Appendix A Greenhouse Gas Reduction Calculations Technical

General Method Description and Results

Modeling portfolio-wide energy savings and greenhouse gas (GHG) emission reductions potential across multiple types of energy measures for multiple types of buildings typically requires in-depth analysis spanning facility surveys and calibrated energy usage models. For buildings proposed and selected for this grant program, such analysis can and should be conducted to refine the savings estimates before finalization of awardees.

In lieu of this in-depth analysis, programmatic scale energy savings estimates were developed for the relevant building types based on publicly available and transparent third-party databases – mostly grounded in past research from the US Department of Energy national laboratories. Unfortunately, in the building energy retrofit sector, especially when focusing on building electrification, there is limited transparent third-party data available. The data that do exist are sufficient and reliable for high-level programmatic evaluation, but the types of energy measures and types of buildings that have been evaluated to such a high degree are limited in scope. As such, the following analysis represents just a subset of the total array of energy measures available for awardees to consider when applying for this grant opportunity. Despite these limits, we expect the findings to be representational of the total savings potential and cost-effectiveness of the broader spectrum of energy savings measures that may be applied in the real-world.

There are seven energy measures that were assessed for GHG emission reductions. Six were based on NREL's ComStock data set with energy efficiency and electrification measures[1] and the last measure focused on installation of solar photovoltaic (PV) systems:

1. Dedicated Outdoor Air System (DOAS) Heat Pump (HP) Mini splits
2. HP Boiler, Electric Backup
3. HP Boiler, Gas Backup
4. HP RTU, Electric Backup
5. HP RTU, Original Heating Fuel Backup
6. Light Emitting Diode (LED) Lighting
7. Solar Photovoltaics (PV)

One GHG reduction calculation methodology was used for all the energy measures from ComStock, as described in detail below. For solar PV GHG reduction calculations, estimated GHG reduction was based on estimated annual electricity generation from PVWatts[2] per kilowatt (kW) of solar PV installed. In general, emissions reductions for ComStock energy measures were first calculated by applying the savings potential from the ComStock database to the baseline energy use intensities (EUI) for Office and Public Assembly building types from the 2018 Commercial Buildings Energy Consumption Survey (CBECS) and converting energy savings into GHG savings per the utility emissions factors sourced from NREL's Cambium 2023 Mid-Case Scenario data[3][4][5][6], as shown in the following equation:

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[1] https://nrel.github.io/ComStock.github.io/docs/upgrade_measures/upgrade_measures.html

[2] https://pvwatts.nrel.gov/index.php

[3] https://www.nrel.gov/buildings/comstock.html#:~:text=ComStock%20is%20a%20U.S.%20Department,Models%20and%20Commercial%20Reference%20Building.

[4] https://www.eia.gov/consumption/commercial/data/2018/index.php?view=microdata

[5] https://www.nrel.gov/analysis/cambium.html

[6] https://www.nrel.gov/docs/fy23osti/84916.pdf

$$Emissions\ Reduced\ per\ Square\ Foot\ =\ Baseline\ EUI\ *\ \%\ EUI\ Savings\ *\ Emissions\ Factor$$

The estimated emissions per square foot was then scaled based on the funding allocated, project size, year of implementation, and cost per upgrade measure which was estimated from Pacific Northwest National Laboratory's (PNNL) cost estimate methodology[7].

$$Emissions\ Reduced = Emissions\ Reduced\ per\ Square\ Foot * \frac{Funding\ Allocation}{Cost\ per\ Square\ Foot}$$

Total emissions were calculated each year from 2025-2050. Cumulative emissions saved were calculated by summing annual emissions reduced each year. General assumptions across the small and large projects include:

- Project installation/construction begins second half of 2027 for both small and large projects.
- Small projects are fully completed by end of 2028 and large projects are fully completed by first half of 2029.

Cumulative and annual GHG reductions for all projects are in Table 12 and Table 13

Table 1.1 Cumulative GHG Reductions

Years	Cumulative $MTCO_2e$ Reduced
2025-2030	23,081
2025-2050	102,765

Table 2. 2 Annual GHG Reductions

Year	Annual $MTCO_2e$ Reduced
2025	0
2026	0
2027	6,265
2028	5,935
2029	5,606
2030	5,276
2031	4,963
2032	4,650
2033	4,336
2034	4,023
2035	3,710
2036	3,716
2037	3,721
2038	3,727
2039	3,733
2040	3,739
2041	3,764
2042	3,789
2043	3,814
2044	3,838
2045	3,863
2046	3,929
2047	3,994

[7] https://www.energycodes.gov/sites/default/files/2021-07/commercial_methodology.pdf

2048	4,060
2049	4,125
2050	4,190

Sample Portfolio of Buildings under Consideration

To emphasize the community benefit of this program, only public-facing facilities were considered for estimating the GHG emissions savings with proposed GHG reduction measures. The City of Austin has previously identified public facing facilities in 2022 as part of their Resilience Hub pilot effort. Based on those facilities, it was assumed that the community facing facilities mainly consist of Office and Public Assembly building types with a 40/60 split. This ratio is broadly representative of the split of building types that may qualify for this program across the public-facing municipal buildings portfolio spanning the Austin-Round Rock MSA. This split was used to align with ComStock and CBECS data sets which are further discussed in the following sections.

Energy Savings for ComStock Energy Measures

Baseline Energy Use Intensity for Municipal Facilities

To obtain the baseline energy use for facilities, data from CBECS was used. CBECS is a national sample survey and is provided from the U.S. Energy Information Administration (EIA) that collects information on the stock of U.S. commercial buildings including energy-related building characteristics and energy usage data (consumption and expenditures). The survey covers all U.S. commercial building typologies but consolidates these typologies and reports it into 16 building types. The 2018 data is the most recent CBECS data available and was used for this analysis[8].

The 2018 CBECS Survey Data was filtered to buildings with the following value selections presented in Table 14.

Table 3. 3 2018 CBECS Data Filters

Variable	Value Selection
Principle Building Activity (PBA)	Office Public Assembly
Census Division	West South Central
Climate	Hot or Very Hot

The energy use intensity (EUI) (kBtu/sqft) was computed for each end use. Each building sample in the CBECS data set has an associated weight to it. The associated weight was used to calculate the average EUI for each end use given a specific building typology (Office or Public Assembly).

$$\frac{\sum(Building\ Sample\ Weight * Building\ Sample\ EUI)}{\sum(Building\ Sample\ Weight * Building\ Sample\ Sqft)}$$

Table 15 summarizes the EUIs per end and building type calculated from CBECS data, specific to the West South Central Census Division and Hot/Very Hot Climate.

[8] https://www.eia.gov/consumption/commercial/data/2018/xls/cbecs2018_final_public.csv

Table 4. Building End Use EUIs

Source	End Use	Office EUI (kbtu/sqft)	Public Assembly EUI (kbtu/sqft)
Electricity	Heating	1.60	1.96
	Cooling	10.77	25.88
	Ventilation	12.67	2.76
	Water Heating	0.46	0.16
	Lighting	8.10	4.72
	Refrigeration	0.12	0.34
	Interior Equipment	17.26	12.88
Natural Gas	Heating	2.95	12.29
	Cooling	0.00	0.00
	Water Systems	0.27	1.78
	Interior Equipment	0.98	4.37

By computing the EUIs of each end use for the type building types, this helped establish a baseline to determine savings.

Estimating EUI Savings per GHG Reduction Measure

ComStock is a U.S. Department of Energy (DOE) model of the U.S. building stock, developed and maintained by NREL. The models use a sample of building characteristics from DOE's Commercial Prototype Building Models and Commercial References Building. The models include results from application of various energy efficiency and electrification measures. This includes overall energy savings, savings per end use and energy intensities per model. New models are released every year with documentation of new energy measures and existing energy measures in the model.

The 2023 metadata and annual results for each upgrade measure by ComStock were taken from ComStock's Open Energy Initiative (OpenEI) Data Lake[9]. The data includes the EUI savings and final EUI consumption for each end use given the upgrade measure type per building model. The data was filtered down to the relevant building models for this analysis including the weather file and state applicable to Travis County. Filters to the data are presented in Table 16.

Table 5. 2023 ComStock Data Filters

Field Name	Value Selection
in.comstock_building_type	Small Office Medium Office Large Office
in.state_name	Texas
In.weather_file_tmy3	Austin_Meuller_Municipal_Ap_U

The ComStock datasets include a variety of measures including HVAC upgrades, building envelope upgrades, ventilation controls and packages that combine upgrade. Table 17 presents the measures evaluated in this analysis.

[9] https://nrel.github.io/ComStock.github.io/

Table 6. Energy Measures Evaluated

Project Size	Measure	Definition
Large Projects	DOAS HP Mini splits	Replace gas-fired and electric resistance rooftop units (RTUs) with high-efficiency (~30 seasonal energy efficiency ratio; 14 heating seasonal performance factor), variable speed MSHPs and a DOAS system with an energy recovery ventilator (ERV) or heat recovery ventilator (HRV). The DOAS system uses the existing ductwork from the replaced RTU.
	HP Boiler, Electric Backup	Replace gas boilers with heat pump boilers.
	HP Boiler, Gas Backup	Replace gas boilers with heat pump boilers.
Small Projects	HP RTU, Electric Backup	Replace gas and electric RTUs with HP-RTU.
	HP RTU, Original Heating Fuel Backup	Replace gas and electric RTUs with HP-RTU. Backup heat source matches fuel type of the original system.
Both	LED Lighting	Upgrade all lighting to LEDs.

Source: ComStock Energy Efficiency and Electrification Measure Documentation

As described previously, due to limitations in publicly available datasets, this table describes the subset of possible measures that were modeled for the purpose of estimating GHG reduction potential. These measures were chosen from ComStock because publicly available data were available for the estimated savings potential and implementation costs that are scalable to the building types under consideration. Other GHG reduction measures, such as building envelope upgrades and demand control ventilation, have much more variable savings and cost estimates that depend on the individual buildings.

To estimate the savings from the Comstock measures, the end uses reported in Comstock (for energy savings) had to be aligned with the end uses reported in CBECS (for energy baseline). Table 18 summarizes how these end uses were aligned.

Table 7. ComStock and CBECS End Use Alignment

Source	ComStock End Uses	CBECS End Use
Electricity	Heating	Heating
	Heat Recovery	
	Cooling	Cooling
	Heat Rejection	
	Pumps	
	Fans	Ventilation
	Water Systems	Water Heating
	Interior Lighting	Lighting
	Exterior Lighting	
	Refrigeration	Refrigeration
	Interior Equipment	Office Equipment
		Computing
		Miscellaneous
		Cooking
Natural Gas	Heating	Heating

Cooling	Cooling
Water Systems	Water Heating
Interior Equipment	Cooking
	Miscellaneous

Estimated savings from the Comstock energy models to the CBECS baseline were applied on a percentage per end-use basis. The following formula was applied to each end use:

$$\%\ EUI\ Savings = \frac{Average\ EUI\ Savings}{Average\ EUI\ Savings + \ Average\ EUI\ Consumption}$$

Percent EUI savings computed for each end use from ComStock were applied and aligned to the end use EUIs computed from CBECS for each building type (Office and Public Assembly). The natural gas heating end use percent EUI savings were adjusted to 100% for all heat pump measures with the assumption that natural gas is completely removed for heating. The total EUI savings per end use were then added up together by source category (electricity and natural gas).

$$EUI\ Savings\ per\ Upgrade\ Measure = \%\ EUI\ Savings\ from\ ComStock * CBECS\ Baseline\ EUI$$

Table 19 presents the total EUI savings per upgrade measure for both electricity and natural gas.

Table 8. EUI Savings per Upgrade Measure

Upgrade Measure	**Office EUI Savings (kbtu/sqft)**		**Public Assembly EUI Savings (kbtu/sqft)**	
	Electricity	**Natural Gas**	**Electricity**	**Natural Gas**
DOAS HP Minisplits	9.35	1.38	8.28	5.76
HP Boiler, Electric Backup	-0.16	2.95	-0.20	12.29
HP Boiler, Gas Backup	-0.14	2.95	-0.17	12.29
HP RTU, Electric Backup	6.94	2.95	5.65	12.29
HP RTU, Original Heating Fuel Backup	6.96	2.95	5.67	12.29
LED Lighting	4.89	-0.09	2.93	-0.38

Uncertainties

Only office building type was chosen from the ComStock data set since Public Assembly building typologies were not available. The EUI savings for Public Assembly building types may defer from the office building type EUI savings, but this is accounted for in aligning the Comstock data to the CBECS data. In addition, due to lack of data, savings associated with domestic hot water boiler conversion to heat pumps were not quantified. This GHG reduction strategy should still be considered when further data is available to better quantify possible GHG savings associated with domestic hot water boiler conversion to heat pumps.

Energy Savings for Solar PV

NREL's PVWatts Calculator helps estimate the energy production of grid-connected PV systems. Entering the City of Austin as the location of interest and system size of 1 kilowatt (kW), it was estimated that the system can output 1,478 kilowatt hours (kWh) per year. Therefore, it was assumed that for every kW of solar PV installed, 1,478 kWh is estimated to be saved per year.

Costing

Because public sources of commercial energy savings cost estimates are unavailable, cost estimates for the GHG reduction measures were taken from previous cost estimates formulated from industry and vendor data. The cost estimate approach is aligned with DOE's method for evaluating cost-effectiveness of commercial energy efficiency codes that was prepared by Pacific Northwest National Laboratory[10].

The following costs were applied for both Office and Public Assembly building types for each GHG reduction measure:

Table 9. Energy Measure Costs

Upgrade Measure	Cost	Cost Unit
DOAS HP Mini splits	6.83	$/Sqft
HP Boiler, Electric Backup	4.50	$/Sqft
HP Boiler, Gas Backup	4.50	$/Sqft
Solar PV	3.00	$/W
HP RTU, Electric Backup	7.43	$/Sqft
HP RTU, Original Heating Fuel Backup	7.43	$/Sqft
LED Lighting	1.50	$/Sqft

Uncertainties

Estimating projects costs can be difficult and come with great uncertainty. Even with multiple credible cost estimates, judgement is often required to determine an appropriate range of first costs. Cost data can vary based on the following: source of cost estimate, economies of scale, market transformation effects, labor, inflation, and any another cost factors.

Project Implementation

Project implementation is front loaded in 2027 to maximize GHG savings. $15 million is assumed to be allocated to small projects and $30 million allocated to large projects. For building energy measures, funding is split between office and public assembly building types and scaled based on the modeled cost-effectiveness of each upgrade measure. EUI savings per upgrade measure were then applied to obtain the annual energy savings in terms of electricity and natural gas:

$$Annual\ Energy\ Savings\ (Electricity\ and\ Gas) = \frac{Funding}{Cost\ per\ Square\ Foot} * \ EUI\ Saved$$

Assumptions:

- Grant funding to be awarded in 2025
- Public Assembly and Office building types were chosen to represent community facing facilities across Travis County. It was assumed that approximately 60% of the buildings that participate in the program will be Public Assembly building type, and that approximately 40% will be Office building type.
- HP Boiler, Gas Backup only applied to Public Assembly building type

[10] https://www.energycodes.gov/sites/default/files/2021-07/commercial_methodology.pdf

Energy savings from solar PV installation was calculated be applying PVWatts' estimated annual savings for 1 kW of solar PV installed:

$$Annual\ Solar\ PV\ Electricity\ Savings = \frac{Funding}{Cost\ per\ kW} * \frac{1{,}478\ kWh}{1\ kW}$$

Funding allocated for the specific GHG reduction measures were assumed to be the following:

Table 10. Funding allocations

Project Size	Measure	Total
Large	DOAS HP Minisplits	$5,000,000
	HP Boiler, Electric Backup	$5,000,000
	HP Boiler, Gas Backup	$5,000,000
	Solar PV	$10,000,000
Small	HP RTU, Electric Backup	$5,000,000
	HP RTU, Original Heating Fuel Backup	$5,000,000
Both	LED Lighting	$10,000,000

Funding allocation for LED lighting was split evenly as a small and large project.

Estimating GHG Emission Savings

Taking the estimated annual electricity and natural gas savings, respective emissions factors were applied to obtain the annual GHG savings per the following formula.

$$Annual\ Emission\ Reduced = Annual\ Energy\ Consumption * \ Emissions\ Factor$$

Emissions were converted to $MTCO_2e$ using the IPCC Fifth Assessment Report 100-year GWP values. Annual GHG emissions savings were rolled up for cumulative GHG savings from 2025-2030 and 2025-2050.

Natural Gas Emissions Factor

The natural gas emissions factor of 53.11 kgCO2/MMBTU is from the EPA Emission Factor for Greenhouse Gas Inventories Document.[11] The natural gas emissions factor is held constant overtime.

Electricity Emission Factor Forecasts

Electricity emissions factors were forecast using NREL's Cambium 2023 Mid-Case Scenario data for the ERCOT generation and emissions assessment region. The Mid-Case Scenario represents a business-as-usual scenario that considers electric sector policies as they existed in September 2023. The emissions factors reflect the average emission rate of all generation within a region for the specified duration of time and no adjustment is made for imported or exported electricity. Forecast values are available every five years starting in 2025 and ending in 2050. Intermittent years' emissions factors were interpolated using this data. Emission factors were converted to $MTCO_2e$ using the IPCC Fifth Assessment Report 100-year GWP values and are presented in Table 22.

[11] https://www.epa.gov/system/files/documents/2024-02/ghg-emission-factors-hub-2024.pdf

Table 11. Electricity Emission Factors

Year	MTCO2e/MWh
2025	0.2680
2026	0.2498
2027	0.2315
2028	0.2133
2029	0.1950
2030	0.1768
2031	0.1595
2032	0.1421
2033	0.1248
2034	0.1074
2035	0.0901
2036	0.0904
2037	0.0907
2038	0.0911
2039	0.0914
2040	0.0917
2041	0.0931
2042	0.0945
2043	0.0958
2044	0.0972
2045	0.0986
2046	0.1022
2047	0.1058
2048	0.1095
2049	0.1131
2050	0.1167

Annual and Cumulative GHG Emission Savings

Estimated electricity and natural savings remain the same from 2027 to 2050 since all are implemented in 2027 and continue to realize GHG savings. The estimated energy consumption savings and emissions are seen in Table 23.

Table 12. Annual Energy Consumption and Emissions Reductions

Year	Annual Electricity Savings (MWh/Year)	Annual Natural Gas Savings (MMBtu/Year)	Annual Emissions Reductions ($MTCO_2e$)
2025	0	0	0
2026	0	0	0
2027	18,065	39,202	6,265
2028	18,065	39,202	5,935
2029	18,065	39,202	5,606
2030	18,065	39,202	5,276
2031	18,065	39,202	4,963
2032	18,065	39,202	4,650
2033	18,065	39,202	4,336
2034	18,065	39,202	4,023
2035	18,065	39,202	3,710
2036	18,065	39,202	3,716
2037	18,065	39,202	3,721

Year	Annual Electricity Savings (MWh/Year)	Annual Natural Gas Savings (MMBtu/Year)	Annual Emissions Reductions ($MTCO_2e$)
2038	18,065	39,202	3,727
2039	18,065	39,202	3,733
2040	18,065	39,202	3,739
2041	18,065	39,202	3,764
2042	18,065	39,202	3,789
2043	18,065	39,202	3,814
2044	18,065	39,202	3,838
2045	18,065	39,202	3,863
2046	18,065	39,202	3,929
2047	18,065	39,202	3,994
2048	18,065	39,202	4,060
2049	18,065	39,202	4,125
2050	18,065	39,202	4,190

Uncertainties

Any electricity emission factor forecasts will come with inherent uncertainty. NREL has noted the following on their Cambium 2023 forecasting: “Although we strive to capture relevant phenomena as comprehensively as possible, the models used to create the data are unavoidably imperfect, and the future is highly uncertain.”[12]

[12] https://www.nrel.gov/docs/fy24osti/88507.pdf