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Montgomery County, MD
Department of Environmental Protection

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Building Energy Performance Standards Development – Technical Analysis

Montgomery County, MD

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EXECUTIVE SUMMARY

BACKGROUND AND SUMMARY OF PROPOSED BEPS LEGISLATION

Montgomery County, MD (County) released its final Climate Action Plan (CAP) in June 2021 with a goal to cut community-wide greenhouse gas emissions (GHG) by 80% by 2027 and 100% by 2035. According to the CAP, "the County will need to deploy a combination of energy performance standards, code requirements, and incentives to support 100% building electrification by 2035."[1]

The County has introduced legislation[2] that would set site energy use intensity (site EUI) building energy performance standards (BEPS) for large commercial and multifamily buildings. The site EUI metric was recommended by Montgomery County stakeholders[3] and is a building energy performance metric that rewards energy efficiency and the electrification of fossil fuel systems. The legislation would segment covered buildings into groups according to their building type and size, phasing in compliance with the performance standards. Each group would be subject to a final performance standard between 2035 and 2037, depending on the group. Each building within a group would be required to meet its final performance standard as well as interim standards in earlier years in 4-year intervals.

GOALS OF THIS REPORT

This report is meant to provide policy makers with technical information relevant to the setting of building energy performance standards. The following goals were identified by the County to consider during the study:

- Create a framework to generate potential energy performance standards for covered buildings.
- Understand how the timing and stringency of potential energy performance standards impact cumulative GHG emissions over the next two decades.
- Evaluate what retrofits are technically feasible, what the total cost might be (independent of who pays), and the cost and carbon benefits of achieving the energy performance standards.
- Assess how a BEPS intervention affects the performance of the covered buildings towards a zero-emissions buildings goal by 2035.

Steven Winter Associates, in close coordination with the Montgomery County Department of Environmental Protection (the "study team") completed this study which provides the following information:

- A review of the building stock and energy benchmarking information of Montgomery County and development of an approximate list of buildings projected to be subject to a BEPS policy. This building stock was separated into building types to set technically feasible site EUI targets.
- A recommended method for setting building performance standards, what the targets can be, and the estimated impacts of meeting those targets.
- Case studies detailing how different energy performance standards can be achieved for a representative sample of buildings.
- An estimate of the total capital investment to reach the standards, which would inform both the cost to building owners and the level of economic impact of the recommended standards.

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[1] Montgomery County. "Montgomery County Climate Action Plan Public Draft". https://www.montgomerycountymd.gov/green/Resources/Files/climate/draft-climate-action-plan-printable.pdf Page xvii.
[2] Bill 16-21 - Environmental Sustainability - Building Energy Use Benchmarking and Performance Standards - Amendments: https://apps.montgomerycountymd.gov/CCLLIMS/BillDetailsPage?RecordId=2707
[3] Montgomery County. "BEPS Stakeholder Recommendation Report". https://www.montgomerycountymd.gov/DEP/Resources/Files/ReportsandPublications/Energy/MC-BEPS-Stakeholder-Report.pdf page 10.

RESULTS

Target Setting Method

Site EUI building performance standards were developed based on technically achievable performance using typical energy use profiles in various building types representative of Montgomery County's building stock and assuming retrofits using commercially available technology. This approach is described in depth in the section *Site Energy Use Intensity Performance Targets*.

The countywide impact analysis evaluated three potential targets. These targets were developed by applying the following methodology to each building type. The result is that all buildings in the same occupancy type grouping have the same EUI targets (e.g., all office buildings have the same site EUI targets, all multifamily buildings have the same site EUI targets, all hospitals have the same site EUI targets).

- **Energy Efficiency (EE) Target**: Sets a target such that all energy end uses were deeply optimized and tuned without impacting occupant use patterns. This target-setting method assumed that typical buildings could maintain the use of fossil-fuel burning systems for typical end uses such as space and water heating but would minimize inefficiencies of those systems.
- **Zero Net Carbon-Compatible (ZNC) Target**: Sets the target to a level simulating the electrification of fossil-fuel end uses using market-ready technology in an energy efficient building. Electrification is one of the deepest forms of energy efficiency since electric equipment operates at a much higher efficiency than fuel-fired equipment This target was intended to be most compatible with Zero Net Carbon goals because it implicitly required the elimination of most on-site fuel burning.
- **Mid-point between EE and ZNC Targets**: This target type exemplifies how the site EUI targets can be chosen anywhere along this spectrum between the EE and ZNC targets. A mid-point target was calculated to identify the impact of splitting the difference between the two targets. This target could be achieved using a combination of energy efficiency measures and partial electrification, or electrification of some, but not all, fossil-fuel-driven systems.

In framing this report, a site EUI target higher than the EE target was deemed unsuitable as it would not drive enough countywide savings. At the other end of the spectrum, a site EUI target lower than the ZNC target may not be technically achievable for most buildings.

Potential site EUI target options and the 2019 median site EUI for each occupancy type are shown in Figure 1.

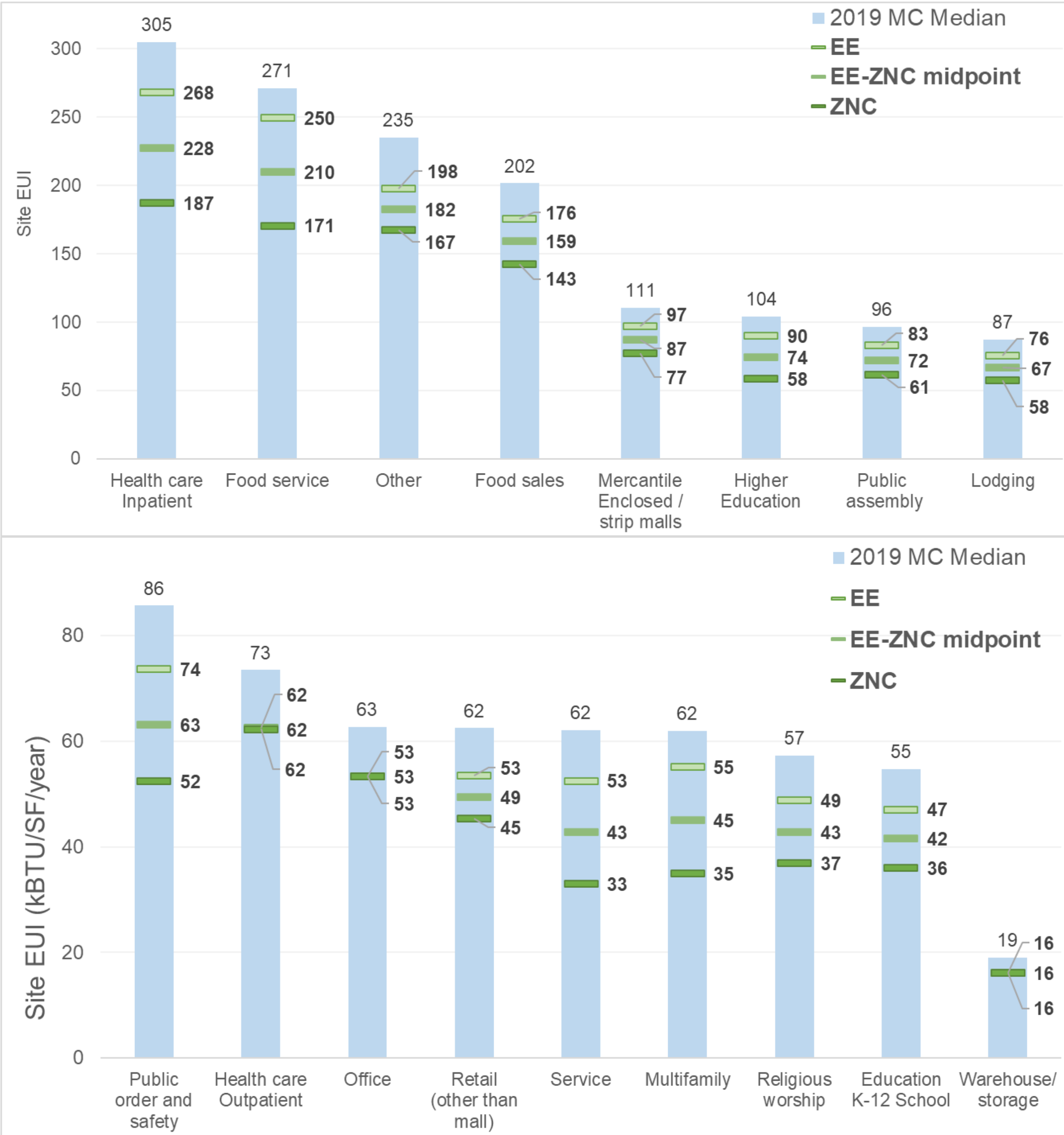

Figure 1. Options for Site EUI targets in Montgomery County based on this study. Building types that are already substantially all-electric, such as Health Care Outpatient, Office, and Warehouse/Storage have nearly identical EE and ZNC targets. Multifamily data median EUI comes from Washington, DC 2019 benchmarking information as multifamily buildings are not currently subject to Montgomery County's benchmarking law.

Energy Use Impacts

Significant energy savings would result from covered buildings reaching any of the identified site EUI targets, both in electricity use and on-site fuel burning. Projected energy savings compared to estimated 2019 energy use is shown in Table 1.

The eliminated energy use is primarily driven by reduction in on-site fuel burning through energy efficiency and electrification. Electric energy efficiency is also incorporated, though reductions in overall electricity use are partially offset by increases due to electrification of fossil fuel systems. Note that electricity savings are lower for the ZNC target than for the EE target. This is because achieving the ZNC target involves more electrification, which increases electricity use, albeit through more efficient electric systems and equipment. The total energy reduction in gas use outweighs the increase in electricity use from electrification. Note that this study did not project new construction trends, so energy use changes only relate to existing buildings.

Table 1. Energy Use Impacts for final Site EUI target options compared to baseline 2019 countywide building energy use.

Countywide Energy Impact of BEPS	Energy Efficiency (EE) Target	EE-ZNC midpoint	Zero-Net-Carbon (ZNC) Compatible Target
Reduction in Site EUI (annual)	23%	28%	35%
Reduction in On-site Fossil Fuel Emissions	46%	66%	86%

Setting the site EUI standards to the ZNC target shows estimated reductions of on-site fossil fuel emissions by 86% by the year of the final standards for the latest group ("final year"). This is because electrification is one of the deepest forms of energy efficiency since electric equipment operates at a much higher efficiency than fuel-fired equipment. Therefore, most buildings would need to electrify their on-site fossil fuel burning systems to reduce site EUI to the level necessary to meet the ZNC standards. The elimination of on-site fuel burning will have a direct contribution to local air quality improvements. The eliminated energy use is primarily driven by reduction in on-site fuel burning through energy efficiency and electrification. The ZNC target provides overall site EUI reductions (for all fuels) of 35%.

In contrast, the EE target is estimated to reduce on-site emissions by 46%, allowing more on-site emissions from fuel-fired equipment that remains in buildings by the final year of compliance compared to the ZNC target. The EE target provides overall site EUI reductions of 23%.

Greenhouse Gas Emissions Impacts

Overall, greenhouse gas emissions reductions result from improved efficiency (i.e., using less energy to perform the same task), electrification of fossil-fuel burning systems, and the decarbonization of the electricity grid. The annual and cumulative greenhouse gas (GHG) impact of each building performance standard option was calculated using current and projected electricity supply and compliance deadlines of different building types.

If the electricity supply is maintained at today's level of emissions, building efficiency improvements would still yield emissions savings from the proposed BEPS policy. Assuming no change to today's electricity grid, the EE target would provide annual GHG reductions of 19% and the ZNC target would provide annual GHG reductions of 26%, compared to the baseline year.

Maryland's current Renewable Portfolio Standard is currently set at a maximum of 50% renewable electricity by 2030. The County's Climate Action Plan (CAP) endeavors for a 100% carbon free electricity supply by 2035 (i.e., considered "zero-emissions" or "carbon-free" by the by the time BEPS is fully implemented[4]).

If the emissions intensity (EEI, in kilograms of carbon dioxide equivalent per kilowatt-hour, kgCO2e/kWh) for electricity supplied to the County was zero the annual emissions from building energy use would drop from the

[4] Supra 1, page 88.

2019 baseline by 87% for covered buildings reaching the EE target or 97% for covered buildings reaching the ZNC target.

While BEPS may appear to have a relatively lesser impact on community-wide emissions compared to transitioning the electric grid to carbon-free sources, the proposed BEPS policy's emphasis on energy efficiency allows building owners to "right-size" their energy use such that the amount of clean energy needed to meet building demand via the grid is less than a business-as-usual scenario. The building energy performance standard would do two things to help achieve the county's climate goals: 1) the reduction in electricity use through efficiency measures would ease the burden on the supply side to provide electricity from carbon-free sources, and 2) the reduction of on-site emissions through fossil fuel efficiency and eventual electrification may be the only way to achieve carbon neutrality.

Policy options to further credit renewable energy in pursuit of BEPS targets were outside of the scope of this study, thus not fully evaluated. Considering this type of credit could serve as a flexible tool for building owners to meet targets in the spirit of the County's climate goals.

The effect of the BEPS policy overlaid with potential electricity supply changes is shown in Table 2.

Table 2: The annual emissions reduction impact of the site EUI targets in this study. Reductions are of annual emissions at the final target year (e.g., 2037 or beyond).

Annual Million Metric Tons CO_2e (% reduction from baseline)	**No BEPS**	**EE**	**EE-ZNC midpoint**	**ZNC**
Electricity supply does not change from today	1.53 (0%)	1.24 (19%)	1.19 (22%)	1.13 (26%)
"Carbon-free" electricity supply	0.36 (76%)	0.19 (87%)	0.12 (92%)	0.05 (97%)

Case Studies that Evaluated the Technical Feasibility of Performance Targets

The study team selected buildings from various building types to test if the ZNC target – the lowest site EUI target – is technically achievable, and to estimate the total capital cost and energy cost savings of meeting or exceeding the ZNC target. The nine case study examples were meant to be representative of Montgomery County's building stock that would have to undertake building energy upgrades to meet a potential BEPS target.

Each case study building was analyzed through a virtual audit to determine the applicable measures for three retrofit packages:

- **A ZNC Target Package**: what measures are needed to reach the building's ZNC Target. This is meant to test whether the ZNC target (and by extension the mid-point target) is technically feasible with today's technology.
- **An EE Target Package:** what measures are needed to reach the building's EE Target. Measures that maximized a building's return on investment were prioritized. In some case studies, partial electrification of end uses may meet this target but some further-optimized, fossil-fuel based systems may remain in the building.
- **A Less-than-Five-Year Payback Package:** what measures may be recommended in the near term without contradicting long-term deep energy efficiency work. These measure packages represent the types of low-cost and lower-savings measures often recommended during standard energy audits and may be useful in reviewing progress toward interim targets. These measures are often investigated by buildings first, regardless of existing equipment replacement cycles, because they can provide cost savings after less than five years of operation. Five years is also an estimate of the capital planning

cycle length for many buildings. The study team selected a "do no harm approach" that did not include installation of new fossil-fuel equipment. These measures were analyzed to compare this type of work and the ZNC target packages needed to achieve larger climate goals. Note that for some newer buildings that have less opportunity for low-cost incremental savings, the Less-than-Five-Year Payback Package may be either small or non-existent.

Most buildings have substantial work to do in order to reach the ZNC target; however, this does not mean reaching the targets is impossible. In all case studies, the ZNC target was technically achievable with existing technology and systems through a ZNC Target Package combining energy efficiency, electrification, and on-site solar PV.

In general, the highest energy savings correspond with relatively high upfront cost, with that cost mainly driven by electrification measures in fossil fuel-heated buildings. While best estimates are used to develop total retrofit costs for measures, each measure is subject to a wide variety of factors within and outside the building. Each cost estimate should be interpreted as a rough estimate that is the result of a high-level review of building conditions and applicable measures.

Capital costs identified via the case studies represent total equipment and labor costs. These total costs evaluate the full cost of a new system, not incremental costs of a more efficient system compared to costs the building would already incur to replace equipment in-kind at the end of its useful life. System electrification or upgrade is assumed to take place at the end of useful life of existing equipment, which was due to occur before the final BEPS year in all case study buildings. Total costs also do not include any other factors that may improve the financial performance of the investment, such as utility incentives, tax credits or depreciation, or financing through entities such as the Montgomery County Green Bank. Savings do not account for labor cost savings from new equipment (e.g., from reduced equipment maintenance or facility maintenance requests due to improved tenant comfort).

Costs for the ZNC Target Package ranged from $11 to $36 per square foot with an average $/SF across all case study buildings of approximately $25.08/SF to reach the ZNC target, where multiple electrification measures drive up the capital cost intensity. This implies some realistic level of expected capital outlay across building typologies. The ZNC Target Package resulted in savings of $0.30 to $1.50 per square foot with an ROI between 2% and 5%. Though the ZNC Target Package resulted in far greater levels of efficiency via electrification, annual dollar savings per square foot are more modest due to the relatively higher cost of electricity compared to natural gas today.

Costs for the EE Target Package ranged from $10 to $26 per square foot with an average $/SF for applicable buildings of approximately $17.10/SF. Similar to the ZNC Target Packages, electrification measures, where included, drive up the capital cost intensity. These EE Target Packages resulted in savings of $0.35 to $1.40 per square foot with an ROI between 3% and 10%. Note that some buildings' EE targets were the same as their respective ZNC targets.

Costs for the Less-than-Five Year Payback Package ranged from $0.20 to $3.60 per square foot and resulted in savings of $0.10 to $1 per square foot with simple payback between 2 and 4 years (per the package parameters). In most cases, the EUI of this package is sufficient to get a building to the first interim ZNC target. However, further work is needed in most cases to meet the EE target and in all cases to reach the ZNC Target.

As a result of meeting the ZNC or EE targets, the case study buildings would significantly reduce GHG emissions. The emissions reductions achieved by implementing the ZNC Target packages are substantial Assuming today's electricity supply, the ZNC Target would reduce the case study buildings emissions by 36% on average. A ZNC target yields an average reduction of 99% with a completely emissions-free grid.

For comparison, the emissions reductions achieved by setting the standards using the EE Target method would lead to less decarbonization. Assuming today's electricity supply, the EE Target would reduce the case study buildings emissions by 32% on average. With a completely emissions-free grid, emissions are reduced by 86%.

Table 3. The emissions reduction impact of the site EUI targets in this study among case study buildings.

% Emissions Reduction in Case Study Buildings (Emissions reductions range)	**EE**	**ZNC**
Electricity supply does not change from today	32% average (Range: 0-52%)	36% average (Range: 22%-62%)
"Carbon-free" electricity supply	86% average (Range: 64% - 100%)	99% average (Range: 95%-100%)

Estimated Total Costs and Benefits for Owners of Covered Buildings

The study team calculated the annual and cumulative energy use and associated costs and emissions for the years 2021-2039 without and with a BEPS policy. No capital cost was assumed under the baseline case, as the study considered the total capital cost of upgrades without including business as usual equipment replacements.

The eliminated energy use is primarily driven by reduction in on-site fuel burning through energy efficiency and electrification. Electric energy efficiency is also incorporated, though those reductions in overall electricity use are partially offset by increases due to electrification of fossil fuel systems.

The results of the countywide model without a BEPS policy intervention are shown in Table 4.

Table 4. The estimated covered buildings' energy and GHG emissions characteristics, both annual and cumulative over the study period.

Cumulative Countywide Baseline 2021-2039	Annual Total (2021)	2021-2039 Cumulative Totals (without a BEPS policy)
Electricity Use [Billion BTU]	12,212	244,200
Gas Use [Billion BTU]	6,574	131,500
GHG emissions of covered buildings [Million tonsCO_2e]	1.33	16.54
Energy Cost [Million$]	$602	$10,860
Capital Cost [Million$]	N/A	N/A

The three potential BEPS target approaches were evaluated for the impact on energy and emissions, energy costs, and capital costs. The countywide results are shown in Table 5. The ZNC target requires the deepest energy use reductions of the three targets, and results in the greatest emissions reductions, both on-site and from purchased electricity.

Table 5. Estimated countywide impact of three building energy performance targets, summing cost, energy savings, and GHG for each Target Method.

Countywide Impact of BEPS 2021 to 2039	**No BEPS**	**Energy Efficiency (EE)**	**EE-ZNC midpoint**	**Zero-Net-Carbon (ZNC) Compatible**	
Electricity Use (2021-2039 cumulative total)	244,200	231,900	233,600	235,600	Billion BTU
Electricity Site Energy Savings *(2021-2039 cumulative total)*	N/A	12,300	10,600	8,600	Billion BTU
% Electricity Energy Savings (2021-2039 cumulative total)	N/A	5%	4%	4%	% lower than baseline cumulative
% Electricity Energy Savings (annual, final year)	N/A	10%	8%	8%	% lower than baseline
Gas Use (2021-2039 cumulative total)	131,500	103,000	91,800	78,500	Billion BTU
Gas Site Energy Savings (2021-2039 cumulative total)	N/A	28,500	39,700	53,000	Billion BTU
% Gas Energy Savings (2021-2039 cumulative total)	N/A	22%	30%	40%	% lower than baseline cumulative
% Gas Energy Savings (annual in final year)	N/A	46%	66%	86%	% lower than baseline
GHG emissions of covered buildings (2021-2039 cumulative total, with grid cleaning)	16.54	14.85	14.25	13.55	Million Tons CO_2e
GHG Savings of Policy	0	1.70	2.30	2.99	Million Tons CO_2e
GHG % Savings of Policy	N/A	10%	14%	18%	% lower than baseline cumulative
GHG Savings by grid cleaning (external to a BEPS program)	14	14	14	14	Million Tons CO_2e
Annual GHG Reduction Including Grid Cleaning (% lower than 2019 baseline)	76%	87%	92%	97%	Percent lower than annual baseline
Energy Costs (2021-2039 cumulative total)	$10.86	$10.05	$9.97	$9.88	Billion
Energy Cost Savings (2021-2039 cumulative total)	$0	$0.82	$0.89	$0.98	Billion
% Energy Cost Savings (2021-2039 cumulative total)	0%	8%	8%	9%	% lower than baseline cumulative
Total Capital Cost* (2021-2039 cumulative total)	$0.00	$1.66	$2.41	$3.22	Billion
Carbon Abatement Cost (2021 - 2039 average)		$980	$1,050	$1,080	dollars / ton CO_2e
Total Capital Cost / SF	0	$7.20	$10.40	$13.90	$ / SF

**Total capital cost does not include avoided cost from the replacement of existing equipment. Cost does not include financial assistance available for energy efficiency retrofits.*

TECHNICAL ANALYSIS CONCLUSIONS

These findings stood out to the study team as key takeaways:

1) While the County has not taken a prescriptive approach to this policy, as the BEPS target gets more stringent, the variety of options to comply with the standard are more limited such that electrification becomes necessary to meet the final target, as illustrated by the case studies.
2) Achieving the ZNC target was technically achievable across the building types analyzed as case studies. In some cases, the ZNC target was met via measures that had significant costs and with a low ROI, especially where electrification would be required to meet the target.
3) Most, but not all, buildings would need to electrify nearly all fossil fuel use to meet the ZNC target. In certain cases, electrification of all end uses was not always the most cost-effective path to meet the whole-building site EUI targets. Other measures, such as on-site solar PV or other efficiency measures, were sometimes more cost effective than the complete elimination of on-site fossil fuels.
4) There is little to no difference between the EE target and the ZNC target for building occupancy types that currently have limited use of on-site fossil fuels, such as commercial offices. The difference between targets is large for building types that have greater use of fossil-fuel systems, such as multifamily and lodging (e.g., hotels, motels). Choosing where to set the targets should consider the impact to these fossil-fuel-dependent building types.
5) A BEPS final year target set to the ZNC target, if implemented along with the realization of a 100% carbon-free electricity supply, would result in the deepest emissions reductions. The EE and EE-ZNC midpoint targets would result in enough on-site combustion to remain in buildings that the County's CAP goal of zero GHG emissions by 2035 is unattainable.
6) The ZNC target would force nearly complete electrification of buildings subject to the BEPS policy. It would be technically attainable, although for some buildings the costs and level of effort, including work inside tenant spaces, would be significant.
7) Selecting an EE target would delay achieving the County's deepest emissions reduction goals because it would allow new fossil-fuel equipment to be installed, locking buildings into a long period of fossil fuel use until the next replacement cycle.
8) Countywide emissions would be reduced if buildings were to meet either the EE or ZNC site EUI targets, regardless of whether the electricity supply becomes emission-free or not. Even with today's relatively fossil-fuel powered electricity supply, efficiency and electrification of buildings would result in significant total emissions reductions compared to a business-as-usual scenario (see Table 19).

BUILDING COST – BENEFIT CASE STUDY OVERVIEW

To test the viability of the targets, the analysis team chose nine building examples in Montgomery County and developed multiple retrofit packages. Each building was assigned a target using the proposed methodology, and a package of energy-reducing measures was created. The technical viability and economics of reaching the targets confirmed that, at least for the types of buildings exemplified in this technical analysis, the targets are reachable. High-level findings are contained in the "Building Cost-Benefit Case Study" section of this report.

The analysis team selected buildings from various occupancy types to show examples of target calculations and energy measure packages to meet a potential performance standard. These nine case study examples are meant to be representative of Montgomery County's building stock that would have to meet a potential BEPS target and have current energy performance that would trigger the need to implement retrofits in order to achieve compliance with the proposed BEPS policy.

Each case study includes a brief description of the key building systems, a summary of the square footage of each property use type, whole building ENERGY STAR score for reference (if available), and calculated site energy use intensity (EUI) for 2019. EUI is a measure of the energy usage at a building per square foot where all fuels have been converted to a common unit of measure, typically thousand Btu per square foot (kBTU / SF). The case studies were anonymized by putting a range on the EUI, which in turn created a range of baselines and interim targets. The methodology describing the utility analysis process is described in the *Utility End Use Assessment* section.

The ***Methodology*** section in Appendix V describes several important aspects of this analysis.

Example Buildings and Pathways to Reach Energy Performance Targets

Each case study building was analyzed through a virtual desk audit to determine the applicable measures for three retrofit packages:

- A Zero Net Carbon-Compatible Target Package: what measures are needed to reach the building's ZNC Target.
- An Energy Efficiency Target Package: what measures are needed to reach the building's EE target.
- A Less-than-Five-Year Payback Package: what measures are identified in a typical energy audit.

The ZNC Target Package is intended to achieve the building's hypothetical ZNC target established using the target-setting methodology in *Site Energy Use Intensity Performance Targets*. The EE Target Package is intended to achieve the building's hypothetical EE target established using the target-setting methodology in *Site Energy Use Intensity Performance Targets*.

Each building has a Less-than-Five-Year Payback Package; in most cases, the EUI of this package is sufficient to get a building to the first interim ZNC target. However, further work is needed in most cases to meet the EE target, and in all cases to reach the ZNC Target. Note that in some building cases, there are no differences between the EE target EUI and the ZNC Target EUI.

The following table contains the baseline EUI for each case study building, the two chosen target EUIs, the projected EUI of the ZNC Target Package, and the projected EUI of the Less-than-Five-Year Payback Package. As seen in Table 6 and Figure 2, most buildings have substantial work to do in order to reach the ZNC target; however, this does not mean reaching the targets are impossible. Each building's ZNC Target Package in this analysis either meets or exceeds the ZNC Target EUI.

Table 6. Basic overview of each building typology, potential EE and ZNC targets, ZNC Target Package, EE Target Package, and Less-than-Five-Year Payback Package.

#	**Typology** Sub-type	**Floor Area [SF]**	**Baseline Site EUI**	**ZNC Target EUI**	**ZNC Interim Target 1 EUI**	**ZNC Interim Target 2 EUI**	**EE Target EUI**	**EE Interim Target 1 EUI**	**EE Interim Target 2 EUI**	**ZNC Target Package EUI**	**EE Target Package EUI**	**Less-than-Five Year Payback Package EUI**
1	**Office** (p *79*) Class A	200,000 – 225,000	70 – 80	53.4	63 – 72	57 – 64	53.4	49 – 53	67 – 75	49 – 53	49 – 53	67 – 75
2	**Office** (p 89) Mixed-fuel HVAC	250,000 – 275,000	80 – 90	57.8	71 – 80	62 – 70	57.9	52 – 57	67 – 75	52 – 57	52 – 57	67 – 75
3	**Office** (p 95) Older All-Electric	225,000 – 250,000	80 – 90	53.4	71 – 80	62 – 70	53.4	47 – 53	57 – 64	47 – 53	47 – 53	57 – 64
4	**Multifamily** (p 109) New – Tall	125,000 – 150,000	50 – 60	38.7	46 – 53	42 – 47	59.1	35 – 38	50 – 60	35 – 38	N/A	50 – 60
5	**Multifamily** (p 119) Old – Tall	125,000 – 150,000	70 – 80	35.4	58 – 65	45 – 50	55.1	65 – 72	60 – 65	32 - 35	50 – 57	64 – 73
6	**Multifamily** (p 131) Short / Garden	50,000 – 75,000	115 – 125	35.4	90 – 95	60 – 65	55.1	95 – 102	75 – 80	31 – 34	51 – 55	107 – 116
7	**Lodging** (p 143) Full-service hotel	150,000 – 175,000	115 – 125	57.8	95 – 105	75 – 85	75.7	102 – 110	88 – 95	53 – 57	72 – 76	94 – 102
8	**Lodging** (p 156) Partial-service hotel	200,000 – 225,000	125 – 135	57.8	101 -110	77 – 85	75.7	108 – 115	90 – 96	53 – 57	72 – 76	99 – 107
9	**Worship** (p 168)	75,000 – 100,000	80 – 90	36.4	65 – 72	50 – 56	47.9	70 – 77	59 – 64	33 – 36	45 – 48	72 – 81

**the blue page numbers are links to the case studies in this report*

Figure 2 on the following page contains a subset of the information contained in Table 6 arranged in graphical format. An asterisk is noted to call out the all-electric building in the case studies.

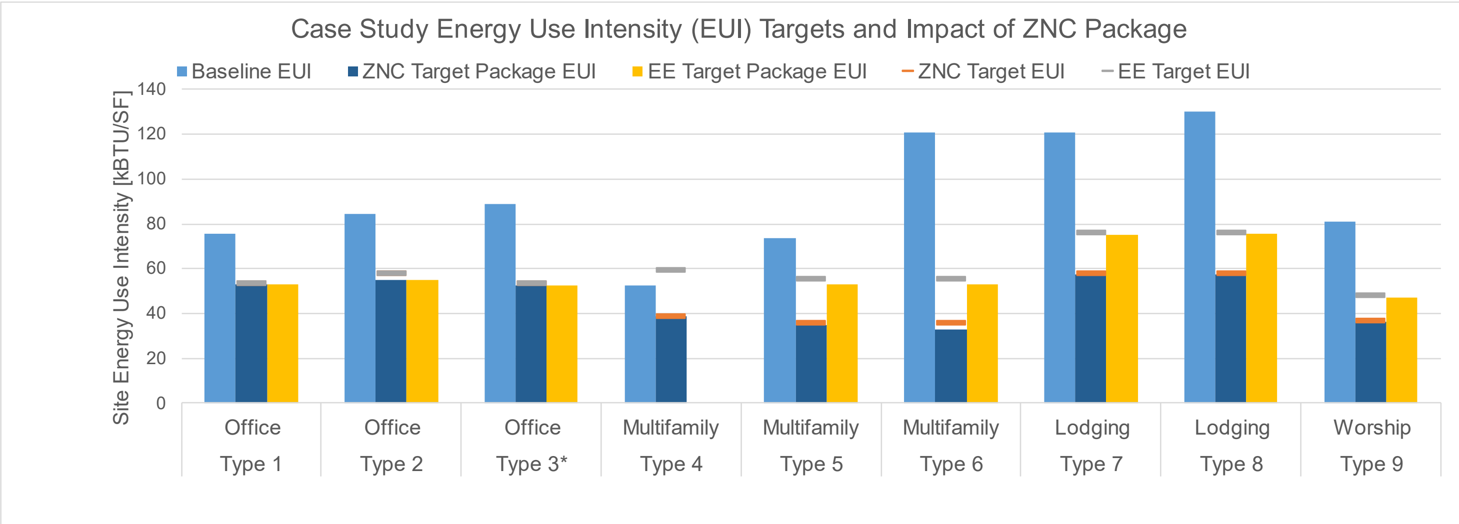

Figure 2. Comparisons of current energy usage of case study buildings to proposed targets and the end results of the ZNC Target Package and EE Target Package. The asterisk denotes an all-electric building.

Table 7 on the following page contains a financial overview of each of the packages. The costs associated with the Less-than-Five-Year Payback Package are often small (most buildings were less than $2 / SF) but generate moderate energy savings; the ZNC Target Package costs are often much higher than the Less-than-Five-Year Payback Package but generate deeper energy savings. The EE Target Package typically falls somewhere in the middle, with buildings further away from the EE target having higher costs.

Total costs were used, without incorporating potential cost reduction avenues such as:

1) avoided cost of business-as-usual equipment replacement,
2) financial assistance from myriad sources, including EmPOWER incentives and Green Bank financing,
3) incentives for efficiency work, or
4) cost pass-through to commercial and residential tenants.

Table 7. Basic overview of ZNC Target Package, EE Target Package, and Less-than-Five-Year Payback Package financials. Building 4's EUI is below the EE Target; no EE package is included.

#	**Primary Occupancy Type** Sub-type	**ZNC Target Package Cost / sq. ft.**	**ZNC Target Package Annual Savings / sq. ft.**	**ZNC Target Package Simple Payback (years)**	**ZNC Target Package ROI (%)**	**EE Target Package Cost / sq. ft.**	**EE Target Package Annual Savings / sq. ft.**	**EE Target Package Simple Payback (years)**	**EE Target Package ROI (%)**	**Less-than-Five Year Payback Package Cost / sq. ft.**	**Less-than-Five Year Payback Package Annual Savings / sq. ft.**	**Less-than-Five-Year Package Simple Payback (years)**	**Less-than-Five Year Payback Package ROI (%)**
1	**Office** (p *79*) Class A	$23 - $26	$0.60 - $0.80	35.1	3%	$23 - $26	$0.60 - $0.80	35.1	3%	$0.80 - $1	$0.30 - $0.40	2.0	49%
2	**Office** (p 89) Mixed-fuel HVAC	$16 - $19	$0.60 - $0.80	26.4	4%	$16 - $19	$0.60 - $0.80	26.4	4%	$1.60 - $1.80	$0.40 - $0.50	4.0	25%
3	**Office** (p 95) Older All-Electric	$25 - $28	$1.30 - $1.50	19.2	5%	$25 - $28	$1.30 - $1.50	19.2	5%	$3.40 - $3.60	$0.90 - $1	3.6	28%
4	**Multifamily** (p 109) New - Tall	$7 - $10	$0.30 - $0.50	31.9	3%	N/A	N/A	N/A	N/A	$0 - $0.20	$0 - $0.10	3.5	28%
5	**Multifamily** (p 119) Old – Tall	$16 - $19	$0.30 - $0.50	57.1	2%	$9 - $12	$0.90 - $1.10	28.3	4%	$0.60 - $0.80	$0.20 - $0.30	3.1	32%
6	**Multifamily** (p 131) Short / Garden	$25 - $28	$0.90 - $1.10	26.8	4%	$20 - $23	$0.70 - $0.90	21.5	5%	$0.60 - $0.80	$0.10 - $0.20	2.9	35%
7	**Lodging** (p 143) Full service hotel	$33 - $36	$0.70 - $0.90	48.9	2%	$10 - $13	$0.70 - $0.90	33.1	7%	$1.90 - $2.10	$0.50 - $0.60	3.5	28%
8	**Lodging** (p 156) Partial-service hotel	$31 - $34	$0.90 - $1.10	34.2	3%	$8 - $11	$0.90 - $1.10	17.3	10%	$3.30 - $3.50	$0.80 - $1.00	3.5	29%
9	**Worship** (p 168)	$33 - $36	$0.90 - $1.10	37.9	3%	$14 - $17	$1.10 - $1.30	13.3	8%	$0.50 - $0.70	$0.20 - $0.30	2.8	35%

**the blue page numbers are links to the case studies in this report*

Figure 3 on the following page contains a subset of the information contained in Table 7 arranged in graphical format. An asterisk is noted to call out the all-electric building in the case studies.

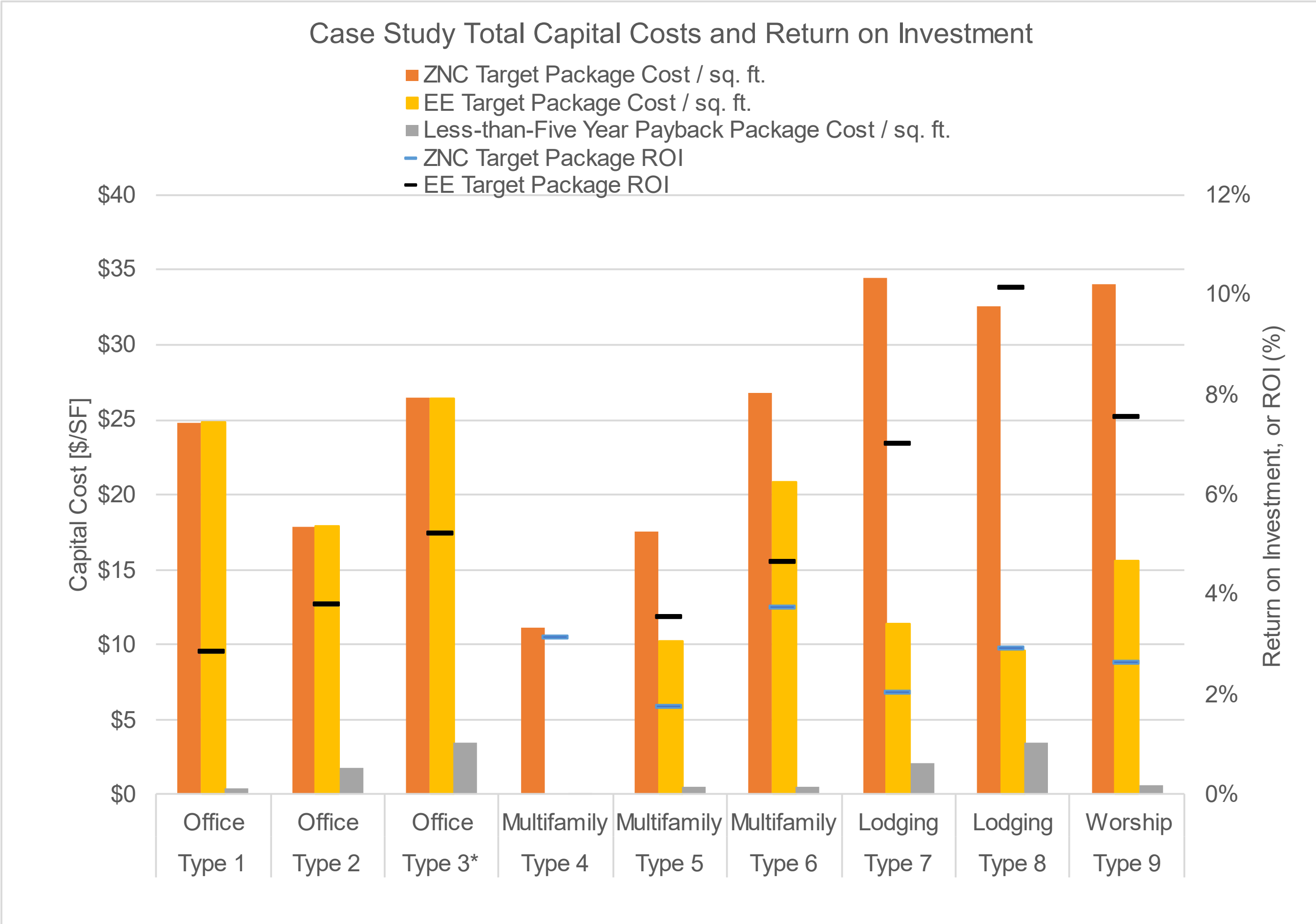

Figure 3. Costs to implement the ZNC Target Package identified for each case study building compared to the EE Target Package and Less-than-Five-Year Payback Package. ROI for the ZNC Target Package is included as a blue line and ROI for the EE Target Package is included as a black line. The ROI for the Less-than-Five Year target is higher than 20% in all cases, thus omitted from this figure. The asterisk denotes an all-electric building.

As seen in Table 6, Table 7, Figure 2, and Figure 3, each building is able to reach the ZNC Target, indicating these targets are technically achievable using today's technology. While the costs for implementing these packages vary significantly by building, the following general conclusions apply:

- Most major in-building equipment (i.e., mechanical equipment) is likely to be replaced prior to 2035. This capital cost can be redirected toward deeper retrofit projects. This creates a lower "effective" cost of compliance, but it should be noted these baseline capital costs are highly building dependent. Financial incentives and financing can fluctuate and are building-specific at a level outside the scope of this report. Baseline capital cost outlay, financial incentives, and financing are not included in this report.
- Utility cost savings from the EE Target Packages are generally similar to the ZNC Target Package for a specific site. Savings do not account for labor cost savings from new equipment (e.g., from reduced equipment maintenance or facility maintenance requests due to improved tenant comfort).
- ZNC Target Packages sometimes have measures that replace existing systems that would otherwise be optimized in EE Target Packages and Less-than-Five-Year Payback Packages. This presents potential risk for future replacement of fossil-fuel-fired equipment with new fossil-fuel-fired equipment.

- Some EE Target Packages—namely, the ones for offices—are the same as the ZNC Target Packages, as their targets are identical.
- The Less-than-Five-Year Payback Package is not sufficient to meet either the EE or ZNC targets in the vast majority of cases, indicating that deeper retrofits are necessary to meet Montgomery County's emissions goals for 2035.
- Building typologies with substantial costs associated with the Less-than-Five-Year Payback Package also have significant savings associated with implementing these measures. In all cases, the return on investment makes financial sense for these projects even with the upfront cost.
- Utility cost savings from the Less-than-Five-Year Payback Package are on average 50% (range: 3%-90%) of the utility cost savings for the ZNC Target Package for a specific site. Savings do not account for labor cost savings from new equipment (e.g., from reduced equipment maintenance or facility maintenance requests due to improved tenant comfort).

Summarizing the case studies into broad building types, the average capital cost intensity for offices, multifamily, and hotels/lodging under the ZNC and EE targets is shown in Figure 4. The chosen building typologies have a relatively consistent ZNC Target Package capital cost intensity in the range of $20 - $30 / SF (with an average $/SF across all case study buildings of approximately $22.85/SF) to reach the final target year, where multiple electrification measures drive up the capital cost intensity. Similarly, the EE Target Package capital cost intensity is between $9.50 - $26.50 / SF. This implies a significant investment will be required across building typologies.

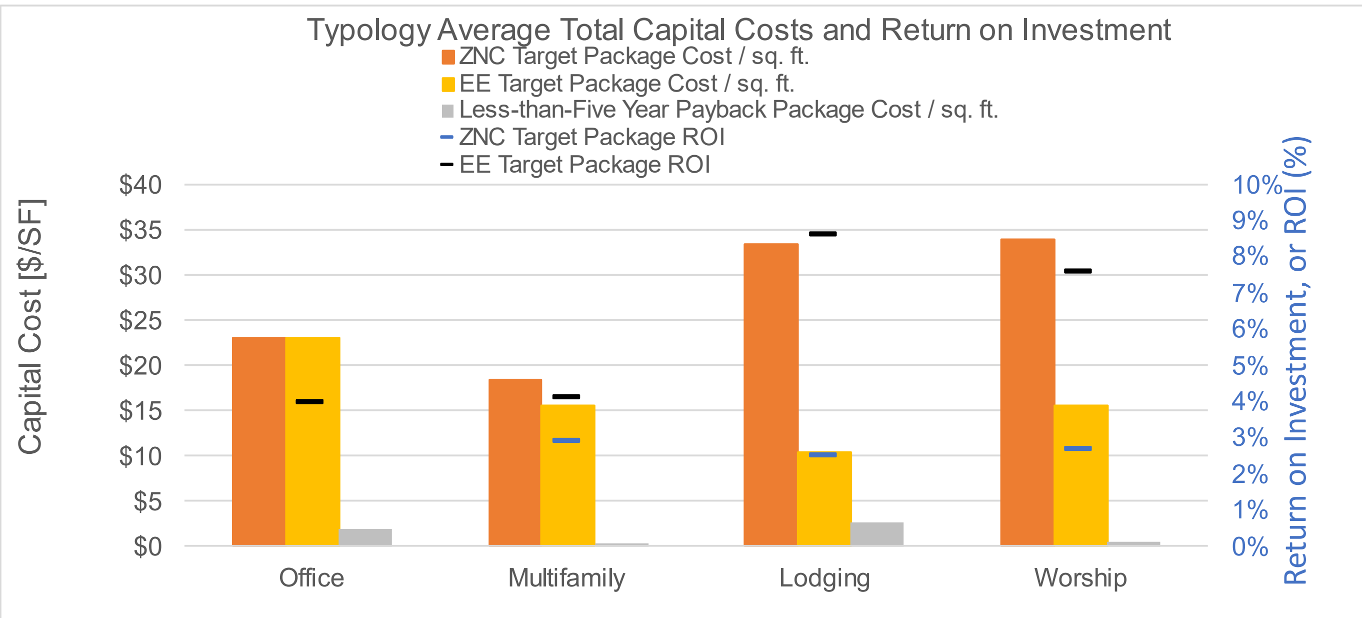

Figure 4. Costs to implement the ZNC Target Package identified for each building typology compared to the EE Target Package and Less-than-Five-Year Payback Package. ROI for the ZNC Target Package is also included as a blue line and ROI for the EE Target Package is included as a black line. The ROI for the Less-than-Five Year target is higher than 20% in all cases, thus omitted from this figure.

Figure 5 compares total capital costs and percent site energy savings for the ZNC target, EE target, and Less-than-Five-Year Payback Package for each building typology. The data in Figure 5 shows that, in general, higher capital cost expense yields larger energy savings towards the target. The highest savings numbers correspond to incredibly deep energy savings, but at a relatively high cost, mainly driven by electrification measures in fuel-heated buildings.

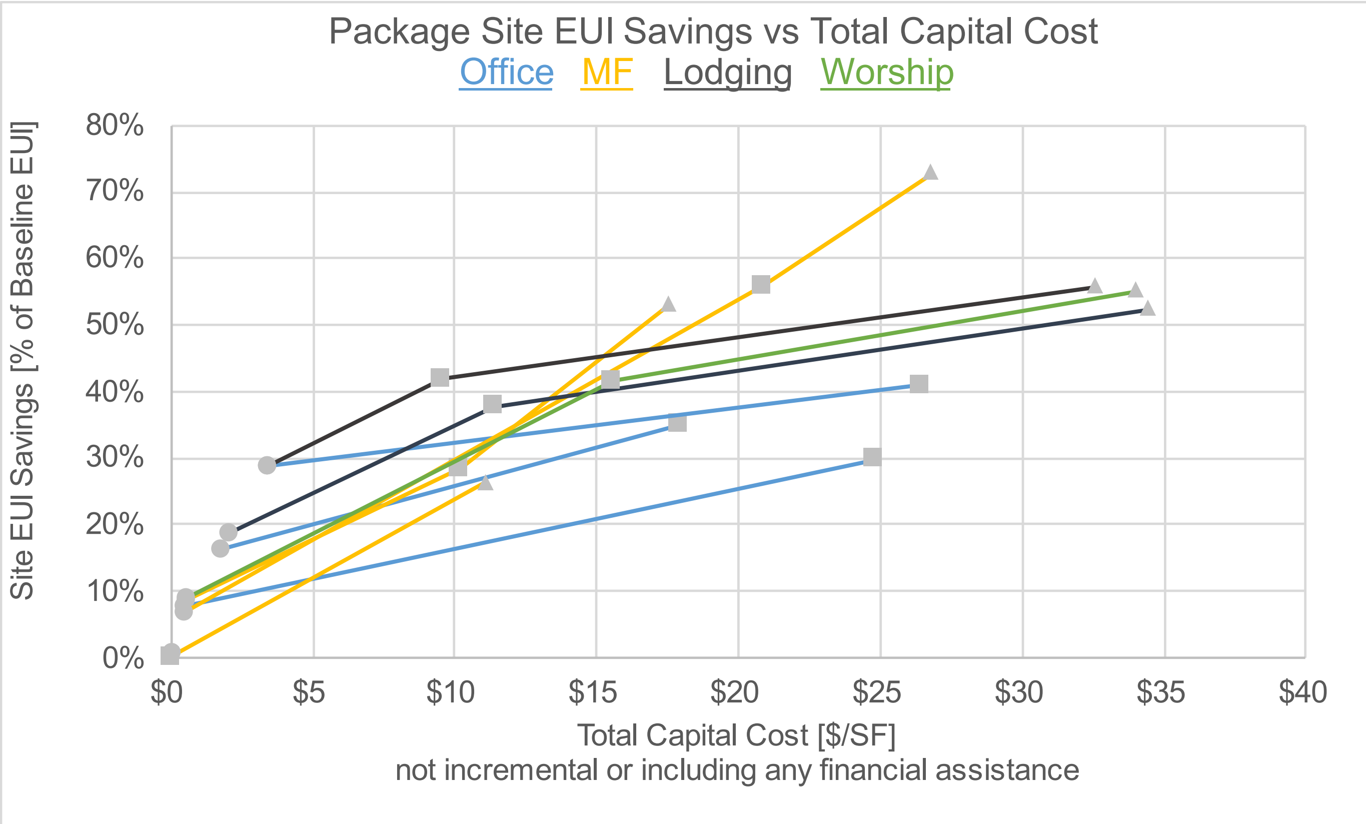

Figure 5. Comparison of capital cost to energy reduction trends, showing that generally more money is needed for deeper savings. This is partly driven by the fossil fuel dominated buildings having high starting EUIs. With electrification being one of the more expensive measures, those buildings spend the most and have the highest site EUI savings from electrification. In this figure, circles represent the Less-than-Five-Year Payback Package, squares represent the EE Target Package, and triangles represent the ZNC Target Package. Building typologies are color-coded.

Greenhouse Gas Impact

The energy reductions that could be achieved under different BEPS targets are converted to greenhouse gas emissions to estimate the change in energy-based emissions of the buildings in their current state, and if the EE or ZNC Package is adopted. Two grid forecasting scenarios are modeled to account for possible changes in the electric grid emissions intensity – in units of $kgCO_2e$ / kBTU:

Table 8. Electricity and natural gas emissions intensities used in this technical analysis.

	Gas $kgCO_2e/kBTU$	Elec $kgCO_2e/kBTU$
Today's Electricity Supply[5]	0.05472	0.0957
50% Renewable Electricity Supply[6]	0.05472	0.0492
100% Renewable Electricity Supply[7]	0.05472	0.0027

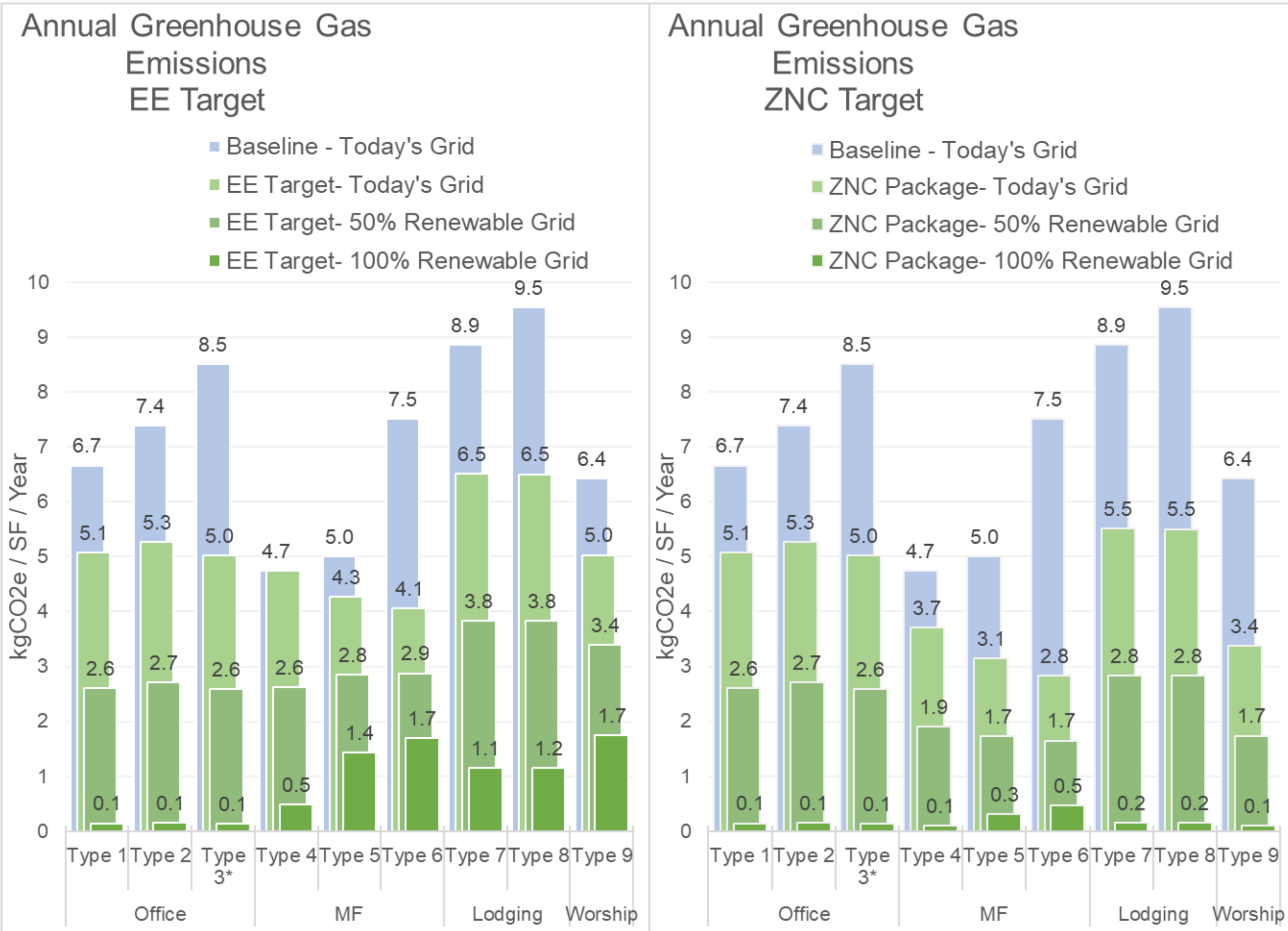

Figure 6. Greenhouse gas emissions impact of implementing the ZNC Target packages (right) under different potential electricity scenarios. At left, an estimate of the emissions reductions if the EE Targets were used, allowing fewer high-cost measures such as electrification, to be used to meet the targets. The asterisk denotes an all-electric building.

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[5] See Appendix VIII for GHG emissions factors data sources from the MC GHG Inventory, used for gas and electricity.

[6] This value corresponds roughly with the Renewable Portfolio Standard (RPS), which requires 50% of the electricity supply to come from renewable sources. The electricity value is half of today's emissions intensity, which is roughly 94% non-renewable. The assumption is that non-renewable sources (gas, oil, coal, and nuclear) will be ramped down evenly to meet the RPS. See page 2 of Pepco "Environmental Fuel Source Information" for June 2020, corresponding to calendar year 2019. https://www.pepco.com/MyAccount/MyBillUsage/Pages/ViewBillInserts.aspx

[7] Assumes ~3% of electricity consumption is from emitting sources, but these are offset through renewable purchases or other offset methods.

The emissions reductions achieved by implementing the ZNC Target packages are substantial. Assuming today's electricity supply, the packages reduce GHG emissions by 36% on average (range: 22% - 62%). With a completely emissions-free grid, emissions are reduced by 97% on average (range: 94% - 98%) with the ZNC Target-reaching packages.

For comparison, the emissions reductions achieved by setting the standards using the EE Target method would allow less decarbonization. Assuming today's electricity supply, the EE Target would reduce the case study buildings emissions by 26% on average (range: 0% - 46%). With a completely emissions-free grid, emissions are reduced by 87% (range: 71% - 98%).

Two observations when comparing the impact of the targets for these case study buildings:

1) Type 4, the newer multifamily building, has an EUI today that is lower than the EE Target, so that building would not need to take any action.
2) For many offices, the EE Target and the ZNC Target are the same because most offices in the county are all-electric already, and the assumption of electrification is the only difference between the two targets.

There are two reasons why a small amount of emissions remains after achieving the ZNC Target. One is that the electricity supply is estimated to still have a small amount of emissions associated with it, which can be offset through renewable energy purchases [8] This is reflected in a non-zero emissions factor for the "100% Renewable Electricity Supply" scenario above.

The second reason is that with a whole building site EUI target, some buildings are capable of meeting the ZNC Target without fully electrifying all fossil fuel end uses. For some buildings, the remaining fossil fuel use could be offset with deeper electricity efficiency to meet the site EUI target.

Disclaimer on Retrofit Capital Costs

While best estimates are used to develop total retrofit costs for measures, each measure is subject to a wide variety of factors within and outside the building. Each cost estimate should be interpreted as a rough estimate that is the result of a high-level review of building conditions and applicable measures. Costs are total equipment and labor costs, not including avoided costs of existing equipment replacements, incentives, or financing agreements which may reduce initial capital costs, all of which are components of developing a net cost of each measure for each building.

[8] Estimate of 3% remaining electricity emissions intensity from conversations with other cities in climate action planning using the CNCA EBPS tool.

SITE ENERGY USE INTENSITY PERFORMANCE TARGETS

The analysis team developed technically achievable whole building site EUI targets that, if met, would help Montgomery County reach its emissions reductions goals for the building sector. The targets and methodology are described in this section and in *Appendix VI – Performance Standard Calculation Inputs* and *Appendix VII - Underlying Assumptions for Target Setting.*

PERFORMANCE STANDARDS CALCULATION

The Montgomery County Stakeholder Recommendation Report[9] has a number of recommendations on how the County should approach a BEPS policy, including the type of metric to use and how to compile the needed information. The report makes a justification for a site EUI target as a way to promote holistic energy efficiency as well as decarbonization of fossil fuel systems. Accordingly, this technical analysis uses site EUI as the performance metric.

This technical analysis aimed to recommend the final year BEPS targets for buildings based on their building types (e.g., office, retail) and energy use patterns in Montgomery County buildings resulting from typical occupant and equipment density. For a given building occupancy group, setting a less aggressive EUI target enables a building to meet the target without significant decarbonization through electrification. Setting more aggressive EUI targets, on the other hand, may compel building owners to electrify, which greatly reduces EUI compared to fossil fuel efficiency measures. There is a technically achievable limit to how low an EUI any given building can be. Setting an EUI target lower than that technically achievable lower limit would result in many buildings being unable to achieve the targets.

The theory of this technical analysis is that there is a site EUI target that is technically achievable for nearly all buildings in an occupancy type that would help the County meet its GHG reduction goals, although it may require deep energy efficiency retrofits and potentially electrification in most buildings.

To identify these site EUI targets, the analysis team relied on the Carbon Neutral Cities Alliance's "Performance Standards for Existing Buildings: Performance Targets and Metrics Final Report"[10]: a methodology and workbook[11] ("CNCA EBPS tool") created to inform technically achievable performance standards across building occupancy types. Steven Winter Associates and Sustainable Energy Partnerships authored this framework in 2020 with participation by expert advisors and government sustainability staff from around the country.[12]

METHODOLOGY

Site EUI building performance standards were created based on technically achievable performance using typical energy use profiles in various building occupancy types and assuming retrofits would be undertaken using commercially available technology. The whole-building energy use targets could be met using a variety of means, but to set the targets, the typical building energy use in each occupancy group was assumed to be reduced through

[9] https://www.montgomerycountymd.gov/DEP/Resources/Files/ReportsandPublications/Energy/MC-BEPS-Stakeholder-Report.pdf
[10] http://carbonneutralcities.org/wp-content/uploads/2020/03/CNCA-Existing-Building-Perf-Standards-Targets-and-Metrics-Memo-Final-March2020.pdf
[11] http://carbonneutralcities.org/wp-content/uploads/2020/03/CNCA-Existing-Building-Perf-Standards-Targets-Workbook-Final.xlsx
[12] Slide 4. http://carbonneutralcities.org/wp-content/uploads/2020/03/CNCA-Existing-Building-Perf-Standards-Project-Summary-Final.pdf

energy efficiency measures and subsequent electrification of fossil fuel end uses. While the targets do not make any assumptions around the addition of on-site solar PV to reduce site EUI, some of the case study building packages (see *Appendix V – Building Cost – Benefit Case Study Details*) did include on-site solar PV to offset some electricity use relatively cost effectively, as the County's BEPS policy may seek to credit on-site solar generation as a potential pathway to make progress towards the target.

Energy use baselines in this technical analysis were based on calendar year 2019 energy use, if available. The proposed BEPS bill would use the two highest years in a three-year baseline period, allowing some flexibility for fluctuations in energy use.

For interim targets, the Stakeholder Recommendation Report suggested the use of a long-range "trajectory model" for interim targets such that each building would need to make steady progress toward a final year target. This technical analysis adopted the use of the trajectory model to set interim targets. See *Appendix IV* – Impact of Trajectory Targets for a discussion of the trajectory model. The rest of this section describes the final year target setting and results.

RECOMMENDED TARGETS TO ACHIEVE COUNTY GOALS OF EMISSIONS REDUCTIONS THROUGH ENERGY EFFICIENCY

Final year targets, which are "the numeric value of site EUI that each covered building must ultimately achieve or exceed" by the final year of the performance standard, were based on the CNCA EBPS tool.

Two final performance standard targets were analyzed in this technical analysis – an Energy Efficiency (EE) target and a Zero Net Carbon-Compatible (ZNC) target. These site EUI targets would be applied to each occupancy type in a building. Buildings with multiple occupancy types would have an area-weighted average target using the below targets applied to each occupancy type, with a whole-building target being proportional to the relative areas of the different occupancy types in the building.

- **Energy Efficiency (EE) Target**: assumed all energy end uses were deeply optimized and tuned without assuming occupant behavior changes such as energy conservation, though conservation would also work toward this target. This target-setting method assumed that typical buildings could maintain the use of fossil-fuel burning systems for typical end uses such as space and water heating but would eliminate inefficiencies of those systems.
- **Zero Net Carbon-Compatible (ZNC) Target**: an EUI level simulating the electrification of all fossil fuel end uses using market-ready technology in an energy efficient building. This target was intended to be compatible with Zero Net Carbon goals because it implicitly required the elimination of most on-site fuel burning.
- **Mid-point between EE and ZNC Targets:** This target type exemplifies how the site EUI targets can be chosen anywhere along this spectrum between the EE and ZNC targets. A mid-point target was calculated to identify the impact of splitting the difference between the two targets. This target could be achieved using a combination of energy efficiency measures and partial electrification, or electrification of some, but not all, fossil-fuel driven systems.

The EE and ZNC targets came from the CNCA Existing Building Performance Standards tool. One is energy efficiency (EE) based, which assumes the median EUI building can reduce energy use through efforts such as existing system optimization, high-efficiency water fixtures and conservation, efficient appliances, and retro-commissioning where appropriate. Numerous studies suggest economically feasible reductions of 10-30%[13,14,15] with an upper limit to reductions in typical buildings of 30%. The US Department of Energy (DOE) Advanced Energy Retrofit Guides list numerous measures and retrofit packages for several commercial building types without considering electrification. See *Appendix X – Literature Review of Deep Retrofit Savings* for more detail on specific measures across a few building types.

The ZNC target assumed on-site fuel burning is eliminated through electrification, further reducing site EUI based on standard assumptions in the CNCA EBPS tool. This Zero Net Carbon-Compatible (ZNC) target can be thought of as a technically feasible limit on building energy performance for each group.

Neither target explicitly assumed the addition of (a) wall insulation to the exterior of the building, (b) high performance window installations, or (c) energy recovery ventilation systems because of the limited applicability of the measures across all building types. However, these measures can greatly improve the performance of buildings and make further decarbonization possible by reducing heating and cooling loads, thereby decreasing the necessary capacity of electric heating and cooling systems. These retrofits could be implemented by any individual building in pursuit of achieving a site EUI target, but the target-setting calculations themselves do not assume the implementation of these retrofits.

The targets were calculated using the 2019 Montgomery County benchmarking data and other sources[16]. The 2019 Median Site EUI for each building type served as the baseline energy use from which the targets were calculated. The resulting targets are shown graphically in Figure 1 and numerically in Table 9. Note that the site EUI targets would be for the whole building site EUI, with no restriction on specific energy sources (e.g., electricity, natural gas) used in a building.

These targets show what is, by the theory of this technical analysis, technically achievable for buildings in each building occupancy type. The largest percentage savings required to reach the targets was in multifamily buildings, particularly older multifamily buildings, which typically have central heating and hot water systems heated by burning fossil fuels. These systems have the most potential for site EUI reduction because the heat pump systems that can replace them are efficient in comparison[17].

Occupancy types with minimal gas use in the 2019 Median column have relatively smaller reductions to reach both the EE and ZNC targets. Within a site EUI framework, all-electric buildings are typically more efficient because electricity-driven systems have fewer opportunities for energy waste, and that waste is expensive because electricity is a relatively expensive commodity compared to natural gas.

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[13] NYC Buildings Technical Working Group. See Rudin Management case study, page 71, among others: https://www1.nyc.gov/assets/sustainability/downloads/pdf/publications/TWGreport_04212016.pdf

[14] https://www.aceee.org/sites/default/files/publications/researchreports/a1402.pdf

[15] DOE Advanced Energy Retrofit Guides (AERGs) for various commercial building types, also detailed in Appendix III: https://www.energy.gov/eere/buildings/advanced-energy-retrofit-guides

[16] See *Estimating the Baseline for Groups with Insufficient Energy Information* for details.

[17] Hopkins, Takahashi, Glick, Whited. “Decarbonization of Heating Energy Use in California Buildings”. October 2018. Synapse Energy Economics, Inc. Page 10 says “*Because a heat pump moves heat rather than generating it, the efficiency of heat pumps can be over 100 percent… for heating season, heat pumps could typically have a COP exceeding 3, meaning a heat output 300 percent of the energy input.”* This 300% efficiency is much more efficient than the <95% efficient gas equipment that a heat pump would replace.

Table 9. Site EUI target options for each building group. The EE standard would require less retrofit work in buildings. Multifamily can be combined to one group (see Multifamily Buildings) with the same standard of 35-55 kBTU/SF as the potential site EUI across the three targets was similar, even though they started at different site EUI levels. This table is sorted by "Current Energy [Billion BTU]".

	2019 Median			EE Target			ZNC - Target				
Performance Standards by Building Type [Site kBTU/SF]	Gas EUI	Elec EUI	**Site EUI**	Gas EUI	Elec EUI	**Site EUI**	Gas EUI	Elec EUI	**Site EUI**	Est Parcel Count	Current Energy [Billion BTU]
Multifamily	38	24	**62**	33	20	**55**	0	35	**35**	336	4,698
Office	0	62	**63**	0	53	**53**	0	53	**53**	391	4,631
Other	56	180	**235**	45	153	**198**	0	167	**167**	76	1,792
Health care Inpatient	188	117	**305**	169	99	**268**	0	187	**187**	10	1,752
Mercantile Enclosed and strip malls	47	64	**111**	43	54	**97**	0	77	**77**	45	1,204
Food sales	72	130	**202**	65	110	**176**	0	143	**143**	55	996
Lodging	38	49	**87**	34	41	**76**	0	58	**58**	73	821
Public assembly	48	49	**96**	42	41	**83**	0	61	**61**	53	335
Mercantile Retail (other than mall)	16	46	**62**	14	39	**53**	0	45	**45**	82	322
Health care Outpatient	0	73	**73**	0	62	**62**	0	62	**62**	38	242
Education - K-12 School	25	30	**55**	21	26	**47**	0	36	**36**	40	183
Warehouse and storage	0	19	**19**	0	16	**16**	0	16	**16**	144	180
Religious worship	24	34	**57**	20	29	**49**	0	37	**37**	71	98
Education	69	34	**104**	61	29	**90**	0	58	**58**	3	39
Public order and safety	40	45	**86**	35	39	**74**	0	52	**52**	11	34
Food service	180	91	**271**	172	78	**250**	0	171	**171**	1	0
Service	36	26	**62**	30	22	**53**	0	33	**33**	1	0
Vacant	0	0	**0**	0	0	**0**	0	0	**0**	0	0

Approach to Technically Feasible Limits to Inform Targets

A description of the approach for each target is shown below as an extended excerpt of the CNCA report[18]. A longer description of the impact on various end uses is included in *Appendix VII - Underlying Assumptions for Target Setting*. This summarizes the approach to target setting, but it does not dictate a specific retrofit package for a particular building. Any individual building would develop a scope of work that reflects how it would achieve or exceed its respective target. The target setting methodology, however, approximates what the typical building of a given occupancy type can achieve using assumptions on existing systems and their efficiency, both current and what is technically achievable.

[18] Supra 10, taken from page 14.

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, high-efficiency water fixtures. [This does not include installation of more efficient gas equipment.]*
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 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 assumes the electrification of all gas 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 the existing heating systems.

The resulting modeled reductions in site EUI for the EE and ZNC targets are shown in Table 10 and Figure 7. The EE reductions use the occupancy type median as the baseline, and the ZNC reductions use the EE target as the baseline. For example, if gas water heating was 10 kBTU/SF for the occupancy type median, the EE target would use 9 kBTU/SF and the ZNC target would use 3.7 kBTU/SF. The ZNC target would also have this 3.7 kBTU/SF be electricity, not gas.

Using the above methodology, each building type has EE and ZNC targets created, summarized graphically using an example in Figure 7.

How Targets are Calculated

All units **Site EUI** [kBTU/SF]

The 2019 median is split into energy end uses, and each is reduced according to the efficiency and electrification potential associated with that end use, using market ready technology.

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 Calculation	Total Site EUI – All Fuels	Total Site Electricity	Total Site Gas	Space Cooling Elec	Other Elec	Space Heating	Water Heating	Cooking	Other
Food service 2019 Median	138	61	77	5	56	12	16	49	0
EE Reduction Potential				*15%*	*15%*	*20%*	*10%*	*0%*	*0%*
Resulting end use EUI				4.25	47.6	9.6	14.4	49	0
Food service EE Target	**125** *(=52+73)*			**52**		**73**			
Electrification Reduction Potential				*0%*	*0%*	*68%*	*59%*	*39%*	*11%*
Resulting end use EUI				4.25	47.6	3.1	4.1	29.9	0
Food service ZNC Target	**89** *(=52 + 37)*			**52**		**37**			

Figure 7. Target calculation, from baseline data through splitting up energy end uses and applying reductions to each end use to arrive at the Energy Efficiency (EE) and Zero Net Carbon-Compatible (ZNC) targets.

Table 10. Reductions in Site EUI for end uses, taken from CNCA EBPS tool.

End Use	Percent reduction from the median for EE target	Percent reduction starting from the EE target for ZNC target
Electricity	15%	0% (no further change)
Gas Space Heating	20%	68%, all electric (COP* 0.80 → 2.50)
Gas Water Heating	10%	59%, all electric (COP 0.90 → 2.20)
Gas Cooking	0%	39%, all electric (COP 0.45 → 0.74)
Gas Laundry/Other	0%	11%, all electric (COP 0.90 → 1.00)

**COP is the Coefficient of Performance of the equipment, defined as energy output (heat) divided by purchased energy input (gas or electricity). A COP of 0.8 is an annual efficiency of 80%. A heat pump can operate at average efficiencies of 250% (COP of 2.50) by extracting heat from the outside air. Efficiency assumptions came from the 'Electrification of Gas End Uses' tab of the CNCA EBPS tool.*

Estimating the Baseline for Groups with Insufficient Energy Information

As described in earlier sections of this report, this technical analysis uses 2019 Montgomery County building energy benchmarking data as the most recent and comprehensive set of local data on individual buildings. The benchmarking data are used to set the baseline EUIs, but several building types that could be covered by a BEPS are underrepresented in the 2019 benchmarking data. This technical analysis identified three main sectors of the building stock this applies to and describes how this technical analysis accommodated these buildings to create site EUI targets.

Multifamily Buildings

Cause: Multifamily residential building types are not currently covered by the benchmarking program.

Considerations: Multifamily building energy use is highly driven by local climate and locally common mechanical systems, and therefore using a local estimate is preferred over a national or even a regional estimate.

Solution for this technical analysis: Montgomery County borders Washington D.C., which has been collecting benchmarking information on multifamily buildings for multiple years. The Washington D.C. benchmarking data from 2019 was thus analyzed using the same cleaning and organizing methodology as the Montgomery County data. The building type was split into three subgroups (MF-New-Tall, MF-Old-Tall, and MF-Short, see *Multifamily* in *Appendix II* - Montgomery County Energy Use Distributions Overview for definitions) and the energy distributions for those types were calculated. Specifically, the average electricity energy use intensity (EUI) and gas EUI were calculated for every decile of site EUI, as shown in Figure 8:

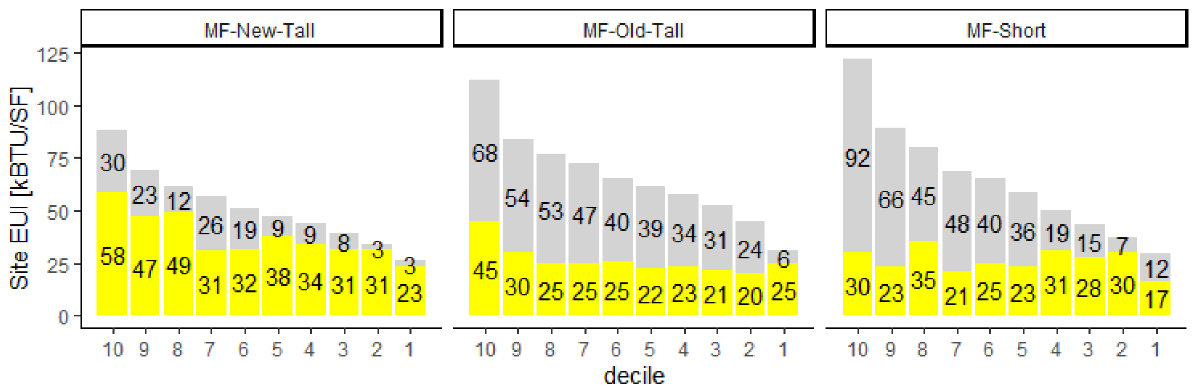

Figure 8. Deciles of energy use intensity from DC Multifamily buildings.

These distributions were mapped to the Montgomery County multifamily buildings identified as the potential covered buildings list, assuming the same energy distributions of each subgroup across the two locations. Each Montgomery County building was assigned an electricity and gas EUI based on its subgroup. For detail on this mapping, see *Appendix III - BEPS Policy Model Methodology.* The potential energy standards were calculated for the multifamily building population using the energy use data from the Washington D.C. multifamily building population.

The deepest technical potential site EUI across the three targets was similar, as shown in Table 11, even though they started at different site EUI levels. To facilitate consistent enforcement, site EUI targets can be set for the whole population instead of distinct targets for each multifamily subgroup and was done in this technical analysis. The highest target of each subgroup was used so that technical feasibility was not exceeded for any one subgroup. The results are shown in Table 11, indicating that the EE site EUI target used for the technical analysis came from the MF-Old-Tall potential, which had the highest site EUI for that target, and the ZNC target came from the MF-New-Tall potential, which had the highest site EUI for that target.

Table 11. Comparison of multifamily median and subgroup targets, using DC data processed with the CNCA EBPS tool, as shown in site EUI.

Median in kBTU/SF	MF-Short	MF-Old-Tall	MF-New-Tall	MF-All highest of the three
Median EUI	62	**64**	48	**64**

Targets in kBTU/SF	MF-Short	MF-Old-Tall	MF-New-Tall	MF-All highest of the three for each target
EE Target	54	**55**	42	**55**
ZNC Target	34	33	**35**	**35**

MF-Old-Tall buildings, which have more fuel-based and more centralized systems, have the highest median site EUI and will have the highest site EUI reductions through efficiency measures alone, since some inherent structural inefficiencies in older fuel-based systems are limited in energy efficiency potential, while newer buildings have more insulation and more efficient systems in general. Short buildings are similar in EUI potential to MF-Old-Tall but slightly lower.

It also makes sense that MF-New-Tall has the highest potential ZNC target EUI because there are generally more electricity-using systems in these buildings today, meaning electricity use can't be reduced as low as in buildings with less electricity-using equipment. In addition, newer buildings tend to have more amenity spaces and interior common area electricity use. While older buildings with fewer amenity spaces and common area electricity use may technically be able to reach slightly lower EUIs, the newer buildings--which often have the potential to be healthier buildings with better services— provide the value for a technically achievable ZNC target for the multifamily occupancy type as a whole.

Commercial and Industrial building types that are not well-represented in the existing Benchmarking data (few samples, or often less than 25,000 SF or Part of Other Buildings)

Cause: There are some examples of covered building types that are typically smaller than 50,000 SF (the 2019 size threshold for private building benchmarking). This primarily applies to small businesses located in shopping malls or as part of a larger single building, where energy use is aggregated with other building types. There are also buildings that are too few in number to generate a confident local area median of the energy use profile. The following building types had fewer than ten benchmarking reports[19]:

Table 12. Building use types with very few instances of the use type as the primary building activity, as represented in the 2019 Montgomery County benchmarking data.

Occupancy type	Example use types	Submissions with data available	Submissions post data screening
Food Service (Restaurants)	Restaurants, fast food, bar, café, etc.	3	1
Service	Salon, mailing center, repair shop, etc.	3	1
Public order and safety	Courthouse, firehouse, police station, etc.	4	2

Considerations: While there are many of these buildings in Montgomery County, the vast majority do not file benchmarking data because they are less than the current square footage size threshold of 50,000 SF and are

[19] Post data screening, see Explanation of Cleaning Flags. Note that hospitals also had less than ten examples (four), but these were discussed among the team and believed to be fairly representative of the hospitals in Montgomery County, so those four samples were used as the baseline to generate performance standards.

metered independently, with independent energy systems which classify them as separate buildings. These types may also be smaller than the proposed BEPS size threshold but make up portions of larger buildings in the form of ground floor retail. These occupancy types need to have targets assigned because the performance target for a given building is based on the area-weighted average of the different space targets in the building.

Solution for this technical analysis: Calculate a BEPS target based on the occupancy type average in the Commercial Building Energy Consumption Survey (CBECS) data set using the CNCA EBPS tools[20], with extrapolation to the local Building America Climate Zone as used in the 2012 CBECS data set[21] to adjust estimated heating and cooling energy use. Table 9 has the target values for these occupancy types.

Campuses

Cause: Campuses have multiple buildings located near each other and may be closely intertwined with energy systems, energy meters, or other characteristics. The proposed BEPS policy is written to define each building as an independently regulated entity, which can be problematic on some campuses where it is difficult to differentiate energy use for individual buildings with shared systems. Campus buildings will have an easier time filing for compliance if the single owner can submit energy information for the campus, which will include multiple buildings, each potentially having a different occupancy type and therefore different target.

Considerations: Each campus in Montgomery County will be somewhat unique in terms of energy systems layout, energy metering configurations, and other connections between buildings that may not have a physical or structural connection. The definition of covered buildings and the method for determining performance standards needs to respect these unique features to be a fair and inclusive performance requirement.

Solution for this technical analysis: As much as possible, final year targets should be calculated as an area-weighted average of different building occupancy types for a single benchmarking submission. While for most buildings, this will be applied to a single building with multiple occupancy types (e.g., ground floor retail in an office building), the approach can also be used for multiple buildings on a single campus where buildings share energy systems, meters, or are otherwise reported in a single benchmarking submission.

The definition of a building still applies in this case, but multiple buildings would be included in a single benchmarking submission. Therefore, each building, as an independent structure, would need to align with the covered building definition in other ways. Specifically, under the definition of a covered building in the proposed BEPS policy[22], each building on a campus would need to be:

> *(1) any single structure utilized or intended for supporting or sheltering any occupancy, except if a single structure contains two or more individually metered units operating independently that have stand-alone heating, cooling, hot water, and other mechanical systems, and no shared interior common areas, or;*
>
> *(2) two or more structures utilized or intended for supporting or sheltering any occupancy, that:*
>
> *(A) are serviced by a common energy meter,*
> *(B) have a common heating or cooling system,*
> *(C) share interior common areas, or*

[20] Energy Performance Standards for Existing Buildings. Carbon Neutral Cities Alliance. https://carbonneutralcities.org/tile/energy-performance-standards-for-existing-buildings/

[21] Montgomery County is in the Building America Climate Region "Mixed-Humid", according to the Building America Best Practices Series Volume 7.3: High Performance Home Technologies: Guide to Determining Climate Regions by County. Prepared by Pacific Northwest National Laboratory, August 2015. Page 20. https://www.energy.gov/sites/default/files/2015/10/f27/ba_climate_region_guide_7.3.pdf. Accessed July 7th 2021.

[22] Montgomery County. Bill 16-21 - Environmental Sustainability - Building Energy Use Benchmarking and Performance Standards - Amendments: https://apps.montgomerycountymd.gov/CCLLIMS/BillDetailsPage?RecordId=2707 Page 3. Proposed legislation packet.

(D) whose configuration otherwise prevents an accurate determination of the energy consumption attributable to each individual structure.

Buildings on a campus that are individually smaller than the size threshold may still be included in the campus submission if any of the above coverage conditions are present for the small building. The intent with this definition is to make the coverage requirements easier on the owners by including buildings where the energy use would be hard to separate from other covered buildings.

The following are some examples of campus layouts, which roughly align with EPA's Portfolio Manager guidance[23] and how the proposed building performance requirements would apply. Potential campus submissions would need to identify which buildings are connected and how (meters and/or systems).

[23] Portfolio Manager FAQs > Property Information > Campuses: "How do I benchmark a campus?" https://energystar-mesa.force.com/PortfolioManager/s/article/How-do-I-benchmark-a-campus-1600088534782 Accessed 5/27/2021.

Table 13. Potential campus-like scenarios and the respective performance standards calculation method.

Case 1: Multiple buildings of different use types, all subject to the same standards deadlines			
Campus Type	*Energy Meters*	*Energy systems*	*Standards Calculation*
1a	Each building has a utility meter for all energy use	Energy systems are not shared between buildings	Each building would submit documentation separately, and each has a separate performance standard based on use type. There may be an option for buildings to submit a single submission for the campus. The target setting process would treat the campus as one building and set standards accordingly.
1b	Each building has a utility meter for electricity energy use	A shared hot water or other thermal system is used between buildings with a central plant	All buildings on the shared energy system would submit documentation together with a total electricity and thermal energy use. The campus would get one performance standard that is an area-weighted average of all the building types and floor areas.
1c	Energy meters are for multiple buildings on the campus	Energy systems are not shared between buildings	All buildings on the shared energy meters would submit documentation together with a total electricity and thermal energy use. The group of buildings would get one performance standard that is an area-weighted average of all the building types and floor areas.
Case 2: Multiple buildings with some smaller than the size threshold (e.g., 25,000 SF) or with mixed compliance deadlines (buildings span multiple "Groups")			
2a	Each building has a utility meter for all energy use	Energy systems are not shared between buildings	Each building would submit documentation separately, and each has a separate performance standard based on use type. Buildings would comply according to their respective Group's timeline. Buildings smaller than the size threshold or an exempt property type would not need to comply.
2b	Each building has a utility meter for electricity energy use	A shared hot water or other thermal system is used between buildings with a central plant	Same as (1b), with the entire campus submitting compliance paperwork with the earliest deadline based on individual building type's Group. Another compliance method could be to align compliance with the date for the central plant's building.
2c	Energy meters are for multiple buildings on the campus	Energy systems are not shared between buildings	Same as (1c), with the entire campus submitting compliance paperwork with the earliest deadline based on individual building type's Group.

Changes to Campus Benchmarking Submission Process Based on the Updated Definition

The current benchmarking process allows a compiled submission for campus owners, regardless of whether the buildings would be classified as individual or not under the proposed BEPS standard. These campuses may need to change how building information is submitted to comply with the current definition. There may also be a case where significant work to a campus results in different metering or energy systems configurations, which could change how the campus buildings are defined and reported. If this occurs after the initial energy monitoring period, some adjustment to energy use standards will need to occur. These properties may need to develop a new energy baseline after the campus reconfiguration is complete and would fall into the compliance cycle timing assigned to the new occupancy type and campus type.

Comparison to Other Building Performance Standard Campus Methods

Washington, D.C.: In Washington DC, the Department of Energy & Environment (DOEE) oversees the Building Energy Performance Standards and energy benchmarking. DOEE used a similar area-weighted average method to develop unique standards for several colleges and universities.[24] The area-weighted Site EUI metric works for campuses in Montgomery County in a similar way to the area-weighted Source EUI metric calculation in the DC BEPS. In DC, DOEE and the BEPS Task Force discussed this method with campus owners for feedback and approval to get a solution that works for most. The Montgomery County standard calculation can use the same method, where each space type (e.g., office, dorm, laboratory) would get an EUI target, and that would be multiplied by the floor area proportion that the respective space type makes up of the whole campus.

St. Louis, MO: In St. Louis, the primary property type calculated for each submission is used to define site EUI targets. A single submission receives a single target based on the primary property use type, without a blending of targets for mixed-use spaces or campuses.[25]

New York City, NY: In New York City, the building emissions law is based on covered tax parcels ("lots"). Coverage is defined as[26]:

- (i) a building that exceeds 25,000 gross square feet (2322.5 m^2) or
- (ii) two or more buildings on the same tax lot that together exceed 50,000 gross square feet (4645m^2), or
- (iii) two or more buildings held in the condominium form of ownership that are governed by the same board of managers and that together exceed 50,000 gross square feet (4645m^2)

The definition would pull in many campus layout buildings, which are often on a shared parcel. Note that definition (iii) would also bring in multiple-building condominiums if under the same board management, since condominiums would have multiple tax parcels across a potential campus system. The performance standard in the New York City law is an area-weighted energy-based GHG emissions limit with a specific GHG intensity limit ($kgCO_2e/SF/yr$) for each building type based on building code occupancy groups.[27] The New York City law does not differentiate coverage by shared equipment or metering configurations.

Boston, MA: Boston has a similar building definition to New York City and can include a multiple building campus held by the same owner and on the same parcel as a single submission[28], with an area-weighted performance target. [29]

[24] DC DOEE. "Guide to the DC BEPS". Version 1.0, 3-30-2021. Sections 4.2 and Appendix C. Accessed 5/10/2021. https://doee.dc.gov/node/1507996
[25] St. Louis Building Energy Improvement Board. "Method for Grouping Property Types". Accessed 7/19/2021. https://www.stlouis-mo.gov/government/departments/public-safety/building/building-energy-improvement-board/documents/upload/Method-for-Grouping-Property-Types-05-03-21.pdf
[26] NYC 2014 Construction Codes – Building Code, Chapter 3, §28.320.1: "Definitions, **Covered Building" Accessed 5/17/2021.
https://www1.nyc.gov/assets/buildings/apps/pdf_viewer/viewer.html?file=2014CC_AC_Chapter3_Maintenance_of_Buildings.pdf&section=conscode_2014
[27] NYC 2014 Construction Codes – Building Code, Chapter 3, §28.320.3: "Building Emissions Limits".
[28] City of Boston. "Building Emissions Reduction and Disclosure Ordinance." Section 7.2.2 – Definition of non-Residential Buildings and Residential Buildings. https://www.boston.gov/sites/default/files/file/2021/10/BERDO.pdf page 4-5.
[29] Supra 28, Section 7.2.2.i.i, page 11.

Washington State: Building use types are entered into ENERGY STAR® Portfolio Manager, and "buildings with multiple unique building activity types may develop an area weighted EUIt (Energy Use Intensity target)"[30] and otherwise follows Portfolio Manager guidance on building submissions. Campuses can be accounted for with an area weighted EUI target.

Site EUI Target Adjustment Factors

The proposed approach accounts for changes in occupancy type, while occupancy rate is proposed to be left out due to a general lack of reliable data.

Occupancy Type Changes After the Baseline Period

The use of a building may change over time. For example, a hotel in 2019 may become a multifamily apartment building in 2030, and a retail space in 2021 may become a grocery store in 2025. Newly constructed buildings would need interim and final year targets. These changes in all or part of a building's intended occupancy use can substantially change the energy use profile and its respective performance standard. The building energy performance standard framework should adjust for these major building use type changes over time.

Proposed Approach

The following three steps can be taken to update a building's targets based on changes in occupancy type:

1. If occupancy group proportions change, then final year target is adjusted to reflect the new proportions. The calculation methodology is the same as for the original target, but with the updated occupancy types.
2. Intermediate performance targets have an adjusted target EUI. Interim deadlines do not change. A new straight line is created from updated EUI (with new occupancy proportions) to the final year target.
    a. For example, an interim target for an office building is 60 kBTU/SF in 2026, and that building changes to a retail store in 2023, with a new calculated interim target of 65 kBTU/SF. That new interim target would still be in 2026, since offices and retail types have the same interim and final year target deadlines. See Figure 6 below for visual examples.
3. Data verification of occupancy type changes can happen at the time of the occupancy type update. This allows for an effective immediate adjustment to the target of a specific building. Otherwise, the occupancy type change would happen at the next scheduled data verification period, which is every three years in the current Benchmarking Law.

Process For Recalculating Targets Based on Occupancy Type Changes

- **New final year target:** The applicable final year target for new occupancy groups or a new blend of occupancy groups where there is more than one group would use the same methodology as the calculation of the original final year target as described in this technical analysis.
- **New interim targets:** Because the interim targets consider the initial EUI of a building in the baseline year/period, the new interim targets need to consider the year of the change in occupancy. This is a possible calculation method to use:

$$New\ Interim\ Target\ EUI = Final\ Target\ EUI + \frac{Final\ Target\ Year - Interim\ Target\ Year}{Final\ Target\ Year - Current\ Year} * (Current\ EUI - Final\ Target\ EUI)$$

[30] Washington State Department of Commerce. "How to Determine Energy Use Intensity Target (EUIt)". Accessed 10/18/2021. https://www.commerce.wa.gov/wp-content/uploads/2021/07/How-to-Determine-EUIt.pdf

Figure 6 at right shows a few examples of how targets can be recalculated for changes in occupancy type.

In 6a, a building in Group 1 starts as a mixed-use Office/Health care Outpatient building and remains so throughout the BEPS period. This building's targets are set as a blend of the two occupancy types and do not change.

In 6b, a building that is 100% Health care Outpatient at the beginning of the BEPS period converts part of the building to be Office in 2024. A new baseline is set in 2024, and the interim and final year target are updated to reflect the new occupancy types – for the final year target – and a new straight line is drawn between the new 2024 baseline to get the new interim targets. Note that the dates of the interim targets do not change.

In 6c, the same scenario happens as in the second example but after the first interim period. In this case, the final year target is recalculated for the final year, and only the second interim target is updated to be on the straight line between the 2028 baseline and the final year target.

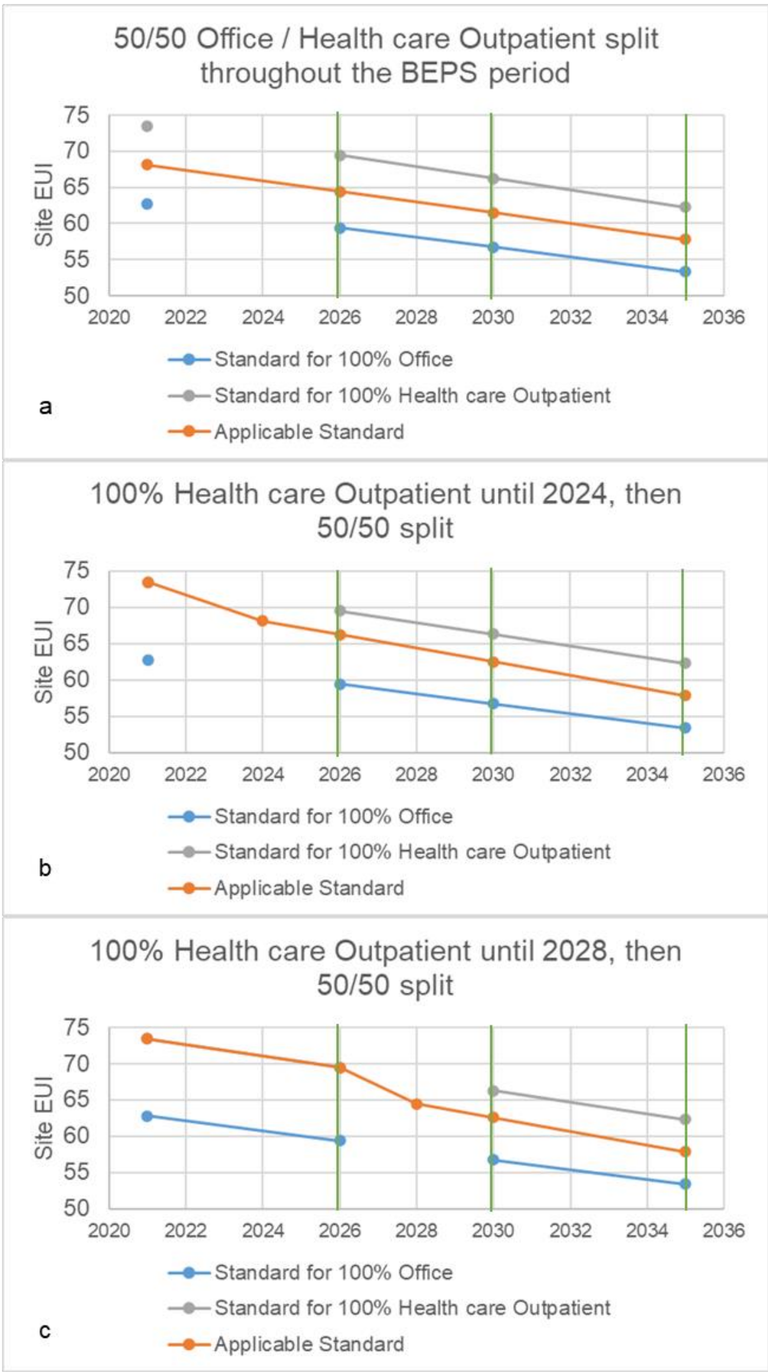

Figure 9. Examples of how a change in occupancy type during the interim period would result in updated interim and final targets. Assumption is that the building starts at the median EUI for its use type and meets each target on time, without exceeding the required performance.

Occupancy Rate Changes

Potential Issue

Some buildings may have an atypical amount of occupancy during their baseline years. The portion of a building that is occupied can play a role in how much energy that building uses. If a building's occupancy rate changes over time, the energy use of the building may substantially increase or decrease.

The energy used by systems and services in a building are dependent on occupants in both the short term (daily occupancy) and long term (leasing status). Lighting, ventilation fans, and heating / cooling equipment can be dependent on daily or hourly fluctuations in occupancy. The leasing status of a building defines long-term occupancy, which affects heating/cooling/ventilation equipment, appliances, and computer infrastructure energy use.

There is limited guidance in Portfolio Manager on defining occupancy rate, but not for all occupancy types, and the occupancy rate does not result in an adjustment of the occupancy type's ENERGY STAR Score. As a result, it was difficult to understand the role that such a broadly defined word as "occupancy" should play in the setting of energy performance standards.

Portfolio Manager's Glossary[31]:

> *Occupancy is the percentage of your property's Gross Floor Area (GFA) that is occupied and operational. This is a measure of the building's occupancy/use, it is not connected to a building's "Maximum Occupancy."*
>
> *… If you are not seeking certification for one of the above property types, you may not find Occupancy very useful (though it is required, so enter your best guess and move on)*
>
> *… There is only one Occupancy rate for each property as a whole. You enter Occupancy when you first create the property, and you can change it on the Details tab. You cannot track occupancy changes over time.*

Treatment of the Occupancy Field in this Technical Analysis

- Currently there is not a reliable way to finely adjust targets, baseline, or performance based on occupancy.
- As a result, this technical analysis' target setting methodology did not incorporate occupancy rate as an adjustment factor or as a filter.
- One possible refinement could be to use the same thresholds as Portfolio Manager to not define targets for buildings that are below a certain occupancy rate. For example, for Offices the minimum occupancy rate is 55% to receive an ENERGY STAR score. This approach is not currently integrated into the technical analysis's target setting, but because the baseline energy use from which targets are calculated centers on the median EUI, the few low-occupancy buildings in some groups will not affect the baseline and target values.
- In other jurisdictions, occupancy rate is mostly ignored in setting and enforcing targets and baselines. While many details need to be worked out in rule-making across the country, Washington DC, New York City, and St. Louis all do not have mechanisms for fine adjustment based on occupancy rate. This is likely because there is not a widespread and reliable way to track occupancy rate in buildings.

Recommendations for Adjustments based on Occupancy

- Final year targets were based on the median EUI of the group, including all buildings regardless of occupancy rate. This approach intuitively gives building owners the benefit of the assumption of a typically occupied building in a given occupancy group.

[31] Entry for "Occupancy": https://portfoliomanager.energystar.gov/pm/glossary Accessed June 22nd 2021.

- Interim targets might need to be adjusted if previously vacant space is filled and the building's EUI increases significantly, but it may require a more nuanced approach than this technical analysis's data set can support.
- The proposed policy sets baseline energy use according to the two highest energy use years of a three-year period, which should smooth out some short-term low occupancy periods in a building's operation.
- As a longer-term next step, the County can determine the feasibility of adding more granular and more reliable vacancy inputs to each building space so they can be used as an adjustment factor. This may require coordination with the EPA to develop granular occupancy outputs that can be used to develop adjustment factors, especially to ensure consistency, transparency, and accuracy of record tracking within the Portfolio Manager platforms. This next step is not in progress as of this report writing.

IMPACT OF ENERGY PERFORMANCE STANDARDS IN MONTGOMERY COUNTY

To estimate the impact of the building energy performance standards, the analysis team developed a model Excel workbook that applied the performance standards to a draft covered buildings list. The analysis team then calculated the cumulative impact of the potential standards on energy use, energy cost, retrofit capital cost, and greenhouse gas (GHG) emissions.

The proposed BEPS policy uses building groups with different compliance deadlines. These groups were adopted for the modeling portion of the technical analysis and referenced within as 'BEPS Groups':

Table 14. Montgomery County BEPS groups used in the proposed BEPS policy, and the year when compliance is monitored (reporting is due in the next calendar year):

	Type and Size	Interim 1	Interim 2	Final
Group 1	Non-Residential greater than 250,000 Gross Square Feet (SF)	2026	2030	2035
Group 2	Non-Residential 50,000 – 250,000 SF	2026	2030	2035
Group 3	Non-Residential 25,000 – 50,000 SF	2028	2032	2036
Group 4	Multifamily greater than 250,000 SF	2028	2032	2036
Group 5	Multifamily 25,000 – 250,000 SF	2029	2033	2037

CREATING THE POTENTIAL COVERED BUILDINGS LIST

Using a combination of Maryland State Department of Assessments and Taxation (SDAT) property records and geographic information system (GIS) data[32], the floor area and covered buildings were identified using the size thresholds and buildings definition in the proposed BEPS policy. See *Appendix III - BEPS Policy Model Methodology* for details.

Determining Multifamily Specific Attributes for Impact Modeling

Multifamily buildings were separated into three sub-groups depending on height and age (MF-New-Tall, MF-Old-Tall, MF-Short) as described for target setting, using data fields in the SDAT data set to make the subgroup determination.

There are likely many MF-Short buildings that would not be covered based on the definition of a covered building regarding shared spaces, interior common areas, single building size vs parcel size. To account for this, the technical analysis's impact modeling used an assumption that the smaller 50% of garden style MF-Short buildings would be exempt from coverage.

Determining Commercial Buildings Coverage and Exemptions

For commercial building types, the various exemptions and building definitions rules were applied to buildings with floor area over 25,000 SF:

- Parcel matchup from benchmarking data to SDAT using the US Department of Energy's Standard Energy Efficiency Data (SEED) matchup provided by MC DEP.
- If the building did not submit benchmarking data, the Land Use Code was used to determine the occupancy type.
- Exempt use types were filtered out by Land Use Code.
- State and federal government owned buildings were removed by filtering for parcel owner name.
- County buildings were flagged using parcel owner name.

[32] Compiled and provided by MC DEP for this technical analysis

- Montgomery County Public School (MCPS) and Montgomery Community College (MCC), which are state regulated entities and are not required to report benchmarking data, were removed using parcel owner name.

The results of this parcel coverage analysis for residential and non-residential buildings are shown in Table 15.

Table 15. Estimated covered buildings resulting from the analysis of tax parcel and GIS building data. At left, the "Total Identified" group of columns is all parcels and buildings that fit the high-level parcel size threshold screening. At right, the "Covered: Used in Analysis" group of columns is the remaining properties after screening for individual building size, exempt use types, and exempt ownership types.

	Total Identified			**Covered: Used in Analysis**		
	Buildings	Parcels	Total Floor Area [Million SF]	Buildings	Parcels	Total Floor Area [Million SF]
MF-New-Tall	333	155	52.1	296	145	49.9
MF-Old-Tall	144	96	29.1	122	90	27.8
MF-Short	156	122	9.9	125	101	9.0
Higher Education	34	9	2.0	7	3	0.4
Education - K-12 School	293	241	30.2	54	40	4.6
Food Sales	110	65	7.3	70	55	6.2
Food Service	3	2	0.06	1	1	0.03
Health care Inpatient	51	13	30.7	22	10	10.1
Health care Outpatient	48	39	3.4	46	38	3.2
Lodging	100	78	10.7	84	73	9.8
Mercantile Enclosed and strip malls	136	59	31.0	67	45	18.0
Mercantile Retail (other than mall)	135	88	10.0	100	82	7.8
Office	548	413	80.3	502	391	76.7
Other	166	103	12.8	94	76	8.9
Public Assembly	106	61	7.6	74	53	5.3
Public order and safety	73	25	5.5	12	11	0.6
Religious Worship	94	80	4.1	75	71	3.7
Service	1	1	0.03	1	1	0.0
Warehouse and storage	292	204	15.1	178	144	9.5
Total	**2,823**	**1,845**	**341.8**	**1,930**	**1,426**	**251.5**

Mapping baseline energy use to non-benchmarked buildings

Buildings with benchmarking data were assigned energy use based on known distribution from benchmarking data. For buildings without energy benchmarking data, the methodology for mapping energy data to buildings without energy data was the same for all building types. The known energy distribution from benchmarking (Montgomery County data for most types; Washington, DC data for multifamily) was split into deciles (10th, 20th, 30th, etc. percentiles). For buildings without energy data in a group, a decile was randomly assigned, and the corresponding EUI was applied to that building. See *Appendix III - BEPS Policy Model Methodology* for more detail. On aggregate, the impact of changing targets for the groups can be estimated this way, even if the energy use for a given non-benchmarked building would not be accurate for that specific building.

APPROXIMATING THE ENERGY REDUCTION PATHS OF COVERED BUILDINGS

For all covered buildings, evaluated on the building level, the following analysis is performed to calculate the impact of the final performance standard:

1. If the building had a lower site EUI than the final performance standard, the energy use did not change (building maintains current energy use through the entire BEPS period).
2. If the building had a higher site EUI than the final performance standard, energy is lowered to the final performance standard by reducing gas use and electricity use through energy efficiency. Once the Energy Efficiency threshold is met through efficiency retrofits, and if the building's target is lower than the EE target for that occupancy type, further energy reductions are made through electrification of gas equipment, while increasing electricity proportionally as a result of the conversion from gas to electric equipment. If electricity needs to be further reduced after gas use is eliminated, it is reduced until the final performance standard is met by the final compliance cycle. Specifically, retrofits happen in this order for each building to meet the two interim targets and the final year target:
    a. If gas EUI was greater than the gas component of the EE threshold, gas use was reduced through efficiency work (without electrification).
    b. If electricity EUI was greater than the electricity component of the EE threshold, electricity used was reduced toward the electricity component of the EE threshold, spread evenly over the three compliance periods (1/3rd of the way each time).
    c. If more reduction was needed, uses were electrified to meet the target.

Baseline energy use was based on calendar year 2019 benchmarking data, the most current year of data available for this technical analysis. From that baseline, each covered building was assumed to meet the interim and final year performance targets by the compliance deadline and maintain that performance until the next deadline.

PERFORMANCE STANDARD IMPACT ANALYSIS RESULTS

BEPS Policy Model Methodology

The impact of various energy performance standards was modeled using an Excel workbook that uses the covered building list and calculates the energy, energy cost, capital cost, and GHG changes of the proposed standards.

For a list of assumptions and model inputs, see *Appendix III - BEPS Policy Model Methodology*.

Energy, Cost, and Greenhouse Gas Emissions

The analysis team calculated the annual and cumulative energy use and associated costs and emissions for the years 2021-2039, show in Table 16, without a BEPS policy. No capital cost was assumed under the baseline case, as the technical analysis considered the total capital cost of upgrades without including business as usual equipment replacements.

Table 16. The estimated covered buildings' energy and GHG emissions characteristics, both annual and cumulative over the technical analysis period.

Cumulative Countywide Baseline 2021-2039	Annual Total (2021)	2021-2039 Cumulative Totals (without a BEPS policy)
Electricity Use [Billion BTU]	12,212	293,057
Gas Use [Billion BTU]	6,574	157,772
GHG emissions of covered buildings [Million tonsCO_2e]	1.33	16.91
Energy Cost [Million$]	$602	$14,445
Capital Cost [Million$]	N/A	N/A

The results of the BEPS analysis are shown in Table 17 along several metrics of capital costs, energy, GHG, and on-site fossil fuel burning which correlates to local air quality.

Table 17. Estimated countywide impact of three building energy performance targets, summing cost, energy savings, and GHG for each Target Method.

Countywide Impact of BEPS 2021-2039	Energy Efficiency (EE) Target	EE-ZNC midpoint	Zero-Net-Carbon (ZNC) Compatible Target	
Electricity Site Energy Savings	17,360	14,700	12,430	Billion BTU
Gas Site Energy Savings	40,650	56,970	75,700	Billion BTU
Cumulative GHG Savings of Policy	1.70	2.30	2.99	Million Tons CO_2e
GHG Savings by grid cleaning (external to a BEPS program)	*14.0*	*14.0*	*14.0*	*Million Tons CO_2e*
Energy Cost Savings	$1.2	$1.3	$1.5	Billion
Total Capital Cost*	$1.7	$2.4	$3.3	Billion
Abatement Cost	$980	$1,050	$1,080	dollars / tonCO_2e
On-site fossil fuel reduction *(correlates to local air quality)*	46%	66%	86%	Percent of annual baseline
Annual GHG Reduction (% lower than 2019 baseline)	87%	92%	97%	Percent of annual baseline

**Total capital cost is gross cost and does not factor in costs that would have been incurred for normal end-of-life replacement of equipment. Cost does not include financial assistance available for energy efficiency retrofits.*

The eliminated energy use is primarily driven by reduction in on-site fuel burning through energy efficiency and electrification. Electric energy efficiency is also incorporated, though those reductions in overall electricity use are partially offset by increases due to electrification of fossil fuel systems. A summary of energy use reductions over the technical analysis period by BEPS Group is shown in Figure 10 for the ZNC target.

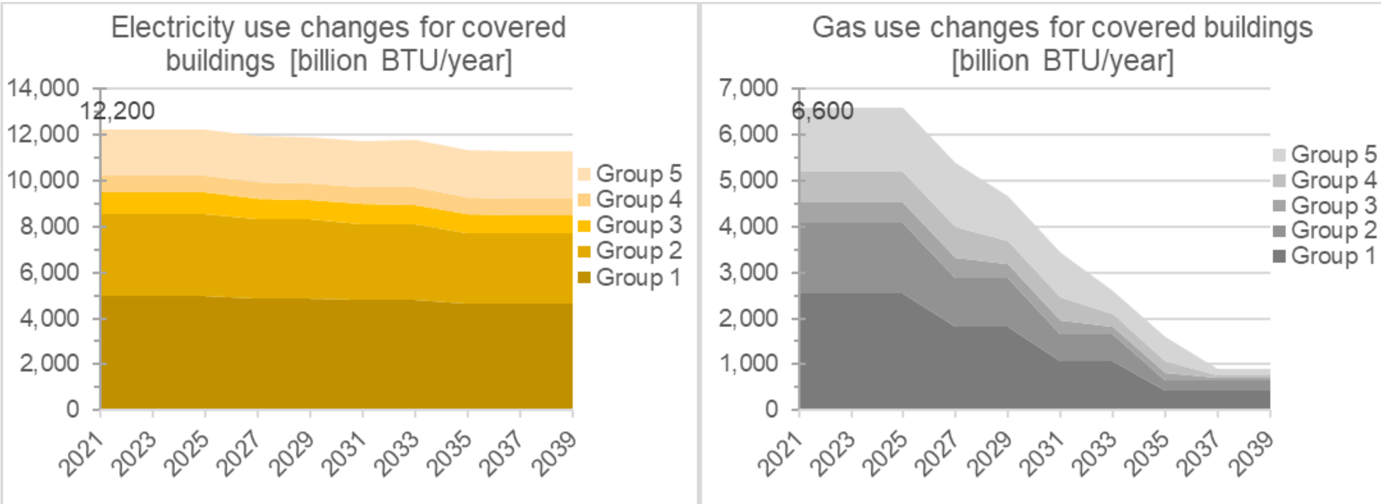

Figure 10. On-site fossil fuel ("gas") and electricity use reductions associated with meeting the ZNC target across the groups of covered buildings during the technical analysis period. Energy use is stacked so the top of the groups represents the covered buildings total.

Greenhouse Gas Impact Calculation

The annual and cumulative greenhouse gas (GHG) impact of each building performance standard option was calculated using current and projected energy supply and compliance deadlines of different building types. The GHG impact was calculated in kilograms or metric tons carbon dioxide equivalent (CO_2e).

Table 18. Greenhouse Gas intensity coefficients for natural gas and electricity.

Energy Type	$kgCO_2e$/ Million BTU	Year for Grid Condition	Data Source
Natural Gas	54.72	All years	MC GHG Inventory[33,34]
Electricity Baseline	95.71	2018	MC GHG Inventory[33,35]
"Emissions Free" Grid	2.696	2035 (variable)	CNCA EBPS Tool[36]

The graphic in Figure 11 shows the annual emissions change for covered buildings using the above GHG assumptions with a starting point in 2021 and going out to 2039. Emissions savings begin after 2025 (shown in dark blue), when the first interim compliance period dates spur energy retrofits.

33 https://www.montgomerycountymd.gov/green/Resources/Files/climate/ghg-inventory-data-summary-july-2020.xlsx
34 Uses 2018 natural gas emissions divided by natural gas consumption to calculate factor. Includes the kgCO2e/kBTU for fugitive natural gas emissions from the same inventory.
35 Uses 2018 total electricity emissions divided by total electricity consumption to calculate the GHG-per-energy factor.
36 Page 30: http://carbonneutralcities.org/wp-content/uploads/2020/03/CNCA-Existing-Building-Perf-Standards-Targets-and-Metrics-Memo-Final-March2020.pdf

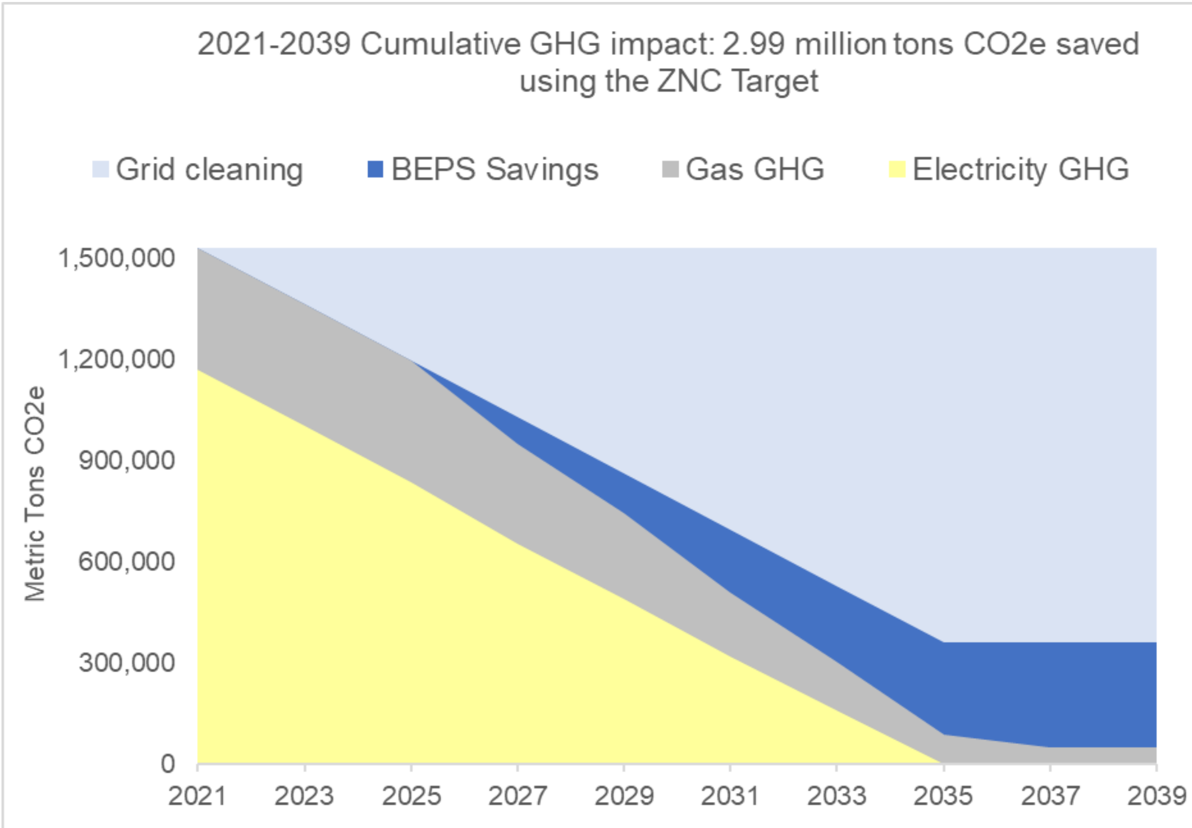

Figure 11. Cumulative GHG impact from 2021-2039 assuming carbon-free electricity supply and the proposed BEPS timeline to reach the ZNC targets for all groups.

If the County's electricity emissions intensity (EEI, in kilograms of carbon dioxide equivalent per kilowatt-hour, kgCO2e/kWh) for purchased electricity was zero, i.e., to be considered "zero-emissions" or "carbon neutral" by 2030, as stated in the CAP[37], the annual emissions from building energy use would drop by 94% for covered buildings from the 2019 baseline, with 70% coming from reductions in EEI and 26% coming from buildings performing retrofits to meet the performance standard. To eliminate the remaining fossil fuel use and resulting emissions, a more specific restriction for on-site emissions may be necessary.

Clearly, the transition to a carbon-free electricity supply will result in the majority of carbon emissions savings in buildings. The building energy performance standard would do two things to enable further emissions to reach the county's climate action plan goal: 1) the reduction in electricity use through efficiency measures would ease the burden on the supply side to provide electricity from carbon-free sources, and 2) the reduction of on-site emissions through fossil fuel efficiency and eventual electrification may be the only way to achieve carbon neutrality.

Using a building energy performance standard and the targets developed in this technical analysis would get the county much closer to a carbon neutral scenario, resulting in a 97% annual emissions reduction versus 76% annual emissions reduction achieved through the cleaning of the grid alone. As shown in Table 19, the difference between the targets is more pronounced under a carbon-free electricity supply than using today's relative emissions-intense electricity supply.

[37] Supra 1, page 88.

Table 19. The annual emissions reduction impact of the site EUI targets in this technical analysis. Reductions are of annual emissions at the final target year (e.g., 2037 or beyond).

Annual Savings in Million Metric Tons CO_2e (% reduction from baseline)	No BEPS	EE	EE-ZNC midpoint	ZNC
Electricity supply does not change from today	1.53 (0%)	1.24 (19%)	1.19 (22%)	1.13 (26%)
"Carbon-free" electricity supply	0.36 (76%)	0.19 (87%)	0.12 (92%)	0.05 (97%)

Impact of Delaying the Compliance Deadlines

If all compliance deadlines were delayed beyond the dates in the proposed BEPS policy, the county would experience additional energy use, GHG emissions, and operating costs. In addition, many buildings would replace equipment with similarly inefficient equipment before the policy would go into effect, locking in high energy use and emissions for a longer period until that new equipment reaches end of useful life. This section has some examples of the difference a timeline delay can make on the economic activity a BEPS program can create.

The proposed timeline created a $1.7 billion investment in building retrofits by 2029, while a four-year delay (i.e., an additional compliance cycle) in the program pushed that level of investment out to 2033. The comparison in Figure 12 shows how productive investment in building retrofits would be delayed for the BEPS groups.

The efficiency and electrification retrofits that would be required to comply with the BEPS targets can improve the building for the occupants by:

1) Adding efficient cooling to buildings without adequate air conditioning[38],
2) Reducing on-site combustion products that decrease indoor[39] and outdoor[40] air quality,
3) Repairing building envelope issues that have created moisture issues, improving indoor air quality through repairs[41], and
4) Lowering energy bills by using efficient equipment.

To realize these benefits to county residents, the retrofits required to meet this technical analysis's performance targets should be undertaken as soon as feasible. Delaying action may result in buildings replacing failing equipment with in-kind replacements that do not improve occupant wellbeing. Those "wasted" capital costs of in-kind equipment replacement are not captured in this analysis.

The benefits to county residents hinge on the timeline of BEPS Groups 4 and 5. Under a four-year delay, improvements to residential buildings would be delayed until the mid- to late-2030s. The estimated total capital cost differences are shown in Figure 12.

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38 Yu Ann Tan and Bomee Jung. "Decarbonizing Homes: Improving Health in Low-Income Communities through Beneficial Electrification". RMI, 2021. Pages 19-21 provide a good overview of cooling benefits. http://www.rmi.org/insight/decarbonizing-homes.

39 Wendee, Nicole. "Cooking Up Indoor Air Pollution: Emissions from Natural Gas Stoves". Environmental Health Perspectives, Volume 122, Number 1. January 2014. https://ehp.niehs.nih.gov/doi/10.1289/ehp.122-a27

40 Combustion of fuels such as natural gas releases various air pollutants such as particulate matter and nitrogen dioxide. See US EPA. https://www.epa.gov/pm-pollution/health-and-environmental-effects-particulate-matter-pm and https://www.epa.gov/no2-pollution/basic-information-about-no2#What%20is%20NO2

41 National Research Council. "Review and Assessment of the Health and Productivity Benefits of Green Schools: An Interim Report". Chapters 2 and 3. National Academies Press. 2006 https://www.nap.edu/read/11574/chapter/4

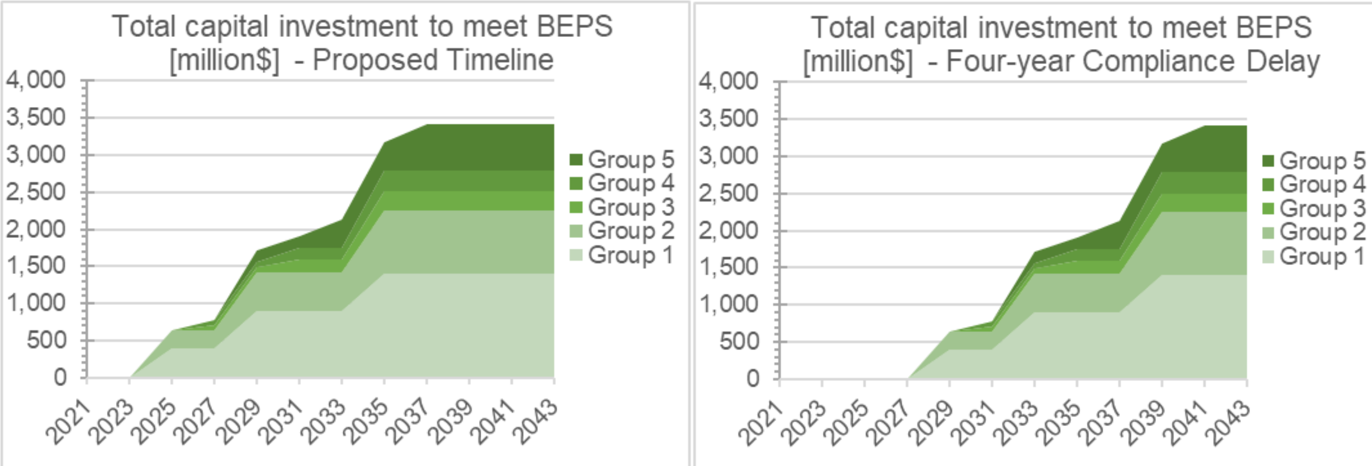

Figure 12. Comparison charts showing the total capital investment of the BEPS policy using different timelines. Groups 1-3 are commercial, while Groups 4 and 5 are multifamily residential building types.

Overall, the end goal of emissions reduction is still achieved, but at a later date. See *Appendix VIII - Sensitivity Tests on Model Impact Results* for more discussion on how alternative capital cost trends (increases or decreases in cost of different technology over time) can change the total capital cost of the BEPS program.

APPENDICES

APPENDIX I - RECOMMENDATIONS FOR BUILDING GROUPS

Recommendations

1. Use building types as defined in the Commercial Building Energy Consumption Survey (CBECS)[42], with sub-types as necessary. The CBECS groupings and data set inform much of the EPA ENERGY STAR Portfolio Manager ratings and adjustments around ENERGY STAR scores.
2. Use SDAT Land Use Codes for mapping to the CBECS building use types. The Land Use Codes are available on the parcel level, which may mask some sub-parcel building use types.

Montgomery County Building Group Classification Method

Of the many potential ways to categorize buildings into groups for the purposes of performance standards, two grouping methods were compared in this technical analysis. One is to use the Energy Information Agency's (EIA) Commercial Building Energy Consumption Survey (CBECS), which serves as much of the data source behind the EPA Portfolio Manager and associated tools. All buildings that use the Portfolio Manager tool for benchmarking are assigned a use type that can be cross-referenced to a CBECS use type—regardless of whether the building is eligible to earn an ENERGY STAR Score. All BEPS-covered buildings in the County would need to have a space use assigned.

> ***CBECS Principal Building Activity:*** *The activity or function occupying the most floorspace in a building. The categories were designed to group buildings that have* <u>*similar patterns of energy consumption*</u>*. Examples of various types of principal activity include office, health care, lodging, and mercantile and service.*[43]

Another method is the International Building Code (IBC) occupancy groups, which is adopted into the Building Code 2018 of Maryland, Section 302.1: Occupancy Classification and Use Designation[44]:

> ***IBC Occupancy Groups Definition:*** *Occupancy classification is the formal designation of the primary purpose of the building, structure or portion thereof. Structures shall be classified into one or more of the occupancy groups listed in this section based on the* <u>*nature of the hazards and risks to building occupants*</u> *generally associated with the intended purpose of the building or structure.*

The CBECS building groupings are more appropriate than the IBC groupings because of how the groups are defined to differentiate energy use patterns (CBECS), rather than occupancy risk patterns (IBC).

The Maryland Land Use Code field in the tax parcel data set was matched up to both building group types to determine what the covered buildings list would look like and how different building types would be grouped together or separated based on the two grouping methods. A detailed list of the building types is in *Appendix IX - Summary of Data Sources.* Figure 13 shows a summary of this matching.

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[42] EIA CBECS Building Type Definitions. https://www.eia.gov/consumption/commercial/building-type-definitions.php
[43] "CBECS Terminology – Principal Building Activity". https://www.eia.gov/consumption/commercial/terminology.php#P
[44] Building Code 2018 of Maryland, Section 302.1. https://up.codes/viewer/maryland/ibc-2018/chapter/3/occupancy-classification-and-use#3

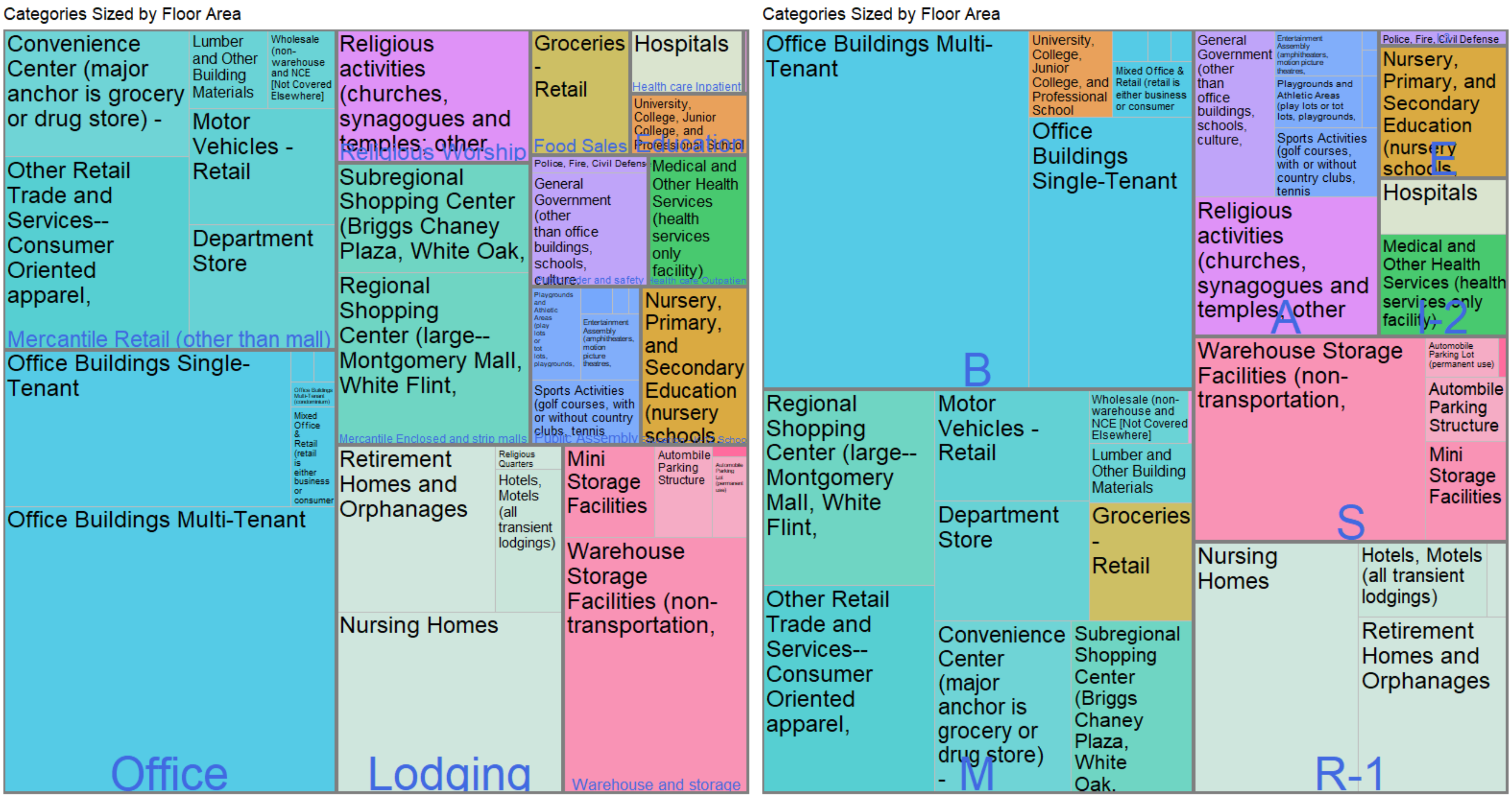

Figure 13. Building Groupings by CBECS type (left) and by IBC type (right). Filtered for coverage (no MCPS, MCC, state or federal buildings, industrial buildings, only individual buildings over 25,000 SF). These charts are commercial only, not multifamily, which would all be R-2 per IBCC. 44 Million SF total. This does not use final covered buildings list, which was refined later in the technical analysis.

A detailed review of the building groups' energy profiles is in *Appendix II - Montgomery County Energy Use Distributions Overview.*

APPENDIX II - MONTGOMERY COUNTY ENERGY USE DISTRIBUTIONS OVERVIEW

Using 2019 benchmarking data provided by DEP, with data cleaning as described in *Benchmarking Data from Montgomery County*, distributions of Site EUI broken down by energy source are shown below.

In these charts:

- Electricity EUI is represented as yellow
- Fossil EUI is represented as grey; fossil energy use includes on-site consumption of natural gas and fuel oil
- District energy is represented as green; district energy was present for buildings on a campus with a shared central plant such that the building received heated or chilled water instead of electricity or fossil fuel. District energy can be entered in Portfolio Manager during benchmarking.
- Each column is a single building; the width of the column corresponds to an individual building's floor area.
- Buildings are sorted by total site EUI descending from left to right.
- Some charts have ENERGY STAR scores (0-100) for individual buildings represented as blue dots.

These charts show the diversity of electricity and gas use across building types. Building types with fewer than three buildings are not shown, including: Food Service, Public Order and Safety, and Service building types.

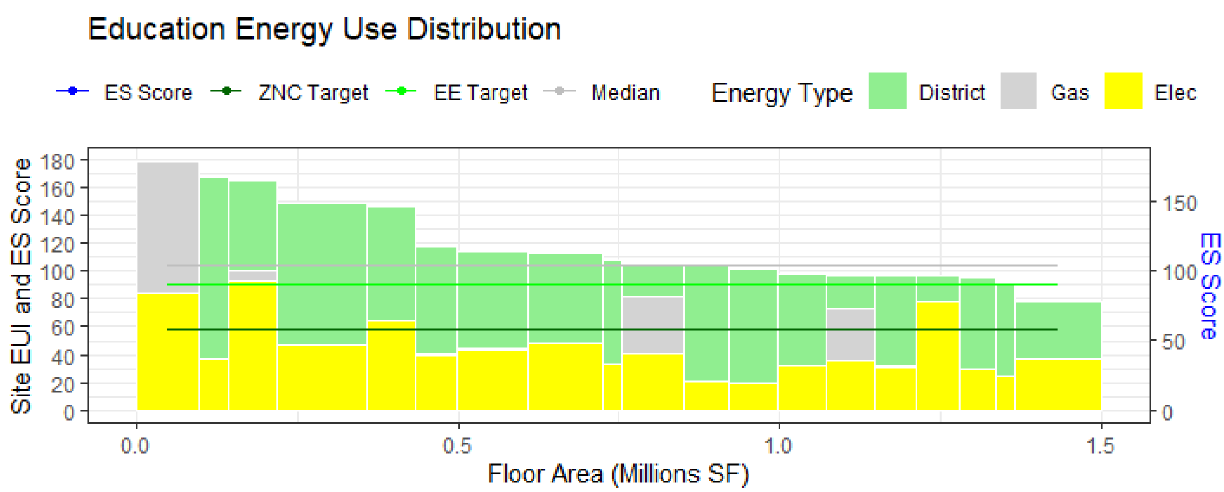

Figure 14: Energy Use Distribution of Education Facilities and Energy Star score, if applicable

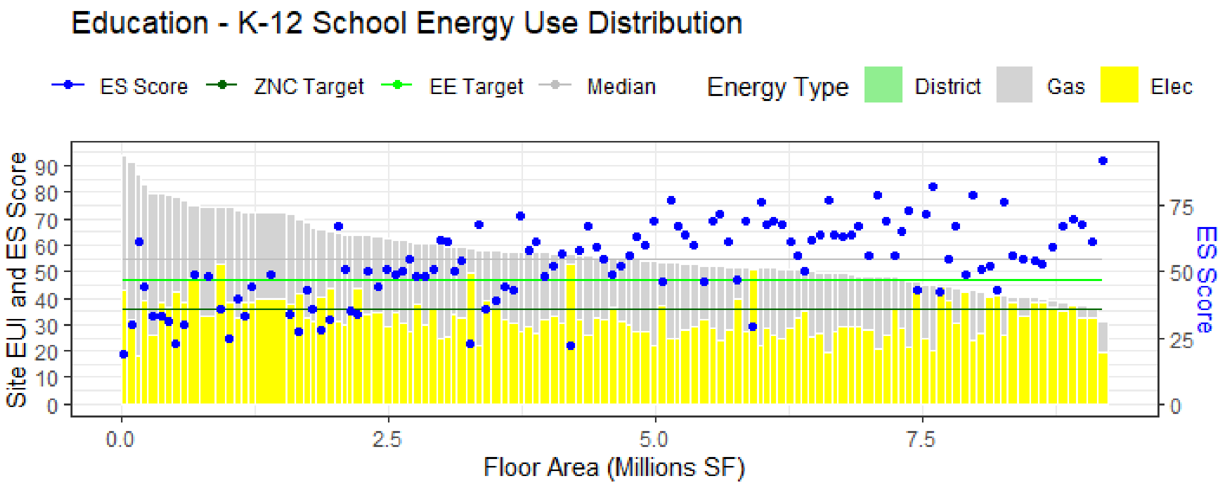

Figure 15: Energy Use Distribution of K-12 School Facilities and Energy Star score, if applicable

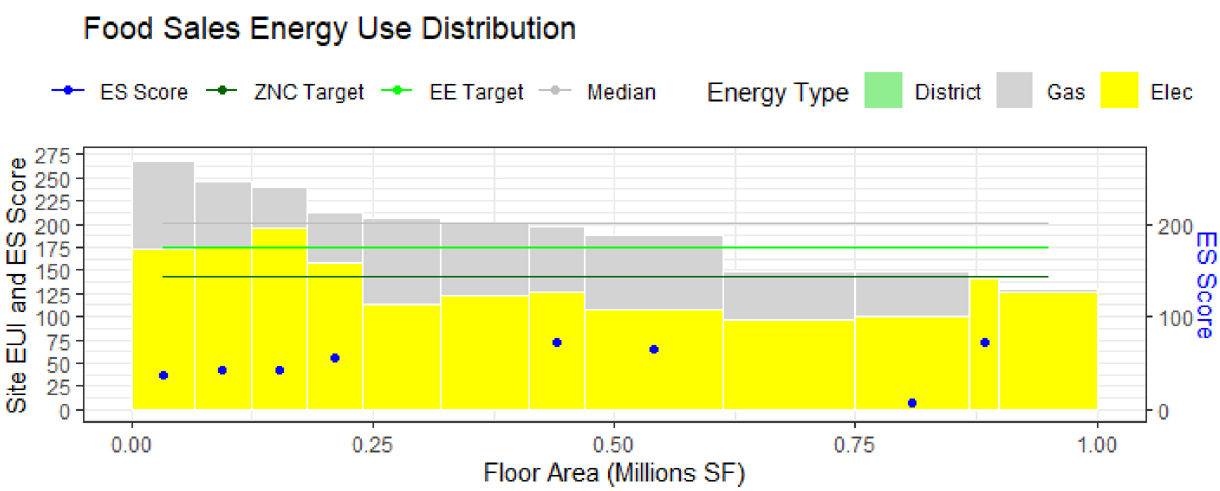

Figure 16: Energy Use Distribution of Food Sales Facilities and Energy Star score, if applicable

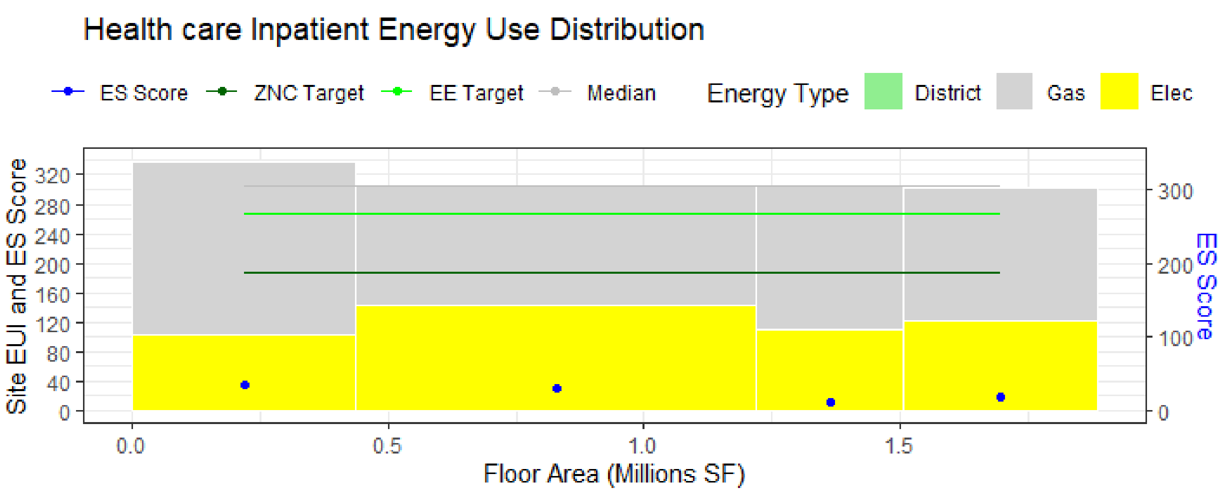

Figure 17: Energy Use Distribution of Inpatient Health Care Facilities and Energy Star score, if applicable

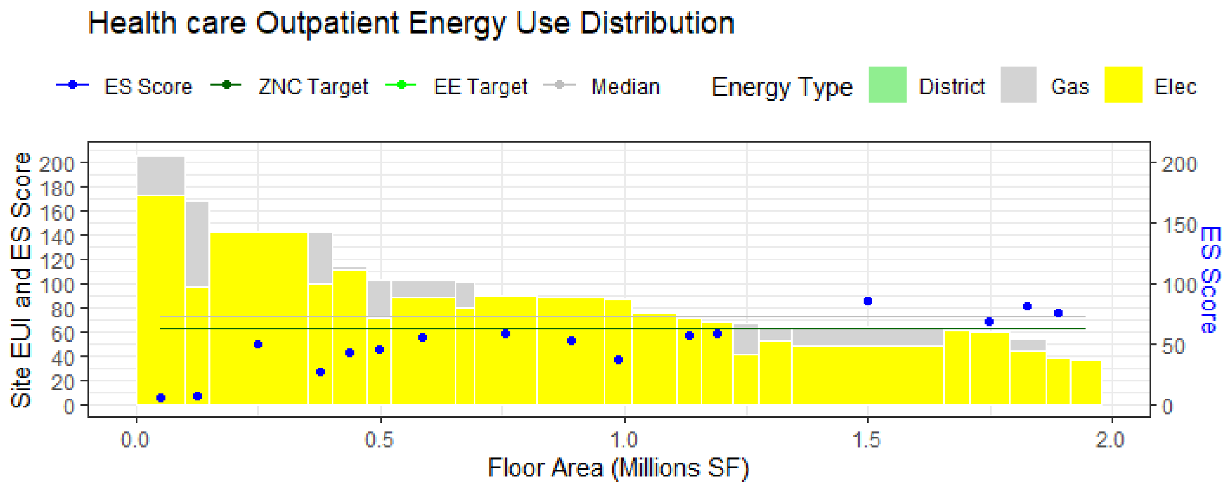

Figure 18: Energy Use Distribution of Outpatient Health Care Facilities and Energy Star score, if applicable

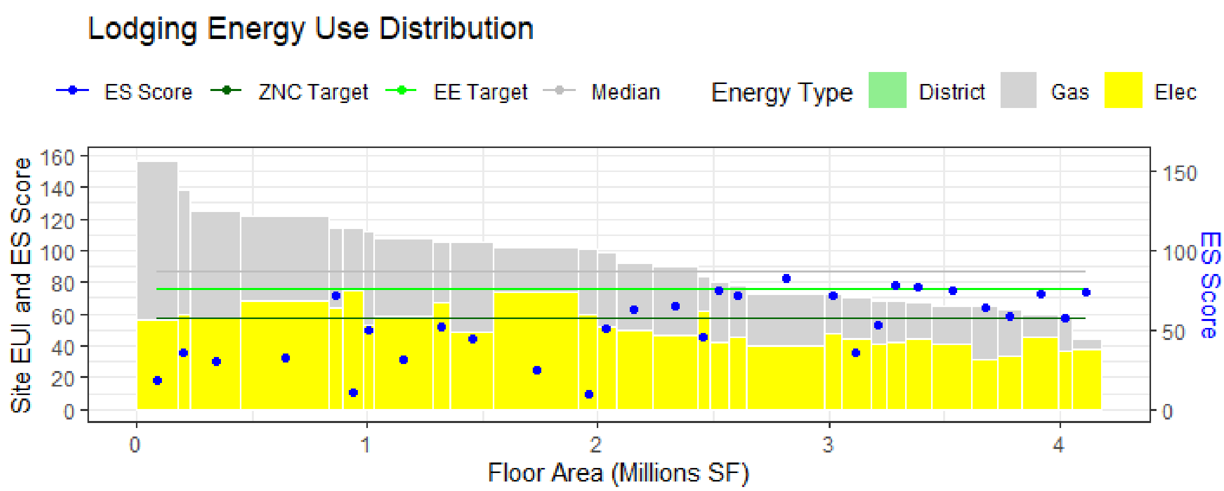

Figure 19: Energy Use Distribution of Lodging Facilities and Energy Star score, if applicable

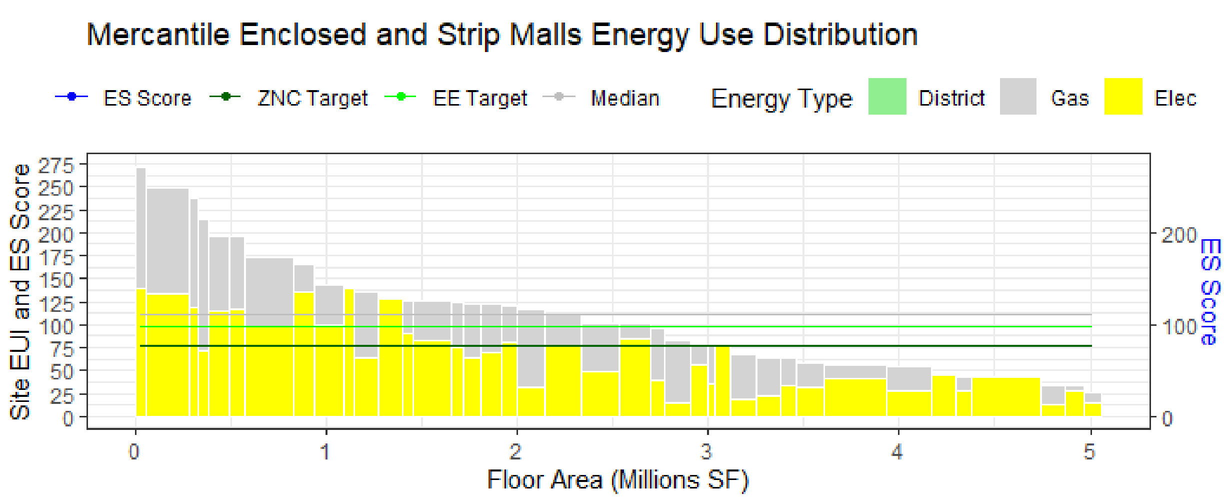

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Figure 20: Energy Use Distribution of Mercantile Enclosed and Strip Malls and Energy Star score, if applicable

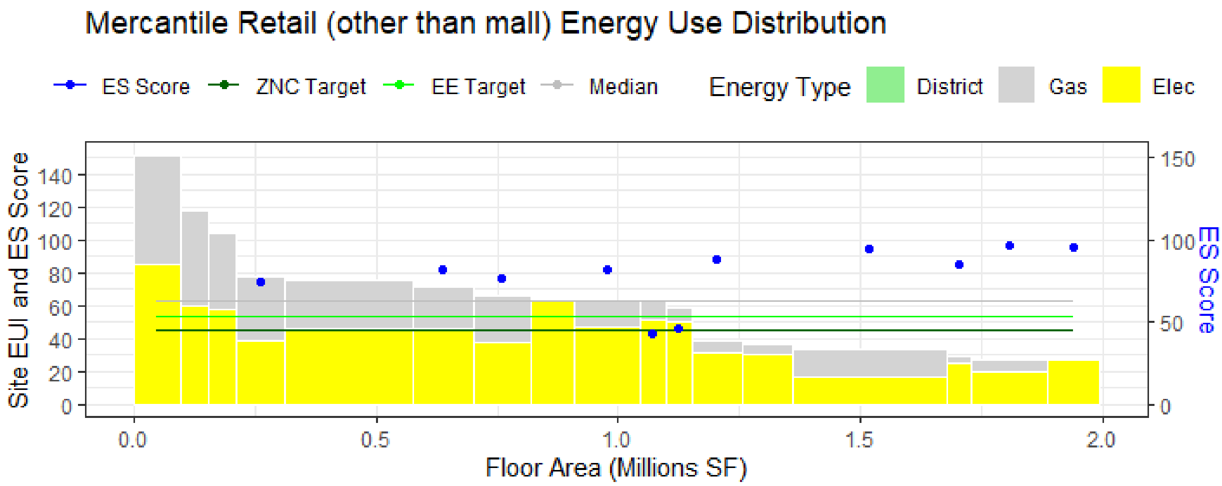

Figure 21: Energy Use Distribution of Mercantile Retail (other than malls) and Energy Star score, if applicable

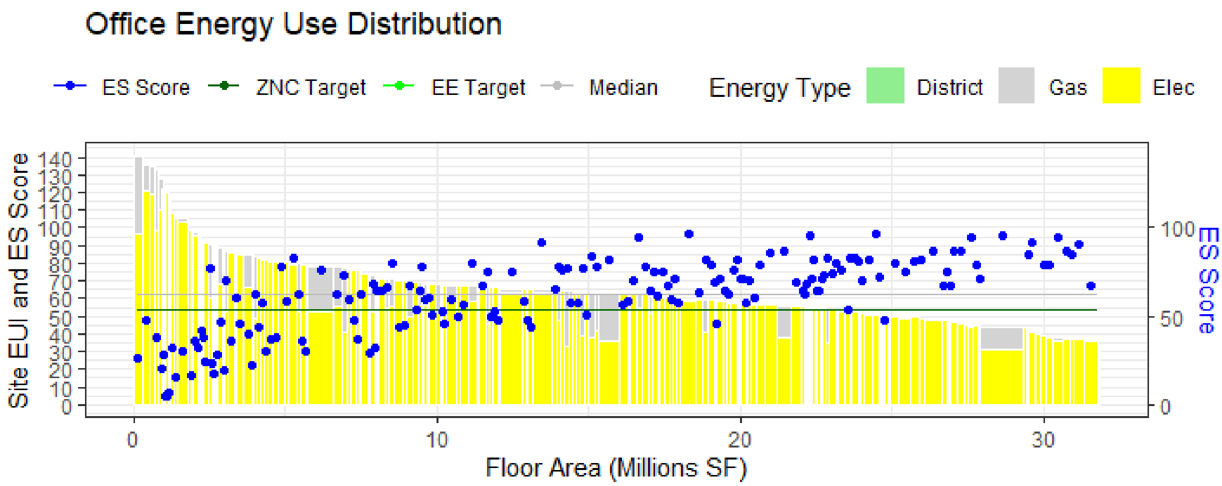

Figure 22: Energy Use Distribution of Office Space and Energy Star score, if applicable

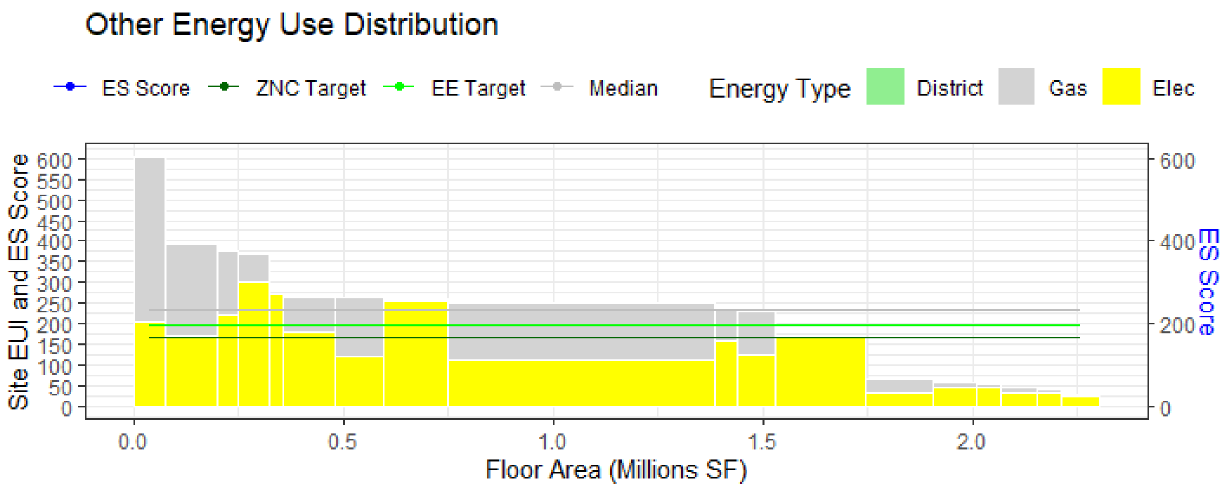

Figure 23: Energy Use Distribution of Other Spaces and Energy Star score, if applicable

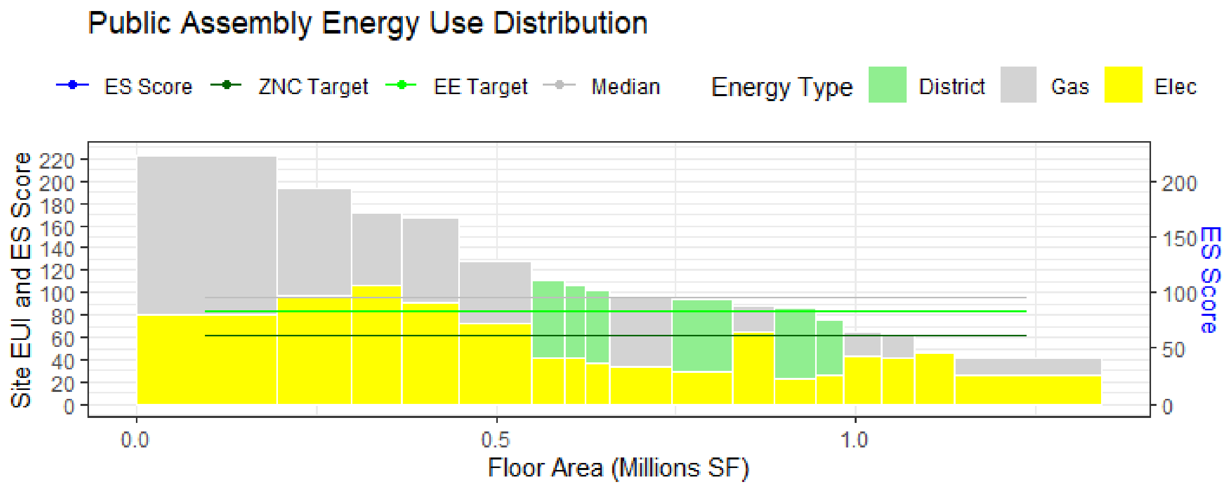

Figure 24: Energy Use Distribution of Public Assembly Facilities and Energy Star score, if applicable

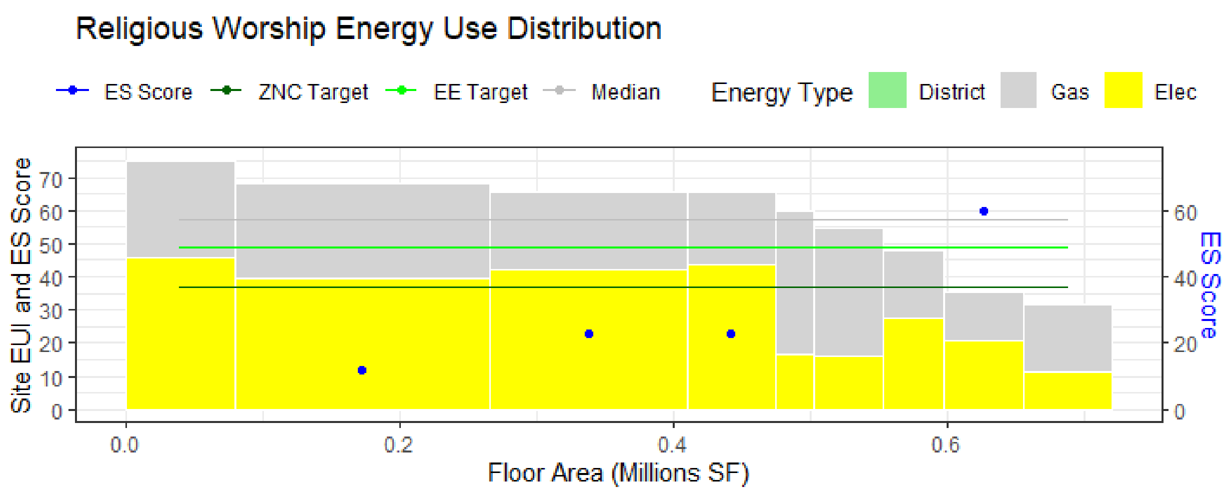

Figure 25: Energy Use Distribution of Religious Worship Facilities and Energy Star score, if applicable

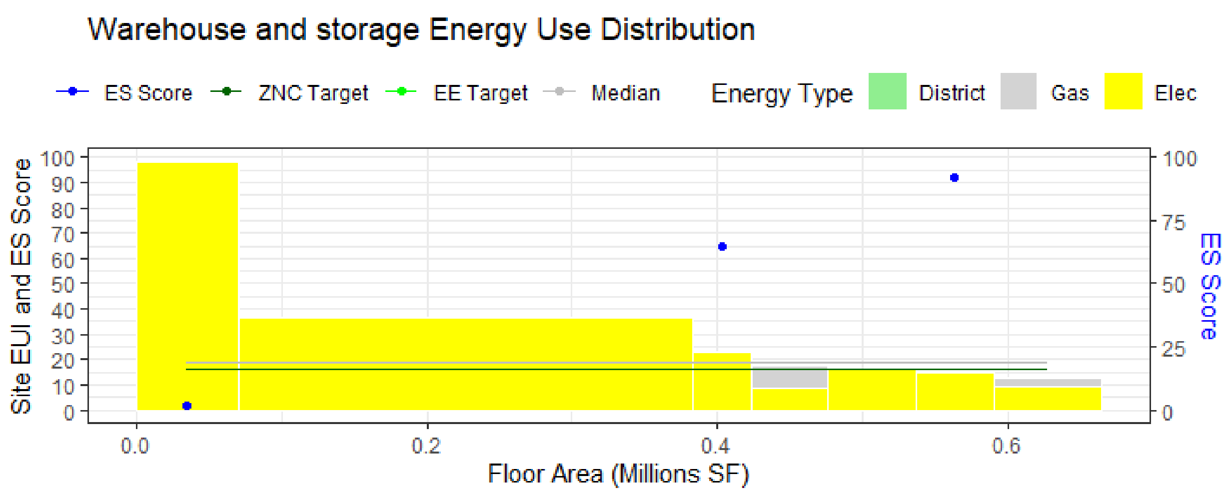

Figure 26: Energy Use Distribution of Warehouse and Storage Facilities and Energy Star score, if applicable

Details for Selected Typologies

Multifamily

For the policy impact model, the following process was used to identify multifamily buildings and categorize into the above sub-groups:

Determining height: if the parcel had a height value in the "NO_STORIES" value, then greater than 3 stories was classified as "Tall", and "Short" otherwise. If the height field was blank or zero, then the Land Use Code was referenced, with the Garden Apartments' codes 112, 113, 114, and 118 being "Short", and "Tall" otherwise.

Determining age: the parcel's YEAR_BUILT field was referenced. If before 1980, the tall buildings were classified as "Old", and "New" otherwise.

Multifamily buildings are grouped into three sub-groups:

- **MF-Short:** all ages, one to three stories: these buildings tend to have little or no interior common areas, no elevators, include garden complexes, and have little mixed use or amenity space in the building. They may also be built to residential code, which generally applies to buildings less than four stories.
- **MF-New-Tall:** post-1979 construction, greater than three stories: these buildings have interior common areas, typically have a provision for cooling (through wall A/Cs or central cooling), and amenity or mixed-use space at street level. As such, this group tends to have higher electricity use as a portion of the total. In addition, these buildings have lower heating loads through the use of more insulation and higher efficiency heating system layouts.
- **MF-Old-Tall:** pre-1980 construction, greater than three stories: these buildings have interior common areas, do not have a provision for cooling (using window A/Cs, some central cooling in very large buildings), and little amenity or mixed-use space at street level. In addition, this group has less insulating envelope materials and could use less efficient heating systems such as steam radiators.

These groupings may have distinct performance limits due to existing equipment and building layout. A single building performance standard for the entirety of multifamily buildings may be appropriate, as long as it considers the highest EUI threshold of these three groups. Potential energy standard targets are described in *Site Energy Use Intensity Performance Targets*.

Benchmarking Data from Washington, DC

While Montgomery County is not yet collecting enough multifamily building benchmarking information to create building performance targets, the analysis team referenced energy information from Washington, D.C. The DC area has similar buildings with energy use characteristics that can be mapped to the County's multifamily building stock. While the distribution of age and size may be different, a groupwise mapping may work by segmenting the DC building stock into subcategories with more homogenous characteristics.

SWA has collected benchmarking data from several regions: Montgomery County, Washington DC, Philadelphia, NYC, Los Angeles, and Seattle WA. Of these, Washington, DC is closest in location and likely best for filling in gaps in Montgomery County building energy information.

The charts below show multifamily buildings from Washington, DC, using 2019 benchmarking information. The population is split into three groups as described above according to typical construction methods, amenity spaces, and the resulting changes in energy signature.

Technical feasibility targets developed for this technical analysis

The median for the group is a straight line in light grey, the EE target is shown in bright green, and the ZNC target is shown in dark green.

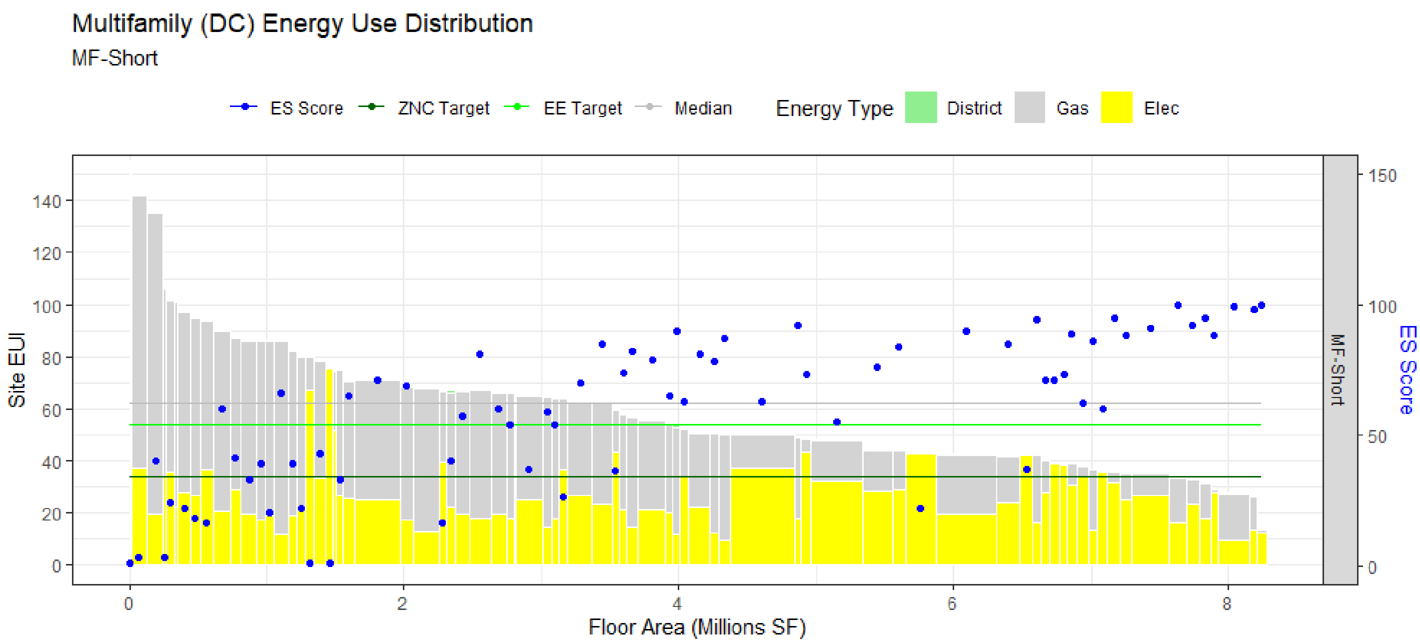

Figure 27. Energy use distribution for short (<4 stories) multifamily buildings in Washington, DC.

The MF-Short group shown in Figure 27 encompasses a reasonable estimate for garden style apartment complexes. While there are a few high electricity users, the majority of energy use comes from on-site fuel use in these building types. The higher energy users use more gas and less electricity, both in proportion and absolute terms.

The number of short MF buildings covered by the BEPS ordinance could vary significantly depending on the definition of covered bulidings.

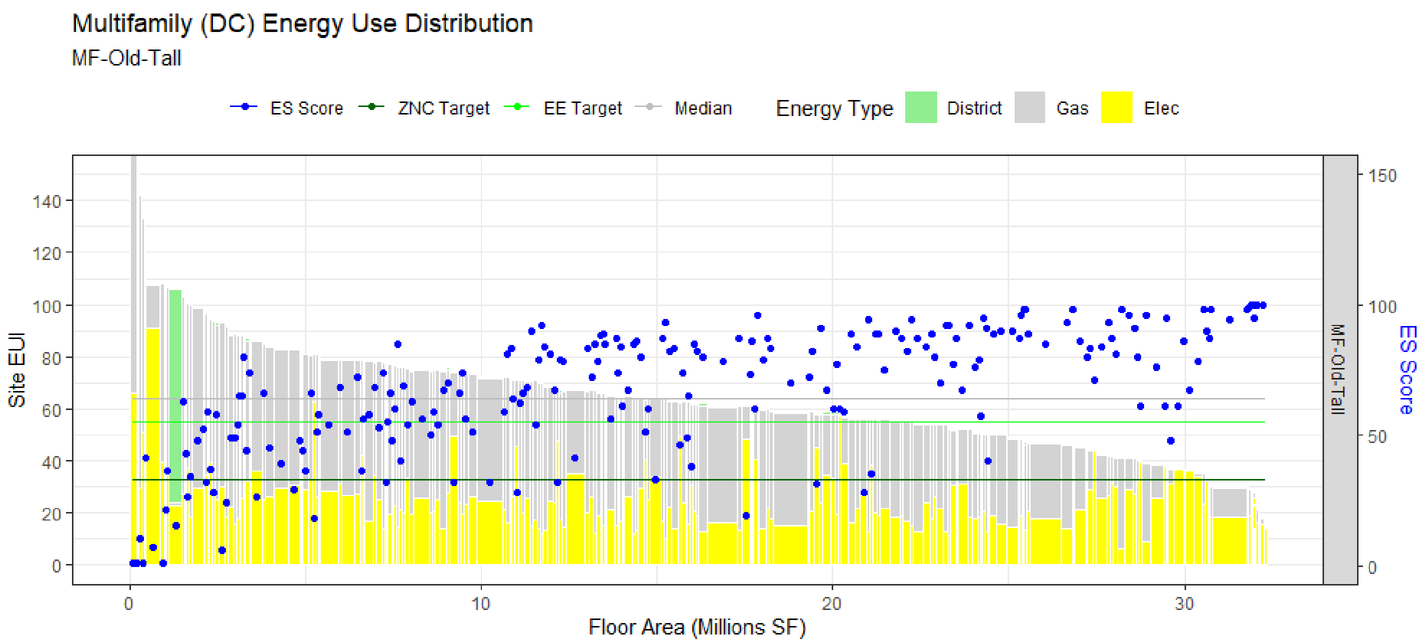

Figure 28. Energy use distribution for older tall (>3 stories, pre-1980 construction) multifamily buildings in Washington, DC.

The MF-Old-Tall group shown in Figure 28 is DC's largest group but Montgomery County's smallest multifamily group. Electricity and gas trends are similar to the MF-Short group.

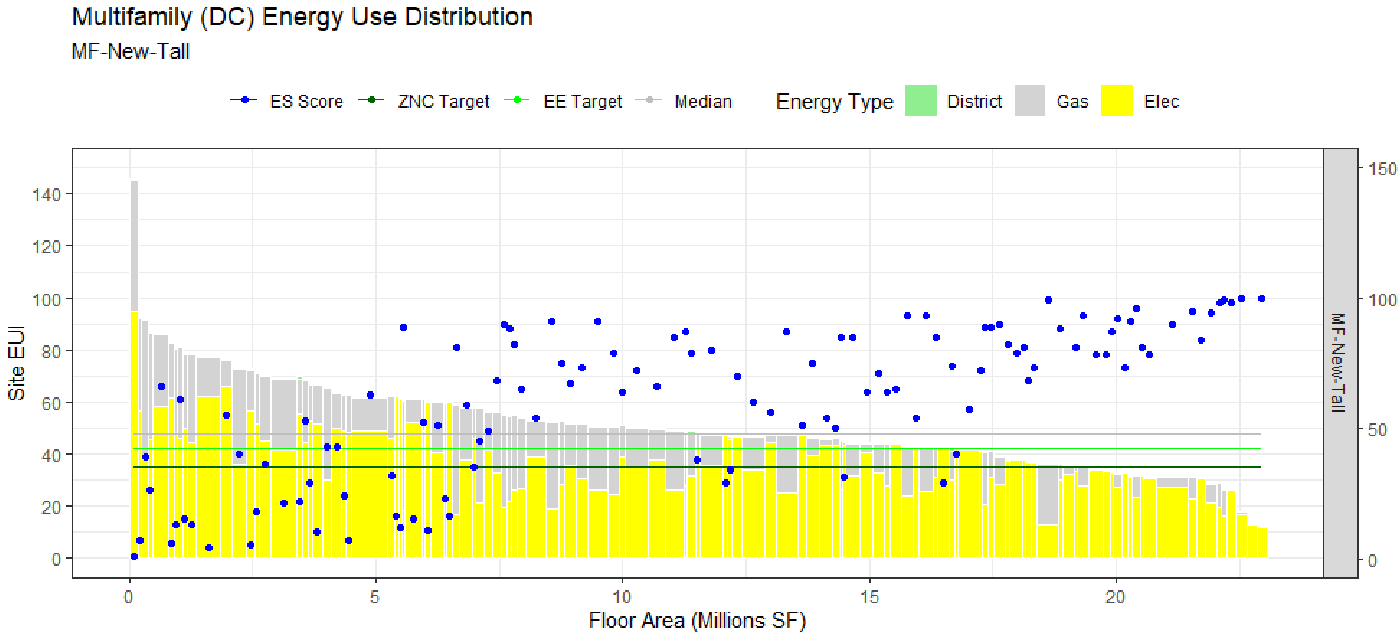

Figure 29. Energy use distribution for newer tall (>3 stories, post-1979 construction) multifamily buildings in Washington, DC.

The MF-New-Tall group shown in Figure 29 has a lower typical gas use and higher electricity use than the older and smaller multifamily groups. These buildings have more amenity spaces and more air conditioning. According to the CoStar data (see Figure 30 and *Appendix IX - Summary of Data Sources*), more than two thirds of this type is regulated affordable housing of some kind. While much of this building stock could have electric heating already, it may not be efficient heat pump heating.

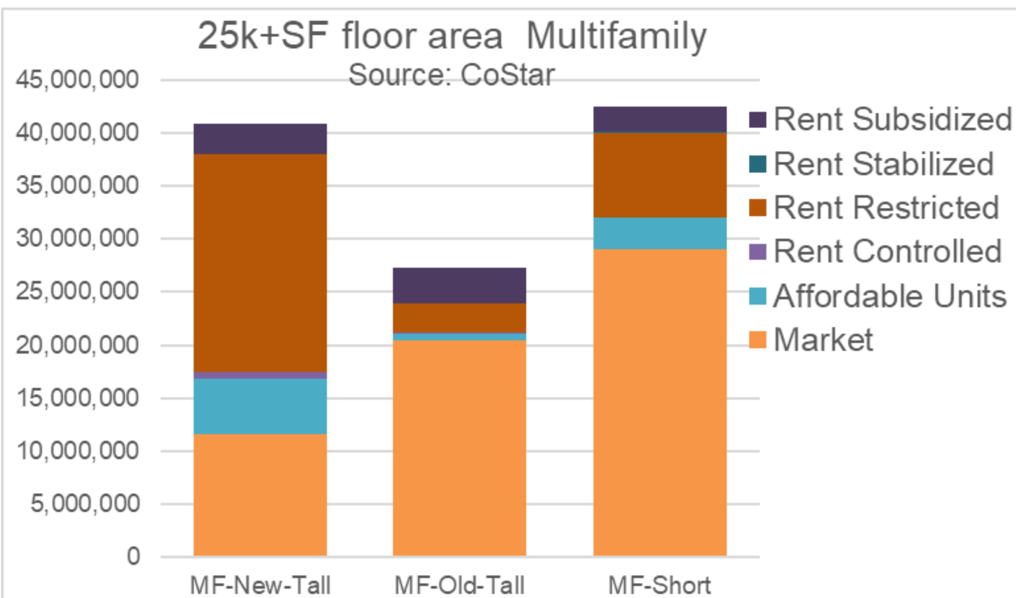

Figure 30. Montgomery County multifamily building population by subgroup and affordability status. Source: CoStar data provided by Montgomery County, accessed January 2021.

Office

From an EUI perspective, all office buildings fall within a relatively narrow range regardless of size or class. A single EUI target could work for this group. Moderate efficiency measures and electrification of the minimal gas use (makeup air space heating, mostly) would suffice to meet feasible targets.

Class A (n=103) and B (n=60) offices using CoStar[45] data matched to 2019 benchmarking data. The leftmost chart shows the buildings where a CoStar matchup based on Montgomery County Building ID (MBID, same as parcel number) or address could not be made. Center and right charts in Figure 31 on the following page show Class A and B, respectively. There are very few Class C buildings captured in this analysis. The median site EUI is nearly identical for the two groups (63 and 63.5 kBTU/SF, respectively). Current ENERGY STAR scores are shown as blue dots for each building. The Class B set has a higher tail of Site EUI than the Class A set. ENERGY STAR scores are lower for the worst-performing Class B buildings, even though they have more gas use.

As the proposed BEPS policy covers smaller buildings, more Class B-type buildings would be captured.

Based on this analysis, there is not a compelling reason to split office building targets by real estate class assignments. Targets can be set for the entire Office group, as defined by CBECS.

[45] CoStar is a "commercial real estate information company" subscription service providing access to a database of properties with characteristics relevant to the commercial real estate industry. The data was accessed by MC DEP in February 2021. www.costar.com

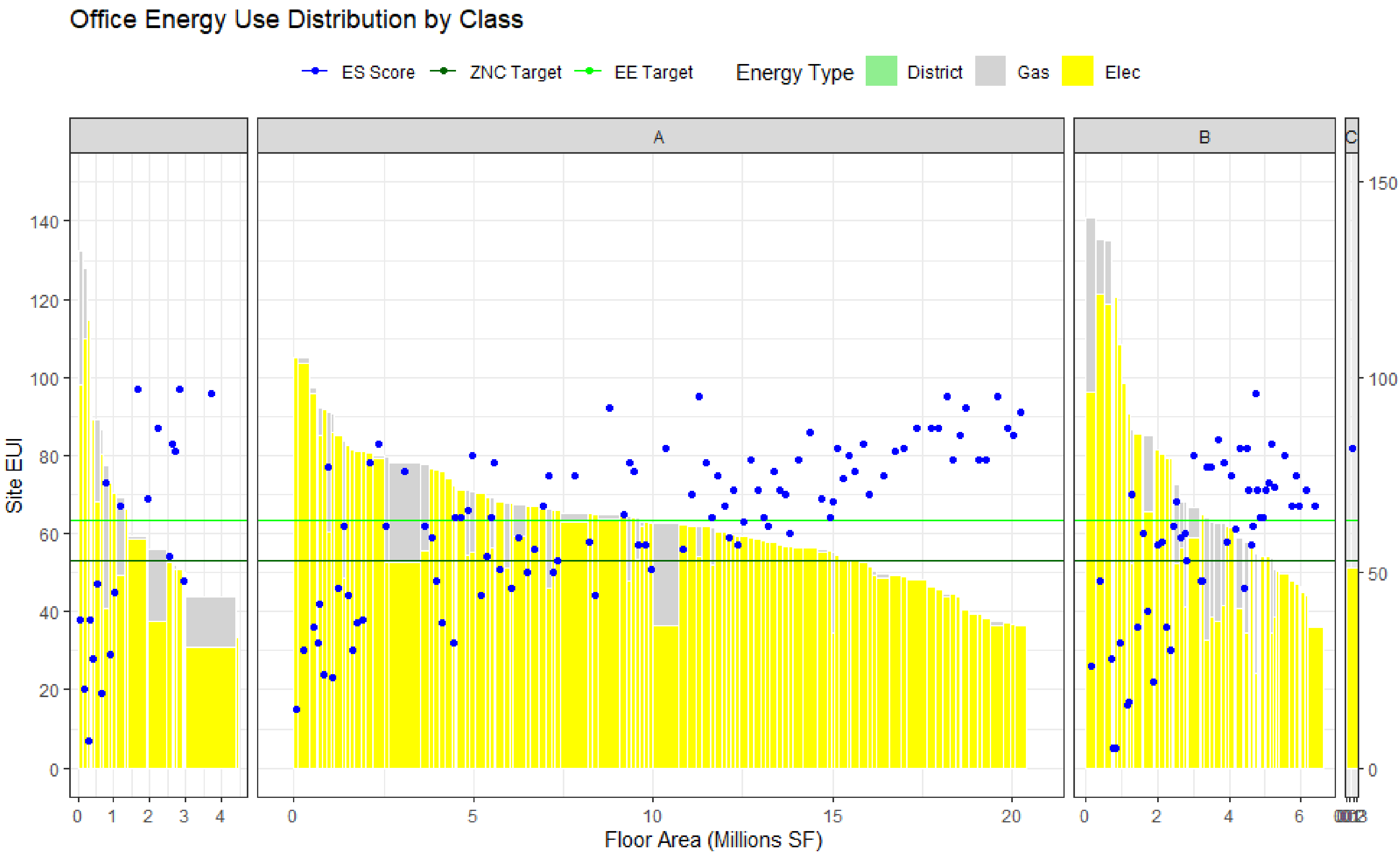

Figure 31. Office building energy use distributions, shown by real estate class. Left: unknown class, center: Class A, right: Class B. There was one Class C building identified in the database.

Retail – Various Types

Many mall (enclosed or strip mall) buildings that submitted benchmarking may not be covered in the future due to proposed building size and independent system definitions. The EUI range is large within the strip mall group. If covered, many buildings in these groups would need to electrify space and water heating to meet EUI targets.

There are four distinct occupancy types from an energy use and operations perspective. The majority of buildings use gas for a variety of end uses. For enclosed and strip malls, gas is used for multiple end uses (heat, water heating, cooking, process), while in retail it is more confined to space heating. For Food Sales, gas-fueled end uses are primarily cooking and space heating. Food Service, which includes restaurants, fast food, etc., is not represented in the MC Benchmarking data, since these buildings are mostly under 50,000 SF and often within malls and strip malls. The CBECS data has typical energy use for this type.

On the following page, Figure 32 shows the EUI profile of the three retail building types represented in the Montgomery County benchmarking data.

Compared to Offices, far fewer buildings are receiving ENERGY STAR scores, which aren't available for strip malls or restaurants or buildings with less than 75% of the space eligible for a score. This disqualifies most retail buildings except for standalone grocery stores or other retail, per EPA eligibility guidance.

Figure 33 shows a disaggregation of the Mercantile Enclosed and Strip Mall CBECS category into Strip Malls vs other malls. The "Not Strip Mall" category is more likely to be covered under the performance ordinance, while many of the "Strip Mall" types could be covered as smaller individual buildings, in which case they may fall more closely under Food Service, Food Sales, or Mercantile Retail. Still, there is considerable overlap between Strip Malls and Malls, as can be seen by how intertwined these two groups are when sorted for site EUI.

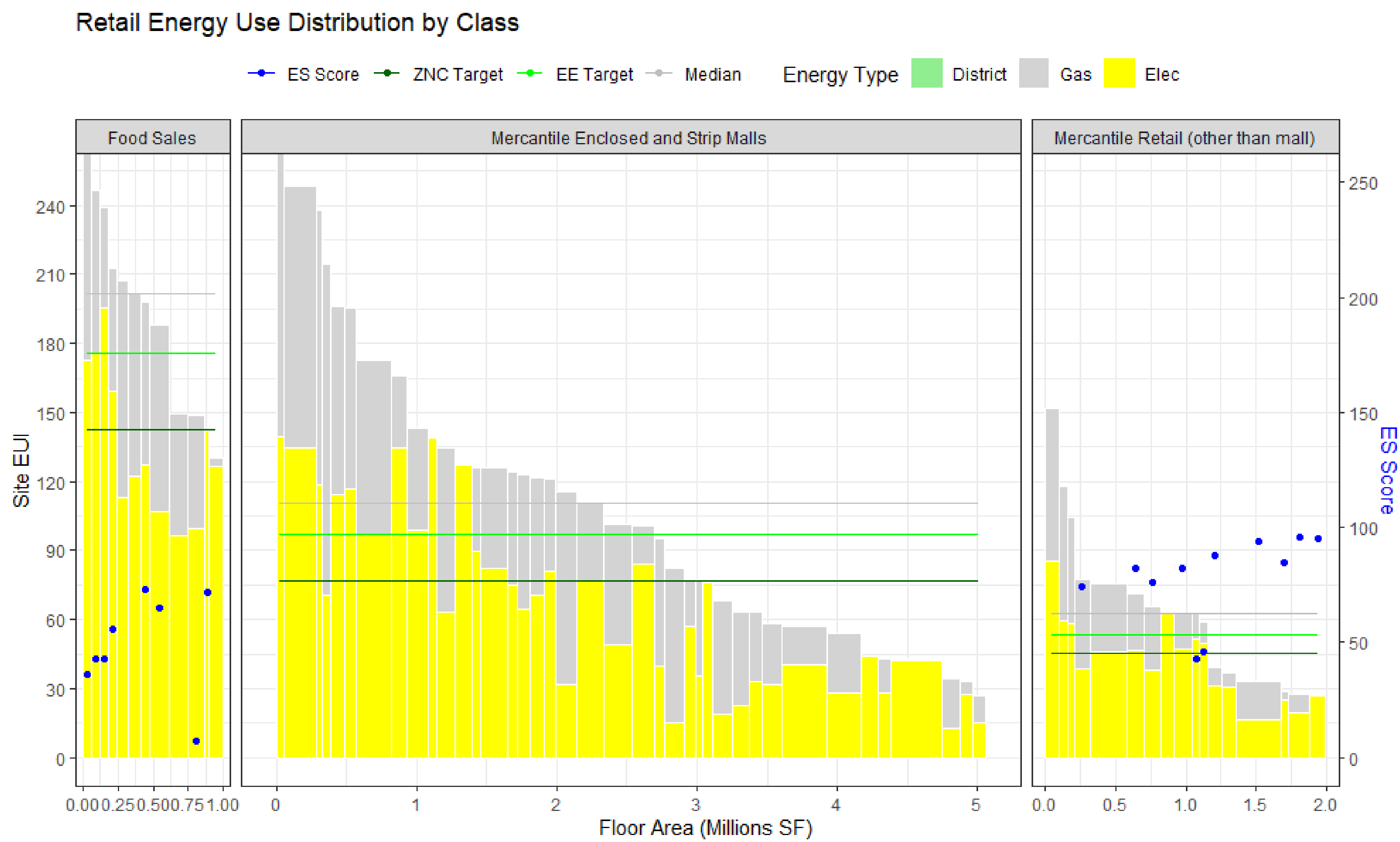

Figure 32. Mercantile building types energy use distributions.

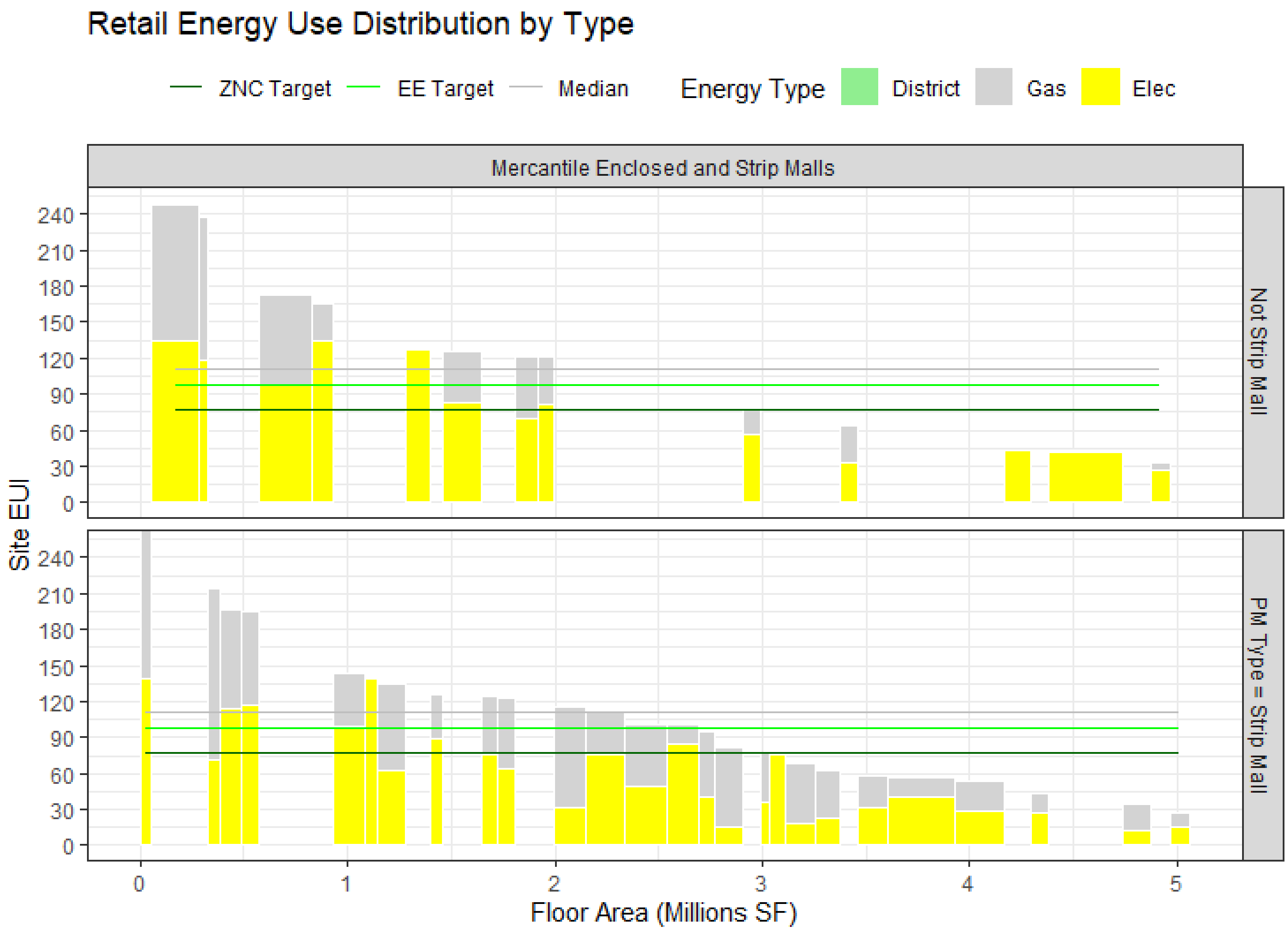

Figure 33. Mercantile Enclosed and Strip Mall category broken out to show enclosed malls and strip malls separately.

Health Care

Inpatient and outpatient health care facilities are different from one another, warranting different targets. The retrofit timeline for inpatient health care needs to consider redundancy requirements for continuous operation. Fossil-fuel on-site generation for emergency backup is a serious consideration for these buildings, often a code requirement, which may drive gas use up if used continuously for on-site electricity generation.

There is a clear difference between inpatient (hospitals) and outpatient health care facilities. The EUI of the few hospitals is fairly consistent and shows significant gas use across all submissions. Electrification technology is likely available for all end uses in a hospital, where most gas use is for space and water heating. However, some processes may be more difficult, such as steam humidification and high-temperature sanitization. Space conditioning efficiency through energy recovery ventilation can help most building types but may be limited for health care as exhausting potential pathogens without contaminating incoming air is a greater concern.

Outpatient health care facilities have a lower total EUI compared to inpatient care and more electricity driven energy use profile, with relatively minimal gas consumption coming again from space and water heating equipment. There is more diversity in energy use across buildings in this group. The total EUI is completely driven by electricity use for this group, which is likely dependent on medical equipment, and it may be difficult to improve the efficiency of such equipment.

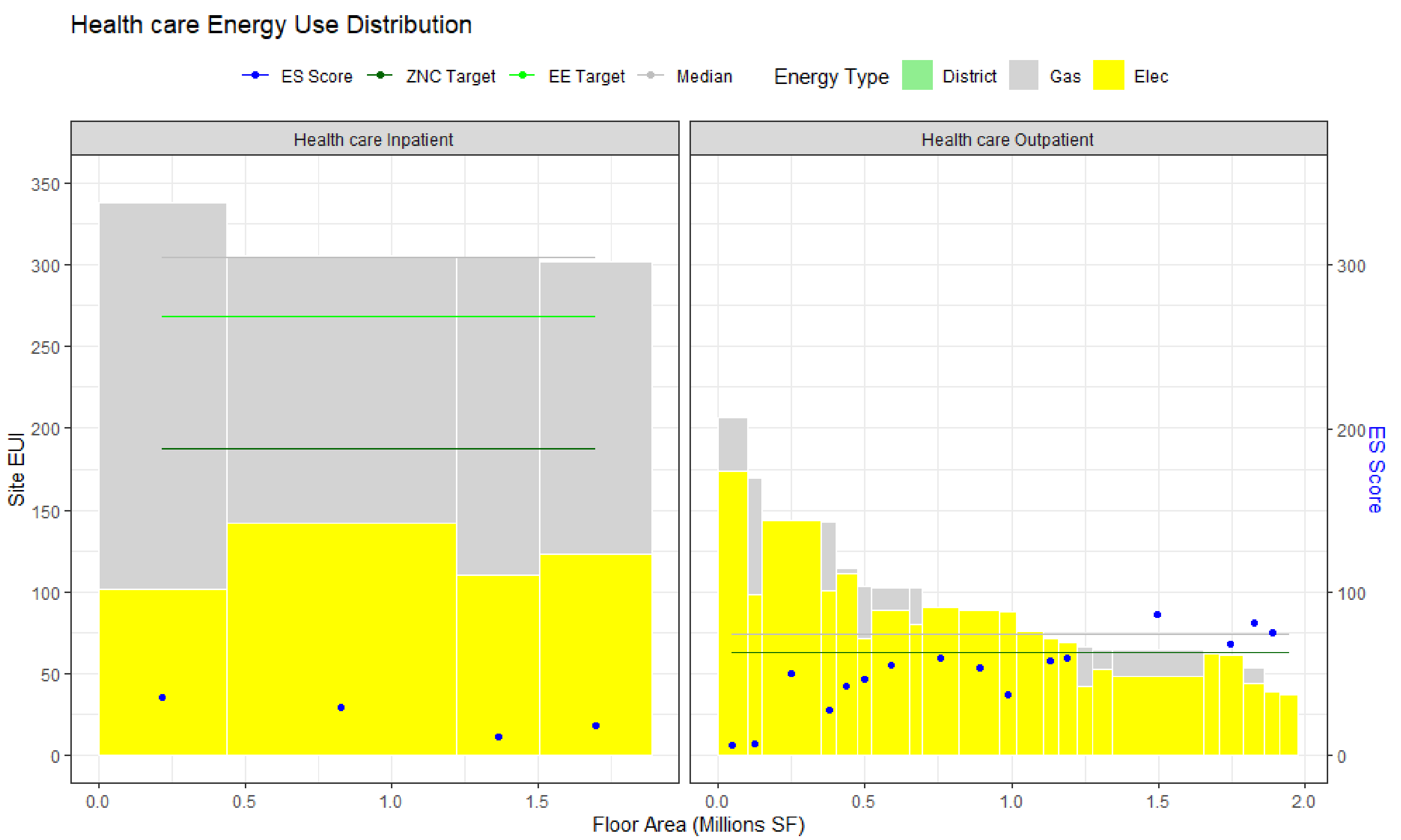

Figure 34. Health care building type energy use distributions.

APPENDIX III - BEPS POLICY MODEL METHODOLOGY

The impact of various energy performance standards was modeled using an Excel workbook that uses the covered building list and calculates the energy and energy cost. This section provides the calculation steps and assumptions made to approximate the impact at the occupancy type and countywide scale.

Creating the Model Covered Buildings List

The list of covered buildings for the policy impact model was developed by the analysis team. Using a combination of Maryland State Department of Assessments and Taxation (SDAT) property records and geographic information system (GIS) data[46], the floor area and covered buildings were identified using the size thresholds and buildings definition in the proposed BEPS policy through the following steps:

1. Documented the number of buildings located on each parcel, using the GIS data set.
2. Matched building location with a parcel to pull all associated parcel info for the building to get all related attributes about the parcel.
3. If there was one building on the parcel:
    a. Used the property tax data field for gross floor area "GR_FLR_AREA" if available.
    b. For multifamily buildings:
        i. If GR_FLR_AREA was zero, then property tax data field residential floor area "SQFT_RESID" was used.
        ii. If that was zero, then the number of residential dwelling units "RES_DWELLU" was multiplied by the median floor area per land use code from parcels with both area and unit count.
4. If there was more than one building on a given parcel:
    a. Used the GIS-calculated footprint shape area multiplied by the number of floors on parcel in tax data. If floor count was not available, the building was reviewed manually for number of floors.
    b. All buildings were assigned the same land use code for the parcel (for occupancy type assignment).
5. For commercial properties that have submitted benchmarking data to Montgomery County for calendar year 2019, used the primary occupancy type and floor area from the benchmarking submission.
6. Compared the floor area calculation for each building to the 25,000 SF threshold in the proposed BEPS policy.

Data Sources and Targets

('MoCo Com EUI Map' tab)

- Parcels were assigned a building occupancy type using submitted benchmarking data, or Land Use code if benchmarking data was not available.
    - Building type and floor area from benchmark data supersedes Land Use code
- Used benchmark data for each building where 2019 MC benchmarking data are available
    - Benchmarking energy use and primary space type was used when that building's submission:
        - Had passed Portfolio Manager data quality checks (if they were run)
        - Was not flagged for outlier energy data (See *Explanation of Cleaning Flags*)
        - Could be mapped to the SDAT parcel information by MBID or street address
- If benchmarking data was not used for a given building:
    - The parcel was assigned a random number 1-10, corresponding to a decile of the energy distribution of the parcels' occupancy type (e.g., Office, Mercantile Retail). Using benchmarked buildings energy distributions, that decile was used to look up a gas and electricity EUI based for that building group. Deciles were uniformly distributed across parcels within a group.

[46] Compiled and provided by MC DEP for this technical analysis

Sensitivity testing of this method indicates that the randomness introduces total (countywide) error of +/-3% of electricity and +/-2% for natural gas use.
    - Parcels were flagged as "estimated".
    - For non-residential building groups, energy distributions were taken from MC benchmarking data on the tab "MoCoprofile".
    - For multifamily residential groups, energy distributions were taken from DC benchmarking data on the tab "DCMFprofile".
- Used DC energy profiles for Multifamily – this can be updated with MC benchmarking data when available
- Each parcel was assigned a single use type. In the proposed BEPS policy, each building could have a mix of space types that would result in an area-weighted whole building target. This analysis lacked non-primary space use types, as these were not available when using the parcels' Land Use codes.
- Parcels were divided into BEPS groups per the proposed BEPS policy (input was a column on the 'RetrofitModelCalcs' tab). Groups had different timing for interim and final performance standards according to the Proposed BEPS policy text.
- Targets were a variable affecting all groups – in the model, the target type could be a percentile target (e.g., all buildings must reduce to the 25th Percentile site EUI of the group) or the CNCA targets (ZNC and EE, or the midpoint between EE and ZNC)
    - Available targets were:
        - Average Site EUI
        - 10th PCT Site EUI
        - 25th PCT Site EUI
        - 50th PCT Site EUI
        - 75th PCT Site EUI
        - 90th PCT Site EUI
        - EE
        - EE-ZNC midpoint
        - ZNC
- One target type was set for all groups on the 'Front Page -Inputs and Outputs' tab
- One final year target, two interim targets were linearly interpolated between starting EUI and final year target
- Model start year of 2021: this is not the start of benchmarking, it was the first year of energy reporting and other calculations.
- Model final year of 2039: Cumulative calculations were for the period 2021-2039.

Parcel Level Simulated Retrofits to Meet Targets

('Retrofit model calcs' tab)

- In this model, energy use did not change if the building was below a target at a given compliance cycle, or if there wasn't a compliance cycle deadline in that year.
- Energy use was reduced in the two-year period before each target deadline, since retrofits were assumed to happen to meet each performance standard in the period immediately before the standard's monitoring year, meaning that all work was done in the two years before the monitoring year. While some buildings might do work more in advance, that was not captured in this model.
- Conversely, some buildings would not meet an interim standard but would catch up with more work by the next standard date. This variation in timing was not captured in the model.
- This was the retrofit roadmap assumption for each building at each compliance cycle:
    - Each building's gas and electricity EUI are compared to the appropriate occupancy type's "Energy Efficiency" threshold gas and electricity EUI
        - Note: "gas" in this case refers to any on-site combustion (e.g., gas, oil, propane).

- Electricity Energy Efficiency: If electricity EUI was greater than the electricity component of the EE target (elecEE), reduced electricity by 1/3 toward the EE target in each cycle. Justification for this assumption:
    - Electric equipment can be highly distributed throughout a building and may take more time to comprehensively address. The max reduction per cycle assumption spreads out electric equipment retrofits so that large reductions are not happening all at once. Large reductions in electricity use may be more disruptive to occupants. Gradual changes in electricity use are likely more tenable to owners who want to keep occupants happy.
    - Occupancy type specific capital costs are applied for electricity energy efficiency work based on commercial, residential, or hospitality spaces. Costs per energy unit are based on prior cost-benefit work for Washington, D.C.
- Gas Energy Efficiency: If gas EUI was greater than the gas component of the EE target (gas_EE), reduce gas (without electrification) to as far as the gas_EE threshold. This can happen in a single compliance cycle if necessary to meet the standard (in addition to any electricity energy efficiency upgrades). Justification for this assumption:
    - Most gas equipment is centralized and can be addressed as needed, so comprehensive energy efficiency projects can be undertaken over a few years.
    - Occupancy type specific capital costs are applied for gas energy efficiency work based on the estimated dominant gas end uses in the building, and the actual energy use reduction.
- If more reduction was needed, electrify gas end uses to meet target. Electricity increased with reduced gas use based on assumed end use proportions of different building types and electrification conversion efficiencies.
    - Electrification is mostly happening in the second and third compliance cycles, after buildings have completed energy efficiency work
    - Occupancy type specific capital costs are applied for gas electrification based on the estimated dominant gas end uses in the building after gas energy efficiency work.

Converting to GHG and Cost

('Cohort time model calcs' tab)

- Building energy use and changes for each interim and final target were added up by fuel for a total per occupancy type (e.g., total gas for Office and total electricity for Office at start, and each performance standard date)
- For each year, GHGyear = elecBTUyear*elecGHGIyear + gasBTUyear*gasGHGIyear
- For no policy scenario, GHGyear= elecBTU2021*elecGHGIyear + gasBTU2021*gasGHGIyear, meaning that BTUs are held constant at 2021 but the GHG for each energy type changes to be the projected GHGI for that year.
- Energy - GHG coefficients for the starting year were based on the 2018 MC GHG Inventory
- Cost rates are the same as used in the case study calculations.
    - $0.129 / kWh for electricity
    - $1.228 / therm for natural gas
- Energy costs can increase or decrease over time. The results in this report assumed constant energy rates. If energy costs were to change annually, the total energy costs would change according to Table 20.

Table 20. The sensitivity of total energy costs to changes in the electricity rate or gas rate.

Total energy cost change over study period based on possible rate changes		Gas rate change per year		
		-2% / year	No change (0%)	+2% / year
Electricity rate change per year	-2% / year	-13%	-4%	5%
	No change (0%)	-9%	0%	10%
	+2% / year	-4%	5%	15%

Calculation Steps for a Sample Building

('Retrofit model calcs' tab):

1) Example building: Office building (100% of the floor area is office for this example)
   a. Elec EUI: 65.8 kBTU/SF
   b. Gas EUI: 19.2 kBTU/SF
   c. Site EUI: 85 kBTU/SF
   d. Floor Area: 270,000 SF
2) Building Final Performance Standard was assigned by occupancy type. The ZNC target was used for this example:
   a. Office ZNC Target: 53.4 kBTU/SF Site EUI
3) Interim Performance Standard Targets 1 and 2 were calculated as 1/3 and 2/3 between current site EUI and final standard
   a. Interim Performance Standard 1: 74.5 kBTU/SF
   b. Interim Performance Standard 2: 64 kBTU/SF
4) Electrification site EUI ratio was calculated per occupancy type using this calculation, which is the weighted average of the electrification ratios for each end use in the building, weighted by the estimated energy use of each end use for the occupancy type[47]:
   a. (ZNC elec EUI – elec_EE EUI) / gas_EE EUI)
   b. =53.4-53.1 / 0.3 = 0.89
5) The building's gas EUI and electricity EUI were both higher than the Energy Efficiency thresholds, so energy efficiency work is modeled to be done to meet the target.
6) For Interim Performance Standard 1:
   a. Electricity use was reduced by 3.5 kBTU/SF through energy efficiency.
      i. The building was able to reduce electricity use by 1/3 of the way toward reaching the EE threshold, but there was gas EE work that could also be done, so some electricity work took place.
   b. Gas use was reduced by 7 kBTU/SF through energy efficiency.
      i. The building was able to reduce gas use to make up the rest of the way to the target without going below the gas EE threshold
   c. Resulting EUI was 85 – 7 – 3.5 = 74.5 kBTU/SF and the building met the Interim Performance Standard 1 standard.
   d. Using the occupancy type specific capital costs for different end uses on a $/kBTU savings basis, costs to meet each target are estimated as:
      i. 3.5kBTU/SF of electricity energy efficiency work * $0.30/kBTU = $1.05/SF = $280,000
      ii. 7kBTU/SF of gas energy efficiency work * $0.64/kBTU = $4.54/SF = $1,230,000
7) For Interim Performance Standard 2, repeated step 6 using the Interim Performance Standard 1 result as the new baseline energy use

[47] Elec_EE EUI and gas_EE EUI are the electricity and gas components of the EE target, as calculated in the CNCA tool. These EUIs are used to compare an individual building's electricity and gas use to the assumed optimal efficiency EUI in each energy type. Achieving a gas EUI lower than the gas_EE EUI in a building would likely require some form of electrification.

8) For Final Performance Standard, repeated step 6 using the Interim Performance Standard 2 result as the new baseline energy use
9) Electricity and gas EUI were multiplied by floor area to do countywide impact calculations in kBTU

Summarizing for Typologies and County

('Cohort time model calcs' tab)

Energy use

1) Energy use was summed by BEPS group (1 through 5).
2) Summed up electricity use by occupancy type in a column, gas use by occupancy type in another column.
3) Did the same for Interim and Final Performance Standard.
4) Assigned the year of the Interim and Final Performance Standards for each occupancy type.
5) The model is done in odd years instead of annually to halve the number of calculations necessary.
6) Every two years from 2021 to 2039, energy use for each occupancy type wouldn't change until a target year is passed. After that target year, the total BTU changes to the modeled post-retrofit number.
    a. Example: Office electricity use in 2021 is 4,368 Billion BTU (BBTU)
    b. Interim Performance Standard 1 is 2027, so office electricity use was 4,368 BBTU in 2021, 2023, and 2025. In 2027 it changed to 4,201 BBTU as the new sum of all the Office buildings at Interim Performance Standard 1.
7) Gas calculations were done the same way. Gas use for offices was 512 BBTU in 2021, 2023, 2025. In 2027 it changed to 290 BBTU once Interim Performance Standard 1 date was passed.
8) After the Final Performance Standard was reached, energy use stayed constant for occupancy type and energy type.

GHG

1) GHG for each occupancy type was calculated by multiplying elec BTU * elec GHGI and gas BTU*gasGHGI
2) Gas GHGI was constant, meaning that gas won't have lower emissions intensity in the future.
3) Elec GHGI started at the value used in the GHG inventory (this is a customizable variable in the tool) and decreased linearly toward the carbon-free value by the year given in the user input (2035 to align with the clean electricity supply plans in the CAP).

Cumulative GHG

1) At each year, the total GHG from all typologies is added up for the countywide total with the policy
2) To estimate business as usual buildings with an improving grid, the starting year total BTU is multiplied by the GHGI for gas and electricity as it changes year to year.
3) Cumulative GHG adds up all BAU years' GHG and subtracts all Policy model years' GHG
    a. Multiply by two since the analysis is only done on odd years

A basic capital cost assumption was assigned to each energy end use to model the cost of energy efficiency and electrification. Table 21 shows the cost assumptions used in the model.

Table 21. Capital cost assumptions for gas and electricity end uses.

Policy Model Capital Cost Assumptions [$/kBTU of affected energy use]	Space heating	Water heating	Cooking	Other
Gas efficiency: cost for gas system optimization[48]	$0.18	$0.18	$0.76	$0.64
Gas electrification: cost for electrifying gas systems[49]	$1.03	$0.23	$0.72	$0.60

	Multifamily	Office	Lodging
Electricity efficiency: average cost for various electricity efficiency measures[50]	$0.25	$0.30	$0.11

The above assumptions are applied to each building in the model to arrive at total capital costs for retrofits. As an example of the results, Table 22 on the following page shows the costs of meeting the ZNC target for the median energy user in each building type. These costs were developed with many large assumptions around estimated energy end use breakdowns (e.g. how much gas is used for heating vs water heating or laundry) in all buildings, scalability of costs, and owner retrofit decisions as described above.

[48] Gas energy efficiency costs are sourced from SWA implementation work for measures such as system balancing, thermostats, air sealing, and low flow water fixtures. Cooking and laundry costs come from one-time appliance upgrade costs.
[49] Gas electrification costs are sourced from the CNCA tool, 'Electrification of Gas End Uses' tab.
[50] Electricity energy efficiency costs are sourced from case study work done in Washington DC in 2020 and 2021.

Table 22. Capital Costs for Median Buildings in Each Occupancy Group, used in the countywide policy impact model. The values in Table 17 are multiplied by the end use energy intensity of each building type to arrive at these estimates.

	Gas EE	Gas Electrification	Electric Efficiency
Building / Occupancy Type	$/Gas_kBTU	$/Gas_kBTU	$/Elec_kBTU
MF-New-Tall	$0.25	$0.29	$0.25
MF-Old-Tall	$0.22	$0.58	$0.25
MF-Short	$0.23	$0.56	$0.25
Higher Education	$0.30	$0.75	$0.30
Food sales	$0.48	$0.81	$0.30
Food service	$0.57	$0.65	$0.30
Health care Inpatient	$0.36	$0.67	$0.30
Health care Outpatient	$0.18	$0.23	$0.30
Lodging	$0.25	$0.45	$0.11
Mercantile Enclosed and strip malls	$0.42	$0.65	$0.30
Mercantile Retail (other than mall)	$0.35	$0.84	$0.30
Office	$0.64	$0.60	$0.30
Other	$0.18	$0.97	$0.30
Public assembly	$0.35	$0.86	$0.30
Public order and safety	$0.23	$0.58	$0.30
Religious worship	$0.34	$0.95	$0.30
Service	$0.18	$0.70	$0.30
Warehouse and storage	$0.51	$0.49	$0.30
Vacant	$0.18	$0.92	$0.30
Education – K-12 School	$0.30	$0.75	$0.04

APPENDIX IV – IMPACT OF TRAJECTORY TARGETS

This technical analysis included a brief discussion of how interim targets can be set for each building. The information below documents that discussion with preliminary modeling information using the ZNC threshold as the final year target. While some parts of the modeling methodology changed since this discussion, the considerations discussed remain valid.

- Trajectory Model
  i. Cycle 1 of 3: site energy use is lowered by 1/3 of the amount between 2019 and the final performance standard
  ii. Cycle 2 of 3: site energy use is lowered by 2/3 of the amount between 2019 and the final performance standard
  iii. Cycle 3 of 3: site energy use is lowered to the final performance standard
- Threshold Model
  iv. Cycle 1 of 3: site energy use is lowered to the 75th percentile (variable) for the group. For buildings below the threshold, no action is needed
  v. Cycle 2 of 3: site energy use is lowered to the 50th percentile (variable) for the group. For buildings below the threshold, no action is needed
  vi. Cycle 3 of 3: site energy use is lowered to the final performance standard

The following charts show examples – using an earlier version of the covered buildings list – of the start, interim and the final performance standard. The first chart is for the whole county of covered buildings. The second is for all “Mercantile Retail (other than mall)”. The third is for “MF-New-Tall” subject to a common multifamily target. Across all three, the number of buildings affected by the trajectory model is the same for each compliance cycle (2027, 2031, 2035, for example), while the threshold model has fewer buildings in the earlier compliance cycles as the buildings below the thresholds do not need to perform retrofits.

Using this earlier building count, approximately 22% of parcels countywide (1353 – 1054 = 299 parcels) would not need to take action to meet their respective final performance standard. These buildings already have a site EUI below the final performance standard for their group.

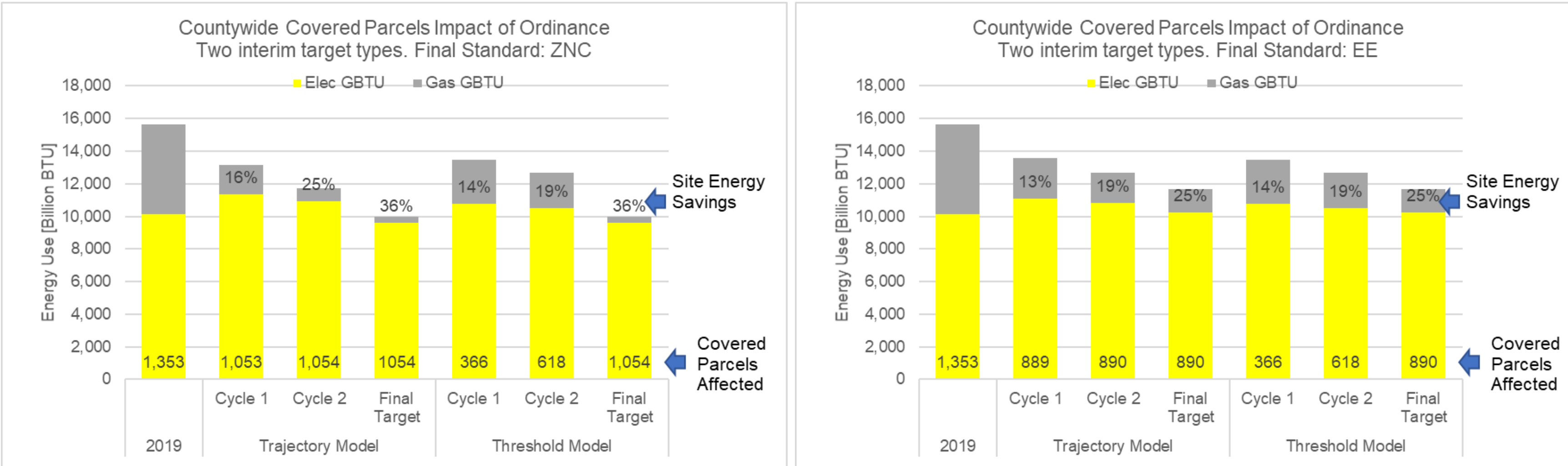

Figure 35. Countywide impact of standards set to two different final year targets: ZNC (left) and EE (right)

APPENDIX V – BUILDING COST – BENEFIT CASE STUDY DETAILS

To test the viability of the targets, the analysis team chose nine building examples in Montgomery County and developed multiple retrofit packages. Each building was assigned a target using the proposed methodology, and a package of energy-reducing measures was created. The technical viability and economics of reaching the targets confirmed that, at least for the types of buildings exemplified in this technical analysis, the targets are reachable. High-level findings are contained in the "Building Cost-Benefit Case Study" section of this report.

Methodology

Selection of Case Study Buildings

The analysis team reviewed proposed covered building types in *Appendix I - Recommendations for Building Groups* and *Appendix II - Montgomery County Energy Use Distributions Overview* to identify typologies with common characteristics and a variety of starting points (mechanical systems, space use type and building layout). Common building types include:

- Commercial offices
- Multifamily buildings
- Lodging: hotels and other hospitality
- Mixed use spaces
- Retail

Because of the prevalence and diversity of office, multifamily, and hospitality buildings, the team evaluated multiple buildings within each typology. Offices were further divided into newer, class-A type offices, older mixed-fuel offices (i.e., office spaces that use both electricity and natural gas), and older all-electric offices. Multifamily buildings were further divided into newer, high-rise mixed-use buildings, older high-rise affordable housing buildings, and garden-style multifamily buildings.

Other spaces considered include different types of lodging with or without a significant amount of amenities, and a multi-function building that serves multiple end uses—for example, a building with both worship and school space.

The team reached out to many building owners seeking participants for this technical analysis and to conduct interviews. Only respondent buildings are included in the technical analysis, which limits building inclusion and eliminated the retail group, which had no respondents able to participate in the case study exercise.

Building Desktop Audits

Case studies were developed through interviews with building managers and site staff to collect – for major equipment only – equipment type, equipment age, operating parameters, types of fuel used for various end uses, information on recent capital upgrades, and any comments on plans for future upgrades and decision-making processes in relation to energy management. Architectural and mechanical drawings and supporting documentation were reviewed when available.

Desktop audits were performed to develop the case studies contained in this report. Desktop audits use information provided from building owners and operators to develop recommendations, but do not contain any onsite observations. This methodology is effective for informing policy-level decisions as it can effectively capture broad-stroke approaches; however, this methodology does not tend to capture measures are more limited in impact (e.g., mechanical systems that only serve part of the building). Applicability of desktop audit measures to a specific building typically requires some amount of onsite investigation in order to determine applicability of measures for any specific building in a given typology. This technical analysis is limited to desktop audits and measure recommendations are limited to what could be recommended based on the data collected by the auditor.

Where possible, supplemental energy audit information performed by others is incorporated into the case studies. These energy audits, which may contain onsite observations, were completed prior to this desktop audit process.

Building Descriptions

Square Footage Calculations

Square footage figures are presented to comply with ENERGY STAR Portfolio Manager guidance. In some cases, the square footage breakdown or totals may differ from 2019 benchmarking data reported to the County. In these cases, the reported figures were adjusted in conjunction with the building representatives to follow Portfolio Manager guidance on benchmarking space use types.

Portfolio Manager Property Type Breakdowns / Guidance

To determine the appropriate site EUI target for each building, individual space use types and square footages needed to be identified. Targets for a total site use a blended site EUI target for each primary space type as a weighted average based on the square footage of each space. The methodology used in this technical analysis follows the Montgomery County benchmarking methodology which in turn relies on Portfolio Manager guidance. See *Appendix XI – Space Type Definition Guidance from EPA Portfolio Manager* for detail on how occupancy types were defined in this technical analysis.

Building System Information

Key building mechanical systems and envelope information were inventoried for each building. Equipment age from interviews, nameplate data, or building drawings is included where available.

End of Useful Life Assumptions

End of Useful Life (EUL) assumptions are included for major equipment. Estimates are derived from the *ASHRAE Equipment Life Expectancy Chart* and the *BOMA Preventative Maintenance Guidebook.*

EUL is the point at which it is no longer economically or physically feasible to continue the use of a piece of equipment or a system. Equipment upgrades are most cost effective at the EUL. Replacement of equipment prior to the end of its useful life will mean incurring replacement costs when existing equipment can still serve the building.

Since system replacement is part of the cost of operating a building, only the difference between in-kind-replacement equipment and an energy efficient upgrade (known as the incremental cost) should be weighed at EUL. Paybacks and returns on investment are more attractive when considering incremental cost rather than full project costs, so building owners should plan around EUL when a required replacement cost is already assumed.

For the purposes of this technical analysis, incremental costs were not calculated. Full project costs that include both soft costs (i.e., design) and hard costs (i.e., installation) were used in this report.

Utility End Use Assessment

Utility data for the case study buildings is sourced from the Montgomery County benchmarking compliance data for each of the case study buildings. Energy use information may differ from the benchmarking submission if any needed corrections were identified through this review. For example, if some energy use data was not included in a benchmarking submission (e.g., tenant or retail use), it was added in for this analysis in conjunction with the building representatives since the BEPS law would consider whole building energy data.

This utility data includes all house/primary utility accounts, tenant, and secondary space usage. Electricity kilowatt hours (kWh) and gas therms are converted into thousands of British Thermal Units (kBTU). Other fuel types such as fuel oil (e.g., propane, diesel) were not included in this analysis. The case study buildings did not use these fuel types in day-to-day operation, although they may use these loads in emergency conditions (e.g., generators).

Using this utility data, an end-use breakdown assessment is conducted for each building using 2019 monthly data. This breakdown assessment is done for each fuel type in order to identify major end uses such as heating load, cooling load, or domestic hot water (DHW) load. These end uses were estimated as described below, then organized by fuel type. Each end use is represented as a portion of site EUI.

Weather-Dependent End Uses

Weather-dependent (heating and cooling) end uses were first estimated by a regression analysis. Daily average temperature data was gathered from the US National Oceanic and Atmospheric Administration public data set. Changes in energy usage were compared in relation to changes in heating degree days (HDD) and cooling degree days (CDD), calculated from Ronald Reagan National Airport (DCA) weather data. Weather data from DCA is reliable, complete, and regularly used for analysis in Montgomery County as the ambient conditions are similar enough to represent a reasonable estimate of Montgomery County weather usage.

HDD and CDD were based on a base temperature of 65ºF. Average kilowatt hour (kWh) or therm usage per HDD or CDD was then applied to a ten-year average of temperatures to estimate an average, hypothetical year of energy usage, rather than just a single year of data. The following totals were used:

Table 23. 2019 Total Heating Degree Days (HDD) and Cooling Degree Days (CDD)

Month Start	Month End	Days	HDD	CDD
1/1/2019	2/1/2019	31	893	-
2/1/2019	3/1/2019	28	651	-
3/1/2019	4/1/2019	31	574	3
4/1/2019	5/1/2019	30	123	28
5/1/2019	6/1/2019	31	29	191
6/1/2019	7/1/2019	30	-	327
7/1/2019	8/1/2019	31	-	510
8/1/2019	9/1/2019	31	-	437
9/1/2019	10/1/2019	30	-	319
10/1/2019	11/1/2019	31	114	59
11/1/2019	12/1/2019	30	581	-
12/1/2019	1/1/2020	31	723	-
Totals		**365**	**3,688**	**1,874**

For example, in a building known to use gas for both heating and domestic hot water (DHW), increases in gas usage accompanying increases in HDD is associated with heating. In a building known to use gas for only DHW, all gas consumption regardless of changes in outdoor temperature is associated with water heating.

The calculated heating and cooling use for each building was compared to national building end use averages taken from the 2012 dataset (the most recent year available) of the United States Energy Information Administration Commercial Buildings Energy Consumption Survey (CBECS) as a reference dataset used by Portfolio Manager for typical building energy uses. The comparison can provide insight where calculated heating and cooling use is very different from CBECS averages, indicating the need to look deeper at the building's weather dependent versus independent energy use profile.

The analysis team also compared the calculated heating and cooling use to assumptions on Montgomery County building end uses compiled from methodology in the CNCA EBPS tool[51]. The CNCA calculations adjust national building end use averages taken from CBECS to Montgomery County's climate and building energy data, giving typical heating and cooling energy use intensity by typology. These values were used in some cases where actual building data was unreliable, incomplete, or lacked granularity.

Non-Weather-Dependent End Uses

The values in the CBECS data were used as a check against the regression analysis and to better estimate non-weather-dependent end uses such as cooking and DHW. Non-weather-dependent end uses are difficult to separate via weather-based regression methods, making supplemental resources such as CBECS useful for estimating these end loads. CBECS data was also used to estimate some weather-dependent end uses where the regression analysis results were not able to clearly separate end uses.

End Use Descriptions

Building energy usage is organized into energy use intensity (EUI) defined as total building energy usage divided by total building square footage (kBTU/SF). These data are inclusive of all house/ master accounts, tenant, and secondary space usage. Electricity kWh and gas therms are converted into kBTU.

Gas

- Heating: Gas used for heating boilers or furnaces. Also includes usage attributed to heating air for central conditioned air supply systems.
- Cooling: Gas used for fossil-fuel fired chillers. No reviewed buildings contained these systems.
- Domestic Hot Water (DHW): Gas attributed to heating boilers which also supply DHW, or for dedicated water heaters, whether centralized or individual units within tenant spaces.
- Baseload: Gas usage not assigned to the above categories; in most cases this takes the form of cooking.

Electricity

- Heating: Electricity used to generate space heating, associated with heat pump, split systems, and central ventilation units for conditioning supply air. Electricity assigned to heating will also appear in some buildings with central gas-fired equipment when electricity is used for distribution and other equipment. For example, buildings with baseboard heaters supplementing central gas-fired hot water boilers will see electrical use attributed to these baseboard heaters.
- Cooling: Electricity use for air conditioning, applies to all central systems such as electric chillers and cooling towers, as well as unitized air conditioners and heat pumps.
- DHW: Electricity used for DHW production, either through central or unitized DHW tanks.
- Baseload: Electricity usage not assigned to the above categories, includes lighting, ventilation fans, tenant plug loads, cooking where applicable, and other process loads such as elevators. This usage also includes baseload HVAC energy use like fans and pumps that run throughout the year, regardless of weather.
    - Commercial lighting estimates reflect primarily fluorescent lighting; lighting EUI for buildings with LED lighting are reduced by 5%-10% based on the amount of LEDs installed at the building as determined via interviews.
    - Estimates for lighting for multifamily buildings are included. Information is based on the 2015 dataset of the United States Energy Information Administration Residential Energy Consumption Survey (RECS); lighting EUI for buildings with LED lighting are reduced by 5%-10% based on the amount of LEDs installed at the building as determined via interviews.

[51] Supra 11.

Case Study Energy Efficiency Measure Calculations

Energy savings resulting from applying various energy efficiency measures (EEMs) are calculated for each of the case study buildings. An EEM is a building upgrade measure that generates energy savings. All energy savings calculations are shown in percent reduction of site EUI.

Measure savings are calculated to be interactive when organized into packages. For this technical analysis, load reduction measures were estimated first, followed by equipment upgrades that are intended to improve upon the reduced load. Except where noted, additional measures that achieve energy savings beyond targeted goals are excluded to minimize costs, even if applicable to the building.

Utility rate assumptions are $0.129 per kWh and $1.228 per therm, based on the US Energy Information Administration (EIA) average rates for the area. While energy rates differ by service class and usage profile, these rates are assumed to represent the average costs for these types of buildings in Montgomery County. These rates are meant to be inclusive of taxes and fees applicable throughout the state, including the current Fuel Energy Tax of $0.01978 per kWh on electricity and $0.17026 per therm on natural gas use.[52]

Each measure's simple payback (SP) is developed based on the expected capital outlay associated with *just the cost of that measure*. Simple Payback is calculated by dividing the total project cost by the energy cost savings per year. In practice, other items may factor into an "effective" SP calculation but are outside the immediate scope of this report. These items include, but are not limited to:

- Replacement costs for aged, existing equipment. Where possible, the approximate equipment age of equipment being replaced was called out at the case study level.
- Potential capital outlay offsets, such as utility incentives
- Effective methods for deferring capital outlay, such as financing

Each measure's return on investment (ROI) is determined by taking the energy cost savings per year divided by the total cost and converting this number to a percentage. Calculating an "effective" ROI is outside the scope of this report for the same reasons as calculating an "effective" SP.

Separately, a table of EEM descriptions, relevant performance standards, cost/savings assumptions, and informational references to assist in creating the proposed EEM packages for each building are included in the *BEPS EEM Matrix* Excel document provided with this report. The document contains EEMs used in this technical analysis, as well as EEMs not recommended for these specific buildings. The data in the *BEPS EEM Matrix* informed the costs and savings for measures in the case studies except where site-specific recommendations are required.

EEM Package Development

Three packages of EEMs were developed.

Zero Net Carbon-Compatible (ZNC) Target Package

This package compiles measures necessary to meet the Zero Net Carbon-Compatible target for the respective building. These measures typically include electrification of natural gas uses. The aim of this package was to create a series of measures that result in the ability of the case study building to meet the ZNC target. Project financials were not a primary driver, but financially desirable measures were included wherever possible.

Descriptions of each package are included in the individual case studies below.

The methodology for developing these packages was generally as follows:

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[52] Montgomery County, Maryland Division of Treasury – Excise Tax Unit. "Public Utility Fuel-Energy Tax Return." https://www.montgomerycountymd.gov/Finance/Resources/Files/FY2021Utility%20Return.pdf

- Potential electrification measures were implemented first when determined they were necessary to meet the ZNC target. This was done for two reasons:
  - Electrified end uses were typically large (i.e., all of a building's heating loads), and
  - Other measures' applicability may change based on these electrified systems. Note that for packages where mechanical systems were changed, some measures that are appropriate based on *existing mechanical equipment* may not be included in the ZNC package. However, they may appear in the Less-than-Five-Year Payback Package.
- Next, measures with large interactive effects were reviewed. These measures were typically either mechanical or controls-based in nature.
- Next, smaller end use reduction measures with limited interactive effects were implemented. These measures typically have a small impact (i.e., less than 5% of overall building usage).
- Lastly, where applicable and necessary, photovoltaic solar (PV) was applied.

Energy Efficiency (EE) Target Package

This package compiles measures necessary to meet the Energy Efficiency target for the respective building. Initial analysis returned multiple ways to think about developing an approach, each with pros and cons. These can be found in Table 24 below.

Table 24: General approaches to developing an EE Target Package.

Package Type	Pros	Cons	Other Items
Fewest Measures	• Simplest to implement • Easiest to understand	• Higher cost and lower ROI	• Electrification of some end uses guaranteed
Best ROI that Meets the EE Target	• Most attractive financial package • Best speaks to financial concerns	• Still will electrify some loads • Better ROI may not be the easiest to implement measures	• This will likely introduce partial electrification of end uses to the study
Minimize Electrification	• Best speaks to the theory behind the EE package	• Would necessitate replacement of gas-fired equipment with new gas-fired equipment	• May not really be viable with case study buildings (but could be viable with other buildings)

This study opted to use the Best ROI that Meets the EE Target approach. The following guidelines apply to this approach:

- Electrification of end uses needed to be considered in practice. Most case study buildings were far enough away from the EE Target that reaching the EE Target without electrification was infeasible without significant occupant energy pattern changes[53].
- Electrification of DHW loads was considered first. Most mechanical systems (which include space heating systems) have low-cost opportunities for optimization while most DHW systems have limited

[53] Energy conservation by occupants can drive significant energy savings (EPA, slide 33). Because of the difficulty in predicting savings (and the persistence of savings) for these sorts of behavioral measures in typical buildings, those savings are not included in this study.

optimization opportunities. This means the combined mechanical system optimization measures plus DHW electrification had a more attractive ROI than space heating electrification measures.

- Mechanical system optimization and retro-commissioning measures were then implemented.
- Next, smaller end use reduction measures with limited interactive effects were implemented. These measures typically have a small impact (i.e., less than 5% of overall building usage).
- Electrification of space heating loads was considered only if electrification of DHW loads was not enough in conjunction with other measures to meet the EE Target *and* minimal system optimization was possible.
- Lastly, where applicable and necessary, photovoltaic solar (PV) was applied.

Less-than-Five-Year Payback Package

This package compiles a set of measures that results in a five year or less total simple payback. This package represents a reasonable approximation of possible outcomes from an energy audit. These measure packages represent the types of low-cost and lower-savings measures often recommended during standard energy audits. These measures are often investigated by buildings first. Note that an energy audit may include other financial tools such as utility incentives, tax deductions/credits, or other assistance, which were not included in this technical analysis.

Where applicable, measures from the Less-than-Five-Year Payback Package were also applied to the ZNC Package. The methodology described under the ZNC Target Package applied to the Less-than-Five-Year Payback Package as well. The following guidelines apply to the Less-than-Five-Year Payback Package:

- Measures with large interactive effects were reviewed. These measures were typically either mechanical or controls-based in nature.
- Retro-commissioning was applied; see below for details.
- Next, smaller end use reduction measures with limited interactive effects were implemented. These measures typically have a small impact (i.e., less than 5% of overall building usage).
- Major building systems were *not* modified in this package. Most system conversions (for example, converting from chilled water to water-source heat pumps) have longer paybacks and would not realistically be included. However, this also means that measures that impact *existing mechanical equipment* would appear here (for example, chilled water pump VFDs when the ZNC Target Package converted a building from chilled water to water-source heat pumps).
- New fossil fuel measures were not included.
- Overall energy savings were not a primary goal of this target; the energy savings resulting from this package was simply the end result of measures that would result in a less than five-year project payback for all measures considered.

Typically, this package may be useful in reviewing progress toward interim targets.

Note that for some newer buildings that have less opportunity for low-cost incremental savings, the Less-than-Five-Year Payback Package may be either small or non-existent.

Technical Considerations

Where applicable, the following guidelines for the case studies were applied:

- In buildings with tenant spaces, the level of intrusiveness and invasiveness was qualitatively weighed against energy savings benefits to determine if a measure was feasible to implement. In some cases, entry to tenant spaces is required to complete measures that save enough to get to the energy performance targets, but in others, the balance of other applicable measures can achieve the same goal without as much disruption to tenants.
- When building systems were fully replaced in the ZNC Target Package, the ZNC Target Package did not include measures that modify existing building systems.

- When building system types were changed in the ZNC Target Package, this was assumed to happen at the end of equipment life. Most equipment in the case study buildings would need to be replaced between now and 2035.
- Existing mechanical systems were not substantially modified for the Less-than-Five-Year Payback Package.
- Envelope measures including exterior wall insulation retrofits and window replacement are labor intensive, carry a high cost, can have long paybacks, and are often difficult to implement in an occupied building. These measures were generally excluded from the case studies unless determined to be absolutely necessary to meet the ZNC package. Depending on technology advancements between now and 2035, these measures may not be necessary in the future.

Baseline Assumptions

Standard baseline assumptions were used for existing building equipment for consistency in calculations, unless noted otherwise:

- Gas-fired boilers and hot water heaters: 82% efficient
- Gas-fired furnaces: 80% efficient
- Electric resistance heaters and hot water heaters: 100% efficient
- Heat Pump Water Heaters: Annual average 2.2 COP
- Space heating air source heat pumps: Annual average 2.5 COP

Retro-commissioning

Retro-commissioning (RCx) is the process of ensuring systems are designed, installed, functionally tested, and capable of being operated and maintained according to the owner's operational needs. It is a crucial process for maintaining existing building performance and is generally recognized as the first stage in the building upgrade process. Starting a staged upgrade approach with RCx accounts for interaction among energy flows within a building and ensures a systematic method to target the greatest possible energy savings. This process is always site-specific but is an effective real-world intervention.

Because the RCx scope of work can vary widely depending on the needs of a building and available budget, industry research estimates whole building energy savings can range widely from 5% to 30%, making precise estimates difficult.

As noted above, retro-commissioning was typically one of the first applied measures in the Less-than-Five-Year Payback Package. The savings percentage applied varied somewhat by building type based upon results from occupant interviews. The following guidelines applied:

- Buildings where the existing building automation system (BAS) had more visibility into terminal equipment had a higher percentage savings.
- Buildings with older equipment had a higher percentage savings estimated than buildings with newer equipment.
- In buildings where *other* terminal upgrades occurred (for example, Guest Room Controls in lodging building types), retro-commissioning measures applied *only* to central equipment.
- For some buildings, RCx was not recommended because of equipment layout (decentralized systems) or because major equipment was being replaced and would not be subject to RCx.

Solar PV Estimates

Estimates for solar photovoltaic (PV) system installation were derived from the NREL PVWatts® Calculator (https://pvwatts.nrel.gov/). Solar PV systems use solar energy to generate electricity.

The following parameters were used in the tool:

- Module Type: Premium

- Array Type: Fixed (roof mount)
- Soiling: 0%
- Tilt:10 degrees

PVWatts makes basic assumptions on permissible roof area, however site-specific inspections are required to determine accurate capacity based on building code and regress requirements.

Solar PV cost savings calculations are based purely on generated energy savings. Other financial incentives such as tax benefits or the sale of solar renewable energy certificates (SRECs) were not included in solar PV financials. SRECs are certificates generated for each megawatt-hour of electricity generated from solar PV that can be sold on an open market to offset the capital cost of a PV system.

Financial & Cost Calculations

Cost information for case study EEMs was derived from SWA industry research, RSMeans data, and interviews with case study properties owners and managers.

Estimated costs were intended to be inclusive of the total cost to complete the project (e.g., engineering, design, equipment and materials, associated work related to equipment installation, and labor). Soft costs for engineering, design, and other considerations were not explicitly itemized as part of the cost estimates. These fees were assumed to be a relatively small percentage of the overall capital cost for whole-building upgrades and generally captured in the cost estimates referenced here from research studies and other case study examples.

These estimated costs are absolute figures. They do not consider other factors that may make financial performance more appealing, including the following:

- Sunk costs for equipment replacement at the EUL
- Utility incentives
- Tax credits or depreciation policies
- Financing through entities such as the Montgomery County Green Bank
- Fines resulting from non-compliance with BEPS, and future liability from approaches that may not comply with potential carbon reduction and electrification requirements.
- Labor cost savings from new equipment (e.g., reduced maintenance, value of tenant comfort)

Each EEM's simple payback – measured by simple payback (SP) – was determined after identifying measures applicable to the building. This was calculated by dividing total measure cost by the measure's annual dollar savings.

Each EEM's return on investment, or ROI, was determined by dividing the annual dollar savings by total measure cost and converting to a percentage.

Case Study 1: Class-A Office

Building Information

This Class A office building in Montgomery County has a restaurant on the first floor. An adjacent parking garage can be used by tenants and visitors to the restaurant. Most of the non-restaurant space is comprised of typical office space (e.g., offices, conference rooms, and ancillary support areas like pantries).

This building was approximately 40% unoccupied based on 2019 data. The impacts of vacancy on targets are discussed more within *Recommendations for Adjustments based on Occupancy*. This case study target is based upon the methodology currently available to Montgomery County.

Table 25. Building Characteristics – Case Study 1

Category	Building Information
Typology	Office
Square Footage	200,000 ft.^{2} – 225,000 ft.^{2} Office: 100% Parking: 150,000 ft.^{2} – 175,000 ft.^{2} (on premises but does not factor into conditioned square footage)
Year Built Range	2005 – 2010
2019 ENERGY STAR Score	60 – 65
2019 Site EUI (kBTU/SF) (calculated for this study)	70 – 80

Building System Information

The basic building system information specific to the case study building is described below.

Table 26. Building System Information – Case Study 1

Category	Type	Fuel	Approximate Equipment Age (Years)	Expected End of Useful Life (Years)
Central BMS	Building automation system controls mechanical equipment	Electric	13	<5
Heating	Distributed electric VAV heaters	Electric	13	10-15
Cooling	2x chillers (in series) w/free cooling HX	Electric	13	10-15
Ventilation	Floor-by-floor AHUs with an ERV. VAV terminal units	Electric	13	10-15
DHW	Distributed electric water heaters	Electric	13	5-10
Lighting	Mostly converted to LED	Electric	5-10	5-10
Envelope	Original to the building	N/A	13	30-35
Metering	Two main electric meters plus a gas meter for the restaurant	Electric, Gas	N/A	N/A

Utility End Use Assessment

The building's energy usage type and estimated end use is displayed below.

- Gas: exclusively used in the restaurant space, totaling 18% of the building's energy use.
- Electricity: used for heating, cooling, ventilation, lighting, and electric plug loads. In total, electricity is 82% of the building's energy use.

Table 27. 2019 Site EUI by End Use – Case Study 1. Components may not sum to 100% due to rounding.

Heating – Gas	Cooling – Gas	DHW – Gas	Baseload – Gas	Heating – Electric	Cooling – Electric	DHW – Electric	Lighting – Electric	Baseload – Electric	Total EUI
0%	0%	0%	18%	17%	10%	0%	43%	12%	**100%**

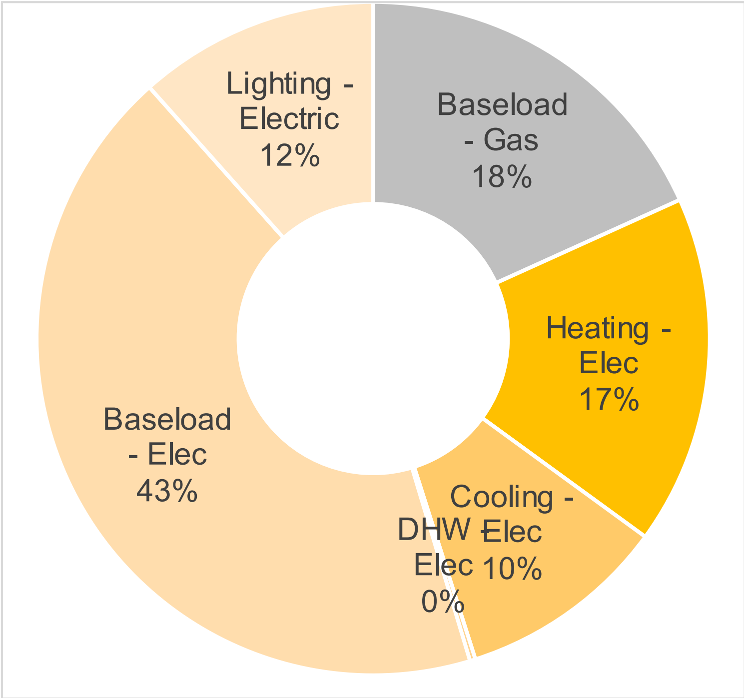

Figure 36. Site EUI Share (%) by End Use – Case Study 1

Target Determination

Total site EUI targets for the building are determined by a weighted average of applicable ZNC targets per space use type. Space use types are provided in Portfolio Manager and via reviews of available drawings. Table 28 contains a breakdown of the space use targets for purposes of calculating the ZNC target. Other building uses are discussed below this table.

A relatively small restaurant is located within the building (less than 5% of the overall floor area). Because this space does not make up more than 25% of the floor area, it does not factor into this building's target calculation. The floor area is instead added to the Office space per EPA ENERGY STAR guidance. The restaurant is the only space that uses gas.

Note that the floor areas shown in the table below are approximated based on Table 26.

All the following analysis uses the ZNC target. The table also has an alternate target ("EE Standard"), which is no different than the ZNC Target for this building. The building will need to take action in order to meet both the ZNC and EE Targets. All the following analysis uses the ZNC target.

Table 28. Space Use Target Methodology Summary – Case Study 1

Specific Space Type	Space Type Group	Area %	Floor Areas	ZNC Standard [Site EUI]	EE Standard [Site EUI]	Weighted ZNC EUI (ZNC * Area%)	Weighted EE EUI (EE * Area%)
Office	Office	100%	225,000	53.4	53.4	53.4	53.4
Total	**-**	**100%**	**225,000**	**-**	**-**	**53.4**	**53.4**

A significant portion of this building is listed as vacant office space based on Portfolio Manager data. While an eventual useful end goal of separating vacant space from occupied space should be pursued (see *Site EUI Target Adjustment Factors*), for case study purposes, the analysis team assumed the initial ZNC target would have to be set based upon information available to Montgomery County today.

The baseline site EUI is derived from whole building 2019 utility data over whole building square footage.

Table 29. ZNC and Interim Targets – Case Study 1

EUI Description	ZNC Target	EE Target
Baseline EUI	70 – 80	70 – 80
2026 – Interim Target 1	63 – 72	63 – 72
2030 – Interim Target 2	57 – 64	57 – 64
2035 – Target	53.4	53.4

Package Overview

EEM packages were compiled based on existing technology for two scenarios:

- *ZNC Target Package* is based upon electrification and energy efficiency measures to reach the ZNC Target for this building.
- *Less-than-Five-Year Payback Package* is based on the results of a package that have a simple payback of less than five years, not accounting for supplemental funding tools such as utility incentives or tax breaks.

An EE Target Package was not developed for this building as the ZNC Target is identical to the EE Target.

All costs are total costs for the measures, not incremental costs. These costs do not include applicable incentives. The following table offers a financial overview of these packages.

Table 30. EEM Package Summary – Case Study 1

Package	Package EUI (kBTU/ft.^{2}/yr)	% Site EUI Savings	Cost Savings ($/yr.)	Capital Costs ($)	SP (yrs)	ROI (%)
ZNC Target Package	49 – 53	30%	$150,400	$5,280,000	35.1	3%
Less-than-Five-Year Payback Package	67 – 75	8%	$47,300	$95,00	2.0	49%

ZNC Target Package

As some ZNC Target measures entail replacement of existing equipment, an additional column is added to Table 31 that shows the estimated remaining life of the equivalent replacement system. An “N/A” indicates the existing system is not replaced, and a “DNE” means does not exist and the package adds a system or piece of equipment not currently onsite. This is discussed in more detail in the Case Study Measures Identification Methodology section below.

Table 31. ZNC Target Package EEMs – Case Study 1. All costs are total capital cost estimates without incentives and without subtracting the cost of replacing existing systems at end of life.

#	Measure	Description	Whole Bldg. EUI Svgs. (%)	Cost Savings ($/yr.)	Measure Cost ($)	SP (yrs)	ROI (%)	Equip. Life (yrs)	Estimated Remaining Life of Equivalent System (yrs)
1	Convert to VRF System	Convert the mechanical system to a VRF system	7.2%	$43,900	$4,682,000	106.6	1%	15	10
2	Electrify Cooking	Convert gas cooking to electric cooking	7.7%	$16,100	$24,000	1.5	66%	15	N/A
3	Retro-commissioning	Retro-commission and implement improvements on building systems	6.8%	$41,400	$74,000	1.8	56%	5	5-10
4	Plug Load Management	Install smart plug load management tools	1.6%	$9,700	$38,000	3.9	25%	10	DNE
5	Solar PV	Install roof-mounted solar PV	6.5%	$39,300	$462,000	11.7	9%	15	DNE
Total			**29.8%**	**$150,400**	**$5,280,000**	**35.1**	**3%**	**-**	

Table 32. Post Retrofit Percent Reductions from Baseline for ZNC Target Package – Case Study 1

Project	Heating – Gas	Cooling – Gas	DHW – Gas	Baseload – Gas	Heating – Electric	Cooling – Electric	DHW – Electric	Baseload – Electric	Lighting – Electric	Total EUI
Baseline	0%	0%	0%	18%	17%	10%	0%	43%	12%	**100%**
End Use Difference	0%	0%	0%	-100%	-69%	51%	-8%	-10%	-8%	**70%**

EE Target Package

This typology has the same ZNC target as EE target; therefore, there is no separate EE target package for this building. The ZNC target package in Table 31 would also serve as an EE target package.

Less-than-Five-Year Payback Package

The Less-than-Five-Year Payback Package allows the building to reach its first interim target threshold.

Table 33. Less-than-Five-Year Payback Package EEMs – Case Study 1. All costs are total capital cost estimates without incentives and without subtracting the cost of replacing existing systems at end of life.

#	Measure	Description	Whole Bldg. EUI Svgs. (%)	Cost Savings ($/yr.)	Measure Cost ($)	SP (yrs)	ROI (%)	Equip. Life (yrs)
1	Retro-Commissioning	Retro-commission and implement improvements on building systems	6.5%	$39,800	$74,000	1.9	53%	5
2	Plug Load Management	Install smart plug load management tools	1.2%	$7,500	$21,000	2.8	35%	10
	Total		**7.8%**	**$47,300**	**$95,000**	**2.0**	**49%**	**-**

Table 34. Post Retrofit Percent Reductions from Baseline for Less-than-Five-Year Payback Package – Case Study 1

Project	Heating – Gas	Cooling – Gas	DHW – Gas	Baseload – Gas	Heating – Electric	Cooling – Electric	DHW – Electric	Baseload – Electric	Lighting – Electric	Total EUI
Baseline	0%	0%	0%	18%	17%	10%	0%	43%	12%	**100%**
End Use Difference	0%	0%	0%	0%	-8%	-8%	-8%	-11%	-8%	**92%**

Package Comparisons to ZNC Target

The following chart shows the site EUI and split between fuels today and for the EEM packages in comparison to the three Targets.

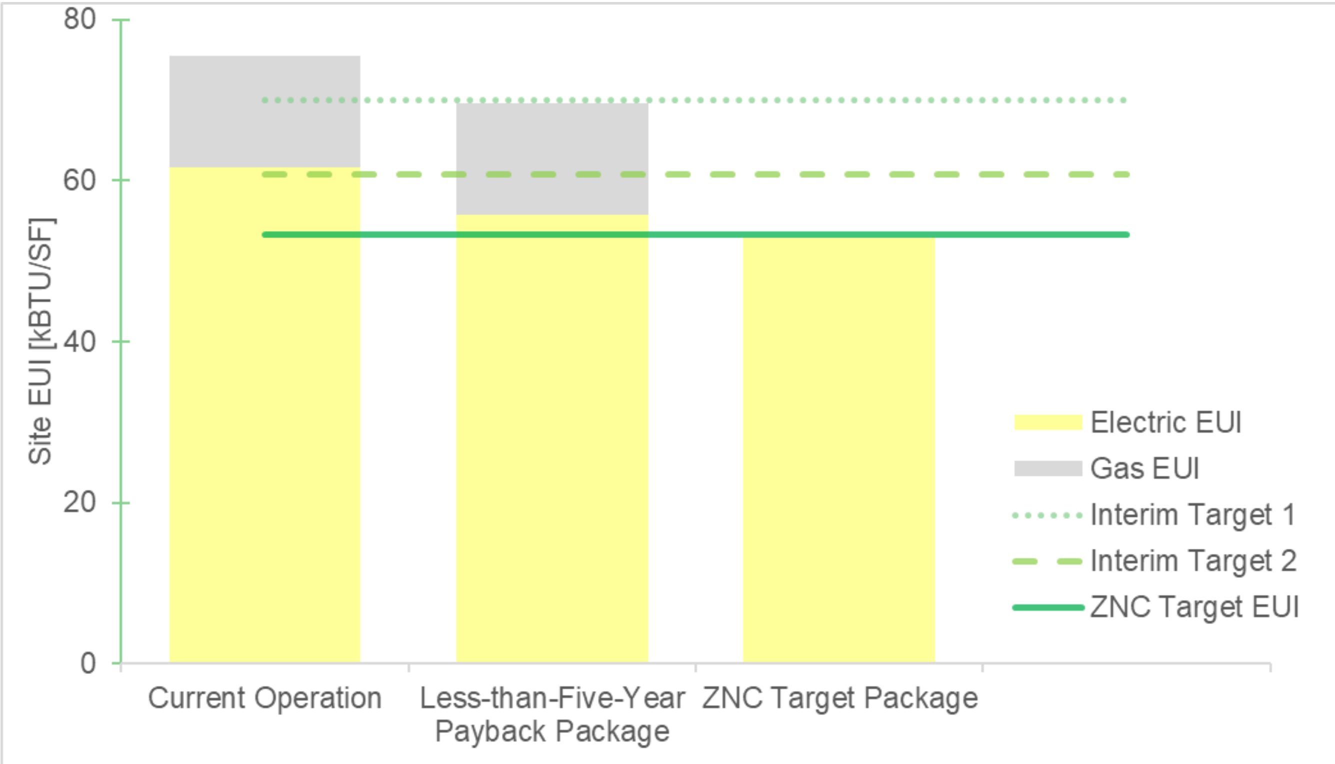

Figure 37. Target-to-Package Comparisons – Case Study 1

The Less-than-Five-Year Payback Package clears the first interim target but leaves the building well short of the ZNC Target.

Building-Specific Technology Assessment

Electric heating is rather inefficient compared to other heat pump technology (for example, either WSHP or VRF systems). Improving heating efficiency represented the best opportunity to reach the ZNC target.

A WSHP conversion would maintain some of the existing piping through the core of the office building; new water piping would need to be run throughout the building perimeter. In addition, the pumping system would be maintained. A VRF conversion would also be intrusive in terms of refrigerant piping; however, the pumping energy required for refrigerant is much less than the pumping energy required for water. This reduction in pumping energy made the energy savings of VRF more attractive than WSHP.

Gas is not used in office spaces at this building. As a result, electrification of the restaurant loads represents the only effective way to eliminate gas usage.

Following these system upgrades, other measures affecting building demand were chosen, such as plug load management. These measures do not have a large overall impact on savings and were generally non-interactive in nature meaning savings from these measures do not appreciably increase or decrease savings from other measures.

Lastly, solar PV is applied to the roof only. Other approaches to solar PV such as canopied PV over the adjacent parking garage or empty lot next door increase the amount of PV and may be a more attractive financial approach than the ZNC Target Package.

The Less-than-Five-Year Payback Package was constructed using nearly the same measures as the ZNC Target Package, with the exception of system conversion, restaurant electrification and solar PV.

This building has substantial unoccupied space which makes the ZNC target easier to reach. The section *Recommendations for Adjustments based on Occupancy* describes possible adjustments to this building (and similar building types with substantial vacancy) which may in turn impact the actual measures chosen.

Package Comparisons

The existing system can be optimized to meet the ZNC target. However, system conversion should be investigated when the existing chilled water system reaches the end of its life, as another type of system could provide greater efficiency.

There are some ways to reduce compliance retrofit costs:

- Some of the total capital cost may be effectively defrayed by subtracting avoided replacement costs of existing mechanical equipment. For example, most mechanical equipment will likely be replaced before the 2035 target. This money can be effectively set aside to help cover part of the costs.
- Financing methods such as the Montgomery County Green Bank are viable.
- Utility incentives through the EmPOWER Maryland program may help offset upfront costs. While not a significant amount relative to the overall project investment, these funds are available today. Funds are available on three-year cycles and the program offerings can change during the program cycle; based on this, incentive estimates are not included in this report.
- Advances in technology between now and the ZNC target date may result in viable alternative approaches, meaning reduction in the ZNC costs and payback ranges described.

The Less-than-Five-Year Payback Package largely utilizes retrofits to existing equipment. Applying a higher estimated savings for retro-commissioning may be possible.

Measures Not Recommended

Measures reviewed for the building but not included in the EEM package are described below.

- DHW: domestic hot water is a minimal load in office buildings and was not examined.
- Envelope: Re-roofing was considered but ultimately determined as non-cost effective and not necessary to meet the ZNC target. The remaining envelope items should still be functional and effective in 2035.

General Methodology Applied to All Case Studies

The following text describes components of this technical analysis that were applied to all case studies about EEM Package Development, Building Desktop Audits, and Utility Rates. After those sections are discussions of the analysis methodology applied specifically to this case study.

EEM Package Development

Two packages of EEMs were developed.

Zero Net Carbon-Compatible (ZNC) Target Package

This package compiles measures necessary to meet the Zero Net Carbon-Compatible target for the respective building. These measures typically include electrification of natural gas uses. The aim of this package was to create a series of measures that result in the ability of the case study building to meet the ZNC target. Project financials were not a primary driver, but financially desirable measures were included wherever possible.

Descriptions of each package are included in the individual case studies below.

The methodology for developing these packages was generally as follows:

- Potential electrification measures were implemented first when determined they were necessary to meet the ZNC target. This was done for two reasons:
  - Electrified end uses were typically large (i.e., all of a building's heating loads), and
  - Other measures' applicability may change based on these electrified systems. Note that for packages where mechanical systems were changed, some measures that are appropriate based on *existing mechanical equipment* may not be included in the ZNC package. However, they may appear in the Less-than-Five-Year Payback Package.
- Next, measures with large interactive effects were reviewed. These measures were typically either mechanical or controls-based in nature.
- Next, smaller end use reduction measures with limited interactive effects were implemented. These measures typically have a small impact (i.e., less than 5% of overall building usage).
- Lastly, where applicable and necessary, photovoltaic solar (PV) was applied.

Energy Efficiency (EE) Target Package (Not Applicable for this Case Study)

This package compiles measures necessary to meet the Energy Efficiency target for the respective building. Initial analysis returned multiple ways to think about developing an approach, each with pros and cons. These can be found in Table 35 below.

Table 35: General approaches to developing an EE Target Package.

Package Type	Pros	Cons	Other Items
Fewest Measures	• Simplest to implement • Easiest to understand	• Higher cost and lower ROI	• Electrification of some end uses guaranteed
Best ROI that Meets the EE Target	• Most attractive financial package • Best speaks to financial concerns	• Still will electrify some loads • Better ROI may not be the easiest to implement measures	• This will likely introduce partial electrification of end uses to the study
Minimize Electrification	• Best speaks to the theory behind the EE package	• Would necessitate replacement of gas-fired equipment with new gas-fired equipment	• May not really be viable with case study buildings (but could be viable with other buildings)

This study opted to use the Best ROI that Meets the EE Target approach. The following guidelines apply to this approach:

- Electrification of end uses needed to be considered in practice. Most case study buildings were far enough away from the EE Target that reaching the EE Target without electrification was infeasible without significant occupant energy pattern changes[54].

[54] Energy conservation by occupants can drive significant energy savings (EPA, slide 33). Because of the difficulty in predicting savings (and the persistence of savings) for these sorts of behavioral measures in typical buildings, those savings are not included in this study.

- Electrification of DHW loads was considered first. Most mechanical systems (which include space heating systems) have low-cost opportunities for optimization while most DHW systems have limited optimization opportunities. This means the combined mechanical system optimization measures plus DHW electrification had a more attractive ROI than space heating electrification measures.
- Mechanical system optimization and retro-commissioning measures were then implemented.
- Next, smaller end use reduction measures with limited interactive effects were implemented. These measures typically have a small impact (i.e., less than 5% of overall building usage).
- Electrification of space heating loads was considered only if electrification of DHW loads was not enough in conjunction with other measures to meet the EE Target *and* minimal system optimization was possible.
- Lastly, where applicable and necessary, photovoltaic solar (PV) was applied.

Less-than-Five-Year Payback Package

This package compiles a set of measures that results in a five year or less total simple payback. This package represents a reasonable approximation of possible outcomes from an energy audit. These measure packages represent the types of low cost and lower-savings measures often recommended during standard energy audits. These measures are often investigated by buildings first. Note that an energy audit may include other financial tools such as utility incentives, tax deductions/credits, or other assistance, which were not included in this technical analysis.

Where applicable, measures from the Less-than-Five-Year Payback Package were also applied to the ZNC Package. The methodology described under the ZNC Target Package applied to the Less-than-Five-Year Payback Package as well. The following guidelines apply to the Less-than-Five-Year Payback Package:

- Measures with large interactive effects were reviewed. These measures were typically either mechanical or controls-based in nature.
- Retro-commissioning was applied; see below for details.
- Next, smaller end use reduction measures with limited interactive effects were implemented. These measures typically have a small impact (i.e., less than 5% of overall building usage).
- Lastly, where applicable and necessary, photovoltaic solar (PV) was applied.
- Major building systems were *not* modified in this package. Most system conversions (for example, converting from chilled water to water-source heat pumps) have longer paybacks and would not realistically be included. However, this also means that measures that impact *existing mechanical equipment* would appear here (for example, chilled water pump VFDs when the ZNC Target Package converted a building from chilled water to water-source heat pumps).
- New fossil fuel measures were not included.
- Overall energy savings were not a primary goal of this target; the energy savings resulting from this package was simply the end result of measures that would result in a less than five year project payback for all measures considered.

Typically, this package may be useful in reviewing progress toward interim targets.

Note that for some newer buildings that have less opportunity for low-cost incremental savings, the Less-than-Five-Year Payback Package may be either small or non-existent.

Building Desktop Audits

Case studies were developed through interviews with building managers and site staff to collect – for major equipment only – equipment type, equipment age, operating parameters, types of fuel used for various end uses, information on recent capital upgrades, and any comments on plans for future upgrades and decision-making processes in relation to energy management. Architectural and mechanical drawings and supporting documentation were reviewed when available.

Desktop audits were performed in order to develop the case studies contained in this report. Desktop audits use information provided from building owners and operators to develop recommendations, but do not contain any onsite observations. This methodology is effective for informing policy-level decisions as it can effectively capture broad-stroke approaches; however, this methodology does not tend to capture measures are more limited in impact (e.g., mechanical systems that only serve part of the building). Applicability of desktop audit measures to a specific building typically requires some amount of onsite investigation in order to determine applicability of measures for any specific building in a given typology. This technical analysis is limited to desktop audits and measure recommendations are limited to what could be recommended based on the data collected by the auditor.

Where possible, supplemental energy audit information performed by others is incorporated into the case studies. These energy audits, which may contain onsite observations, were completed prior to this desktop audit process.

Utility Rates

Utility rate assumptions are $0.129 per kWh and $1.228 per therm, based on the US Energy Information Administration (EIA) average rates for the area. While energy rates differ by service class and usage profile, these rates are assumed to represent the average costs for these types of buildings in Montgomery County. These rates are meant to be inclusive of taxes and fees applicable throughout the state, including the current Fuel Energy Tax of $0.01978 per kWh on electricity and $0.17026 per therm on natural gas use.

Case Study 2: Older Mixed Fuel Office

Building Information

The building was constructed in the 1970s, and most mechanical equipment has been replaced once since original construction. The building is heated and cooled by water source heat pumps (WSHPs) connected to a condenser water loop, with a central boiler and cooling tower to provide heat and heat rejection, respectively, for this system. Onsite parking is available.

The ground floor of this building has retail and restaurants, which in total make up less than five percent of the overall floor area. These tenants generally have their own mechanical systems and meters.

Table 36. Building Characteristics – Case Study 2

Category	Building Information
Typology	Office
Floor Area	Total: 250,000 ft.^{2} – 275,000 ft.^{2} Office: 50% Medical Office: 50% Parking: 50,000 ft.^{2} -75,000 ft.^{2} (on premises but does not factor into conditioned square footage)
Year Built	1970-1975
2019 ENERGY STAR Score	40 – 45
2019 Site EUI (kBTU/SF) (calculated for this study)	80 – 90

Building System Information

The basic building system information specific to the case study building is described below.

Table 37. Building System Information – Case Study 2

Category	Type	Fuel	Approximate Equipment Age (Years)	Expected End of Useful Life (Years)
Central BMS	Manages central plant/major equipment only. Perimeter heat pumps operated on stop/start only	Electric	Unknown (estimated 15 years)	Unknown (est. <5)
Heating	Distributed WSHPs with central boiler for heating	Gas	5	15-20
Cooling	Distributed WSHPs with cooling tower for heat rejection. Larger central WSHPs also provide fresh air.	Electric	9-14	5-10
Ventilation	No dedicated ventilation equipment. Outdoor air delivered via ventilation shaft to each mechanical room	Electric	N/A	N/A
DHW	Two electric DHW heaters	Electric	Unknown (estimated 10 years)	Unknown (est. 5-10)
Lighting	Mostly completed LED upgrades	Electric	0-2	5-10
Envelope	Brick with poured concrete exterior. Façade components are original, though the west side of the building has window tint.	N/A	50	5-10
Metering	Retail and restaurant spaces on separate meters	Electric, Gas	N/A	N/A

Utility Energy End Use Assessment

The building's energy usage type and estimated end use is displayed below.

- Gas: used in the office space for space heating via the central boiler. The retail spaces, including the restaurant, also use gas. Gas makes up 21% of the building's site energy use.
- Electricity: used for heating and cooling (through WSHPs), ventilation, lighting, and electric plug loads. Electricity makes up 79% of the building's site energy use.

Table 38. 2019 Site EUI by End Use – Case Study 2. Components may not sum to 100% due to rounding.

Heating – Gas	Cooling – Gas	DHW – Gas	Baseload – Gas	Heating – Elec	Cooling – Elec	DHW – Elec	Baseload – Elec	Lighting – Elec	Total EUI
16%	0%	0%	4%	13%	8%	0%	47%	10%	**100%**

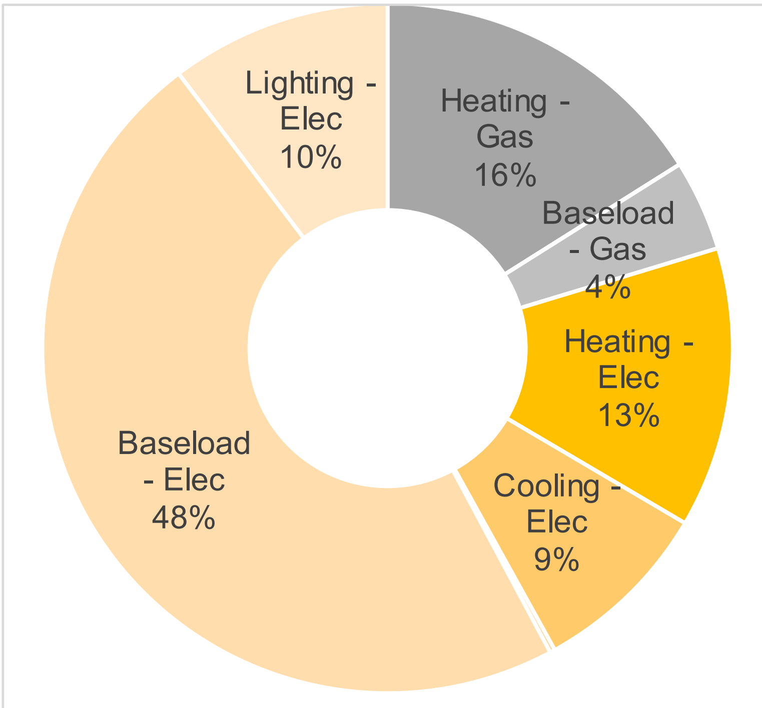

Figure 38. Site EUI Share (%) by End Use – Case Study 2

Target Determination

Site EUI targets are determined by a weighted average of applicable ZNC targets per space use type. Space use types are provided in Portfolio Manager and via reviews of available drawings. Table 39 contains a breakdown of the space use targets for purposes of calculating the ZNC target. Other building uses are discussed below this table. The table also has an alternate target ("EE Standard"), which is no different than the ZNC Target for this building. The building will need to take action in order to meet both the ZNC and EE Targets. All the following analysis uses the ZNC target.

Note that the floor areas shown in the table below are approximated based on Table 37.

Table 39. Space Use Target Methodology Summary – Case Study 2

Specific Space Type	Space Type Group	Area %	Floor Areas (ft.^{2})	ZNC Standard [Site EUI]	EE Standard [Site EUI]	Weighted ZNC EUI (ZNC * Area%)	Weighted EE EUI (ZNC * Area%)
Office	Office	50%	125,000	53	53	26.7	26.7
Medical Office	Health Care Outpatient	50%	125,000	62	62	31.1	31.1
Total	**-**	**100%**	**250,000**	**-**		**57.8**	**57.8**

This building has restaurant and other retail spaces. These spaces are relatively small (less than 5% of the overall floor area). Because the ground floor retail spaces do not make up more than 25% of the floor area, these spaces' individual targets do not factor into this building's target calculation. These retail floor areas are instead spread evenly across the Office and Health Care Outpatient spaces.

The baseline EUI is derived from whole building 2019 utility data over whole building square footage.

Table 40. ZNC and Interim Targets – Case Study 2

Target	ZNC Target	EE Target
Baseline EUI	80 – 90	80 – 90
2026 – Interim Target 1	71 – 80	71 – 80
2030 – Interim Target 2	62 – 70	62 – 70
2035 – ZNC Target	57.8	57.8

Package Overview

EEM packages were compiled based on existing technology for two scenarios:

- *ZNC Target Package* is based upon electrification and energy efficiency measures to reach the ZNC Target for this building.
- *Less-than-Five-Year Payback Package* is based on the results of a package that would have a simple payback of less than five years, not accounting for supplemental funding tools such as utility incentives or tax credits.

An EE Target Package was not developed for this building as the ZNC Target is identical to the EE Target.

All costs are total costs for the measures, not incremental costs. These costs do not include applicable incentives. The following table offers a financial overview of these packages.

Table 41. EEM Package Summary – Case Study 2

Package	Package EUI (kBTU/ft.^{2}/yr)	% Site EUI Savings	Cost Savings ($/yr.)	Capital Costs ($)	SP (yrs)	ROI (%)
ZNC Target Package	52 – 57	35%	$183,000	$4,832,000	26.4	4%
Less-than-Five-Year Payback Package	67 – 75	16%	$118,100	$476,000	4.0	25%

ZNC Target Package

As some ZNC Target measures entail replacement of existing equipment, an additional column is added to Table 42 that shows the estimated remaining life of the equivalent replacement system. An "N/A" indicates the existing system is not replaced, and a "DNE" means does not exist and the package adds a system or piece of equipment not currently onsite. This is discussed in more detail in the Case Study Measures Identification Methodology section below.

Table 42. ZNC Target Package EEMs – Case Study 2. All costs are total capital cost estimates without incentives and without subtracting the cost of replacing existing systems at end of life.

#	Measure	Description	Whole Bldg. EUI Svgs. (%)	Cost Savings ($/yr.)	Measure Cost ($)	SP (yrs)	ROI (%)	Equip. Life (yrs)	Estimated Remaining Life of Equivalent System (yrs)
1	Electrify Space Heating	Convert the central boiler to an air-to-water heat pump	11.8%	$8,000	$3,730,000	466	0%	18	15-20
2	Electrify Restaurant	Convert gas cooking to electric cooking	1.7%	($10,500)	$12,000	N/A	N/A	10	Unknown (estimated 10 years)
3	Retro-commissioning	Retro-commission and implement improvements on central building systems	6.9%	$59,600	$95,000	1.6	63%	5	N/A
4	HVAC Schedule Adjustments	Adjust existing HVAC schedules to align with occupancy	6.6%	$57,000	$3,000	0.0	2,281%	5	N/A
5	Electric Submetering	Install submeters to incentivize tenants to reduce their energy use	1.0%	$8,800	$149,000	16.9	6%	10	DNE
6	Lighting Occupancy Presence Sensors	Install lighting sensors to sense occupants in offices	0.1%	$1,300	$59,000	46.7	2%	10	DNE
7	Daylighting Controls	Install daylighting sensors to turn off lights in perimeter spaces	0.2%	$1,900	$95,000	51.0	2%	10	DNE
8	Garage LED upgrade	Complete ongoing LED conversion for the parking garage	0.3%	$2,200	$48,000	21.7	5%	10	0-5
9	Plug Load Management	Install smart plug load management tools	1.3%	$11,500	$27,000	2.4	42%	10	DNE
10	Solar PV	Install roof-mounted solar PV	5.0%	$43,200	$614,000	14.2	7%	15	DNE
Total			**34.9%**	**$183,000**	**$4,832,000**	**26.4**	**4%**	**-**	

Table 43. Post Retrofit Site EUI by End Use & Percent Reductions from Baseline for ZNC Target Package – Case Study 2

Project	Heating – Gas	Cooling – Gas	DHW – Gas	Baseload – Gas	Heating – Electric	Cooling – Electric	DHW – Electric	Baseload – Electric	Lighting – Electric	Total EUI (%)
Baseline	16%	0%	0%	4%	13%	8%	0%	47%	10%	**100%**
End Use Difference	-100%	0%	0%	-100%	1%	-24%	0%	-23%	-15%	**65%**

EE Target Package

This typology has the same ZNC target as EE target; therefore, there is no separate EE target package for this building. The ZNC target package in Table 42 would also serve as an EE target package.

Less-than-Five-Year Payback Package

The Less-than-Five-Year Payback Package allows the building to reach its first interim target threshold.

Table 44. Less-than-Five-Year Payback Package EEMs – Case Study 2. All costs are total capital cost estimates without incentives and without subtracting the cost of replacing existing systems at end of life.

#	Measure	Description	Whole Bldg. EUI Svgs. (%)	Cost Savings ($/yr.)	Measure Cost ($)	SP (yrs)	ROI (%)	Equip. Life (yrs)
1	Retro-commissioning	Retro-commission and implement improvements on central building systems	7.6%	$58,500	$95,000	1.6	62%	5
2	HVAC Schedule Adjustments	Adjust existing HVAC schedules to align with occupancy	5.5%	$34,100	$3,000	0.1	1,365%	5
3	Electric Submetering	Install submeters to incentivize tenants to reduce their energy use	1.0%	$8,500	$149,000	17.6	6%	10
4	Lighting Occupancy Presence Sensors	Install lighting sensors to sense occupants in offices	0.1%	$1,300	$59,000	46.1	2%	10
5	Daylighting Controls	Install daylighting sensors to turn off lights in perimeter spaces	0.2%	$1,900	$95,000	50.5	2%	10
6	Garage LED upgrade	Complete ongoing LED conversion for the parking garage	0.3%	$2,200	$48,000	21.7	5%	10
7	Plug Load Management	Install smart plug load management tools	1.3%	$11,600	$27,000	2.3	43%	10
	Total		**16.1%**	**$118,100**	**$476,000**	**4.0**	**25%**	**-**

Table 45. Post Retrofit Site EUI by End Use & Percent Reductions from Baseline for Less-than-Five-Year Payback Package – Case Study 2

Project	Heating – Gas	Cooling – Gas	DHW – Gas	Baseload – Gas	Heating – Electric	Cooling – Electric	DHW – Electric	Baseload – Electric	Lighting – Electric	Total EUI
Baseline	16%	0%	0%	4%	13%	8%	0%	47%	10%	**100%**
End Use Difference	-23%	0%	0%	0%	-24%	-24%	0%	-12%	-15%	**84%**

Package Comparisons to ZNC Target

The following chart shows the site EUI and split between fuels today and for the EEM packages in comparison to the three Targets.

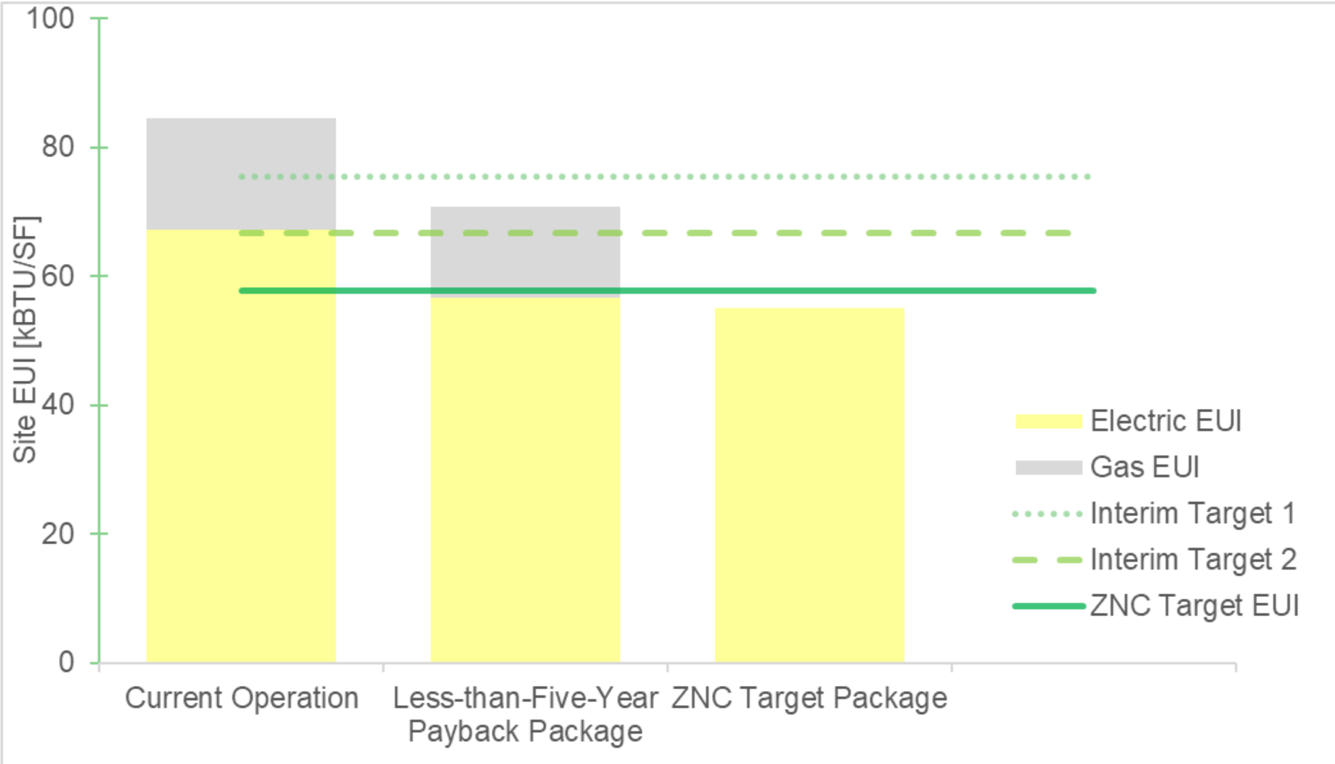

Figure 39. Target-to-Package Comparisons – Case Study 2

As seen in Figure 39, the Less-than-Five-Year Payback Package results in a savings amount below the first interim target. As discussed below, savings above and beyond the ZNC Target are certainly possible for this building.

Building-Specific Technology Assessment

When offices have a substantial gas load, it is typically for space heating. Given this, electrification for this building would consist of electrifying the boiler system by converting it to an air-to-water heat pump and then electrifying any of the smaller retail loads.

Once these improvements are completed, optimization of the remaining building systems can occur. These additional savings measures can be complicated to implement for a heat pump loop building, since most of the building efficiencies already lay within the system itself. The controls system can help somewhat, but the main benefit employed here is around scheduling. About 13 hours per week of run-time can be reasonably reduced, to a total of 65 hours per week based on information provided by building operators. Further run-time reductions may be possible, but in general 65 hours per week is a reasonable approximation of average run-time for offices of this building type.

Retro-commissioning is applied to the ZNC Target Package; since most of the mechanical equipment (except the central heating plant) will remain, retro-commissioning is viable for this building.

Other measures affecting building energy demand were reviewed such as LED lighting conversions and high-efficiency water aerators. These measures do not have a large overall impact on savings and are generally non-interactive in nature, meaning savings from these measures do not appreciably increase or decrease savings from other measures.

Plug Load Management is applied to both packages, and roof-mounted solar PV is applied to the ZNC Target Package. In practice, solar PV needs to be coordinated with other measures that require roof space.

The Less-than-Five-Year Payback Package is largely constructed using similar measures as the ZNC Target Package.

Package Comparisons

Although this building can reach its ZNC target with technology available today, doing so incurs a significant cost without factoring in incentives and grants. There are some ways to reduce compliance retrofit costs and spread the upfront capital costs over time with financing, which improves the cash flow of a building as well:

- Other detailed savings measures (i.e., applicability of sensors and more advanced control techniques) may result in larger savings amounts than estimated in Table 2-6. These types of improvements may be possible with a more detailed look at the building.
- Some of the total capital cost may be effectively defrayed by accounting for avoided replacement costs of existing mechanical equipment. For example, most mechanical equipment will likely be replaced before the 2035 target. This money can be effectively set aside to help cover part of the costs.
- Financing methods such as the Montgomery County Green Bank are viable.
- Utility incentives through the EmPOWER Maryland program may help offset upfront costs. While not a significant amount relative to the overall project investment, these funds are available today. Funds are available on three-year cycles and the program offerings can change during the program cycle; based on this, incentive estimates are not included in this report.

The Less-than-Five-Year Payback Package largely utilizes retrofits to existing equipment. Applying a higher estimated savings for retro-commissioning and lighting measures may be possible, depending on the deficiencies found during the retro-commissioning process.

Advances in technology between now and the ZNC target date may result in viable alternative approaches, meaning reduction in the ZNC costs and payback ranges described.

Measures Not Recommended

Measures reviewed for the building but not included in the EEM package are described below.

- HVAC: a full replacement to the heating and cooling system with a refrigerant-based distribution system may yield higher savings but costs substantially more and is far more intrusive to tenant spaces throughout the building. In addition, more aggressive schedule adjustments (i.e., operating HVAC only 10 hours a day instead of 12) are not included.
- Dedicated Outdoor Air Systems: A DOAS may be required by code if a substantial renovation of the building occurs prior to 2035; however, the ZNC Target pathway that included DOAS as an option is a less attractive financial package than the ZNC Target Package in Table 2-6. Installation of a DOAS will result in energy reductions, presenting a possible alternative pathway to reaching the ZNC Target that is not included in this report.
- Envelope: envelope measures were reviewed but not included in either package. Other measures such as electrification generate more energy savings at similar capital outlays and are a more effective way to reach the ZNC target.

General Methodology Applied to All Case Studies

The following text describes components of this technical analysis that were applied to all case studies about EEM Package Development, Building Desktop Audits, and Utility Rates. After those sections are discussions of the analysis methodology applied specifically to this case study.

EEM Package Development

Three packages of EEMs were developed.

Zero Net Carbon-Compatible (ZNC) Target Package

This package compiles measures necessary to meet the Zero Net Carbon-Compatible target for the respective building. These measures typically include electrification of natural gas uses. The aim of this package was to create a series of measures that result in the ability of the case study building to meet the ZNC target. Project financials were not a primary driver, but financially desirable measures were included wherever possible.

Descriptions of each package are included in the individual case studies below.

The methodology for developing these packages was generally as follows:

- Potential electrification measures were implemented first when determined they were necessary to meet the ZNC target. This was done for two reasons:
  - Electrified end uses were typically large (i.e., all of a building's heating loads), and
  - Other measures' applicability may change based on these electrified systems. Note that for packages where mechanical systems were changed, some measures that are appropriate based on *existing mechanical equipment* may not be included in the ZNC package. However, they may appear in the Less-than-Five-Year Payback Package.
- Next, measures with large interactive effects were reviewed. These measures were typically either mechanical or controls-based in nature.
- Next, smaller end use reduction measures with limited interactive effects were implemented. These measures typically have a small impact (i.e., less than 5% of overall building usage).
- Lastly, where applicable and necessary, photovoltaic solar (PV) was applied.

Energy Efficiency (EE) Target Package (Not Applicable for this Case Study)

This package compiles measures necessary to meet the Energy Efficiency target for the respective building. Initial analysis returned multiple ways to think about developing an approach, each with pros and cons. These can be found in Table 46 below.

Table 46: General approaches to developing an EE Target Package.

Package Type	**Pros**	**Cons**	**Other Items**
Fewest Measures	• Simplest to implement • Easiest to understand	• Higher cost and lower ROI	• Electrification of some end uses guaranteed
Best ROI that Meets the EE Target	• Most attractive financial package • Best speaks to financial concerns	• Still will electrify some loads • Better ROI may not be the easiest to implement measures	• This will likely introduce partial electrification of end uses to the study
Minimize Electrification	• Best speaks to the theory behind the EE package	• Would necessitate replacement of gas-fired equipment with new gas-fired equipment	• May not really be viable with case study buildings (but could be viable with other buildings)

This study opted to use the Best ROI that Meets the EE Target approach. The following guidelines apply to this approach:

- Electrification of end uses needed to be considered in practice. Most case study buildings were far enough away from the EE Target that reaching the EE Target without electrification was infeasible without significant occupant energy pattern changes[55].
- Electrification of DHW loads was considered first. Most mechanical systems (which include space heating systems) have low-cost opportunities for optimization while most DHW systems have limited optimization opportunities. This means the combined mechanical system optimization measures plus DHW electrification had a more attractive ROI than space heating electrification measures.
- Mechanical system optimization and retro-commissioning measures were then implemented.
- Next, smaller end use reduction measures with limited interactive effects were implemented. These measures typically have a small impact (i.e., less than 5% of overall building usage).
- Electrification of space heating loads was considered only if electrification of DHW loads was not enough in conjunction with other measures to meet the EE Target *and* minimal system optimization was possible.
- Lastly, where applicable and necessary, photovoltaic solar (PV) was applied.

Less-than-Five-Year Payback Package

This package compiles a set of measures that results in a five year or less total simple payback. This package represents a reasonable approximation of possible outcomes from an energy audit. These measure packages represent the types of low cost and lower-savings measures often recommended during standard energy audits. These measures are often investigated by buildings first. Note that an energy audit may include other financial tools such as utility incentives, tax deductions/credits, or other assistance, which were not included in this technical analysis.

Where applicable, measures from the Less-than-Five-Year Payback Package were also applied to the ZNC Package. The methodology described under the ZNC Target Package applied to the Less-than-Five-Year Payback Package as well. The following guidelines apply to the Less-than-Five-Year Payback Package:

- Measures with large interactive effects were reviewed. These measures were typically either mechanical or controls-based in nature.
- Retro-commissioning was applied; see below for details.
- Next, smaller end use reduction measures with limited interactive effects were implemented. These measures typically have a small impact (i.e., less than 5% of overall building usage).
- Lastly, where applicable and necessary, photovoltaic solar (PV) was applied.
- Major building systems were *not* modified in this package. Most system conversions (for example, converting from chilled water to water-source heat pumps) have longer paybacks and would not realistically be included. However, this also means that measures that impact *existing mechanical equipment* would appear here (for example, chilled water pump VFDs when the ZNC Target Package converted a building from chilled water to water-source heat pumps).
- New fossil fuel measures were not included.
- Overall energy savings were not a primary goal of this target; the energy savings resulting from this package was simply the end result of measures that would result in a less than five-year project payback for all measures considered.

Typically, this package may be useful in reviewing progress toward interim targets.

Note that for some newer buildings that have less opportunity for low-cost incremental savings, the Less-than-Five-Year Payback Package may be either small or non-existent.

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[55] Energy conservation by occupants can drive significant energy savings (EPA, slide 33). Because of the difficulty in predicting savings (and the persistence of savings) for these sorts of behavioral measures in typical buildings, those savings are not included in this study.

Building Desktop Audits

Case studies were developed through interviews with building managers and site staff to collect – for major equipment only – equipment type, equipment age, operating parameters, types of fuel used for various end uses, information on recent capital upgrades, and any comments on plans for future upgrades and decision-making processes in relation to energy management. Architectural and mechanical drawings and supporting documentation were reviewed when available.

Desktop audits were performed in order to develop the case studies contained in this report. Desktop audits use information provided from building owners and operators to develop recommendations, but do not contain any onsite observations. This methodology is effective for informing policy-level decisions as it can effectively capture broad-stroke approaches; however, this methodology does not tend to capture measures are more limited in impact (e.g., mechanical systems that only serve part of the building). Applicability of desktop audit measures to a specific building typically requires some amount of onsite investigation in order to determine applicability of measures for any specific building in a given typology. This technical analysis is limited to desktop audits and measure recommendations are limited to what could be recommended based on the data collected by the auditor.

Where possible, supplemental energy audit information performed by others is incorporated into the case studies. These energy audits, which may contain onsite observations, were completed prior to this desktop audit process.

Utility Rates

Utility rate assumptions are $0.129 per kWh and $1.228 per therm, based on the US Energy Information Administration (EIA) average rates for the area. While energy rates differ by service class and usage profile, these rates are assumed to represent the average costs for these types of buildings in Montgomery County. These rates are meant to be inclusive of taxes and fees applicable throughout the state, including the current Fuel Energy Tax of $0.01978 per kWh on electricity and $0.17026 per therm on natural gas use.

Case Study 3: Older All-Electric Office

Building Information

This office building was constructed in the 1970s. Most of this office space is dedicated to various office-related functions such as meeting rooms, offices, and other similar uses. This building also has a dining facility. This building also has a large base load.

Table 47. Building Characteristics – Case Study 3

Category	Building Information
Typology	Office
Square Footage	225,000 – 250,000 ft.^{2} Office: 100%
Year Built	1970 – 1975
2019 ENERGY STAR Score	30 – 35
2019 Site EUI (kBTU/SF) (calculated for this study)	80 – 90

Building System Information

The basic building system information specific to the case study building is described below.

Table 48. Building System Information – Case Study 3

Category	Type	Fuel	Approximate Equipment Age (Years)	Expected End of Useful Life (Years)
Central BMS	Building automation system for central equipment only (central plant, AHUs, duct heaters), but no control over chillers.	Electric	Unknown (estimated 10 years for central, 35 years terminal)	5-10 (central), <5 (terminal)
Heating	Central electric duct heaters, perimeter VAV reheat	Electric	~40	<5
Cooling	Two centrifugal chillers; condenser water via 2-cell axial-fan cooling tower; some self-contained units (SCUs) on first floor on separate condenser loop	Electric	25	5-10
Ventilation	2x large VAV AHUs; no energy recovery	Electric	~40	<5
DHW	Unitized DHW	Electric	10-30	<5-10 (depending on heater)
Lighting	Mostly T8; one floor retrofit to LED	Electric	Unknown (estimated 10 years)	<5
Envelope	Original to the building, except roof; windows double-pane but sealing issues abound	Electric	35 (most components)	5-10
Metering	Four electric meters	Electric	N/A	N/A

Utility End Use Assessment

The building's energy usage type and estimated end use is displayed below.

- Gas is not used at this building.
- Electricity is used for all functions of this building.

Table 49. 2019 Site EUI by End Use – Case Study 3. Components may not sum to 100% due to rounding.

Heating – Gas	Cooling – Gas	DHW – Gas	Baseload – Gas	Heating – Electric	Cooling – Electric	DHW – Electric	Baseload – Electric	Lighting – Electric	Total EUI
0%	0%	0%	0%	12%	9%	1%	68%	10%	**100%**

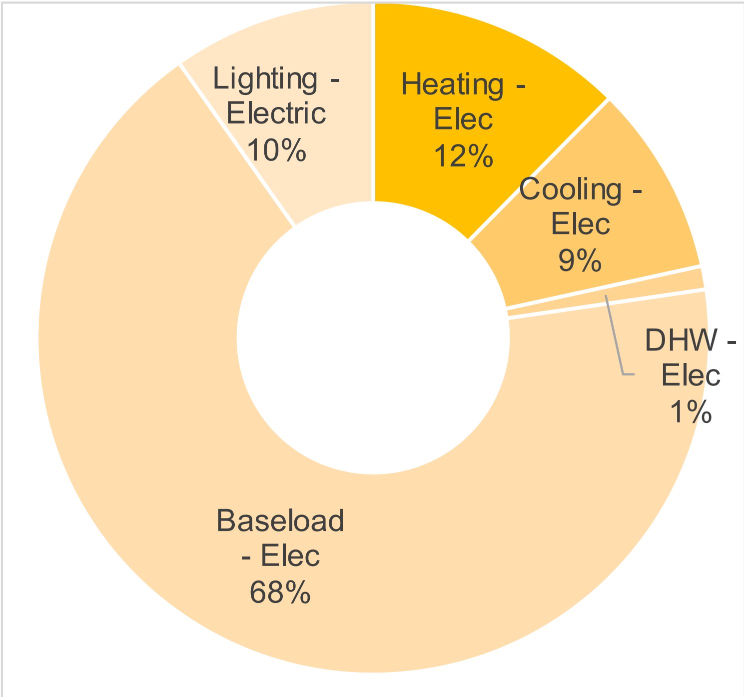

Figure 40. Site EUI Share (%) by End Use – Case Study 3

Target Determination

Site EUI targets are determined by a weighted average of applicable ZNC targets per space use type. Space use types are provided in Portfolio Manager and via reviews of available drawings. The table also has an alternate target ("EE Standard"), which is no different than the ZNC Target for this building. The building will need to take action in order to meet both the ZNC and EE Targets. All the following analysis uses the ZNC target.

Note that the floor areas shown in the table below are approximated based on Table 48.

Table 50. Space Use Target Methodology Summary – Case Study 3

Specific Space Type	Space Type Group	Area %	Floor Areas	ZNC Standard [Site EUI]	EE Standard [Site EUI]	Weighted ZNC EUI (ZNC * Area%)	Weighted EE EUI (EE * Area%)
Office	Office	100%	250,000	53.4	53.4	53.4	53.4
Total	**-**	**100%**	**250,000**	**-**	**-**	**53.4**	**53.4**

The baseline EUI is derived from whole building 2019 utility data over whole building square footage.

Table 51. ZNC and Interim Targets – Case Study 3

EUI Description	ZNC Target	EE Target
Baseline EUI	80 – 90	80 – 90
2026 – Interim Target 1	71 – 80	71 – 80
2030 – Interim Target 2	62 – 70	62 – 70
2035 – Target	53.4	53.4

Package Overview

EEM packages were compiled based on existing technology for two scenarios:

- *ZNC Target Package* is based upon electrification and energy efficiency measures to reach the ZNC Target for this building.
- *Less-than-Five-Year Payback Package* is based on the results of a package that would have a simple payback of less than five years, not accounting for supplemental funding tools such as utility incentives or tax credits.

An EE Target Package was not developed for this building as the ZNC Target is identical to the EE Target.

All costs are total costs for the measures, not incremental costs. These costs do not include applicable incentives. The following table offers a financial overview of these packages.

Table 52. EEM Package Summary – Case Study 3

Package	Package EUI (kBTU/ft.^{2}/yr)	% Site EUI Savings	Cost Savings ($/yr.)	Capital Costs ($)	SP (yrs)	ROI (%)
ZNC Target Package	47 – 53	41%	$323,900	$6,215,000	19.2	5%
Less-than-Five-Year Payback Package	57 – 64	29%	$226,600	$811,000	3.6	28%

ZNC Target Package

As some ZNC Target measures entail replacement of existing equipment, an additional column is added to Table 53 that shows the estimated remaining life of the equivalent replacement system. An “N/A” indicates the existing system is not replaced, and a “DNE” means does not exist and the package adds a system or piece of equipment not currently onsite. This is discussed in more detail in the Case Study Measures Identification Methodology section below.

Table 53. ZNC Target Package EEMs – Case Study 3. All costs are total capital cost estimates without incentives and without subtracting the cost of replacing existing systems at end of life.

Measure #	Measure	Description	Whole Bldg. EUI Svgs. (%)	Cost Savings ($/yr.)	Measure Cost ($)	SP (yrs)	ROI (%)	Equip. Life (yrs)	Estimated Remaining Life of Equivalent System (yrs)
1	Convert to VRF	Convert the mechanical system to a VRF system	25.4%	$200,600	$5,169,000	25.8	4%	18	5-10
2	Install ERV	Install an exhaust recovery ventilation unit	7.0%	$55,100	$470,000	8.5	12%	15	DNE
3	HVAC Schedule Adjustments	Adjust existing HVAC schedules to align with occupancy	3.5%	$27,900	$3,000	0.1	1,116%	5	N/A
4	Finish LED Conversion	Convert the remaining lighting systems to LED	1.4%	$10,800	$207,000	19.1	5%	10	<5
5	Plug Load Management	Install smart plug load management tools	1.4%	$11,300	$23,000	2.1	48%	10	DNE
6	Solar PV	Install roof-mounted solar PV	2.3%	$18,200	$343,000	18.8	5%	15	DNE
Total			**41.0%**	**$323,900**	**$6,215,000**	**19.2**	**5%**	**-**	

Table 54. Post Retrofit Site EUI by End Use & Percent Reductions from Baseline for ZNC Target Package – Case Study 3

Project	Heating – Gas	Cooling – Gas	DHW – Gas	Baseload – Gas	Heating – Electric	Cooling – Electric	DHW – Electric	Baseload – Electric	Lighting – Electric	Total EUI
Baseline	0%	0%	0%	0%	12%	9%	1%	68%	10%	**100%**
End Use Difference	0%	0%	0%	0%	-80%	-47%	0%	-37%	-14%	**59%**

EE Target Package

This typology has the same ZNC target as EE target; therefore, there is no separate EE target package for this building. The ZNC target package in Table 53 would also serve as an EE target package.

Less-than-Five-Year Payback Package

The Less-than-Five-Year Payback package allows the building to reach its second interim target threshold.

Table 55. Less-than-Five-Year Payback Package EEMs – Case Study 3. All costs are total capital cost estimates without incentives and without subtracting the cost of replacing existing systems at end of life.

Measure #	Measure	Description	Whole Bldg. EUI Svgs. (%)	Cost Savings ($/yr.)	Measure Cost ($)	SP (yrs)	ROI (%)	Equip. Life (yrs)
1	Install ERV	Install an exhaust recovery ventilation unit	9.6%	$75,900	$470,000	6.2	16%	15
2	HVAC Schedule Adjustments	Adjust existing HVAC schedules to align with occupancy	13.9%	$110,000	$3,000	0.0	4,400%	5
3	Retro-commissioning	Retro-commission and implement improvements on central building systems	1.6%	$12,700	$82,000	6.5	15%	5
4	Primary Chilled Water Pump VFDs	Install primary chilled water pump variable frequency drives	0.1%	$1,000	$7,000	7.3	14%	15
5	Condenser Water Pump VFDs	Install condenser water pump variable frequency drives	0.4%	$3,400	$19,000	5.5	18%	15
6	Finish LED Conversion	Convert the remaining lighting systems to LED	1.4%	$10,800	$207,000	19.1	5%	10
7	Plug Load Management	Install smart plug load management tools	1.6%	$12,800	$23,000	1.8	55%	10
	Total		**28.7%**	**$226,600**	**$811,000**	**3.6**	**28%**	**-**

Table 56. Post Retrofit Site EUI by End Use & Percent Reductions from Baseline for Less-than-Five-Year Payback Package – Case Study 3

Project	Heating – Gas	Cooling – Gas	DHW – Gas	Baseload – Gas	Heating – Electric	Cooling – Electric	DHW – Electric	Baseload – Electric	Lighting – Electric	Total EUI
Baseline	0%	0%	0%	0%	12%	9%	1%	68%	10%	**100%**
End Use Difference	0%	0%	0%	0%	-52%	-42%	0%	-25%	-14%	**71%**

Package Comparisons to ZNC Target

The following chart shows the site EUI and split between fuels today and for the EEM packages in comparison to the three Targets.

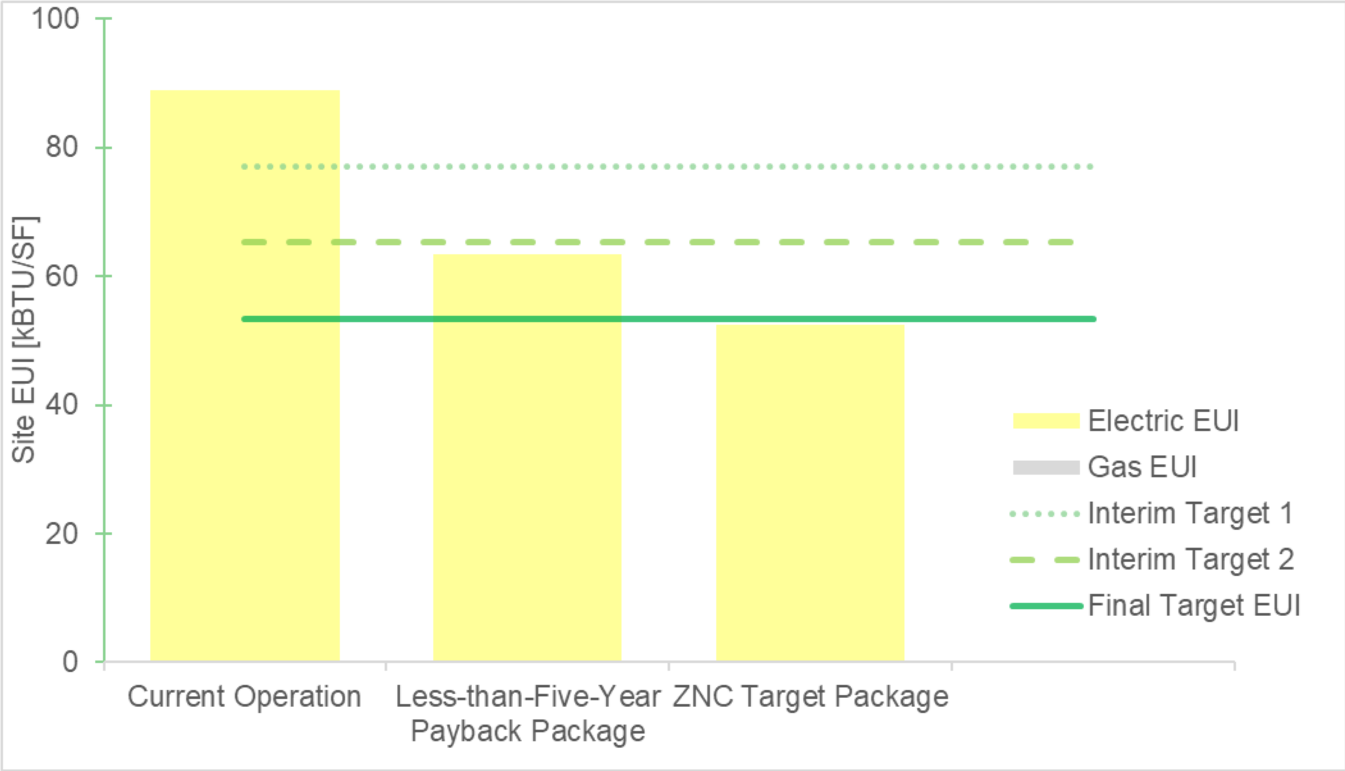

Figure 41. Target-to-Package Comparisons – Case Study 3

This building is unique among case study buildings: the Less-than-Five-Year Payback Package gets this building below the second interim target. The primary reason for this is the large reduction in energy usage from improvements in scheduling of HVAC equipment operation.

Building-Specific Technology Assessment

This office is all-electric. However, the electric heating system is relatively inefficient, and improvements are possible. This improvement can be achieved with a change to a VRF system.

VRF was determined to be a more effective measure than conversion to a heat pump loop for a handful of reasons:

- Water piping is only present in the central plant and mechanical rooms; terminal unit replacement for a WSHP loop would entail running water piping throughout the building. Refrigerant piping necessary for a VRF system is comparatively smaller.
- Removal of the existing pump loops also allows for claiming of pump and cooling tower energy savings, which is instrumental in reaching the ZNC target.

Installation of a exhaust recovery ventilation system (ERV) makes sense, as existing fresh air ductwork can be co-opted relatively easily. The combination of VRF and ERV measures consist of the major mechanical adjustments.

It should be noted that the schedule adjustments here are relatively unique. Based upon information from the building owner's staff, in 2019 this building's mechanical system was operating continually (i.e., during the technical analysis period, the building was operating continually). Since this time period, the building schedules were adjusted to run from 5:30 AM to 11 PM on each weekday, representing a 54% reduction in run-time. This type of run-time reduction is relatively uncommon across commercial typologies but was reasonable based upon information obtained at this site.

Since 2019 data was used as the baseline period, scheduling improvements were able to be claimed for both the Less-than-Five-Year and ZNC Target Packages. In the ZNC Target Package case, the schedule adjustments should be performed at the same time as the mechanical system conversions and not handled separately.

LED conversion is not needed to meet the ZNC target but can be included in the Less-than-Five-Year Target Package thanks to the large energy cost savings found from scheduling improvements. This measure is included in the ZNC Target Package since it is likely this work would occur prior to any system conversions. In addition, utility incentives are available that would help the financial performance of this measure.

Plug Load Management is applied to both packages, and solar PV is applied to the ZNC Target Package. In practice, solar PV needs to be coordinated with other measures that require roof space (e.g., VRF system installations, DOAS installation).

A handful of items appear in the Less-than-Five-Year Payback Package that are not included in the ZNC Target Package. Since the ZNC Target Package changes the type of mechanical system, the following measures are not physically possible to implement in ZNC Target Package:

- *Retro-commissioning:* similar to other building typologies with mechanical system changes, retro-commissioning for new building systems does not make practical sense. A slightly lower end use estimate for retro-commissioning is taken for conservative reasons; in practice, the schedule adjustments seen at this building are likely *not* typical for this typology. However, combined savings of scheduling plus retro-commissioning may be reasonable. SWA assumed that some of the savings that would typically be seen via retro-commissioning are instead realized via schedule adjustments.
- *Primary Chilled Water Pump VFDs and Condenser Water Pump VFDs:* these systems appear in the baseline building but not in the new mechanical systems, as the VRF system does not have these loops.

Package Comparisons

Although this building can reach its ZNC target with technology available today, doing so incurs a significant cost and substantial disruption. There are some ways to reduce compliance retrofit costs:

- Other detailed savings measures for the existing building mechanical systems *may* be enough to reach ZNC. These types of improvements may be possible with a more detailed look at the building, which is outside the scope of this technical analysis. With enough additional realized savings, this may render other upgrades such as air sealing or installing a DOAS unnecessary to reach ZNC.
- A substantial renovation occurring between now and 2035 may trigger some method of outdoor heat recovery due to code requirements (i.e, the DOAS installation). Although this work would have to take place and be paid for regardless, if a DOAS is installed for code compliance reasons, this would not be a cost associated with compliance with the ZNC target.
- Some of the total capital cost may be effectively defrayed by accounting for avoided replacement costs of existing mechanical equipment. For example, most mechanical equipment would likely be replaced before the 2035 target. This money can be effectively set aside to help cover part of the costs.
- Financing methods such as the Montgomery County Green Bank are viable.
- Utility incentives through the EmPOWER Maryland program may help offset upfront costs. While not a significant amount relative to the overall project investment, these funds are available today. Funds are available on three-year cycles and the program offerings can change during the program cycle; based on this, incentive estimates are not included in this report.

The Less-than-Five-Year Payback Package largely utilizes retrofits to existing equipment. Applying a higher estimated savings for retro-commissioning may be possible.

If the ZNC Target is unattainable or economically infeasible for this building, the owner may want to consider filing a Building Performance Improvement Plan.

Measures Not Recommended

Measures reviewed for the building but not included in the EEM package are described below.

- Building Controls: existing pneumatic controls located in individual spaces are a likely source of significant energy waste; however, developing costs for this measure is highly site-specific and beyond the scope of this case study. Based on generally accepted practices, this measure would likely have not applied for the Less-than-Five-Year Payback Package due to costs and would not be applicable to the ZNC Target Package as the pneumatic VAV controls would have been converted to a new mechanical system.
- DHW: domestic hot water is a minimal load in office buildings and was not examined.
- Envelope: envelope measures were not necessary to meet the ZNC Target.

General Methodology Applied to All Case Studies

The following text describes components of this technical analysis that were applied to all case studies about EEM Package Development, Building Desktop Audits, and Utility Rates. After those sections are discussions of the analysis methodology applied specifically to this case study.

EEM Package Development

Three packages of EEMs were developed.

Zero Net Carbon-Compatible (ZNC) Target Package

This package compiles measures necessary to meet the Zero Net Carbon-Compatible target for the respective building. These measures typically include electrification of natural gas uses. The aim of this package was to create a series of measures that result in the ability of the case study building to meet the ZNC target. Project financials were not a primary driver, but financially desirable measures were included wherever possible.

Descriptions of each package are included in the individual case studies below.

The methodology for developing these packages was generally as follows:

- Potential electrification measures were implemented first when determined they were necessary to meet the ZNC target. This was done for two reasons:
  - Electrified end uses were typically large (i.e., all of a building's heating loads), and
  - Other measures' applicability may change based on these electrified systems. Note that for packages where mechanical systems were changed, some measures that are appropriate based on *existing mechanical equipment* may not be included in the ZNC package. However, they may appear in the Less-than-Five-Year Payback Package.
- Next, measures with large interactive effects were reviewed. These measures were typically either mechanical or controls-based in nature.
- Next, smaller end use reduction measures with limited interactive effects were implemented. These measures typically have a small impact (i.e., less than 5% of overall building usage).
- Lastly, where applicable and necessary, photovoltaic solar (PV) was applied.

Energy Efficiency (EE) Target Package (Not Applicable for this Case Study)

This package compiles measures necessary to meet the Energy Efficiency target for the respective building. Initial analysis returned multiple ways to think about developing an approach, each with pros and cons. These can be found in Table 57 below.

Table 57: General approaches to developing an EE Target Package.

Package Type	Pros	Cons	Other Items
Fewest Measures	• Simplest to implement • Easiest to understand	• Higher cost and lower ROI	• Electrification of some end uses guaranteed
Best ROI that Meets the EE Target	• Most attractive financial package • Best speaks to financial concerns	• Still will electrify some loads • Better ROI may not be the easiest to implement measures	• This will likely introduce partial electrification of end uses to the study
Minimize Electrification	• Best speaks to the theory behind the EE package	• Would necessitate replacement of gas-fired equipment with new gas-fired equipment	• May not really be viable with case study buildings (but could be viable with other buildings)

This study opted to use the Best ROI that Meets the EE Target approach. The following guidelines apply to this approach:

- Electrification of end uses needed to be considered in practice. Most case study buildings were far enough away from the EE Target that reaching the EE Target without electrification was infeasible without significant occupant energy pattern changes[56].
- Electrification of DHW loads was considered first. Most mechanical systems (which include space heating systems) have low-cost opportunities for optimization while most DHW systems have limited optimization opportunities. This means the combined mechanical system optimization measures plus DHW electrification had a more attractive ROI than space heating electrification measures.
- Mechanical system optimization and retro-commissioning measures were then implemented.
- Next, smaller end use reduction measures with limited interactive effects were implemented. These measures typically have a small impact (i.e., less than 5% of overall building usage).
- Electrification of space heating loads was considered only if electrification of DHW loads was not enough in conjunction with other measures to meet the EE Target *and* minimal system optimization was possible.
- Lastly, where applicable and necessary, photovoltaic solar (PV) was applied.

Less-than-Five-Year Payback Package

This package compiles a set of measures that results in a five year or less total simple payback. This package represents a reasonable approximation of possible outcomes from an energy audit. These measure packages represent the types of low cost and lower-savings measures often recommended during standard energy audits. These measures are often investigated by buildings first. Note that an energy audit may include other financial tools such as utility incentives, tax deductions/credits, or other assistance, which were not included in this technical analysis.

Where applicable, measures from the Less-than-Five-Year Payback Package were also applied to the ZNC Package. The methodology described under the ZNC Target Package applied to the Less-than-Five-Year Payback Package as well. The following guidelines apply to the Less-than-Five-Year Payback Package:

[56] Energy conservation by occupants can drive significant energy savings (EPA, slide 33). Because of the difficulty in predicting savings (and the persistence of savings) for these sorts of behavioral measures in typical buildings, those savings are not included in this study.

- Measures with large interactive effects were reviewed. These measures were typically either mechanical or controls-based in nature.
- Retro-commissioning was applied; see below for details.
- Next, smaller end use reduction measures with limited interactive effects were implemented. These measures typically have a small impact (i.e., less than 5% of overall building usage).
- Lastly, where applicable and necessary, photovoltaic solar (PV) was applied.
- Major building systems were *not* modified in this package. Most system conversions (for example, converting from chilled water to water-source heat pumps) have longer paybacks and would not realistically be included. However, this also means that measures that impact *existing mechanical equipment* would appear here (for example, chilled water pump VFDs when the ZNC Target Package converted a building from chilled water to water-source heat pumps).
- New fossil fuel measures were not included.
- Overall energy savings were not a primary goal of this target; the energy savings resulting from this package was simply the end result of measures that would result in a less than five year project payback for all measures considered.

Typically, this package may be useful in reviewing progress toward interim targets.

Note that for some newer buildings that have less opportunity for low-cost incremental savings, the Less-than-Five-Year Payback Package may be either small or non-existent.

Building Desktop Audits

Case studies were developed through interviews with building managers and site staff to collect – for major equipment only – equipment type, equipment age, operating parameters, types of fuel used for various end uses, information on recent capital upgrades, and any comments on plans for future upgrades and decision-making processes in relation to energy management. Architectural and mechanical drawings and supporting documentation were reviewed when available.

Desktop audits were performed in order to develop the case studies contained in this report. Desktop audits use information provided from building owners and operators to develop recommendations, but do not contain any onsite observations. This methodology is effective for informing policy-level decisions as it can effectively capture broad-stroke approaches; however, this methodology does not tend to capture measures are more limited in impact (e.g., mechanical systems that only serve part of the building). Applicability of desktop audit measures to a specific building typically requires some amount of onsite investigation in order to determine applicability of measures for any specific building in a given typology. This technical analysis is limited to desktop audits and measure recommendations are limited to what could be recommended based on the data collected by the auditor.

Where possible, supplemental energy audit information performed by others is incorporated into the case studies. These energy audits, which may contain onsite observations, were completed prior to this desktop audit process.

Utility Rates

Utility rate assumptions are $0.129 per kWh and $1.228 per therm, based on the US Energy Information Administration (EIA) average rates for the area. While energy rates differ by service class and usage profile, these rates are assumed to represent the average costs for these types of buildings in Montgomery County. These rates are meant to be inclusive of taxes and fees applicable throughout the state, including the current Fuel Energy Tax of $0.01978 per kWh on electricity and $0.17026 per therm on natural gas use.

Case Study 4: New High-Rise Mixed-Use Multifamily

Building Information

This is a newer multifamily complex of two buildings; since this complex has no shared building systems or physical connections between buildings, only one building in this complex was chosen for the case study. This building has first floor retail, which is a mix of restaurants and other general-purpose retail. The site contains both above ground and below grade parking. The building has in-unit electric heating and cooling systems and in-unit electric water heating that residents pay for, as well as shared common and amenity areas.

Table 58. Building Characteristics – Case Study 4

Category	Building Information
Typology	Multifamily
Square Footage	125,000 ft.^{2} – 150,000 ft.^{2} Multifamily: 92% Retail: 3% Restaurant: 2% Fitness Centers: 3%
Year Built	2000 – 2005
2019 ENERGY STAR Score	20 – 25
2019 Site EUI (kBTU/SF) (calculated for this study)	50 – 60

Building System Information

The basic building system information specific to the case study building is described below.

Table 59. Building System Information – Case Study 4

Category	Type	Fuel	Approximate Equipment Age (Years)	Expected End of Useful Life (Years)
Central BMS	None	N/A	N/A	N/A
Heating	Each apartment has ducted heat pumps with electric resistance backup	Electric	Unknown (estimated 20 years)	<5
Cooling	Each apartment has ducted A/C with individual in-unit condenser equipment going through the wall	Electric	Unknown (estimated 20 years)	<5
Ventilation	DOAS units for hallways, fresh air delivered to apartments via undercuts on the door to each apartment	Electric/Gas	Unknown (estimated 20 years)	<5
DHW	Electric resistance water heaters in each apartment	Electric	Unknown (estimated 20 years)	<5
Lighting	Mostly converted to LED except for corridors and apartment fixtures	Electric	0-5	5-10
Envelope	Windows – double insulated window w/ thermal break. Wood frame construction and insulation	N/A	Windows: ~10 years, Frame: ~20 years	25-30
Metering	Apartments separately metered, retail separately metered	Electric/Gas	N/A	N/A
Other	Outdoor Pool, in-unit washer/dryer, dishwasher, disposal	Electric	Unknown (estimated 10 years)	Unknown (appliances likely 0-2 years; pool 5-10 years)

Utility End Use Assessment

The building's energy usage type and estimated end use is displayed below.

- Gas: used in the retail spaces including restaurant or retail cooking and possibly their respective domestic hot water or heating needs. Gas is also used to heat outdoor air for the corridors. Gas makes up 13% of the building's site energy use.
- Electricity: used for nearly all needs in the multifamily portion of the building, including cooking, heating, and domestic hot water for apartments. Electricity makes up 87% of the building's site energy use.

Table 60. 2019 Site EUI by End Use – Case Study 4. Components may not sum to 100% due to rounding.

Heating – Gas	Cooling – Gas	DHW – Gas	Baseload – Gas	Heating – Elec	Cooling – Elec	DHW – Elec	Baseload – Elec	Lighting – Electric	Total EUI
9%	0%	0%	4%	16%	10%	21%	34%	6%	**100%**

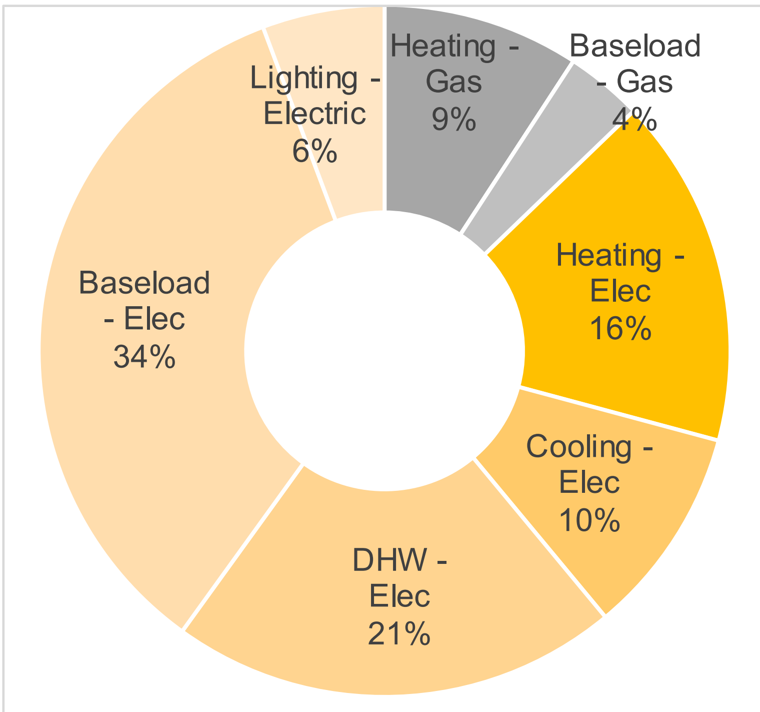

Figure 42. Site EUI Share (%) by End Use – Case Study 4

Target Determination

Site EUI targets are determined by a weighted average of applicable ZNC targets per space use type. Space use types are provided in Portfolio Manager and via reviews of available drawings. The table also has an alternate target ("EE Standard"), which is higher than the current EUI of the building, indicating that the building would not need to take any action beyond maintaining current performance if the EE Standard was used. The building will need to take action in order to meet the ZNC Target. All the following analysis uses the ZNC target.

Note that the floor areas shown in the table below are approximated based on Table 59.

Table 61. Space Use Target Methodology Summary – Case Study 4

Specific Space Type	Space Type Group	Area %	Floor Areas	ZNC Standard [Site EUI]	EE Standard [Site EUI]	Weighted ZNC EUI (ZNC * Area%)	Weighted EE EUI (EE * Area%)
Multifamily Housing	Multifamily	92%	125,000	35.4	55.1	32.5	50.7
Retail Store	Mercantile Retail (other than mall)	3%	5,000	45.3	53.4	1.4	1.6
Restaurant	Food Service	2%	5,000	170.6	249.7	2.7	3.9
Fitness Center	Public Assembly	3%	5,000	61.3	83.0	2.1	2.8
Total	**-**	**100%**	**140,000**	**-**	**-**	**38.7**	**59.1**

The baseline EUI is derived from whole building 2019 utility data over whole building square footage.

Table 62. ZNC and Interim Targets – Case Study 4

EUI Description	ZNC Target	EE Target
Baseline EUI	50 – 60	50 – 60
2029 – Interim Target 1	46 – 53	50 – 60
2033 – Interim Target 2	42 – 47	50 – 60
2037 – Target	38.7	59.1

Package Overview

EEM packages were compiled based on existing technology for two scenarios:

- *ZNC Target Package* is based upon electrification and energy efficiency measures to reach the ZNC Target for this building.
- *Less-than-Five-Year Payback Package* is based on the results of a package that would have a simple payback of less than five years, not accounting for supplemental funding tools such as utility incentives or tax credits.

An EE Target Package was not developed for this building as this building is below the EE Target.

All costs are total costs for the measures, not incremental costs. These costs do not include applicable incentives. The following table offers a financial overview of the packages.

Table 63. EEM Package Summary – Group 4 Case Study 4

Package	Package EUI (kBTU/ft.^{2}/yr)	% Site EUI Savings	Cost Savings ($/yr.)	Capital Costs ($)	SP (yrs)	ROI (%)
ZNC Target Package	35 – 38	28%	$45,000	$1,434,000	31.9	3%
Less-than-Five-Year Payback Package	50 – 60	1%	$1,500	$5,000	3.5	28%

ZNC Target Package

As some ZNC Target measures entail replacement of existing equipment, an additional column is added to Table 64 that shows the estimated remaining life of the equivalent replacement system. A "N/A" indicates the existing system is not replaced, and a "DNE" means does not exist and the package adds a system or piece of equipment not currently onsite. This is discussed in more detail in the Case Study Measures Identification Methodology section below.

Table 64. ZNC Target Package EEMs – Case Study 4. All costs are total capital cost estimates without incentives and without subtracting the cost of replacing existing systems at end of life.

Measure #	Measure	Description	Whole Bldg. EUI Svgs. (%)	Cost Savings ($/yr.)	Measure Cost ($)	SP (yrs)	ROI (%)	Equip. Life (yrs)	Estimated Remaining Life of Equivalent System (yrs)
1	DOAS Conversion to Electric	Install a dedicated electric outdoor air system with heat recovery capabilities	7.2%	$2,600	$323,000	123.3	1%	15	<5
2	Electrify Retail and Restaurant	Convert tenant gas use to electric	1.4%	($2,600)	$15,000	N/A	N/A	10	Unknown (estimating 5-10)
3	Add Programmable Thermostats	Add programmable thermostats to apartments, provide instructions to occupants on use	0.8%	$2,000	$67,000	33.5	3%	10	Existing thermostats likely <10
4	High-Efficiency Water Aerators	Install low flow aerators in faucets and showers	0.6%	$1,500	$5,000	3.5	28%	10	DNE
5	Solar PV	Install canopied solar PV	16.2%	$41,500	$1,025,000	24.7	4%	15	DNE
Total			**26.2%**	**$45,000**	**$1,435,000**	**31.9**	**3%**	**-**	

Table 65. Post Retrofit Site EUI by End Use & Percent Reductions from Baseline for ZNC Target Package – Case Study 4

Project	Heating – Gas	Cooling – Gas	DHW – Gas	Baseload – Gas	Heating – Electric	Cooling – Electric	DHW – Electric	Baseload – Electric	Lighting – Electric	Total EUI
Baseline	9%	0%	0%	4%	16%	10%	21%	34%	6%	**100%**
End Use Difference	-100%	0%	0%	-100%	10%	-2%	-3%	-41%	0%	**74%**

EE Target Package

This building already meets the EE target; no EE package was developed.

Less-than-Five-Year Payback Package

The Less-than-Five-Year Payback package does not allow the building to meet any interim targets.

Table 66. Less-than-Five-Year Payback Package EEMs – Case Study 4. All costs are total capital cost estimates without incentives and without subtracting the cost of replacing existing systems at end of life.

Measure #	Measure	Description	Whole Bldg. EUI Svgs. (%)	Cost Savings ($/yr.)	Measure Cost ($)	SP (yrs)	ROI (%)	Equip. Life (yrs)
1	High-Efficiency Water Aerators	Install low flow aerators in faucets and showers	0.6%	$1,500	$5,000	3.5	28%	10
	Total		**0.6%**	**$1,500**	**$5,000**	**3.5**	**28%**	**-**

Table 67. Post Retrofit Site EUI by End Use & Percent Reductions from Baseline for Less-than-Five-Year Payback Package – Case Study 4

Project	Heating – Gas	Cooling – Gas	DHW – Gas	Baseload – Gas	Heating – Electric	Cooling – Electric	DHW – Electric	Baseload – Electric	Lighting – Electric	Total EUI
Baseline	9%	0%	0%	4%	16%	10%	21%	34%	6%	**100%**
End Use Difference	0%	0%	0%	0%	0%	0%	-3%	0%	0%	**99%**

Package Comparisons to ZNC Target

The following chart shows the site EUI and split between fuels today and for the EEM packages in comparison to the three Targets.

Figure 43. Target-to-Package Comparisons – Case Study 4

As seen in Figure 43, viable measures apply to the ZNC Target Package. However, the ZNC target is well within range for this typology.

Building-Specific Technology Assessment

This multifamily building is a newer building; the only current gas usage in the apartment building is to heat outdoor air for the hallways. Electrification at this building entails converting that outdoor air unit and any restaurant or retail gas usage.

The heating, cooling, and hot water systems in the building use a large portion of the building's energy and upgrades to that equipment may result in energy savings. However, upgrades to this distributed equipment in each apartment would be highly intrusive to residents. Additionally, the equipment is already all electric and while the space and water heating equipment could be upgraded to heat pumps to improve efficiency, the savings may not justify the disruption to tenants. Therefore, improvements to the space heating/cooling and water heating are not included in this package.

Programmable thermostats could improve existing technology while providing an amenity to residents. Programmable thermostat savings are highly dependent upon each resident's actions to ensure that schedules are created and maintained. Actual realized savings for this measure may be notably more or less than the estimated amount.

Following these considerations, other measures affecting building energy demand were then chosen (items like LED lighting conversions and high-efficiency aerators). These measures did not have a large overall impact on savings and were generally non-interactive in nature, meaning any resultant savings from these measures do not appreciably increase or decrease savings from other measures.

Lastly, solar PV was applied. This building has a relatively complex roof structure with both flat and pitched sections, and mechanical equipment distributed on the roof. For this building, a canopy solar PV system was evaluated. A canopy solar PV system is structured to sit above the roof over other equipment. The parking garage for this building is underground, so there is no opportunity to incorporate solar PV on the garage.

Package Comparisons

Reaching the ZNC target for this building is a relatively simple exercise through building upgrades but is not particularly cost effective from a total cost perspective. Most other building typologies take advantage of the savings offered by the Less-than-Five-Year Payback Package to build cost savings to pay for the ZNC Target Package. In this building, there are not measures with high energy cost savings potential to improve the overall package economics.

There are some ways to reduce compliance retrofit costs:

- Some of the total capital cost may be effectively defrayed by accounting for avoided replacement costs of existing mechanical equipment. For example, most mechanical equipment would likely be replaced before the 2035 target. This money can be effectively set aside to help cover parts of the costs.
- Financing methods such as the Montgomery County Green Bank are viable.
- Utility incentives through the EmPOWER Maryland program may help offset upfront costs. While not a significant amount relative to the overall project investment, these funds are available today. These funds are available on three-year cycles, and the program offerings can change during the program cycle, so incentive estimates are not included in this report.

Measures Not Recommended

Measures reviewed for the building but not included in the EEM package are described below.

- HVAC: upgrades to resident heating and cooling equipment to use variable refrigerant flow (VRF) systems would decrease energy use, but because the in-unit heating is already a heat pump with supplemental electric resistance, the savings would be relatively small. This measure would also be highly intrusive to tenants unless completed at apartment turnover across a longer time horizon. Still, long term improvements to in-unit HVAC equipment would gradually decrease whole building electricity use, which can contribute to meeting the performance standard. Given the age of the HVAC systems it is likely some upgrade to the HVAC system is needed prior to 2035; at this time, a VRF system should be considered. However, it was not necessary in this package to meet the ZNC.

- Retro-commissioning: the main benefits from retro-commissioning would be from reviewing and adjusting in-unit HVAC, as that makes up the majority of the heating and cooling energy use. Typically, retro-commissioning is done on large pieces of base building equipment. Most base building equipment replacement is part of the ZNC package, and new equipment would be commissioned as part of the installation process. The maintenance of in-unit equipment is performed by building staff when apartment access is feasible, such as at apartment turnover. A short-term effort to retro-commissioning in-unit equipment would be a highly intrusive process as it would require building staff to enter each apartment and investigate each piece of equipment. Persistence of savings would also be difficult to maintain, as it would require each occupant to commit to not making individual adjustments through the lifetime of the equipment.
- Lighting: completing an LED conversion was reviewed. Conversion options for existing 4-pin fixtures do exist but were determined to be a less cost-effective measure than other measures included within the ZNC Target Package. Utility incentives may help defray some of these costs.
- Appliances: Conversion of in-unit appliances to high-efficiency was reviewed. Similar to lighting, this conversion can occur but would not be as cost-effective as other measures included within the ZNC Target Package.
- Domestic hot water: The in-unit water heaters are electric resistance and upgrading to heat pump water heaters would be a difficult and costly measure. The energy savings from heat pump water heaters was not needed to reach the ZNC target and would be highly intrusive.
- Envelope: Envelope measures are not needed for this building to reach the ZNC target. Being a recently constructed building, the wall and window insulation levels are adequate, making upgrades less cost effective resulting in less energy savings.

General Methodology Applied to All Case Studies

The following text describes components of this technical analysis that were applied to all case studies about EEM Package Development, Building Desktop Audits, and Utility Rates. After those sections are discussions of the analysis methodology applied specifically to this case study.

EEM Package Development

Three packages of EEMs were developed.

Zero Net Carbon-Compatible (ZNC) Target Package

This package compiles measures necessary to meet the Zero Net Carbon-Compatible target for the respective building. These measures typically include electrification of natural gas uses. The aim of this package was to create a series of measures that result in the ability of the case study building to meet the ZNC target. Project financials were not a primary driver, but financially desirable measures were included wherever possible.

Descriptions of each package are included in the individual case studies below.

The methodology for developing these packages was generally as follows:

- Potential electrification measures were implemented first when determined they were necessary to meet the ZNC target. This was done for two reasons:
    - Electrified end uses were typically large (i.e., all of a building's heating loads), and
    - Other measures' applicability may change based on these electrified systems. Note that for packages where mechanical systems were changed, some measures that are appropriate based on *existing mechanical equipment* may not be included in the ZNC package. However, they may appear in the Less-than-Five-Year Payback Package.
- Next, measures with large interactive effects were reviewed. These measures were typically either mechanical or controls-based in nature.

- Next, smaller end use reduction measures with limited interactive effects were implemented. These measures typically have a small impact (i.e., less than 5% of overall building usage).
- Lastly, where applicable and necessary, photovoltaic solar (PV) was applied.

Energy Efficiency (EE) Target Package (Not Applicable for this Case Study)

This package compiles measures necessary to meet the Energy Efficiency target for the respective building. Initial analysis returned multiple ways to think about developing an approach, each with pros and cons. These can be found in Table 68 below.

Table 68: General approaches to developing an EE Target Package.

Package Type	Pros	Cons	Other Items
Fewest Measures	• Simplest to implement • Easiest to understand	• Higher cost and lower ROI	• Electrification of some end uses guaranteed
Best ROI that Meets the EE Target	• Most attractive financial package • Best speaks to financial concerns	• Still will electrify some loads • Better ROI may not be the easiest to implement measures	• This will likely introduce partial electrification of end uses to the study
Minimize Electrification	• Best speaks to the theory behind the EE package	• Would necessitate replacement of gas-fired equipment with new gas-fired equipment	• May not really be viable with case study buildings (but could be viable with other buildings)

This study opted to use the Best ROI that Meets the EE Target approach. The following guidelines apply to this approach:

- Electrification of end uses needed to be considered in practice. Most case study buildings were far enough away from the EE Target that reaching the EE Target without electrification was infeasible without significant occupant energy pattern changes[57].
- Electrification of DHW loads was considered first. Most mechanical systems (which include space heating systems) have low-cost opportunities for optimization while most DHW systems have limited optimization opportunities. This means the combined mechanical system optimization measures plus DHW electrification had a more attractive ROI than space heating electrification measures.
- Mechanical system optimization and retro-commissioning measures were then implemented.
- Next, smaller end use reduction measures with limited interactive effects were implemented. These measures typically have a small impact (i.e., less than 5% of overall building usage).
- Electrification of space heating loads was considered only if electrification of DHW loads was not enough in conjunction with other measures to meet the EE Target *and* minimal system optimization was possible.
- Lastly, where applicable and necessary, photovoltaic solar (PV) was applied.

Less-than-Five-Year Payback Package

This package compiles a set of measures that results in a five year or less total simple payback. This package represents a reasonable approximation of possible outcomes from an energy audit. These measure packages

[57] Energy conservation by occupants can drive significant energy savings (EPA, slide 33). Because of the difficulty in predicting savings (and the persistence of savings) for these sorts of behavioral measures in typical buildings, those savings are not included in this study.

represent the types of low cost and lower-savings measures often recommended during standard energy audits. These measures are often investigated by buildings first. Note that an energy audit may include other financial tools such as utility incentives, tax deductions/credits, or other assistance, which were not included in this technical analysis.

Where applicable, measures from the Less-than-Five-Year Payback Package were also applied to the ZNC Package. The methodology described under the ZNC Target Package applied to the Less-than-Five-Year Payback Package as well. The following guidelines apply to the Less-than-Five-Year Payback Package:

- Measures with large interactive effects were reviewed. These measures were typically either mechanical or controls-based in nature.
- Retro-commissioning was applied; see below for details.
- Next, smaller end use reduction measures with limited interactive effects were implemented. These measures typically have a small impact (i.e., less than 5% of overall building usage).
- Lastly, where applicable and necessary, photovoltaic solar (PV) was applied.
- Major building systems were *not* modified in this package. Most system conversions (for example, converting from chilled water to water-source heat pumps) have longer paybacks and would not realistically be included. However, this also means that measures that impact *existing mechanical equipment* would appear here (for example, chilled water pump VFDs when the ZNC Target Package converted a building from chilled water to water-source heat pumps).
- New fossil fuel measures were not included.
- Overall energy savings were not a primary goal of this target; the energy savings resulting from this package was simply the end result of measures that would result in a less than five year project payback for all measures considered.

Typically, this package may be useful in reviewing progress toward interim targets.

Note that for some newer buildings that have less opportunity for low-cost incremental savings, the Less-than-Five-Year Payback Package may be either small or non-existent.

Building Desktop Audits

Case studies were developed through interviews with building managers and site staff to collect – for major equipment only – equipment type, equipment age, operating parameters, types of fuel used for various end uses, information on recent capital upgrades, and any comments on plans for future upgrades and decision-making processes in relation to energy management. Architectural and mechanical drawings and supporting documentation were reviewed when available.

Desktop audits were performed in order to develop the case studies contained in this report. Desktop audits use information provided from building owners and operators to develop recommendations, but do not contain any onsite observations. This methodology is effective for informing policy-level decisions as it can effectively capture broad-stroke approaches; however, this methodology does not tend to capture measures are more limited in impact (e.g., mechanical systems that only serve part of the building). Applicability of desktop audit measures to a specific building typically requires some amount of onsite investigation in order to determine applicability of measures for any specific building in a given typology. This technical analysis is limited to desktop audits and measure recommendations are limited to what could be recommended based on the data collected by the auditor.

Where possible, supplemental energy audit information performed by others is incorporated into the case studies. These energy audits, which may contain onsite observations, were completed prior to this desktop audit process.

Utility Rates

Utility rate assumptions are $0.129 per kWh and $1.228 per therm, based on the US Energy Information Administration (EIA) average rates for the area. While energy rates differ by service class and usage profile, these rates are assumed to represent the average costs for these types of buildings in Montgomery County. These rates are meant to be inclusive of taxes and fees applicable throughout the state, including the current Fuel Energy Tax of $0.01978 per kWh on electricity and $0.17026 per therm on natural gas use.

Case Study 5: Old High-Rise Affordable Multifamily

Building Information

This is an older high-rise multifamily building. It underwent a substantial internal and external renovation within the last decade, including new double-paned windows, central cooling, and solar hot water collector system. Heating and cooling are provided to apartments via a fan-coil distribution system.

Table 69. Building Characteristics – Case Study 5

Category	Building Information
Typology	Multifamily
Square Footage	125,000 ft.^{2} – 150,000 ft.^{2} Multifamily Housing: 100%
Year Built	1965 – 1970
2019 ENERGY STAR Score	N/A*
2019 Site EUI (kBTU/SF)	70 – 80

**This building was not benchmarked, as multifamily buildings are not required to benchmark under the County's Benchmarking Law at the time of this case study's completion.*

Building System Information

The basic building system information specific to the case study building is described below.

Table 70. Building System Information – Case Study 5

Category	Type	Fuel	Approximate Equipment Age (Years)	Expected End of Useful Life (Years)
Central BMS	None	N/A	N/A	N/A
Heating	2x gas-fired boilers, which also serve supplemental DHW, hydronic heating distribution	Gas	8	15-20
Cooling	1x 150-ton screw chiller; fan coils in apartments. Both heating and cooling supplied via two-pipe system (i.e., system can only operate in heating or cooling)	Electric	8	15-20
Ventilation	2x rooftop units with gas heat and electric compressors	Electric (cooling); gas (heating)	8	10-15
DHW	Solar DHW with heating boilers as backup	Solar / gas	8	10 (solar) 15-20 (boilers)
Lighting	Most lighting converted to LED	Electric	3	5-8
Envelope	Windows upgraded recently; rest of envelope original	N/A	8 (windows); ~50 years (others)	~30 years (windows); 5-15 years (other envelope components)
Metering	Centrally metered electric and gas	Electric, Gas	N/A	N/A

Utility End Use Assessment

The building's energy usage type and estimated end use are displayed below.

- Gas: used for heating and domestic hot water plus in-unit cooking. Sixty-eight percent of the building's energy use is in the form of gas. The solar hot water collectors serve to partially offset some of the domestic hot water load.
- Electricity: used for cooling, ventilation, lighting, and electric plug loads. Thirty-two percent of the building's energy use is in the form of electricity.

Table 71. 2019 Site EUI by End Use – Case Study 5. Components may not sum to 100% due to rounding.

Heating – Gas	Cooling – Gas	DHW – Gas	Baseload – Gas	Heating – Electric	Cooling – Electric	DHW – Electric	Baseload – Electric	Lighting – Electric	Total EUI
46%	0%	16%	6%	0%	5%	0%	24%	3%	**100%**

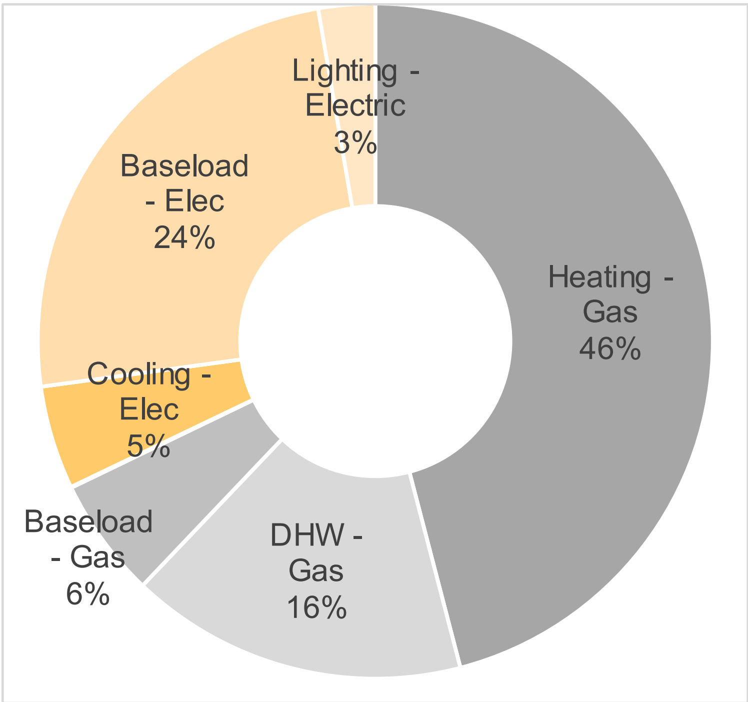

Figure 44. Site EUI Share (%) by End Use – Case Study 5

Target Determination

EUI targets are determined by a weighted average of applicable ZNC targets per space use type. Space use types are provided in Portfolio Manager and via reviews of available drawings. The table also has an alternate target ("EE Standard"); the building will need to take action in order to meet both the ZNC and EE Targets. All the following analysis uses the ZNC target.

Table 72. Space Use Target Methodology Summary – Case Study 5

Specific Space Type	Space Type Group	Area %	Floor Areas	ZNC Standard [Site EUI]	EE Standard [Site EUI]	Weighted ZNC EUI (ZNC * Area%)	Weighted EE EUI (EE * Area%)
Multifamily Housing	Multifamily	100%	125,000	35.4	55.1	35.4	55.1
Total	**-**	**100%**	**125,000**	**-**		**35.4**	**55.1**

The baseline EUI is derived from whole building 2019 utility data over whole building square footage.

Table 73: ZNC and Interim Targets – Case Study 5

EUI Description	ZNC Target	EE Target
Baseline EUI	70 – 80	70 – 80
2029 – Interim Target 1	58 – 65	65 – 72
2033 – Interim Target 2	45 – 50	60 – 65
2037 –Target	35.4	55.1

Package Overview

EEM packages were compiled based on existing technology for two scenarios:

- *ZNC Target Package* is based upon electrification and energy efficiency measures to reach the ZNC Target for this building.
- *EE Target Package* is based upon energy efficiency measures to reach the EE Target for this building. Note that the ZNC Target Package can also be used to reach the EE Target, but the EE Target Package reduces EUI only as far as needed to meet the EE Target.
- *Less-than-Five-Year Payback Package* is based on the results of a package that would have a simple payback of less than five years, not accounting for supplemental funding tools such as utility incentives or tax credits.

All costs are total costs for the measures, not incremental costs. These costs do not include applicable incentives. The following table offers a financial overview of these packages.

Table 74. EEM Package Summary – Case Study 5

Package	Package EUI (kBTU/ft.^{2}/yr)	% Site EUI Savings	Cost Savings ($/yr.)	Capital Costs ($)	SP (yrs)	ROI (%)
ZNC Target Package	32 – 35	53%	$38,900	$2,221,000	57.1	2%
EE Target Package	50 – 57	28%	$46,000	$1,293,000	28.3	4%
Less-than-Five-Year Payback Package	64 – 73	9%	$31,700	$89,000	2.8	32%

ZNC Target Package

As some ZNC Target measures entail replacement of existing equipment, an additional column is added to Table 75 that shows the estimated remaining life of the equivalent replacement system. An "N/A" indicates the existing system is not replaced, and a "DNE" means does not exist and the package adds a system or piece of equipment not currently onsite. This is discussed in more detail in the Case Study Measures Identification Methodology section below.

Table 75. ZNC Target Package EEMs – Case Study 5. All costs are total capital cost estimates without incentives and without subtracting the cost of replacing existing systems at end of life.

#	Measure	Description	Whole Bldg. EUI Svgs. (%)	Cost Savings ($/yr.)	Measure Cost ($)	SP (yrs)	ROI (%)	Equip. Life (yrs)	Estimated Remaining Life of Equivalent System (yrs)
1	Electrify Space Heating	Convert the central mechanical system to an air-to-water heat pump system	35.4%	$15,300	$1,294,000	84.7	1%	15	15-20
2	Electrify DHW	Convert domestic hot water gas heating to electric air-to-water heat pump systems	10.1%	($2,800)	$625,000	N/A	N/A	15	15-20
3	Central Plant Pump VFDs	Install variable frequency drives on central distribution pumps	2.9%	$10,300	$8,000	0.8	131%	15	DNE
4	Booster Pump VFDs	Install variable frequency drives on domestic water booster pumps	0.4%	$1,400	$5,000	3.7	27%	15	DNE
5	High-Efficiency Water Aerators	Install high-efficiency aerators in faucets and showers	0.2%	$600	$5,000	8.4	12%	10	DNE
6	Solar PV	Install roof-mounted solar PV	4.0%	$14,100	$284,000	20.1	5%	15	DNE
Total			**53.0%**	**$38,900**	**$2,221,000**	**57.1**	**2%**	**-**	

Table 76: Post Retrofit Site EUI by End Use & Percent Reductions from Baseline for ZNC Target Package – Case Study 5

Project	Heating – Gas	Cooling – Gas	DHW – Gas	Baseload – Gas	Heating – Electric	Cooling – Electric	DHW – Electric	Baseload – Electric	Lighting – Electric	Total EUI
Baseline	46%	0%	16%	6%	0%	5%	0%	24%	3%	**100%**
End Use Difference	-100%	0%	-100%	0%	100%	16%	100%	-36%	0%	**47%**

EE Target Package

As some EE Target measures entail replacement of existing equipment, an additional column is added to Table 77 that shows the estimated remaining life of the equivalent replacement system. An "N/A" indicates the existing system is not replaced, and a "DNE" means does not exist and the package adds a system or piece of equipment not currently onsite. This is discussed in more detail in the Case Study Measures Identification Methodology section below.

Table 77. EE Target Package EEMs – Case Study 5. All costs are total capital cost estimates without incentives and without subtracting the cost of replacing existing systems at end of life.

#	Measure	Description	Whole Bldg. EUI Svgs. (%)	Cost Savings ($/yr.)	Measure Cost ($)	SP (yrs)	ROI (%)	Equip. Life (yrs)	Estimated Remaining Life of Equivalent System (yrs)
1	Electrify DHW	Convert domestic hot water gas heating to electric air-to-water heat pump systems	10.1%	($2,800)	$625,000	N/A	N/A	15	15-20
2	Install ERV	Install an exhaust recovery ventilation unit	7.9%	$17,000	$317,000	18.7	5%	15	DNE
3	Retro-Commissioning	Retro-commission and implement improvements on central building systems	3.8%	$8,500	$44,000	5.2	19%	5	DNE
4	Central Plant Pump VFDs	Install variable frequency drives on central distribution pumps	2.5%	$8,800	$8,000	0.9	112%	10	DNE
5	CW Pump VFDs	Install variable frequency drives on condenser water pumps	0.3%	$1,100	$6,000	5.2	19%	15	DNE
6	Booster Pump VFDs	Install variable frequency drives on domestic water booster pumps	0.3%	$1,200	$5,000	4.5	22%	15	DNE
7	High-Efficiency Water Aerators	Install high-efficiency aerators in faucets and showers	0.2%	$600	$5,000	8.8	11%	10	DNE
8	Solar PV	Install roof-mounted solar PV	3.2%	$11,300	$284,000	25.1	4%	15	DNE
Total			**28.4%**	**$45,700**	**$1,294,000**	**28.3**	4%	**-**	

Table 78: Post Retrofit Site EUI by End Use & Percent Reductions from Baseline for EE Target Package – Case Study 5

Project	Heating – Gas	Cooling – Gas	DHW – Gas	Baseload – Gas	Heating – Electric	Cooling – Electric	DHW – Electric	Baseload – Electric	Lighting – Electric	Total EUI
Baseline	46%	0%	16%	6%	0%	5%	0%	24%	3%	**100%**
End Use Difference	-15%	0%	-100%	0%	0%	-22%	0%	-46%	-5%	**72%**

Less-than-Five-Year Payback Package

The Less-than-Five-Year Payback package does not allow the building to meet any interim targets.

Table 79. Less-than-Five-Year Payback Package EEMs – Case Study 5. All costs are total capital cost estimates without incentives and without subtracting the cost of replacing existing systems at end of life.

Measure #	Measure	Description	Whole Bldg. EUI Svgs. (%)	Cost Savings ($/yr.)	Measure Cost ($)	SP (yrs)	ROI (%)	Equip. Life (yrs)
1	Retro-Commissioning	Retro-commission and implement improvements on central building systems	4.7%	$9,200	$44,000	4.8	21%	5
2	Central Plant Pump VFDs	Install variable frequency drives on central distribution pumps	2.8%	$9,700	$8,000	0.8	124%	10
3	CW Pump VFDs	Install variable frequency drives on condenser water pumps	0.4%	$1,300	$6,000	4.7	21%	15
4	Booster Pump VFDs	Install variable frequency drives on domestic water booster pumps	0.4%	$1,300	$5,000	4.0	25%	15
5	High-Efficiency Water Aerators	Install high-efficiency aerators in faucets and showers	0.4%	$500	$5,000	10.1	10%	10
	Total		**8.6%**	**$22,000**	**$68,000**	**3.1**	**32%**	**-**

Table 80. Post Retrofit Site EUI by End Use & Percent Reductions from Baseline for Less-than-Five-Year Payback Package – Case Study 5

Project	Heating – Gas	Cooling – Gas	DHW – Gas	Baseload – Gas	Heating – Electric	Cooling – Electric	DHW – Electric	Baseload – Electric	Lighting – Electric	Total EUI
Baseline	46%	0%	16%	6%	0%	5%	0%	24%	3%	**100%**
End Use Difference	-5%	0%	-8%	0%	0%	-5%	0%	-19%	-5%	**91%**

Package Comparisons to ZNC Target

The following chart shows the site EUI and split between fuels today and for the EEM packages in comparison to the three Targets.

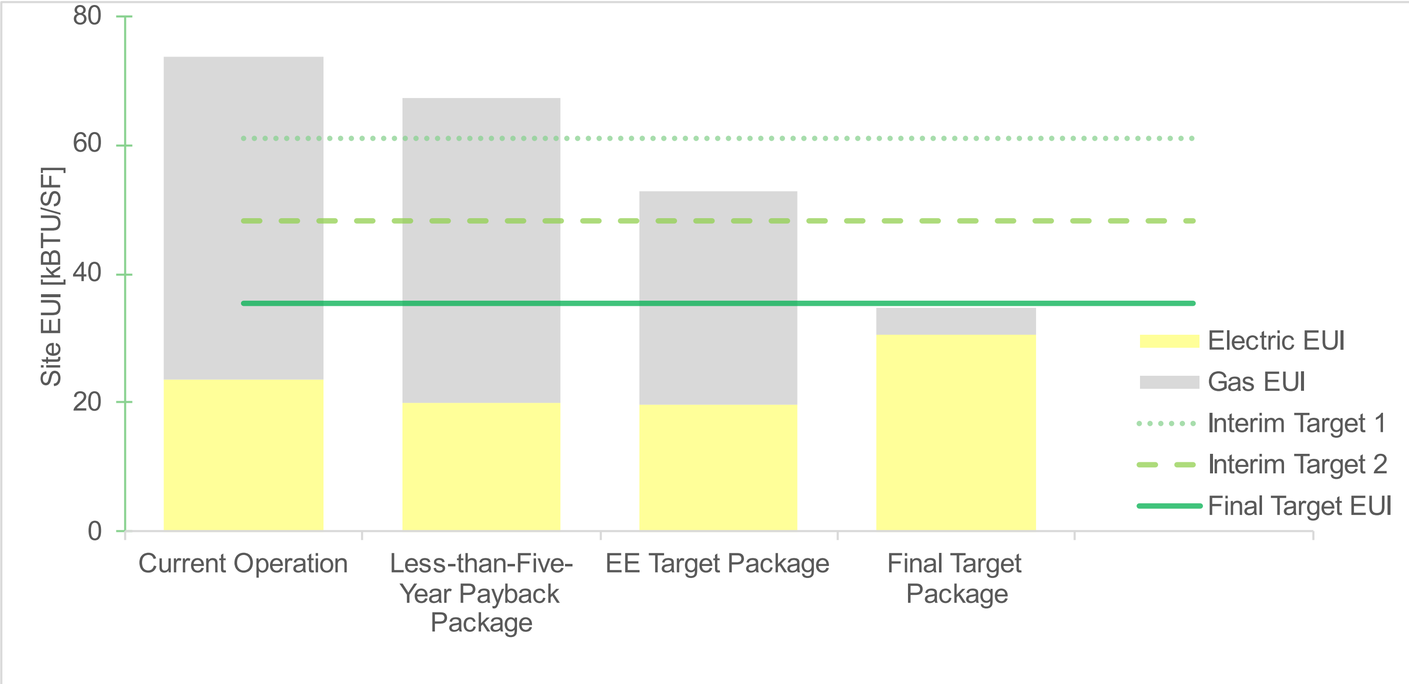

Figure 45. Target-to-Package Comparisons – Case Study 5

Although some low-cost measures make it into the Less-Than-Five-Year Payback Package, this package is insufficient to reach any of the Interim Targets, much less the ZNC Target. The EE Target Package would get the facility most of the way to the 2nd Interim Target; the EE Target Package mostly reduces gas usage compared to the Less-than-Five-Year Payback Package.

The ZNC Target can be reached with substantial onsite electrification converting existing gas loads to electric. Additional discussion is available in the Case Study Measures Identification Methodology.

Building-Specific Technology Assessment

This multifamily building has two major issues making it difficult for it to reach the ZNC Target with the current systems:

- A large amount of gas use (68%) which acts as a limit on how effective non-fuel-switching measures can be in reducing site EUI.
- The distance between current usage and the ZNC Target is substantial, representing a 53% reduction in current energy usage.

Given those items, electrification of building loads represents the only realistic path for this site to reach the ZNC Target. For this building, converting the existing fan coil system to a water-source heat pump system gains the benefit of reusing existing piping risers compared to other electrification conversion technology (i.e., VRF) which entails entirely new piping runs throughout the building.

For this building, reaching the EE target is a comparatively simpler lift, representing only a 28% reduction in energy use. However, this still requires some electrification in order to be reached.

Some electrification considerations for this facility are as follows:

- Aiming for efficiency gains in existing gas-fired equipment is not realistic based on technology available today. While some optimization methods can help (and do appear in the Less-than-Five-Year Payback Package), they do not cover this energy gap.
- Electrifying heating but not DHW does not reach the ZNC Target Package; however, it *does* serve to reach the EE Target on its own. However, this would be a less cost-effective method than the method used in this case study.
- Electrifying DHW but not heating also does not reach the ZNC Target Package, but it does allow for the EE Target Package to take advantage of incremental improvements to the HVAC system of the building, which in turn create a more cost-effective package. This approach was used to develop the EE Target Package.
- Electrifying cooking loads in lieu of electrifying either HVAC or DHW does not do enough on its own to reach ZNC or EE. Electrifying cooking loads *can* be an alternative path compared to the EEMs shown in Table 75 to meet the ZNC target once HVAC and DHW loads are electrified (and this would also remove the remaining on-site fuel used), but other, more cost-effective methods are used in this case study.

The EE Target Package also includes installation of an ERV. This measure is not included in either the ZNC Target Package or the Less-than-Five-Year Payback Package for the following reasons:

- The ZNC Target can be met with space heating, DHW electrification, and other smaller measures indicated in Table 75. These measures offer a better ROI in total than ERV installation.
- ERV installation is not cost-effective enough to include in the Less-than-Five-Year Payback Package.

A handful of measures in the Less-than-Five-Year Payback Package are also included in the EE Target and/or ZNC Target Packages. These are relatively low-cost measures that help bring down the overall payback of this option and include some central plant retrofits such as central plant VFDs and other ancillary upgrades such as low flow aerators; these measures do not have a large overall impact on savings and are generally non-interactive in nature.

Once these measures were identified, solar PV savings are applied to the building. This building has existing solar hot water collectors. In order to make “room” for the solar PV system, these hot water collectors need to be removed. This increases the domestic hot water load met by the hot water system and negatively impacts the finances of the solar PV system. To make the most use of the solar DHW, the solar PV can be installed at the end of the functional life of the solar DHW system, which is likely before the final target date of the performance standard.

Once electrification of HVAC and DHW loads were implemented, the ZNC target for this building can be satisfied by either installing solar PV or by electrifying cooking; since electrifying cooking results in an energy cost increase for the building, solar PV is used instead.

The Less-than-Five-Year Payback Package are largely constructed using similar measures as the ZNC Target Package with two notable exceptions:

- Retro-commissioning is applied to the central plant equipment to remain only. In-unit retro-commissioning would be a highly intrusive process and not realistic for the Less-Than-Five-Year Package. The HVAC system will largely be replaced in the ZNC Target Package and so retro-commissioning is not an eligible measure in the ZNC target.
- Condenser Water Pump VFDs does not apply. With conversion to a heat pump loop, the central plant pumps serve both the heating and condenser water loop, making this measure unnecessary.

Package Comparisons

Reaching ZNC targets incurs a large overall cost to the property; most of these costs are borne from either electrification measures such as heat pump conversion or electrifying domestic hot water. However, the ZNC target for this building is reachable with technologies available today.

There are some ways to reduce compliance retrofit costs:

- Some of the total capital costs may be effectively defrayed by accounting for avoided replacement costs of existing mechanical equipment. For example, most mechanical equipment will likely be replaced before the 2035 target. This money can be set aside to help cover parts of the costs.
- Financing methods such as the Montgomery County Green Bank are viable.
- Utility incentives through the EmPOWER Maryland program may help offset upfront costs. While not a significant amount relative to the overall project investment, these funds are available today. These funds are available on three-year cycles and the program offerings can change during the program cycle; based on this, incentive estimates are not included in this report.

The EE Target Package incurs less overall cost than the ZNC Target Package and higher cost savings.

The Less-than-Five-Year Payback Package largely utilizes retrofits to existing equipment. Applying a higher estimated savings for retro-commissioning may be possible.

Measures Not Recommended

Measures reviewed for the building but not included in either EEM package are described below.

- Envelope: envelope improvements are not needed to meet the ZNC target and are not cost-effective enough to include in the Less-than-Five-Year Payback Package.
- Cooking: electrifying cooking is not needed to meet ZNC or EE as described above. Furthermore, this measure increases energy cost given the utility rates used for this analysis.

General Methodology Applied to All Case Studies

The following text describes components of this technical analysis that were applied to all case studies about EEM Package Development, Building Desktop Audits, and Utility Rates. After those sections are discussions of the analysis methodology applied specifically to this case study.

EEM Package Development

Three packages of EEMs were developed.

Zero Net Carbon-Compatible (ZNC) Target Package

This package compiles measures necessary to meet the Zero Net Carbon-Compatible target for the respective building. These measures typically include electrification of natural gas uses. The aim of this package was to create a series of measures that result in the ability of the case study building to meet the ZNC target. Project financials were not a primary driver, but financially desirable measures were included wherever possible.

Descriptions of each package are included in the individual case studies below.

The methodology for developing these packages was generally as follows:

- Potential electrification measures were implemented first when determined they were necessary to meet the ZNC target. This was done for two reasons:
  - Electrified end uses were typically large (i.e., all of a building’s heating loads), and
  - Other measures’ applicability may change based on these electrified systems. Note that for packages where mechanical systems were changed, some measures that are appropriate based on *existing mechanical equipment* may not be included in the ZNC package. However, they may appear in the However, they may appear in the EE Target Package or Less-than-Five-Year Payback Package.

- Next, measures with large interactive effects were reviewed. These measures were typically either mechanical or controls-based in nature.
- Next, smaller end use reduction measures with limited interactive effects were implemented. These measures typically have a small impact (i.e., less than 5% of overall building usage).
- Lastly, where applicable and necessary, photovoltaic solar (PV) was applied.

Energy Efficiency (EE) Target Package

This package compiles measures necessary to meet the Energy Efficiency target for the respective building. Initial analysis returned multiple ways to think about developing an approach, each with pros and cons. These can be found in Table 81 below.

Table 81: General approaches to developing an EE Target Package.

Package Type	Pros	Cons	Other Items
Fewest Measures	• Simplest to implement • Easiest to understand	• Higher cost and lower ROI	• Electrification of some end uses guaranteed
Best ROI that Meets the EE Target	• Most attractive financial package • Best speaks to financial concerns	• Still will electrify some loads • Better ROI may not be the easiest to implement measures	• This will likely introduce partial electrification of end uses to the study
Minimize Electrification	• Best speaks to the theory behind the EE package	• Would necessitate replacement of gas-fired equipment with new gas-fired equipment	• May not really be viable with case study buildings (but could be viable with other buildings)

This study opted to use the Best ROI that Meets the EE Target approach. The following guidelines apply to this approach:

- Electrification of end uses needed to be considered in practice. Most case study buildings were far enough away from the EE Target that reaching the EE Target without electrification was infeasible without significant occupant energy pattern changes[58].
- Electrification of DHW loads was considered first. Most mechanical systems (which include space heating systems) have low-cost opportunities for optimization while most DHW systems have limited optimization opportunities. This means the combined mechanical system optimization measures plus DHW electrification had a more attractive ROI than space heating electrification measures.
- Mechanical system optimization and retro-commissioning measures were then implemented.
- Next, smaller end use reduction measures with limited interactive effects were implemented. These measures typically have a small impact (i.e., less than 5% of overall building usage).
- Electrification of space heating loads was considered only if electrification of DHW loads was not enough in conjunction with other measures to meet the EE Target *and* minimal system optimization was possible.
- Lastly, where applicable and necessary, photovoltaic solar (PV) was applied.

[58] Energy conservation by occupants can drive significant energy savings (EPA, slide 33). Because of the difficulty in predicting savings (and the persistence of savings) for these sorts of behavioral measures in typical buildings, those savings are not included in this study.

Less-than-Five-Year Payback Package

This package compiles a set of measures that results in a five year or less total simple payback. This package represents a reasonable approximation of possible outcomes from an energy audit. These measure packages represent the types of low cost and lower-savings measures often recommended during standard energy audits. These measures are often investigated by buildings first. Note that an energy audit may include other financial tools such as utility incentives, tax deductions/credits, or other assistance, which were not included in this technical analysis.

Where applicable, measures from the Less-than-Five-Year Payback Package were also applied to the ZNC Package. The methodology described under the ZNC Target Package applied to the Less-than-Five-Year Payback Package as well. The following guidelines apply to the Less-than-Five-Year Payback Package:

- Measures with large interactive effects were reviewed. These measures were typically either mechanical or controls-based in nature.
- Retro-commissioning was applied; see below for details.
- Next, smaller end use reduction measures with limited interactive effects were implemented. These measures typically have a small impact (i.e., less than 5% of overall building usage).
- Lastly, where applicable and necessary, photovoltaic solar (PV) was applied.
- Major building systems were *not* modified in this package. Most system conversions (for example, converting from chilled water to water-source heat pumps) have longer paybacks and would not realistically be included. However, this also means that measures that impact *existing mechanical equipment* would appear here (for example, chilled water pump VFDs when the ZNC Target Package converted a building from chilled water to water-source heat pumps).
- New fossil fuel measures were not included.
- Overall energy savings were not a primary goal of this target; the energy savings resulting from this package was simply the end result of measures that would result in a less than five year project payback for all measures considered.

Typically, this package may be useful in reviewing progress toward interim targets.

Note that for some newer buildings that have less opportunity for low-cost incremental savings, the Less-than-Five-Year Payback Package may be either small or non-existent.

Building Desktop Audits

Case studies were developed through interviews with building managers and site staff to collect – for major equipment only – equipment type, equipment age, operating parameters, types of fuel used for various end uses, information on recent capital upgrades, and any comments on plans for future upgrades and decision-making processes in relation to energy management. Architectural and mechanical drawings and supporting documentation were reviewed when available.

Desktop audits were performed in order to develop the case studies contained in this report. Desktop audits use information provided from building owners and operators to develop recommendations, but do not contain any onsite observations. This methodology is effective for informing policy-level decisions as it can effectively capture broad-stroke approaches; however, this methodology does not tend to capture measures are more limited in impact (e.g., mechanical systems that only serve part of the building). Applicability of desktop audit measures to a specific building typically requires some amount of onsite investigation in order to determine applicability of measures for any specific building in a given typology. This technical analysis is limited to desktop audits and measure recommendations are limited to what could be recommended based on the data collected by the auditor.

Where possible, supplemental energy audit information performed by others is incorporated into the case studies. These energy audits, which may contain onsite observations, were completed prior to this desktop audit process.

Utility Rates

Utility rate assumptions are $0.129 per kWh and $1.228 per therm, based on the US Energy Information Administration (EIA) average rates for the area. While energy rates differ by service class and usage profile, these rates are assumed to represent the average costs for these types of buildings in Montgomery County. These rates are meant to be inclusive of taxes and fees applicable throughout the state, including the current Fuel Energy Tax of $0.01978 per kWh on electricity and $0.17026 per therm on natural gas use.

Case Study 6: Garden-Style Multifamily

Building Information

This case study is an affordable housing garden-style apartment complex. The complex has multiple 3-to-4 story buildings with approximately 75 apartment units. The complex has a central heating hot water and domestic hot water plant with window air conditioners for cooling. The building is master metered for electricity and natural gas. There is a common area laundry facility on site, and above ground open parking.

Table 82. Building Characteristics – Case Study 6

Category	Building Information
Typology	Multifamily
Square Footage	50,000 ft.^{2} – 75,000 ft.^{2} Multifamily Housing: 100%
Year Built	1950 – 1955
2019 ENERGY STAR Score	N/A*
2019 Site EUI (kBTU/SF)	115 – 125

**This building was not benchmarked, as it was not required to benchmark under the County's Benchmarking Law at the time of this case study's completion.*

Building System Information

The basic building system information specific to the case study building is described below.

Table 83. Building System Information – Case Study 6

Category	Type	Fuel	Approximate Equipment Age (Years)	Expected End of Useful Life (Years)
Central BMS	None	N/A	N/A	N/A
Heating	Two hot water boilers, hydronic heating distribution across all buildings	Gas	Unknown (estimated >10 years)	Unknown (estimated 5-10 years)
Cooling	Window AC units	Electric	Unknown (estimated 1-8 years)	Unknown (estimated 0-5 years)
Ventilation	Sidewall vents in kitchens and bathrooms only	N/A	N/A	N/A
DHW	Two hot water DHW heaters	Gas	3	12-17
Lighting	Primarily fluorescent / CFL	Electric	Unknown (estimated 5 years)	Unknown (estimated 0-5 years)
Envelope	Likely original	N/A	Unknown (estimated 40 years)	Unknown (estimated 40 years)
Metering	One electric meter for the complex Three gas meters: one with the boilers, two for residential cooking	Electric, Gas	N/A	N/A

Utility End Use Assessment

The building's energy usage type and estimated end use is displayed below.

- Gas: used for heating hot water, domestic hot water, and residential cooking. 82% of the building's energy use is in the form of gas.
- Electricity: used for cooling, pumping, ventilation, lighting, and electric plug loads. 18% of the building's energy use is in the form of electricity.

Table 84. 2019 Site EUI by End Use – Case Study 6. Components may not sum to 100% due to rounding.

Heating – Gas	Cooling – Gas	DHW – Gas	Baseload – Gas	Heating – Electric	Cooling – Electric	DHW – Electric	Lighting – Electric	Baseload – Electric	Total EUI
51%	0%	25%	6%	3%	4%	0%	9%	2%	**100%**

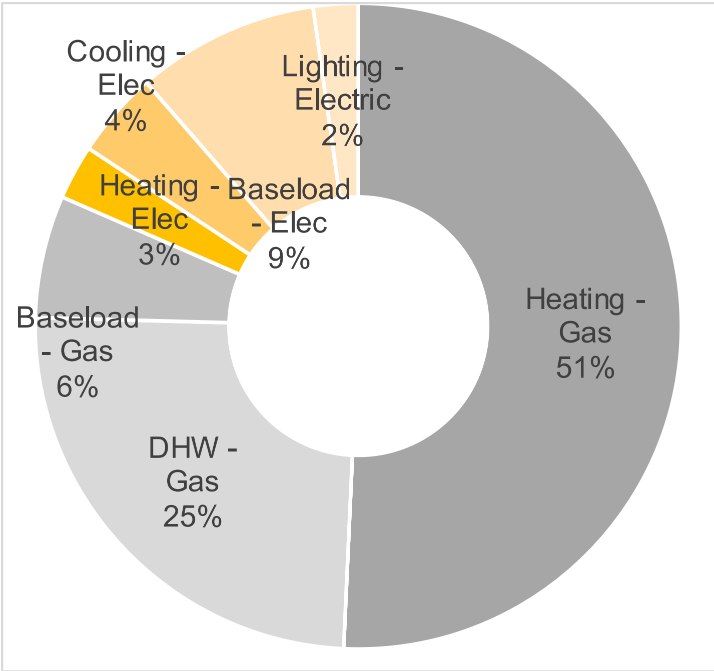

Figure 46. Site EUI Share (%) by End Use – Case Study 6

Target Determination

EUI targets are determined by a weighted average of applicable ZNC targets per space use type. The table also has an alternate target ("EE Standard"); the building will need to take action in order to meet both the ZNC and EE Targets. All the following analysis uses the ZNC target.

Table 85. Space Use Target Methodology Summary – Case Study 6

Specific Space Type	Space Type Group	Area %	Floor Areas	ZNC Standard [Site EUI]	EE Standard [Site EUI]	Weighted ZNC EUI (ZNC * Area%)	Weighted EE EUI (EE * Area%)
Multifamily Housing	Multifamily	100%	50,000	35.4	55.1	35.4	55.1
Total	**-**	**100%**	**50,000**	**-**	**-**	**35.4**	**55.1**

The baseline EUI is derived from whole building 2019 utility data over whole building square footage.

Table 86: ZNC and Interim Targets – Case Study 6

EUI Description	ZNC Target	EE Target
Baseline EUI	115 – 125	115 – 125
2029 – Interim Target 1	90 – 95	95 – 102
2033 – Interim Target 2	60 – 65	75 – 80
2037 – Target	35.4	55.1

Package Overview

EEM packages were compiled based on existing technology for two scenarios:

- *ZNC Target Package* is based upon electrification and energy efficiency measures to reach the ZNC Target for this building.
- *EE Target Package* is based upon energy efficiency measures to reach the EE Target for this building. Note that the ZNC Target Package can also be used to reach the EE Target, but the EE Target Package reduces EUI only as far as needed to meet the EE Target.
- *Less-than-Five-Year Payback Package* is based on the results of a package that would have a simple payback of less than five years, not accounting for supplemental funding tools such as utility incentives or tax credits.

All costs are total costs for the measures, not incremental costs. These costs do not include applicable incentives. The following table offers a financial overview of these packages.

Table 87. EEM Package Summary – Case Study 6

Package	Package EUI (kBTU/ft.^{2}/yr)	% Site EUI Savings	Cost Savings ($/yr.)	Capital Costs ($)	SP (yrs)	ROI (%)
ZNC Target Package	31 – 34	73%	$60,400	$1,621,000	26.8	4%
EE Target Package	51 – 55	56%	$58,700	$1,261,000	21.5	5%
Less-than-Five-Year Payback Package	107 – 117	7%	$10,500	$30,300	2.9	35%

ZNC Target Package

As some ZNC Target measures entail replacement of existing equipment, an additional column is added to Table 88 that shows the estimated remaining life of the equivalent replacement system. A "N/A" indicates the existing system is not replaced, and a "DNE" means the package adds a system or piece of equipment that does not currently exist onsite. This is discussed in more detail in the Case Study Measures Identification Methodology section below.

Table 88. ZNC Target Package EEMs – Case Study 6. All costs are total capital cost estimates without incentives and without subtracting the cost of replacing existing systems at end of life.

#	Measure	Description	Whole Bldg. EUI Svgs. (%)	Cost Savings ($/yr.)	Measure Cost ($)	SP (yrs)	ROI	Equip. Life (yrs)	Estimated Remaining Life of Equivalent System (yrs)
1	Electrify Space Heating	Convert the central mechanical system to a ductless split heat pump system	41.0%	$18,500	$745,000	40.2	2%	15	5-10
2	Electrify Water Heating	Convert domestic hot water gas heating to electric air-to-water heat pump systems	17.3%	$1,800	$360,000	201.7	1%	15	12-17
3	High-Efficiency Water Aerators	Install low flow aerators in faucets and showers	0.2%	$500	$3,000	5.9	17%	15	DNE
4	Solar PV	Install roof-mounted solar PV	14.3%	$39,600	$513,000	13.0	8%	15	DNE
Total			**72.8%**	**$60,400**	**$1,621,000**	**26.8**	**4%**	**-**	

Table 89. Post Retrofit Site EUI by End Use & Percent Reductions from Baseline for ZNC Target Package – Case Study 6

Project	Heating – Gas	Cooling – Gas	DHW – Gas	Baseload – Gas	Heating – Electric	Cooling – Electric	DHW – Electric	Baseload – Electric	Lighting – Electric	Total EUI
Baseline	51%	0%	25%	6%	3%	4%	0%	9%	2%	**100%**
End Use Difference	-100%	0%	-100%	0%	171%	-41%	100%	-41%	-41%	**27%**

EE Target Package

As some EE Target measures entail replacement of existing equipment, an additional column is added to Table 90 that shows the estimated remaining life of the equivalent replacement system. An "N/A" indicates the existing system is not replaced, and a "DNE" means does not exist and the package adds a system or piece of equipment not currently onsite. This is discussed in more detail in the Case Study Measures Identification Methodology section below.

Table 90. EE Target Package EEMs – Case Study 6. All costs are total capital cost estimates without incentives and without subtracting the cost of replacing existing systems at end of life.

#	Measure	Description	Whole Bldg. EUI Svgs. (%)	Cost Savings ($/yr.)	Measure Cost ($)	SP (yrs)	ROI (%)	Equip. Life (yrs)	Estimated Remaining Life of Equivalent System (yrs)
1	Electrify Space Heating	Convert the central mechanical system to a mini-split DX system	41.0%	$18,500	$745,000	40.2	2%	15	15-20
2	High-Efficiency Water Aerators	Install low flow aerators in faucets and showers	0.6%	$500	$3,000	5.4	18%	15	DNE
3	Solar PV	Install roof-mounted solar PV	14.3%	$39,600	$513,000	13.0	8%	15	DNE
Total			**55.9%**	**$58,600**	**$1,261,000**	**21.5**	**5%**	**-**	

Table 91: Post Retrofit Site EUI by End Use & Percent Reductions from Baseline for EE Target Package – Case Study 6

Project	Heating – Gas	Cooling – Gas	DHW – Gas	Baseload – Gas	Heating – Electric	Cooling – Electric	DHW – Electric	Baseload – Electric	Lighting – Electric	Total EUI
Baseline	51%	0%	25%	6%	3%	4%	0%	9%	2%	**100%**
End Use Difference	-100%	0%	-2%	0%	124%	-51%	0%	-51%	-51%	**44%**

Less-than-Five-Year Payback Package

The Less-than-Five-Year Payback package does not allow the building to meet any interim targets.

Table 92. Less-than-Five-Year Payback Package EEMs – Case Study 6. All costs are total capital cost estimates without incentives and without subtracting the cost of replacing existing systems at end of life.

Measure #	Measure	Description	Whole Bldg. EUI Svgs. (%)	Cost Savings ($/yr.)	Measure Cost ($)	SP (yrs)	ROI (%)	Equip. Life (yrs)
1	Retro-Commissioning	Retro-commission and implement improvements on central building systems	4.3%	$4,900	$21,000	4.3	23%	5
2	Hot Water Pump VFDs	Install variable frequency drives on heating hot water pumps	1.8%	$5,100	$6,000	1.3	80%	15
3	High-Efficiency Water Aerators	Install low flow aerators in faucets and showers	0.6%	$500	$3,000	5.7	18%	15
	Total		**6.7%**	**$10,500**	**$30,000**	**2.9**	**35%**	**-**

Table 93. Post Retrofit Site EUI by End Use & Percent Reductions from Baseline for Less-than-Five-Year Payback Package – Case Study 6

Project	Heating – Gas	Cooling – Gas	DHW – Gas	Baseload – Gas	Heating – Electric	Cooling – Electric	DHW – Electric	Baseload – Electric	Lighting – Electric	Total EUI
Baseline	51%	0%	25%	6%	3%	4%	0%	9%	2%	**100%**
End Use Difference	-7%	0%	-5%	0%	0%	0%	0%	-25%	-5%	**93%**

Package Comparisons to ZNC Target

The following chart shows the site EUI and split between fuels today and for the EEM packages in comparison to the three Targets.

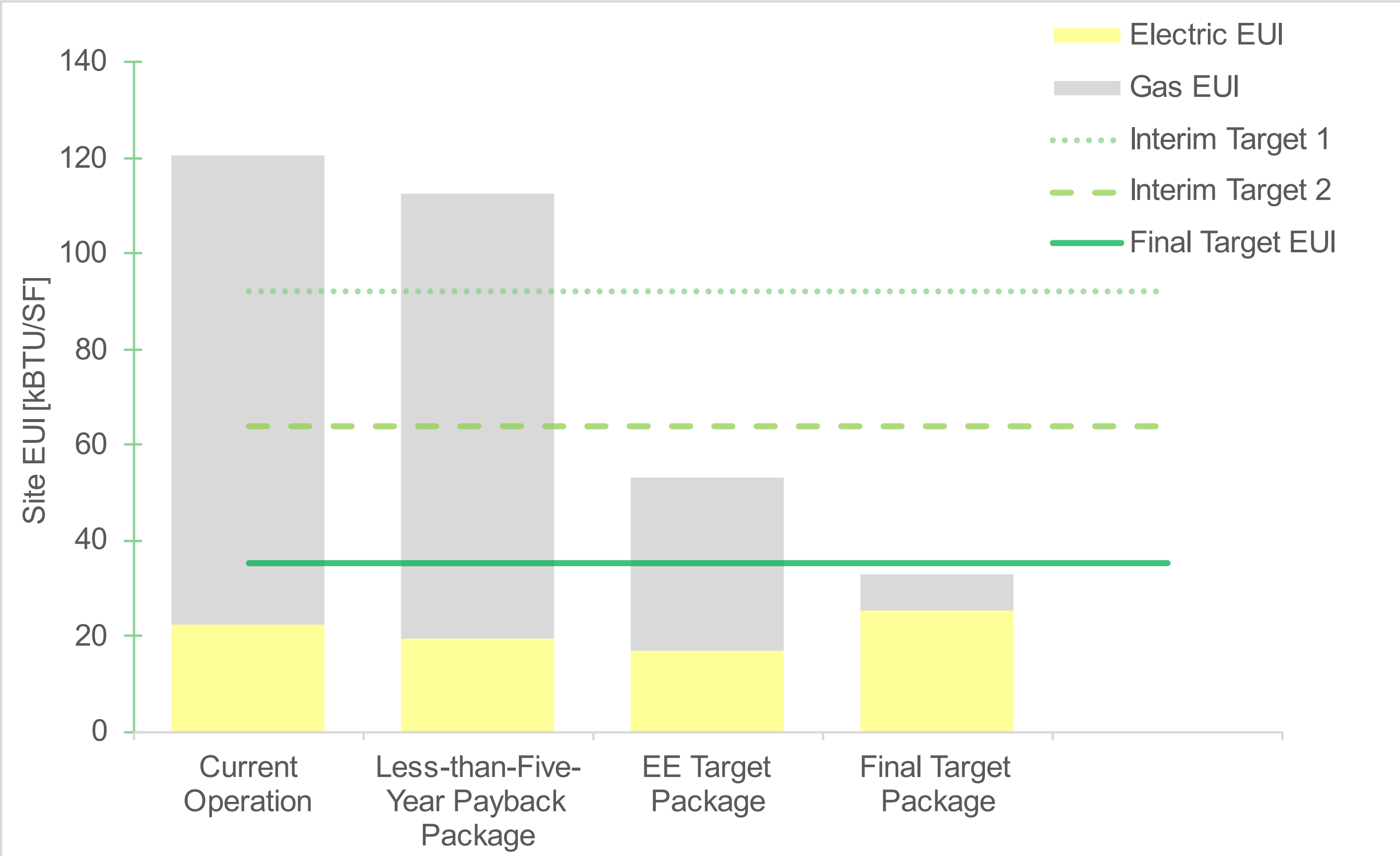

Figure 47. Target-to-Package Comparisons – Case Study 6

The chart above indicates the limitations of the Less-than-Five-Year Payback Package to realize substantial onsite savings. The EE Target Package reaches the second interim target but requires substantial electrification. The building can meet the ZNC target even without fully electrifying. This is due to garden-style building's ability to offset a larger portion of their energy usage effectively by solar.

Building-Specific Technology Assessment

This multifamily building has two issues making it difficult for it to reach the ZNC Target with current technology:

- A large amount of gas use (82%) which acts as a limit on how effective non-fuel-switching measures can be in reducing site EUI. Furthermore, this is the only building among those included in this analysis where heating represents at least 50% of total building energy.
- The distance between current usage and the ZNC Target is substantial, representing a 71% reduction in current energy usage.

Similar issues exist with the EE Target, although the end goal is a 55% reduction instead of a 71% reduction.

Some approaches were discussed:

- Aiming for efficiency gains in existing equipment did not seem realistic based on technology available today. In effect, gas-fired equipment would need to approach or exceed 100% efficiency in order to be

in range of the ZNC or EE Targets. While some optimization methods can help (and do appear in the Less-than-Five-Year Payback Package), they do not cover this energy gap.
- Partial electrification was reviewed but this was determined to not appreciably impact the ability of the building to reach ZNC. However, partial electrification was found to be useful for the EE Target Package.

For the EE Target Package, electrification of the space heating system represented the better approach. This was for two reasons:

- A large percentage of energy use (over 50%) is used for space heating. Electrifying this load represented a far better option for saving energy instead of DHW, which is only 25% of building energy use.
- There were not many options "lost" through optimizing the existing mechanical system, as the mechanical system for this building is not easily able to be optimized. As a result, there is minimal opportunity cost loss.

Electrification of the HVAC and DHW end uses represented the only realistic path for this site to reach the ZNC Target. For HVAC, converting the system to distributed ductless heat pumps was chosen as the most realistic option. For DHW, a semi-distributed option with a hot water heat pump plant per building was chosen.

Electrification on its own was not sufficient to reach the ZNC target.

Once electrification measures were identified, other measures affecting building demand were then choisen (items like high-efficiency aerators); these measures did not have a large overall impact on savings and were generally non-interactive in nature.

Applying solar PV to this property reduces grid-supplied electricity use substantially. This building type has a large roof area for its total square footage, which in turn would allow for a large amount of solar to be installed. This amount of solar was sufficient to meet the ZNC target in conjunction with other package measures.

An alternative approach would be to electrify cooking, which would reduce the need to maximize the size of a solar PV array by reduce cooking energy use. However, this is likely to be a less financially attractive approach.

There were minimal differences between the EE Target Package and the ZNC Target Package; as noted above, electrifying the HHW system represented the best option for this building to save energy, but electrifying the DHW system was less financially attractive than solar PV. Only one of these measures would be needed to reach the EE Target; based on the methodology chosen for this study, solar PV was used instead of electrifying DHW.

The Less-than-Five-Year Payback Package was largely constructed using similar measures as the ZNC Target Package with two notable exceptions:

- Retro-commissioning would be applied to the central plant equipment only. In-unit retro-commissioning would be a highly intrusive process, and there isn't much equipment or savings potential in the apartments, so in-unit retro-commissioning is not included in the Less-Than-Five-Year Package. The HVAC system would be replaced in the ZNC Target Package and EE Target Package.
- Hot Water Pump VFDs would not apply; with conversion to a distributed heat pump system, the central plant pumps would no longer be necessary, making this measure unnecessary.

Package Comparisons

Reaching ZNC targets incur a large overall cost to the property. Most of these costs are borne from either electrification measures such as heat pump conversion or envelope measures such as air sealing and adding insulation. However, the ZNC target for this building is reachable with technologies available today.

There are some ways to reduce compliance retrofit costs:

- Some of the total capital cost may be effectively defrayed by accounting for avoided replacement costs of existing mechanical equipment. For example, most mechanical equipment would likely be replaced before the 2035 target. This money can be effectively set aside to help cover parts of the costs.
- Financing methods such as the Montgomery County Green Bank are viable.
- Utility incentives through the EmPOWER Maryland program may help offset upfront costs. While not a significant amount relative to the overall project investment, these funds are available today. These funds are available on three-year cycles and the program offerings can change during the program cycle; based on this, incentive estimates are not included in this report.

The EE Target Package incurs less overall cost than the ZNC Target Package and higher cost savings.

The Less-than-Five-Year Payback Package largely utilizes retrofits to existing equipment. Applying a higher estimated savings for retro-commissioning may be possible.

Measures Not Recommended

Measures reviewed for the building but not included in the EEM package are described below.

- Envelope: Window replacements were considered but ultimately determined to not be needed to meet the ZNC target and were not cost-effective enough to include in the Less-than-Five-Year Payback Package.
- Cooking: electrifying cooking was not needed to meet ZNC if the solar PV system size is maximized. Furthermore, this measure increases energy cost given utility rates used for this analysis.

General Methodology Applied to All Case Studies

The following text describes components of this technical analysis that were applied to all case studies about EEM Package Development, Building Desktop Audits, and Utility Rates. After those sections are discussions of the analysis methodology applied specifically to this case study.

EEM Package Development

Three packages of EEMs were developed.

Zero Net Carbon-Compatible (ZNC) Target Package

This package compiles measures necessary to meet the Zero Net Carbon-Compatible target for the respective building. These measures typically include electrification of natural gas uses. The aim of this package was to create a series of measures that result in the ability of the case study building to meet the ZNC target. Project financials were not a primary driver, but financially desirable measures were included wherever possible.

Descriptions of each package are included in the individual case studies below.

The methodology for developing these packages was generally as follows:

- Potential electrification measures were implemented first when determined they were necessary to meet the ZNC target. This was done for two reasons:
    - Electrified end uses were typically large (i.e., all of a building's heating loads), and
    - Other measures' applicability may change based on these electrified systems. Note that for packages where mechanical systems were changed, some measures that are appropriate based on *existing mechanical equipment* may not be included in the ZNC package. However, they may appear in the EE Target Package or Less-than-Five-Year Payback Package.
- Next, measures with large interactive effects were reviewed. These measures were typically either mechanical or controls-based in nature.
- Next, smaller end use reduction measures with limited interactive effects were implemented. These measures typically have a small impact (i.e., less than 5% of overall building usage).

- Lastly, where applicable and necessary, photovoltaic solar (PV) was applied.

Energy Efficiency (EE) Target Package

This package compiles measures necessary to meet the Energy Efficiency target for the respective building. Initial analysis returned multiple ways to think about developing an approach, each with pros and cons. These can be found in Table 94 below.

Table 94: General approaches to developing an EE Target Package.

Package Type	Pros	Cons	Other Items
Fewest Measures	• Simplest to implement • Easiest to understand	• Higher cost and lower ROI	• Electrification of some end uses guaranteed
Best ROI that Meets the EE Target	• Most attractive financial package • Best speaks to financial concerns	• Still will electrify some loads • Better ROI may not be the easiest to implement measures	• This will likely introduce partial electrification of end uses to the study
Minimize Electrification	• Best speaks to the theory behind the EE package	• Would necessitate replacement of gas-fired equipment with new gas-fired equipment	• May not really be viable with case study buildings (but could be viable with other buildings)

This study opted to use the Best ROI that Meets the EE Target approach. The following guidelines apply to this approach:

- Electrification of end uses needed to be considered in practice. Most case study buildings were far enough away from the EE Target that reaching the EE Target without electrification was infeasible without significant occupant energy pattern changes[59].
- Electrification of DHW loads was considered first. Most mechanical systems (which include space heating systems) have low-cost opportunities for optimization while most DHW systems have limited optimization opportunities. This means the combined mechanical system optimization measures plus DHW electrification had a more attractive ROI than space heating electrification measures.
- Mechanical system optimization and retro-commissioning measures were then implemented.
- Next, smaller end use reduction measures with limited interactive effects were implemented. These measures typically have a small impact (i.e., less than 5% of overall building usage).
- Electrification of space heating loads was considered only if electrification of DHW loads was not enough in conjunction with other measures to meet the EE Target *and* minimal system optimization was possible.
- Lastly, where applicable and necessary, photovoltaic solar (PV) was applied.

Less-than-Five-Year Payback Package

This package compiles a set of measures that results in a five year or less total simple payback. This package represents a reasonable approximation of possible outcomes from an energy audit. These measure packages represent the types of low cost and lower-savings measures often recommended during standard energy audits. These measures are often investigated by buildings first. Note that an energy audit may include other

[59] Energy conservation by occupants can drive significant energy savings (EPA, slide 33). Because of the difficulty in predicting savings (and the persistence of savings) for these sorts of behavioral measures in typical buildings, those savings are not included in this study.

financial tools such as utility incentives, tax deductions/credits, or other assistance, which were not included in this technical analysis.

Where applicable, measures from the Less-than-Five-Year Payback Package were also applied to the ZNC Package. The methodology described under the ZNC Target Package applied to the Less-than-Five-Year Payback Package as well. The following guidelines apply to the Less-than-Five-Year Payback Package:

- Measures with large interactive effects were reviewed. These measures were typically either mechanical or controls-based in nature.
- Retro-commissioning was applied; see below for details.
- Next, smaller end use reduction measures with limited interactive effects were implemented. These measures typically have a small impact (i.e., less than 5% of overall building usage).
- Lastly, where applicable and necessary, photovoltaic solar (PV) was applied.
- Major building systems were *not* modified in this package. Most system conversions (for example, converting from chilled water to water-source heat pumps) have longer paybacks and would not realistically be included. However, this also means that measures that impact *existing mechanical equipment* would appear here (for example, chilled water pump VFDs when the ZNC Target Package converted a building from chilled water to water-source heat pumps).
- New fossil fuel measures were not included.
- Overall energy savings were not a primary goal of this target; the energy savings resulting from this package was simply the end result of measures that would result in a less than five year project payback for all measures considered.

Typically, this package may be useful in reviewing progress toward interim targets.

Note that for some newer buildings that have less opportunity for low-cost incremental savings, the Less-than-Five-Year Payback Package may be either small or non-existent.

Building Desktop Audits

Case studies were developed through interviews with building managers and site staff to collect – for major equipment only – equipment type, equipment age, operating parameters, types of fuel used for various end uses, information on recent capital upgrades, and any comments on plans for future upgrades and decision-making processes in relation to energy management. Architectural and mechanical drawings and supporting documentation were reviewed when available.

Desktop audits were performed in order to develop the case studies contained in this report. Desktop audits use information provided from building owners and operators to develop recommendations, but do not contain any onsite observations. This methodology is effective for informing policy-level decisions as it can effectively capture broad-stroke approaches; however, this methodology does not tend to capture measures are more limited in impact (e.g., mechanical systems that only serve part of the building). Applicability of desktop audit measures to a specific building typically requires some amount of onsite investigation in order to determine applicability of measures for any specific building in a given typology. This technical analysis is limited to desktop audits and measure recommendations are limited to what could be recommended based on the data collected by the auditor.

Where possible, supplemental energy audit information performed by others is incorporated into the case studies. These energy audits, which may contain onsite observations, were completed prior to this desktop audit process.

Utility Rates

Utility rate assumptions are $0.129 per kWh and $1.228 per therm, based on the US Energy Information Administration (EIA) average rates for the area. While energy rates differ by service class and usage profile, these rates are assumed to represent the average costs for these types of buildings in Montgomery County. These rates are meant to be inclusive of taxes and fees applicable throughout the state, including the current Fuel Energy Tax of $0.01978 per kWh on electricity and $0.17026 per therm on natural gas use.

Case Study 7: Mid-Sized Hotel with Conference and Other High-Use Spaces

Building Information

This is a mid-size hotel with notable common areas, such as a conference center, restaurant, and room service. The facility originally had a pool, but it has been converted to additional meeting space.

Fan coil units serve the hotel rooms. A dedicated outdoor air ventilation system provides fresh air to the hotel rooms via hotel corridors.

Table 95. Building Characteristics – Case Study 7

Category	Building Information
Typology	Lodging
Square Footage	150,000 ft.^{2} – 175,000 ft.^{2} Hotel: 100%
Year Built	1990 – 1995
2019 ENERGY STAR Score	30 – 35
2019 Site EUI (kBTU/SF) (calculated for this study)	115 – 125

Building System Information

The basic building system information specific to the case study building is described below.

Table 96. Building System Information – Case Study 7

Category	Type	Fuel	Approximate Equipment Age (Years)	Expected End of Useful Life (Years)
Central BMS	Energy Controls System (main HVAC equipment); central control system installation scheduled for hotel rooms	Electric	Unknown (estimated 10 years)	Unknown (estimated 5-10 years)
Heating	Four hot water boilers, 2000 kBTU each. Four-pipe fan coil distribution	Gas	15	5-10
Cooling	Two recently overhauled 175 ton chillers with a heat exchanger for free cooling in the winter. Four-pipe fan coil distribution	Electric	30	<5
Ventilation	DOAS serving the corridors; FCUs (4-pipe) in hotel rooms. AHUs have separate outdoor air introduction than the DOAS	Electric	Unknown (estimated 25-30 years)	Unknown (estimated 0-5 years)
DHW	Two boilers, non-condensing	Gas	15	5-10
Lighting	Mostly LED – back of house and parking are not LED	Electric	28	<5
Envelope	Largely unchanged in last 5-10 years	N/A	Unknown (estimated 30 years)	Unknown (estimated 15-20 years depending on component, save roof)
Metering	Centrally metered electric and gas	Electric, Gas	N/A	N/A

Utility End Use Assessment

The building's energy usage type and estimated end use are displayed below.

- Gas: used primarily for heating hot water and domestic hot water usage. An onsite restaurant also uses some gas (described in this report as base load), as does onsite laundry. Gas makes up 55% of the building's energy use.
- Electricity: used for cooling, ventilation, lighting, and electric plug loads. Electricity makes up 45% of the building's energy use. Fan coil units (FCUs) in hotel rooms and air handling units (AHUs) in common spaces provide conditioned air from a central heating and cooling plant.

Table 97. 2019 Site EUI by End Use – Case Study 7. Components may not sum to 100% due to rounding.

Heating – Gas	Cooling – Gas	DHW – Gas	Baseload – Gas	Heating – Electric	Cooling – Electric	DHW – Electric	Baseload – Electric	Lighting – Electric	Total EUI
23%	0%	29%	3%	0%	8%	0%	32%	5%	**100%**

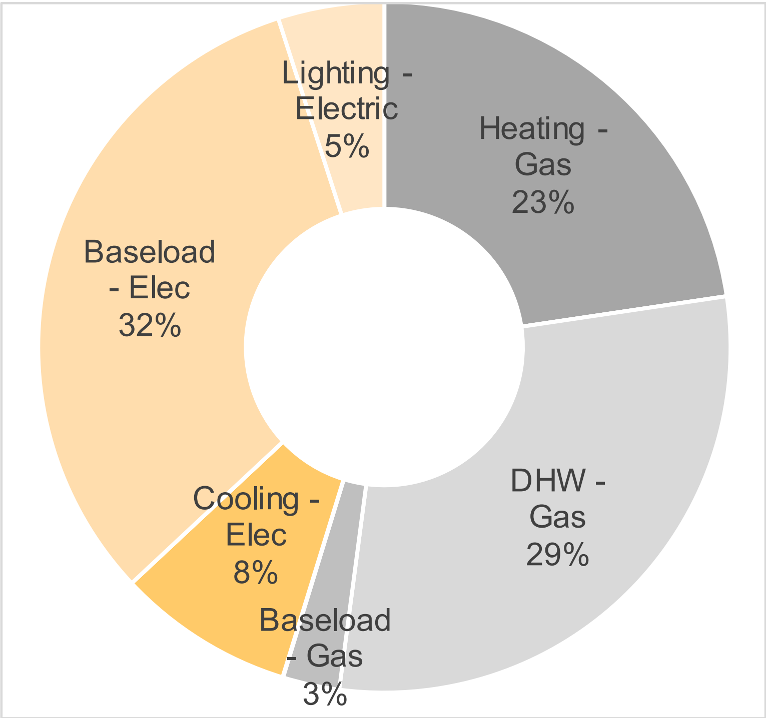

Figure 48. Site EUI Share (%) by End Use – Case Study 7

Target Determination

EUI targets are determined by a weighted average of applicable ZNC targets per space use type. Space use types are provided in Portfolio Manager and via reviews of available drawings. Table 98 contains a breakdown of the space use targets for purposes of calculating the ZNC target. Other building uses are discussed below this table. The table also has an alternate target ("EE Standard"); the building will need to take action in order to meet both the ZNC and EE Targets. All the following analysis uses the ZNC target.

Table 98. Space Use Target Methodology Summary – Case Study 7

Specific Space Type	Space Type Group	Area %	Floor Areas	ZNC Standard [Site EUI]	EE Standard [Site EUI]	Weighted ZNC EUI (ZNC * Area%)	Weighted EE EUI (ZNC * Area%)
Hotel	Lodging	100%	175,000	57.8	75.7	57.8	75.7
Total	**-**	**100%**	**175,000**	**-**	**-**	**57.8**	**75.7**

In addition to the overall hotel space (i.e., rooms, corridors, the main lobby), other support areas are present such as a restaurant with kitchen and conference center. Most of these support areas are small (less than 5% of the overall building footprint).

The baseline EUI is derived from whole building 2019 utility data over whole building square footage.

Table 99. ZNC and Interim Targets – Case Study 7

EUI Description	ZNC Target	ZNC Target
Baseline EUI	115 – 125	115 – 125
2026 – Interim Target 1	95 – 105	102 – 110
2030 – Interim Target 2	75 – 85	88 – 95
2035 – Target	57.8	75.7

Package Overview

EEM packages were compiled based on existing technology for two scenarios:

- *ZNC Target Package* is based upon electrification and energy efficiency measures to reach the ZNC Target for this building.
- *EE Target Package* is based upon energy efficiency measures to reach the EE Target for this building. Note that the ZNC Target Package can also be used to reach the EE Target, but the EE Target Package reduces EUI only as far as needed to meet the EE Target.
- *Less-than-Five-Year Payback Package* is based on the results of a package that would have a simple payback of less than five years, not accounting for supplemental funding tools such as utility incentives or tax credits.

All costs are total costs for the measures, not incremental costs of equipment replacement as compared to a business as usual replacement schedule. These costs do not include applicable incentives. The following table offers a financial overview of these packages.

Table 100. EEM Package Summary – Case Study 7

Package	Package EUI (kBTU/ft.^{2}/yr)	% Site EUI Savings	Cost Savings ($/yr.)	Capital Costs ($)	SP (yrs)	ROI (%)
ZNC Target Package	53 – 57	53%	$121,600	$5,959,000	48.9	2%
EE Target Package	72 – 76	38%	$138,200	$1,967,000	14.2	7%
Less-than-Five-Year Payback Package	94 – 102	19%	$99,800	$353,000	3.5	28%

ZNC Target Package

As some ZNC Target measures entail replacement of existing equipment, an additional column is added to Table 101 that shows the estimated remaining life of the equivalent replacement system. An "N/A" indicates the existing system is not replaced, and "DNE" means does not exist and the package adds a system or piece of equipment not currently onsite. This is discussed in more detail in the Case Study Measures Identification Methodology section below.

Table 101. ZNC Target Package EEMs – Case Study 7. All costs are total capital cost estimates without incentives and without subtracting the cost of replacing existing systems at end of life.

Measure #	Measure	Description	Whole Bldg. EUI Svgs. (%)	Cost Savings ($/yr.)	Measure Cost ($)	SP (yrs)	ROI	Equip. Life (yrs)	Estimated Remaining Life of Equivalent System (yrs)
1	Electrify Space Heating	Convert existing HVAC system to an electric heat pump system	17.8%	$19,900	$3,804,000	191.2	1%	18	5-10
2	Electrify Water Heating	Convert existing DHW system to electric DHW	18.5%	($11,300)	$1,270,000	N/A	N/A	15	5-10
3	Electrify Cooking	Convert gas cooking to electric cooking	1.0%	($6,000)	$11,000	N/A	N/A	10	Unknown (estimated 10 years)
4	Install ERV	Install an exhaust recovery ventilation unit	5.3%	$41,900	$432,000	10.3	10%	15	DNE
5	Guest Room Controls	Add automatic guest room controls to limit extra energy usage during unoccupied times	5.2%	$41,300	$88,000	2.1	47%	10	Unknown (estimated 10 years)
6	Wider Deadbands	Expand deadbands for central mechanical equipment	0.1%	$1,000	$3,000	2.6	39%	5	N/A
7	CW Pump VFDs	Install condenser water pump variable frequency drives	0.4%	$3,200	$27,000	8.4	12%	15	DNE
8	Finish LED Conversion	Complete ongoing LED conversion	0.2%	$1,200	$38,000	30.4	3%	15	5-10
9	Plug Load Management	Install smart plug load management tools	1.5%	$11,700	$17,000	1.5	67%	10	DNE
10	High-Efficiency Water Aerators	Install low flow aerators in hotel room faucets and showers	0.3%	$2,200	$10,000	4.6	22%	10	DNE
11	General Air Sealing	Air seal gaps in masonry, between window/wall sealing, doors, and other envelope	0.3%	$2,000	$31,000	15.6	6%	15	DNE
12	Solar PV	Install roof-mounted solar PV	1.8%	$14,500	$228,000	15.7	6%	15	N/A
Total			**52.4%**	**$121,600**	**$5,161,000**	**42.4**	**2%**	**-**	

Table 102. Post Retrofit Site EUI by End Use & Percent Reductions from Baseline for ZNC Target Package – Case Study 7

Project	Heating – Gas	Cooling – Gas	DHW – Gas	Baseload – Gas	Heating – Electric	Cooling – Electric	DHW – Electric	Baseload – Electric	Lighting – Electric	Total EUI
Baseline	23%	0%	29%	3%	0%	8%	0%	32%	5%	**100%**
End Use Difference	-100%	0%	-100%	-100%	100%	-27%	100%	-26%	-12%	**48%**

EE Target Package

As some EE Target measures entail replacement of existing equipment, an additional column is added to Table 103 (on the following page) that shows the estimated remaining life of the equivalent replacement system. An "N/A" indicates the existing system is not replaced, and a "DNE" means does not exist and the package adds a system or piece of equipment not currently onsite. This is discussed in more detail in the Case Study Measures Identification Methodology section below.

Table 103. EE Target Package EEMs – Case Study 7. All costs are total capital cost estimates without incentives and without subtracting the cost of replacing existing systems at end of life.

#	Measure	Description	Whole Bldg. EUI Svgs. (%)	Cost Savings ($/yr.)	Measure Cost ($)	SP (yrs)	ROI (%)	Equip. Life (yrs)	Estimated Remaining Life of Equivalent System (yrs)
1	Partially Electrify Water Heating	Convert existing DHW system to electric DHW with gas backup	15.1%	($9,200)	$953,000	N/A	N/A	15	5-10
2	Install ERV	Install an exhaust recovery ventilation unit	6.9%	$42,600	$432,000	10.1	10%	15	DNE
3	Retro-commissioning	Retro-commission and implement improvements on central building systems	3.5%	$22,200	$61,000	2.7	37%	5	DNE
4	Guest Room Controls	Add automatic guest room controls to limit extra energy usage during unoccupied times	6.1%	$38,500	$88,000	2.3	44%	10	DNE
5	Wider Deadbands	Expand deadbands for central mechanical equipment	0.4%	$1,300	$3,000	2.3	52%	5	DNE
6	CHW Pump VFDs	Install chilled water pump variable frequency drives	0.4%	$2,900	$23,000	7.9	13%	15	DNE
7	CW Pump VFDs	Install condenser water pump variable frequency drives	0.4%	$3,500	$27,000	7.7	13%	15	DNE
8	HW Pump VFDs	Install hot water pump variable frequency drives	0.3%	$2,000	$8,000	4.0	26%	15	DNE
9	Air Handling Unit VFDs	Install air handling unit fan variable frequency drives	0.9%	$7,000	$48,000	6.9	14%	15	DNE
10	Finish LED Conversion	Complete ongoing LED conversion	0.2%	$1,200	$38,000	31.7	3%	15	5-10
11	Plug Load Management	Install smart plug load management tools	1.3%	$9,900	$17,000	1.7	57%	10	DNE
12	Low Flow Aerators	Install low flow aerators in hotel room faucets and showers	0.2%	$1,700	$10,000	5.9	17%	10	DNE
13	General Air Sealing	Air seal gaps in masonry, between window/wall sealing, doors, and other envelope	0.6%	$2,300	$31,000	13.5	7%	15	DNE
14	Solar PV	Install roof-mounted solar PV	1.6%	$12,300	$228,000	18.5	5%	15	DNE
Total			**37.8%**	**$138,200**	**$1,967,000**	**14.2**	**7%**	**-**	

Table 104: Post Retrofit Site EUI by End Use & Percent Reductions from Baseline for EE Target Package – Case Study 7

Project	Heating – Gas	Cooling – Gas	DHW – Gas	Baseload – Gas	Heating – Electric	Cooling – Electric	DHW – Electric	Baseload – Electric	Lighting – Electric	Total EUI
Baseline	46%	0%	16%	6%	0%	5%	0%	24%	3%	**100%**
End Use Difference	-26%	0%	-82%	0%	-26%	-31%	0%	-37%	-17%	**62%**

Less-than-Five-Year Payback Package

The Less-than-Five-Year Payback package allows the building to meet its first interim target threshold.

Table 105. Less-than-Five-Year Payback Package EEMs – Case Study 7. All costs are total capital cost estimates without incentives and without subtracting the cost of replacing existing systems at end of life.

Measure #	Measure	Description	Whole Bldg. EUI Svgs. (%)	Cost Savings ($/yr.)	Measure Cost ($)	SP (yrs)	ROI	Equip. Life (yrs)
1	Retro-commissioning	Retro-commission and implement improvements on central building systems	4.9%	$24,600	$61,000	2.5	41%	5
2	Guest Room Controls	Add automatic guest room controls to limit extra energy usage during unoccupied times	8.4%	$42,500	$88,000	2.1	48%	10
3	Wider Deadbands	Expand deadbands for central mechanical equipment	0.5%	$1,400	$3,000	2.1	58%	5
4	CHW Pump VFDs	Install chilled water pump variable frequency drives	0.4%	$3,300	$23,000	7.0	14%	15
5	CW Pump VFDs	Install condenser water pump variable frequency drives	0.5%	$3,800	$27,000	7.1	14%	15
6	HW Pump VFDs	Install hot water pump variable frequency drives	0.3%	$2,300	$8,000	3.5	29%	15
7	Air Handling Unit VFDs	Install air handling unit fan variable frequency drives	0.7%	$5,200	$48,000	9.2	11%	15
8	Finish LED Conversion	Complete ongoing LED conversion	0.2%	$1,200	$38,000	31.7	3%	15
9	Plug Load Management	Install smart plug load management tools	1.4%	$11,100	$17,000	1.5	64%	10
10	Low Flow Aerators	Install low flow aerators in hotel room faucets and showers	0.7%	$1,800	$10,000	5.6	18%	10
11	General Air Sealing	Air seal gaps in masonry, between window/wall sealing, doors, and other envelope	0.7%	$2,600	$31,000	11.9	8%	15
	Total		**18.5%**	**$99,800**	**$354,000**	**3.5**	**28%**	**-**

Table 106. Post Retrofit Site EUI by End Use & Percent Reductions from Baseline for Less-than-Five-Year Payback Package – Case Study 7

Project	Heating – Gas	Cooling – Gas	DHW – Gas	Baseload – Gas	Heating – Electric	Cooling – Electric	DHW – Electric	Baseload – Electric	Lighting – Electric	Total EUI
Baseline	23%	0%	29%	3%	0%	8%	0%	32%	5%	**100%**
End Use Difference	-18%	0%	-16%	0%	-3%	-16%	0%	-24%	-17%	**-19%**

Package Comparisons to ZNC Target

The following chart shows the site EUI and split between fuels today and for the EEM packages in comparison to the three Targets.

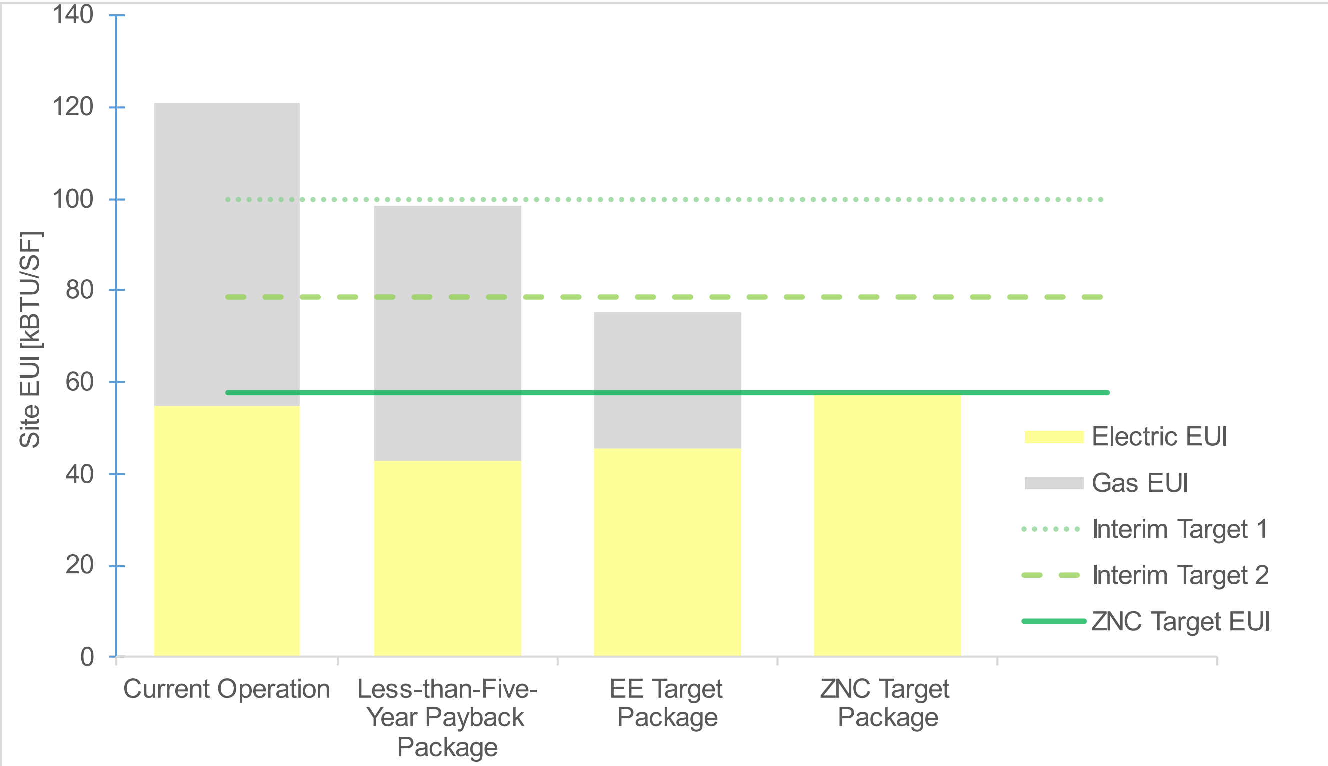

Figure 49. Target-to-Package Comparisons – Case Study 7

As seen in Figure 49, the Less-Than-Five-Year Payback Package results in a savings amount about equivalent to the first interim target. However, this package is still well short of the ZNC Target.

The EE Target Package does not fully electrify the building but does partially electrify some loads. As a result, electric use increases compared to the Less-Than-Five-Year Payback Package while gas use substantially decreases. This approach also gets the building below the 2nd interim target.

Building-Specific Technology Assessment

Given the large gas load at this building, electrification of primary loads-space heating, domestic hot water, cooking, and other similar base loads–are the main drivers behind the ZNC Target Package. These measures entail substantial renovations, but given the age of the mechanical system, a large-scale upgrade is likely during the next 10-15 years. As a result, electrification measures are the main energy savings driver in the ZNC Target Package.

Similarly, electrification of building loads needed to be evaluated for the EE Target. Although this is a comparatively smaller lift than the ZNC Target—on the order of 35% instead of 50%--this target cannot be reached without some amount of electrification.

Electrification considerations for this building are as follows:

- As noted above, electrification of all gas-fired loads is necessary in order to reach the ZNC Target. Electrifying all loads also represents a possible pathway to reaching the EE Target, although not a financially attractive one.
- Electrifying space heating would mean other measures to improve the building mechanical system could not be included in the EE Target Package. Since mechanical upgrades are typically more

common and offer better financial returns than domestic hot water or cooking upgrades, electrifying space heating was *not* included in the EE Target Package.

- *Completely* electrifying domestic hot water loads creates a slightly less attractive financial package than *partially* electrifying domestic hot water loads. In this partial electrification scenario, *only* enough electric DHW would be installed in order to meet the EE Target; the remaining capacity would be handled by gas systems. This also allows for backup gas systems to remain in case of emergency. The percentage of electrified systems was identified as described below.
- Electrifying cooking represents a rather small percentage of overall gas usage; other, more cost-effective measures can be used to reach the EE Target.

Once electrification measures were identified, then other measures to upgrade or optimize the building mechanical system were chosen. This includes items such as installing an ERV to lessen the heating and cooling load of the building. In this building, hotel guest room controls are applicable even with the system conversions so guest room controls were applied to all packages. Variable frequency drives (VFDs) were applied to mechanical systems that were not modified.

Following these mechanical system upgrades, other measures affecting building demand were applied (items like LED lighting conversions and high-efficiency aerators). These measures do not have a large overall impact on savings and were generally non-interactive in nature, meaning any resultant savings from these measures do not appreciably increase or decrease savings from other measures.

Lastly, roof-mounted solar PV is applied to the ZNC and EE Target Packages. In practice, solar PV needs to be coordinated with other measures that require roof space. A possible alternative method of ZNC compliance would be to expand solar PV to include a canopied PV system over the parking lot; however, based on the financial analysis done within this case study this is less financially advantageous than the package of measures chosen.

The Less-than-Five-Year Payback Package is largely constructed using similar measures as the ZNC Target Package with two notable exceptions:

- Retro-commissioning is applied to the existing systems only. Wholesale changeout of building mechanical systems would render any realized retro-commissioning savings irrelevant in the ZNC Target Package and so it was not included.
- Chilled Water Pump VFDs and Hot Water Pump VFDs are included in this package but not in the ZNC Target Package. The ZNC Target Package removes these loops from the building and instead includes a condenser water loop serving as the main building loop.

Once the Less-than-Five-Year Payback Package was constructed, measures for systems that remained were applied to the EE Target Package. These measures on their own were insufficient to reach the EE Target; in order to complete the EE Target Package, Solar PV (from the ZNC Target Package) and partial electrification of the DHW loop was applied. Electrifying approximately 80% of the DHW System was enough to reach the EE Target.

Package Comparisons

Reaching ZNC targets incurs a large overall cost to the property; most of these costs are borne from either electrification measures such as heat pump conversion or envelope measures such as air sealing and adding insulation. However, the ZNC target for this building is reachable with technologies available today.

There are some ways to reduce compliance retrofit costs:

- Some of the total capital costs may be defrayed by accounting for avoided replacement costs of existing mechanical equipment. For example, most mechanical equipment will likely be replaced before the 2035 target. This money can be effectively set aside to help cover parts of the costs.

- Financing methods such as the Montgomery County Green Bank are viable.
- Utility incentives through the EmPOWER Maryland program may help offset upfront costs. While not a significant amount relative to the overall project investment, these funds are available today. These funds are available on three-year cycles and the program offerings can change during the program cycle; based on this, incentive estimates are not included in this report.

The EE Target Package incurs less overall cost than the ZNC Target Package and higher cost savings.

The Less-than-Five-Year Payback Package largely utilizes retrofits to existing equipment. Applying a higher estimated savings for retro-commissioning may be possible. It should be noted that with more retro-commissioning savings realized, the "Install ERV" measure (EEM 4 in the ZNC Target Package) be eligible for inclusion in the Less-than-Five-Year Payback Package.

Advances in technology between now and the ZNC target date may result in viable alternative approaches, meaning reductions in the ZNC costs and payback ranges described here. This applies primarily to envelope measures.

Measures Not Recommended

Measures reviewed for the building but not included in the EEM package are described below.

- Envelope: window and roof replacements were considered but ultimately not needed to meet the ZNC target and not cost-effective enough to include in the Less-than-Five-Year Payback Package.
- Canopy-mounted parking lot solar PV: while parking lot space here may allow for canopy-mounted solar PV, this is a much more expensive option than the roof-mounted solar PV approach chosen; this measure would displace other, more financially attractive measures.

General Methodology Applied to All Case Studies

The following text describes components of this technical analysis that were applied to all case studies about EEM Package Development, Building Desktop Audits, and Utility Rates. After those sections are discussions of the analysis methodology applied specifically to this case study.

EEM Package Development

Three packages of EEMs were developed.

Zero Net Carbon-Compatible (ZNC) Target Package

This package compiles measures necessary to meet the Zero Net Carbon-Compatible target for the respective building. These measures typically include electrification of natural gas uses. The aim of this package was to create a series of measures that result in the ability of the case study building to meet the ZNC target. Project financials were not a primary driver, but financially desirable measures were included wherever possible.

Descriptions of each package are included in the individual case studies below.

The methodology for developing these packages was generally as follows:

- Potential electrification measures were implemented first when determined they were necessary to meet the ZNC target. This was done for two reasons:
  - Electrified end uses were typically large (i.e., all of a building's heating loads), and
  - Other measures' applicability may change based on these electrified systems. Note that for packages where mechanical systems were changed, some measures that are appropriate based on *existing mechanical equipment* may not be included in the ZNC package. However, they may appear in the However, they may appear in the EE Target Package or Less-than-Five-Year Payback Package.

- Next, measures with large interactive effects were reviewed. These measures were typically either mechanical or controls-based in nature.
- Next, smaller end use reduction measures with limited interactive effects were implemented. These measures typically have a small impact (i.e., less than 5% of overall building usage).
- Lastly, where applicable and necessary, photovoltaic solar (PV) was applied.

Energy Efficiency (EE) Target Package

This package compiles measures necessary to meet the Energy Efficiency target for the respective building. Initial analysis returned multiple ways to think about developing an approach, each with pros and cons. These can be found in Table 107 below.

Table 107: General approaches to developing an EE Target Package.

Package Type	Pros	Cons	Other Items
Fewest Measures	• Simplest to implement • Easiest to understand	• Higher cost and lower ROI	• Electrification of some end uses guaranteed
Best ROI that Meets the EE Target	• Most attractive financial package • Best speaks to financial concerns	• Still will electrify some loads • Better ROI may not be the easiest to implement measures	• This will likely introduce partial electrification of end uses to the study
Minimize Electrification	• Best speaks to the theory behind the EE package	• Would necessitate replacement of gas-fired equipment with new gas-fired equipment	• May not really be viable with case study buildings (but could be viable with other buildings)

This study opted to use the Best ROI that Meets the EE Target approach. The following guidelines apply to this approach:

- Electrification of end uses needed to be considered in practice. Most case study buildings were far enough away from the EE Target that reaching the EE Target without electrification was infeasible without significant occupant energy pattern changes[60].
- Electrification of DHW loads was considered first. Most mechanical systems (which include space heating systems) have low-cost opportunities for optimization while most DHW systems have limited optimization opportunities. This means the combined mechanical system optimization measures plus DHW electrification had a more attractive ROI than space heating electrification measures.
- Mechanical system optimization and retro-commissioning measures were then implemented.
- Next, smaller end use reduction measures with limited interactive effects were implemented. These measures typically have a small impact (i.e., less than 5% of overall building usage).
- Electrification of space heating loads was considered only if electrification of DHW loads was not enough in conjunction with other measures to meet the EE Target *and* minimal system optimization was possible.
- Lastly, where applicable and necessary, photovoltaic solar (PV) was applied.

[60] Energy conservation by occupants can drive significant energy savings (EPA, slide 33). Because of the difficulty in predicting savings (and the persistence of savings) for these sorts of behavioral measures in typical buildings, those savings are not included in this study.

Less-than-Five-Year Payback Package

This package compiles a set of measures that results in a five year or less total simple payback. This package represents a reasonable approximation of possible outcomes from an energy audit. These measure packages represent the types of low cost and lower-savings measures often recommended during standard energy audits. These measures are often investigated by buildings first. Note that an energy audit may include other financial tools such as utility incentives, tax deductions/credits, or other assistance, which were not included in this technical analysis.

Where applicable, measures from the Less-than-Five-Year Payback Package were also applied to the ZNC Package. The methodology described under the ZNC Target Package applied to the Less-than-Five-Year Payback Package as well. The following guidelines apply to the Less-than-Five-Year Payback Package:

- Measures with large interactive effects were reviewed. These measures were typically either mechanical or controls-based in nature.
- Retro-commissioning was applied; see below for details.
- Next, smaller end use reduction measures with limited interactive effects were implemented. These measures typically have a small impact (i.e., less than 5% of overall building usage).
- Lastly, where applicable and necessary, photovoltaic solar (PV) was applied.
- Major building systems were *not* modified in this package. Most system conversions (for example, converting from chilled water to water-source heat pumps) have longer paybacks and would not realistically be included. However, this also means that measures that impact *existing mechanical equipment* would appear here (for example, chilled water pump VFDs when the ZNC Target Package converted a building from chilled water to water-source heat pumps).
- New fossil fuel measures were not included.
- Overall energy savings were not a primary goal of this target; the energy savings resulting from this package was simply the end result of measures that would result in a less than five year project payback for all measures considered.

Typically, this package may be useful in reviewing progress toward interim targets.

Note that for some newer buildings that have less opportunity for low-cost incremental savings, the Less-than-Five-Year Payback Package may be either small or non-existent.

Building Desktop Audits

Case studies were developed through interviews with building managers and site staff to collect – for major equipment only – equipment type, equipment age, operating parameters, types of fuel used for various end uses, information on recent capital upgrades, and any comments on plans for future upgrades and decision-making processes in relation to energy management. Architectural and mechanical drawings and supporting documentation were reviewed when available.

Desktop audits were performed in order to develop the case studies contained in this report. Desktop audits use information provided from building owners and operators to develop recommendations, but do not contain any onsite observations. This methodology is effective for informing policy-level decisions as it can effectively capture broad-stroke approaches; however, this methodology does not tend to capture measures are more limited in impact (e.g., mechanical systems that only serve part of the building). Applicability of desktop audit measures to a specific building typically requires some amount of onsite investigation in order to determine applicability of measures for any specific building in a given typology. This technical analysis is limited to desktop audits and measure recommendations are limited to what could be recommended based on the data collected by the auditor.

Where possible, supplemental energy audit information performed by others is incorporated into the case studies. These energy audits, which may contain onsite observations, were completed prior to this desktop audit process.

Utility Rates

Utility rate assumptions are $0.129 per kWh and $1.228 per therm, based on the US Energy Information Administration (EIA) average rates for the area. While energy rates differ by service class and usage profile, these rates are assumed to represent the average costs for these types of buildings in Montgomery County. These rates are meant to be inclusive of taxes and fees applicable throughout the state, including the current Fuel Energy Tax of $0.01978 per kWh on electricity and $0.17026 per therm on natural gas use.

Case Study 8: Standard Hotel without Extra Use Spaces

Building Information

This is a standard hotel without major extra use spaces such as conference centers. However, a restaurant and small retail space is on the premises. In addition, a covered parking garage serves the facility; its energy usage is on the electricity meter serving the building. Fan coil units are located in individual hotel rooms. Fresh air is provided to the hotel rooms via the hotel corridors; this air is pre-conditioned with exhaust air heat recovery systems.

Table 108. Building Characteristics – Case Study 8

Category	Building Information
Typology	Lodging
Square Footage	200,000 ft.^{2} – 225,000 ft.^{2} Hotel: 100%
Year Built	1990 – 1995
2019 ENERGY STAR Score	30 – 35
2019 Site EUI (kBTU/SF) (calculated for this study)	125 – 135

Building System Information

The basic building system information specific to the case study building is described below.

Table 109. Building System Information – Case Study 8

Category	Type	Fuel	Approximate Equipment Age (Years)	Expected End of Useful Life (Years)
Central BMS	None – pneumatics installed on main equipment.	Electric	30 (estimated)	<5
Heating	Condensing HHW boilers feeding 4-pipe FCU system. Pumps original but have VFDs installed.	Gas (pumps, FCU motors electric)	2	20-25
Cooling	Chilled water; chillers about 30 years old. Cooling towers about 15 years old. No VFDs on CT fans.	Electric	30	<5
Ventilation	Semco heat recovery units serving corridors	Electric	10	10-15
DHW	Two sealed combustion hot water heaters	Gas (pumps, FCU motors electric)	12-14	5-10
Lighting	LED	Electric	2-3	5-10
Envelope	Largely unchanged in last 5-10 years	N/A	30 (estimated)	15-20
Metering	Centrally metered electric and gas	Electric, Gas	N/A	N/A

Utility End Use Assessment

The building's energy usage type and estimated end uses are displayed below.

- Gas: used for heating hot water and domestic hot water usage primarily. An onsite restaurant also uses some gas (described in this report as base load), as does pool heating. 55% of the building's energy use is in the form of gas.
- Electricity: used for cooling, ventilation, lighting, and electric plug loads. 45% of the building's energy use is in the form of electricity. Fan coil units (FCUs) in hotel rooms and air handling units (AHUs) in common spaces provide conditioned air from a central heating and cooling plant. Parking lot lighting energy usage is included in this metric as it was not separately metered.

Table 110. 2019 Site EUI by End Use – Case Study 8. Components may not sum to 100% due to rounding.

Heating – Gas	Cooling – Gas	DHW – Gas	Baseload – Gas	Heating – Electric	Cooling – Electric	DHW – Electric	Baseload – Electric	Lighting – Electric	Total EUI
16%	0%	35%	4%	0%	8%	0%	33%	5%	**100%**

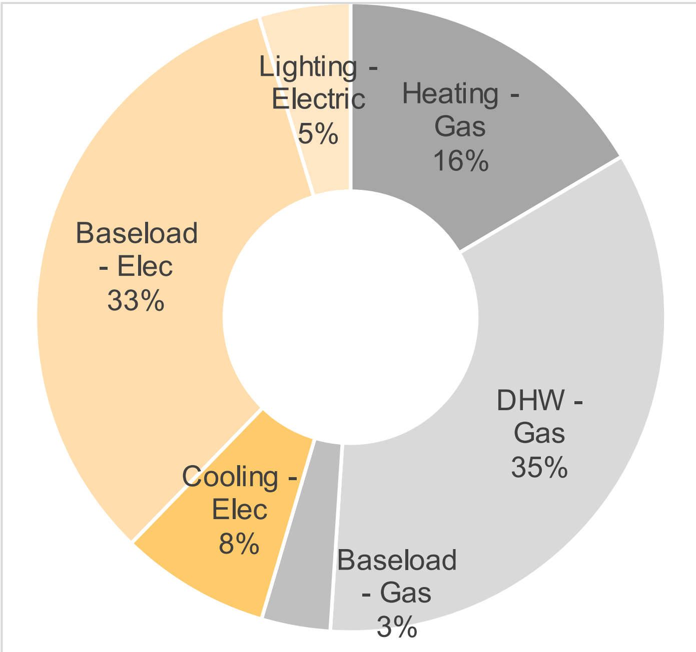

Figure 50. Site EUI Share (%) by End Use – Case Study 8

Target Determination

EUI targets are determined by a weighted average of applicable ZNC targets per space use type. Space use types are provided in Portfolio Manager and via reviews of available drawings. The table also has an alternate target ("EE Standard"); the building will need to take action in order to meet both the ZNC and EE Targets. All the following analysis uses the ZNC target.

Table 111. Space Use Target Methodology Summary – Case Study 8

Specific Space Type	Space Type Group	Area %	Floor Areas	ZNC Standard [Site EUI]	EE Standard [Site EUI]	Weighted ZNC EUI (ZNC * Area%)	Weighted EE EUI (ZNC * Area%)
Hotel	Lodging	100%	225,000	57.8	75.7	57.8	75.7
Total	**-**	**100%**	**225,000**	**-**	**-**	**57.8**	**75.7**

In addition to the overall hotel space (i.e., rooms, corridors, the main lobby), other support areas are present such as a restaurant with kitchen, conference center, and above-ground covered parking. Most of these support areas are small (less than 5% of the overall building footprint), and parking is not included in any target-setting metrics.

The baseline EUI is derived from whole building 2019 utility data over whole building square footage.

Table 112. ZNC and Interim Targets – Case Study 8

EUI Description	ZNC Target	EE Target
Baseline EUI	125 – 135	125 – 135
2026 – Interim Target 1	101 – 110	108 – 115
2030 – Interim Target 2	77 – 85	90 – 96
2035 – Target	57.8	75.7

Package Overview

EEM packages were compiled based on existing technology for two scenarios:

- *ZNC Target Package* is based upon electrification and energy efficiency measures to reach the ZNC Target for this building.
- *EE Target Package* is based upon energy efficiency measures to reach the EE Target for this building. Note that the ZNC Target Package can also be used to reach the EE Target, but the EE Target Package reduces EUI only as far as needed to meet the EE Target.
- *Less-than-Five-Year Payback Package* is based on the results of a package that would have a simple payback of less than five years, not accounting for supplemental funding tools such as utility incentives or tax credits.

All costs are total costs for the measures, not incremental costs. These costs do not include applicable incentives. The following table offers a financial overview of these packages.

Table 113. EEM Package Summary – Case Study 8

Package	Package EUI (kBTU/ft.^{2}/yr)	% Site EUI Savings	Cost Savings ($/yr.)	Capital Costs ($)	SP (yrs)	ROI (%)
Final Target Package	53 – 57	56%	$209,600	$7,170,000	34.2	3%
EE Target Package	72 – 76	42%	$213,400	$2,105,000	9.9	10%
Less-than-Five-Year Payback Package	89 – 96	29%	$214,300	$751,000	3.5	29%

ZNC Target Package

As some ZNC Target measures entail replacement of existing equipment, an additional column is added to Table 114 that shows the estimated remaining life of the equivalent replacement system. An "N/A" indicates the existing system is not replaced, and "DNE" means does not exist and the package adds a system or piece of equipment not currently onsite. This is discussed in more detail in the Case Study Measures Identification Methodology section below.

Table 114. ZNC Target Package EEMs – Case Study 8. All costs are total capital cost estimates without incentives and without subtracting the cost of replacing existing systems at end of life.

#	Measure	Description	Whole Bldg. EUI Svgs. (%)	Cost Savings ($/yr.)	Measure Cost ($)	SP (yrs)	ROI (%)	Equip. Life (yrs)	Estimated Remaining Life of Equivalent System (yrs)
1	Electrify Space Heating	Convert existing HVAC system to an electric heat pump system	11.5%	$4,400	$4,844,000	N/A	N/A	19	20-25
2	Electrify Water Heating	Convert existing DHW system to electric DHW	21.7%	($13,800)	$1,370,000	N/A	N/A	19	5-10
3	Electrify Cooking	Convert gas cooking to electric cooking	1.4%	($11,000)	$11,000	N/A	N/A	10	Unknown (estimated 10 years)
4	Guest Room Controls	Add automatic guest room controls to limit extra energy usage during unoccupied times	6.4%	$69,500	$112,000	1.6	62%	15	Unknown (estimated 5-10 years)
5	Pneumatic Conversion to DDC	Convert central plant pneumatics to DDC and calibrate/optimize system	8.9%	$96,000	$440,000	4.6	22%	15	<5
6	Recommission Heat Recovery	Recommission existing heat recovery ventilation system	2.2%	$23,400	$22,000	0.9	106%	5	N/A
7	Cooling Tower Fan VFDs	Install cooling tower fan variable frequency drives	0.4%	$3,900	$12,000	3.0	33%	15	DNE
8	Plug Load Management	Install smart plug load management tools	1.5%	$15,900	$22,000	1.4	72%	10	DNE
9	High-Efficiency Water Aerators	Install low flow aerators in hotel room faucets and showers	0.3%	$3,000	$11,000	3.7	27%	10	DNE
10	Solar PV	Install roof-mounted solar PV	1.7%	$18,300	$326,000	17.8	6%	15	DNE
Total			**56.2%**	**$209,600**	**$7,170,000**	**34.2**	**3%**	**-**	

Table 115. Post Retrofit Site EUI by End Use & Percent Reductions from Baseline for ZNC Target Package – Case Study 8

Project	Heating – Gas	Cooling – Gas	DHW – Gas	Baseload – Gas	Heating – Electric	Cooling – Electric	DHW – Electric	Baseload – Electric	Lighting – Electric	Total EUI
Baseline	16%	0%	35%	4%	0%	8%	0%	33%	5%	**100%**
End Use Difference	-100%	0%	-100%	-100%	0%	-28%	0%	-34%	-23%	**44%**

EE Target Package

As some EE Target measures entail replacement of existing equipment, an additional column is added to Table 116 that shows the estimated remaining life of the equivalent replacement system. An “N/A” indicates the existing system is not replaced, and a “DNE” means does not exist and the package adds a system or piece of equipment not currently onsite. This is discussed in more detail in the Case Study Measures Identification Methodology section below.

Table 116. EE Target Package EEMs – Case Study 8. All costs are total capital cost estimates without incentives and without subtracting the cost of replacing existing systems at end of life.

#	Measure	Description	Whole Bldg. EUI Svgs. (%)	Cost Savings ($/yr.)	Measure Cost ($)	SP (yrs)	ROI (%)	Equip. Life (yrs)	Estimated Remaining Life of Equivalent System (yrs)
1	Electrify Water Heating	Convert existing DHW system to electric DHW with gas backup	17.8%	($14,900)	$1,028,000	N/A	N/A	15	15-20
2	Install Free Cooling HX	Install a plate-and-frame heat exchanger to provide chilled water during cold ambient conditions	1.3%	$13,800	$107,000	7.8	13%	15	15-20
3	Guest Room Controls	Add automatic guest room controls to limit extra energy usage during unoccupied times	7.0%	$63,800	$112,000	1.8	57%	10	DNE
4	Pneumatic Conversion to DDC	Convert central plant pneumatics to DDC and calibrate/optimize system	9.6%	$88,100	$440,000	5.0	20%	5	0-5
5	Recommission Heat Recovery	Recommission existing heat recovery ventilation system	2.4%	$21,800	$22,000	1.0	99%	15	DNE
6	Cooling Tower Fan VFDs	Install cooling tower fan variable frequency drives	0.3%	$3,700	$12,000	3.2	31%	15	DNE
7	Air Handling Unit VFDs	Install air handling unit fan variable frequency drives	0.3%	$2,700	$25,000	9.1	11%	10	DNE
8	Plug Load Management	Install smart plug load management tools	1.4%	$14,800	$22,000	1.5	67%	15	DNE
9	Low Flow Aerators	Install low flow aerators in hotel room faucets and showers	0.2%	$2,500	$11,000	4.5	22%	10	DNE
10	Solar PV	Install roof-mounted solar PV	1.6%	$17,000	$326,000	19.2	5%	15	DNE
Total			**41.8%**	**$213,300**	**$2,105,000**	**9.9**	**10%**	**-**	

Table 117: Post Retrofit Site EUI by End Use & Percent Reductions from Baseline for EE Target Package – Case Study 8

Project	Heating – Gas	Cooling – Gas	DHW – Gas	Baseload – Gas	Heating – Electric	Cooling – Electric	DHW – Electric	Baseload – Electric	Lighting – Electric	Total EUI
Baseline	46%	0%	16%	6%	0%	5%	0%	24%	3%	**100%**
End Use Difference	-27%	0%	-82%	0%	0%	-40%	0%	-39%	-23%	**58%**

Less-than-Five-Year Payback Package

The Less-than-Five-Year Payback package allows the building to meet its first interim target threshold.

Table 118. Less-than-Five-Year Payback Package EEMs – Case Study 8. All costs are total capital cost estimates without incentives and without subtracting the cost of replacing existing systems at end of life.

#	Measure	Description	Whole Bldg. EUI Svgs. (%)	Cost Savings ($/yr.)	Measure Cost ($)	SP (yrs)	ROI (%)	Equip. Life (yrs)
1	Install Free Cooling HX	Install a plate-and-frame heat exchanger to provide chilled water during cold ambient conditions	1.3%	$13,800	$107,000	7.8	13%	15
2	Guest Room Controls	Add automatic guest room controls to limit extra energy usage during unoccupied times	9.3%	$64,500	$112,000	1.7	57%	15
3	Pneumatic Conversion to DDC	Convert central plant pneumatics to DDC and calibrate/optimize system	12.9%	$89,100	$440,000	4.9	20%	10
4	Recommission Heat Recovery	Recommission existing heat recovery ventilation system	2.4%	$21,800	$22,000	1.0	99%	5
5	Cooling Tower Fan VFDs	Install cooling tower fan variable frequency drives	0.3%	$3,700	$12,000	3.2	31%	15
6	Air Handling Unit VFDs	Install air handling unit fan variable frequency drives	0.4%	$4,000	$25,000	6.1	16%	15
7	Plug Load Management	Install smart plug load management tools	1.4%	$14,700	$22,000	1.5	67%	10
8	Low Flow Aerators	Install low flow aerators in hotel room faucets and showers	0.7%	$2,600	$11,000	4.2	24%	15
	Total		**28.7%**	**$214,200**	**$751,000**	**3.5**	**29%**	**-**

Table 119. Post Retrofit Site EUI by End Use & Percent Reductions from Baseline for Less-than-Five-Year Payback Package – Case Study 8

Project	Heating – Gas	Cooling – Gas	DHW – Gas	Baseload – Gas	Heating – Electric	Cooling – Electric	DHW – Electric	Baseload – Electric	Lighting – Electric	Total EUI
Baseline	16%	0%	35%	4%	0%	8%	0%	33%	5%	**100%**
End Use Difference	-27%	0%	-25%	0%	0%	-40%	0%	-34%	-23%	**71%**

Package Comparisons to ZNC Target

The following chart shows the site EUI and split between fuels today and for the EEM packages in comparison to the three Targets.

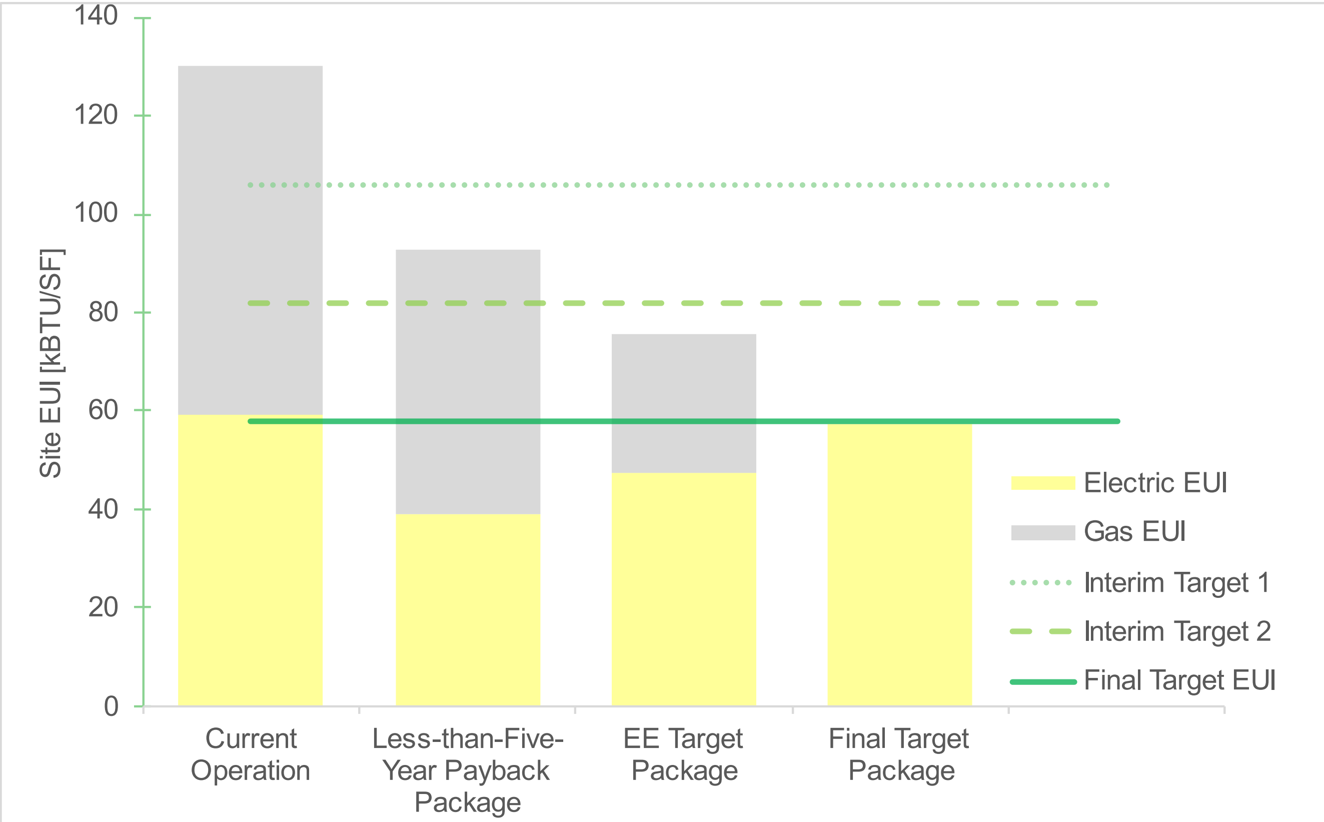

Figure 51. Target-to-Package Comparisons – Case Study 8

As seen in Figure 51, the Less-Than-Five-Year Payback Package results in a savings amount approximate to the first interim target.

The EE Target Package does not fully electrify the building but does partially electrify some loads. As a result, electric use increases compared to the Less-Than-Five-Year Payback Package while gas use substantially decreases. This approach also gets the building below the 2nd interim target.

Building-Specific Technology Assessment

This hotel has a large gas load which is dominated by domestic hot water use. In addition, this hotel has a central control system which is a large source of building inefficiencies.

Given the large gas load at this building, electrification of primary loads-mechanical heating and cooling, domestic hot water, cooking, and other similar base loads–are the main drivers behind the ZNC Target Package. These measures entail substantial renovations, but given the age of the mechanical system, a large-scale upgrade is likely during the next 10-15 years. As a result, electrification measures are included in the ZNC Target Package.

Similarly, electrification of building loads needed to be evaluated for the EE Target. Although this is a comparatively smaller lift than the ZNC Target—on the order of 40% instead of 55%--this target cannot be reached without some measure of electrification.

Electrification considerations for this building are as follows:

- As noted above, electrification of all gas-fired loads is necessary in order to reach the ZNC Target. Electrifying all loads also represents a possible pathway to reaching the EE Target, although not a financially attractive one.
- Electrifying space heating would mean other measures to improve the building mechanical and controls systems could not be included in the EE Target Package. Since mechanical upgrades are typically more common and offer better financial returns than domestic hot water or cooking upgrades, electrifying space heating was *not* included in the EE Target Package.
- *Completely* electrifying domestic hot water loads creates a slightly less attractive financial package than *partially* electrifying domestic hot water loads. In this partial electrification scenario, *only* enough electric DHW would be installed in order to meet the EE Target; the remaining capacity would be handled by gas systems. This also allows for backup gas systems to remain in case of emergency. The percentage of electrified systems was identified as described below.
- Electrifying cooking represents a rather small percentage of overall gas usage; other measures can be used to reach the EE Target.

For this building, converting the existing fan coil system to a water-source heat pump system gains the benefit of reusing existing piping risers compared to other electrification conversion technology (i.e., VRF) which entails entirely new piping runs throughout the building.

Some alternative approaches were reviewed:

- Aiming for efficiency gains from existing equipment is not realistic based on technology available today. In effect, gas-fired equipment needs to approach or exceed 100% efficiency in order to be in range of the ZNC target. While some optimization methods can help and do appear in the Less-than-Five-Year Payback Package, they do not cover this energy gap.
- More efficient similar system types have the same issues. While—for example—replacement of aged chillers with new chillers would generate substantial chilled water savings, it does not solve the issue around gas usage as described above.

Once electrification measures are completed, other measures to improve building controls were chosen, including advanced guest room controls and converting the existing pneumatic control system to direct digital controls (DDC). Pneumatic controls are old, inefficient mechanical system controls that use compressed air to start and stop equipment and control critical points such as space temperature. However, they require frequent calibration (recommended every six months) and are prone to failure. Direct digital controls use electronic devices and control signals to control mechanical equipment; these require less frequent calibration, are more accurate, and allow for more advanced, energy savings control. Because the system upgrades undertaken for electrification leave some piping and pumping in place, upgrading these controls to DDC are necessary to realize the total system benefit.

Smaller but still significant mechanical optimization measures such as recommissioning the existing heat recovery system and installing VFDs on fans were chosen.

Following these mechanical system upgrades, other measures affecting building demand were applied (items like LED lighting conversions and high-efficiency aerators). These measures do not have a large overall impact on savings and were generally non-interactive in nature, meaning any resultant savings from these measures do not appreciably increase or decrease savings from other measures.

Lastly, roof-mounted solar PV is applied to the ZNC and EE Target Packages. In practice, solar PV needs to be coordinated with other measures that require roof space.

The Less-than-Five-Year Payback Package and EE Target Package uses similar measures as the ZNC Target Package with a handful of exceptions or changes:

- Installing a free cooling heat exchanger (HX) is viable for a chilled water plant system, but not viable if the building is converted to a heat pump loop. Free cooling heat exchangers use water as a medium to remove heat from the building without the use of electricity or other fuels when ambient conditions are cool enough; this can result in substantial energy savings in buildings requiring cooling during colder months.
- Pneumatic Conversion with DDC assumed the central plant and primary air handling units would also be converted from their existing pneumatics to DDC. Pneumatic controls operate equipment in the building (usually key mechanical equipment) but are a much older type of control system that frequently falls out of calibration, generating energy waste. DDC controls eliminate this issue.
- Air Handling Unit Fan VFDs apply to the Less-than-Five-Year Payback Package and EE Target Package, but not the ZNC Target Package; electrifying space heating in the ZNC Target Package would replace these air handling units.

Package Comparisons

Most energy cost savings with this building are achieved with the Less-than-Five-Year Payback Package. This is due to two factors:

- Most equipment at the building is running relatively inefficiently, most notably the regular presence of pneumatic controls. Removal of these controls and addition of direct digital (DDC) controls drives a large portion of both total cost and total savings.
- Electrification measures have high costs. Based on the usage profile of this hotel, large-scale electric conversion of domestic hot water and cooking incur not only upgrade costs, but also higher energy costs.

Reaching ZNC targets incurs a large overall cost to the property; most of these costs are borne from either electrification measures such as heat pump conversion or envelope measures such as air sealing and adding insulation. However, the ZNC target for this building is reachable with technologies available today.

The EE Target Package incurs less overall cost than the ZNC Target Package and higher cost savings.

There are some ways to reduce compliance retrofit costs:

- Some of the total capital costs may be defrayed by accounting for avoided replacement costs of existing mechanical equipment. For example, most mechanical equipment will likely be replaced before the 2035 target. This money can be effectively set aside to help cover parts of the costs.
- Financing methods such as the Montgomery County Green Bank are viable.
- Utility incentives through the EmPOWER Maryland program may help offset upfront costs. While not a significant amount relative to the overall project investment, these funds are available today on three-year cycles. The program offerings can change during the program cycle; based on this, incentive estimates are not included in this report.

Note that some of the differences between savings amounts reflected in the different packages (most notably the pneumatic conversion to DDC) are dependent on existing or replaced technology. Specifically, if the mechanical system is converted to a heat pump system, the chilled water plant will not be needed and no savings will be realized.

Advances in technology between now and the ZNC target date may result in other viable approaches, meaning reduction in the ZNC costs and payback ranges described here. This applies primarily to envelope measures.

Measures Not Recommended

Measures reviewed for the building but not included in the EEM package are described below.

- Envelope: window and roof replacements were considered but ultimately unneeded to meet the ZNC target and not cost-effective enough to include in the Less-than-Five-Year Payback Package.

General Methodology Applied to All Case Studies

The following text describes components of this technical analysis that were applied to all case studies about EEM Package Development, Building Desktop Audits, and Utility Rates. After those sections are discussions of the analysis methodology applied specifically to this case study.

EEM Package Development

Three packages of EEMs were developed.

Zero Net Carbon-Compatible (ZNC) Target Package

This package compiles measures necessary to meet the Zero Net Carbon-Compatible target for the respective building. These measures typically include electrification of natural gas uses. The aim of this package was to create a series of measures that result in the ability of the case study building to meet the ZNC target. Project financials were not a primary driver, but financially desirable measures were included wherever possible.

Descriptions of each package are included in the individual case studies below.

The methodology for developing these packages was generally as follows:

- Potential electrification measures were implemented first when determined they were necessary to meet the ZNC target. This was done for two reasons:
    - Electrified end uses were typically large (i.e., all of a building’s heating loads), and
    - Other measures’ applicability may change based on these electrified systems. Note that for packages where mechanical systems were changed, some measures that are appropriate based on *existing mechanical equipment* may not be included in the ZNC package. However, they may appear in the However, they may appear in the EE Target Package or Less-than-Five-Year Payback Package.
- Next, measures with large interactive effects were reviewed. These measures were typically either mechanical or controls-based in nature.
- Next, smaller end use reduction measures with limited interactive effects were implemented. These measures typically have a small impact (i.e., less than 5% of overall building usage).
- Lastly, where applicable and necessary, photovoltaic solar (PV) was applied.

Energy Efficiency (EE) Target Package

This package compiles measures necessary to meet the Energy Efficiency target for the respective building. Initial analysis returned multiple ways to think about developing an approach, each with pros and cons. These can be found in Table 120.

Table 120: General approaches to developing an EE Target Package.

Package Type	Pros	Cons	Other Items
Fewest Measures	• Simplest to implement • Easiest to understand	• Higher cost and lower ROI	• Electrification of some end uses guaranteed
Best ROI that Meets the EE Target	• Most attractive financial package • Best speaks to financial concerns	• Still will electrify some loads • Better ROI may not be the easiest to implement measures	• This will likely introduce partial electrification of end uses to the study
Minimize Electrification	• Best speaks to the theory behind the EE package	• Would necessitate replacement of gas-fired equipment with new gas-fired equipment	• May not really be viable with case study buildings (but could be viable with other buildings)

This study opted to use the Best ROI that Meets the EE Target approach. The following guidelines apply to this approach:

- Electrification of end uses needed to be considered in practice. Most case study buildings were far enough away from the EE Target that reaching the EE Target without electrification was infeasible without significant occupant energy pattern changes[61].
- Electrification of DHW loads was considered first. Most mechanical systems (which include space heating systems) have low-cost opportunities for optimization while most DHW systems have limited optimization opportunities. This means the combined mechanical system optimization measures plus DHW electrification had a more attractive ROI than space heating electrification measures.
- Mechanical system optimization and retro-commissioning measures were then implemented.
- Next, smaller end use reduction measures with limited interactive effects were implemented. These measures typically have a small impact (i.e., less than 5% of overall building usage).
- Electrification of space heating loads was considered only if electrification of DHW loads was not enough in conjunction with other measures to meet the EE Target *and* minimal system optimization was possible.
- Lastly, where applicable and necessary, photovoltaic solar (PV) was applied.

Less-than-Five-Year Payback Package

This package compiles a set of measures that results in a five year or less total simple payback. This package represents a reasonable approximation of possible outcomes from an energy audit. These measure packages represent the types of low cost and lower-savings measures often recommended during standard energy audits. These measures are often investigated by buildings first. Note that an energy audit may include other financial tools such as utility incentives, tax deductions/credits, or other assistance, which were not included in this technical analysis.

Where applicable, measures from the Less-than-Five-Year Payback Package were also applied to the ZNC Package. The methodology described under the ZNC Target Package applied to the Less-than-Five-Year Payback Package as well. The following guidelines apply to the Less-than-Five-Year Payback Package:

[61] Energy conservation by occupants can drive significant energy savings (EPA, slide 33). Because of the difficulty in predicting savings (and the persistence of savings) for these sorts of behavioral measures in typical buildings, those savings are not included in this study.

- Measures with large interactive effects were reviewed. These measures were typically either mechanical or controls-based in nature.
- Retro-commissioning was applied; see below for details.
- Next, smaller end use reduction measures with limited interactive effects were implemented. These measures typically have a small impact (i.e., less than 5% of overall building usage).
- Lastly, where applicable and necessary, photovoltaic solar (PV) was applied.
- Major building systems were *not* modified in this package. Most system conversions (for example, converting from chilled water to water-source heat pumps) have longer paybacks and would not realistically be included. However, this also means that measures that impact *existing mechanical equipment* would appear here (for example, chilled water pump VFDs when the ZNC Target Package converted a building from chilled water to water-source heat pumps).
- New fossil fuel measures were not included.
- Overall energy savings were not a primary goal of this target; the energy savings resulting from this package was simply the end result of measures that would result in a less than five year project payback for all measures considered.

Typically, this package may be useful in reviewing progress toward interim targets.

Note that for some newer buildings that have less opportunity for low-cost incremental savings, the Less-than-Five-Year Payback Package may be either small or non-existent.

Building Desktop Audits

Case studies were developed through interviews with building managers and site staff to collect – for major equipment only – equipment type, equipment age, operating parameters, types of fuel used for various end uses, information on recent capital upgrades, and any comments on plans for future upgrades and decision-making processes in relation to energy management. Architectural and mechanical drawings and supporting documentation were reviewed when available.

Desktop audits were performed in order to develop the case studies contained in this report. Desktop audits use information provided from building owners and operators to develop recommendations, but do not contain any onsite observations. This methodology is effective for informing policy-level decisions as it can effectively capture broad-stroke approaches; however, this methodology does not tend to capture measures are more limited in impact (e.g., mechanical systems that only serve part of the building). Applicability of desktop audit measures to a specific building typically requires some amount of onsite investigation in order to determine applicability of measures for any specific building in a given typology. This technical analysis is limited to desktop audits and measure recommendations are limited to what could be recommended based on the data collected by the auditor.

Where possible, supplemental energy audit information performed by others is incorporated into the case studies. These energy audits, which may contain onsite observations, were completed prior to this desktop audit process.

Utility Rates

Utility rate assumptions are $0.129 per kWh and $1.228 per therm, based on the US Energy Information Administration (EIA) average rates for the area. While energy rates differ by service class and usage profile, these rates are assumed to represent the average costs for these types of buildings in Montgomery County. These rates are meant to be inclusive of taxes and fees applicable throughout the state, including the current Fuel Energy Tax of $0.01978 per kWh on electricity and $0.17026 per therm on natural gas use.

Case Study 9: Worship/Education Mixed-Use

This is a multi-function building that acts as a worship facility, school, and gathering place. The facility was built in two phases. The old building houses mostly school spaces. Space uses are generally divided across the new and old building. Similarly, the mechanical and other building systems are largely separate between the old building and the addition, with the exception of the outdoor air system which is shared across both buildings.

This case study distinguishes measures between the old and new buildings, as specific measures may only be applicable to specific parts of the building. This type of approach would be common in buildings that have substantially different types of building systems in additions.

Table 121. Building Characteristics – Case Study 9

Category	Building Information
Typology	Worship/Education
Square Footage	75,000 ft.^{2} – 100,000 ft.^{2} School: 50% Religious Worship: 50%
Year Built	1995 – 2005 (old building) 2005 – 2015 (new addition)
2019 ENERGY STAR Score	30 – 35
2019 Site EUI (kBTU/SF) (calculated for this study)	80 – 90

Building System Information

The basic building system information specific to the case study buildings are described below.

Table 122. Building System Information – Case Study 9

Category	Type	Fuel	Approximate Equipment Age (Years)	Expected End of Useful Life (Years)
Central BMS	Building automation system in the new building No central controls in the old building	Electric	10 (new) N/A (old)	5-10 (new); <5 (old)
Heating	Gas-fired boilers (primary) in new building WSHP with electric boiler backup in old building	Electric/Gas	10 (new) 20 (old)	10-15 (new) 5-10 (old)
Cooling	Chilled water in new building WSHP in old building	Electric	10 (new) 20 (old)	10-15 (new) <5 (old)
Ventilation	ERVs in new building; through-wall ventilation in old building. ERVs and some AHUs serve some old building spaces	Electric	10 (new) 20 (old)	5-10 (new) <5 (old)
DHW	Unitized electric DHW for both buildings	Electric	10 (new) 20 (old)	10-15 (new) 5-10 (old)
Lighting	Converted to LED in 2016 (including parking lot spaces)	Electric	5	5 – 10
Envelope	Largely unchanged in last 5-10 years	N/A	10 (new) 20 (old)	30-40
Metering	One electric and one gas meter for both buildings	Electric, Gas	N/A	N/A

Utility End Use Assessment

The buildings' energy usage type and estimated end use are displayed below.

- Gas: used for heating hot water in the new building only. Forty percent of the building's energy usage is in the form of gas.
- Electricity: used for cooling and heating in the old building; ventilation, lighting, and electric plug loads. Sixty percent of the building's energy use is in the form of electricity.

Table 123. 2019 Site EUI by End Use – Case Study 9. Components may not sum to 100% due to rounding.

Heating – Gas	Cooling – Gas	DHW – Gas	Baseload – Gas	Heating – Electric	Cooling – Electric	DHW – Electric	Baseload – Electric	Lighting – Electric	Total EUI
40%	0%	0%	0%	6%	10%	1%	37%	7%	**100%**

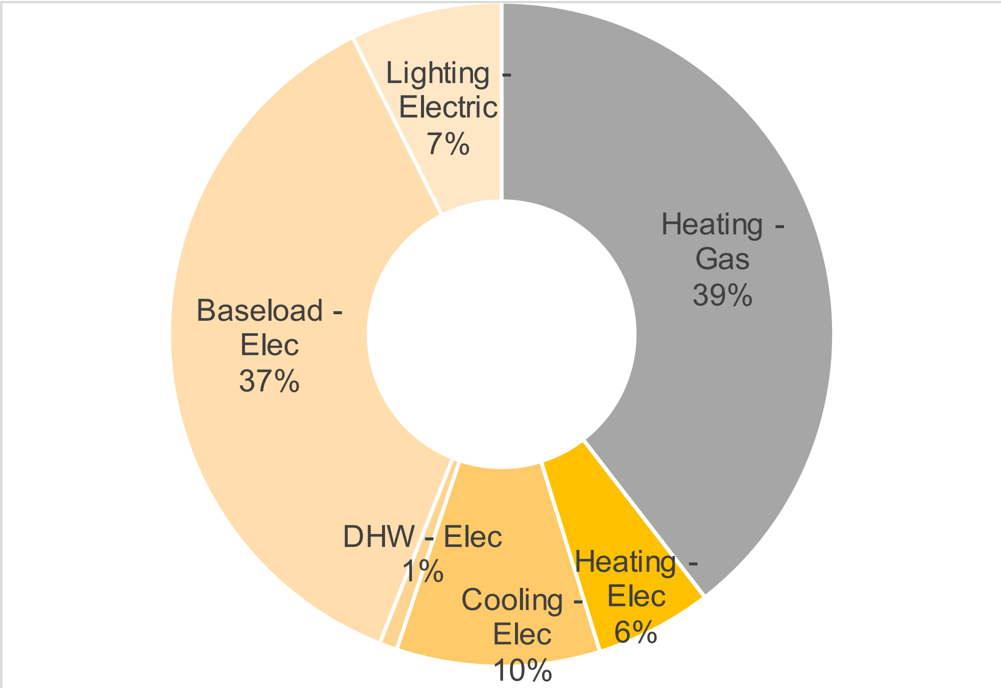

Figure 52. Site EUI Share (%) by End Use – Case Study 9

Target Determination

EUI targets are determined by a weighted average of applicable ZNC targets per space use type. Space use types are provided in Portfolio Manager and via reviews of available drawings. The table also includes an alternate "EE Standard" target. The building will need to take action in order to meet both the ZNC and EE Targets. All the following analysis uses the ZNC target.

Table 124. Space Use Target Methodology Summary – Case Study 9

Specific Space Type	Space Type Group	Area %	Floor Areas	ZNC Standard [Site EUI]	EE Standard [Site EUI]	Weighted ZNC EUI (ZNC * Area%)	Weighted EE EUI (ZNC * Area%)
K-12 School	Education – K-12 School	50%	50,000	36.0	47.1	26.0	24.3
Worship Facility	Religious Worship	50%	50,000	36.9	48.8	10.2	23.6
Total	**-**	**100%**	**100,000**	**-**	**-**	**36.2**	**47.9**

The baseline EUI is derived from whole building 2019 utility data over whole building square footage.

Table 125. ZNC and Interim Targets – Case Study 9

EUI Description	ZNC Target	ZNC Target
Baseline EUI	80 – 90	80 – 90
2026 – Interim Target 1	65 – 72	70 – 77
2030 – Interim Target 2	50 – 56	59 – 64
2035 – Target	36.4	47.9

Package Overview

EEM packages were compiled based on existing technology for two scenarios:

- *ZNC Target Package* is based upon electrification and energy efficiency measures to reach the ZNC Target for this building.
- *EE Target Package* is based upon energy efficiency measures to reach the EE Target for this building. Note that the ZNC Target Package can also be used to reach the EE Target, but the EE Target Package reduces EUI only as far as needed to meet the EE Target.
- *Less-than-Five-Year Payback Package* is based on the results of a package that would have a simple payback of less than five years, not accounting for supplemental funding tools such as utility incentives or tax credits.

All costs are total costs for the measures, not incremental costs. These costs do not include applicable incentives. The following table offers a financial overview of these packages.

Table 126. EEM Package Summary – Case Study 9

Package	Package EUI (kBTU/ft.^{2}/yr)	% Site EUI Savings	Cost Savings ($/yr.)	Capital Costs ($)	SP (yrs)	ROI (%)
ZNC Target Package (Option 1)	33 – 36	55%	$80,800	$3,062,000	37.9	3%
ZNC Target Package (Option 2)	33 – 36	56%	$155,300	$2,445,000	15.7	6%
EE Target Package	45 – 48	42%	$105,700	$1,400,000	13.3	8%
Less-than-5-year Payback Package	72 – 81	10%	$18,800	$53,000	2.8	35%

Note that for the ZNC Target Package, SWA determined that two packages were viable based on energy savings and applicability to this building. This case study contains the results of both of these packages.

ZNC Target Package

As some ZNC Target measures entail replacement of existing equipment, an additional column is added to Table 127 and Table 129 that shows the estimated remaining life of the equivalent replacement system. An "N/A" indicates the existing system is not replaced, and a "DNE" means does not exist and the package adds a system or piece of equipment not currently onsite. This is discussed in more detail in the Case Study Measures Identification Methodology section below.

Table 127. ZNC Target Package EEMs – Case Study 9, Option 1. All costs are total capital cost estimates without incentives and without subtracting the cost of replacing existing systems at end of life.

#	Measure	Description	Whole Bldg. EUI Svgs. (%)	Cost Savings ($/yr.)	Measure Cost ($)	SP (yrs)	ROI (%)	Equip. Life (yrs)	Estimated Remaining Life of Equivalent System (yrs)
1	Electrify Space Heating (new bldg.)	Convert existing gas heating system in the old building to an electric heat pump system	27.7%	$2,600	$978,000	369.0	0%	15	10 – 15
2	Install ERV (old bldg.)	Install a dedicated outdoor air system with heat recovery capabilities in the old building	3.6%	$12,600	$114,000	9.0	11%	15	DNE
3	Retro-commissioning (new building)	Retro-commission and implement improvements on central building systems for the new building	2.7%	$7,500	$16,000	2.1	48%	5	N/A
4	Retro-commissioning (old building)	Retro-commission and implement improvements on central building systems for the old building	2.7%	$7,300	$16,000	2.2	46%	5	N/A
5	Loop Pump VFDs (old bldg.)	Install VFDs on the loop pumps for the old building	0.9%	$2,500	$21,000	8.7	12%	15	DNE
6	Solar PV	Install roof-mounted solar PV and some canopy-mounted solar PV over the parking lot	17.5%	$48,200	$1,918,000	39.8	3%	15	DNE
Total			**55.1%**	**$80,700**	**$3,063,000**	**37.9**	3%	**-**	

Table 128. Post Retrofit Site EUI by End Use & Percent Reductions from Baseline for ZNC Target Package – Case Study 9, Option 1.

Project	Heating – Gas	Cooling – Gas	DHW – Gas	Baseload – Gas	Heating – Electric	Cooling – Electric	DHW – Electric	Baseload – Electric	Lighting – Electric	Total EUI
Baseline	40%	0%	0%	0%	6%	10%	1%	37%	7%	**100%**
End Use Difference	-100%	0%	0%	0%	170%	-16%	-8%	-63%	-8%	**45%**

Table 129. ZNC Target Package EEMs – Case Study 9, Option 2. All costs are total capital cost estimates without incentives and without subtracting the cost of replacing existing systems at end of life.

#	Measure	Description	Whole Bldg. EUI Svgs. (%)	Cost Savings ($/yr.)	Measure Cost ($)	SP (yrs)	ROI (%)	Equip. Life (yrs)	Estimated Remaining Life of Equivalent System (yrs)
1	Retro-commissioning (new building)	Retro-commission and implement improvements on central building systems for the new building	5.1%	$8,200	$16,000	1.9	53%	5	N/A
2	Retro-commissioning (old building)	Retro-commission and implement improvements on central building systems for the old building	2.9%	$16,200	$16,000	1.0	102%	5	N/A
3	Loop Pump VFDs (old 172ldg.)	Install VFDs on the loop pumps for the old building	0.9%	$2,600	$21,000	8.3	12%	15	DNE
4	Solar PV	Install roof-mounted solar PV and canopy-mounted solar PV over the parking lot	46.6%	$128,300	$2,392,000	18.6	5%	15	DNE
Total			**55.6%**	**$155,300**	**$2,445,000**	**15.7**	**6%**	**-**	

Table 130. Post Retrofit Site EUI by End Use & Percent Reductions from Baseline for ZNC Target Package – Case Study 9, Option 2.

Project	Heating – Gas	Cooling – Gas	DHW – Gas	Baseload – Gas	Heating – Electric	Cooling – Electric	DHW – Electric	Baseload – Electric	Lighting – Electric	Total EUI
Baseline	40%	0%	0%	0%	6%	10%	1%	37%	7%	**100%**
End Use Difference	-8%	0%	0%	0%	-86%	-86%	-86%	-87%	-86%	**44%**

EE Target Package

As some EE Target measures entail replacement of existing equipment, an additional column is added to Table 131 that shows the estimated remaining life of the equivalent replacement system. An "N/A" indicates the existing system is not replaced, and a "DNE" means does not exist and the package adds a system or piece of equipment not currently onsite. This is discussed in more detail in the Case Study Measures Identification Methodology section below.

Table 131. EE Target Package EEMs – Case Study 9. All costs are total capital cost estimates without incentives and without subtracting the cost of replacing existing systems at end of life.

#	Measure	Description	Whole Bldg. EUI Svgs. (%)	Cost Savings ($/yr.)	Measure Cost ($)	SP (yrs)	ROI (%)	Equip. Life (yrs)	Estimated Remaining Life of Equivalent System (yrs)
1	Install ERV (old bldg.)	Install a dedicated outdoor air system with heat recovery capabilities in the old building	3.6%	$9,900	$114,000	11.5	9%	15	15-20
2	Retro-commissioning (new building)	Retro-commission and implement improvements on central building systems for the new building	5.1%	$8,200	$16,000	1.9	52%	5	15-20
3	Retro-commissioning (old building)	Retro-commission and implement improvements on central building systems for the old building	3.7%	$7,400	$16,000	1	47%	5	DNE
4	Loop Pump VFDs (old bldg.)	Install VFDs on the loop pumps for the old building	0.9%	$2,500	$21,000	8.7	11%	15	DNE
5	Solar PV	Install roof-mounted solar PV and some canopy-mounted solar PV over the parking lot	28.2%	$77,700	$1,234,000	15.9	6%	15	DNE
Total			**41.5%**	**$105,700**	**$1,401,000**	**13.3**	**8%**	**-**	

Table 132: Post Retrofit Site EUI by End Use & Percent Reductions from Baseline for EE Target Package – Case Study 9

Project	Heating – Gas	Cooling – Gas	DHW – Gas	Baseload – Gas	Heating – Electric	Cooling – Electric	DHW – Electric	Baseload – Electric	Lighting – Electric	Total EUI
Baseline	46%	0%	16%	6%	0%	5%	0%	24%	3%	**100%**
End Use Difference	-12%	0%	0%	0%	-61%	-62%	-58%	-61%	-58%	**58%**

Less-than-Five-Year Payback Package

The Less-than-Five-Year Payback package allows the building to meet its first interim target threshold.

Table 133. Less-than-Five-Year Payback Package EEMs – Case Study 9. All costs are total capital cost estimates without incentives and without subtracting the cost of replacing existing systems at end of life.

#	Measure	Description	Whole Bldg. EUI Svgs. (%)	Cost Savings ($/yr.)	Measure Cost ($)	SP (yrs)	ROI (%)	Equip. Life (yrs)
1	Retro-commissioning (new building)	Retro-commission and implement improvements on central building systems for the new building	5.1%	$8,200	$16,000	1.9	52%	5
2	Retro-commissioning (old building)	Retro-commission and implement improvements on central building systems for the old building	2.9%	$8,000	$16,000	2.0	50%	5
3	Loop Pump VFDs (old bldg.)	Install VFDs on the loop pumps for the old building	0.9%	$2,600	$21,000	8.3	12%	15
	Total		**8.9%**	**$18,800**	**$53,000**	**2.8**	**35%**	**-**

Table 134. Post Retrofit Site EUI by End Use & Percent Reductions from Baseline for Less-than-Five-Year Payback Package – Case Study 9

Project	Heating – Gas	Cooling – Gas	DHW – Gas	Baseload – Gas	Heating – Electric	Cooling – Electric	DHW – Electric	Baseload – Electric	Lighting – Electric	Total EUI
Baseline	40%	0%	0%	0%	6%	10%	1%	37%	7%	**100%**
End Use Difference	-8%	0%	0%	0%	-8%	-8%	-8%	-11%	-8%	**91%**

Package Comparisons to ZNC Target

The following chart shows the site EUI and split between fuels today and for the EEM packages in comparison to the three Targets.

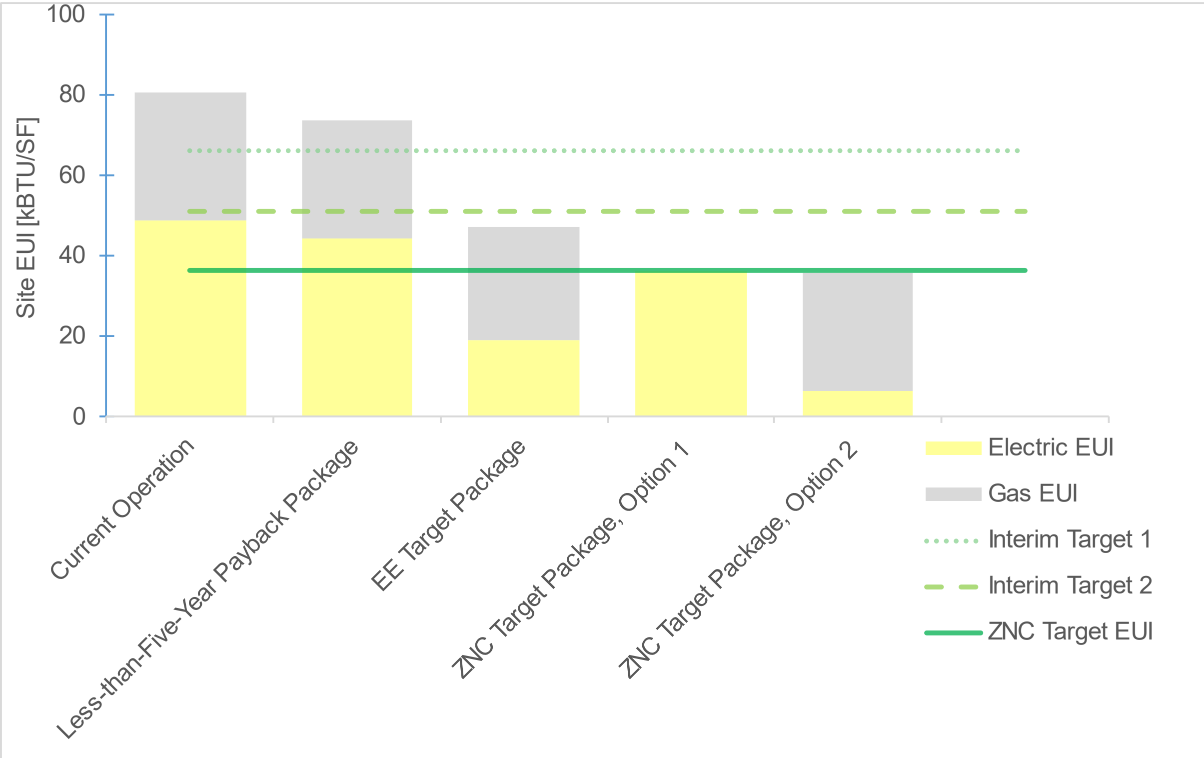

Figure 53. Target-to-Package Comparisons – Case Study 9

As referenced above, both ZNC Target Packages do reach ZNC. However, while one ZNC Target Package reaches the target via electrification, the other package reaches the target through extensive use of solar PV.

The EE Target Package is similar in approach to the ZNC Target Package, Option 2 and looks similar in Figure 53 as a result. However, less solar PV is required to meet the EE Target. This approach also gets the building below the 2nd interim target.

Building-Specific Technology Assessment

This building has multiple uses, varied operating hours, and different mechanical systems across the old and new areas of the building. As a result, addressing building systems needs to consider unique solutions per building wing.

The only item to electrify is the heating hot water loop in the new building. An ERV can also be installed on the old building, and retro-commissioning can be applied to both wings of the building. This represents a reasonable first pass at predominantly mechanical system measures to reach ZNC.

Alternatively, this building is relatively flat compared to its total square footage with a high roof to total square footage ratio, and it also has a large parking lot. Given both of these features, the site is a natural candidate for solar PV.

Current electric demand can be met by solar PV. Additional solar PV is physically possible on additional available roof space and extra parking lot space If approximately 40% of the parking lot is covered in PV, the site can reach satisfy all onsite electricity needs without electrifying the hot water loop.

Since this building was unique among the case study buildings in having two reasonably obvious options for reaching the ZNC Target, both options were presented.

Similar methodology was used to create the EE Target Package as the ZNC Target Package, Option 2. However, less solar PV would be required to meet the EE Target. This also implies that midpoints between the ZNC and EE Targets could be satisfied using different amounts of solar PV.

Following electrification and solar PV consideration, other measures affecting building demand were chosen such as distribution loop pump VFDs. These measures do not have a large overall impact on savings and were generally non-interactive in nature meaning savings from these measures do not appreciably increase or decrease savings from other measures.

The Less-than-Five-Year Payback Package is constructed using applicable measures from either ZNC Target Package.

Package Comparisons

Reaching ZNC targets incur a large overall cost to the property; most of these costs are borne from either electrification measures such as heat pump conversion or solar PV. However, the ZNC target for this building is reachable with technologies available today.

There are some ways to reduce compliance retrofit costs:

- Some of the total capital costs may be defrayed by accounting for avoided replacement costs of existing mechanical equipment. For example, most mechanical equipment will likely be replaced before the 2035 target. This money can be effectively set aside to help cover parts of the costs.
- Financing methods such as the Montgomery County Green Bank are viable.
- Utility incentives through the EmPOWER Maryland program may help offset upfront costs. While not a significant amount relative to the overall project investment, these funds are available today. These funds are available on three-year cycles and the program offerings can change during the program cycle; based on this, incentive estimates are not included in this report.

The EE Target Package incurs less overall cost than the ZNC Target Package and higher cost savings.

The Less-than-Five-Year Payback Package largely utilizes retrofits to existing equipment. Applying a higher estimated savings for retro-commissioning may be possible.

Measures Not Recommended

Measures reviewed for the building but not included in the EEM package are described below.

- Building controls: while adding controls to the old building HVAC system may result in savings, this was not deemed as necessary to meet ZNC in either of the approaches taken.
- DHW: domestic hot water is a minimal load and was not examined.
- Envelope: Window and roof replacements were considered but ultimately unneeded to meet the ZNC target and are not cost-effective enough to include in the Less-than-Five-Year Payback Package.

General Methodology Applied to All Case Studies

The following text describes components of this technical analysis that were applied to all case studies about EEM Package Development, Building Desktop Audits, and Utility Rates. After those sections are discussions of the analysis methodology applied specifically to this case study.

EEM Package Development

Three packages of EEMs were developed.

Zero Net Carbon-Compatible (ZNC) Target Package

This package compiles measures necessary to meet the Zero Net Carbon-Compatible target for the respective building. These measures typically include electrification of natural gas uses. The aim of this package was to create a series of measures that result in the ability of the case study building to meet the ZNC target. Project financials were not a primary driver, but financially desirable measures were included wherever possible.

Descriptions of each package are included in the individual case studies below.

The methodology for developing these packages was generally as follows:

- Potential electrification measures were implemented first when determined they were necessary to meet the ZNC target. This was done for two reasons:
    - Electrified end uses were typically large (i.e., all of a building's heating loads), and
    - Other measures' applicability may change based on these electrified systems. Note that for packages where mechanical systems were changed, some measures that are appropriate based on *existing mechanical equipment* may not be included in the ZNC package. However, they may appear in the However, they may appear in the EE Target Package or Less-than-Five-Year Payback Package.
- Next, measures with large interactive effects were reviewed. These measures were typically either mechanical or controls-based in nature.
- Next, smaller end use reduction measures with limited interactive effects were implemented. These measures typically have a small impact (i.e., less than 5% of overall building usage).
- Lastly, where applicable and necessary, photovoltaic solar (PV) was applied.

Energy Efficiency (EE) Target Package

This package compiles measures necessary to meet the Energy Efficiency target for the respective building. Initial analysis returned multiple ways to think about developing an approach, each with pros and cons. These can be found in Table 135 below.

Table 135: General approaches to developing an EE Target Package.

Package Type	Pros	Cons	Other Items
Fewest Measures	• Simplest to implement • Easiest to understand	• Higher cost and lower ROI	• Electrification of some end uses guaranteed
Best ROI that Meets the EE Target	• Most attractive financial package • Best speaks to financial concerns	• Still will electrify some loads • Better ROI may not be the easiest to implement measures	• This will likely introduce partial electrification of end uses to the study
Minimize Electrification	• Best speaks to the theory behind the EE package	• Would necessitate replacement of gas-fired equipment with new gas-fired equipment	• May not really be viable with case study buildings (but could be viable with other buildings)

This study opted to use the Best ROI that Meets the EE Target approach. The following guidelines apply to this approach:

- Electrification of end uses needed to be considered in practice. Most case study buildings were far enough away from the EE Target that reaching the EE Target without electrification was infeasible without significant occupant energy pattern changes[62].
- Electrification of DHW loads was considered first. Most mechanical systems (which include space heating systems) have low-cost opportunities for optimization while most DHW systems have limited optimization opportunities. This means the combined mechanical system optimization measures plus DHW electrification had a more attractive ROI than space heating electrification measures.
- Mechanical system optimization and retro-commissioning measures were then implemented.
- Next, smaller end use reduction measures with limited interactive effects were implemented. These measures typically have a small impact (i.e., less than 5% of overall building usage).
- Electrification of space heating loads was considered only if electrification of DHW loads was not enough in conjunction with other measures to meet the EE Target *and* minimal system optimization was possible.
- Lastly, where applicable and necessary, photovoltaic solar (PV) was applied.

Less-than-Five-Year Payback Package

This package compiles a set of measures that results in a five year or less total simple payback. This package represents a reasonable approximation of possible outcomes from an energy audit. These measure packages represent the types of low cost and lower-savings measures often recommended during standard energy audits. These measures are often investigated by buildings first. Note that an energy audit may include other financial tools such as utility incentives, tax deductions/credits, or other assistance, which were not included in this technical analysis.

Where applicable, measures from the Less-than-Five-Year Payback Package were also applied to the ZNC Package. The methodology described under the ZNC Target Package applied to the Less-than-Five-Year Payback Package as well. The following guidelines apply to the Less-than-Five-Year Payback Package:

- Measures with large interactive effects were reviewed. These measures were typically either mechanical or controls-based in nature.
- Retro-commissioning was applied; see below for details.
- Next, smaller end use reduction measures with limited interactive effects were implemented. These measures typically have a small impact (i.e., less than 5% of overall building usage).
- Lastly, where applicable and necessary, photovoltaic solar (PV) was applied.
- Major building systems were *not* modified in this package. Most system conversions (for example, converting from chilled water to water-source heat pumps) have longer paybacks and would not realistically be included. However, this also means that measures that impact *existing mechanical equipment* would appear here (for example, chilled water pump VFDs when the ZNC Target Package converted a building from chilled water to water-source heat pumps).
- New fossil fuel measures were not included.
- Overall energy savings were not a primary goal of this target; the energy savings resulting from this package was simply the end result of measures that would result in a less than five year project payback for all measures considered.

Typically, this package may be useful in reviewing progress toward interim targets.

Note that for some newer buildings that have less opportunity for low-cost incremental savings, the Less-than-Five-Year Payback Package may be either small or non-existent.

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[62] Energy conservation by occupants can drive significant energy savings (EPA, slide 33). Because of the difficulty in predicting savings (and the persistence of savings) for these sorts of behavioral measures in typical buildings, those savings are not included in this study.

Building Desktop Audits

Case studies were developed through interviews with building managers and site staff to collect – for major equipment only – equipment type, equipment age, operating parameters, types of fuel used for various end uses, information on recent capital upgrades, and any comments on plans for future upgrades and decision-making processes in relation to energy management. Architectural and mechanical drawings and supporting documentation were reviewed when available.

Desktop audits were performed in order to develop the case studies contained in this report. Desktop audits use information provided from building owners and operators to develop recommendations, but do not contain any onsite observations. This methodology is effective for informing policy-level decisions as it can effectively capture broad-stroke approaches; however, this methodology does not tend to capture measures are more limited in impact (e.g., mechanical systems that only serve part of the building). Applicability of desktop audit measures to a specific building typically requires some amount of onsite investigation in order to determine applicability of measures for any specific building in a given typology. This technical analysis is limited to desktop audits and measure recommendations are limited to what could be recommended based on the data collected by the auditor.

Where possible, supplemental energy audit information performed by others is incorporated into the case studies. These energy audits, which may contain onsite observations, were completed prior to this desktop audit process.

Utility Rates

Utility rate assumptions are $0.129 per kWh and $1.228 per therm, based on the US Energy Information Administration (EIA) average rates for the area. While energy rates differ by service class and usage profile, these rates are assumed to represent the average costs for these types of buildings in Montgomery County. These rates are meant to be inclusive of taxes and fees applicable throughout the state, including the current Fuel Energy Tax of $0.01978 per kWh on electricity and $0.17026 per therm on natural gas use.

Case Study 10: Retail

No retail candidate elected to participate in the case studies.

The analysis team searched for a retail case study that met specific criteria (e.g., EUI was above the ZNC target, roughly the 30th percentile, for that buildings group, larger single retailer already benchmarking in Portfolio Manager and reporting to Montgomery County, would be covered under the amended building definition), but were unable to identify an appropriate case study candidate that was able to participate. If a candidate is identified, this analysis can be amended with the additional case study.

Input Used to Produce Targets with the CNCA EBPS Tool

Table 136 is a summary of median site EUI and estimated end use site EUI. Most building types used the County's benchmarking information, though some had little representation (e.g., Food service, Public order and safety, Service) and used CBECS data in the absence of local data. Multifamily building data was from Washington, DC (see *Estimating the Baseline for Groups with Insufficient Energy Information*. The CNCA EBPS tool adjusted heating and cooling end uses for the Montgomery County climate when splitting out end uses from the local energy data by energy type (fuel vs electricity).

Table 136. Site energy totals and end use breakdown for all typologies for Montgomery County. This information was used to calculate technical feasibility limits.

All units Site EUI [kBTU/SF] ***Source: CNCA EBPS Tool using 2019 MC Benchmarking Data***		**Occupancy type Median Site EUI**			**Estimate of Electricity End Use Site EUI**			**Estimate of Gas or Oil End Use Site EUI**			
Principal Building Activity	Energy Data Source	**Site EUI Median**	Total Elec	Total Gas + Oil	Elec Heat	Elec Cool	Elec Other	Gas Heat	Gas WH	Gas Cook	Gas Other
MF-New-Tall	DC	48	36	12	8	13	14	0	11	1	0
MF-Old-Tall	DC	64	22	42	0	7	15	17	22	3	0
MF-Short	DC	62	24	38	0	7	17	14	21	3	0
Higher Education	County	104	34	69	0	9	26	37	16	4	13
Food sales	County	202	130	72	0	5	125	29	5	37	0
Food service	CBECS	271	91	180	0	19	72	20	39	121	0
Health care Inpatient	County	305	117	188	0	33	84	69	54	26	39
Health care Outpatient	County	73	73	0	2.0	8	63	0	0	0	0
Lodging	County	87	49	38	0	9	40	8	24	0	6
Mercantile Enclosed and strip malls	County	111	64	47	0	9	55	12	13	15	7
Mercantile Retail (other than mall)	County	62	46	16	0	8	39	10	2	5	0
Office	County	63	62	0	1.8	10	51	0	0	0	0.31
Other	County	235	180	56	0	29	151	51	4	0	0
Public assembly	County	96	49	48	0	20	28	29	3	9	7
Public order and safety	CBECS	86	45	40	0	12	33	15	21	4	0
Religious worship	County	57	34	24	0	8	26	17	0	6	0
Service	CBECS	62	26	36	0	5	21	21	15	0	0
Warehouse and storage	County	19	19	0	0.5	3	15	0	0	0	0
Vacant	County	25	15	10	0	2	12	9	1	0	0
Education K-12	County	55	30	25	0	8	23	13	6	1	5

APPENDIX VII - UNDERLYING ASSUMPTIONS FOR TARGET SETTING

The framework for site EUI target-setting comes from the CNCA toolset referenced earlier in this report. That report provides detail on how each energy end use is addressed to create the whole building targets, both for the Energy Efficiency target and the Zero Net Carbon-Compatible target. This summarizes the approach to target setting, but it does not dictate a specific retrofit package for a particular building. Any individual building would develop a scope of work that reflects how it would achieve or exceed its respective target. The target setting methodology, however, approximates what the typical building of a given occupancy type can achieve using assumptions on existing systems and their efficiency, both current and what is technically achievable.

Excerpt from CNCA report describing efficiency and electrification target underlying assumptions

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[63] and Seattle[64]. 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 technical analysis.*

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 technical analysis. 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.

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*

[63] 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
[64] 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

up 4% of gas use nationwide[65]. 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[66] 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%.*

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*

[65] 2012 CBECS Table E7. https://www.eia.gov/consumption/commercial/data/2012/c&e/cfm/e7.php
[66] https://www.energystar.gov/products/water_heaters/residential_water_heaters_key_product_criteria

equipment with varying efficiency ratings[67], a past study[68] 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[69]. 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.*

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[67] 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%

[68] 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

[69] 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 54 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	BM Count	Total Site – All Fuels	Total Site Electricity	Total Site Gas	Space Cooling Elec	Other Elec	Space Heating	Water Heating	Cooking	Other
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

Energy Efficiency **(EE) Target** EUI as a Percent of Baseline	70%		70%	100%		
			Space heating	Water heating	Cooking	Other
Zero Net Carbon **(ZNC) Target** EUI as a Percent of Baseline Converts gas EUI to electricity EUI	100%		**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	77	61	**138**	74	49	**122**	0	88	**88**
Health care Inpatient	120	81	**201**	104	65	**169**	0	117	**117**

Figure 54. 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 49 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 49 kBTU/SF is multiplied by 61%, converting it to about 30 kBTU/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.

APPENDIX VIII - SENSITIVITY TESTS ON MODEL IMPACT RESULTS

Long-term projections are the result of a number of assumptions including estimates of capital costs, operating costs, and compliance rates. In acknowledgement of the variability of the results, several input assumptions were modified to understand how dependent the outputs are to the various assumptions used for these projects.

For example, the cost of completing energy efficiency work in buildings can change with time. This can be caused by multiple factors including but not limited to new technology, new financing options, and supply chain improvements. Precise prediction of these trends was not completed for this technical analysis.

Instead, the analysis team varied the costs of compliance efficiency work in the policy model (not in the case study packages) to show how the countywide capital cost would change if measure costs changed to be as little as 10% of today's estimates (multiplier of 0.1), and up to 200% of today's estimates (multiplier of 2.0). Each end use was modified individually along efficiency and electrification measures.

Of the measure categories, space heating electrification had the greatest impact on total countywide costs, indicating that space heating electrification may be a major driver of the total capital costs needed for buildings to meet a BEPS in Montgomery County. If all other measure costs remained unchanged, but space heating electrification costs doubled from the estimate used in the technical analysis, then total countywide capital costs would increase 39% from the technical analysis estimate. At the other end of the spectrum, if space heating electrification costs were reduced to 10% of today's cost estimates, the total cost of compliance would be 65% of the technical analysis estimate. These results are highlighted in yellow in the total cost sensitivity results shown in Table 117. By comparison, the cost of space heating energy efficiency (improving existing gas-based systems where present) would drive total costs up or down by just 6% (represented as 94% to 106% of study estimate in table).

The next largest driver of total costs is electrical energy efficiency work in commercial buildings (bottom table section), which can drive a +/-15% variation in capital cost depending on measure cost changes over time.

These results helped the analysis team to focus efforts on costs of measures for the impact model and for the case study measure cost estimates.

Table 137. Sensitivity test results of total countywide capital costs of the BEPS to changes in energy efficiency measure costs.

Sensitivity of total capital cost to the cost of retrofit types				
Not incremental costs		Efficiency cost multiplier		
	Space Heating	0.1	1	2
Electrification cost multiplier	0.1	59%	65%	71%
	1	94%	100%	106%
	2	133%	139%	145%
		Efficiency cost multiplier		
	DHW	0.1	1	2
Electrification cost multiplier	0.1	86%	90%	93%
	1	97%	100%	104%
	2	108%	112%	115%
		Efficiency cost multiplier		
	Cooking	0.1	1	2
Electrification cost multiplier	0.1	88%	92%	95%
	1	97%	100%	103%
	2	106%	109%	113%
		Efficiency cost multiplier		
	Process/Other	0.1	1	2
Electrification cost multiplier	0.1	96%	97%	98%
	1	99%	100%	101%
	2	103%	104%	105%
		Commercial cost multiplier		
	Elec Efficiency	0.1	1	2
Resi. cost multiplier	0.1	81%	95%	112%
	1	85%	100%	116%
	2	91%	105%	122%

APPENDIX IX - SUMMARY OF DATA SOURCES

The first task undertaken by the analysis team was to summarize the data needs to complete the analysis, both for creating performance standards and for completing the cost and benefit analysis of the created performance standards. The analysis team compiled relevant data sources to complete these tasks. This appendix section summarizes those data sources and their respective uses.

Data Sources Building Type Groupings

The team used SDAT tax data to quantify building counts, building age, occupancy use type, and gross floor area for countywide analyses. The Montgomery County benchmarking data was used to inform baseline energy usage for all groupings with significant representation, initially defined as ten building submissions.

Table 138. Data Sources used to inform building stock and groupings, focusing on the anticipated covered building types.

	MC DEP Supplied			Publicly Available		
Data Sources for Building Groupings	**SDAT & GIS**	**CoStar Export**	**County Benchmarking (2019)**	**DC Benchmarking (2019)**	**Census ACS2019**	**CBECS[70] + RECS[71]**
Has MC Specific data?	Yes	Yes	Yes	No	Yes	No
Size Threshold	25k SF+	25k SF+	50k SF+	50k SF+	5+ units	5+ Units
MF Buildings	Yes (parcel only)	Yes	**No**	**Yes**	Yes	Yes
Com. Buildings	Yes	Yes	Yes	Yes	No	Yes
Gov't Bldgs	Yes	Yes	Yes	Yes	No	Yes
Exempt Use Types	Yes	Yes	No	No	No	Yes
Energy Use Data	No	No	**Yes**	**Yes**	No	Yes
MBID Parcel ID	Yes	Yes	Yes	N/A	No	No
Granularity of Submissions	Parcel and buildings	Buildings	Mostly by parcel	No	Apt Units	Building Types

[70] Commercial Building Energy Consumption Survey (CBECS). 2012 data used. https://www.eia.gov/consumption/commercial/data/2012/
[71]Residential Energy Consumption Survey (RECS). 2015 data used. https://www.eia.gov/consumption/residential/data/2015/

Benchmarking Data from Montgomery County

Focusing on the benchmarking data from 2019, which was analyzed to identify gaps in building sample sizes and persistent data quality issues. Note: this does not filter for the anticipated covered buildings list respective to use type or ownership exemptions.

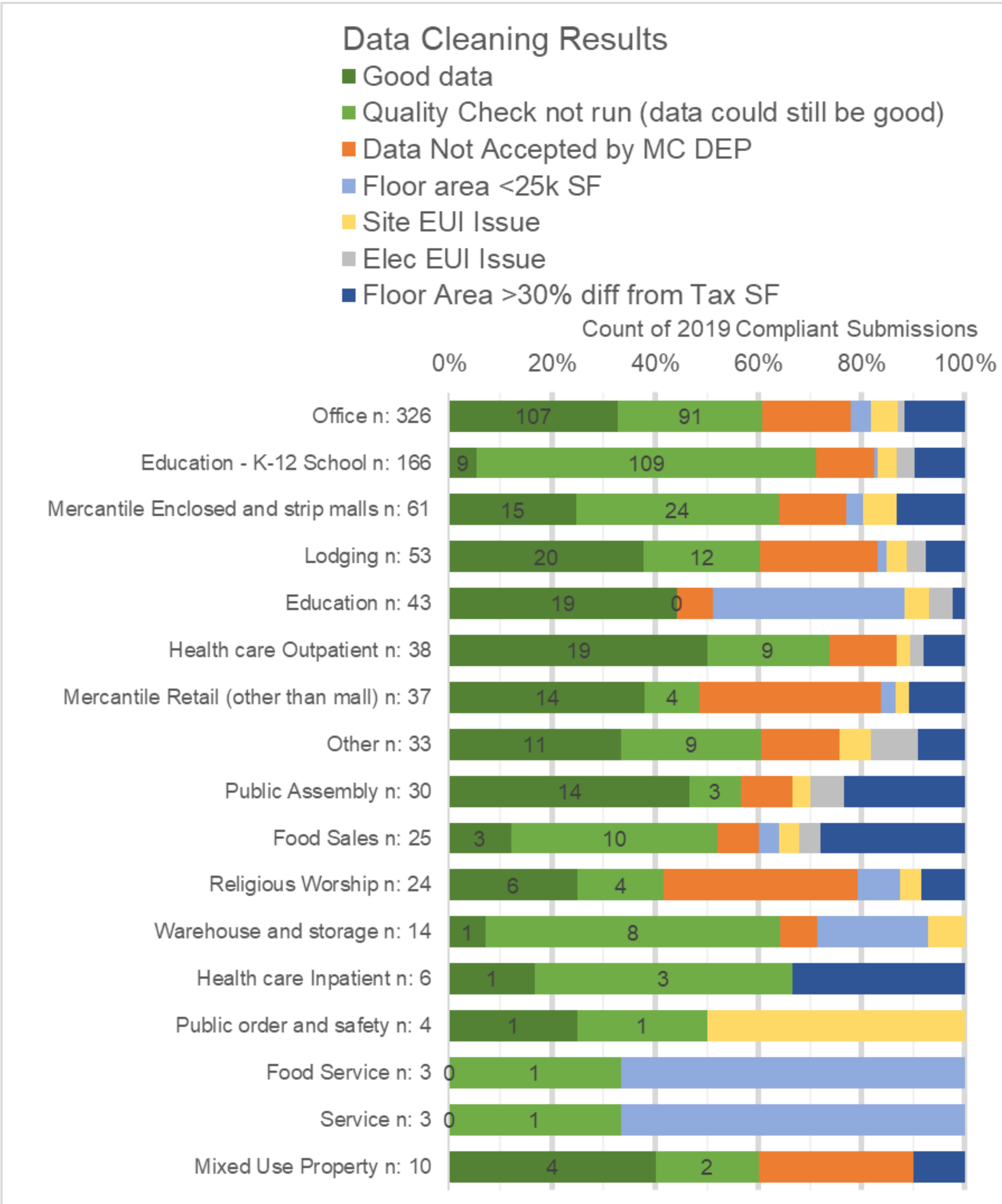

Figure 55. The relative number of properties per building grouping in each data quality result field. Montgomery County benchmarking data 2019. The chart is scaled to 100% of each groups submissions. See next chart for absolute counts.

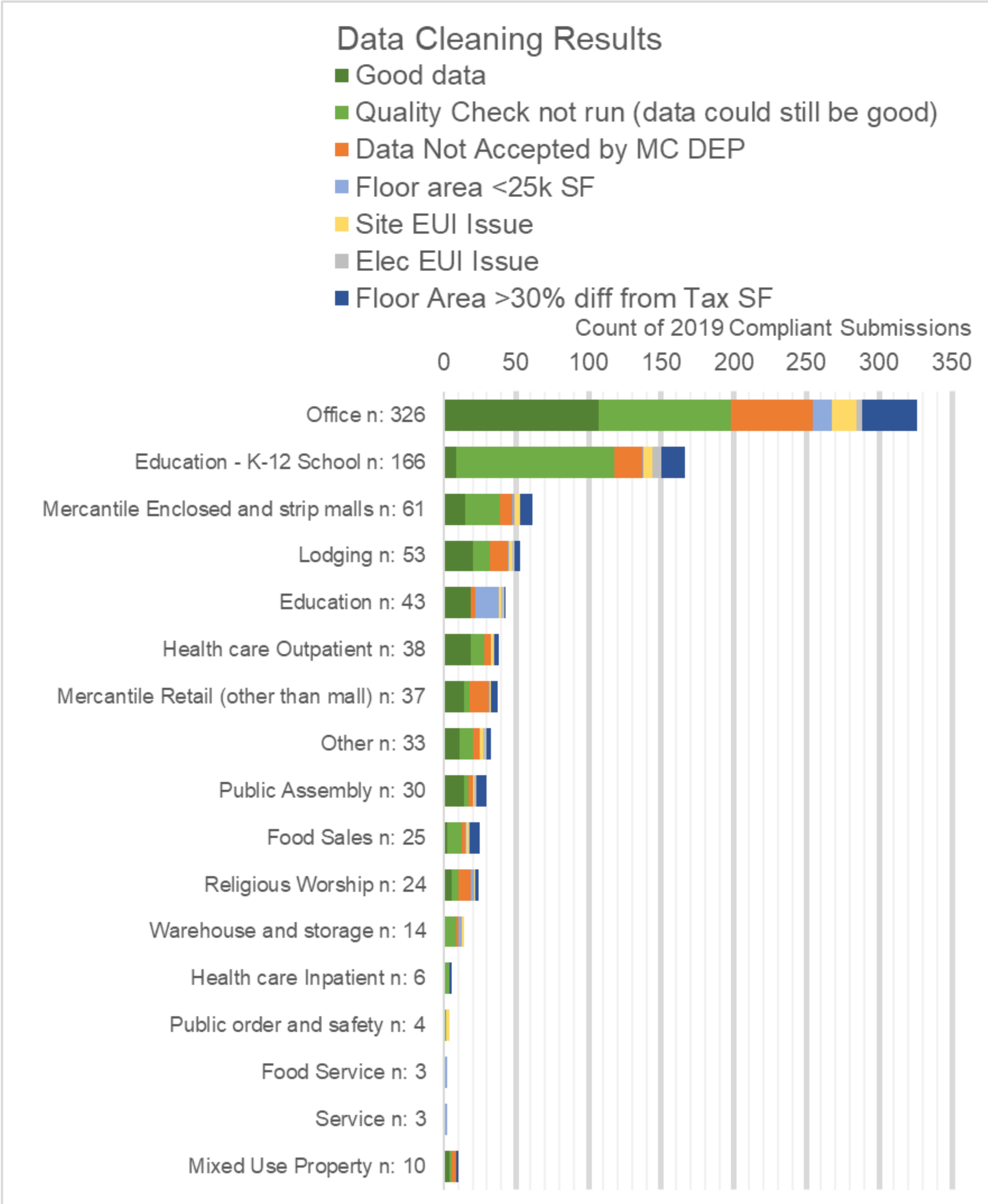

Figure 56. The absolute number of properties per building grouping in each data quality result field. Montgomery County benchmarking data 2019.

Explanation of Cleaning Flags

- Good data: no issues identified, and the PM Data Quality Checker[72] was run and didn't find any issues.
- Quality Check not run: the PM Quality Checker was not run for the building by the benchmarking provider or building owner, for whatever reason, so some flags (such as less than 12 months of data) could not be

[72] The ENERGY STAR Portfolio Manager Data Quality Checker flags if there are gaps or overlaps in energy data, or if energy data uses estimate data from PM defaults. It is a good tool for checking for complete data in the benchmarking submission, but there isn't a test for appropriate data beyond submission completeness.

identified. Many of these buildings are good data since the benchmarking submission does not require running the quality checker tool.

- Data Not Accepted by MC DEP: MC DEP determined any buildings with data flags in the PM Data Quality Checker, or a building was not in compliance with the data verification requirement due in 2019, and contacted the building owners to make corrections and resubmit reports
- Floor Area <25k SF: building is smaller than the proposed BEPS policy would cover
- Site EUI Issue: the site EUI was outside a mean +/- 2 standard deviation range for the CBECS occupancy type using a log-normal transformation
- Elec EUI Issue: the electricity EUI was outside a mean +/- 2 standard deviation range for the CBECS occupancy type using a lognormal transformation
- Floor Area >30% different from Tax SF: the reported gross floor area (not including parking) was more than 30% different than the SDAT gross building floor area. This flag looked prominent in building types that may have indoor parking affecting the tax data floor area.

Secondary Multifamily Data Sources

There were several potential data sources for multifamily buildings beyond SDAT and benchmarking data that were referenced as necessary to supplement the information needed to complete the analysis.

CoStar

Multifamily buildings in Montgomery County were also reviewed using CoStar data, which gave some detail on ownership type and quantity of multifamily buildings in the county.

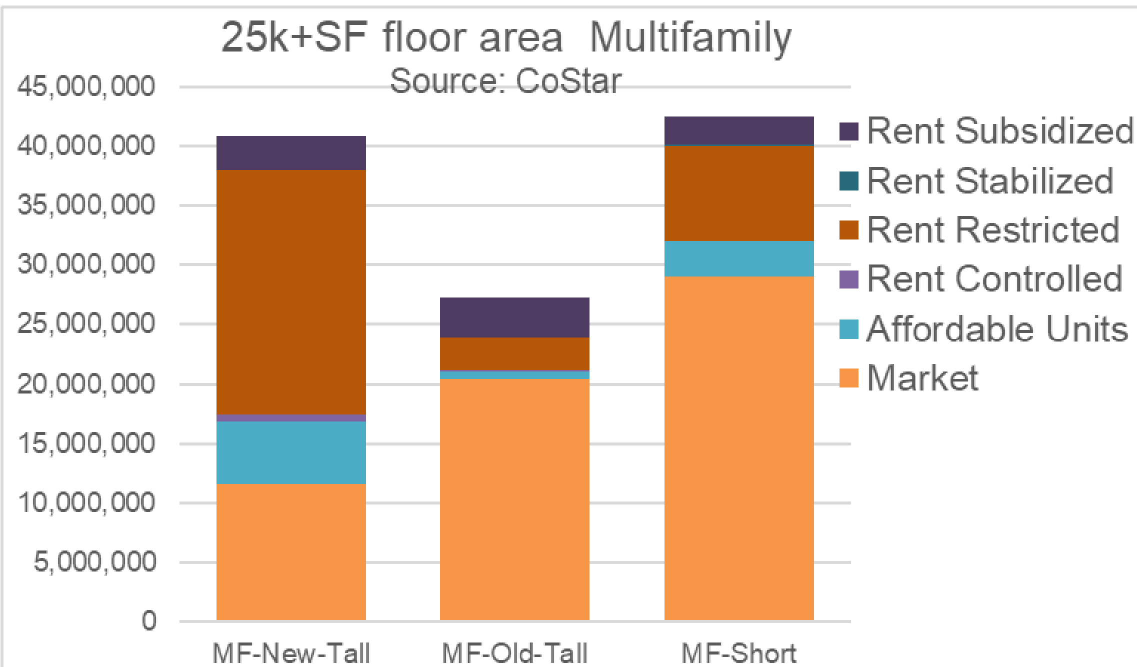

Figure 57. CoStar Multifamily buildings in Montgomery County. See definitions below.

CoStar Definitions of Rent Types (Multifamily)[73]

- Market Rent: Rents that are set by the owner/operator and are independent of any regulatory conditions or restrictions.
- Affordable: **All** of the community's rents are discounted or below market. Affordable properties must be further categorized with an Affordable Subtype.

[73] CoStar Glossary. https://www.costar.com/about/costar-glossary. Accessed 1/31/2021

- Market/Affordable: A **portion** of the community's rents are discounted or below market. Once the project is flagged as Affordable or Market Affordable, it is categorized into the following rental subtypes:
    - Rent Restricted: Properties classified as Rent Restricted most commonly have rental rates based on Area Median Income (AMI). These properties typically receive tax-advantaged equity and/or debt financing, including Low-Income Housing Tax Credits (**LIHTC**). Low-income renters at these communities typically have an annual household income that is less than 80% of AMI but greater than 30% of AMI. This is the most common type of Affordable Subtype classification.
    - Rent Subsidized: Rents are subsidized by the Department of Housing and Urban Development (HUD) **Section 8** or other federal programs. Low-income renters at these properties typically earn less than what is needed to qualify for Rent Restricted housing and pay rent and other housing costs at a rate equal to a specific percentage of their annual household income.
    - Other classifications in Montgomery County are likely data entry errors as those programs may not be available in MC.

Census ACS

Data from the Federal Census' American Community Survey (ACS)[74] was referenced for estimates of housing structure in Montgomery County. This was compared to Montgomery County tax data (SDAT) for large multifamily property statistics.

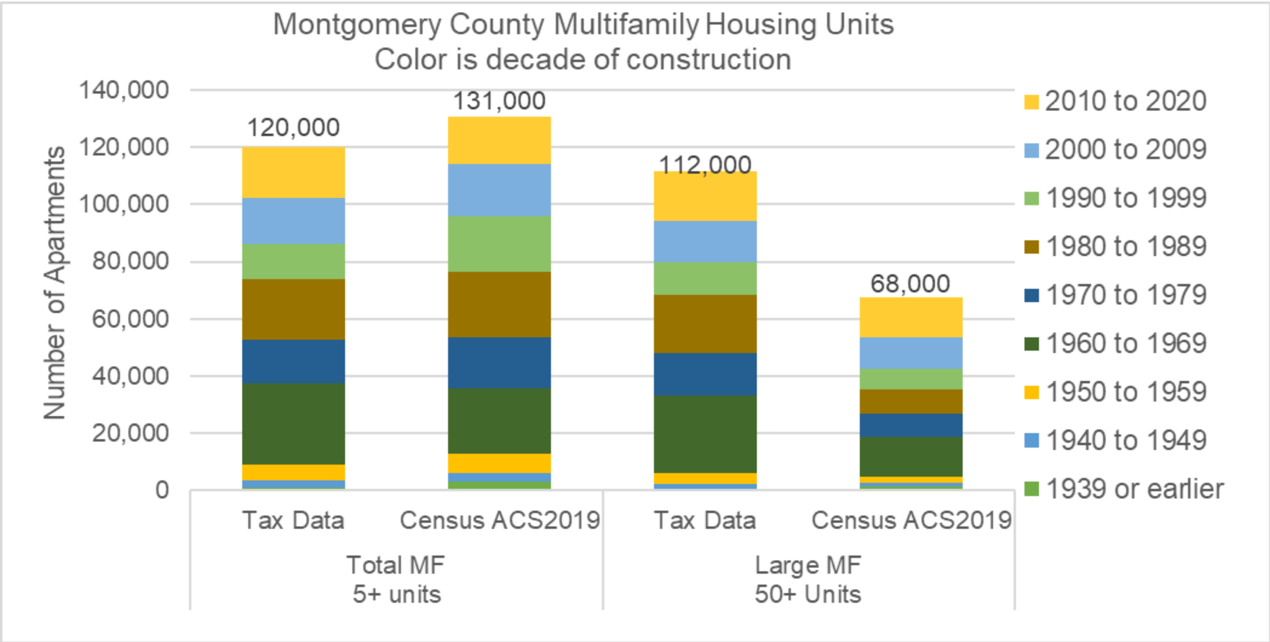

Figure 58. A comparison of multifamily building information between Census and County data sources.

This data showed a discrepancy in the Census data for the total number of large multifamily. This discrepancy could be due to the way buildings are sampled, with tax assessments consolidating multiple buildings on a tax lot, while census surveys consider the size of the single physical building. This could cause the discrepancy, particularly in garden-style apartments (MF-Short). The analysis used the tax data as it was likely more representative of how owners will interact with the proposed BEPS policy. Based on this review, the technical analysis used the SDAT tax data since the ACS data appeared to show an inaccurate picture of large multifamily units in the county.

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74 Survey/Program: American Community Survey, 2019 Microdata, query: https://data.census.gov/mdat/#/search?ds=ACSPUMS1Y2019&cv=BLD&rv=YBL,ucgid&wt=WGTP&g=7950000US2401001,2401002,2401003,2401004,2401005,2401006,2401007

Data Sources for Structuring Interim and Final Performance Standards for Covered Buildings

- The Montgomery County Stakeholder Recommendation Report[75] has a number of recommendations on the type of metric to use and how to compile the needed information.
- Carbon Neutral Cities Alliance's "Performance Standards for Existing Buildings: Performance Targets and Metrics Final Report"[76] is a methodology and workbook[77] that was used to inform interim and final performance standards across buildings types. This framework has been used by Seattle, WA, and Los Angeles, CA, to provide insight to stakeholders on the potential performance of buildings undergoing deep retrofits over the next 20-30 years. SWA was the author of this work with participation by expert advisors and city staff around the country.[78] Montgomery County was an observer to the project.
- SWA referenced existing studies on projected cost and benefit trends – technology, energy cost, workforce development.
- Projecting Business-as-Usual (BAU) energy use change over time
  - Year-on-year changes in electricity use for commercial and residential buildings: AEO2020 Buildings report projects an electricity intensity change of -0.2% EUI per year through 2050, due to a balance of increased electronics and IT tempered by improving lighting and appliance efficiency.[79] This results in a total electric EUI decrease of 3% from 2020 by 2035. However, the observed error of these projections is generally larger[80] than the projected growth over a 15-year forecasting period, at 10-13%.[81,82] The analysis team used a constant energy use assumption to simplify the findings.

Data Sources for Impacts of Performance Standards on County Goals

- Projected power supply changes over time toward a renewable-based grid. In lieu of a detailed plan, the team used the grid coefficient today and drew a straight line to zero for the projected date when the electricity supply would be 100% emissions free.
- Energy emissions intensities from the Montgomery County Calendar Year 2018 GHG Inventory[83] were used for the primary energy types[84] of electricity and natural gas.
- These numbers roughly agree with the EPA Portfolio Manager coefficients for the county today, though the GHG inventory incorporates some amount of fugitive natural gas leakage, while the EPA emissions intensity assumes zero gas leakage.

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75 https://www.montgomerycountymd.gov/DEP/Resources/Files/ReportsandPublications/Energy/MC-BEPS-Stakeholder-Report.pdf
76 http://carbonneutralcities.org/wp-content/uploads/2020/03/CNCA-Existing-Building-Perf-Standards-Targets-and-Metrics-Memo-Final-March2020.pdf
77 http://carbonneutralcities.org/wp-content/uploads/2020/03/CNCA-Existing-Building-Perf-Standards-Targets-Workbook-Final.xlsx
78 Slide 4. http://carbonneutralcities.org/wp-content/uploads/2020/03/CNCA-Existing-Building-Perf-Standards-Project-Summary-Final.pdf
79 EIA, 2020. "Annual Energy Outlook: Buildings". Slides 11 and 12. https://www.eia.gov/outlooks/aeo/pdf/AEO2020%20Buildings.pdf
80 EIA, 2020. "Annual Energy Outlook Retrospective Review". Tables 18 and 19. https://www.eia.gov/outlooks/aeo/retrospective/
81 EIA, 2020. "Annual Energy Outlook Retrospective Review". Table 2. https://www.eia.gov/outlooks/aeo/retrospective/
82 Sakva, D. "Evaluation of errors in national energy forecasts." (2005) Thesis. Rochester Institute of Technology. https://scholarworks.rit.edu/cgi/viewcontent.cgi?article=8181&context=theses&httpsredir=1&referer=
83 Montgomery County Community Wide Greenhouse Gas Emissions Inventory. https://www.montgomerycountymd.gov/green/climate/ghg-inventory.html accessed 2/1/2021
84 Calculated from GHG Inventory Data – July 2020.xlsx https://www.montgomerycountymd.gov/green/Resources/Files/climate/ghg-inventory-data-summary-july-2020.xlsx

Data Sources Costs and Benefits of Performance Standards

Electricity and Natural Gas Rates

The team referenced Pepco and Washington Gas proposed rates.[85] Montgomery County has a specific Fuel Energy Tax[86,87] which adds to ratepayer energy costs. The supply charges ("Purchased Gas Charge") for Washington Gas are difficult to calculate from the text in their tariff structure, but this appears to have final costs for different rates, but only for Jan-Feb 2021: https://www.washingtongas.com/-/media/ee15bdb7a3f4424bbd799202b0d88496.pdf

This is a listing with the Maryland Public Service Commission (MD PSC) for the past three years for multiple MD gas utilities: https://www.psc.state.md.us/gas/wp-content/uploads/sites/4/Gas-Fact-Sheet-January-2021.pdf

Statewide electric and natural gas rates, used for range checking to make sure calculated rates are reasonably close to energy rates that a Montgomery County building owner may have:

Table 139. Statewide electricity rates[88].

Electricity Customer Type	Cents/kWh	$/MMBTU
Residential	13.12	38.5
Commercial	9.97	29.2
Industrial	7.80	22.9
Other	NA	NA
Transportation	7.37	21.6
Total	11.24	32.9

Statewide Electricity $/MMBTU	Winter	Non-winter
Residential	$39	$38
Commercial	$29	$28

Rates Used for this Analysis

This analysis used a single blended rate for all building types. Metering configurations and the diversity of supply and delivery charges made the above averages less meaningful. Non-residential buildings pay different rates based on complex energy supply contracts. Many residential buildings use a combination of commercial and residential rates to serve different areas of the building.

Table 140. Energy rates used in this analysis across commercial and residential buildings.

Energy Type	Base Rate	+MC Fuel Energy Tax (FET)	Total blended rate
Gas ($/therm)	$ 1.049	$ 0.17026	$ 1.2280
Electricity ($/kWh)	$ 0.126	$ 0.01978	$ 0.1229

85 Current Washington Gas Rates: https://www.washingtongas.com/my-account/account-services-support/current-rates/maryland-tariff-info
Potential Washington Gas Rates (pending PSC approval): https://www.washingtongas.com/-/media/f6111a418b694d619e5486776fec58a3.pdf
Current Pepco Rates: https://www.pepco.com/MyAccount/MyBillUsage/Pages/MD/CurrentTariffsMD.aspx
86 Washington Gas: https://www.washingtongas.com/media-center/montgomery-county-fuel-energy-tax
Pepco: https://www.pepco.com/MyAccount/MyBillUsage/Documents/Pepco%20MD%20Other%20Surcharges%20-%20012021.pdf
87 https://www.montgomerycountymd.gov/Finance/Resources/Files/FY2021Utility%20Return.pdf
88 Source: https://www.eia.gov/electricity/state/maryland/ . Accessed January 2021.

Cost and Expected Savings for Retrofits

- Maryland/Mid Atlantic Technical Reference Manual, Version 10[89]
- Washington DC actual project cost information: collected by SWA for the DOEE Cost and Benefits Grant from building owners and industry consultants. Note: this resource may be subject to some data sharing limitations.
- Washington DC Building Electrification Institute (BEI) project estimates: collected by SWA and BEI as part of work for DC DOEE analyzing the economics of multifamily electrification retrofits
- Washington DC RS Means cost & labor lookup: collected by SWA to supplement cost estimates for industry standard work where actual cost data are not available
- New York City Technical Working Group report cost estimates
- New York City actual project cost information: SWA audit and energy consulting experience
- Washington Gas and Pepco energy efficiency program cost database, which may be acquired with MC DEP help through the utilities' consultants.
- Survey respondents from Montgomery County Building Survey to be distributed as part of this project

[89] Shelter Analytics and Northeast Energy Efficiency Partnerships. March 2020. https://neep.org/sites/default/files/resources/Maryland-MidAtlantic%20TRMv10.pdf

APPENDIX X – LITERATURE REVIEW OF DEEP RETROFIT SAVINGS

Energy Efficiency Retrofit Savings

The Montgomery County climate falls between the “Marine” and “Cold” climates in the Advanced Energy Retrofit Guide (AERG) studies.

DOE Advanced Energy Retrofit Guide – Offices[90]

The savings beyond the modeled existing building retro-commissioning (EBCx) are modeled as 14-16% using cost-effective measures from a list of possible options. In the AERG analysis, the post-EBCx site EUI is similar to the Montgomery County median site EUI for Offices, and the standard retrofit brings that EUI to the EE standard of ~53kBTU/SF.

	Site Energy Use Intensity (EUI) (kBtu/sf)		Site EUI Reduction		
	Baseline	Post-Standard Retrofit	Post-EBCx	Post-Standard Retrofit	Reduction Beyond EBCx
Hot & Humid	88	**59**	15%	**33%**	18%
Hot & Dry	97	**58**	22%	**40%**	18%
Marine	94	**54**	27%	**43%**	16%
Cold	86	**53**	24%	**38%**	14%
Very Cold	91	**57**	25%	**38%**	13%
Average	91	**56**	23%	**38%**	15%

Figure 59. Extracted Table 4.2 from the Office AERG, showing cost effective savings of 14-16% EUI reduction for a typical building that has already completed retro-commissioning.

Common measures used in the AERG analysis are shown in Table 4.3 of the document. Other measures would be more applicable for certain building and equipment types. The document has a more extensive list of possible retrofits in Table 4.1.

System	Measure Description	Climate Zones	Appendix Page # Ref.
Lighting	L6. Install occupancy sensors to control interior lighting	All	140
Lighting	L7. Add daylight harvesting	All	142
Lighting	L8. Retrofit exterior fixtures to reduce lighting power density, and add exterior lighting control	All	143
HVAC - Air Side	HA11. Widen zone temperature deadband (replace pneumatic thermostats)	All	160
HVAC - Air Side	HA12. Lower VAV box minimum flow setpoints (rebalance pneumatic boxes)	All	161

Figure 60. Table 4.3 from the AERG-Offices[91].

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[90] Pacific Northwest National Lab (PNNL) and PECI. September 2011. “Advanced Energy Retrofit Guides: Office Buildings”. https://www.pnnl.gov/main/publications/external/technical_reports/PNNL-20761.pdf

[91] Supra 90, page 62.

DOE Advanced Energy Retrofit Guide – Retail[92]

The savings beyond the modeled existing building retro-commissioning (EBCx) are modeled as 21-22% using cost-effective measures from a list of possible options. In the AERG analysis, the post-EBCx site EUI (78-85 kBTU/SF) is higher than the Montgomery County median site EUI for Retail (other than mall) at 63 kBTU/SF. This could be due to advances in lighting technology and the proliferation of fluorescent and LED lighting in retail spaces. If so, some HVAC optimization measures recommended by the AERG analysis may be more applicable, which are a blend of EBCx and standard retrofit options.

	Site Energy Use Intensity (EUI) Savings (kBtu/sf/yr)			Site EUI Reduction	
	Baseline	**Post-Standard Retrofit**	Post-EBCx	**Post-Standard Retrofit**	Reduction beyond EBCx
Hot & Humid	107	**73**	13%	**32%**	18%
Hot & Dry	103	**69**	15%	**33%**	18%
Marine	90	**58**	14%	**36%**	22%
Cold	100	**64**	15%	**36%**	21%
Very Cold	102	**63**	16%	**38%**	22%
Average	100	**66**	15%	**35%**	20%

Figure 61. Extracted Table 4.2 from the Retail AERG, showing cost effective savings of 21-22% EUI reduction for a typical building that has already completed retro-commissioning.

A concise list of commonly applicable measures is shown in Table 4-3, which is reprinted from the DOE Advanced Energy Retrofit Guide and so follows the naming conventions in that document:

Table 4.3. Standard Retrofit Recommended Package Measures

System	Measure Description	Climate Zone	Appendix Page # Ref.
Lighting	L3. Add daylight harvesting	All	134
Lighting	L4. Re circuit and schedule lighting system by end use	All	135
Lighting	L5. Retrofit interior fixtures to reduce lighting power density by 13%	All	136
Lighting	L9. Retrofit exterior fixtures to reduce lighting power density, and add exterior lighting control	All	141
HVAC	H18. Remove heat from front entry	Marine, Cold, Very Cold	159

A more comprehensive list of options is shown in Table 4-1 of the DOE Advanced Energy Retrofit Guide.

[92] Pacific Northwest National Lab (PNNL) and PECI. September 2011. "Advanced Energy Retrofit Guides: Retail Buildings". https://www.pnnl.gov/main/publications/external/technical_reports/PNNL-20814.pdf

DOE Advanced Energy Retrofit Guide – Food Sales[93]

Supermarkets in this analysis have a post-EBCx site EUI of 198-226 for the nearest climates, which is close to the MC median site EUI of 200 kBTU/SF. After the recommended measures are implemented, site EUI in the AERG analysis drops to 155-176, a savings of 22%. The EE standard for Montgomery County is 172 kBTU/SF.

Location	EUI (kBtu/ft²)*		
	Baseline	Post-EBCx	% Reduction From Baseline
Miami (Hot & Humid)	203	184	9%
Las Vegas (Hot & Dry)	219	189	14%
Seattle (Marine)	238	198	17%
Chicago (Cold)	265	226	15%
Duluth (Very Cold)	301	254	15%
Average	245	210	14%

*Annual cost and energy savings are first year values. Cost savings are expressed in 2011 dollars.

Location	EUI (kBtu/ft²)		
	Baseline	Post-Retrofit	Percent Reduction
Miami (Hot & Humid)	203	160	21.0%
Las Vegas (Hot & Dry)	219	168	23.3%
Seattle (Marine)	238	155	34.5%
Chicago (Cold)	265	176	33.5%
Duluth (Very Cold)	301	200	33.3%
Average	245	172	29.1%

*Energy savings for retrofit packages do not include the effects of EBCx.

Figure 62. Extracted Tables 3-2 and 4-3 from Grocery Store AERG, showing 15-17% savings from retro-commissioning and an additional 17-18% from retrofits.

The applicable measures used in the retrofit are in the Table 4-4 shown below.

Table 4-4 Measures Included in the Recommended Retrofit Packages

System	Measure Description	Climate Zone	Section
Lighting	Replace T-12 fluorescent lamps and magnetic ballasts with high-efficiency T-8 lamps and instant-start electronic ballasts	Hot & humid	F.1.1
Lighting	Replace incandescent ambient lighting with CFL and accent/display lighting with metal halide	All	F.1.2
Lighting	Replace refrigerated display case lighting with LEDs	All	F.1.3
Lighting	Install photosensors and dimming ballasts to dim lights when daylighting is sufficient	Hot & humid, hot & dry	F.1.6
Refrigeration	Install high efficiency EC evaporator fan motors	All	F.2.1
Refrigeration	Install doors on open refrigerated cases	Marine, cold, very cold	F.2.3
Refrigeration	Install controls to disable anti-sweat heaters when dew point is low	Cold, very cold	F.2.4
Refrigeration	Install strip curtains and weather seal walk-in freezer doors	All	F.2.7
HVAC	Install variable speed drive kitchen hood exhaust fans with demand control ventilation	All	F.2.13
HVAC	Replace inefficient motors with right-sized NEMA premium efficiency	All	F.3.7
HVAC	Convert constant volume or dual duct air handling systems to variable air volume	All	F.3.8
HVAC	Upgrade to demand control ventilation to reduce outdoor airflow during partial occupancy	All	F.4.1

Figure 63. Extracted Table 4-4 from Grocery Store AERG, showing applicable measures for groceries stores that could be sufficient for meeting an energy efficiency target.

93 National Renewable Energy Lab (NREL), et al. July 2013. “Advanced Energy Retrofit Guides- Grocery Stores”. https://www.nrel.gov/docs/fy13osti/54243.pdf

DOE Advanced Energy Retrofit Guide – Health Care Inpatient[94]

Montgomery County's hospitals have a higher EUI than this analysis' models, at 305 kBTU/SF compared to the AERG analysis' 263 kBTU/SF. Assuming an intervention including both EBCx and standard retrofit scopes, the resulting EUI is in the 200-240 range. In this building type, the AERG analysis found that more savings were available through EBCx, so those measures are shown, extracted from Table 3-3 in the report.

Location	EUI (kBtu/ft²)*		
	Baseline	Post-EBCx	% Reduction From Baseline
Miami (Hot-Humid)	263	226	14%
Las Vegas (Hot-Dry)	268	214	20%
Seattle (Marine)	263	198	25%
Chicago (Cold)	263	205	22%
Duluth (Very Cold)	249	192	23%
Average	261	207	21%

* Annual cost and energy savings are first year values. Cost savings are expressed in 2011 doll...

Location	EUI (kBtu/ft²)		
	Baseline	Post- Retrofit	Percent Reduction
Miami (Hot-Humid)	263	257	2.1%
Las Vegas (Hot-Dry)	268	262	2.2%
Seattle (Marine)	263	240	8.6%
Chicago (Cold)	263	253	3.6%
Duluth (Very Cold)	249	204	18.1%
Average	261	243	6.9%

* Energy savings for retrofit packages do not include the effects of EBCx.

Figure 64. Extracted Tables 3-2 and 4-3 from Health care Facility AERG, showing 22-25% savings from retro-commissioning (left) and an additional 3-8% from retrofits(right).

Table 3-3 EBCx Measures in Recommended Package

System	EEM Description	Climate Region	Section
Lighting	Calibrate lighting controls and optimize settings based on building usage patterns and daylight availability	All	E.1.1
Plug and process loads	Control computer power management settings facility wide through software or logon scripts, except for computers in critical applications in hospitals	All	E.2.2
HVAC	TAB AHUs, flow modulation devices, chilled water pumps and valves, and refrigerant lines to ensure that flow rates and supply air temperatures meet cooling loads and no unnecessary flow restrictions are present	All	E.5.1
	Verify correct operation of OA economizer if one is installed. In Miami and other hot-humid climates, it is important to confirm that the economizer is contributing to energy savings. In these climates, economizers can use more energy than they save, and maintenance costs can sometimes exceed energy cost savings.	All	E.5.6
	Turn off or set back HVAC equipment overnight in areas that are not being used (cafeterias, educational areas, office space) (hospitals only)	All	E.5.8
	Reoptimize supply air temperature reset based on current building loads and usage patterns	All	E.5.12
	Reoptimize boiler temperature reset based on current building loads and usage patterns	All	E.5.13
	Reduce ventilation levels in operating rooms, delivery rooms, laboratories, and other intermittently used spaces when unoccupied, while maintaining pressurization (hospital only)	All	E.6.2

Figure 65. Extracted Table 3-3 from Health care Facilities AERG, showing applicable measures for could contribute to meeting an energy efficiency target.

[94] National Renewable Energy Lab (NREL), et al. September 2013. "Advanced Energy Retrofit Guides- Healthcare Facilities". https://www.nrel.gov/docs/fy13osti/54243.pdf

APPENDIX XI – SPACE TYPE DEFINITION GUIDANCE FROM EPA PORTFOLIO MANAGER

The following is the current Portfolio Manager guidance for each impacted property type used in the cost-benefit case studies at the time of this report preparation.[95]

Multifamily Housing

Portfolio Manager guidance on multifamily square footage is as follows:

"Gross Floor Area (GFA) should include all buildings that are part of the multifamily property, including any separate management offices or other buildings that may not contain living units.

Gross Floor Area should include all fully-enclosed space within the outside surfaces of the exterior walls of the building(s) including living space in each unit (including occupied and unoccupied units), interior common areas (e.g. lobbies, offices, community rooms, restrooms, common kitchens, fitness rooms, indoor pools), hallways, stairwells, elevator shafts, connecting corridors between buildings, storage areas, and mechanical space such as a boiler room. Open air stairwells, breezeways, and other similar areas that are not fully-enclosed should not be included in the GFA."

For this technical analysis and determination of BEPS targets, commercial retail spaces are included toward the total square footage, but not as multifamily square footage. The square footage of the commercial spaces uses a different multiplier toward the BEPS target.

Office

Portfolio Manager guidance on office square footage is as follows:

"Office refers to buildings used to conduct commercial or governmental business activities. This includes administrative and professional offices. Gross Floor Area (GFA) should include all space within the building(s) including offices, conference rooms and auditoriums, break rooms, restrooms, kitchens, lobbies, fitness areas, basements, storage areas, stairways, and elevator shafts.
If you have restaurants, retail, or services (dry cleaners) within the Office, you should most likely include this square footage and energy in the Office Property Use.

There are 4 exceptions to this rule when you should create a separate Property Use:

- *If it is a Property Use Type that can get an ENERGY STAR Score (note: Retail can only get a score if it is greater than 5,000 square feet)*
- *If it accounts for more than 25% of the property's GFA*
- *If it is a vacant/unoccupied Office*
- *If the Hours of Operation differ by more than 10 hours from the main Property Use"*

Hotel (Lodging)

Portfolio Manager guidance on hotel square footage is as follows:

"Hotel refers to buildings renting overnight accommodations on a room/suite and nightly basis, and typically include a bath/shower and other facilities in guest rooms. Hotel properties typically have daily services available to guests including housekeeping/laundry and a front desk/concierge.

Hotel does not apply to properties where more than 50% of the floor area is occupied by fractional ownership units such as condominiums or vacation timeshares, or to private residences that are rented out on a daily or

[95] Energy Star Portfolio Manager Glossary. Accessed May 2021. https://portfoliomanager.energystar.gov/pm/glossary

weekly basis. Hotel properties should be majority-owned by a single entity and have rooms available on a nightly basis. Condominiums or Timeshares should select the Multifamily Housing property use.

Gross Floor Area should include all interior space within the building(s), including guestrooms, halls, lobbies, atriums, food preparation and restaurant space, conference and banquet space, fitness centers/spas, indoor pool areas, laundry facilities, elevator shafts, stairways, mechanical rooms, storage areas, employee break rooms, restrooms, and back-of-house offices."

Retail

Portfolio Manager guidance on Retail square footage is as follows:

"Retail Store refers to individual stores used to conduct the retail sale of non-food consumer goods such as Department Stores, Discount Stores, Drug Stores, Dollar Stores, Hardware Stores, and Apparel/Specialty Stores (e.g. books, clothing, office products, sporting goods, toys, home goods, and electronics). Buildings containing multiple stores should be classified as enclosed mall, lifestyle center, or strip mall.

Gross Floor Area should include all space within the building(s), including sales areas, storage areas, offices staff break rooms, elevators, and stairwells."

Worship Facility

Portfolio Manager guidance on Worship Faculties square footage is as follows:

"Worship Facility refers to buildings that are used as places of worship. This includes churches, temples, mosques, synagogues, meetinghouses, or any other buildings that primarily function as a place of religious worship.

Gross Floor Area should include all areas inside the building that includes the primary worship area, including food preparation, community rooms, classrooms, and supporting areas such as restrooms, storage areas, hallways, and elevator shafts.

The ENERGY STAR score for Worship Facilities applies to buildings that function as the primary place of worship and not to other buildings that may be associated with a religious organization, such as living quarters, schools, or buildings used primarily for other community activities. To receive an ENERGY STAR score, a Worship facility must have at least 25 seats, but cannot have more than 4,000."

Parking

Exterior, partially-enclosed, and enclosed parking is not included in the square footage calculations to determine the BEPS targets or EUI calculations.

APPENDIX XII – ACRONYMS

AHU:	air handling unit
ASHRAE:	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
AWHP:	air-to-water heat pump
BBTU:	Billion British thermal units
BEPS:	Building Energy Performance Standards
BMS:	building management system
BOMA:	Building Owners and Managers Association
CBECS:	Commercial Buildings Energy Consumption Survey
CDD:	cooling degree days
CFL:	compact fluorescent lamp
CNCA:	Carbon Neutral Cities Alliance
COP:	coefficient of performance
CT:	cooling tower
DDC:	direct digital control
DHW:	domestic hot water
DNE:	does not exist
DOAS:	dedicated outdoor air system
DX:	direct expansion
EEM:	energy efficiency measure
EIA:	US Energy Information Administration
ERV:	energy recovery ventilator
EUI:	energy use intensity
EUL:	end of useful life
FCU:	fan coil unit
GHG:	greenhouse gases
HDD:	heating degree days
HVAC:	heating, ventilation, and air conditioning
HX:	heat exchanger
IAQ:	indoor air quality
kBTU:	one thousand British thermal units
kW:	kilowatt
kWh:	kilowatt hour
MCDEP:	Montgomery County Department of Environmental Protection
N/A:	not applicable
O&M:	operations and maintenance
PV:	photovoltaic
RECS:	Residential Energy Consumption Survey
RCx:	retro-commissioning
RTU:	roof top unit
SCU:	self-contained unit
SF:	square feet
SHGC:	solar heat gain coefficient
SP:	simple payback
SRECs:	solar renewable energy credits
SWA:	Steven Winter Associates
US:	United States
VAV:	variable air volume
VFD:	variable frequency drive
VRF:	variable refrigerant flow
WSHP:	water source heat pump