City of Rochester, NY Climate Pollution Reduction Grants Program
(CPRG) EPA-R-OAR-CPRGI-23-07: Technical Appendix

CPRG Calculations Description, Assumptions, and References

General Assumptions

The following general assumptions and references are used across each of the four project calculations described below:

- Residential electric rate per kWh is based on average costs for supply and delivery for residential Rochester Gas and Electric (RG&E) customers in Rochester, NY.
- Municipal electric rate per kWh is based on anticipated new supply and delivery rate that is to be negotiated for City of Rochester facilities with RG&E.
- Natural gas rate per therm is based on a 12-month average supply rate from RG&E from January 1, 2023 through December 31, 2023. The rate selected is based on an average of Residential (SC 1) off-peak rates and Residential on-peak (SC 4) rates.
- GHG emissions per kilowatt-hour (kWh) were calculated using data from NYISO, 2019.
    - These values include carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) emissions produced per kWh.
- Quantities of methane (CH_4) and nitrous oxide (N_2O) have been converted into carbon dioxide equivalent (CO_2e) using the Global Warming Potential (GWP) Cumulative Forcing over 20 years value presented in the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report, Box 3.2, Table 1.

General Calculations

The following calculations were performed for all four projects:

Carbon Dioxide Equivalent Calculations:

- GHG emissions for CO_2, CH_4, and N_2O were calculated using the following values:
    - CO_2:
        - 1 kWh = 0.2947 lb CO_2
        - 1 mmBTU = 117 lb CO_2
    - CH_4:
        - 1 kWh = 2.1×10^{-5} lb CH_4
        - 1 mmBTU = 2.2 lb CH_4
        - GWP (20 years) = 84
    - N_2O:
        - 1 kWh = 3×10^{-6} LB N_2O
        - 1 mmBTU = 0.22 lb N_2O
        - GWP (20 years) = 264

CH_4 and N_2O were converted into CO2e by multiplying the total weight of these gases generated by the 20-year GWP. CO2e is then converted into metric tons.

Annual Impact on GHG Emissions:

- *Estimated Annual GHG Reduction ($mtCO_2e$):* The estimated annual reduction in GHG emissions once a project has been completed.

- *Qualified GHG Reductions from CPRG Funding ($mtCO_2e$):* GHG emissions reduction that are a direct result of CPRG funding. This value is a requirement of the CPRG funding.

Short-Term Cumulative Impact on GHG Emissions – 2025 Through 2030:

- *Estimated Cumulative GHG Reduction ($mtCO_2e$)*: The estimated cumulative GHG emissions reduction for each project, from 2025 through 2030. This interval takes into account the estimated amount of time it will take to implement each project.
- *Qualified Cumulative GHG Reductions from CPRG Funding ($mtCO_2e$)*: Cumulative GHG emissions reduction that are a direct result of CPRG funding from 2025 through 2030. This value is used to estimate the cost-effectiveness of each project, and is a requirement of CPRG funding.

Long-Term Cumulative Impact on GHG Emissions – 2025 Through 2050:

- *Cumulative GHG Reduction Through 2050 ($mtCO_2e$)*: The estimated cumulative GHG emissions reduction for each project, from 2025 through 2050.
- *Qualified Cumulative GHG Reduction from CPRG Funding ($mtCO_2e$)*: Cumulative GHG emissions that are a direct result of CPRG funding from 2025 through 2050. This value is a requirement of the CPRG funding.

Project #1 – Residential Rooftop Solar Program

The City of Rochester currently provides rooftop replacements for lower income households that have aging roofs. Under this grant program, the City would install rooftop solar on eligible, feasible households to offset their energy costs and reduce the City's greenhouse gas (GHG) emissions. In order to calculate the total energy produced and total reduction in GHG emissions from installation of proposed residential rooftop arrays, the following quantities are needed:

1. Average rooftop size that is replaced as part of this program;
2. Number of rooftops on which solar installations are expected to be installed over the length of the program;
3. Average percentage of rooftop area expected to be covered by a solar installation;
4. Average panel efficiency for Rochester, NY, including losses; and
5. Average daily available sunlight for solar generation in Rochester, NY.

Values #1 and #2 were provided by the City of Rochester. Value #3 is a reasonable assumption based on potential available area for a solar array on a residential property. Values #4 and #5 were provided by GreenSpark Solar, a solar developer based in the Rochester, NY area that has extensive experience with solar installations in Western New York. These five values are denoted in the calculation spreadsheet for Project #1. Using these assigned values, the calculation to determine the average electricity produced from a rooftop solar array is:

$$\begin{aligned} &System\ Capacity\ [kW] \\ &= (Total\ Rooftop\ Area\ [ft^2])(\%\ Area\ Available)(Electricity\ Produced\ per\ Unit\ Area\ \left[\frac{kW}{ft^2}\right]) \end{aligned}$$

Next, the total amount of power generated on an annual basis was calculated using the following equation:

$$\text{Annual Power Generated } \left[\frac{kWh}{yr}\right] = (\text{System Capacity } [kW])(\text{Hours Sunlight per Day } \left[\frac{hr}{day}\right])(\text{Days per Year } [\frac{day}{yr}])$$

The following assumptions were made when calculating the average electricity produced per ft^2 of available array area:

Finally, the total annual GHG emissions (CO_2, CH_4, and N_2O) were calculated and converted to CO_2e.

Additionally, average annual savings to individual homeowners were calculated to provide additional data for the City. The following assumptions were made when calculating the above values:

- *Panel Efficiency*: 17.55 W/ft^2
    - This value was obtained from GreenSpark Solar, a solar company that has partnered with the City of Rochester.
    - *ASSUMPTION*: This panel efficiency value accounts for system losses due to wiring, DC/AC conversion, shading, and other losses.
- *Average Hours of Usable Sunlight/Day*: 3.42 hr/day
    - This value is was provided from GreenSpark Solar and checked using the NREL PVWatts calculator.
- *Array Type*: Fixed Tilt

Project #2 – Residential Clean Heating and Cooling Program

Under this program, the City of Rochester currently replaces furnaces or hot water tanks that have failed at single- or multi-family residences for a variety of reasons. The City intends to begin replacing furnaces and hot water tanks with air-source heat pumps (ASHPs) and Heat Pump Water Heaters (HPWHs), respectively, for a five-year period as part of this program.

Natural Gas Furnace Replacement with an ASHP:

In order to calculate the total reduction in greenhouse gas (GHG) emissions as a result of furnace electrification, the following quantities are required:

1. Total expected number of furnaces to be replaced each year;
2. Average home size (in ft^2); and
3. Average furnace run time for the Rochester, NY area.

First, the amount of annual natural gas usage is calculated using the "Annual Fossil Fuel Energy Savings" equation provided in the New York State Technical Resource Manual, Version 11 (Effective January 1, 2024), p. 250. This equation provides a total annual consumption of natural gas, in million British Thermal Units (BTUs).

Next, it is assumed that this quantity of energy (in MMBtu) will be required to replace the existing furnace in-kind with an ASHP. The electricity consumed by an ASHP is calculated using the "Annual Electric Energy Savings" equation provided in the New York State Technical Resource Manual, Version 11 (Effective January 1, 2024), p. 250. This is calculated the amount of electricity required to heat an average house with an ASHP. Using pricing derived from Rochester Gas & Electric (RG&E), costs for operating the existing natural gas furnace and an in-kind ASHP can be calculated.

Finally, the total GHG emissions derived from operating the natural gas furnace versus emissions from generating electricity for the ASHP are calculated using conversion factors that are derived below. The GHG emissions from operation of a new ASHP are subtracted from the GHG emissions from operation of the existing furnace to derive the reduction in total GHG emissions. This difference is multiplied by the number of furnaces replaced annually to calculate the total reduction in GHG emissions as a result of this program.

<u>Natural Gas Water Heater Replacement with a HPWH:</u>
In order to calculate the total reduction in GHG emissions as a result of hot water tank electrification, the following parameters are required:

1. The total number of hot water tanks expected to be replaced each year;
2. The average hot water tank size; and
3. The average hot water tank usage in gallons per day.

First, the amount of annual natural gas usage is calculated using the "Annual Fossil Fuel Energy Savings" equation provided in the New York State Technical Resource Manual, Version 11 (Effective January 1, 2024), p. 137. This equation provides a total annual consumption of natural gas, in million British Thermal Units (BTUs).

Next, it is assumed that a similarly-sized HPWH will be installed to replace the existing natural gas hot water tank. The energy consumed by this new HPWH is calculated using the "Annual Electric Energy Savings" equation provided in the New York State Technical Resource Manual, Version 11 (Effective January 1, 2024), p. 136.

Costs to operate the existing natural gas water tank are compared to operating costs for the new HPWH using pricing derived from Rochester Gas & Electric (RG&E) for 2023. Finally, the total GHG emissions derived from operating the natural gas furnace versus emissions from generating electricity for the ASHP are calculated using conversion factors that are derived below. The GHG emissions from operation of a new ASHP are subtracted from the GHG emissions from operation of the existing furnace to derive the reduction in total GHG emissions. This difference is multiplied by the number of furnaces replaced annually to calculate the total reduction in GHG emissions as a result of this program.

Sources for the calculation inputs are provided below and correspond to the annotations in the "Project #2: Residential Clean Heating and Cooling Program" sheet. If the values provided are assumptions, these assumptions are clearly stated below. Each of these values are denoted in the calculation spreadsheet for Project #2.

<u>Program Parameters:</u>

1. Average furnace replacement rate, average hot water tank replacement rate, and average home size were all provided by the City of Rochester based on past data collected as part of the furnace and hot water tank replacement program.
2. Effects of insulation and air sealing are not incorporated into these calculations due to the high variability of these measures from house-to-house.

<u>Furnace Replacement Parameters:</u>

3. The typical building heat load is 25 British Thermal Units (BTU) per hour-ft^2;
    a. *ASSUMPTION:* This assumption is based on the assumed heating needs of a household in the Western New York region.
4. The Fossil Fuel Heating Factor ($F_{FuelHeat}$) is derived from the New York State (NYS) Technical Resource Manual (TRM), Version 11 (Effective January 1, 2024), "Heat Pump – Air Source (ccASHP)" Section (p. 250).
5. The Efficiency Rating of Fossil Fuel Heating Equipment ($Eff_{baseline}$) is derived from the NYS TRM Version 11, "Heat Pump – Air Source (ccASHP)" Section (p. 250).
    a. *ASSUMPTION*: The selected value assumes a warm air furnace, gas fired is currently in place and will be replaced as part of this program.
6. Heating Equivalent Full-Load Hours ($BEFLH_{heating}$) are derived from the NYS TRM Version 11, "Heat Pump – Air Source (ccASHP)" Section (p. 250).
    a. *ASSUMPTION*: The selected value is for Single-Family Dethatched Heating for an old building in Buffalo, NY (values for Rochester, NY are not provided). This is found on p. 261 of the NYS TRM Version 11, "Heat Pump – Air Source (ccASHP)" Section (p. 250).
7. The Adjustment Factor for Seasonal Heating Load ($F_{load,heating}$) is derived from the NYS TRM Version 11, "Heat Pump – Air Source (ccASHP)" Section (p. 250).
8. The Heating Load Fraction Modification (F_{ctrl}) is derived from the NYS TRM Version 11, "Heat Pump – Air Source (ccASHP)" Section (p. 250).
9. The Seasonally-Adjusted Coefficient of Performance ($COP_{season,baseline}$) is calculated using the equation provided on p. 255 of the NYS TRM, based on values for *HSPF* (Parameter #24 below) and the HSPF Climate Adjustment Factor (Parameter #12 below). Assumptions used to select these values are provided below.
10. The Coefficient of Performance of Energy-Efficient Equipment ($COP_{season,ee}$) is derived from the NYS TRM Version 11, "Heat Pump – Air Source (ccASHP)" Section (p. 250).
    a. *ASSUMPTION*: This value is calculated based on the assumption of Scenario 1d presented on p. 257 (Central ASHP, Ducted, Whole or Full Load, 1.0 HP Sizing Parameter).
11. The Electric Heating Factor ($F_{ElecHeat}$) is derived from the NYS TRM Version 11, "Heat Pump – Air Source (ccASHP)" Section (p. 250).
12. The New Electric Heating Factor ($F_{ElecHeat,new}$) is derived from the NYS TRM Version 11, "Heat Pump – Air Source (ccASHP)" Section (p. 250).
13. The HSPF Climate Adjustment Factor (F_{HSPF}) is derived from the NYS TRM Version 11, "Heat Pump – Air Source (ccASHP)" Section (p. 250).
    a. *ASSUMPTION*: This value is selected based on the selected *HSFP* value (Parameter #24 below) for Buffalo, NY.

<u>Hot Water Tank Replacement Parameters:</u>

14. The average existing hot water tank capacity is based on a typical hot water tank capacity for a single-family household.
    a. *ASSUMPTION*: This value is an assumption based on professional experience.
15. The average new hot water tank capacity is based on commercially available ASHPs approximately sized to existing hot water tank capacity.

    a. *ASSUMPTION:* This value is an assumption based on assumed tank size in #8 and commercially available ASHP hot water heaters.

16. The average daily hot water usage is based on a family of four, where 18.75 gal/person of hot water is used daily.
    a. *ASSUMPTION*: This value is an assumption based on professional experience.
17. Change in Water Temperature (ΔT_{main}) is derived from the NYS TRM Version 11, "Heat Pump Water Heater (HPWH) – Air Source" Section (p. 136).
    a. *ASSUMPTION*: This value assumes that water will be heated to 125°F from the average water main temperature of 55.1°F in Buffalo, NY (found on p. 296 of the NYS TRM).
18. Fossil Fuel Water Heating Factor (F_{FFDHW}) is derived from the NYS TRM Version 11, "Heat Pump Water Heater (HPWH) – Air Source" Section (p. 136).
19. The Uniform Energy Factor ($UEF_{baseline}$) for a natural gas-fueled tank is derived from the NYS TRM Version 11, "Heat Pump Water Heater (HPWH) – Air Source" Section (p. 136).
    a. *ASSUMPTION*: This value is based on the assumption that the existing gas-fired storage water heater has a rated storage volume and input rating greater than or equal to 20 gallons and less than or equal to 55 gallons and is utilizing a "high" draw pattern. This is found on p. 183 of the NYS TRM.
20. The Annual Fuel Utilization Efficiency (*AFUE*) is derived from the NYS TRM Version 11, "Heat Pump Water Heater (HPWH) – Air Source" Section (p. 136).
    a. *ASSUMPTION*: AFUE assumed to be 0.80 based on a warm air furnace, gas fired on p. 143 of the NYS TRM.
21. The Uniform Energy Factor (UEF_{ee}) for a HPWH is derived from typical values for 59 gallon capacity, ENERGY STAR-certified units.
    a. *ASSUMPTION*: This value is assumed based on available ENERGY STAR-certified units.
22. The Installation Location Factor (F_{loc}) is derived from the NYS TRM Version 11, "Heat Pump Water Heater (HPWH) – Air Source" Section (p. 136).
    a. *ASSUMPTION*: This value assumes that the HPWH will be installed in a conditioned space.
23. The Heating Factor (F_{heat}) is derived from the NYS TRM Version 11, "Heat Pump Water Heater (HPWH) – Air Source" Section (p. 136).
    a. *ASSUMPTION*: This value is based on the value for Buffalo, NY (no value listed for Rochester, NY) found on p. 141 of the NYS TRM.
24. The Electric Water Heating Factor (F_{eDHW}) is derived from the NYS TRM Version 11, "Heat Pump Water Heater (HPWH) – Air Source" Section (p. 136). This is assigned a value of 0, as houses where a HWHP will be installed do not currently have water heated with electricity.
25. The Efficiency Derating Factor (F_{derate}) is derived from the NYS TRM Version 11, "Heat Pump Water Heater (HPWH) – Air Source" Section (p. 136). This is assigned a value of 1, as HWHP installations are expected to be installed in conditioned locations.
26. The Heating Seasonal Performance Factor (*HSPF*) is derived from the NYS TRM Version 11, "Heat Pump Water Heater (HPWH) – Air Source" Section (p. 136). This is assigned a value of 8.2 based on the guidance provided on p. 139 of the NYS TRM.
27. The HSPF Climate Adjustment Factor (F_{HSPF}) is derived from the
28. The Cooling Factor (F_{cool}) is derived from the NYS TRM Version 11, "Heat Pump Water Heater (HPWH) – Air Source" Section (p. 136).

    a. *ASSUMPTION:* This value is based on the cooling factor for Buffalo, NY (no value listed for Rochester, NY) found in p. 141 of the NYS TRM.

29. The Seasonal Energy Efficiency Ratio (*SEER*) is derived from the NYS TRM Version 11, "Heat Pump Water Heater (HPWH) – Air Source" Section (p. 136). This is assigned a value of 13 based on the guidance provided on p. 139 of the NYS TRM.

Energy Cost Inputs:

30. Electric rate per kWh is based on 12-month average supply rate for Residential customers (SC 1) from Rochester Gas & Electric (RG&E) from January 1, 2023 through December 31, 2023.
    a. ASSUMPTION: This value assumes that equipment will operate equally during off-peak and on-peak times.
31. Natural gas rate per therm is based on a 12-month average supply rate from RG&E from January 1, 2023 through December 31, 2023. The rate selected is based on an average of Residential (SC 1) off-peak rates and Residential on-peak (SC 4) rates.

Conversion Factors:

32. Conversion factor from BTU to kilowatt-hours (kWh) is derived from the NYS TRM Version 11, "Heat Pump Water Heater (HPWH) – Air Source" Section (p. 136) and "Heat Pump – Air Source (ccASHP)" Section (p. 759).

Project #3 – Municipal Rooftop Solar

Under this project, the City intends to install solar arrays on the rooftops of municipal buildings to help offset their electricity consumption and reduce GHG emissions from traditional electricity generation. The City has identified the following building/properties where they would like to install roof-mounted solar arrays:

- Blue Cross Arena – *One War Memorial Square, Rochester, NY 14614* (125,000 ft^2)
- Rochester Riverside Convention Center – *123 E. Main St., Rochester, NY 14614* (57,700 ft^2)
- Public Safety Building – *185 Exchange Blvd., Rochester, NY 14614* (29,000 ft^2)

In order to calculate the total energy produced and total reduction in GHG emissions from installation of a proposed solar array, the following quantities are needed:

1. Total available rooftop area at each facility;
2. Percentage of rooftop area available for solar array;
3. Average panel efficiency for Rochester, NY, including losses; and
4. Average daily available sunlight for solar generation in Rochester, NY.

Values #1 and #2 were provided by the City of Rochester and reasonable assumptions for total available roof area were made for each facility. Values #3 and #4 were provided by GreenSpark Solar, a solar developer based in the Rochester, NY area that has extensive experience with solar installations in Western New York. These four values are denoted in the calculation spreadsheet for Project #3. Using these assigned values, the calculations provided in Program #1 were utilized to determine overall system capacity, annual power generated, annual GHG emissions reduction, and average annual energy cost savings for each facility.

The following assumptions were made when calculating the above values:

- *Panel Efficiency*: 17.50 W/ft^2
  - This value was obtained from GreenSpark Solar, a solar company that has partnered with the City of Rochester.
  - *ASSUMPTION*: This panel efficiency value accounts for system losses due to wiring, DC/AC conversion, shading, and other losses.
- *Average Hours of Usable Sunlight/Day*: 3.42 hr/day
  - This value is was provided from GreenSpark Solar and checked using the NREL PVWatts calculator.
- *Array Type*: Fixed Tilt

Project #4 – Solid Waste Management Facility Sustainable Upgrades

This program includes sustainable upgrades at the Solid Waste Management Facility (210 Colfax St., Rochester, NY; "target facility") which includes installation of a rooftop solar array, replacing the existing boiler system and window air-conditioning (AC) units with a ground-source heat pump (GSHP), insulating the building envelope to improve heating and cooling retention, installing high-efficiency windows, and installing new LED lighting throughout the complex.

Rooftop solar electricity generation and GHG emissions were calculated using the same process as Project #3. Effects of insulation and air sealing are not incorporated into these calculations due to large portions of the facility being a relatively open garage that services trucks for the City.

In order to calculate GHG emissions reductions by transitional from the natural gas boiler and window AC units to a GSHP, conservation-of-energy calculations were utilized using existing natural gas usage and electricity usage for the target facility. The following variables were used to calculate GHG emissions reductions from heating and cooling:

1. Available natural gas usage data for the target facility from 2022 – 2023;
2. Available electricity usage data for the target facility from 2022 – 2023;
3. Required cooling capacity for the office portion of the target facility;
4. Typical coefficient of performance (COP) for heating for a GSHP;
5. Typical COP for cooling for a GSHP;
6. Existing AC unit COP;
7. Cooling equivalent full-load hours (value from NYS TRM for warehouse; Buffalo, NY)
8. Office space footprint (ft^2); and
9. Overall building footprint (ft^2).

The following assumptions were made when calculating overall GHG emissions reduction as part of GSHP installation:

1. All natural gas usage for 2022 – 2023 at the facility was used for building heating purposes.
2. Natural gas usage for 2022 – 2023 was used to heat the entire building footprint of 45,400 ft^2. Natural gas usage was consistent per square foot for the facility.
3. The new GSHP will be used for heating and cooling in the office space at the building only (approximately 15,000 ft^2 total).

4. Coefficients of performance (COP) were obtained using a 40-ton (480,000 BTU/hr) central GSHP to replace the existing boiler system for office space heating.
    a. GSHP model used is a Nordic W-500 Ground Loop Cooling GSHP (40-ton nominal size).
5. Building cooling load for the office space portion of the building is 480,000 BTU/hr, provided by a buildings engineering consultant for the City of Rochester.
6. Cooling equivalent full-load hours are estimated for a low-rise office building, Zone 5A, built post-1980. These values were obtained from the NYS TRM Version 11, "Operating Hours" table, p. 805.
7. Natural gas heating systems will remain in place for the garage portions of the target facility.
8. The COP for existing AC units is assumed to be 2.5.

GHG emissions from natural gas usage for the target facility are calculated by dividing the office space square footage by the overall building square footage, then multiplying this by the overall annual natural gas usage for 2022 – 2023. This is calculated to be the heating requirement for the office space portion of the facility. Next, this natural gas usage is converted to equivalent kWh by dividing required BTU by 3,412 BTU/kWh:

$$Equivalent\ Electrical\ Energy\ (Heat)\ [kWh] = \frac{Natural\ Gas\ Usage\ [BTU]}{3{,}412\ BTU/kWh}$$

Finally, the equivalent electricity usage to heat the office space of the building is calculated using the coefficient of performance (heating) for the selected typical GSHP (listed above):

$$GSHP\ Heating\ Energy\ [kWh] = \frac{Equivalent\ Electrical\ Energy\ (Heat)\ [kWh]}{COP_{heat}}$$

Next, the total electricity usage at the facility (including lighting, cooling, and other functions) was provided and therefore the fraction of electricity currently used for office space cooling must be estimated. The total electrical demand for cooling is calculated using the following equation:

$$Equivalent\ Electrical\ Energy\ (Cool)\ [kWh] = \frac{Building\ Cooling\ Load\ \left[\frac{BTU}{hr}\right] x\ Cooling\ Equivalent\ Full\ Load\ Hours\ [hr]}{3{,}412\ BTU/kWh}$$

This equivalent electrical energy dedicated to cooling is then multiplied by the fraction of building dedicated to office space divided by the total building area. Finally, this equivalent electrical energy is divided by the assumed COP for existing AC units to calculate the power used to cool the office space under existing conditions.

Finally, the new energy required to cool the office space is calculated using the Equivalent Electrical Energy (Cool) calculation above. This value is then divided by the new COP for the GSHP and is multiplied by the office space area over the total building area. This value is the new power demand to cool the office space using the GSHP.

In order to calculate the total projected energy reduction and projected GHG emissions reduction from LED lighting installation, the following quantities are needed:

1. Reduction in energy usage from existing bulb to proposed bulb;

2. Number of bulbs to be replaced;
3. Average annual operation time of bulbs;
4. Average GHG emissions produced from utilizing energy in the Rochester, NY region; and
5. Average cost of electricity per kilowatt-hour (kWh) in Rochester, NY.

Values for #1, #2, and #5 were provided by the City of Rochester. The following assumptions were made when determining values for #3 and #4:

- Average annual operation time of bulbs is assumed to be 12 hours per day, 6 days per week, 52 weeks per year for a total of 3,744 hours.
- Average GHG emissions assumptions are presented at the beginning of this section.

Once these values were obtained, the following calculations were performed:

- For each type of existing lightbulb to be replaced, the difference in energy reduction was calculated:

$$Energy\ Reduction\ [W] = Existing\ Bulb\ [W] - New\ LED\ Bulb\ [W]$$

- Next, energy reduction was multiplied by the number of bulbs to be replaced to get the total wattage reduction per type of bulb replaced:

$$Wattage\ Reduction\ [W] = (Energy\ Reduction[W])(No. Bulbs\ Replaced)$$

- Next, the total annual energy reduction per type of bulb replaced was calculated:

$$Annual\ Energy\ Reduction\ [kWh] = (Wattage\ Reduction\ [W])(Annual\ Operation\ Time\ [hr])$$

- Finally, the total annual GHG emissions reduction was calculated:

$$Annual\ GHG\ Reduction\ [mmtCO_2e] = (Annual\ Energy\ Reduction\ [kWh])(GHG\ Emissions\ Factor\ [\frac{mmtCO_2e}{kWh}]$$