California Air Resources Board

California Climate Investments Quantification Methodology Emission Factor Database Documentation

Appendix B: Energy Efficiency and Clean Energy

Note:
This document accompanies the California Climate Investments Quantification Methodology Emission Factor Database available on the California Climate Investments resources webpage. This document explains how emission factors used in California Air Resources Board (CARB) quantification methodologies are developed and updated.

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List of Acronyms and Abbreviations

Acronym	Term
Btu	British Thermal Unit
CARB	California Air Resources Board
CEC	California Energy Commission
CFC	Chlorofluorocarbon
CFR	Code of Federal Regulations
CH_4	Methane
CO_2e	Carbon Dioxide Equivalent
Database	California Climate Investments Quantification Methodology Emission Factor Database
°F	Degree Fahrenheit
g	Gram
gal	Gallon
GHG	Greenhouse Gas
GWP	Global Warming Potential
HCFC	Hydrochlorofluorocarbon
HFC	Hydrofluorocarbon
HVAC	Heating, Ventilation, and Air Conditioning
IPCC	Intergovernmental Panel on Climate Change
kg	Kilogram
kWh	Kilowatt-hour
lb	Pound
MJ	Megajoule
MMBtu	Million British Thermal Units
MT	Metric Ton
MWh	Megawatt-hour
NO_2	Nitrogen Dioxide
NOx	Oxides of Nitrogen
$PM_{2.5}$	Particulate Matter that have a Diameter Less than 2.5 Micrometers
PM_{10}	Particulate Matter that have a Diameter Less than 10 Micrometers
ROG	Reactive Organic Gas
scf	Standard Cubic Feet
U.S. EIA	United States Energy Information Administration
U.S. EPA	United States Environmental Protection Agency
Wh	Watt-hour

Introduction

The California Climate Investments Investment Plan identifies energy efficiency and renewable energy as one of its priority investment areas, reducing emissions from stationary sources both upstream and downstream. Core strategies for reducing emissions include increasing energy and water efficiency to reduce the need for energy generation, transitioning away from natural gas, and installing renewable energy generation and energy storage to avoid the use of fossil fuels. However, there are other emerging strategies such as reducing the use of high global warming potential (GWP) hydrofluorocarbon (HFC) gases, used in refrigeration and air conditioning, and innovative strategies to reduce the embedded emissions associated with building construction and materials. These methods of building decarbonization for the residential, commercial, and industrial sectors are an emerging priority for the state.

This document outlines the generalized calculation approaches used by the suite of California Climate Investments programs to quantify greenhouse gas and air pollutant emission reductions from projects characterized as contributing towards energy efficiency and clean energy for stationary uses. For more details about how the emission factors are used in specific quantification methodologies and accompanying benefit calculator tools tailored to each California Climate Investments program, the quantification methodologies are available on the California Climate Investments resources webpage. The CARB quantification methodologies estimate both GHGs and select co-benefits utilizing project-specific inputs and emission factors specific to the type of project being quantified. When appropriate, CARB quantification methodologies use the same emission factors across project types.

Energy Efficiency and Clean Energy

Investments in the Energy Efficiency and Clean Energy sector reduce GHG emissions primarily via reducing energy demand and/or reducing or displacing fossil fuel use.

Emission Factor Documentation

CARB has developed emission factors to estimate both GHG emission reductions and select criteria and toxic air pollutant emission co-benefits. Methods used to develop emission factors used in Energy Efficiency and Clean Energy sector CARB quantification methodologies are described on the subsequent pages. Emission factors for the following sources are currently included in the Database:

- Grid Electricity
- Natural Gas Combustion
- Propane Combustion
- Woodsmoke Reduction
- Refrigerants

Grid Electricity

Grid electricity emission factors are used in the quantification methodologies for the California Climate Investments programs named in Table 1.

Table 1. Programs Using Grid Electricity Emission Factors

Agency	Program
California Air Resources Board	Low Carbon Transportation Program – Clean Mobility Options
California Air Resources Board	Low Carbon Transportation Program – Clean Mobility in Schools Pilot Project
California Conservation Corps	Energy Corps
California Department of Community Services and Development	Community Solar Pilot Program
California Department of Community Services and Development	Low-Income Weatherization Program
California Department of Food and Agriculture	Dairy Digester Research and Development Program
California Department of Forestry and Fire Protection	Forest Health Program
California Department of Forestry and Fire Protection	Urban and Community Forestry Program
California Department of Resources Recycling and Recovery	Food Waste Prevention and Rescue Program
California Department of Resources Recycling and Recovery	Organics Grant Program
California Department of Resources Recycling and Recovery	Recycled Fiber, Plastics, and Glass Grant Program
California Energy Commission	Food Production Investment Program
California Energy Commission	California Schools Healthy Air, Plumbing, and Efficiency Program
California Energy Commission	Low Carbon Fuel Production Program
California Energy Commission	Renewable Energy for Agriculture Program
California Natural Resources Agency	Urban Greening Program
Strategic Growth Council	Affordable Housing and Sustainable Communities Program

GHG Emission Factors

For the purposes of California Climate Investments quantification methodologies, CARB developed a California grid average electricity GHG emission factor based on total in-state and imported electricity emissions (in $MTCO_2e$) divided by total consumption (in kWh) as calculated in Equation 1.

Statewide electricity emissions data were obtained from the most recent edition of CARB's GHG Emission Inventory. The total in-state electricity generation is combined with the total imported electricity to determine the total emissions for grid electricity. The total electricity consumption data was derived by summing electricity generation and imports obtained from the CEC's California Energy Almanac.

Equation 1: California Grid Average Electricity Emission Factor

$$EF = \frac{Electricity\ Emissions}{Electricity\ Consumption}$$

Where,			Units
EF	=	California grid average electricity emission factor	$MTCO_2e/kWh$
Electricity Emissions	=	Total in-state electricity and imported electricity emissions	$MTCO_2e$
Electricity Consumption	=	Total California electricity generation and imports	kWh

Equation 1. The GHG emission factor for California grid average electricity is calculated as the total in-state electricity and imported electricity emissions divided by the total California amount of electricity generated and imported.

See the "Grid Electricity" tab of the Database for specific emission factors.

Criteria Pollutant Emission Factors

CARB developed and applied a California average grid emission factor (in $MTCO_2e$ per MWh) to quantify GHG emission reductions associated with decreased electricity consumption. A U.S. EPA GHG inventory natural gas emission factor is used to quantify GHG emission reductions associated with decreased natural gas consumption. The California average grid emission factor used data from CARB’s GHG inventory to identify the relevant CO_2e emissions and CEC’s Energy Almanac to identify the relevant MWh generated. Both of these data resources provide a complete picture of California’s electricity grid consisting of both in-state electricity generated and imported electricity.

While methods used to develop the GHG emission factor for grid electricity account for both in-state generated and imported electricity, criteria pollutant emission factors are estimated using only criteria pollutant emissions data for only in-state generation of electricity due to the localized impacts of criteria pollutants in comparison to the global impacts of GHG emissions. Like the GHG emission factor, consumption data for in-state generation were obtained from the CEC Energy Almanac and criteria pollutant emissions data were obtained from CARB's Criteria Pollutant Emissions Inventory.

See the “Grid Electricity” tab of the Database for specific emission factors.

Natural Gas Combustion

Natural gas combustion emission factors are used in the quantification methodologies for the California Climate Investments programs named in Table 2.

Table 2. Programs Using Natural Gas Combustion Emission Factors

Agency	Program
California Department of Community Services and Development	Low-Income Weatherization Program
California Department of Forestry and Fire Protection	Urban and Community Forestry Program
California Department of Resources Recycling and Recovery	Organics Grant Program
California Energy Commission	California Schools Healthy Air, Plumbing, and Efficiency Program
California Energy Commission	Food Production Investment Program
California Energy Commission	Low Carbon Fuel Production Program
California Natural Resources Agency	Urban Greening Program

GHG Emission Factors

The GHG emission factor for natural gas was derived from the U.S. EPA's Emission Factors for Greenhouse Gas Inventories. Emissions of CO_2, CH_4, and N_2O from natural gas were converted to CO_2e by using the global warming potentials from the IPCC Fourth Assessment Report.

See the "Natural Gas" tab of the Database for specific emission factors.

Criteria Pollutant Emission Factors

CARB derived criteria pollutant emission factors for natural gas combustion based on U.S. EPA's AP 42 Table 1.4-1 factors for various sized natural gas boilers and residential heating sources.

Note: ROG emission factors were derived using the speciation of organic compounds list in Table 1.4-3 in AP 42 and removing the compounds consistent with the CARB definition of ROG.

See the "Natural Gas" tab of the Database for specific emission factors.

Propane Combustion

Propane combustion emission factors are used in the quantification methodologies for the California Climate Investments programs named in Table 3.

Table 3. Programs Using Propane Combustion Emission Factors

Agency	Program
California Strategic Growth Council	Sustainable Agricultural Lands Conservation Program
California Wildlife Conservation Board	Climate Adaptation Readiness Program

GHG Emission Factors

The GHG emission factor for propane was derived from the U.S. EPA's Emission Factors for Greenhouse Gas Inventories. Emissions of CO_2, CH_4, and N_2O from propane were converted to CO_2e by using the global warming potentials from the IPCC Fourth Assessment Report.

See the "Propane" tab of the Database for specific emission factors.

Criteria Pollutant Emission Factors

CARB derived criteria pollutant emission factors for propane combustion based on U.S. EPA's AP 42 Table 1.5-1 factors for various sized propane boilers.

Note: ROG emission factors were derived using the speciation of organic compounds list in Table 1.4-3 in AP 42 and removing the compounds consistent with the CARB definition of ROG.

See the "Propane" tab of the Database for specific emission factors.

Woodsmoke Reduction

Woodsmoke Reduction emission factors are used in the quantification methodologies for the California Climate Investments programs named in Table 4.

Table 4. Programs Using Woodsmoke Reduction Emission Factors

Agency	Program
California Air Resources Board	Woodsmoke Reduction Program

GHG Emission Factors

Woodsmoke reduction annual household heating energy data were obtained from *U.S. EIA* *Residential Energy Consumption Survey Consumption and Energy Table 3.5* and *U.S. Census Bureau* *American Community Survey 1-Year Estimates* for California house heating fuel. Stove efficiencies were derived from *U.S. EIA* *Heating Fuel Comparison Calculator*, *U.S. Department of Energy* *Electric Resistance Heating*, and *U.S. EPA* *AP-42 Table 1.10-5*.

CARB first derived the California average household heating energy need if heating devices were 100% efficient using Equation 2.

Equation 2: California Average Household Heating Energy Need if Devices is 100% Efficient

$$HH_{MMBtu} = \frac{HHEC}{HHE}$$

Where,			Units
HH_{MMBtu}	=	California average household heating energy need assuming 100% device efficiency	MMBtu/ household/year
HHEC	=	California average household heating energy consumption	MMBtu/ household/year
HHE	=	California average household heating device efficiency	percent

Equation 2. The California average household heating energy need is calculated as the California average household heating energy consumption divided by the California average household heating device efficiency.

Annual household energy use required for each heating device is calculated using Equation 3.

Equation 3: Annual Household Energy Use for Home Heating Devices

$$EU_{device} = \frac{HH_{MMBtu}}{DE}$$

Where,			Units
EU_{device}	=	Energy use for home heating device type per year	MMBtu/ household/year
HH_{MMBtu}	=	California average household heating energy need assuming 100% device efficiency	MMBtu/ household/year
DE	=	Device type efficiency expressed as a percentage for all types	percent

Equation 3. The annual energy use for home heating devices is calculated as the California average annual household heating energy divided by the efficiency of the device type.

GHG emission factors were obtained from the U.S. EPA 40 CFR Part 98, *2013 Revisions to the Greenhouse Gas Reporting Rule and Final Confidentiality Determinations for New or Substantially Revised Data Elements*. Global Warming potentials for GHGs were derived from *CARB Global Warming Potentials*. CARB derived the GHG emission factors by device-type using Equation 4 – Equation 8.

Equation 4: GHG Emission Factors for Fireplaces, Certified & Uncertified Wood Stoves or Inserts, and Certified Pellet Stoves or Inserts

$$GHG_{fwp} = \left(\frac{EU_{device} \times CO_2 \times GWP_{CO2} + EU_{device} \times N_2O \times GWP_{N2O} + EU_{device} \times CH_4 \times GWP_{CH4}}{1{,}000} \right) \times Years$$

Where,			Units
GHG_{fwp}	=	Device-specific GHG emission factor for fireplace, certified and uncertified wood stoves or inserts, and certified pellet stoves or inserts	$MTCO_2e$
EU_{device}	=	Energy use for home heating device type per year	MMBtu/ household/year
CO_2	=	CO_2 emissions from device-specific fuel combustion	kg/MMBtu
N_2O	=	N_2O emissions from device-specific fuel combustion	kg/MMBtu
CH_4	=	CH_4 emissions from device-specific fuel combustion	kg/MMBtu
GWP_{CO2}	=	Global warming potential for CO_2	CO_2e
GWP_{N2O}	=	Global warming potential for N_2O	CO_2e
GWP_{CH4}	=	Global warming potential for CH_4	CO_2e
1,000	=	Conversion factor for kilograms to metric ton	kg/MT
Years	=	Quantification period for new device	years

Equation 4. The device-specific GHG emission factor for fireplace, certified and uncertified wood stoves or inserts, and certified pellet stoves or inserts is calculated as the quantification period multiplied by half the sum of GHG emissions from carbon dioxide, nitrous oxide, and methane. The GHG emissions from carbon dioxide, nitrous oxide, and methane are each calculated by multiplying their respective emissions by their global warming potential.

Equation 5: GHG Emission Factors for Certified Non-catalytic, Hybrid, or Catalytic Wood Stoves or Inserts

$$GHG_{ncc} = \left(\frac{EU_{device} \times CO_2 \times GWP_{CO2} + EU_{device} \times N_2O \times GWP_{N2O} + EU_{device} \times CH_4 \times (1 - RED_{CH4}) \times GWP_{CH4}}{1{,}000} \times Years \right)$$

Where,			Units
GHG_{ncc}	=	Device-specific GHG emission factor for certified non-catalytic or catalytic stoves or inserts	$MTCO_2e$
EU_{device}	=	Energy use for home heating device type per year	MMBtu/ household/year
CO_2	=	CO_2 emissions from device-specific fuel combustion	kg/MMBtu
N_2O	=	N_2O emissions from device-specific fuel combustion	kg/MMBtu
CH_4	=	CH_4 emissions from device-specific fuel combustion	kg/MMBtu
RED_{CH4}	=	CH_4 emissions reduction for switch to certified non-catalytic or catalytic wood stove	percent
GWP_{CO2}	=	Global warming potential for CO_2	CO_2e
GWP_{N2O}	=	Global warming potential for N_2O	CO_2e
GWP_{CH4}	=	Global warming potential for CH_4	CO_2e
1,000	=	Conversion factor for kilograms to metric ton	kg/MT
Years	=	Quantification period for new device	years

Equation 5. The device-specific GHG emission factor for certified non-catalytic, hybrid, or catalytic stoves or inserts is calculated as the quantification period multiplied by half the sum of GHG emissions from carbon dioxide, nitrous oxide, and methane. The GHG emissions from carbon dioxide, nitrous oxide, and methane are each calculated by multiplying their respective emissions by their global warming potential. However, methane emission are also multiplied by the one minus the percentage of methane emissions reductions for switching to a certified non-catalytic, hybrid, or catalytic wood stove.

Equation 6: GHG Emission Factors for Electric Heat Pump

$$GHG_{hp} = \left(\frac{EU_{device} \times CO_2e}{1{,}000} + REFR\right) \times Years$$

Where,			Units
GHG_{hp}	=	Device-specific emission factor for electric heat pump	$MTCO_2e$
EU_{device}	=	Energy use for stove per household per year	MMBtu/ household/year
CO_2e	=	CO_2e emissions for electricity usage	kg CO_2e/MMBtu
REFR	=	Electric heat pump refrigerant emissions	$MTCO_2e$/year
1,000	=	Conversion factor for kilograms to metric ton	kg/MT
Years	=	Quantification period for new device	years

Equation 6. The device-specific GHG emission factor for electric heat pump is calculated as the quantification period multiplied by half the sum of heat pump refrigerant emissions and stove electricity emissions. Stove electricity emissions is calculated as the energy use for stove per household per year multiplied by the carbon dioxide equivalent emission factor for electricity usage.

Equation 7: GHG Emissions from Refrigerant Use in Electric Heat Pump

$$REFR = \left(\frac{Leak \times Charge \times GWP_{REFR}}{2{,}204.623}\right)$$

Where,			Units
REFR	=	Electric heat pump refrigerant emissions	$MTCO_2e$/year
Leak	=	Annual refrigerant leak rate of electric heat pump	percent
Charge	=	Refrigerant charge size	lbs
GWP_{REFR}	=	Electric heat pump refrigerant emissions	CO_2e
2,204.623	=	Conversion factor for pounds to metric ton	lbs/MT

Equation 7. The ductless mini-split heat pump refrigerant GHG emissions is calculated as the multiplication of annual refrigerant leak rate of electric heat pump, refrigerant charge size, and the electric heat pump refrigerant emissions.

Equation 8: GHG Emission Factors for Electric, Propane, and Natural Gas Home Heating Devices

$$GHG_{epn} = \left(\frac{EU_{device} \times CO_2e}{1,000}\right) \times Years$$

Where,			Units
GHG_{epn}	=	Device-specific emission factor for electric device	$MTCO_2e$
EU_{device}	=	Energy use for stove or insert per household per year	MMBtu/ household/year
CO_2e	=	CO_2e emissions for electricity usage	kg CO_2e/MMBtu
1,000	=	Conversion factor for kilograms to metric ton	kg/MT
Years	=	Quantification period for new device	years

Equation 8. The device-specific GHG emission factor for electric devices is calculated as the quantification period multiplied by half the product of energy use for stove or insert per household per year and the carbon dioxide equivalent emissions for electricity usage.

See the "Woodsmoke Reduction" tab of the Database for specific emission factors.

Criteria Pollutant Emission Factors

Criteria pollutant emissions factors for wood burning devices were calculated based on the amount of wood use for each home heating device type. For wood burning home heating devices, the quantity of wood used per year was calculated using Equation 9.

Equation 9: Annual Wood Use

$$WU_{device} = \frac{EU_{device}}{HV}$$

Where,			Units
WU_{device}	=	Wood use per year for wood burning devices	tons/ household/year
EU_{device}	=	Energy use for home heating device per year	MMBtu/ household/year
HV	=	Heating value of wood or wood pellets	MMBtu/dry ton

Equation 9. The annual wood use for wood burning devices is calculated as the Energy use for home heating device per year from Equation 3 multiplied by the heating value of wood or wood pellets.

$PM_{2.5}$ emission factors for wood burning home heating devices were calculated based on PM_{10} emission factors obtained from the *CARB Methodology for Residential Wood Combustion* and *U.S. EPA Regulatory Impact Analysis for Residential Wood Heaters*. CARB derived the $PM_{2.5}$ emission factors by device-type using Equation 10.

Equation 10: $PM_{2.5}$ Emission Factors from for Wood Burning Devices

$$PM_{device} = (WU_{device} \times PM_{10} \times F_{PM2.5} \times 50\%) \times Years$$

Where,			Units
PM_{device}	=	Device-specific $PM_{2.5}$ emission factor for wood burning device type	lbs
WU_{device}	=	Wood use per year for wood burning devices	ton/household/year
PM_{10}	=	PM_{10} emissions from wood combustion	lb/ton
$F_{PM2.5}$	=	$PM_{2.5}$ as a fraction of PM_{10}	percent
50%	=	50% discount for assumed household heating runtime	percent
Years	=	Quantification period for new device	years

Equation 10. The device-specific PM2.5 emission factor for a wood burning device type is calculated as half of the multiplication of the annual wood use, PM10 emission factor for wood combustion, the PM2.5 fraction of PM10, and the quantification period.

Black carbon emission factors for wood burning home heating devices were calculated based on $PM_{2.5}$ emission factors using Equation 11.

Equation 11: Black Carbon Emission Factors for Wood Burning Devices

$$BC_{device} = (PM_{device} \times F_{BC})$$

Where,			Units
BC_{device}	=	Device-specific black carbon emission factor for wood burning device type	lbs
PM_{device}	=	Particulate emission factor for all stove types	lbs
F_{BC}	=	Black carbon as a fraction of $PM_{2.5}$	percent

Equation 11. The device-specific black carbon emission factor for a wood burning device type is calculated as the particulate emission factor for all stove types multiplied by the black carbon fraction of PM2.5.

NO_x emission factors were obtained from the *CARB Methodology for Residential Wood Combustion* and *U.S. EPA AP-42 Section 1.5 Table 1.5-1*. CARB derived the NOx emission factors for wood burning home heating devices using Equation 12.

Equation 12: NO_x Emission Factors for Wood Burning Devices

$$NOx_{device} = (WU_{device} \times NO_x \times 50\%) \times Years$$

Where,			Units
NOx_{device}	=	Device-specific NO_x emission factor for wood burning device type	lbs
WU_{device}	=	Wood use per year for wood burning devices	ton/household/year
NO_x	=	NO_x emissions from wood combustion	lb/ton
50%	=	50% discount for assumed household heating runtime	percent
Years	=	Quantification period for new device	years

Equation 12. The device-specific NOx emission factor for a wood burning device type is calculated as half of the multiplication of the annual wood use, NOx emission factor for wood combustion, and the quantification period.

ROG emission factors were obtained from the *CARB Methodology for Residential Wood Combustion* and *U.S. EPA AP-42 Section 1.5 Table 1.5-1*. CARB derived the ROG emission factors for wood burning home heating devices using Equation 13.

Equation 13: ROG Emission Factors for Wood Burning Devices

$$ROG_{device} = (WU_{device} \times ROG \times 50\%) \times Years$$

$$ROG_{device} = (WU_{device} \times ROG \times 50\%) \times Years$$

Where,			Units
ROG_{device}	=	Device-specific ROG emission factor for wood burning device type	lbs
WU_{device}	=	Wood use per year for wood burning devices	ton/household/year
ROG	=	ROG emissions from wood combustion	lb/ton
50%	=	50% discount for assumed household heating runtime	percent
Years	=	Quantification period for new device	years

Equation 13. The device-specific ROG emission factor for a wood burning device type is calculated as half of the multiplication of the annual wood use, ROG emission factor for wood combustion, and the quantification period.

Note: While not identical, for the purposes of this estimation, VOC is used as a surrogate for ROG as there are only minor variations of exempted pollutants between the two terms.

See the "Woodsmoke Reduction" tab of the Database for specific emission factors.

Refrigerants

Refrigerant emission factors are used in the quantification methodologies for the California Climate Investments programs named in Table 5.

Table 5. Programs Using Refrigeration Emission Factors

Agency	Program
California Air Resources Board	F-Gas Reduction Incentive Program
California Department of Community Services and Development	Low-Income Weatherization Program
California Department of Resources Recycling and Recovery	Organics Grant Program

GHG Emission Factors

All refrigerants are considered to be greenhouse gases, but each refrigerant compound can impact the atmosphere to varying extents. The magnitude of how destructive a climate pollutant is, is measured by the refrigerant's Global Warming Potential, or GWP. The GWP of a gas refers to the total contribution to global warming resulting from the emission of one unit of that gas relative to one unit of the reference gas, CO_2, which is assigned a value of 1. GWPs can also be used to define the impact greenhouse gases will have on global warming over different time periods or time horizons. A time horizon of 100 years is used by regulators, including CARB. Global Warming Potentials are sourced from CARB's table of refrigerant GWPs, derived from the Intergovernmental Panel on Climate Change's (IPCC's) fourth and fifth Assessment Reports on climate change. Chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), and hydrofluorocarbons (HFCs) are examples of refrigerants that are highly potent greenhouse gases, which are typically thousands of times more potent than carbon dioxide.

Thus, the escape or release of refrigerants from refrigeration systems and heating, ventilation, and air conditioning (HVAC) systems directly contribute to significant GHG emissions. Potential ways to reduce GHG emissions from refrigeration and HVAC systems include the installation of or conversion to an ultra-low Global Warming Potential (GWP) refrigeration system or retrofit to a lower-GWP refrigerant, as well as via energy efficiency improvements.

Refrigerant GHG emissions from the refrigeration system include emissions from refrigerant leakage over the system's lifetime and end-of-life refrigerant leakage, as shown in Equation 14. Lifetime refrigerant leakage occurs over a refrigeration system's lifetime during its operation as well as during servicing and maintenance, while end-of-life emissions occur when refrigeration systems reach the end of their life. For refrigeration systems that are combined with a heating, ventilation, and air conditioning (HVAC) system, the HVAC system refrigerants are added into the calculation. Default assumptions for refrigerant leakage and charge are obtained from CARB's Emission Inventory Methodology and Technical Support Document for California's High Global Warming Potential Gases Emission Inventory.

Equation 14: GHG Emissions from Refrigerants

$$E_{GHG} = \frac{[(RC \times GWP \times LR \times Q) + (RC \times GWP \times PLC)]}{2{,}205}$$

Where,			Units
E_{GHG}	=	GHG emissions from refrigeration or HVAC system	$MTCO_2e$
RC	=	Refrigeration or HVAC system charge	lb
GWP	=	Global Warming Potential of the refrigerant	lb-CO_2e/lb
LR	=	Refrigerant annual leakage rate	percent/yr
Q	=	Quantification period of the project	years
PLC	=	Refrigeration or HVAC system end-of-life leakage	percent
2,205	=	Conversion factor from pounds to metric tons	lb/MT

Equation 14. GHG emissions from the refrigeration or HVAC systems are estimated as the sum of lifetime leakage emissions and end-of-life leakage emissions, divided by a conversion factor (2,205). Lifetime leakage emissions are a product of the refrigerant charge, global warming potential, annual leakage rate, and quantification period of the project. End-of-life leakage emissions are a product of the refrigerant charge, global warming potential, and end-of-life leakage.

Refrigeration projects may also achieve GHG emission reductions from improvements in energy efficiency, quantified using the Grid Electricity emission factors.

See the "Refrigeration" tab of the Database for specific emission factors.

Criteria Pollutant Emission Factors

For refrigeration projects, there are no air pollutant emission reduction benefits directly associated with refrigerant replacement (i.e., system lifetime and end-of-life leakage), but there may be optional reductions in remote air pollutant emissions resulting from reduced energy consumption. Thus, only remote air pollutant emissions are potentially quantified for refrigeration projects. Remote air pollutant emissions are emissions that occur away from the project site (e.g., grid electricity emissions resulting from an offsite power plant). These emissions are calculated using the emission factors for grid electricity, as presented in the prior section for Grid Electricity

See the "Grid Electricity" tab of the Database for specific emission factors.

Heating, Ventilation, and Air Conditioning

Heating, ventilation, and air conditioning (HVAC) emission factors are used in the quantification methodologies for the California Climate Investments programs named in Table 6.

Table 6. Programs Using Heating, Ventilation, and Air Conditioning Emission Factors

Agency	Program
California Energy Commission	California Schools Healthy Air, Plumbing, and Efficiency Program

GHG Emission Factors

GHG emission reductions are quantified for the replacement of existing HVAC equipment with more energy-efficient HVAC equipment, and/or conversion from natural gas HVAC equipment to electric HVAC equipment. The calculation is based on the amount of electricity and/or natural gas saved by the project.
Energy consumption is estimated using cooling degree hours and heating degree hours, which represent the required energy to cool or warm the indoor environment to a set thermostat temperature relative to the average outdoor ambient temperature.

Cooling degree hours is a measure of how much (in degrees), and for how long (in hours), the outside air temperature is higher than a specific base or setpoint cooling temperature. Conversely, heating degree hours is a measure of how much (in degrees), and for how long (in hours), the outside air temperature is lower than a specific base or setpoint heating temperature. The more extreme the outside temperature, the higher the number of degree hours. A high number of degree hours generally results in higher levels of energy use for cooling or heating.

Equation 15 and Equation 16 show how to calculate cooling and heating degree hours. Historical average hourly ambient temperatures were sourced from the National Oceanic and Atmospheric Administration's 30-Year U.S. Climate Normals and grouped by county and climate zone (as defined by the California Energy Code). For counties with multiple weather stations, hourly temperature was averaged across the stations. For counties with no weather station data available, the average temperature of counties with comparable climate zones was used as a surrogate.

Equation 15: Cooling Degree Hours

$$CDH = \sum_{D1}^{DF} \sum_{H1}^{HF} \left(T_{Out,H,D} - T_{SetpointC}\right)^{+}$$

Where,

			Units
CDH	=	Cooling degree hours	°F- hours/year
D1	=	First day of HVAC annual operation	unitless
DF	=	Final day of HVAC annual operation	unitless
H1	=	Typical weekly HVAC thermostat starting hour	unitless
HF	=	Typical weekly HVAC thermostat ending hour	unitless
$T_{Out, H, D}$	=	Average hourly outdoor temperature for a particular hour and day, in a specific county	°F
$T_{SetpointC}$	=	Setpoint temperature for cooling	°F

Equation 15. Cooling degree hours are calculated as the positive difference between the average hourly outdoor temperature and the thermostat cooling setpoint temperature, summed for all the hours and days when the equipment is operational. When the average hourly outdoor temperature is below the thermostat cooling setpoint temperature, it is not included in the summation.

Equation 16: Heating Degree Hours

$$HDH = \sum_{D1}^{DF} \sum_{H1}^{HF} \left(T_{SetpointH} - T_{Out,H,D}\right)^{+}$$

Where,

			Units
HDH	=	Heating degree hours	°F- hours/year
D1	=	First day of HVAC annual operation	unitless
DF	=	Final day of HVAC annual operation	unitless
H1	=	Typical weekly HVAC thermostat starting hour	unitless
HF	=	Typical weekly HVAC thermostat ending hour	unitless
$T_{SetpointH}$	=	Setpoint temperature for heating	°F
$T_{Out, H, D}$	=	Average hourly outdoor temperature for a particular hour and day, in a specific county	°F

Equation 16. Heating degree hours are calculated as the positive difference between the thermostat heating setpoint temperature and the average hourly outdoor temperature and the, summed for all the hours and days when the equipment is

operational. When the average hourly outdoor temperature is above the thermostat heating setpoint temperature, it is not included in the summation.

The amount of necessary cooling and/or heating is then determined in terms of equivalent full load hours (EFLH). EFLH is the number of hours that an HVAC system would need to operate at full load to equal the amount of cooling or heating delivered by the system at a constant temperature (e.g., thermostat setting) over a year. Although the simplest and most direct method to calculate EFLH is using energy consumption data, this data is not always available, especially when estimating the impact of prospective projects. When metering data unavailable, it may be estimated using colling and heating degree hours as shown in Equation 17 and Equation 18. EFLH is approximately estimated as the cumulative amount of cooling or heating temperature differences over the difference the between the equipment's test design temperature and an operating setpoint temperature.

Equation 17: Equivalent Full Load Cooling Hours

$$EFLH_C = \frac{CDH}{T_{DesignC} - T_{SetpointC}}$$

Where,			Units
$EFLH_C$	=	Equivalent full load cooling hours	hours/year
CDH	=	Cooling degree hours	°F- hours/year
$T_{DesignC}$	=	HVAC system total capacity cooling design temperature	°F
$T_{SetpointC}$	=	Thermostat setpoint temperature for cooling	°F

Equation 17. The equivalent full load cooling hours is calculated as the total annual cooling degree hours divided by the difference between the HVAC system's total capacity cooling design temperature and the operating setpoint cooling temperature.

For heating applications, equivalent full load heating hours and heating degree hours are calculated, analogous to their cooling counterpart. Heating degree hours is a measure of how much (in degrees), and for how long (in hours), the outside air temperature is lower than a specific base or setpoint temperature.

Equation 18: Equivalent Full Load Heating Hours

$$EFLH_H = \frac{HDH}{T_{DesignH} - T_{SetpointH}}$$

$$EFLH_H = \frac{HDH}{T_{DesignH} - T_{SetpointH}}$$

Where,

			Units
$EFLH_C$	=	Equivalent full load heating hours	hours/year
HDH	=	Heating degree hours	°F- hours/year
$T_{SetpointH}$	=	Thermostat setpoint temperature for heating	°F
$T_{DesignH}$	=	HVAC system total capacity heating design temperature	°F

Equation 18. The equivalent full load heating hours is calculated as the total annual heating degree hours divided by the difference between the operating setpoint heating temperature and the HVAC system's total capacity heating design temperature.

The energy consumption of HVAC equipment is then calculated for cooling and heating systems using Equation 19 and Equation 20, respectively.

Equation 19: Electricity Consumption from Cooling Systems

For air conditioners and heat pumps with cooling capacities < 65,000 Btu/hr:

$$C_{Elec} = \left(\frac{CAP_C}{1{,}000}\right) \times \left(\frac{1}{SEER}\right) \times EFLH_C \times UL \times N$$

For air conditioners and heat pumps with cooling capacities ≥ 65,000 Btu/hr:

$$C_{Elec} = \left(\frac{CAP_C}{1{,}000}\right) \times \left(\frac{1}{EER}\right) \times EFLH_C \times UL \times N$$

For chillers:

$$C_{Elec} = \left(\frac{CAP_C}{12{,}000}\right) \times IPLV \times EFLH_C \times UL \times N$$

Where,			Units
C_{Elec}	=	Electricity consumption	kWh
Cap_C	=	Full load cooling output capacity	Btu/hr
SEER	=	Seasonal energy efficiency ratio	Btu/Wh
EER	=	Energy efficiency ratio	Btu/Wh
IPLV	=	Integrated Part Load Value	kW/ton
$EFLH_C$	=	Equivalent full load cooling hours	hours/year
UL	=	Useful life of the HVAC unit	years
N	=	Number of HVAC units	[unitless]

Equation 19. For electric cooling systems, the electricity consumption is calculated as the full load cooling output capacity multiplied by the inverse efficiency, the equivalent full load cooling hours, the useful life of the equipment, and the number of HVAC units.

Equation 20: Electricity Consumption from Heating Systems

For electric furnaces:

$$C_{Elec} = \left(\frac{CAP_H}{3{,}412}\right) \times EFLH_H \times UL \times N$$

For heat pumps with heating capacities < 65,000 Btu/hr:

$$C_{Elec} = \left(\frac{CAP_H}{1{,}000}\right) \times \left(\frac{1}{HSPF}\right) \times EFLH_H \times UL$$

For heat pumps with heating capacities ≥ 65,000 Btu/hr:

$$C_{Elec} = \left(\frac{CAP_H}{1{,}000}\right) \times \left(\frac{1}{3.412 \times COP}\right) \times EFLH_H \times UL$$

Where,			Units
C_{Elec}	=	Electricity consumption	kWh
Cap_H	=	Full load heating output capacity	Btu/hr
HSPF	=	Heating seasonal performance factor	Btu/Wh
COP	=	Coefficient of performance	unitless
$EFLH_H$	=	Equivalent full load heating hours	hours/year
UL	=	Useful life of the HVAC unit	years
N	=	Number of HVAC units	[unitless]

Equation 20. For electric cooling systems, the electricity consumption is calculated as the full load cooling output capacity multiplied by the inverse efficiency, the equivalent full load heating hours, the useful life of the equipment, and the number of HVAC units.

For heating systems powered by natural gas, Equation 21 is used to calculate the natural gas consumption based on the equivalent full load heating hours.

Equation 21: Natural Gas Consumption from Heating Systems

For natural gas furnaces and boilers:

$$C_{NG} = \left(\frac{CAP_H}{100{,}000}\right) \times \left(\frac{1}{AFUE}\right) \times EFLH_H \times UL \times N$$

Where,			Units
C_{NG}	=	Natural gas consumption	therm
Cap_H	=	Full load heating output capacity	Btu/hr
AFUE	=	Annual Fuel Utilization Efficiency rating	%
$EFLH_H$	=	Equivalent full load heating hours	hours/year
UL	=	Useful life of the gas heater	Years
N	=	Number of gas heaters	[unitless]
100,000	=	Conversion from therm to Btu	Btu/therm

Equation 21. Natural gas consumption for heating systems is calculated as the full load heating output capacity divided by the annual fuel utilization efficiency rating, and then multiplied by the equivalent full load heating hours, useful life of the heaters, and number of heaters.

See the "Climate Normals", "Grid Electricity", and "Natural Gas" tabs of the Database for specific emission factors.

Criteria Pollutant Emission Factors

Air pollutant emission reductions from heating, cooling, and air conditioning systems are calculated as the sum of reductions in remote air pollutant emissions and local air pollutant emissions. Remote air pollutant emissions are emissions that occur away from the project site (e.g., grid electricity emissions resulting from an offsite power plant). Conversely, local air pollutant emissions are emissions that occur at the project site and directly impact the surrounding community (e.g., onsite natural gas combustion). Refer to the Grid Electricity and Natural Gas sections for the specific emission factors used.

See the "Grid Electricity" and "Natural Gas" tabs of the Database for specific emission factors.