energy efficiency improvements to all electricity using end uses. In a carbon-neutral grid scenario, this measure reduces electricity loads and constraints on the grid when gas end uses are electrified.
2. Basic air sealing and enhanced thermal efficiency of most commonly replaceable envelope elements (i.e. windows, roofs), typically at end of life.
3. Energy efficiency of gas-based space heating systems – better heating controls, low flow water fixtures.
4. Potential efficient electrification of domestic hot water or space heating would not be required but could be done as a way to meet the target.
5. Potential efficient electrification of cooking, laundry and other gas process loads. This would not be required but could be done as a way to meet the target.
6. Some potential increase in the use of space cooling in accordance with social trends around supplying cooling as either an amenity or an adaptation strategy for heat wave safety in residential buildings.

Zero Net Carbon – Compatible Performance Target – Path Assumptions and Incremental Upgrades

To achieve carbon neutrality, the ZNC performance standards electrify all gas using end uses. The electrification of end uses assumes that those end uses are optimized through the energy efficiency assumptions laid out in the Energy Efficiency target. While the order may not always be sequential, the technical potential of buildings would be realized by optimizing end uses, especially space heating and cooling uses and electrifying beyond those uses. Alternatively, it may be easier for some buildings, such as those with difficult-to-optimize heating systems (i.e., central steam plants) to electrify immediately and undertake the energy efficiency measures in parallel. Energy efficiency of heating and cooling may be achieved with the act of modernizing the system, enabling better control and heat delivery, instead of undertaking the often-challenging task of optimizing existing heating systems.

Using the results from the EE Target analysis as the starting point for each end use, the electrification process converts gas end uses with the factors described in the section below "Achievable Energy Use Performance Through Electrification of Gas End Uses".

Zero Net Carbon – Compatible Reduced Consumption Performance Standard – Path Assumptions and Incremental Upgrades

One potential pathway, here called the Reduced Consumption pathway, is to minimize space conditioning loads beyond the energy efficiency pathway. Additional retrofit measures are added exterior wall insulation, more comprehensive ventilation load balancing and heat recovery, and higher performance windows. This analysis uses the Passive House Institute's EnerPhit[14] standard as an end point for heating and cooling energy use. The EnerPHit standard uses some climate adjustment, but the classification for cities is not straightforward, so the "cool-temperate" climate region was used for all core cities, giving a heating and cooling **load** requirement of 7.92 kBTU/SF and 4.75 kBTU/SF, respectively. If a space heating heat pump with an efficiency of 250% is assumed – as it is in this analysis – the site EUI for space heating is 7.92 kBTU/SF / 2.5 = 3.168 kBTU/SF/yr. For cities where the heating load resulting from meeting the Energy Efficiency Target is as low or lower than the EnerPHit requirement, the ZNC Reduced Consumption target is not different than the ZNC target. Cooling site EUI is given an allowance for internal gains coming from the Passive House[15] method to allow an extra kBTU/SF for each internal gain kBTU/SF above a calculated 5.87 kBTU/SF/yr. If the calculation is more than a 30% reduction in cooling EUI, the ZNC Reduced Consumption cooling EUI is not reduced further than 30% from the Energy Efficiency target, since advisor feedback indicated that larger reductions in space conditioning usage are difficult to obtain in a retrofit of a typical (median) building.

Reduced consumption from other end uses such as cooking and laundry requires the compilation of resources for each building type and end use to estimate potential end use reductions (less cooking, less laundry) that can happen through a wide variety of mechanisms including behavior and business practice change. These assumptions are not built into this study but are available in the workbook tool to customize process load reductions across typologies.

[14] Passive House Institute. "Criteria for the Passive House EnerpHit and PHI Low Energy Building Standard (IP Version)". 2018. Page 9 has a table that indicates the criteria for the energy demand method for space heating. https://passipedia.org/_media/picopen/9f_180112_phi_building_criteria_en_ip.pdf

[15] Supra 14 Table 1, note 6. "…In the case of internal heat gains greater than 0.67 BTU/(hr.ft^2) the [cooling] limit value will increase by the difference between the actual internal heat gains and 0.67 BTU/(hr.ft^2)." Annualized, this value is 0.67*8760/1000 = 5.87 kBTU/ft^2.

Baseline Site Energy Use Intensity Estimates for Core Cities

For cities with benchmarking data, if there is a sufficient sample size, the median baseline gas EUI is calculated for each building type. If there is not a sufficient sample set per building type, the CBECS average gas EUI is used as the baseline. Below, Table 9 shows building count information and median EUIs in Seattle using this approach. The regional space heating adjustment for Seattle, which is in the Marine climate zone, is 0.86x the national average space heating EUI, which modifies the relative proportions of the end uses and results in the baseline estimates shown in the table. The other core city baseline existing data is shown on the three following tables.

Table 9. Seattle benchmarked buildings[16] mapped to CBECS space types with median electricity, gas, and gas end use EUIs. All units except property count in kBTU/SF.

Typology	Property Count	Total Site – All Fuels	Total Site Electricity	Total Site Gas	Space Cooling Electricity	Other Electricity	Space Heating	Water Heating	Cooking	Other
MF-New-Tall	305	30	23	7	3	20	0	6	1	0
MF-Old-Tall	106	33	31	2	4	27	0	0	2	0
MF-Short	104	32	31	1	4	28	0	0	1	0
Education	157	44	22	22	2	20	14	4	1	3
Food Sales	27	217	130	87	2	128	43	5	38	0
Food Service	12	138	61	77	5	56	12	16	49	0
Health care Inpatient	5	201	81	120	8	73	55	29	14	21
Health care Outpatient	27	75	64	11	3	61	10	1	0	0
Lodging	108	68	34	35	2	32	9	20	0	5
Mercantile Enclosed / strip malls	11	64	41	23	2	39	8	6	6	3
Mercantile Retail (other than mall)	67	58	41	17	2	39	12	2	4	0
Office	324	52	49	3	3	46	0	1	0	2
Other	95	62	39	23	6	33	22	1	0	0
Public Assembly	46	85	39	45	4	36	32	2	7	5
Public order and safety	3	78	38	40	3	35	19	18	3	0
Religious Worship	51	38	12	26	1	11	20	0	5	0
Service	11	99	33	67	2	31	45	22	0	0
Warehouse and storage	236	31	20	11	1	19	6	1	0	3
Vacant		24	13	10	1	13	9	1	0	0

**Building count is for benchmarked buildings that are at least 10% non-electricity energy use by site EUI.*
***A sample size of 10 buildings or greater is used to decide whether the energy use from the city data should be used, or whether the CBECs baseline should be used with regional climate adjustments applied.*

Electricity Use	"Gas" (Gas, Oil, District Steam) Use

Baseline assumes gas heating and gas hot water
Due to rounding, components may not add up to 100% of total

[16] Building count and median energy use per building type using Seattle 2017 Building Energy Benchmarking

Table 10. Washington DC benchmarked buildings[17] mapped to CBECS space types and gas end uses.

Typology	Property Count	Total Site – All Fuels	Total Site Electricity	Total Site Gas	Space Cooling Electricity	Other Electricity	Space Heating	Water Heating	Cooking	Other
MF-New-Tall	153	44	35	9	13	22	3	5	1	0
MF-Old-Tall	289	63	19	44	6	13	17	24	3	0
MF-Short	173	59	24	35	7	16	13	19	3	0
Education	161	67	40	27	10	30	16	5	1	4
Food Sales	14	195	136	58	5	131	29	3	26	0
Food Service	1	271	91	180	19	72	27	37	115	0
Health care Inpatient	6	219	99	120	28	71	54	30	14	22
Health care Outpatient	12	73	66	7	7	58	7	1	0	0
Lodging	155	86	52	34	9	43	9	20	0	5
Mercantile Enclosed / strip malls	6	118	68	50	11	57	17	13	14	6
Mercantile Retail (other than mall)	5	70	49	21	7	42	14	2	5	0
Office	445	61	60	1	9	51	1	0	0	0
Other	41	84	59	25	25	34	24	1	0	0
Public Assembly	31	101	61	41	16	45	28	2	6	4
Public order and safety	37	87	52	35	12	40	16	16	3	0
Religious Worship	14	58	32	26	6	26	21	0	5	0
Service	2	62	26	36	4	22	24	12	0	0
Warehouse and storage	25	13	12	1	2	10	1	0	0	0
Vacant	0	25	15	10	2	12	9	1	0	0

**Building count is for benchmarked buildings that are at least 10% non-electricity energy use by site EUI.*
***A sample size of 10 buildings or greater is used to decide whether the energy use from the city data should be used, or whether the CBECs baseline should be used with regional climate adjustments applied.*

Electricity Use	"Gas" (Gas, Oil, District Steam) Use

Baseline assumes gas heating and gas hot water
Due to rounding, components may not add up to 100% of total

[17] Building count and median energy use per building type using Washington DC 2017 Building Energy Benchmarking

Table 11. New York City benchmarked buildings[18] mapped to CBECS building types with median electricity, gas, and gas end use EUIs.

Typology	Property Count	Total Site – All Fuels	Total Site Electricity	Total Site Gas	Space Cooling Electricity	Other Electricity	Space Heating	Water Heating	Cooking	Other
MF-New-Tall	1,865	85	31	55	6	24	35	17	2	0
MF-Old-Tall	9,183	97	20	77	4	17	54	20	3	0
MF-Short	314	108	56	52	10	47	35	15	2	0
Education	1,529	65	21	44	3	18	31	6	2	5
Food Sales	18	115	115	0	2	112	0	0	0	0
Food Service	7	315	83	232	10	73	51	45	137	0
Health care Inpatient	15	180	67	113	10	56	64	22	11	16
Health care Outpatient	75	91	56	36	3	52	33	2	0	0
Lodging	519	122	61	61	6	55	22	31	0	8
Mercantile Enclosed / strip malls	32	92	83	9	7	75	4	2	2	1
Mercantile Retail (other than mall)	132	94	71	23	5	66	18	2	4	0
Office	1,255	82	52	30	4	47	21	3	0	6
Other	232	73	41	32	9	31	31	1	0	0
Public Assembly	218	97	50	46	7	43	36	2	5	4
Public order and safety	162	114	47	67	6	40	39	24	4	0
Religious Worship	55	81	39	42	4	35	36	0	6	0
Service	88	122	32	89	3	29	68	22	0	0
Warehouse and storage	296	68	39	29	3	35	20	3	0	6
Vacant	0	47	14	33	1	13	31	2	0	0

**Building count for gas EUI baseline analysis is for benchmarked buildings that are at least 10% non-electricity energy use by site EUI.*
***A sample size of 10 buildings or greater is used to decide whether the energy use from the city data should be used, or whether the CBECS baseline should be used with regional climate adjustments applied.*

Electricity Use	"Gas" (Gas, Oil, District Steam) Use

Baseline assumes gas heating and gas hot water
Due to rounding, components may not add up to 100% of total

[18] Building count and median energy use per building type using NYC 2017 Building Energy Benchmarking

To illustrate how this methodology can be used to develop baseline information for a city without benchmarking data, the table below shows the estimates generated for Santa Monica. The building counts are taken from tax data mapped to CBECS Principal Building Activity and the count of buildings was summed for each type. Without energy data, the CBECS energy use information was used for all types. The regional climate adjustments for space heating and cooling use are also applied to develop the baseline estimate of end uses.

Table 12. Santa Monica building parcel data[19] mapped to CBECS space types and gas end uses.

Typology	Property Count (tax data)	Total Site – All Fuels	Total Site Electricity	Total Site Gas	Space Cooling Electricity	Other Electricity	Space Heating	Water Heating	Cooking	Other
MF-New-Tall	57	45	16	29	5	11	9	18	2	0
MF-Old-Tall	128	46	14	31	4	10	11	18	2	0
MF-Short	2178	43	16	26	4	12	9	15	2	0
Education	44	61	33	28	7	26	14	7	2	6
Food Sales	17	208	149	59	5	144	22	4	33	0
Food Service	91	265	88	177	15	73	18	39	120	0
Health care Inpatient	15	208	94	114	22	72	39	34	16	25
Health care Outpatient	0	82	59	24	6	53	20	4	0	0
Lodging	92	83	42	41	6	36	8	26	0	7
Mercantile Enclosed / strip malls	18	115	67	48	9	58	12	14	15	7
Mercantile Retail (other than mall)	792	66	47	19	5	42	11	2	6	0
Office	384	78	50	27	7	44	13	5	0	9
Other	199	118	92	25	33	60	23	2	0	0
Public Assembly	28	73	42	31	9	33	18	2	6	5
Public order and safety	210	82	43	38	9	35	13	21	3	0
Religious Worship	48	34	15	18	2	13	13	0	6	0
Service	190	58	25	33	3	22	18	15	0	0
Warehouse and storage	346	40	21	18	3	18	9	3	0	7
Vacant	0	24	14	9	2	13	8	1	0	0

Electricity Use	"Gas" (Gas, Oil, District Steam) Use

Baseline assumes gas heating and gas hot water
Due to rounding, components may not add up to 100% of total

[19] LA County Opendata. 2018 Assessor Parcel data, filtering column TaxRateArea_CITY for "Santa Monica". https://data.lacounty.gov/Parcel-/Assessor-Parcels-Data-2018/mk7y-hq5p

Achievable Energy Performance Through Energy Efficiency

This section describes interim steps that can be taken to gas-using end uses to reduce energy use without electrification. These standards are useful to inform what the performance standards can be set to in an interim time step that does not require electrification of gas-using equipment. The resulting energy efficiency performance targets will not be enough to achieve a zero-net carbon target since gas and on-site combustion are implicitly allowed.

Space heating: The default performance target for space heating would be that of a central gas-fired plant without distribution inefficiencies. Space heating distribution inefficiencies include overheating due to poor control and central plant efficiency derating due to poor operations. Space heating energy efficiency targets were developed using a combination of benchmarking data to compare gas use in similar building types across the core cities and the target analyses done in New York City[20] and Seattle[21] . While the previous studies did not cover all building types, the space heating in multifamily and commercial office spaces was analyzed. The typical commercial office building was estimated to be able to save approximately 30% on space heating. That same percentage savings is carried across to the CBECS building types to develop the energy efficiency targets.

Interim energy efficiency target methodology: space heating EUI is reduced by 30% for each typology.

Water heating: for buildings where central water heating plants are typically present, an energy efficiency target is developed that assumes minimal distribution losses and water-conserving fixtures. For spaces that typically use more discrete water heating appliances, distribution losses are assumed negligible and the use of water-conserving fixtures is assumed. Water heater annual efficiency is assumed to be 80%.

Interim energy efficiency target methodology: in spaces where central plants are assumed dominant, water heating energy efficiency targets are an allowance for each space based on floor area and space type. In spaces where water heating is mostly done at point of use, the energy efficiency target is the same as the baseline usage. This results in a water heating EUI performance standard.

Cooking: these are point of use appliances, and energy efficiency targets for cooking equipment are not different than the space's existing use. While there are often opportunities to conserve cooking gas energy, those energy efficiency improvements are not assumed in this study.

Interim energy efficiency target methodology: energy efficiency target is same as the baseline usage for any given space type.

Laundry Dryers: these are typically appliances which burn gas at the point of use, and the efficiency for a given laundry demand can't be reduced without changing the appliance. As with cooking energy, conservation of laundry energy by changing operations for existing equipment is not assumed in this study. Energy efficiency targets for laundry equipment are not different than the space's existing use.

Interim energy efficiency target methodology: energy efficiency target is same as the baseline usage for any given space type.

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[20] One City Built to Last: Transforming New York City Buildings for a Low-Carbon Future, Technical Working Group Report. April 2016. https://www1.nyc.gov/html/gbee/downloads/pdf/TWGreport_2ndEdition_sm.pdf

[21] Building Energy Use Intensity Targets Final Report, prepared by Ecotope for the City of Seattle, Office of Sustainability and Environment. March 30, 2017. http://www.seattle.gov/Documents/Departments/OSE/BldgEngy_Targets_2017-03-30_FINAL.pdf

Other Gas Process Loads: there are end uses which do not fall neatly into the above end use categories. According to CEUS data, the "Miscellaneous" and "Process" loads make up 1.8% and 5.9% of commercial building gas use in California. The CBECS 2012 data indicate that "Other" gas loads, including laundry, make up 4% of gas use nationwide[22]. This category is made up of many types of end uses, such as cleaning, lab equipment, etc. The energy efficiency potential of such a grouping is not possible without detailed end use information that will not be available for every building in a given city unless audits are done on each building. As such, the energy efficiency target for other process loads will be assumed the same as the existing loads.

Electricity Loads: Electricity use reduction potential has been estimated at 30% across most building types, based on NYC Technical Working Group modeling using the following measures:

- Reduce Lighting Power Density (LPD) using lower wattage lamps and ballast changes
- Replace appliances with ENERGY STAR rated equivalents
- Occupancy sensors included to reduce the operating hours for lighting when spaces are not occupied
- Daylight sensors for all perimeter spaces
- Plug load management: vampire load reduction, master switching, smart plugs
- Replace old elevators

The savings from these end loads are assumed true across cities, as these improvements are not climate dependent and reflect improvements that can be made by the commercial building industry as a whole.

Note that the assumptions around required electricity energy efficiency improvements are contingent on overall capacity constraints and the relative cost of new transmission, distribution, and generation. The above measures are technically feasible and can be promoted and implemented as needed to alleviate capacity constraints at the building, community, and city levels.

Achievable Energy Use Performance Through Electrification of Gas End Uses

The energy efficiency targets are then fed in by end use type to an electrification target analysis. The analysis assumes a change in appliance efficiency when transitioning from a combustion-based system to an electricity-based system. The efficiency change is developed by end use by comparing efficient gas appliances to efficient electric appliances for each end use type.

The location-specific and time-of-use cost of electricity compared to gas, combined with different operational characteristics and control may drive lower energy use, resulting in in additional energy use savings that are not broadly achievable through optimization of existing gas equipment alone. Those additional energy use savings are not added to these electrification targets but may make the overall performance targets easier to achieve when undertaking electrification.

For many buildings and space types, electrification will be a reset of the building system operations and therefore creates the opportunity to minimize waste through improved design, controls, and operations.

Space heating: gas appliances are assumed to deliver steam / hot water / hot air with an overall efficiency of ~80%. Electric heat pumps are assumed to deliver heating energy with an efficiency of ~250%.

Water heating: gas appliances are assumed to deliver hot water at the current ENERGY STAR rated[23] thermal efficiency for gas equipment of 90%. Electric heat pump water heaters are assumed to deliver hot water at the current ENERGY STAR water heater rated efficiency of 220%.

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[22] 2012 CBECS Table E7. https://www.eia.gov/consumption/commercial/data/2012/c&e/cfm/e7.php
[23] https://www.energystar.gov/products/water_heaters/residential_water_heaters_key_product_criteria

Cooking: gas appliances are assumed to deliver cooking energy at the current ENERGY STAR rated efficiency for gas equipment of 46%. Electric appliances are assumed to deliver cooking energy at the current ENERGY STAR rated efficiency for electric equipment of 74%. Because there are multiple types of cooking equipment with varying efficiency ratings[24], a past study[25] was referenced for typical runtimes of equipment in restaurants to create a weighted average efficiency.

Laundry and Dryers: gas appliances are assumed to operate at the current ENERGY STAR rated efficiency for gas equipment ~91% of electric appliances[26]. Electric appliances are assumed to operate at the current ENERGY STAR rated efficiency of 100%.

Other Gas Process Loads: a conservative assumption for the electrification of these process loads is that it would only be technically feasible to convert them to electricity with minimal efficiency gains. Assuming the conversion efficiency is similar to laundry dryers, the electric energy used will be 91% of the existing gas use for process loads. This conversion ratio is technically feasible even for process loads that require high temperatures such as steam cleaning since it is roughly the difference between high efficiency gas combustion and electric resistance.

[24] Cooking Equipment Efficiency Ratings:

ENERGY STAR Requirements Comparison	Gas Efficiency [%]	Electric Efficiency [%]
ENERGY STAR - Ovens	46%	71%
ENERGY STAR - Fryers	50%	80%
ENERGY STAR - Griddles	38%	70%

[25] Livchak, D. "Energy Reduction in Commercial Kitchens". San Francisco Institute of Architecture. 2017. Table 10: https://fishnick.com/publications/fieldstudies/Energy_Reduction_in_Commercial_Kitchens_SFIA.pdf

[26] Dryers are not rated in terms of thermal efficiency but Clean Energy Factor. Gas units have a requirement of 3.48 CEF while electric units have a requirement of 3.93 CEF, a ratio of 91%.

The summary graphic in Figure 3 shows how the baseline, EE Target, and ZNC compatible target parameters are used to generate the technically achievable energy performance numbers for each typology using the approximations for each end use from whole-fuel data in the baseline.

How Targets are Calculated
All units **Site EUI** [kBTU/SF]

Electricity Use | "Gas" (Gas, Oil, District Steam) Use
Baseline assumes gas heating and gas hot water
Due to rounding, components may not add up to 100% of total

Baseline	Property Count	Total Site - All fuels	Total Site Electricity	Space Cooling Electricity	Other Electricity	Total Site Gas	Space Heating	Water Heating	Cooking	Other
Food service	11	169	80	6	74	89	14	18	57	0
Health care Inpatient	2	201	81	8	73	120	55	29	14	21
Energy Efficiency **(EE) Target** EUI as a Percent of Baseline			70%				70%	100%		
Zero Net Carbon **(ZNC) Target** EUI as a Percent of Baseline Converts gas EUI to electricity EUI			100%				Space heating	Water heating	Cooking	Other
							32%	**41%**	**61%**	**89%**

(sum of products)

	Baseline			**EE Target**			**ZNC Target**		
	Total Site Gas	Total Site Electricity	Total Site – All Fuels	Total Site Gas	Total Site Electricity	Total Site – All Fuels	Total Site Gas	Total Site Electricity	Total Site – All Fuels
Food service	89	80	169	85	56	141	0	103	103
Health care Inpatient	120	81	201	104	57	161	0	114	114

Figure 3. Summary of target calculation methodology with default Energy Efficiency reductions shown.

The ZNC Target calculation builds off the EE Target as a new baseline and converts all fuel-burning end uses to electricity using a ratio for that end use. For example, the food service building (i.e., a restaurant of sorts) has a cooking EUI at the baseline up at the top in gray of 57 site kBTU/SF. This energy use doesn't change for the interim target energy efficiency target under the assumption that some level of energy efficiency is already implemented. That 57 kBTU/SF is multiplied by 61%, converting it to about 35kBTU/SF. This is done under the assumption that all-electric cooking appliances use 61% of the site energy as their equivalent gas counterparts, assuming the same amount of food is cooked in the same ways. That conversion ratio was developed for all gas end uses and is applied to the baseline in the same way, resulting in a new EUI.

SITE ENERGY USE INTENSITY PERFORMANCE TARGETS FOR FOUR CORE CITIES – ALL TYPES

The following Energy Efficiency and ZNC Targets are calculated for the Core Cities in this section. Note that the future targets may implicitly require electrification of the “gas” end uses contributing to the gas EUI. The split is shown to indicate the possible reductions in each group of end uses, one being those driven by gas in the baseline and the other being those already using electricity.

Table 13. Performance targets for Seattle existing buildings. All units site kBTU/SF.

	Baseline			Interim - EE Standard Target			ZNC - Standard Target			ZNC Reduced Consumption Target		
	Gas EUI	Elec EUI	Site EUI	Gas EUI	Elec EUI	Site EUI	Gas EUI	Elec EUI	Site EUI	Gas EUI	Elec EUI	Site EUI
MF-New-Tall	7	23	**30**	7	19	**25**	0	21	**21**	0	21	**21**
MF-Old-Tall	2	31	**33**	2	25	**27**	0	26	**26**	0	26	**26**
MF-Short	1	31	**32**	1	25	**26**	0	25	**25**	0	25	**25**
Education	22	22	**44**	18	18	**36**	0	26	**26**	0	26	**26**
Food sales	87	130	**217**	74	104	**178**	0	139	**139**	0	132	**132**
Food service	77	61	**138**	74	49	**122**	0	88	**88**	0	88	**88**
Health care Inpatient	120	81	**201**	104	65	**169**	0	117	**117**	0	107	**107**
Health care Outpatient	11	64	**75**	8	51	**59**	0	54	**54**	0	54	**54**
Lodging	35	34	**68**	32	27	**59**	0	42	**42**	0	42	**42**
Mercantile Enclosed and strip malls	23	41	**64**	21	33	**54**	0	43	**43**	0	43	**43**
Mercantile Retail (other than mall)	17	41	**58**	14	33	**47**	0	38	**38**	0	38	**38**
Office	3	49	**52**	3	39	**42**	0	41	**41**	0	41	**41**
Other	23	39	**62**	17	31	**48**	0	37	**37**	0	35	**35**
Public assembly	45	39	**85**	36	32	**67**	0	48	**48**	0	44	**44**
Public order and safety	40	38	**78**	35	30	**65**	0	44	**44**	0	42	**42**
Religious worship	26	12	**38**	20	10	**29**	0	17	**17**	0	16	**16**
Service	67	33	**99**	53	26	**79**	0	45	**45**	0	38	**38**
Warehouse and storage	11	20	**31**	9	16	**25**	0	21	**21**	0	20	**20**
Vacant	10	13	**24**	8	11	**18**	0	13	**13**	0	13	**13**

Electricity Use	“Gas” (Gas, Oil, District Steam) Use

Baseline assumes gas heating and gas hot water

Due to rounding, components may not add up to 100% of total

Table 14. Performance targets for Washington DC existing buildings. All units site kBTU/SF.

	Baseline			Interim - EE Standard Target			ZNC - Standard Target			ZNC Reduced Consumption Target		
	Gas EUI	Elec EUI	Site EUI	Gas EUI	Elec EUI	Site EUI	Gas EUI	Elec EUI	Site EUI	Gas EUI	Elec EUI	Site EUI
MF-New-Tall	9	35	**44**	8	30	**38**	0	33	**33**	0	31	**31**
MF-Old-Tall	44	19	**63**	39	16	**55**	0	32	**32**	0	30	**30**
MF-Short	35	24	**59**	31	20	**51**	0	33	**33**	0	32	**32**
Education	27	40	**67**	22	34	**56**	0	44	**44**	0	45	**45**
Food sales	58	136	**195**	50	116	**166**	0	140	**140**	0	136	**136**
Food service	180	91	**271**	172	78	**249**	0	169	**169**	0	163	**163**
Health care Inpatient	120	99	**219**	104	84	**188**	0	136	**136**	0	127	**127**
Health care Outpatient	7	66	**73**	5	56	**61**	0	58	**58**	0	57	**57**
Lodging	34	52	**86**	32	44	**76**	0	59	**59**	0	57	**57**
Mercantile Enclosed and strip malls	50	68	**118**	45	58	**103**	0	81	**81**	0	79	**79**
Mercantile Retail (other than mall)	21	49	**70**	17	41	**58**	0	48	**48**	0	47	**47**
Office	1	60	**61**	1	51	**52**	0	51	**51**	0	50	**50**
Other	25	59	**84**	18	50	**68**	0	56	**56**	0	50	**50**
Public assembly	41	61	**101**	32	52	**84**	0	66	**66**	0	65	**65**
Public order and safety	35	52	**87**	30	44	**74**	0	56	**56**	0	54	**54**
Religious worship	26	32	**58**	20	27	**47**	0	35	**35**	0	33	**33**
Service	36	26	**62**	29	22	**51**	0	32	**32**	0	30	**30**
Warehouse and storage	1	12	**13**	1	10	**11**	0	10	**10**	0	10	**10**
Vacant	10	15	**25**	8	13	**20**	0	15	**15**	0	15	**15**

Electricity Use	"Gas" (Gas, Oil, District Steam) Use

Baseline assumes gas heating and gas hot water
Due to rounding, components may not add up to 100% of total

Table 15. Performance targets for New York City existing buildings. All units site kBTU/SF.

	Baseline			Interim - EE Standard Target			ZNC - Standard Target			ZNC Reduced Consumption Target		
	Gas EUI	Elec EUI	Site EUI	Gas EUI	Elec EUI	Site EUI	Gas EUI	Elec EUI	Site EUI	Gas EUI	Elec EUI	Site EUI
MF-New-Tall	55	31	**85**	44	21	**65**	0	38	**38**	0	33	**33**
MF-Old-Tall	77	20	**97**	60	14	**75**	0	36	**36**	0	27	**27**
MF-Short	52	56	**108**	41	39	**81**	0	55	**55**	0	50	**50**
Education	44	21	**65**	35	14	**49**	0	29	**29**	0	26	**26**
Food sales	0	115	**115**	0	80	**80**	0	80	**80**	0	80	**80**
Food service	232	83	**315**	217	58	**275**	0	171	**171**	0	163	**163**
Health care Inpatient	113	67	**180**	94	47	**141**	0	91	**91**	0	80	**80**
Health care Outpatient	36	56	**91**	26	39	**65**	0	47	**47**	0	43	**43**
Lodging	61	61	**122**	54	43	**97**	0	67	**67**	0	65	**65**
Mercantile Enclosed and strip malls	9	83	**92**	8	58	**66**	0	62	**62**	0	62	**62**
Mercantile Retail (other than mall)	23	71	**94**	18	50	**68**	0	57	**57**	0	56	**56**
Office	30	52	**82**	24	36	**60**	0	47	**47**	0	46	**46**
Other	32	41	**73**	23	29	**51**	0	36	**36**	0	34	**34**
Public assembly	46	50	**97**	36	35	**71**	0	50	**50**	0	45	**45**
Public order and safety	67	47	**114**	55	33	**88**	0	54	**54**	0	48	**48**
Religious worship	42	39	**81**	31	27	**59**	0	39	**39**	0	34	**34**
Service	89	32	**122**	69	23	**92**	0	47	**47**	0	35	**35**
Warehouse and storage	29	39	**68**	23	27	**50**	0	38	**38**	0	37	**37**
Vacant	33	14	**47**	24	10	**34**	0	18	**18**	0	14	**14**

Electricity Use	"Gas" (Gas, Oil, District Steam) Use

Baseline assumes gas heating and gas hot water
Due to rounding, components may not add up to 100% of total

Table 16. Performance targets for Santa Monica existing buildings. All units site kBTU/SF.

	Baseline			Interim - EE Standard Target			ZNC - Standard Target			ZNC Reduced Consumption Target		
	Gas EUI	Elec EUI	Site EUI	Gas EUI	Elec EUI	Site EUI	Gas EUI	Elec EUI	Site EUI	Gas EUI	Elec EUI	Site EUI
MF-New-Tall	29	16	**45**	26	11	**38**	0	22	**22**	0	22	**22**
MF-Old-Tall	31	14	**46**	28	10	**38**	0	21	**21**	0	21	**21**
MF-Short	26	16	**43**	24	11	**35**	0	21	**21**	0	21	**21**
Education	28	33	**61**	24	23	**47**	0	35	**35**	0	37	**37**
Food sales	59	149	**208**	53	104	**157**	0	131	**131**	0	129	**129**
Food service	177	88	**265**	172	62	**234**	0	155	**155**	0	154	**154**
Health care Inpatient	114	94	**208**	102	66	**168**	0	120	**120**	0	119	**119**
Health care Outpatient	24	59	**82**	18	41	**59**	0	47	**47**	0	46	**46**
Lodging	41	42	**83**	38	30	**68**	0	48	**48**	0	48	**48**
Mercantile Enclosed and strip malls	48	67	**115**	44	47	**91**	0	71	**71**	0	71	**71**
Mercantile Retail (other than mall)	19	47	**66**	16	33	**49**	0	40	**40**	0	40	**40**
Office	27	50	**78**	23	35	**59**	0	49	**49**	0	49	**49**
Other	25	92	**118**	18	65	**83**	0	71	**71**	0	69	**69**
Public assembly	31	42	**73**	26	29	**55**	0	42	**42**	0	44	**44**
Public order and safety	38	43	**82**	34	30	**65**	0	44	**44**	0	44	**44**
Religious worship	18	15	**34**	15	11	**25**	0	17	**17**	0	17	**17**
Service	33	25	**58**	28	18	**45**	0	28	**28**	0	27	**27**
Warehouse and storage	18	21	**40**	16	15	**31**	0	24	**24**	0	24	**24**
Vacant	9	14	**24**	7	10	**17**	0	12	**12**	0	12	**12**

Electricity Use	"Gas" (Gas, Oil, District Steam) Use

Baseline assumes gas heating and gas hot water
Due to rounding, components may not add up to 100% of total

Example

This example shows how an existing building would have performance targets applied based on building type. The baseline use is shown in non-electric energy use intensity, electricity use intensity, and total site EUI. The two targets are taken from Table 14 using the "Mercantile Retail (other than mall)" building category that applies to this building. The non-electric and electric energy use intensities are shown, but the performance target can be applied using these or as an overall site EUI requirement. This building would need to reduce overall site EUI by 30% to reach the energy efficiency target and reduce 47% of overall site EUI to reach the ZNC target. As described, the interim target is likely to be achievable through energy efficiency measures without necessarily needing full HVAC system and process load electrification. The ZNC target is likely aggressive enough such that full electrification or an equally aggressive site energy reduction plan is required.

Example of a retail store in Seattle being subject to Energy Efficiency and ZNC targets.

Retail store, **Seattle** **23,067 SF** **Baseline Usage** **(2017 Consumption)**			Seattle EE Target Mercantile Retail (other than mall)			Seattle ZNC – Compatible Target Mercantile Retail (other than mall)		
Non-Elec EUI	Elec EUI	Site EUI	Non-Elec EUI	Elec EUI	Site EUI	Non-Elec EUI	Elec EUI	Site EUI
26	40	**66**	15	28	**43**	0	35	**35**

35% reduction from baseline

47% reduction from baseline

Figure 4. Example of a retail store in Seattle being subject to EE and ZNC compatible targets.

Modifying typology results to represent buildings other than the median

The analysis being set up this way allows different scenarios for each typology by putting in different electricity and gas EUIs and selecting whether there is gas space or water heating. Comparing targets reveals that technically achievable interim and ZNC targets may be different for the different parts of a given typology. An example of this is shown below.

The resulting analysis can be modified for different scenarios by inputting different fuel splits for a given typology to approximate the wider population of the typology instead of just the median.

An example is shown here which shows that while the median office building has a baseline site EUI of 62 kBTU/SF, there are quite a few buildings that use a lot of gas that have higher baselines and thus may have a harder time getting to a typology-wide target. With energy efficiency alone, all buildings make some progress, but it is the gas based buildings that may need to electrify in order to hit even the interim target, since gas energy efficiency can only go so far

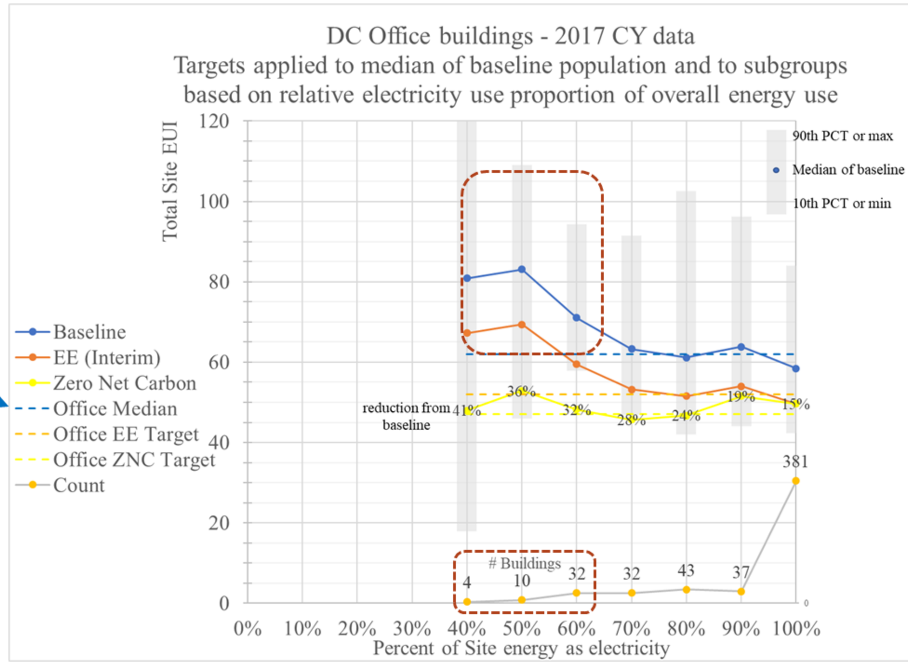

Figure 5. An example of how the median site EUI, and targets based solely off the median, may be more or less difficult for different buildings to obtain within a typology in a given city. In this case, it may be more difficult for the heavy gas using office buildings in DC to reach a median-based target.

EMISSIONS AND COST IMPLICATIONS OF TARGETS

This section converts the performance targets for the core cities into GHG intensity, provides a rough estimate of cost implications to convert from gas to electric end uses, and evaluates the costs in relation to GHG emissions reductions for the ZNC targets.

Table 17. Greenhouse Gas coefficients for electricity in the core cities, and natural gas GHG coefficients across all cities. Long-term, electricity will be produced at net zero GHG emissions, so all cities converge on a near-zero number in the ZNC scenario.

Core City	eGRID Subreg.	State	eGRID baseload [Lb/kBTU]	eGRID non-baseload [Lb/kBTU]	**City GHG Inventory [Lb/kBTU]**	eGRID State-based	**Today GHG [kg/kBTU]**	ZNC GHG [kg/kBTU]
DC	RFCE	DC	0.2234	0.4224	**0.4224**	0.1416	**0.1916**	0.0027
NYC	NYCW	NYC	0.1867	0.3115	**0.1676**	0.1365	**0.0760**	0.0027
Santa Mon	CAMX	CA	0.1553	0.2771	**0.1553**	0.1331	**0.0704**	0.0027
Seattle	NWPP	WA	0.1921	0.4495	**0.0059**	0.0551	**0.0027**	0.0027
Natural Gas [27]					**0.0531**		**0.0531**	**0.0531**

Cost estimating for the ambitious targets over a period of the coming thirty plus years is a significant challenge. As new regulations are implemented and building retrofits move to scale, it is expected that costs for many types of retrofits will come down significantly. Cost estimating is always challenging and making estimates about costs for projects that may not be done until 10 to 25 years from now introduces a thick layer of complexity to this forecasting exercise.

To make estimates of the incremental costs to reach the targets described earlier in this report, costs for switching from fossil fueled space heating systems to heat pumps, and for more efficient envelope systems, were adapted from two recent studies that included more detailed cost estimating:

- Heat Pump Retrofit Strategies for Multifamily Buildings[28] (prepared for Natural Resources Defense Council); and
- Pursuing Passive[29] (prepared by the Building Energy Exchange).

Both of these studies performed or compiled detailed cost estimates, which have been summarized in the spreadsheet tool that accompanies this report. The focus of these studies was space heating systems, which are assumed to be somewhat translatable across building types, even though these studies focused on multifamily buildings. For different end uses and building typologies, we have estimated the "baseline, business as usual (BAU)" costs over the coming 20-30 years, assuming normal equipment replacement schedules, and then the increased costs to get to ZNC compatibility. More detailed specific information about these cost estimates are provided in the spreadsheet tool Reference Tabs (specifically in the "Electrification of Gas End Uses" sheets in the workbook).

A cost analysis was done on the basis of replacing gas appliances with electric appliances. A representative product replacement was selected for each gas end use. The efficiency and cost were scaled to the product's

[27] US EPA. "ENERGY STAR Portfolio Manager Technical Reference: Greenhouse Gas Emissions". Updated August 2019. Page 7, Figure 1: https://portfoliomanager.energystar.gov/pdf/reference/Emissions.pdf
[28] Heat Pump Retrofit Strategies for Multifamily Buildings, April 2019: https://www.nrdc.org/sites/default/files/heat-pump-retrofit-strategies-report-05082019.pdf
[29] Pursuing Passive, October 2018: https://be-exchange.org/wp-content/uploads/2018/10/BEX_PursuingPassive_181101.pdf

annual usage so that an incremental $/kBTU could be generated and applied to each kBTU of gas being replaced by electricity. The cost estimates were applied to each gas end use being electrified to arrive at a total electrification cost per building type based on gas end uses. A cost was not developed for the interim energy efficiency state because the retrofits required and the mechanisms to implement energy efficiency improvements are too variable to estimate with any usable precision.

Excluded from the cost estimates are:

1. Potential infrastructure changes to the electricity service both within and outside each building to fully accommodate the ZNC equipment retrofits. These are likely highly variable both in project cost and in any building's starting point of electricity service. Other infrastructure changes that are not fully captured in these costs are commercial cooking and laundry ventilation changes, which may be required when moving from gas to electricity appliances. The estimates presented here are meant to provide a rough order of magnitude given today's relative cost of electricity and gas equipment.
2. Operating cost differences resulting from electrification. Current rates and rate structures are not likely a good indicator of future operating costs for energy.

Table 18. Installation cost estimates for different gas end use equipment. Details on cost estimates are available in the accompanying spreadsheet tool.

	Space heating	**Water heating**	**Cooking**	**Other**
New electricity EUI as a percentage of old gas EUI	**32%**	**41%**	**61%**	**89%**
BAU Installation cost/ (first year kBTU) for gas appliances (1 replacement cycle) One-time cost to replace with gas appliance	$0.10	$0.10	$0.76	$0.64
Installation cost/ (first year kBTU) for conversion to electric appliances	$1.03	$0.23	$0.72	$0.60
Installation cost ratio electricity / gas	1037%	222%	95%	93%

The following tables summarize the targets for each building type in terms of GHG intensity changes and cost implications. Dividing cost by GHG reduction gives a carbon abatement cost per building type, which is the equipment cost required for each kgCO2e to be reduced. Assessed in this way, the relative level of effort can be examined across building types. Groups of buildings with a high GHG intensity today and a low carbon abatement cost are good targets for electrification soon, while those with high carbon abatement costs will have a tougher time saving the same amount of emissions.

Table 19. Seattle target GHG and cost impact estimate, compared to Business-as-usual (BAU) costs.

Seattle	**Greenhouse Gas Intensity [kgCO2e/SF/yr]**			**Installation Cost Intensity for Retrofits [$/SF]**			**Abatement Costs**	
GHG & Installation Cost Impact	Baseline	Interim	ZNC compatible	Baseline BAU Cost	ZNC compatible systems	Increased cost for ZNC compatibility % above BAU	Cost for first year GHG reductions [$/kgCO2e]	Cost for first year Gas reductions [$/kBTU gas EUI]
MF-New-Tall	0.4	0.4	0.1	$1	$2	59%	$1.99	$0.11
MF-Old-Tall	0.2	0.2	0.1	$2	$2	-5%	($0.60)	($0.04)
MF-Short	0.1	0.1	0.1	$1	$1	-5%	($0.51)	($0.04)
Education	1.2	1.0	0.1	$5	$18	277%	$11.17	$0.72
Food sales	5.0	4.2	0.4	$34	$73	118%	$8.67	$0.54
Food service	4.3	4.1	0.2	$40	$52	28%	$2.84	$0.16
Health care Inpatient	6.6	5.7	0.3	$33	$87	162%	$8.50	$0.52
Health care Outpatient	0.8	0.6	0.1	$1	$11	849%	$15.25	$1.16
Lodging	1.9	1.8	0.1	$6	$17	179%	$6.14	$0.35
Mercantile Enclosed and strip malls	1.3	1.2	0.1	$8	$16	96%	$6.38	$0.38
Mercantile Retail (other than mall)	1.0	0.8	0.1	$4	$15	252%	$11.82	$0.79
Office	0.3	0.2	0.1	$1	$1	3%	$0.23	$0.01
Other	1.3	1.0	0.1	$2	$23	889%	$16.57	$1.23
Public assembly	2.5	2.0	0.1	$12	$41	254%	$12.26	$0.82
Public order and safety	2.2	1.9	0.1	$6	$26	329%	$9.37	$0.58
Religious worship	1.4	1.1	0.0	$6	$25	311%	$13.91	$0.96
Service	3.6	2.9	0.1	$7	$51	661%	$12.66	$0.83
Warehouse and storage	0.6	0.5	0.1	$3	$9	217%	$10.46	$0.67
Vacant	0.6	0.4	0.0	$1	$10	854%	$16.02	$1.17

Table 20. Washington DC target GHG and cost impact estimate, compared to Business-as-usual (BAU) costs.

Washington DC	**Greenhouse Gas Intensity [kgCO2e/SF/yr]**			**Installation Cost Intensity for Retrofits [$/SF]**			**Abatement Costs**	
GHG & Cost Impact	Baseline	Interim	Cost for first year GHG reductions [$/kgCO2e]	Cost for first year GHG reductions [$/kgCO2e]	ZNC compatibl e systems	Increased cost for ZNC compatibility % above BAU	Cost for first year reductions [$/kgCO2e]	Cost for first year reductions [$/kBTU gas EUI]
MF-New-Tall	7.2	3.3	0.1	$1	$5	253%	$0.48	$0.43
MF-Old-Tall	6.0	3.6	0.1	$7	$26	290%	$3.24	$0.49
MF-Short	6.4	3.6	0.1	$6	$20	256%	$2.28	$0.46
Education	9.1	4.4	0.1	$6	$21	272%	$1.73	$0.71
Food sales	29.3	13.8	0.4	$23	$49	115%	$0.92	$0.53
Food service	27.0	16.6	0.5	$94	$120	28%	$0.98	$0.15
Health care Inpatient	25.3	13.5	0.4	$33	$86	158%	$2.12	$0.51
Health care Outpatient	13.0	5.6	0.2	$1	$7	847%	$0.48	$1.15
Lodging	11.7	5.9	0.2	$6	$17	176%	$0.95	$0.35
Mercantile Enclosed and strip malls	15.7	7.9	0.2	$17	$34	94%	$1.06	$0.37
Mercantile Retail (other than mall)	10.4	4.9	0.1	$5	$18	248%	$1.26	$0.78
Office	11.5	4.9	0.1	$0	$1	235%	$0.04	$0.69
Other	12.6	5.8	0.2	$3	$25	888%	$1.79	$1.23
Public assembly	13.8	6.7	0.2	$10	$36	249%	$1.90	$0.81
Public order and safety	11.9	5.9	0.2	$5	$22	324%	$1.45	$0.57
Religious worship	7.5	3.7	0.1	$6	$25	306%	$2.56	$0.95
Service	6.9	3.6	0.1	$4	$28	656%	$3.52	$0.83
Warehouse and storage	2.3	1.0	0.0	$0	$1	213%	$0.31	$0.67
Vacant	3.4	1.6	0.0	$1	$10	852%	$2.63	$1.16

Table 21. New York City target GHG and cost impact estimate, compared to Business-as-usual (BAU) costs.

New York City	**Greenhouse Gas Intensity [kgCO2e/SF/yr]**			**Installation Cost Intensity for Retrofits [$/SF]**			**Carbon Abatement**	
GHG & Cost Impact	Baseline	Interim	ZNC compatible	Baseline BAU Cost	ZNC compatible systems	Increased cost for ZNC compatibility % above BAU	Cost for first year GHG reductions [$/kgCO2e]	Cost for first year reductions [$/kBTU gas EUI]
MF-New-Tall	5.2	3.2	0.1	$7	$42	502%	$6.83	$0.80
MF-Old-Tall	5.6	3.8	0.1	$9	$62	551%	$9.48	$0.86
MF-Short	7.0	3.7	0.1	$7	$41	508%	$4.98	$0.83
Education	3.9	2.4	0.1	$8	$38	364%	$7.72	$0.85
Food sales	8.7	3.1	0.2	$0	$0	170%	$0.01	$0.68
Food service	18.6	13.7	0.5	$113	$162	43%	$2.65	$0.22
Health care Inpatient	11.1	6.8	0.2	$27	$88	224%	$5.64	$0.65
Health care Outpatient	6.1	2.8	0.1	$4	$35	877%	$5.19	$1.21
Lodging	7.9	4.5	0.2	$10	$35	235%	$3.17	$0.45
Mercantile Enclosed and strip malls	6.8	2.6	0.2	$3	$7	137%	$0.60	$0.49
Mercantile Retail (other than mall)	6.6	2.8	0.2	$5	$21	337%	$2.53	$0.92
Office	5.5	2.6	0.1	$6	$26	322%	$3.70	$0.84
Other	4.8	2.3	0.1	$3	$32	905%	$6.13	$1.27
Public assembly	6.3	3.2	0.1	$10	$43	340%	$5.45	$0.94
Public order and safety	7.1	4.2	0.1	$9	$48	415%	$5.60	$0.70
Religious worship	5.2	2.7	0.1	$8	$41	406%	$6.54	$1.06
Service	7.2	4.5	0.1	$9	$75	733%	$9.29	$0.95
Warehouse and storage	4.5	2.2	0.1	$6	$25	295%	$4.28	$0.81
Vacant	2.8	1.6	0.0	$3	$33	881%	$10.57	$1.22

Table 22. Santa Monica target GHG and cost impact estimate, compared to Business-as-usual (BAU) costs.

Santa Monica	**Greenhouse Gas Intensity [kgCO2e/SF/yr]**			**Installation Cost Intensity for Retrofits [$/SF]**			**Carbon Abatement**	
GHG & Cost Impact	Baseline	Interim	ZNC compatible	Baseline BAU Cost	ZNC compatible systems	Increased cost for ZNC compatibility % above BAU	Cost for first year GHG reductions [$/kgCO2e]	Cost for first year reductions [$/kBTU gas EUI]
MF-New-Tall	2.7	1.8	0.1	$5	$15	231%	$3.99	$0.40
MF-Old-Tall	2.7	1.8	0.1	$5	$17	265%	$4.81	$0.45
MF-Short	2.5	1.7	0.1	$4	$14	233%	$3.96	$0.42
Education	3.8	2.1	0.1	$7	$20	192%	$3.59	$0.56
Food sales	13.6	6.5	0.4	$27	$48	74%	$1.53	$0.39
Food service	15.6	11.3	0.4	$97	$114	18%	$1.13	$0.10
Health care Inpatient	12.7	7.8	0.3	$36	$74	108%	$3.12	$0.38
Health care Outpatient	5.4	2.4	0.1	$2	$22	802%	$3.64	$1.07
Lodging	5.1	3.1	0.1	$8	$18	131%	$2.02	$0.26
Mercantile Enclosed and strip malls	7.2	4.0	0.2	$19	$30	63%	$1.65	$0.26
Mercantile Retail (other than mall)	4.4	2.0	0.1	$6	$16	172%	$2.35	$0.63
Office	5.0	2.5	0.1	$8	$20	162%	$2.58	$0.54
Other	7.8	3.3	0.2	$3	$24	861%	$2.83	$1.18
Public assembly	4.6	2.4	0.1	$10	$27	172%	$3.73	$0.65
Public order and safety	5.1	2.9	0.1	$6	$21	244%	$3.03	$0.44
Religious worship	2.1	1.2	0.0	$5	$17	216%	$5.84	$0.81
Service	3.5	2.1	0.1	$3	$22	564%	$5.48	$0.68
Warehouse and storage	2.5	1.4	0.1	$6	$14	145%	$3.36	$0.51
Vacant	1.5	0.7	0.0	$1	$8	809%	$5.01	$1.08

PERFORMANCE METRICS FOR EXISTING BUILDINGS

OBJECTIVE

Task 3: Identify the potential energy and emissions standards and metrics relevant to achieving the identified targets, with variations by building type as needed, and evaluation of applicability (e.g. pros and cons).

BASELINE ASSUMPTIONS FOR PERFORMANCE STANDARDS

1. Metrics are based on each building's measured energy use and resulting emissions. An alternative would be a set of qualitative characteristic requirements such as:
   - Verifying and limiting the type of energy (e.g., no oil or gas)
   - A prescriptive list of characteristics that buildings need to have through some retrofit requirement (e.g., retro-commissioning + certain energy conservation measures)
   - Prohibition of certain gas equipment replacement or permitting (e.g., no new boilers)
2. Energy use is the total of what is needed from outside the building boundary, i.e., what is in front of the metered interface with energy utilities. The performance standards developed in this study reflect energy use requirements assuming no on-site energy sources. Contributions from on-site energy sources could be used as an overlay to these standards.

OBJECTIVES OF PERFORMANCE METRICS

1. **Greenhouse Gas Emissions:** Enable reductions to meet city climate goals
2. **Consumption:** Overall energy consumption should be reduced in a way that moves building stock towards citywide GHG emissions goals
3. **Demand:** Energy demands should be conducive to grid and renewables integration, minimizing peak demands and adding demand flexibility
4. **Administration/Enforceability:** Does not place an undue administrative burden and is acceptable to building owners and city administrators alike, which means considering many of the following factors (in no particular order):
   - ***Fair and transparent*** *to energy users across major use types*
   - ***Easy to understand*** *for building owners so they know what to do*
   - ***Reproducible*** *by different parties, using objective parameters*
   - ***Repeatable*** *over time (annually, every five years, etc.) and across locations and jurisdictions*

5. **Encourages GHG emissions reductions** both today and for the foreseeable future that will accommodate changing infrastructure, integration of renewables, and new technologies
6. **Create/ensure carbon neutral buildings:** long term goal

TYPES OF PERFORMANCE METRICS

A variety of different performance metrics could be considered for establishing existing building performance standards. Per one recent review of building performance metrics and policy considerations:

> *Policymakers often provide consumers with tools and incentives to help them make choices that align with policy goals. These tools range from direct rebate incentives on certain equipment, minimum appliance standards, energy "scores" that rate the performance of their home, or ENERGY STAR labels. These tools depend on technical analysis that must be periodically updated as technology changes or the policies incentivize the wrong choices, leading to sub-optimal outcomes. A period of rapid technology change makes updating these tools all the more urgent.*[30]

The most common metric used is energy intensity, generally expressed in energy consumption per unit of floor area (in the U.S., usually in KBTU/square foot). In any sort of metric like this, there is both a numerator and a denominator, but there are nuances in whether the energy is expressed as "site" vs. source energy, or energy cost, or an alternative. Similarly, the denominator is most regularly floor area, but others might be considered. The following tables summarize some of the different potential alternatives, and how the metric may impact a push for electrification as a carbon reduction tool.

Table 23. Types of performance metric numerators that account for building performance in various ways. Examples are where these approaches are in use today.

Numerator Type	Strengths	Weaknesses	Example Approach
Site Energy	Number measured on site or directly from utility bill Reflects what owners can control and are responsible for	Not directly a GHG measurement Allows owners to forget about energy production methods outside their buildings Strong signal for efficient electrification, since heat pumps and electric systems tend to have higher equipment efficiency than gas systems	Seattle Energy Benchmarking
Source Energy	Some consideration of transmission and distribution losses impacting energy input	The source energy conversion factor can only be used for national summaries of measured energy if using ESPM Does not represent GHG emissions Variability of source:site ratio over time Not directly related to policy goals: weak signal for electrification; strong signal for increasing natural gas infrastructure with on-site cogeneration of electricity and heat.	ESPM, ENERGY STAR Score
Energy Cost	In-line with building owner's primary considerations	Not related to GHG May prioritize cheaper fuel over efficiency Variability of rates over time	ASHRAE 90.1 Energy Cost Budget[31]

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[30] Dennis, Keith. "Environmentally Beneficial Electrification: Electricity as the End-Use Option". The Electricity Journal. Volume 28 Issue 9, November 2015. https://www.sciencedirect.com/science/article/pii/S104061901500202X

[31] ASHRAE 90.1 Energy Cost Budget – energy cost as determined through procedures spelled out in ASHRAE Standard 90.1 (Energy Standard for Buildings Except Low-Rise Residential Buildings)

CO2e Emissions	In line with policy goals of GHG reduction if appropriate forecasting of carbon coefficient is used	Dependency on factors outside the building that owners have no control over Variability due to fuel mix of electricity production and potential for revisions to gas GHG coefficients over time Typically scope 1 for fuels, scope 2 for electricity, which neglects fugitive emissions and waste in transit[32]	NYC LL97/2019[33] Tokyo Cap and Trade[34]
Coincident Demand (at system peak)[35]	Demand on infrastructure is important if the grid and/or distribution network is constrained	Sensitive to building location within the city for distribution constraints, making metrics calculation difficult Requires utilities to map out constraints and system peaks for all buildings and provide times of limitation so buildings have actionable feedback	Utility pricing models based on demand

Table 24. Normalizing factors that can be used as denominators in a performance metric.

Denominator / Normalizing Variable	Strengths	Weaknesses	Example Approach
Floor Area	Physical characteristic of building; verified once unless significant change to floor area Consistent over time as occupancy or space use may change Simplicity	Process and appliance loads may not scale this way if highly dependent on equipment type	ENERGY STAR
Occupant Density	Aligns with major driver of GHG emissions for some end uses	Very hard to measure and validate	NYC Carbon Challenge[36]

[32] The GHG Protocol has definitions of Scope 1 and Scope 2 in section 3.5: https://ghgprotocol.org/sites/default/files/standards/GHGP_GPC_0.pdf The EPA ESPM emissions factors take into account EGRID electricity carbon emissions intensity reports, which incorporate fuel mix used for generation of electricity. This falls under a Scope 2 calculation. The EPA ESPM emissions factor for fuels, however, only considers the emissions from on-site combustion of fuel, not the fugitive emissions or other emissions inherent in the use of these fuels. See "Portfolio Manager Technical Reference: Greenhouse Gas Emissions" for methodology. https://portfoliomanager.energystar.gov/pdf/reference/Emissions.pdf

[33] New York City Local Law 97 or 2019, establishes GHG/floor area limits, more details at https://www1.nyc.gov/assets/buildings/local_laws/ll97of2019.pdf

[34] More information at: http://www.kankyo.metro.tokyo.jp/en/climate/cap_and_trade/index.html

[35] Coincident Demand – The demand of a device, circuit, or building that occurs at the same time as the peak demand of a utility's system load or at the same time as some other peak of interest, such as building or facility peak demand. The peak of interest should be specified (e.g. "demand coincident with the utility system peak"). From NEEP Glossary of Terms version 2.1.

[36] See https://www1.nyc.gov/html/gbee/html/challenge/mayor-carbon-challenge.shtml

Person-hour (occupants *hours of occupation)	Aligns with two major drivers of GHG emissions	Even harder to measure and validate Complicated to legislate	NYC Carbon Challenge
Specific measure of output (customers served, sales amount, etc.)	Most relevant for some building types where activity does not scale directly with floor area or occupant density	Extremely difficult to measure and validate Could change dramatically year over year	
Absolute (Total energy or carbon; no denominator)	Straight-forward for individual buildings	Penalizes large buildings More complex calculation for initial limit/allocation	Tokyo Cap & Trade
For Residential Buildings			
Apartments Or Units	Verifiable for residential buildings	Not all end uses scale this way – space conditioning more proportional to floor area Occupant density and unit count are not necessarily linked	
Bedrooms	Verifiable for residential buildings Perhaps more closely tied to actual occupancy	Actual occupancy and bedroom count are not necessarily linked	

Table 25. Performance metrics in use or worth closely evaluating as part of a policy framework.

Metric	Strengths	Weaknesses
Site EUI kBTU/SF	Easiest way to measure energy use directly from energy bills Floor area is fixed once verified Applies to every space use type	Does not account for occupancy Overall consumption and GHG emissions are not necessarily correlated, and may further diverge in the future Needs weather-normalization to account for year on year changes
Work needed to implement: Site EUI needs an appropriate conversion of site energy to citywide goal of GHG and setting Site EUI thresholds and targets that incentivize the right energy reductions. This report provides an approach that includes long-term performance potential and one way to create interim targets, but implementation by building type and region needs to be evaluated by the city based on local conditions. Site EUI also requires a determination of energy-to-GHG conversion factors to develop future limits on site energy use that move building performance in the right direction in the near and long term. This requires energy type differentiation, since electricity use has a different GHG impact from gas or district steam use. Considerations for Cities/Stakeholders: Site EUI is likely understood by building owners and managers, as it is calculated directly from utility bills and floor area. Owners can directly control site energy usage. This can make initial messaging straightforward for cities. However, site EUI does not directly link to carbon goals and different fuel mixes significantly affect the carbon intensity of a building with a given site EUI.		

Metric	Strengths	Weaknesses
Issues to get city to carbon goals: Leaves more up to other policies to manage carbon content of fuels (primarily electricity) and does not have the direct link to city carbon goals, creating an additional layer of complexity in how building performance is reported and managed.		
GHG Intensity kgCO2e/SF (annual)	Comparable measure of annual GHG emissions quantified for each building	Annual carbon emissions do not factor in time of use fuel mix for electricity Individual building performance is more difficult to compare year on year if the coefficients change, unless it is artificially fixed for segments of time.
Work needed to implement: GHG conversion factors need to be 1) defensible given current energy sources, and 2) appropriate for long-term planning. The current electricity grid may use GHG-intensive energy sources such as natural gas, oil, and coal. While the GHG-intensity of the grid may go down, some localities may provide a long term signal away from electrification if the current grid is used to develop GHG intensity numbers. Considerations for Cities/Stakeholders: GHG is the goal for most cities for their carbon neutrality target, making this a defensible metric to use by cities. However, it may be challenging for building owners, as carbon content of electricity is outside their control and few are accustomed to thinking in terms of GHG emissions. Cities can fix electricity carbon intensity as one way to minimize owner concerns about grid fuel mix changes. Issues to get city to carbon goals: Using a GHG intensity metric for policy is an obvious and direct metric for working toward carbon neutrality goals for cities, an objective that is transparently translated to building owners.		
ENERGY STAR Score	Most stakeholders familiar with ENERGY STAR score, and it is part of most benchmarking and disclosure policies Good for graduated performance improvements by recalculating scores to reflect city progress	Requires multiple inputs, some of which are difficult to verify, opening the possibility of falsified data Involves updating the scoring curve regularly, though it only makes sense to do so using a city-specific sample Source energy does not represent carbon emissions or site energy efficiency, and the factors are only on the national scale, neglecting local energy generation specifics
ENERGY STAR is well known and accepted by most stakeholders as a fair metric for measuring and comparing relative energy efficiency between buildings with the same use (office, multifamily, school, etc.), with inputs to adjust raw energy consumption and calculated energy intensity for the factors that most directly drive energy consumption, such as occupancy levels, hours of operation, computer equipment, etc., simplifying all of those inputs down to a 1 to 100 “normalized” score. ENERGY STAR is the metric used in the Washington, DC Building Energy Performance mandate. The biggest challenge with ENERGY STAR as a metric for building performance policies is validation/verification of the range of inputs that go into generating an ENERGY STAR score. The flaw with ENERGY STAR Score is that it currently uses source energy		
Coincident Demand Intensity at System Peak + on-site combustion limits Max kW + Gas EUI	Encourages load flexibility to be grid-optimal, a requirement for renewables-based electricity grids Can support demand response and peak shifting with feedback from electricity suppliers	Needs to be combined with a fossil fuel usage requirement Relies on interval meters and utility cooperation/coordination Potentially requires multiple utility cooperation to enforce both electricity and gas limitations separately and accurately.

Metric	Strengths	Weaknesses
Work needed to implement: short interval electricity meters are needed to measure electricity demand for all covered building types. Transparent demand and load factor calculations by the utility and enforcement agencies will give building owners the correct guidance to manage coincident demand. To prevent new fuel usage, a fossil fuel limitation of some sort is needed in parallel with an electricity demand limitation. Considerations for Cities/Stakeholders: demand-based metrics can help prevent mass electrification and thus prevent major grid supply issues. Building owners are likely familiar with managing peak demand in cities where utilities charge large buildings based on electricity demand peaks, though coincidence with system peaks have not been a driver of decision making for conservation. A fossil fuel limit in conjunction with demand limiting can drive fossil fuel reductions, a key goal for cities necessary to achieve for carbon neutrality. Issues to get city to carbon goals: demand measurement is not directly linked to carbon goals but can be important for managing price challenges of electrification. If gradually brought down, fossil fuel use targets promote electrification, and can be reduced incrementally based on interim target setting.		
Thermal Energy Demand Intensity (TEDI)[37] [kWh/m^2/yr] or [kBTU/SF/yr]	Focus on HVAC energy use efficiency, allowing flexibility for different space use types	Requires energy model, not calibrated to actual building energy use Neglects non-HVAC loads Can't be tracked annually
Total System Performance Ratio (TSPR)[38] [kBTU/lbCO2e]	Sets relative whole system efficiency for HVAC systems, instead of just individual components Ratio of predicted heating, cooling & ventilation load to carbon emissions	Requires energy model, not calibrated to actual building energy use Neglects non-HVAC loads The model doesn't change year to year unless equipment changes. Not available for all building types[39]

DISCUSSION: ENERGY CONSUMPTION VS PEAK DEMAND METRICS

This study focuses on total annual energy consumption across building types and cities. The electrification targets developed here are based on identifying physical limits of buildings, pairing electrification with optimal replacement of envelope components, interactive occupant behavior change and electric end use efficiency. A low carbon or carbon neutral future requires lowered energy consumption in buildings.

However, while energy consumption is the focus of this and prior studies, it doesn't reflect the electricity supply interactivity required in a renewables-based future state.

Energy consumption targets are therefore a necessary but incomplete signal to achieve desired policy goals at the community/regional scale.

In a future state that approaches carbon neutrality, the total quantity of energy use may become much less important than when and where that energy is used. Today's fossil fuel-based electricity supply dispatches flexible supply ("peaker" power plants) to meet relatively fixed demand. In many markets, a renewables-based energy supply may need flexible demand dispatched to meet relatively fixed supply (i.e. when sun shines and

[37] Canada Green Building Council. "Zero Carbon Building Energy Modelling Guidelines" 2017. Section 2: "Calculating TEDI". https://www.cagbc.org/cagbcdocs/zerocarbon/CaGBC_EMG_for_ZCB_v01.pdf
[38] https://carbonneutralcities.org/wp-content/uploads/2018/11/TSPR-The-Total-System-Performance-Ratio-as-a-Metric-for-HVAC.pdf
see also "HVAC Total System Performance Ratio: Frequently Asked Questions". https://carbonneutralcities.org/wp-content/uploads/2018/11/TSPR-FAQs.pdf
[39] https://fortress.wa.gov/es/apps/sbcc/File.ashx?cid=7295

wind blows). Hypothetically, relaxing consumption targets and coupling with aggressive demand flexibility may be both more supportive of policy goals and less expensive for the market to implement. In this case, from a policy perspective, the relaxed requirements for envelope components, lighting and appliances could be handled prescriptively by codes in sync with natural replacement cycles.

Table 26. Combination of metrics that address peak energy demand on infrastructure and energy supply sources. While these do not address total energy consumption, they may be worth assessing when a time-dependent or location-dependent strain on the local energy supply is forecasted.

Metric	Strengths	Weaknesses	Example Approach
Coincident Demand Intensity at System Peak [kW/SF at system peak]	Encourages load flexibility to be grid-optimal Can support demand response and peak shifting with feedback from electricity suppliers	Needs to be combined with a fossil fuel usage requirement Relies on interval meters and utility cooperation/coordination	NY and NE use Installed Capacity (ICAP) tag Mid Atlantic / PJM uses Peak Load Contribution LA County uses weather dependent table for demand pricing lookup SCL uses time-of-day 6am-10pm peak time but is otherwise unconstrained

Table 27. Adjustment factors that can alleviate concerns of performance matric accuracy and appropriate target-setting.

Correction Needed	Adjustment	Method to Implement
Occupancy: Occupancy can be different within equal sized buildings, changing energy use profile.	Occupancy-based adjustment to allow higher density areas more energy use	Use ENERGY STAR occupancy accounting methods for different space types (# bedrooms, room density, or number of computers)
Weather: Climate and weather changes - hot years and cold years have different energy use requirements.	Year-on-year weather normalization within a city	ENERGY STAR weather normalization methodology and use of weather-normalized energy outputs from PM
Mixed Use Buildings: Multiple space uses within a single building can affect overall performance, and some buildings share systems across space use types.	Require accurate accounting of space use types in buildings.	Use performance requirements based on entered space use types, resulting in an area weighted requirement Put the onus on building owners to sub-meter minor spaces

SPREADSHEET TOOL INSTRUCTIONS

This report has an accompanying calculation workbook that can be used to examine the performance targets in more detail and develop targets for other cities or by using other typologies. Below are brief instructions which are repeated on the Readme tab of the workbook file.

Starting Points:

1) Property tax – level data. Count and floor area by space use type, but no energy data.
2) Benchmarking-level data. Whole building energy data by energy type (gas + electricity) by space use type, but not end-use specific information.
3) End-use – level data. Energy type data specific to each end use from audit or survey data.

Descriptions of building types are on the table on the Readme tab.

Starting Point 1: enter count and floor area by space use type into the respective columns in the City Template sheet (or the sheet already created for a Core City). Select Building America Climate Zone and make any edits to the heating and electricity EUI savings estimates, if desired, or leave defaults. Targets are developed based on estimated end use proportions and energy type totals from CBECS information and climate adjustments.

Starting Point 2: enter count, floor area, and energy use medians for gas and electricity EUIs. Select Building America Climate Zone and make any edits to the heating and electricity EUI savings estimates, if desired, or leave defaults. Targets are developed based on estimated end use proportions mapped to energy type totals.

Starting Point 3: enter count, floor area, and energy use medians for gas and electricity EUIs. Select Building America Climate Zone and make any edits to the heating and electricity EUI savings estimates, if desired, or leave defaults. In the section below, replace default end use estimates with actual end use EUIs per end use. note that typology names can also be changed in the “Baseline” section of the sheet if the end use default estimates are not needed.

Energy-specific GHG intensity coefficients: The GHG coefficient for natural gas is a fixed number as it does not change depending on location or type of use (assuming it is all burned in some way). The GHG coefficient for electricity is looked up from the table on the Readme tab. The GHG coefficients can be overridden on any particular City tab for a more customized analysis.