Maryland Building Energy Performance Standards Impact Analysis

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Background

Building Energy Performance Standards (BEPS) are outcome-based policies and laws aimed at reducing the carbon impact of the built environment by requiring existing buildings to meet energy and/or greenhouse gas emissions-based performance targets. BEPS are powerful policy tools that provide a lifecycle approach to building performance and can empower state and local governments to deliver on their energy and carbon goals for the building sector.

The Department of Energy (DOE) Building Technologies Office, through the Building Energy Codes Program, is providing technical assistance (TA) to jurisdictions interested in exploring BEPS programs through a National BEPS TA Network. From November 2022 through July 2023, through the engagement with this network, Lawrence Berkeley National Laboratory (LBNL) and Pacific Northwest National Laboratory (PNNL) provided the Maryland Department of the Environment (MDE) with the following BEPS technical assistance:

- Building stock analyses including analysis of energy and emission impacts associated with BEPS adoption
- Performance target-setting and trajectories
- Measure and technology prioritization and packaging
- Cost-effectiveness analyses

In support of MDE, LBNL and PNNL leveraged a growing body of research and modeling for jurisdictions receiving technical assistance through DOE, including Aspen, Berkeley, New York City, San Francisco, Seattle, Washington DC and the State of Washington, as well as ASHRAE. The methods and results for the National BEPS TA are presented in this *Maryland BEPS Impact Analysis*.

Overview

The *Maryland BEPS Impact Analysis* describes the methodologies used by LBNL and PNNL for estimating the impacts of Maryland's BEPS regulation. The analysis included three objectives:

- Objective One: Model and compute performance targets for Maryland's BEPS, including direct greenhouse gas emissions and energy use intensity (EUI) standards

- Objective Two: Identify and model measures for Maryland's covered buildings to meet BEPS performance targets to conduct cost-effectiveness analysis
- Objective Three: Model the Maryland BEPS impacts by estimating the energy and emissions impacts of Maryland's BEPS adoption

The underlying assumptions and process to meet each objective are described below with the associated outputs.

Objective One: Computing targets

LBNL followed the following four steps to meet the first objective to model and compute performance targets for Maryland's BEPS, including direct greenhouse gas emissions and EUI standards:

- Step One: Establish baseline median EUIs
- Step Two: Develop end-use estimates for natural gas use
- Step Three: Calculate site-EUI targets
- Step Four: Calculate direct-emissions targets

Step One: Establish Baseline Median EUIs by Property Type

A dataset provided by the United States Environmental Protection Agency (EPA) that aggregated ENERGY STAR Portfolio Manager (ESPM) buildings by property type for Maryland was used to get initial estimates of electric and gas EUI for each ESPM property type [1]. LBNL mapped each ESPM type to a set of property types in the EPA dataset, computed the median site EUI and electric/site ratio for the buildings in the EPA dataset, and used those data to compute electric and gas EUI (see Table 3). When there were at least five buildings in the EPA dataset, the ESPM property type was mapped to the same type in the EPA dataset. In other cases, multiple property types were grouped (see Table 3) based on data availability and on the suggested property type groupings in EPA's published mappings [2].

Weather-normalized site EUI data were not available in the EPA dataset. To evaluate the impact of weather-normalization, LBNL used Montgomery County, Maryland benchmarking data to compare weather-normalized and non-normalized site EUI medians for each of the 69 property types and found that only one type (Parking) had a difference greater than 4%. Therefore, it was concluded that weather-normalized site EUI data was likely not significantly different from the non-normalized site EUI data) for this analysis.

Step Two: Develop End-Use Estimates for Natural Gas Use

LBNL used data from the Commercial Buildings Energy Consumption Survey (CBECS) [3] and the Residential Energy Consumption Survey (RECS) [4] to determine the proportion of gas used for space heating, water heating, cooking, and other uses. While CBECS and RECS are national

surveys, the South Atlantic and Middle Atlantic census divisions and the Mixed mild (for CBECS) or Mixed-Humid (for RECS) climate zones were used for the Maryland analyses. CBECS withholds climate information from most hospitals, therefore for this property type only, the climate zone restriction was removed and all hospitals in the South Atlantic and Middle Atlantic divisions were included.

CBECS/RECS data for buildings that did not use gas were excluded from the analysis, as all-electric buildings do not contribute useful data for gas end-use breakdowns ESPM property types were mapped to either one or more specific CBECS building types (i.e., the PBAPLUS column) or to one general CBECS building type (i.e., the PBA column). This mapping was largely based on EPA's suggested mapping [2], but additional types were included when data availability was insufficient. This mapping is included in the "CBECS/RECS Types" column in Table 3.
The CBECS/RECS analysis resulted in the proportion of natural gas used for space heating, water heating, cooking, and other uses. These results were subsequently used for initial impact modeling, site EUI target setting (per step three below), and cost modeling for electrification. All results are presented in Table 3 MD BEPS Impact Analysis Final Results Table.

Step Three: Calculate Site EUI Targets

LBNL leveraged the work from Montgomery County, Maryland who partnered with Steven Winter Associates (SWA) to develop decarbonization pathways for commercial buildings. LBNL utilized the methodology from “How Targets Are Calculated” (Figure 7, page 26) of the SWA report for Montgomery County [5] for the Zero Net Carbon (ZNC) scenario to compute the final site EUI target for buildings across the state. These final site EUI targets can be found in Table 3 MD BEPS Impact Analysis Final Results Table under column “Final Site EUI Target (kBtu/SF)”.

Step Four: Calculate Direct Emissions Targets

Interim gas EUI targets were computed for each property type using the initial gas EUI from the EPA dataset (as in Step One, except only for buildings that use gas), and reducing it by 20% for the 2030 target or 60% for the 2035 target. These targets are aligned with MDE’s stated goals of 20% reduction by 2030 and net zero by 2040. Gas EUI targets were converted to direct emissions intensity targets based on a weighted average of the emissions factors (i.e., due to natural gas, district steam, district chilled water) for the energy mix across all buildings in the EPA dataset. These direct emissions targets can be found in Table 3 MD BEPS Impact Analysis Final Results Table under columns “2030 Direct Emissions Target (kg CO2e / SF)” + “2035 Direct Emissions Target (kg CO2e / SF)”.

Objective Two: Estimating measure costs

PNNL estimated the costs of implementing building modifications in three different categories: conventional energy efficiency measures (EEMs), electrification measures, and normal replacement costs. Using the cost estimates developed by PNNL, LBNL modeled the behavior of

Maryland's covered buildings' compliance to BEPS, as discussed in Objective Three: Modeling BEPS Impacts.

Conventional EEMs: These are measures that do not involve electrification or a change of fuel source. Through a robust literature review of studies performed for the implementation of building performance standards across the U.S. as well as research from the latest model energy code development, PNNL identified EEMs that include lighting, HVAC, envelope, retro-commissioning, plug load control, and other measures. Costs and savings were aggregated for the list of identified EEMs in order to establish a cost curve for these measures. The cost curves were developed by sorting the measures from low to high cost per unit of EUI savings, which is a measure of cost-effectiveness, and by developing a regression curve that could represent the cost for deeper levels of savings. The approach to developing the cost curve assumes that building owners will be most likely to implement energy efficiency improvements starting with the most cost-effective measures and continue with more costly measures to meet requirements. These cost relationships were developed for three building types: multifamily, office and other. The curve for "other" was applied to all other building types for which a specific curve was not developed.

Figure 1 shows a cost curve example for a multifamily application with increasing costs per unit energy saved as the total EUI savings increases. Gas use was modeled to be eliminated through electrification and the process for developing electrification costs is described below in the assessment of electrification measures. The complete list of EEMs with corresponding costs as well as the cost curves for the three building types analyzed are shown in Table 4 and Figures 4, 5, and 6.

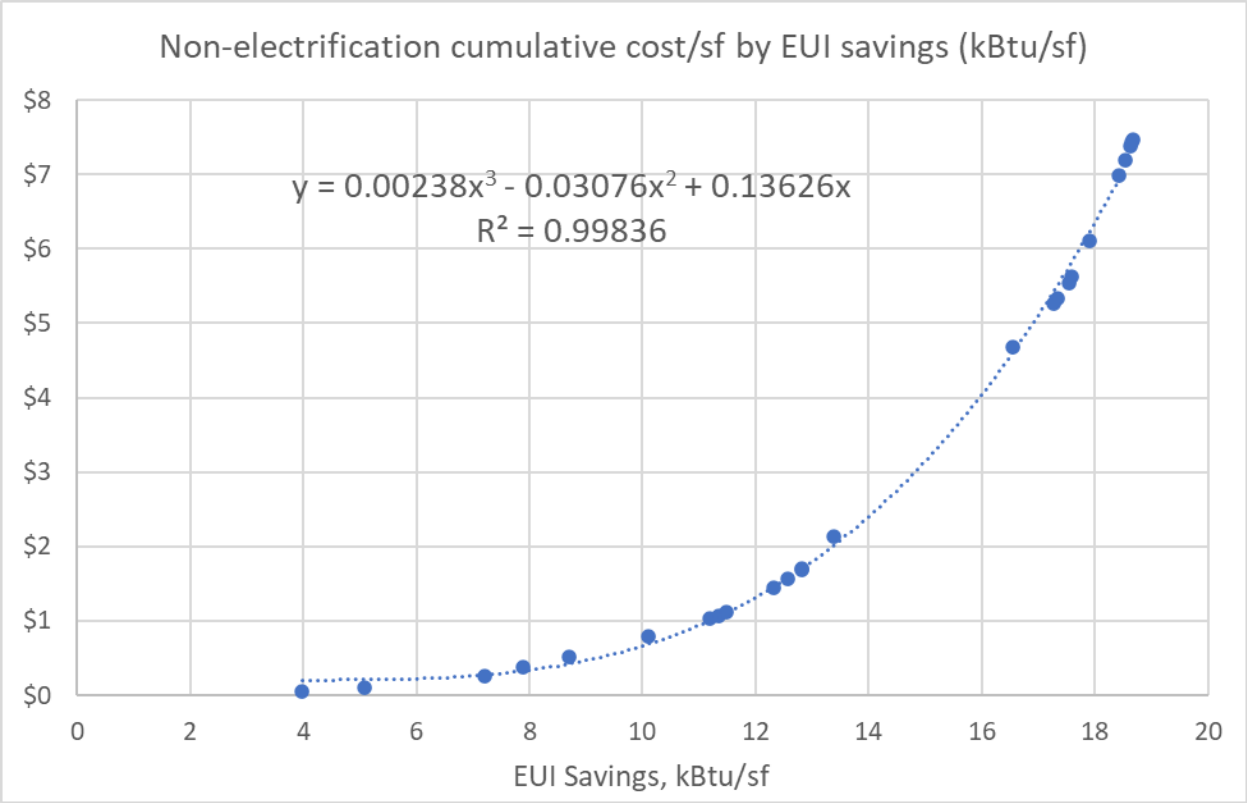

Figure 1: Non-electrification cumulative cost/sf by EUI savings (kBtu/sf) – Multifamily Building Type

Electrification measures: These are measures where fossil fuel-fired equipment is replaced with electric equipment. Typically, reverse cycle refrigeration equipment and heat pumps are used as the replacement technology for space and water heating and other electric technologies are used for other fossil fuel-fired equipment such as food service equipment and clothes dryers. Costs for these electrification measures were analyzed per square foot of floor area based on studies conducted for Washington D.C. [8], Montgomery County [5], and Maryland [7]. Table 5 Electrification Costs shows the electrification costs (capital or "first costs") used in the model.

Baseline Replacement Costs: These are costs associated with replacing fossil fuel-fired space and water heating equipment with new fossil fired-equipment when the existing equipment reaches the end of its useful life. These costs were evaluated to understand the incremental cost of electrification, i.e. the additional cost that would be required to install electric equipment instead of a like-for-like fossil fired-equipment. In aggregate across the building stock, it was found that $0.91 per square foot would be spent on baseline system replacements, whereas $6.48 per square foot would be spent on electrification, yielding an incremental cost of $5.57 per square foot for system electrification. Baseline replacement costs were estimated from tools used to develop the state-level cost effectiveness for ASHRAE Standard 90.1-2019 [6]. These costs reflect the most recent research of typical costs for equipment that would comply with current

Maryland energy codes. Costs were normalized by site EUI. Table 6. Baseline Replacement Costs shows the baseline replacement costs used in the model.

Objective Three: Modeling BEPS impacts

LBNL used the analysis of potentially covered buildings provided by MDE as the set of buildings to be analyzed, including each building's type and floor area. LBNL mapped the building types from the MDE analysis of potentially covered buildings to ESPM property types. LBNL used the same methodology as Step One in Objective One to sample site EUI and the electric/site ratio from buildings with the corresponding building type in the EPA dataset. LBNL applied the same methodology as Step Two in Objective One to subdivide each building's gas use into space heating, water heating, and everything else. The resulting dataset with building type, floor area, electric use, and gas use (split into space heating, water heating, and other) was the starting point for the BEPS impact analysis.

LBNL constructed a model that predicts the behavior of each building from 2025 through 2050 under several potential BEPS policy implementations. Each year, a building is subjected to BEPS targets, reduces its energy use (via efficiency, electrification, or replacement as described above), and the model predicts the resulting energy use (by fuel and end use), GHG emissions, and costs. Table 1 provides an overview of the model's inputs and sources.

Table 1. MD BEPS Impact Analysis Model Inputs and Sources

Model Input	**Factors**	**Data Source**
Electricity GHG Emissions Factor	By year	MDE 2030 GGRA Plan
Natural Gas GHG Emissions Factor	53.11 kgCO2e/MBtu	ESPM
Electricity and gas rate projections	By year	Study conducted by Energy and Environmental Economics (E3) [7]
Site EUI and Direct Emissions Targets	Table 3. MD BEPS Impact Analysis Final Results Table	LBNL, as described in Objective One
EEM costs	Table 4. EEM Costs and Figures 4, 5, and 6.	PNNL, as described in Objective Two
Electrification costs	Table 5. Electrification Costs.	SWA
Baseline replacement costs	Table 6. Baseline Replacement Costs	ASHRAE Standard 90.1-2019

Non-compliance fee estimates	For site EUI targets: $0.10 per kBtu in excess of the target For direct emissions: $230/MtCO2e in excess of the target in 2030 and increasing by $4/MtCO2e each year	MDE

The model predicts BEPS impacts under three scenarios: baseline, full compliance, and finance-driven compliance.

Scenario One: Baseline

In the baseline scenario, buildings are not subject to any BEPS targets. Buildings replace their space heating and water heating system once during the analysis period, and incur replacement costs from Objective Two Baseline Replacement Costs. Space and water heating systems are replaced like-for-like, so gas consumption decreases, but electricity consumption does not change. Since there are no targets, buildings do not pay non-compliance fees, and have little incentive to reduce energy consumption or GHG emissions with each replacement or renovation.

Scenario Two: Full Compliance

In the full compliance scenario, buildings are subject to the site EUI and direct emissions intensity targets found in Table 3. During each five-year compliance cycle, each building first tries to meet its direct emissions target through gas efficiency (up to 20% reduction for space heating). If gas efficiency savings are not sufficient to meet the target, it then electrifies space heating, water heating, and other end uses until the emissions target is met. The logic applied to prioritize electrification of end-uses was developed to minimize project size for each compliance cycle. First – a building considers if either space heating, water heating, or a combination of both can satisfy the target, electing to electrify the minimum amount needed for compliance. Second – if space heating and water heating are already electrified, ‘other’ end-uses are electrified at a lower assumed efficiency. For electrification, the efficiencies described in Objective Two electrification measures were applied. The building is modeled to reduce electricity consumption via efficiency until its site EUI target is met. All buildings comply with all targets, regardless of cost, so no buildings pay non-compliance fees.

Scenario Three - Finance-driven Compliance

In the finance-driven compliance scenario, buildings are subject to the same targets as the full compliance schedule, and use the same reduction strategy to meet the targets, except that they only make reductions if they are cost effective. At each modeling step (i.e., gas efficiency, gas electrification, electric efficiency), a building compares the cost of implementing the reduction and the cost savings due to purchasing energy to possible non-compliance fees. When considering electrification, the building factors in baselines replacement cost as described in Objective Two Baseline Replacement Cost. The building uses a 10-year outlook when considering implementing efficiency measures, and a 30-year outlook when considering electrification. If possible non-compliance fees are less expensive, the building chooses not to make any energy reductions and pays the non-compliance fees instead.

Results

For each scenario, LBNL modeled estimated energy impacts, emissions impacts and costs from 2025-2050. The results are summarized in Table 2 MD BEPS Impact Analysis Model Results Summary.

Table 2. MD BEPS Impact Analysis Model Results Summary.

	Energy Use (billion kBtu)	Emissions (billion kgCO2e)	Total Cost (billion $)
Baseline Scenario	1832.94	58.86	69.84
Financial-Driven Compliance	1256.41	40.58	65.42
Full Compliance	1214.63	39.81	66.93
Savings - Financial-Driven Compliance	576.53	18.28	4.42
Savings - Full Compliance	618.31	19.05	2.92

In the finance-driven compliance scenario, natural gas consumption decreases almost to zero by 2040, and electricity consumption decreases 36%.

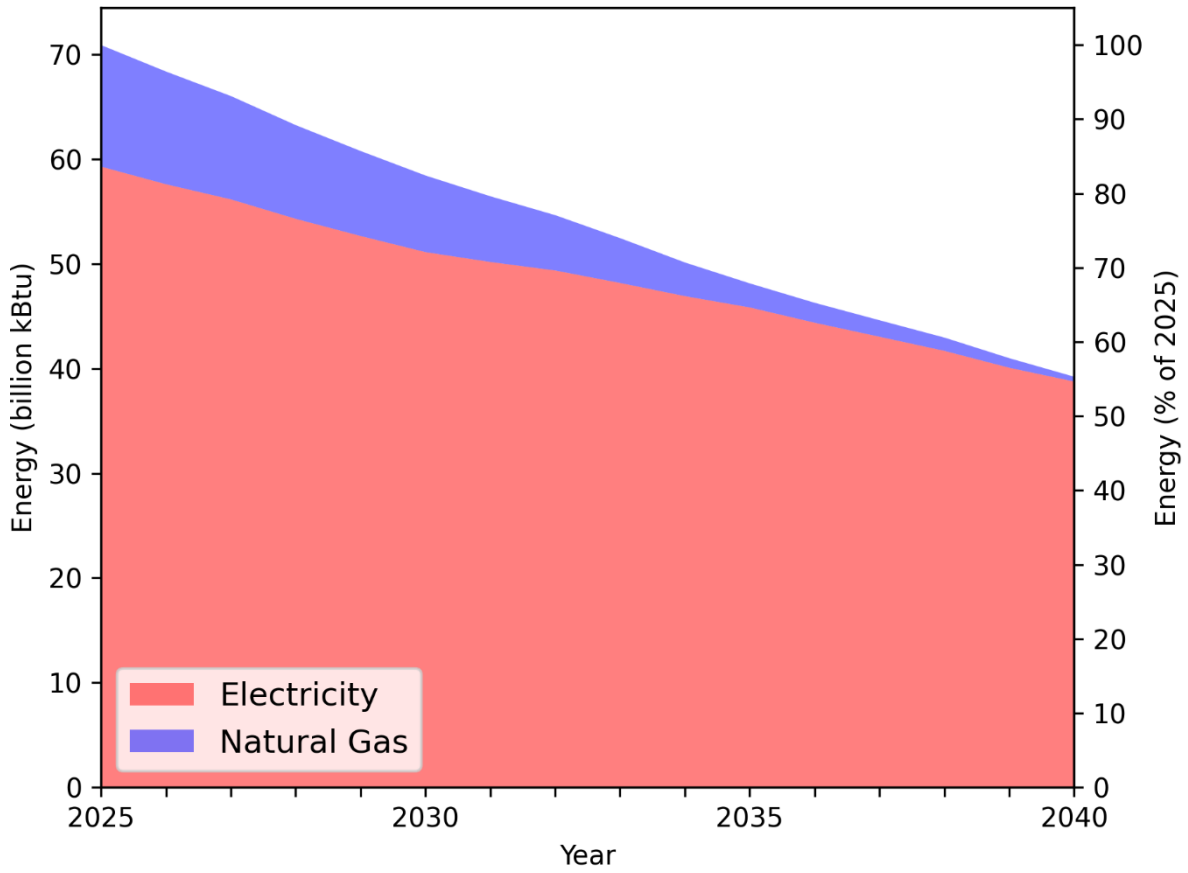

Figure 2: Finance-Driven Compliance Scenario – Projected State-wide Covered Building Energy Consumption

Similarly, emissions from natural gas decrease almost to zero by 2040, but emissions from electricity decrease 88%, largely due to the electric grid getting cleaner. In the baseline scenario, electricity consumption does not decrease, but emissions from electricity decrease 80%.

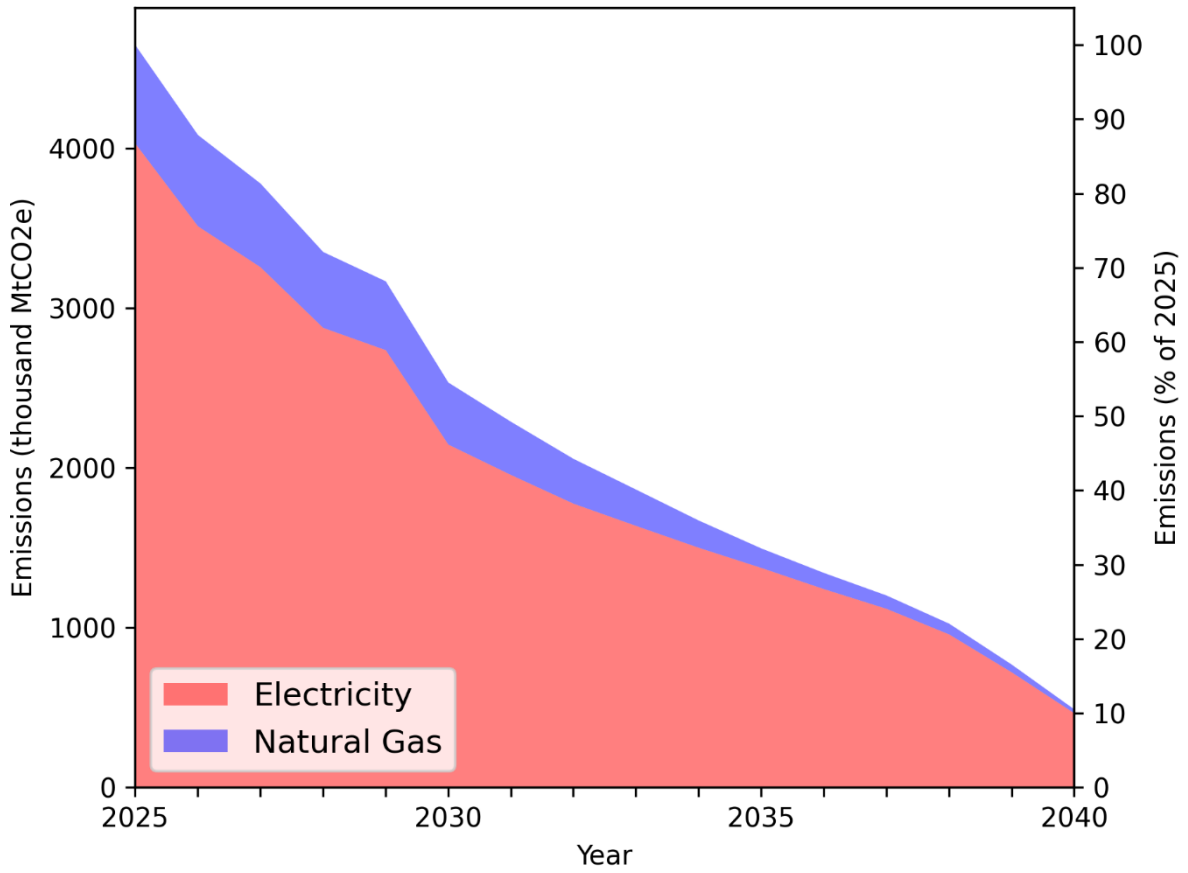

Figure 3: Finance-Driven Compliance Scenario – Projected State-wide Covered Building Emissions

In the full compliance scenario, energy savings are 10% more than in the finance-driven compliance scenario, but emissions savings are essentially equal (due to the electric grid getting cleaner). On average, and cumulatively across the 2025-2050 time horizon, buildings save $4.47/sqft, but there is significant variation: 25% of buildings save >$9.29/sqft and 25% lose >$4.43/sqft.

References

[1] U.S. Environmental Protection Agency. “Property Types in Portfolio Manager”. https://www.energystar.gov/buildings/benchmark/understand_metrics/property_types.

[2] U.S. Environmental Protection Agency. “U.S. Energy Intensity by Property Type”. April 2021. https://portfoliomanager.energystar.gov/pdf/reference/US%20National%20Median%20Table.pdf .

[3] U.S. Energy Information Administration. “Commercial Buildings Energy Consumption Survey”. 2018. https://www.eia.gov/consumption/commercial/data/2018/.

[4] U.S. Energy Information Administration. “Residential Energy Consumption Survey”. 2015. https://www.eia.gov/consumption/residential/data/2015/.

[5] Steven Winter Associates. “Building Energy Performance Standards Development – Technical Analysis”. February 2022. https://www.montgomerycountymd.gov/green/Resources/Files/energy/Montgomery%20County%20Performance%20Ordinance%20-%20Building%20Energy%20Performance%20Standards%20Report%20-%20final.pdf.

[6] Tyler, Xie, Poehlman, and Rosenberg. “Cost-Effectiveness of ANSI/ASHRAE/IES Standard 90.1-2019 for Maryland”. Pacific Northwest National Laboratory. July 2021.

[7] Energy and Environmental Economics. “Maryland Building Decarbonization Study”. October 20, 2021.

[8] DC Department of Energy and Environment (DOEE). “Cost and Benefit Impact Study of the Building Energy Performance Standards Program”. March 2022.

Tables and Figures

Table 3. MD BEPS Impact Analysis Final Results Table

ESPM Property Type	EPA Type Grouping	EPA Count	Elec EUI (kBtu/ SF)	Gas EUI (kBtu/ SF)	Site EUI (kBtu/ SF)	Elec/Site Ratio	SWA Type	CBECS/RECS Types	CBECS/ RECS Count	CBECS/RECS Site EUI (kBtu/SF)	Gas Space Ratio	Gas Water Ratio	Gas Cook Ratio	Gas Other Ratio	Final Site EUI Target (kBtu/SF)	2030 Direct Emissions Target (kg CO2e / SF)	2035 Direct Emissions Target (kg CO2e / SF)
Adult Education	Adult Education Other - Education Vocational School	11	42.7	28	70.7	0.604	Higher Education	Education	125	66.1	0.737	0.111	0.089	0.063	45.8	2.335	1.168
Ambulatory Surgical Center	Urgent Care/Clinic/Other Outpatient	9	43.5	32.9	76.4	0.57	Health Care Outpatient	Outpatient health care	23	49.6	0.984	0.014	0.001	0.001	45.5	1.76	0.88
Aquarium	Movie Theater Museum Other - Entertainment/Public Assembly Performing Arts Stadium (Closed) Stadium (Open)	54	44.1	14.1	58.2	0.758	Public Assembly	Public assembly	35	58.8	0.96	0.008	0.026	0.006	41.3	1.033	0.517
Bank Branch	Bank Branch	364	99.6	0.9	100.5	0.991	Office	Office	150	57.1	0.823	0.107	0.019	0.051	85	1.006	0.503
Bar/Nightclub	Food Service	137	242.6	26.1	268.7	0.903	Food Service	Food service	15	288.6	0.201	0.122	0.671	0.006	219.6	1.697	0.848
Barracks	Barracks Other - Lodging/Residential Residence Hall/Dormitory	44	45.1	0.1	45.2	0.999	Lodging	Dormitory/ fraternity/ sorority	15	96.4	0.158	0.287	0.256	0.299	38.4	0.573	0.286
Bowling Alley	Fitness Center/Health Club/Gym Ice/Curling Rink Other - Recreation Swimming Pool	83	98.3	2	100.3	0.981	Public Assembly	Recreation	7	39.3	0.981	0.002	0.016	0	84.1	2.067	1.034
Casino	Movie Theater Museum Other - Entertainment/Public Assembly	54	44.1	14.1	58.2	0.758	Public Assembly	Public assembly	35	58.8	0.96	0.008	0.026	0.006	41.3	1.033	0.517

ESPM Property Type	EPA Type Grouping	EPA Count	Elec EUI (kBtu/ SF)	Gas EUI (kBtu/ SF)	Site EUI (kBtu/ SF)	Elec/Site Ratio	SWA Type	CBECS/RECS Types	CBECS/ RECS Count	CBECS/RECS Site EUI (kBtu/SF)	Gas Space Ratio	Gas Water Ratio	Gas Cook Ratio	Gas Other Ratio	Final Site EUI Target (kBtu/SF)	2030 Direct Emissions Target (kg CO2e / SF)	2035 Direct Emissions Target (kg CO2e / SF)
	Performing Arts Stadium (Closed) Stadium (Open)																
College/ University	College/University	58	47.7	47.3	95	0.502	Higher Education	Education	125	66.1	0.737	0.111	0.089	0.063	56.6	2.428	1.214
Convenience Store with Gas Station	Convenience Store with Gas Station Supermarket/Grocery Store	158	137.5	49.1	186.7	0.737	Food Sales	Grocery store/food market	2	331.6	0.595	0.004	0.36	0.042	137	2.254	1.127
Convenience Store without Gas Station	Convenience Store without Gas Station Supermarket/Grocery Store	157	137.3	49.1	186.4	0.736	Food Sales	Grocery store/food market	2	331.6	0.595	0.004	0.36	0.042	136.8	2.254	1.127
Convention Center	Convention Center	5	47.6	0	47.6	0.999	Public Assembly	Social/meeting	10	59.5	0.943	0.012	0.044	0.002	40.4	0.387	0.193
Courthouse	Courthouse	17	46.7	25.7	72.4	0.646	Public Order/ Safety	Service	20	47.1	0.88	0.118	0.001	0	46.6	1.138	0.569
Data Center	Data Center	7	170.9	0.2	171.1	0.999	Other	Other	5	59	0.613	0.006	0.031	0.351	145.4	1.258	0.629
Distribution Center	Distribution Center	19	20.3	8.1	28.4	0.716	Warehouse/ storage	Distribution/ shipping center	38	44.5	0.986	0.004	0	0.009	19.4	0.577	0.288
Enclosed Mall	Enclosed Mall	11	51.6	0.1	51.7	0.998	Enclosed/ Strip Mall	Enclosed mall Other retail Retail store Strip shopping mall	40	39.2	0.769	0.174	0.04	0.018	43.9	0.243	0.122
Financial Office	Financial Office	13	66.3	5.9	72.2	0.918	Office	Office	150	57.1	0.823	0.107	0.019	0.051	58.2	0.318	0.159
Fire Station	Fire Station	15	43.6	38.6	82.2	0.53	Public Order/ Safety	Fire station/police station	1	75.6	1	0	0	0	46.9	1.701	0.851
Fitness Center/Health Club/Gym	Fitness Center/Health Club/Gym	11	49.5	65.1	114.6	0.432	Public Assembly	Recreation	7	39.3	0.981	0.002	0.016	0	59.1	2.867	1.434

ESPM Property Type	EPA Type Grouping	EPA Count	Elec EUI (kBtu/ SF)	Gas EUI (kBtu/ SF)	Site EUI (kBtu/ SF)	Elec/Site Ratio	SWA Type	CBECS/RECS Types	CBECS/ RECS Count	CBECS/RECS Site EUI (kBtu/SF)	Gas Space Ratio	Gas Water Ratio	Gas Cook Ratio	Gas Other Ratio	Final Site EUI Target (kBtu/SF)	2030 Direct Emissions Target (kg CO2e / SF)	2035 Direct Emissions Target (kg CO2e / SF)
Food Sales	Supermarket/Grocery Store	156	136.9	49.2	186.2	0.736	Food Sales	Grocery store/food market	2	331.6	0.595	0.004	0.36	0.042	136.6	2.249	1.125
Heated Swimming Pool	Fitness Center/Health Club/Gym Ice/Curling Rink Other - Recreation Heated Swimming Pool	83	98.3	2	100.3	0.981	Public Assembly	Recreation	7	39.3	0.981	0.002	0.016	0	84.1	2.067	1.034
Hospital (General Medical & Surgical)	Hospital (General Medical & Surgical)	29	103.7	135.2	238.9	0.434	Health Care Inpatient	Hospital/ inpatient health	83	172.5	0.382	0.36	0.177	0.081	143.7	6.099	3.05
Hotel	Hotel	86	48.7	33.3	82	0.594	Lodging	Lodging	17	81.5	0.156	0.286	0.261	0.297	60.4	1.473	0.737
Ice/Curling Rink	Fitness Center/Health Club/Gym Ice/Curling Rink Other - Recreation Swimming Pool	83	98.3	2	100.3	0.981	Public Assembly	Recreation	7	39.3	0.981	0.002	0.016	0	84.1	2.067	1.034
Indoor Arena	Movie Theater Museum Other - Entertainment/Public Assembly Performing Arts Stadium (Closed) Stadium (Open)	54	44.1	14.1	58.2	0.758	Public Assembly	Public assembly	35	58.8	0.96	0.008	0.026	0.006	41.3	1.033	0.517
Laboratory	Laboratory	40	118.9	113.2	232.1	0.512	Other	Laboratory	13	206.3	0.754	0.019	0.089	0.138	143.8	5.349	2.675
Library	Library	26	52.2	39.2	91.4	0.571	Public Order/ Safety	Library	7	110	0.967	0.008	0	0.025	55.1	1.922	0.961
Lifestyle Center	Lifestyle Center	10	67.9	1	68.9	0.985	Enclosed/ Strip Mall	Strip shopping mall	18	112	0.731	0.118	0.134	0.016	58	0.912	0.456
Medical Office	Medical Office	68	82.7	0	82.7	0.999	Health Care Outpatient	Medical office (diagnostic)	12	40	0.99	0.008	0	0.002	70.3	0.181	0.09

ESPM Property Type	EPA Type Grouping	EPA Count	Elec EUI (kBtu/ SF)	Gas EUI (kBtu/ SF)	Site EUI (kBtu/ SF)	Elec/Site Ratio	SWA Type	CBECS/RECS Types	CBECS/ RECS Count	CBECS/RECS Site EUI (kBtu/SF)	Gas Space Ratio	Gas Water Ratio	Gas Cook Ratio	Gas Other Ratio	Final Site EUI Target (kBtu/SF)	2030 Direct Emissions Target (kg CO2e / SF)	2035 Direct Emissions Target (kg CO2e / SF)
								Medical office (non-diagnostic)									
Movie Theater	Movie Theater	5	61.2	17.8	79	0.775	Public Assembly	Public assembly	35	58.8	0.96	0.008	0.026	0.006	56.8	0.783	0.392
Multifamily Housing	Multifamily Housing	435	26.4	12.4	38.8	0.68	Multifamily	Apartment in a building with 2 to 4 units Apartment in a building with 5 or more units	196	49.2	0.274	0.229	0.118	0.379	29.4	0.823	0.412
Museum	Museum	22	32.1	7.3	39.4	0.815	Public Assembly	Public assembly	35	58.8	0.96	0.008	0.026	0.006	29.2	0.751	0.376
Non-Refrigerated Warehouse	Non-Refrigerated Warehouse	44	35	0.3	35.2	0.993	Warehouse/ storage	Non-refrigerated warehouse	19	16.1	0.993	0.004	0	0.002	29.8	0.086	0.043
Office	Office	636	64.1	0.1	64.2	0.999	Office	Office	150	57.1	0.823	0.107	0.019	0.051	54.5	0.218	0.109
Other - Education	Other - Education	8	46.1	17.2	63.3	0.729	Higher Education	Education	125	66.1	0.737	0.111	0.089	0.063	45	1.592	0.796
Other - Entertainment/ Public Assembly	Other - Entertainment/Public Assembly	7	56	0.1	56.1	0.998	Public Assembly	Public assembly	35	58.8	0.96	0.008	0.026	0.006	47.6	0.539	0.27
Other - Lodging/ Residential	Other - Lodging/Residential	11	43.6	0	43.6	1	Lodging	Lodging	17	81.5	0.156	0.286	0.261	0.297	37.1	0.002	0.001
Other - Mall	Other - Mall	11	81.7	38.5	120.2	0.679	Enclosed/ Strip Mall	Enclosed mall Other retail Retail store Strip shopping mall	40	39.2	0.769	0.174	0.04	0.018	81	1.404	0.702
Other - Other	Other - Other	125	50.8	22.3	73.1	0.696	Other	Other	5	59	0.613	0.006	0.031	0.351	54.1	1.602	0.801
Other - Public Service	Other - Public Service	24	69.9	5.7	75.6	0.925	Public Order/ Safety	Service	20	47.1	0.88	0.118	0.001	0	61	2.118	1.059

ESPM Property Type	EPA Type Grouping	EPA Count	Elec EUI (kBtu/ SF)	Gas EUI (kBtu/ SF)	Site EUI (kBtu/ SF)	Elec/Site Ratio	SWA Type	CBECS/RECS Types	CBECS/ RECS Count	CBECS/RECS Site EUI (kBtu/SF)	Gas Space Ratio	Gas Water Ratio	Gas Cook Ratio	Gas Other Ratio	Final Site EUI Target (kBtu/SF)	2030 Direct Emissions Target (kg CO2e / SF)	2035 Direct Emissions Target (kg CO2e / SF)
Other - Recreation	Other - Recreation	69	92	0	92	1	Public Assembly	Recreation	7	39.3	0.981	0.002	0.016	0	78.2	0.702	0.351
Other - Services	Other - Services	5	51.7	26	77.7	0.665	Service	Service	20	47.1	0.88	0.118	0.001	0	50.9	2.628	1.314
Other - Specialty Hospital	Hospital (General Medical & Surgical)	29	103.7	135.2	238.9	0.434	Health Care Inpatient	Hospital/ inpatient health	83	172.5	0.382	0.36	0.177	0.081	143.7	6.099	3.05
Other - Stadium	Stadium (Closed) Stadium (Open)	8	24.4	6.5	30.9	0.789	Public Assembly	Public assembly	35	58.8	0.96	0.008	0.026	0.006	22.5	0.313	0.157
Other - Technology/ Science	Other - Technology/Science	32	215.1	0	215.1	1	Other	Other	5	59	0.613	0.006	0.031	0.351	182.9	0.001	0.001
Outpatient Rehabilitation/ Physical Therapy	Urgent Care/Clinic/Other Outpatient	9	43.5	32.9	76.4	0.57	Health Care Outpatient	Outpatient health care	23	49.6	0.984	0.014	0.001	0.001	45.5	1.76	0.88
Performing Arts	Performing Arts	12	50.1	54	104.2	0.481	Public Assembly	Public assembly	35	58.8	0.96	0.008	0.026	0.006	57.2	2.379	1.19
Personal Services (Health/ Beauty, Dry Cleaning, etc.)	Other - Public Service Other - Services Repair Services (Vehicle, Shoe, Locksmith, etc.)	37	45.1	32.6	77.7	0.58	Service	Service	20	47.1	0.88	0.118	0.001	0	47.1	2.171	1.085
Police Station	Police Station	20	53.1	34.9	88	0.604	Public Order/ Safety	Fire station/police station	1	75.6	1	0	0	0	54.1	1.522	0.761
Pre-school/ Daycare	Pre-school/Daycare	10	30.2	41	71.2	0.424	K-12 School	Preschool/ daycare	2	65.7	0.297	0.313	0.005	0.384	47.7	2.453	1.226
Prison/ Incarceration	Barracks Other - Lodging/Residential Residence Hall/Dormitory	44	45.1	0.1	45.2	0.999	Public Order/ Safety	Public order and safety	4	82.8	0.984	0.012	0.004	0	38.4	0.573	0.286

ESPM Property Type	EPA Type Grouping	EPA Count	Elec EUI (kBtu/ SF)	Gas EUI (kBtu/ SF)	Site EUI (kBtu/ SF)	Elec/Site Ratio	SWA Type	CBECS/RECS Types	CBECS/ RECS Count	CBECS/RECS Site EUI (kBtu/SF)	Gas Space Ratio	Gas Water Ratio	Gas Cook Ratio	Gas Other Ratio	Final Site EUI Target (kBtu/SF)	2030 Direct Emissions Target (kg CO2e / SF)	2035 Direct Emissions Target (kg CO2e / SF)
Race Track	Movie Theater Museum Other - Entertainment/Public Assembly Performing Arts Stadium (Closed) Stadium (Open)	54	44.1	14.1	58.2	0.758	Public Assembly	Public assembly	35	58.8	0.96	0.008	0.026	0.006	41.3	1.033	0.517
Refrigerated Warehouse	Refrigerated Warehouse	5	35.2	31.1	66.3	0.53	Warehouse/ storage	Refrigerated warehouse	1	98.4	0.993	0.007	0	0	37.9	1.372	0.686
Repair Services (Vehicle, Shoe, Locksmith, etc.)	Repair Services (Vehicle, Shoe, Locksmith, etc.)	8	46.1	49.1	95.2	0.484	Service	Service	20	47.1	0.88	0.118	0.001	0	52.4	2.164	1.082
Residence Hall/ Dormitory	Residence Hall/Dormitory	31	38.5	9	47.5	0.81	Lodging	Dormitory/ fraternity/ sorority	15	96.4	0.158	0.287	0.256	0.299	37.8	0.702	0.351
Residential Care Facility	Senior Living Community	52	49	31.8	80.8	0.606	Health Care Outpatient	Outpatient health care	23	49.6	0.984	0.014	0.001	0.001	49.9	1.431	0.716
Retail Store	Retail Store	580	52.4	13.2	65.6	0.799	Retail	Retail store	18	35	0.954	0	0.011	0.034	48.3	0.602	0.301
Roller Rink	Fitness Center/Health Club/Gym Ice/Curling Rink Other - Recreation Swimming Pool	83	98.3	2	100.3	0.981	Public Assembly	Recreation	7	39.3	0.981	0.002	0.016	0	84.1	2.067	1.034
Self-Storage Facility	Self-Storage Facility	48	7.1	3.6	10.7	0.665	Warehouse/ storage	Non-refrigerated warehouse	19	16.1	0.993	0.004	0	0.002	7	0.194	0.097
Senior Living Community	Senior Living Community	52	49	31.8	80.8	0.606	Health Care Outpatient	Outpatient health care	23	49.6	0.984	0.014	0.001	0.001	49.9	1.431	0.716
Social/Meeting Hall	Social/Meeting Hall	32	40	19.8	59.8	0.669	Public Assembly	Social/meeting	10	59.5	0.943	0.012	0.044	0.002	39.4	1.527	0.763
Stadium (Closed)	Stadium (Closed) Stadium (Open)	8	24.4	6.5	30.9	0.789	Public Assembly	Public assembly	35	58.8	0.96	0.008	0.026	0.006	22.5	0.313	0.157

ESPM Property Type	EPA Type Grouping	EPA Count	Elec EUI (kBtu/ SF)	Gas EUI (kBtu/ SF)	Site EUI (kBtu/ SF)	Elec/Site Ratio	SWA Type	CBECS/RECS Types	CBECS/ RECS Count	CBECS/RECS Site EUI (kBtu/SF)	Gas Space Ratio	Gas Water Ratio	Gas Cook Ratio	Gas Other Ratio	Final Site EUI Target (kBtu/SF)	2030 Direct Emissions Target (kg CO2e / SF)	2035 Direct Emissions Target (kg CO2e / SF)
Stadium (Open)	Stadium (Open)	7	22.3	6	28.3	0.789	Public Assembly	Public assembly	35	58.8	0.96	0.008	0.026	0.006	20.6	0.322	0.161
Strip Mall	Strip Mall	54	54	38.2	92.2	0.586	Enclosed/ Strip Mall	Strip shopping mall	18	112	0.731	0.118	0.134	0.016	58.4	1.9	0.95
Supermarket/ Grocery Store	Supermarket/Grocery Store	156	136.9	49.2	186.2	0.736	Food Sales	Grocery store/food market	2	331.6	0.595	0.004	0.36	0.042	136.6	2.249	1.125
Transportation Terminal/ Station	Transportation Terminal/Station	5	55.7	33.3	89	0.625	Public Order/ Safety	Public assembly	35	58.8	0.96	0.008	0.026	0.006	56.3	2.224	1.112
Urgent Care/ Clinic/Other Outpatient	Urgent Care/Clinic/Other Outpatient	9	43.5	32.9	76.4	0.57	Health Care Outpatient	Clinic/other outpatient health	13	113.1	0.977	0.017	0.003	0.003	45.6	1.76	0.88
Vehicle Dealership	Vehicle Dealership	22	54.5	48.7	103.2	0.528	Retail	Retail other than mall	22	38	0.782	0.194	0.006	0.018	60.5	2.233	1.116
Veterinary Office	Urgent Care/Clinic/Other Outpatient	9	43.5	32.9	76.4	0.57	Health Care Outpatient	Clinic/other outpatient health	13	113.1	0.977	0.017	0.003	0.003	45.6	1.76	0.88
Vocational School	Adult Education Other - Education Vocational School	11	42.7	28	70.7	0.604	Higher Education	Education	125	66.1	0.737	0.111	0.089	0.063	45.8	2.335	1.168
Wholesale Club/ Supercenter	Retail Store Wholesale Club/Supercenter	582	52.5	13.3	65.8	0.798	Retail	Retail store	18	35	0.954	0	0.011	0.034	48.4	0.603	0.301
Worship Facility	Worship Facility	31	28	19.4	47.4	0.591	Religious worship	Religious worship	19	32.8	0.589	0.133	0.116	0.162	31.8	0.873	0.437
Zoo	Movie Theater Museum Other - Entertainment/Public Assembly Performing Arts Stadium (Closed) Stadium (Open)	54	44.1	14.1	58.2	0.758	Public Assembly	Public assembly	35	58.8	0.96	0.008	0.026	0.006	41.3	1.033	0.517

Table 4. EEM Costs

The Energy Efficiency Measure (EEM) costs used in the analysis for multifamily, office, and warehouse buildings are shown below. Note that these costs are intended to provide a high-level estimate of the overall cost of energy efficiency retrofits across the Maryland building stock and are not intended to be representative of costs at any particular building. The specific measures and costs for a specific building will be dependent on the building's unique characteristics and systems.

	Cost ($/square foot)		
EEM	Multifamily	Office	Warehouse
Add Plug Load Control	0.03	-	-
Add R-10 Roof Insulation	7.2	5.6	-
Add R-5.0ci Wall Insulation	5.5	1.0	3.4
Add Vestibule			3.1
Adjust HVAC Schedules	-	0.0	0.0
Close Shaft Vents	5.3	-	-
Conduct Commissioning - Stage 1: 1-month payback	0.01	0.03	0.01
Conduct Commissioning - Stage 2: 1-year payback	0.3	0.2	0.2
Conduct Commissioning - Stage 3: 3-year payback	0.8	0.4	0.7
Improve Fenestration	7.0	-	-
Increase Daylit Area	-	-	0.3
Install a Heat Pump Clothes Dryer	7.4	-	-
Install an Exhaust Recovery Ventilation Unit	4.7	3.1	3.0
Install Central Temperature Controls	1.4	-	1.1
Install DOAS/fan control	-	0.9	-
Install Fault Detection and Diagnosis	5.6	0.2	0.8
Install Low Flow Aerators in Faucets and Showers	7.5	-	-
Install Occupancy Controls	-	1.2	0.3
Install Primary Chilled Water Pump Variable Frequency Drives	-	1.2	-
Install Programmable Thermostats	6.1	-	-
Install Residential HVAC Controls	0.5	-	-
Install Residential Lighting Controls	1.7	-	-
Install Service Hot Water Shower Drain Heat Recovery	1.0	-	-
Install Smart Plug Load Management Tools	-	0.6	0.5

	Cost ($/square foot)		
EEM	Multifamily	Office	Warehouse
Install Tenant Submeteres	-	5.3	-
Install Thermostatic Balancing Valves	1.7	-	-
Install Variable Frequency Drives on Central Distribution Pumps	0.1	-	-
Install Variable Frequency Drives on Condenser Water Pumps	1.1	1.0	-
Install Variable Frequency Drives on Domestic Water Booster Pumps	1.1	-	-
Install Variable Frequency Drives on Heating Hot Water Pumps	0.4	-	-
Insulate Service Hot Water Piping	7.4	-	-
Reduce Envelope Leakage	0.05	0.04	0.1
Reduce Lighting Power Density	1.6	3.6	0.4
Upgrade Elevator Efficiency	-	3.8	-
Upgrade Exhaust Fans	2.1	-	-
Upgrade Interior Lighting to LED	-	4.7	4.2
Upgrade In-Unit Appliances	5.3	-	-
Upgrader Parking Garage Lighting to LED	-	5.4	-

The cost curves developed using these costs are shown in the figures below.

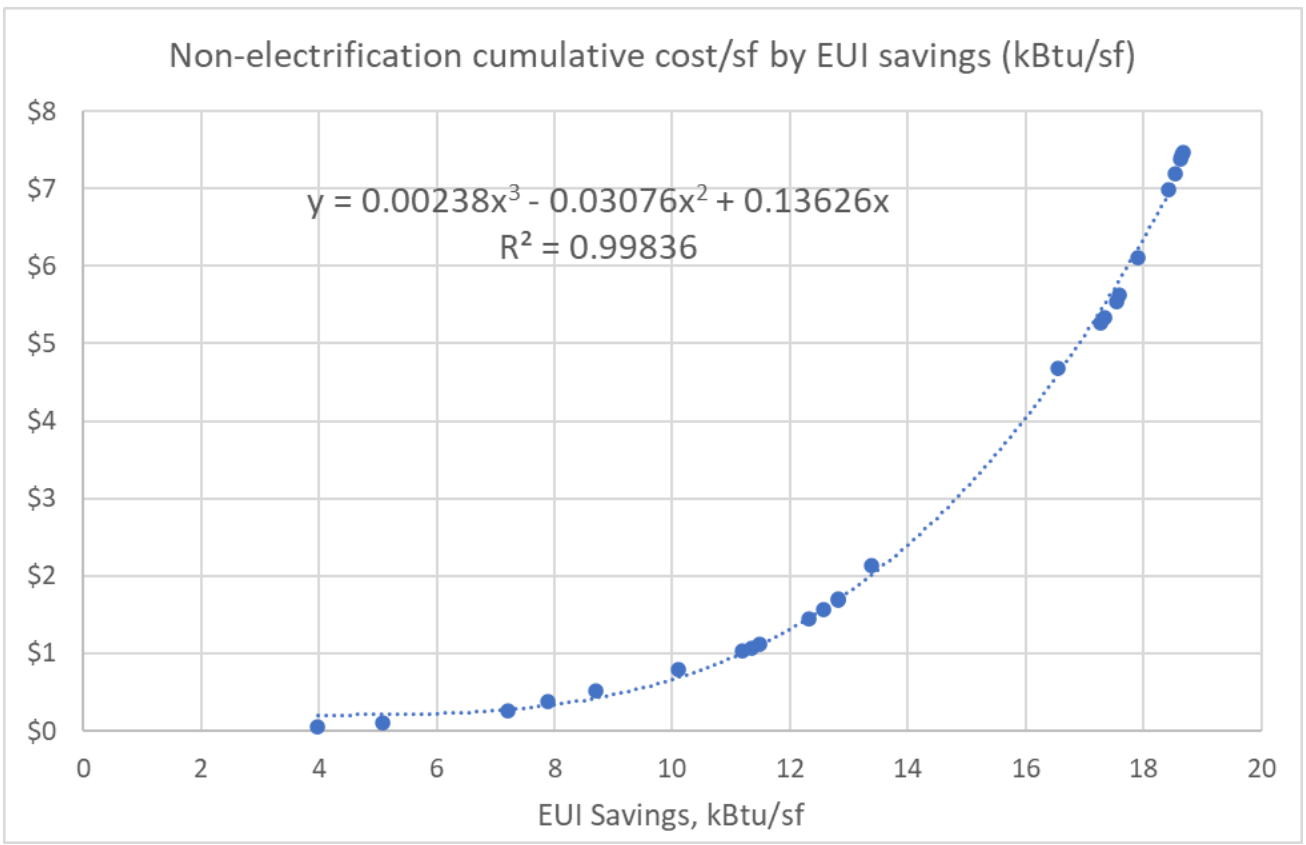

Figure 4: Non-electrification cumulative cost/sf by EUI savings (kBtu/sf) – Multifamily Building Type

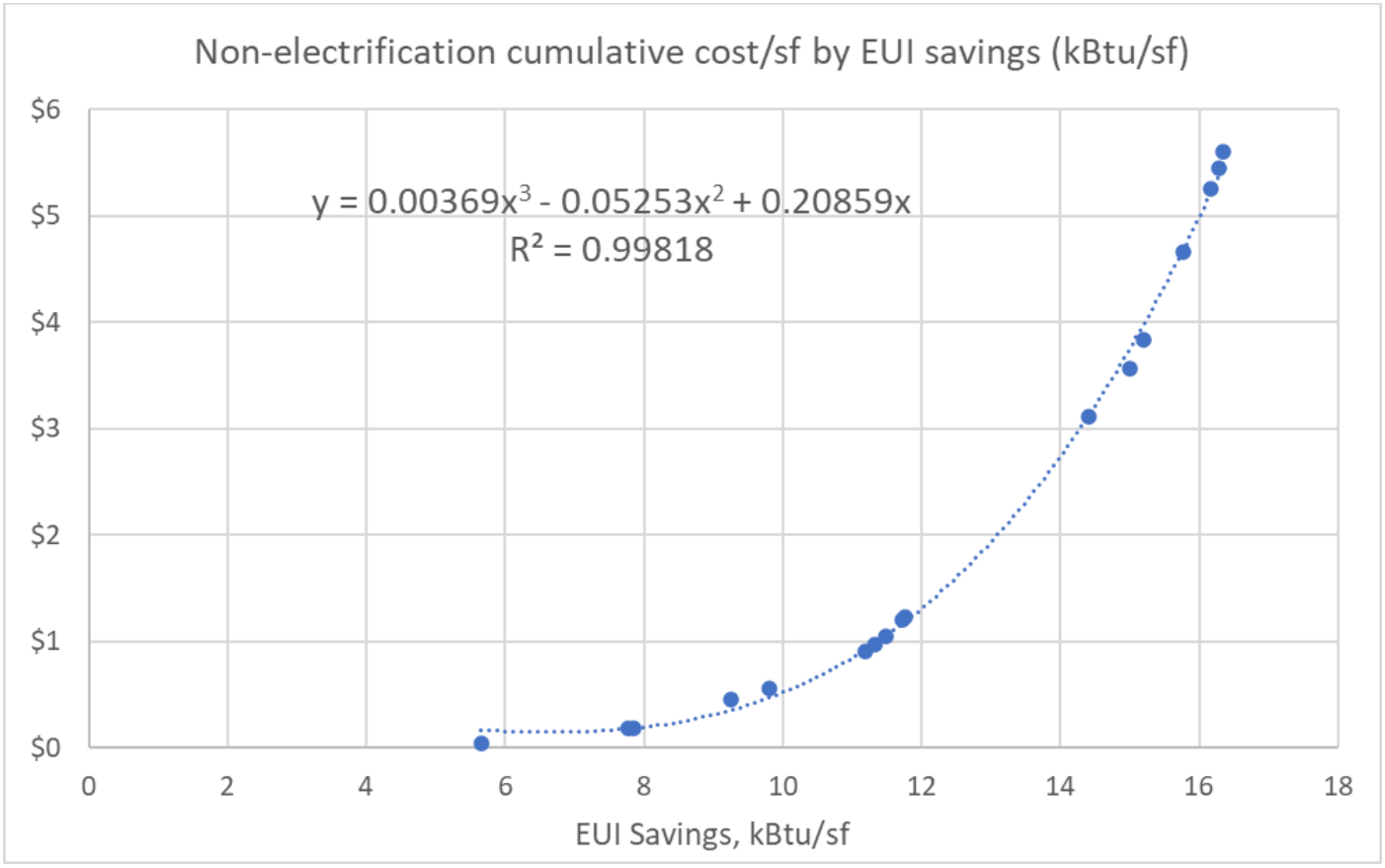

Figure 5: Non-electrification cumulative cost/sf by EUI savings (kBtu/sf) – Office Building Type

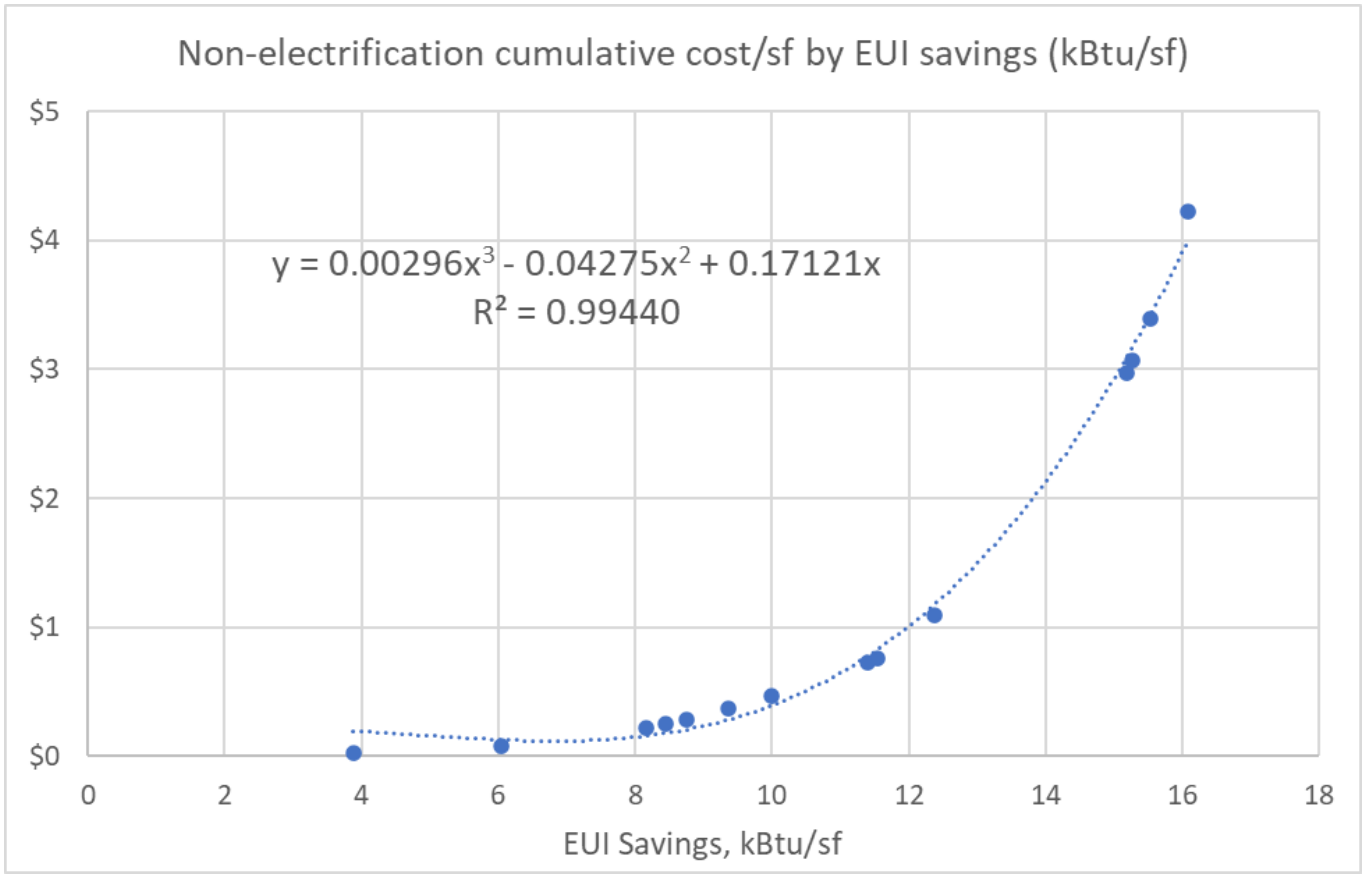

Figure 6: Non-electrification cumulative cost/sf by EUI savings (kBtu/sf) – Warehouse Building Type

Table 5. Electrification Costs.

Electrification costs used in the analysis are shown below. The costs were determined by averaging the cost per square foot of electrification projects by building type as shown in studies conducted for Washington D.C. [8], Montgomery County [5], and Maryland [7]. These costs are high-level and are not intended to represent exact electrification costs at any particular building.

Building Type	**Space Heating Electrification ($/sf)**	**Water Heating Electrification ($/sf)**	**Other Equipment Electrification ($/sf)**
Residential	$7.99	$5.17	$0.84
Commercial	$9.16		$0.12

Table 6. Baseline Replacement Costs

Baseline replacement costs used in the model are shown in the table below.

Building Type[1] [MA2]	**End Use**	**Heating**	**Cost ($/kBtu/year)**
Large Office	Space heating	Boiler gas-fired	0.13
Small Office	Space heating	PSZ with gas heating	0.11
Midrise Apartment	Space heating	Split A/C with gas heating	1.19
Warehouse	Space heating	PSZ with gas heating	0.01
Large Office	Water heating	Commercial gas storage	0.05
Small Office	Water heating	Commercial gas storage	0.12
Midrise Apartment	Water heating	Residential gas storage	0.11
Warehouse	Water heating	Commercial gas storage	0.10