Verified Carbon Standard

Draft VCS Methodology

VM0008

WEATHERIZATION OF SINGLE-FAMILY AND MULTI-FAMILY BUILDINGS

Draft Version 1.2

12 December

Sectoral Scope 3: Energy Demand

Version 1.0 of this methodology was developed by the Maine State Housing Authority (MaineHousing) in collaboration with Lucille Van Hook, Lee International, and Climate Focus.

Version 1.1 of this methodology was developed by Climate Neutral Business Network (CNBN) and EcoSmart Solution.

The draft of this revised methodology was developed by Climate Neutral Business Network (CNBN) and Renu Communities.

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1 SUMMARY DESCRIPTION

Additionality, Crediting Method, and Mitigation Outcome	
Additionality	Performance Method: Categories A, B, and C Project Method: Category D
Crediting Baseline	Project Method: Categories A, B, C, and D
Mitigation Outcome	Reductions

This methodology covers weatherization of dwellings and implementation of energy efficiency measures in single-family homes, multi-family buildings, or mobile homes that reduce energy consumption. Examples include but are not limited to, improved air sealing, enhanced insulation, replacements of refrigerators and air conditioning units, and upgrades to heating/cooling systems, such as heat pumps (HP) and heat pump water heaters (HPWH).

2 SOURCES

The methodology uses the most recent versions of the following tools:

- *VT0008 Additionality Assessment*

*VT0011 Electricity System Emission Factors*The methodology also references or draws on ideas, data, and definitions from the following sources:

- *ASHRAE building standard 90.1-2004*
- *IAF Guidance on the Application of ISO/IEC Guide 66 Issue 4 IAF GD:2006*
- *Marrakesh Accords, Article 48 (c), 2001*
- *National Manufactured Housing Construction and Safety Standards Act of 1974 section 603*
- Nationally recognized weatherization best practice standards (e.g., training curricula, core competencies, and example best practice standards for weatherization activities) offered by Department of Energy Weatherization Assistance Program and the Building Performance Institute
- *US Environmental Protection Agency Refrigerants Global Warming Potentials*
- *US Department of Energy Buildings Energy Data Book*

3 DEFINITIONS

Appliance

A household powered by electricity or another fuel source, including but not limited to, a refrigerator, microwave, dishwasher, clothes washer or dryer, space heater, or water heater. It also includes heat pumps for space heating, space cooling, and water heating where their GHG reductions can be determined on a discrete basis (e.g., using building weather adjusted energy modelling systems or HERS audit ratings). Central heating and cooling systems are excluded. An appliance operates as a discrete, standalone unit.

Building envelope

The exterior thermal boundary of the physical structure of an individual building. Thermal boundary typically includes the ceiling/roof, wall, floor, attic floor, window, or door that separates the habitable, occupiable, and conditioned spaces from the outdoor weather.

Cooling degree days (CDD)

Measure the cumulative degree difference between the warmer outside temperature and the base temperature of the conditioned space on a daily basis during the cooling season. CDD are determined by summing the daily degree days, which are calculated as the average daily temperature minus the base temperature. The average daily temperature is calculated by summing the daily high temperature and the daily low temperature and dividing by two. The average daily temperature can also be calculated by averaging the daily temperature over shorter time intervals, rather than just the high and low temperature. CDD reported by weather stations are often reported in sixty or thirty minute time intervals. In the US, the cooling base temperature is 78° F.

Dwelling

A residential unit, including single-family homes, mobile homes, multi-family buildings, apartments within multi-family buildings, or other housing types defined in the CBECS Lodging category. It also includes non-traditional buildings listed under the CBECS Public Order category, such as fire stations, jails, reformatories, or penitentiaries. Beyond traditional multi-family housing, multi-family buildings may include commercial residential facilities, such as hotels, dormitories, and nursing homes.[1]

Energy load

The sum of the heat load, cooling load and the electricity demand per Dwelling. Heat load means the total fuel consumed, including electricity (in Btus, GJ or kWh) to provide comfort in a conditioned space in a given year. Cooling load means the total electricity, or other fuel type in the case of central cooling systems, consumed (in Btus, GJ or kWh) necessary to remove heat from the conditioned space to provide comfort in a given year.

[1] In the United States, multi-family buildings that are over three stories above grade are considered commercial under the ASHRAE building standard 90.1-2004. These are also covered by the methodology.

Fuel switching

A change in the energy or fuel source (e.g., switching from natural gas to electricity)

Heat Pump Appliance

An air sourced heat pump (both self-contained and central systems), split heat pump heating/cooling system, heat pump water heater, or geothermal[2] heat pump direct exchange heating/cooling system.

Heating degree days (HDD)

Measure the cumulative degree difference between the colder outside temperature and the base temperature of the conditioned space on a daily basis during the heating season. HDD are determined by summing the daily degree days, which are calculated as the base temperature minus the average daily temperature.[3] The average daily temperature is calculated by summing the daily high temperature and the daily low temperature and dividing by two. The average daily temperature can also be calculated by averaging the daily temperature over shorter time intervals, rather than just the high and low temperature. HDD reported by weather stations are often reported in sixty or thirty minute time intervals. In the US, the base temperature is 65°F. In the UK, the base temperature is 15°C.

R-value

A measurement of thermal resistance as expressed by a recognized authority, such as the U.S. Department of Energy, or the American Society of Heating, Refrigerating and Air-conditioning Engineers (ASHRAE). The R-value of insulation in the floor, walls, ceiling, skirting or any other element will depend on the thickness and specific material of the installed insulation.

Same building stock

Dwellings 1) in the same state, province, or region, 2) in the same category (single family or multi-family), and 3) inhabited by the same income group (low-income, middle-income or high-income) as defined by a recognized authority.[4]

U-value

The thermal conductance of a material or, in other words, the total heat transmission in GJ per square meter per hour with a 1°C temperature difference between the inside and the outside. The U-value of the window is the inverse of the R-value or 1/R. The U-value for the make and

[2] As distinct from large scale geothermal energy/electricity power production systems (e.g https://www.nrel.gov/research/re-geo-elec-production.html#:~:text=The%20steam%20comes%20from%20reservoirs,more%20below%20the%20earth's%20surface.&text=The%20steam%20rotates%20a%20turbine,flash%20steam%2C%20and%20binary%20cycle.)

[3] For example, a winter day (24 hours) has a low daily temperature of 20°F and a high daily temperature of 35°F. The total HDD for that day are calculated as: 65°F (base temperature) – ((35°F+20°F)/2). The HDD for that day are 37.5. If, the next day is slightly warmer and the daily low is 30°F and the daily high is 38°F, then the HDD for that day are 31. The cumulative HDD for the two days are 68.5. HDD for the heating season are cumulative.

[4] In the US, The Department of Health and Human Services issues guidelines that define the term "low-income" as a multiple of the income level defined as poverty level on an annual basis. For example, the 2009 poverty level was $10,400 for a single person, and $21,200 for a family of four. Households are considered low income if their household income is no more than 200% of poverty level.

model of a window can often be found on a window manufacturer's specification sheet included with the window.

Weatherization

Energy efficiency measures in dwellings. Weatherizing refers to the act of installing energy efficiency measures in dwellings.

4 APPLICABILITY CONDITIONS

This methodology covers weatherization of dwellings and implementation of energy efficiency measures in single-family homes, multi-family buildings, or mobile homes that reduce energy consumption. Examples include but are not limited to, improved air sealing, enhanced insulation, replacements of refrigerators or air conditioning units, and upgrades to heating/cooling systems, such as heat pumps (HP) and heat pump water heaters (HPWH).

This methodology is applicable under the following conditions:

1) The project activity consists of the weatherization of dwellings and/or implementation of energy efficiency measures in single-family homes, multi-family buildings, or mobile homes to reduce energy consumption. Project activities may include weatherizing whole buildings, replacing mobile homes, or implementing individual energy efficiency measures within existing dwellings.
2) The condition of the dwelling is and remains adequate for project activities according to nationally recognized weatherization best practice standards.[5] Project activities do not result in a violation of health and safety, environmental, or other relevant regulations.
3) The replacement appliances and mobile homes replaces functioning appliances, or occupied homes.
4) The dwelling is occupied. Vacancy is permitted on an intermittent basis for up to three months, or if the dwelling is occupied seasonally on an annual basis.
5) The capacity of any replacement appliance or replacement component of a central heating/cooling system satisfies the post-retrofit heat load, cooling load and electricity demand ("energy load") within the dwelling.
6) In the case of heating/cooling systems that serve multiple dwellings, all residential dwellings connected to the system is included in the project.
7) The dwelling meets or exceeds the performance benchmark as calculated for the same building stock.

[5] For example, in the United States, the Department of Energy Weatherization Assistance Program and the Building Performance Institute provide training curricula, core competencies, and example best practice standards for Weatherization activities, which are available at: http://www.waptac.org/sp.asp?mc=training_resources and http://www.bpi.org/standards.aspx.

Applicable interventions fall into one of the following categories:

Category A. All energy retrofit: A combination of energy efficiency measures directed at the building envelope (i.e., air infiltration, insulation), improving the efficiency of the central heating and/or cooling system and reducing energy consumption of appliances (i.e., replacement of refrigerators, air conditioning units, lamps, showerheads).

Category B. Efficiency enhancement of the building envelope and central heating and/or cooling system only.

Category C. Replacement of appliances currently in service.

Category D. Replacement of a mobile home currently occupied.

Fuel switching is allowed where it is provided for in the *VCS Standard* requirements for fuel switching practices.[6]

In the case of "replacement" of a mobile home, the word "retrofit" must be read to mean replacement throughout the methodology.

The methodology is applicable in any geographic region, provided appropriate data exist to establish the level of the performance benchmark for the same building stock of a project's geographic region.

When sampling, the minimum number of dwellings or appliances to be sampled must be the square root of the total number of dwellings *i*, or appliances included in the project. Statistically sound sampling approaches must be used. When the control group approach (Section 8.3) is utilized, the size of the control group must be the square root of the total number of dwellings in the project, but need not exceed 100 dwellings. In any sampling approach, the following conditions must be met:

1) The sample must be one of the following options and statistically valid:
    a) Simple random sample
    b) Systematic sampling
    c) Stratified sampling within the same building stock
    d) Cluster sampling
2) The sample must be representative of the population.
3) The data must come from an approved source (i.e., a certified energy auditor) or a nationally recognized data source.
4) Actions that may bias the sample must be avoided. Sampling must include dwellings that are dispersed geographically. For each defined building stock included in the project activity, sampling must occur. Criteria include region, dwelling type, and income.

When conducting modelling for heat pump / heat pump water heater (HP/HPWH) as appliances (e.g., in Category C), tools such as EnergyPlus, Home Energy Rating System (HERS), utility-grade

[6] See *VCS Standard*, Table 1.

deemed savings models,[7] utility-grade monitored savings model,[8] or geothermal heat pump OEM models (e.g., Wright Suite) and other industry specific models may be used for establishing HP/HPWH baseline and project energy consumption values provided:

a) The model includes weather-normalized adjustments spanning at least a 10-year basis;

b) The modelling system meets ASHRAE standard requirements;[9]

c) When modelling is conducted for appliances separately from other potential whole house improvements (in Category C and D), any other post retrofit building design inputs must be applied to the baseline heat/cooling mechanical systems modelling in order to conservatively exclude other building improvements' energy savings (e.g., from fenestration, insulation etc) from the appliance-only modelling results.

1) At least one geothermal installer per site must be certified or trained by the OEMs supplying the geothermal equipment.

2) If OEMs or utilities seek to issue credits for HP/HPWHs in Category C (e.g., using regional "any-any" utility-grade modeling rather than models tailored to the specific buildings where HP/HPWH are known to have been installed by other project proponents in the same region (e.g., real estate developers, energy efficiency service companies, HP installers)) they must deduct any VCUs issued in their region by such other project proponents from their requested VCU volumes to avoid double counting of issued credits.

    - OEMs must also include utilities in their list of other project proponents in the same region with issued VCUs

5 PROJECT BOUNDARY

The project boundary is the building envelope of the dwelling(s) and its heating/cooling equipment.

The following greenhouse gas sources are included in and excluded from the baseline and the project.

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[7] Such utility-grade deemed savings models include examples such as the RTF "any any" models used by northwestern utilities to establish deemed savings for HP/HPWHs where the specific building where the HP/HPWH are installed are not known

[8] NYSERDA, for example, applies such modeling systems where the specific locations of the HP/HPWH installations are known through the incentive program information.

[9] ASHRAE Guideline 14 when calibrating and energy model using historical energy bills

ANSI/BPI-1200-S-2017

ANSI/RESNET/ICC 301-2022

Table 1. Greenhouse gas sources included and excluded in the baseline and project

Source		Gas	Included?	Justification/Explanation
Baseline	Grid electricity consumption by cooling systems or other electric appliances	CO_2	Included	Only CO_2 emissions from grid connected electricity generation must be accounted for.
		CH_4	Excluded	
		N_2O	Excluded	
		Other	Excluded	
	Fossil fuel consumption by heating systems or appliances	CO_2	Included	Only CO_2 emissions from fossil fuel combustion must be accounted for.
		CH_4	Excluded	
		N_2O	Excluded	
		Other	Excluded	
	Emissions from wood combustion for heat	CO_2	Excluded	Excluded for simplification and to be conservative.
		CH_4	Excluded	
		N_2O	Excluded	
		Other	Excluded	
Project	Grid electricity consumption by cooling systems or other electric appliances	CO_2	Included	Only CO_2 emissions from grid connected electricity generation must be accounted for.
		CH_4	Excluded	
		N_2O	Excluded	
		Other	Excluded	
	Fossil fuel consumption by heating systems or appliances	CO_2	Included	Only CO_2 emissions from fossil fuel combustion must be accounted for.
		CH_4	Excluded	
		N_2O	Excluded	
		Other	Excluded	
	Emissions from wood combustion for heat	CO_2	Excluded	Excluded for simplification and to be conservative.
		CH_4	Excluded	
		N_2O	Excluded	
		Other	Excluded	
Leakage	Emissions from improper disposal of appliances and operational use of new appliances (e.g., refrigerators, air conditioners, heat pumps)	CO_2	Included	When the appliance is not disposed of according to applicable laws and regulations there will be leakage from continued operation. The leakage emissions must be calculated and excluded from GHG emission reductions as described in the methodology. HFC emissions from refrigerant leaks during operational use of applicable installed appliances must be included.
		HFCs	Included	
		CH_4	Excluded	
		N_2O	Excluded	
		Other	Excluded	

Leakage

Appliances, heating/cooling equipment and/or mobile homes that are replaced must be properly disposed of and their disposal must be documented. The disposal documentation must confirm that:

1) the appliances have been disposed of in a manner that prevents operation of the appliance; and
2) the disposal procedure complies with applicable law and regulations. If not documented, CO_2 emissions from continued operation of replaced appliances, heating/cooling equipment and/or mobile homes and HFC emissions from refrigerators or air conditioners must be accounted for as leakage.

6 BASELINE SCENARIO

The baseline scenario represents the conditions most likely to occur in the absence of the project.

Category A. All energy retrofit: the baseline scenario consists of fossil fuel and electricity consumed to satisfy the heat and cooling load and the appliance plug/fuel load prior to project implementation.

Category B. Efficiency enhancement of the building envelope and/or central heating/cooling system: the baseline scenario consists of fossil fuel consumed to satisfy the heat and cooling load prior to project implementation. Electricity must only be included when it is a heating or cooling source within the dwelling. Appliances and their corresponding electricity consumption must not be included.

Category C. Replacement of appliances: the baseline scenario consists of electricity or other fuel consumed by the appliances to be replaced prior to project implementation.

Category D. Replacement of a mobile home: the baseline scenario consists of fossil fuel and electricity consumed to satisfy the heat and cooling load and the appliance plug load of the mobile home to be replaced prior to project implementation.

7 ADDITIONALITY

All projects must demonstrate regulatory surplus (Section 7.1).

Project activities in Category D must demonstrate additionality by applying the project method, either conducting an investment or barrier analysis, and a common practice analysis (Section 7.2).

Project activities in Category A, B, or C must demonstrate additionality by applying the performance method that incorporates the performance benchmark (Section 7.3).

7.1 Regulatory Surplus (Categories A, B, C and D)

The project proponent must demonstrate regulatory surplus in accordance with the rules and requirements regarding regulatory surplus set out in the most recent versions of the *VCS Standard* and *VCS Methodology Requirements*.

The regulatory surplus must be assessed for each of the weatherization and energy efficiency measures included in the project activity.

Where the project activity demonstrates regulatory surplus, proceed to the project method (Category D) or performance method (Categories A, B and C). Otherwise, the project activity is not additional.

7.2 Project Method (Category D)

7.2.1 Barrier analysis and/or investment analysis

Project proponents must follow the procedures and requirements of the most recent version of *VT0008 Additionality Assessment* to conduct either a barrier analysis (Step 2 of the tool) or an investment analysis (Step 3 of the tool). Project proponents may choose to apply both analyses to further strengthen the additionality demonstration.

Where the project activity demonstrates that all conditions of either the barrier analysis or the investment analysis per *VT0008* are met, proceed to the next step (common practice analysis). Otherwise, the project activity is not additional.

7.2.2 Common practice analysis

Project proponents must follow the procedures and requirements of either Step 4b or 4c of the most recent version of *VT0008 Additionality Assessment* to conduct the common practice analysis.

Where the project activity satisfies all previous steps and demonstrates that it is not common practice, it is additional. Otherwise, the project activity is not additional.

7.3 Performance Method (Categories A, B and C)

Category A. All energy retrofit: The percent savings in the pre- and post-retrofit energy load of each dwelling in the project must be equal to or greater than the performance benchmark. The performance benchmark is a value above average performance that represents a percent savings in energy consumption that dwellings are not likely to reach with 80% certainty in the absence of the project. The average performance is the annual average percent savings in weather-normalized energy consumption in dwellings from the same building stock over the three most recent years for which data are available[10]. Dwellings weatherized as part of the project may be excluded.

Category B. Efficiency enhancement of the building envelope and/or central heating/cooling system: The percent savings in the pre- and post-retrofit energy load of each dwelling in the project must be equal to or greater than the performance benchmark. The performance benchmark is the same as defined in Category A. Although Category B comprises measures to the building envelope only, the same performance benchmark can be used if the percent savings is calculated for the entire energy consumption of the dwelling and not just for the consumption of heating and cooling energy. This way, savings achieved under the project are comparable to overall trends. By broadening the base, savings from the project are diluted. They would be higher if calculated for the savings in heat and cooling energy alone.

The performance benchmark for Category A and Category B, *x*, must be calculated as follows:[11]

For data following a normal distribution:

The performance benchmark is based on the standard deviation of the sample.

$$x = a + 0.84\sigma \quad (1)$$

Where:

x	=	Performance benchmark
a	=	Average performance[12]
σ	=	Standard deviation (sigma) of the percent savings in the same building stock energy load

For data not following a normal distribution:

The performance benchmark is equal to the 80th percentile value within the numerically ordered sample. To calculate the 80th percentile the sample data point values (v_1, v_2...v_N) must be ordered from least to greatest. The 80th percentile value is equal to the value of the data point with the rank at which 80% of the data falls below.

[10] Energy Load must be used to determine whether the dwelling is additional because the energy load is established during the energy audit. Energy consumption is used to calculate the mean percent savings within the same building stock because that is the data available. Energy load and energy consumption may be used in conjunction because energy consumption may be projected based on energy load.

[11] Under a normal bell curve distribution, the mean plus or minus 2σ encompasses 95% of the statistical sample. Therefore 97.5% of the data falls below the value *x*, if *x* is calculated as the mean plus 2σ. A 80% likelihood of the data falling below the value *x* is calculated as the mean plus 0.84 σ.

[12] To correct for any potential increase in electricity consumption due to an increase in electric appliances, the statewide percent increase in electricity consumption, as reported by the US Department of Energy or other recognized authority, will be added to the value of the average performance to make the performance benchmark even more rigorous and conservative if such electricity data are reasonably available and it is feasible to do so. For example, in the US the value of the increase in regional electricity consumption may be obtained from the following website: http://apps1.eere.energy.gov/states/state_information.cfm

$$n = \left(\frac{NP_{80}}{100}\right) + 0.05 \quad (2)$$

Where:

n	=	Rank of the ordered data point falling at the 80th percentile
N	=	Standard deviation (sigma) of the percent savings in the same building stock energy load
P_{80}	=	80th percentile

To be additional, dwellings must satisfy the following condition:

$$\frac{EL_{Pre,i} - EL_{Post,i}}{EL_{Pre,i}} * 100 \geq x \quad (3)$$

Where:

x	=	Performance benchmark; value of the data point at rank n in Equation (2)
$EL_{pre,i}$	=	Pre-retrofit energy load of dwelling i
$EL_{pre,i}$	=	Post-retrofit energy load of dwelling i

Figure 1 shows the percent savings in energy consumption of buildings and dwellings within the same building stock. The percent savings is calculated from the change in weather normalized energy consumption in dwellings from the same building stock over at least the three most recent years for which data are available. The average performance, on which the performance benchmark is based, is calculated from these data. Dwellings with a high percent savings in energy consumption will fall to the right of the average performance, and dwellings with a low percent savings in energy consumption will fall to the left of the average performance.

Figure 1. Percent savings in same building stock energy consumption

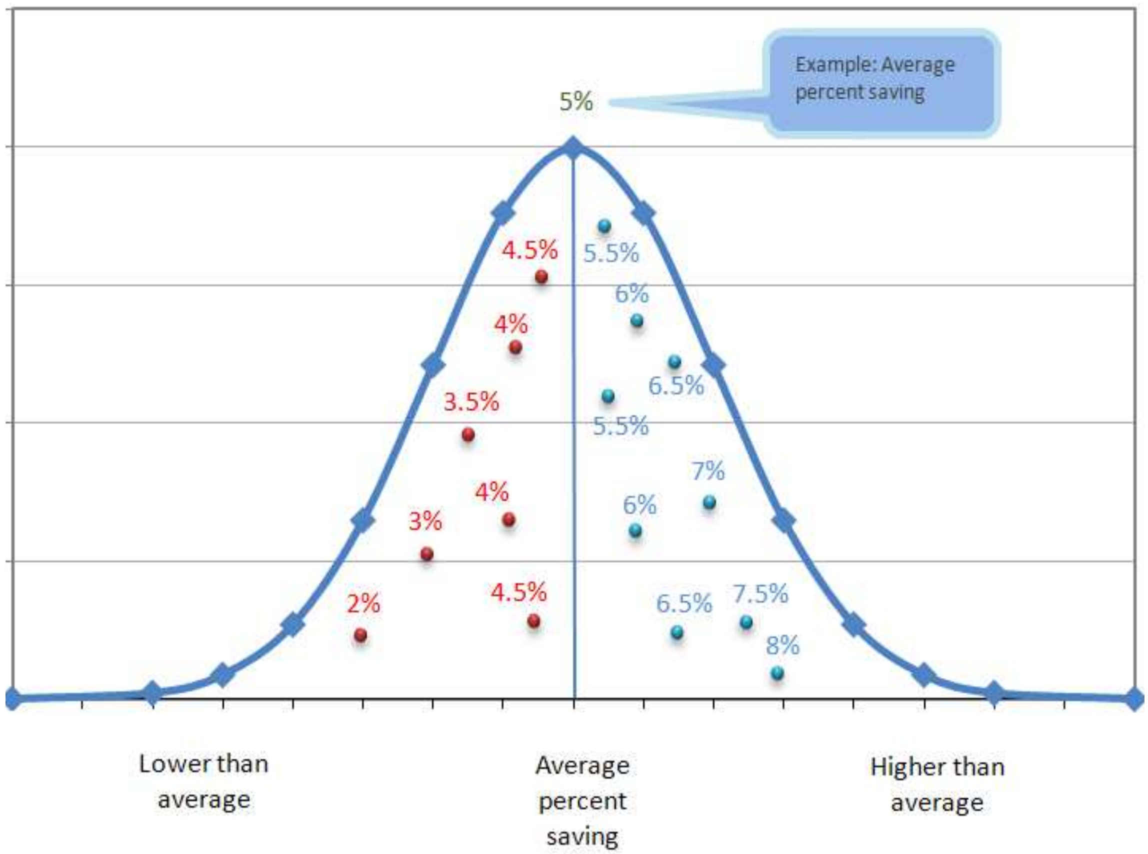
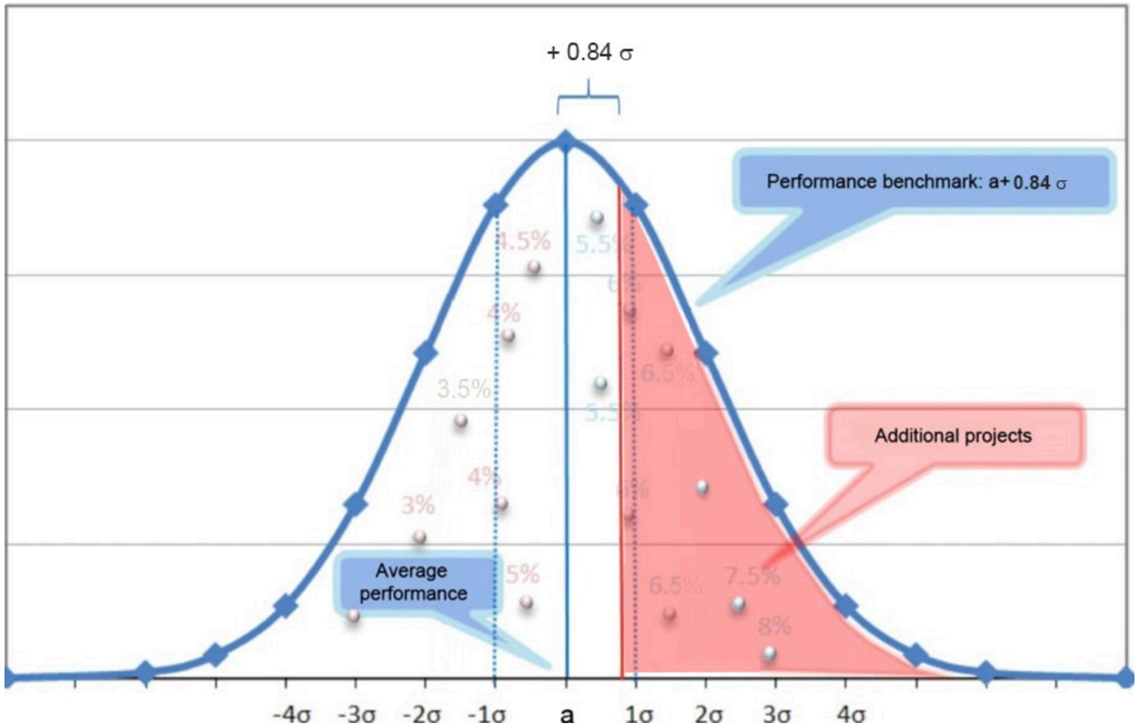


Figure 2 shows how the performance benchmark (vertical red line to the right) is calculated by determining the average performance (vertical solid blue line), defined as the annual average of the percent savings in weather-normalized energy consumption in the same building stock over the past three years, and adding 0.84σ . The standard deviation (σ) is calculated from the actual data obtained from the same building stock within the past three years. The numbers along the horizontal axis represent the number of standard deviations from the average value (average performance). For example, the data point 7% falls in line with 2σ, which means that 7% is two standard deviations away from the average performance, meaning that 97.5% of all buildings do not reach a 7% savings in energy consumption or higher.

Figure 2. Performance benchmark for categories A and B



The parameters to be monitored for calculating the average performance and standard deviation for Category A and Category B are listed in Section 9.

Category C. Replacement of appliances: the energy consumption of the replacement appliance must meet or fall below the performance benchmark. The performance benchmark is a value below the average performance that represents a level of energy consumption per appliance that appliances are not likely to reach with 80% certainty in the absence of the project. The average performance is the annual average energy consumption by existing appliances of the same appliance type, as defined by the particular make and model of the appliance. Appliances replaced as part of the project may be excluded. National appliance data may be used due to the uniformity of appliances available in the market. Data may be further differentiated (i.e., by income class) as appropriate data are available.

The performance benchmark for Category C, *x*, must be calculated as follows:

For data following a normal distribution:

The performance benchmark is based on the standard deviation of the sample.

$$x = a + 0.84\sigma \quad (4)$$

Where:

x	=	Performance benchmark
a	=	Average performance

σ = Standard deviation (sigma) of the annual energy consumption of existing Appliances in operation

<u>For data not following a normal distribution</u>:

The performance benchmark is equal to the 80th percentile value within the numerically ordered sample. To calculate the 80th percentile the sample data point values ($v_1, v_2 \ldots v_N$) must be ordered from greatest to least. The 80th percentile value is equal to the value of the data point with the rank at which 80% of the data fall below.

$$n = \left(\frac{NP_{80}}{100}\right) + 0.05 \quad (5a)$$

x = the value of the data point at rank *n* calculated in equation 5a (5b)

Where:

x	=	Performance benchmark
n	=	Rank of the ordered data point falling at the 80th percentile
N	=	Standard deviation (sigma) of the percent savings in the same building stock energy load
P_{80}	=	80th percentile

To be additional, dwellings must satisfy the following condition:

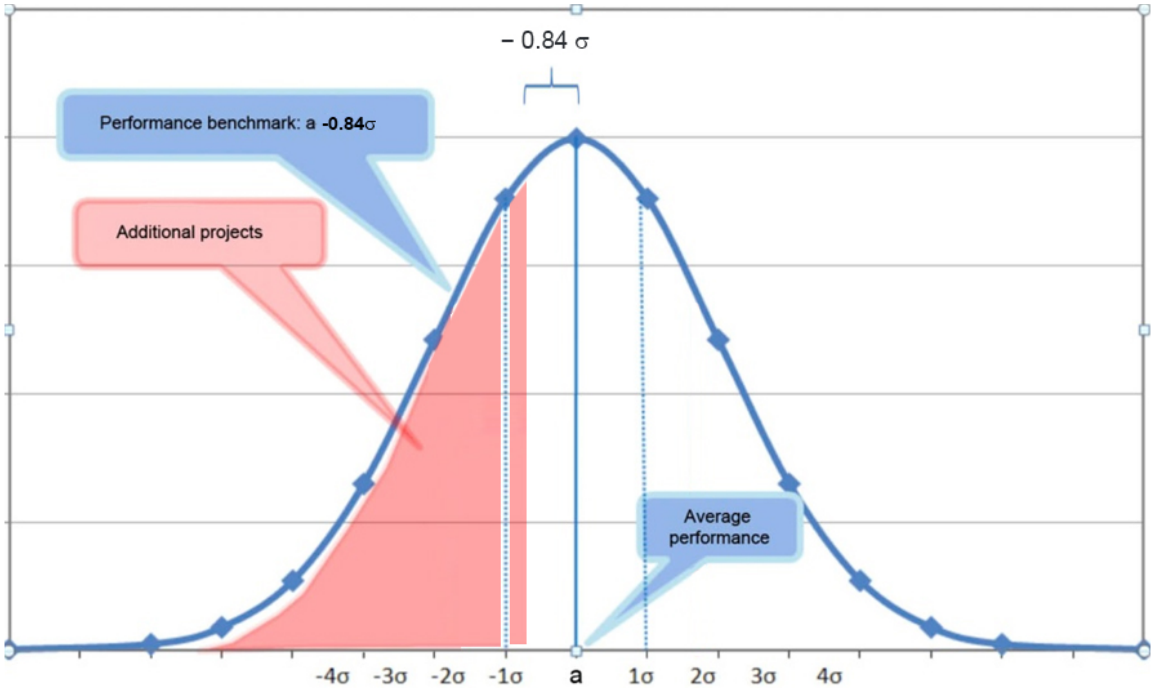
$$a_{rc,k} \leq x \quad (6)$$

Where:

x	=	Performance benchmark
$a_{rc,k}$	=	Annual energy consumption per appliance of the replacement appliance, type *k*

Figure 3 shows how the performance benchmark (vertical red line to the left) is calculated by determining the average performance (vertical solid blue line), defined as the annual average energy consumption by existing appliances of the same appliance type and subtracting 0.84σ. The standard deviation (σ) is calculated from the existing appliance data obtained from the population. The numbers along the horizontal axis represent the number of standard deviations from the average value (average performance). The shaded red section represents replacement appliances with an annual energy consumption values that fall below the performance benchmark, and are considered additional.

Figure 3. Performance benchmark for Category C



The parameters to be monitored for calculating the average performance and standard deviation for Category C are listed in Section 9.

Category D. Replacement of a mobile home: No performance benchmark is defined.

7.4 Performance Benchmark Level

The level of the performance benchmark established using the performance method is based on the rigorous requirement that with 80% certainty, dwellings deemed additional under the methodology would not have reached the improvement in energy efficiency on their own. This is evidenced by performance data of dwellings from the same building stock as defined in the methodology. The methodology formulates a universally applicable approach. The actual value of the performance benchmark (i.e., the 80th percentile of percentage improvement in energy efficiency over the three most recent years) then has to be calculated for the specific project area where the methodology is applied. Hence, the same rigour applies wherever the methodology is used. Example case data from the US shows that only a tiny fraction of houses have undergone weatherization in recent years and that on average, energy use is still on the rise, making substantial energy efficiency improvements not a likely occurrence on their own.

The choice of 80% as confidence level for the performance method aligns with or exceeds similar requirements set forth in guidance pertaining to the CDM:

1) The Marrakech Accords of the UNFCCC foresee three optional approaches to additionality of CDM projects of which one consists in the formulation of a benchmark. Article 48 (c) defines the benchmark as “The average emissions of similar project activities undertaken in the previous five years in similar social, economic, environmental and technological circumstances, and whose performance is among the

top 20 per cent of their category". The proposed top 10 percent in *VM0008* is a more conservative approach.

2) *VM0008* provides for significant rigour in applying the performance method, far exceeding previous cases of methodologies that were not accepted. For example, a new CDM methodology, 302 "CDM methodology for cement and clinker production facilities based on benchmarking", was proposed using the top 20% performing installations as a performance benchmark for additionality. This methodology has not been accepted by the CDM EB (as time of writing) on several grounds. We chose to be far more stringent in *VM0008*.

7.5 Distribution of Performance in the Sector

There is an abundance of data showing that energy use in existing US buildings is inefficient and increasing over time, and that there are significant barriers to increased penetration of energy efficiency measures. Studies show that the trends in energy use and efficiency are largely similar across the world, although there are some programs (e.g., the United Kingdom Green Deal under the Energy Act of 2011) which target economy-wide energy efficiency program implementation on a large scale.

It is important to note that the level of the performance benchmark is dictated by the performance in a particular geographic area as defined by the same building stock. Therefore, even though there may be programs in different geographic areas that promote residential energy efficiency measures, projects in those locations would still need to exceed the locally applicable performance benchmark.

By extension, in geographic locations where programs exist to promote energy efficiency measures, the performance benchmark can be expected to represent a level of savings that is more stringent than in locations where no such programs exist. The performance method is designed to ensure that the level of the performance benchmark automatically becomes more stringent in geographic locations with increasing levels of residential energy efficiency activities.

The following status quo description for residential buildings in the US serves solely to provide examples of relevant data for the establishment of a same building stock and its particular performance benchmark. The following example case information does not limit the applicability of the performance method to the US. Each performance benchmark must be calculated relative to each same building stock and its particular geographical boundary.

Relative to the US, studies show:

- In 2005, the US housing stock was found to be comprised of dwellings classified by household type as follows: single family (71.7%), multi-family (22.0%) and mobile homes (6.2%) (DOE Building Energy Data Book 2010, Table 2.2.2).
- In 2005, the following average energy intensities were found in each building stock: single family, 106.6 million Btu per household; multi-family, 64.1 million Btu per

household; mobile homes, 70.4 million Btu per household (DOE Building Energy Data Book 2010, Table 2.1.11).

- In 2008, the breakdown in energy use in US residential buildings was approximately: natural gas, 35%; petroleum, 6%, coal, 35%, renewables, 8%; and nuclear, 14%. Projected values are not expected to vary by more than ±5% from 2008 to 2035 (DOE Building Energy Data Book 2010, Table 2.1.2).
- There are “significant and persistent barriers” to implementing energy efficiency measures in the US including structural, behavioral, and availability barriers (McKinsey 2009).
- Rates of US residential energy efficiency program penetration range broadly from 16% to 0.5% or less (American Council for an Energy Efficiency Economy, 2011). On average, less than 5% of homes in the US have undergone an energy-efficiency retrofit (Gigaton Throwdown 2009).
- Residential sector energy use is projected to increase at 0.4% per year under a business-as-usual scenario between 2008 and 2020 (McKinsey 2009).
- A typical residence uses up to 40% more energy than it needs to operate economically (Gigaton Throwdown 2009).
- Worldwide residential energy use increased 19% between 1990 and 2005 (International Energy Agency 2008).
- Only weatherization measures that systematically address the thermal envelope or significantly improve the efficiency of end-use appliances are likely to enable a project to exceed a performance benchmark:
    - Evaluations of physical weatherization measures in residential dwellings demonstrate savings of around 20-30%. See, for example: Oak Ridge National Laboratories, ORNL/CON-493, 2005; and Cadmus Group, Efficiency Maine Trust Home Energy Savings Program Final Evaluation Report, 2011.
    - By comparison, evaluations of behavior change programs (e.g., providing information to encourage occupants to turn off unneeded lighting and equipment) demonstrate levels of energy savings ranging from levels not statistically different than 0 to energy savings levels of up to about 3%. See, for example: Navigant, Evaluation Report: OPOWER SMUD Pilot Year 2, 2011; and Energy Center of Wisconsin, Focus on Power-PowerCost Monitor Study, 2010.

7.6 Evaluation of the Tradeoff between False Negatives and False Positives

The level of the performance benchmark was determined after careful consideration of the tradeoff between false negatives and false positives.

False negatives, in the context of the methodology, are dwellings that have been excluded by the performance method (found not to be additional) even though the efficiency upgrades to these dwellings would not have occurred in the absence of the project. False positives are dwellings that are included in the project even though their efficiency upgrades would have happened anyway. The latter can be considered free-riders.

In elaborating the performance method, the team originally intended to develop a performance benchmark value for efficiency that dwellings would have to attain in order to be considered additional, in the form kWh/m^2 or a comparable metric. This metric however was shown to create a risk of producing an unacceptable number of false negatives. During stakeholder consultations, Joel Eisenberg, Weatherization Evaluation Consultant for the US Department of Energy acting as Program Manager at Oak Ridge National Laboratory, pointed out that weatherization efforts directed at low income houses typically target the most energy inefficient houses. While the impact of weatherization is large, both in terms of energy savings compared to the baseline and in social impact, these dwellings are unlikely to meet a high energy efficiency standard even after weatherization. To avoid unnecessary and inappropriate disqualification of low income dwellings, the decision was made to elaborate the performance method based on a percentage change rather than an absolute performance level.

In setting the performance benchmark, the 80th percentile was deemed a sufficiently rigorous requirement for exclusion of free-riders. If the performance benchmark were to be established using a higher level (e.g., 95% or even 99%), there would be a significant risk that the level of energy efficiency enhancement to be exceeded by dwellings in the project would be determined by singular and random occurrences rather than a systematic trend in the population. For instance, there are households which undertake energy efficiency improvements based on personal environmental consciousness, or because residents are particularly handy and can do the work themselves, or because houses are so drafty that air sealing is necessary to improve living comfort. Special cases with high energy efficiency gains should not be considered the norm. To consider these the norm would lead to the perverse result of disqualifying many weatherization projects.

In choosing a benchmark value of 80% that is more rigorous than comparable CDM guidance yet does not allow for rare occurrences to set the performance benchmark, and by focusing on percentage changes in efficiency enhancements rather than absolute levels of efficiency, *VM0008* seeks to minimize and optimally balance the tradeoff between false positives and false negatives.

7.7 Geographic Scope

When using a performance benchmark for Category A, Category B, or Category C activities, project proponents must calculate the performance benchmark for each same building stock identified in the project description. While the methodology does not set out a geographic limitation on project location, this requirement restricts each performance benchmark to a specific geographic area defined in a project description (e.g., a state, province or region).

7.8 Data Selection and Use

In developing a performance benchmark, project proponents must select and use data sources that meet the following requirements:

1) Data collected directly from primary sources must comply with relevant and appropriate standards, where available, for data collection and analysis, and be audited at an appropriate frequency by an appropriately qualified, independent organization.

2) Data collected from secondary sources must be available from a recognized, credible source and must be reviewed for publication by an appropriately qualified, independent organization or appropriate peer review group, or be published by a government agency.

3) Where sampling is applied in data collection, the project proponent must demonstrate that sampling results provide an unbiased and reliable estimate of the true mean value (i.e., the sampling does not systematically underestimate or overestimate the true mean value). Project proponents may choose to demonstrate the appropriateness of sampling results based on a qualitative description of data sources and methods, where appropriate.

4) Data must be publicly available, where appropriate (not confidential). Proprietary data (e.g., data pertaining to individual facilities) may be aggregated, and therefore not made individually publicly available, as there are demonstrable confidentiality considerations. However, sufficient data must be publicly available to provide transparency and credibility to the dataset.

5) All data must be made available, under appropriate confidentiality agreements as necessary, to Verra and each of the validation/verification bodies assessing the proposed performance benchmark, to allow them to reproduce the determination of the performance benchmark. Data must be presented in a manner that enables them to independently assess the presented data.

6) All reasonable efforts must be undertaken to collect sufficient data and the use of expert judgment as a substitute for data must only be permitted where it can be demonstrated that there is a paucity of data. Expert judgment may be applied in interpreting data. Where expert judgment is used, good practice methods for eliciting expert judgment must be used (e.g., *IPCC 2006 Guidelines for National GHG Inventories*).

7) Where data must be maintained in a central repository on an on-going basis (e.g., in a database that holds sector data for use by project proponents in establishing specific performance benchmarks for their projects), there must be clear and robust custody arrangements for the data and defined roles and responsibilities with respect to the central repository.

7.9 Data Maintenance

Project proponents must maintain data used to establish any performance benchmark in a manner that meets the following requirements:

The dataset may be documented in the project description or in a separate repository that is referenced by the project description. Datasets documented and contained within the project description are static datasets, where all project activities use the level of the relevant performance benchmark that is specified in the project description.

The following applies with respect to datasets maintained in a separate repository:

1) The dataset may be static or dynamic (i.e., may or may not be periodically updated).
2) The project description must establish criteria and procedures for the use of the dataset and for establishing a specific performance benchmark for each same building stock.
3) The project description may specify that projects use the level of the performance benchmark metric available at project validation for the duration of their project crediting periods, or may specify that projects use an updated level of the performance benchmark at each verification event. The frequency that data is updated within the dataset must be determined by the project proponent.
4) It must be demonstrated that procedures are in place to maintain the dataset in accordance with the applicable requirements set out in Section 7.8.

8 QUANTIFICATION OF REDUCTIONS AND REMOVALS

This section presents five approaches to calculating GHG emission reductions (reductions) and related monitoring parameters:

1) adjusted consumption approach;
2) pre-and post-retrofit audit approach;
3) control group approach;
4) deemed savings approach; and
5) mobile homes approach.

Equations required to calculate reductions under each approach and monitoring parameters applicable to each approach are listed in this section.

Reductions are calculated directly under each approach; in other words, baseline and project emissions are not calculated separately under the methodology. This method results in a simplified and accurate estimation of project emissions normalized for weather and electricity correction factors. Leakage is calculated separately under each approach.

Category A. All energy retrofits: calculation of the reductions and monitoring must be based on either:

1) The adjusted consumption approach;
2) The pre- and post-retrofit audit approach; or
3) The control group approach.

Category B. Efficiency enhancements of the building envelope and central heating/cooling: calculation of the reductions and monitoring must be based on either:

1) The adjusted consumption approach;
2) The pre- and post-retrofit audit approach; or
3) The control group approach.

In Category B, electricity must only be included in the calculation of reductions when it is a heating or cooling source within the building or dwelling.

Category C. Appliance replacement: calculation of the reductions and monitoring must be based on:

1) The deemed savings approach.

Category D. Replacement of a mobile home: calculation of the reductions and monitoring must be based on either:

1) The adjusted consumption approach;
3) The control group approach; or
5) The mobile homes approach.

8.1 Adjusted Consumption Approach

In the adjusted consumption approach, measured energy consumption pre-retrofit, the baseline consumption, must be corrected for changes in electricity demand over time and adjusted for heating/cooling degree days using an electricity correction factor (ECF) and heating/cooling degree day correction factors (HDDCF or CDDCF as applicable). A sample may be used to measure energy consumption pre-retrofit. Project consumption of fuel and electricity must be subtracted from the adjusted baseline consumption. The result must be multiplied by an emission factor for the fuel or electricity used in the baseline. A control group of non-weatherized, or non-retrofitted, dwellings must be monitored as a quality assurance measure.

Reductions in the adjusted consumption approach must be calculated as follows:

$$ER_y = \sum_{i=l}^{I}\left(Elec_{b,i} * ECF_y * CDDCF_y - Elec_{p,y,i}\right) * Elec_{CO2} + \sum_{i,j=1}^{I,J}\left(F_{b,i,j} * HDDCF_y - F_{p,y,i,j}\right) * Cal_j * F_{CO2j} - L_y \quad (7)$$

Where:

ER_y	=	Reductions in year *y* (t CO_2e/yr)
I	=	Dwelling

$Elec_{b,i}$	=	Electricity consumed in the year prior to project implementation for dwelling *i* (baseline consumption) (kWh)[13]
$Elec_{p,y,i}$	=	Electricity consumed by the project in year *y* for dwelling *i* (project consumption) (kWh)
ECF_y	=	Electricity correction factor for year *y* to be applied to the baseline
$CDDCF_y$	=	Cooling degree days correction factor for year *y*
$HDDCF_y$	=	Heating degree days correction factor[14] for year *y*
$F_{b,i,j}$	=	Fuel type *j* consumed in the year prior to project implementation for dwelling *i* in the appropriate mass or volume unit (baseline consumption)
$F_{p,y,i,j}$	=	Fuel type *j* consumed by the project in year *y* for dwelling *i* in the appropriate mass or volume unit (project consumption)
Cal_j	=	Calorific value of fuel type *j* (GJ/mass or volume)
$Elec_{CO2}$	=	Grid emission factor (t CO_2e/kWh)
$F_{CO2,j}$	=	CO_2 emission factor per unit of energy of fuel type *j* (t CO_2e/GJ)
L_y	=	Leakage emissions in year *y* (tCO_2/yr)
I	=	Number of dwellings
J	=	Number of fuel types
j	=	Fuel type
y	=	Any consecutive twelve months during the project's crediting period, and must be defined with an integer from 1 on in a consecutive manner

Leakage emissions must be calculated as follows:

$$L_y = L_{CO2,y} + L_{HFC,y} + L_{HFC\ OP,y} \tag{8}$$

Where:

$L_{CO2,y}$	=	Leakage emissions from continued operation of appliances in year *y* (t CO_2/yr)
$L_{HFC,y}$	=	Leakage emissions from improper disposal of refrigerators, air conditioners or heat pumps in year *y* (t CO_2/yr)
$L_{HFC\ OP,y}$	=	Leakage emissions from refrigerant leaks during operation in year *y* (t CO_2/yr)

Leakage from continued operation of appliances must be calculated as follows:

$$L_{CO2,y} = \sum_{k=l}^{K} \left(a_{np,k,y} * h_k * E_{dem,pre,k}\right) * Elec_{CO2} + \sum_{t=1}^{T-1} L_{(y-t),CO2} \tag{9a}$$

[13] If multiple dwellings within a single building are served by a single meter, the electricity consumption unit must change to kWh/m^2 and the equation must be multiplied by the area of each individual dwelling. Consequently, the area of each dwelling must be recorded and included in the monitoring parameters.

[14] When fossil fuel is the cooling source the CDDCF must replace the HDDCF in the equation. Conversely, when electricity is the heating source the HDDCF must replace the CDDCF in the equation.

Where:

$a_{np,k,y}$	=	Appliance type *k* not properly disposed of in year *y*
K	=	Number of appliance types
$E_{dem,pre,k}$	=	Electricity demand of appliance type *k* before replacement
h_k	=	Annual working hours of appliance type *k*
$Elec_{CO2}$	=	Emission factor for grid electricity (t CO_2e/kWh)
T	=	Years from the beginning of the crediting period (number)

When fuel switching applies, $EF_{f,CO2}$ will substitute for $Elec_{CO2}$ and $E_{f,dem,pre,k}$ will be applied across each energy source *f* using Equation (9b):

$$L_{CO2,y} = \sum_{k=1\ to\ K,f} (a_{np,k,y} * E_{f,dem.pre,k} * h_{k-pre}) * EF_{f,CO2} + \sum_{t=1\ to\ T-1} L_{(y-t),CO2} \quad (9b)$$

Where:

$EF_{f,CO2}$	=	Emission factor for energy source *f* (t CO_2e/Btu)
$E_{f,dem,pre,k}$	=	Energy demand of appliance type *k* using energy source *f* before replacement (Btu/hour)
$h_{k\text{-}pre}$	=	Annual working hours of appliance type *k* before replacement

Leakage from improper disposal of refrigerators, air conditioners or heat pumps must be calculated as follows:

$$L_{HFC,y} = \sum_{k=l}^{K} a_{np,k,y} * RCC_a * GWP_R * \frac{1_t}{1{,}000{,}000_g} \quad (10)$$

Where:

RCC_a	=	Charge capacity of refrigerant gas of replaced cooling or heat pump appliance *a* (grams)
GWP_R	=	Global Warming Potential of refrigerant gas *R* used in appliance (t CO_2e/t gas)

Refrigeration equipment often uses blends of HFC refrigerant gases. The GWP of these blends must be calculated based on the proportion of different refrigerants used.[15] The GWP values from the most recent version of the *VCS Standard* must be used.

Leakage emissions from refrigerant leaks during operation must be accounted for unless the project proponent can demonstrate that one of the following conditions is met:

[15] Examples of the available compositions of refrigerant blends are available at the US Environmental Protection Agency website: http://www.epa.gov/Ozone/snap/refrigerants/refblend.html

a) the installation/operation of the new refrigerators, air conditioners or heat pumps replace baseline appliances which also contain refrigerants;[16] or

b) $L_{HFC\ OP,y}$, can be demonstrated to be de minimis.

Otherwise, leakage emissions from refrigerant leaks during operation must be calculated per Equation (11). Such leakage emissions must also be accounted for if the project proponent cannot demonstrate which baseline appliances are replaced or demonstrate that the baseline appliances did not contain refrigerants.

$$L_{HFC\ OP,y} = \sum_{k=1\ thru\ K} a_{k,y,OPS} * RCCinstalled_a * GWP_r * LR\%_{a,y}/1000000 \tag{11}$$

Where:

$a_{k,y,\ OPS}$	=	Number of appliances of type *k* in operation during project year *y*
$RCCinstalled_a$	=	Charge capacity of refrigerant gas of installed cooling or heat pump appliance *a* (grams)
GWP_R	=	Global Warming Potential of refrigerant gas *R* used in appliance (t CO_2e/t gas)
$LR\%_y$	=	Annual leakage rate of refrigerant gas *R* used in appliance (t CO_2e/t gas)
K	=	Number of appliance types
k	=	Appliance type

LR% default values may be applied:

Table 2. LR % Values

Technology	LR% Value	Source Reference
Heat Pumps		DEFRA[17], EPA/industry experts[18]
Air source HP, split system	1-4% if justified to VVB or 3.5% as default value	
Air source HP, self contained central system	<1%	
HPWH	0.3%	
Geothermal Closed Loop HP	0.3%	
Air Conditioning		EPA[19]

[16] In this case, there is reasonable comparability between operational leak rates for baseline and project appliances so that $L_{HFC\ OP,y}$, can be set at zero (e.g., if a refrigerator replaces an old refrigerator, if a heat pump replaces an old air conditioner).

[17] https://www.gov.uk/government/publications/impacts-of-leakage-from-refrigerants-in-heat-pumps

[18] https://www.epa.gov/sites/default/files/2016-12/documents/international_transitioning_to_low-gwp_alternatives_in_res_and_com_ac_chillers.pdf

[19] https://www.epa.gov/sites/default/files/2016-12/documents/international_transitioning_to_low-gwp_alternatives_in_res_and_com_ac_chillers.pdf

Small, self contained	<1%	
Small, split system	1-4%	
Refrigerators	0.3%	DEFRA[20]

The grid emission factor ($Elec_{CO2}$) must be calculated in a transparent and conservative manner based on one of the following approaches:

1) A combined margin, consisting of the combination of operating margin and build margin according to the procedures prescribed in the most recent version of *VT0011 Electricity System Emission Factors*The grid emission factor must be monitored following either the Ex ante option or the Ex post option within the tool.

   OR

2) The weighted average emissions (in t CO_2e/kWh) of the current generation mix obtained from a regulated source. The data from the most recent year for which data are available must be used. The grid emission factor must be monitored annually, and updated as the regulated source publishes data. If the grid emission factor is published later than year *y*, the emission factor from an earlier year, up to three years prior (*y* − 3), may be used.

The ECF represents the trend in electricity demand based on average electricity consumption within a region or state over a period of at least ten years. Historical data from a recognized national authority may be used to determine the ECF. Projected trends in changes in the rate of electricity demand reported by a national authority may also be used as the ECF.[21] The ECF must be stated as a multiplier. For example, 0.98 represents an electricity consumption growth rate of −2%.

The ECF is used to update the baseline electricity consumption based on decreases in electricity demand over time. The ECF must only be applied when it is less than 1 to maintain conservativeness in the emission reduction calculation. This factor must be applied to the calculation of the emission reductions after project implementation because electricity consumption in the baseline may not remain the same (see Figure 3). The factor must be determined from local, regional or national electricity household consumption data from a government agency, a public utility or regulatory agency, or a recognized energy research organization.

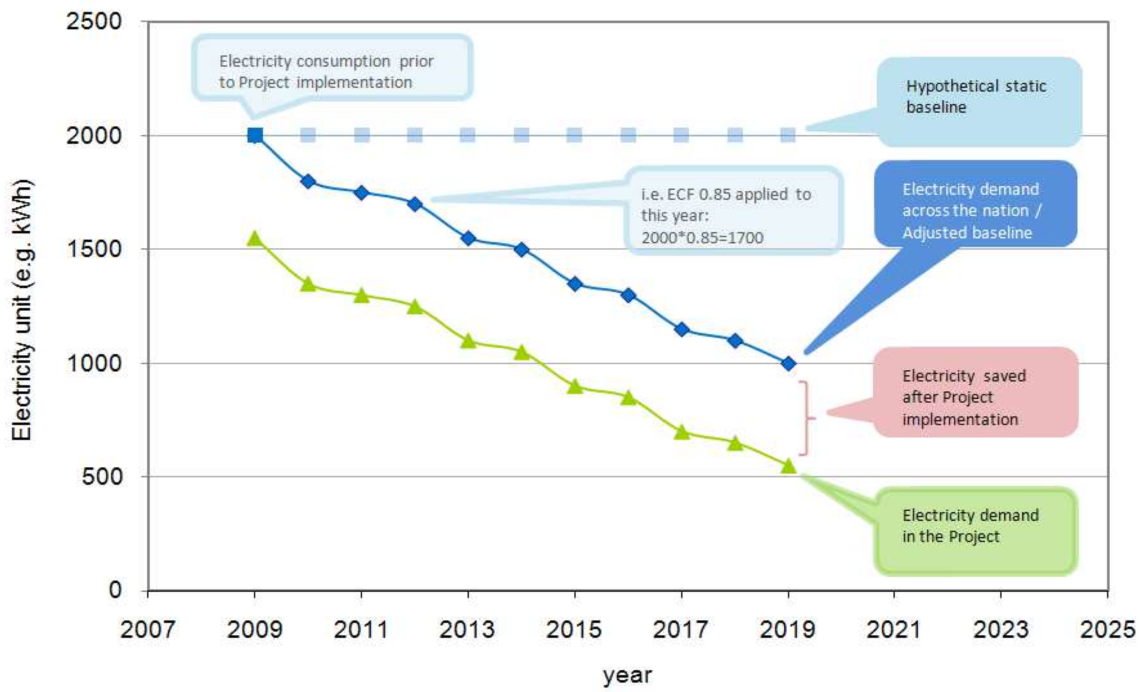
In a situation where overall electricity consumption decreases, the Electricity Correction Factor ECF ensures against over-estimation of emission reductions (see Figure 4).

[20] https://www.gov.uk/government/publications/impacts-of-leakage-from-refrigerants-in-heat-pumps

[21] Examples of reported values that may be used as an ECF are available at the Department of Energy website: http://apps1.eere.energy.gov/states/electricity.cfm/state=ME.

Figure 4 shows how the adjusted consumption approach takes into account a reduction in electricity consumption over time. Failure to adjust for decreasing consumption over time would result in an over-estimation of emission reductions.

Figure 4. Reduction in electricity consumption as a result of an adjusted consumption approach



The heating/cooling degree day correction factors (HDDCF and CDDCF) are used to update the baseline energy consumption annually based on changes in temperature. These factors account for changes in heating/cooling degree days and associated changes in heating and cooling loads (see Figure 3). The factors must be determined based on data from reputable regional or national meteorological organizations.[22]

The heating degree day correction factor must be calculated as follows:

$$HDDCF_y = \frac{HDD_y}{HDD_b} \tag{12}$$

Where:

HDD_y = Heating degree days for year *y* after the retrofit

HDD_b = Heating degree days for one year before the retrofit

The cooling degree day correction factor must be calculated as follows:

[22] An example of such organization is the National Oceanic and Atmospheric Administration (NOAA) in the United States.

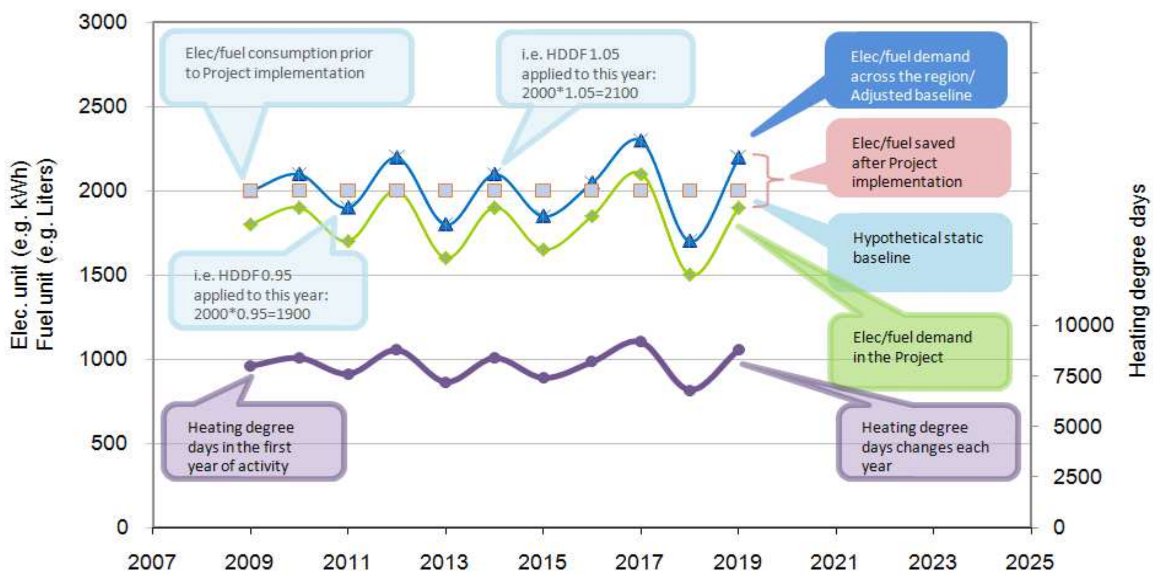
$$CDDCF_y = \frac{CDD_y}{CDD_b} \tag{13}$$

Where:

CDD_y	=	Cooling degree days for year *y* after the retrofit
CDD_b	=	Cooling degree days for one year before the retrofit

Figure 5 shows how heating degree days affect fuel/electricity consumption over time. Failure to adjust the baseline based on changes in temperature would result in inaccurate calculation of emission reductions.

Figure 5. Fuel/electricity consumption change caused by heating degree days



8.1.1 Quality Assurance

When using the adjusted consumption approach, a sample group of dwellings weatherized as part of the project must be monitored to ensure the reduction in energy consumption and resulting reduction in emissions is real. The sample group must measure the emission reductions resulting from the change in energy consumption. In case of a significant discrepancy between emission reductions calculated according to the approach and emission reductions calculated from the sample group, the adjusted baseline consumption approach must be calibrated accordingly. The sample size of the sample group must be established by multiplying 0.6 by the square root of the total number of dwellings, *i*, or appliances, included in the project.[23] Monitoring of the sample group for quality assurance must occur for two years and must consist of collecting electricity and fuels bills that represent a twelve month period.

When the data come from two different processes, such as the adjusted consumption calculation and the measurements from the sample group, significant discrepancy is defined on the basis of an independent two-sample t-test for equality of two means. If the value T of the above statistic obtained from a t-value table or calculation is greater than the corresponding value of the t-distribution for a 95% confidence level and degrees of freedom given by $2n - 2$, then the null hypothesis of equal means is rejected and the observed discrepancy is concluded to be significant.

A t-test is a standard statistical tool and readily available. One of the t-tests set forth below must be applied. The particular test must be determined by the type of samples, samples sizes and assumptions made on the underlying population variances.

1) An independent two-sample t-test for samples of equal sizes and equal variances must be used when the number of observations (data points) in both samples is equal and it can reasonably be assumed that the population variance of both samples is the same.
2) An independent two-sample t-test for unequal sample sizes and equal variances must be used when the number of observations (data points) in both samples is not equal and it can reasonably be assumed that the population variance of both samples is the same.
3) An independent two-sample t-test for unequal sample sizes and unequal variances must be used when the two data samples are of unequal size and it can be reasonably assumed that the population variance is different. This test is referred to as Welch's t-test.

The parameters to be monitored in the adjusted consumption approach are listed in Section 9.

8.2 Pre- and Post-Retrofit Audit Approach

The project carbon stock change is calculated as follows:

Monitoring emission reductions must be based on the data generated by a pre- and post-retrofit energy audit for a sample of the dwellings. A pre-retrofit audit must take place once before project implementation for every dwelling and a post-retrofit audit must take place once after the retrofit has been completed for a sample of the dwellings. In every multi-family building, a representative sample of the dwellings must undergo a pre- and post-retrofit audit. The pre-retrofit audit must determine the electricity demand and heat load in the baseline. The pre-retrofit electricity demand and heat load must then be compared to the post-retrofit electricity demand and heat load. This comparison must provide the electricity demand

[23] The equation for determining the minimum sample size number for quality assurance purposes was taken from the surveillance requirements in the IAF Guidance on the Application of ISO/IEC Guide 66 Issue 4 IAF GD: 2006.

reduction factor and the heat load reduction factor, which must be used to calculate emission reductions created by the project.

To calculate GHG emission reductions, the reduction factors obtained from the pre- and post-energy audit must be applied to the baseline consumption of electricity and fuel. The result must then be multiplied by the emission factor of the fuel type. Reductions must be adjusted for changes in electricity demand over time and adjusted for heating/cooling degree days during the project crediting period.

Energy auditors must be certified by a public authority or a private certification program recognized by a public authority. Energy audits must be conducted using industry best-practices, cover both fuel and electricity consumption, include diagnostic tests (such as a blower door test, pressure pan test or thermal imaging) and use energy modeling software, or appropriate calculations.[24]

The electricity demand reduction factor (EDF) must be calculated for a sample of the dwellings as follows:

$$EDF = 1 - \frac{\sum_{s=1}^{S} E_{dem,post,s}}{\sum_{s=1}^{S} E_{dem,pre,s}} \quad (14)$$

Where:

EDF	=	Electricity demand reduction factor (no unit)
$E_{dem,post,s}$	=	Electricity demand post-retrofit for dwelling s (kW)
$E_{dem,pre,s}$	=	Electricity demand pre-retrofit for dwelling s (kW)
S	=	Number of sample dwellings
s	=	Sample dwelling undergoing post retrofit audit

The heat load reduction factor (HLF) must be calculated for a sample of the dwellings as follows:

$$HLF = 1 - \frac{\sum_{s=1}^{S} H_{load,post,s}}{\sum_{s=1}^{S} H_{load,pre,s}} \quad (15)$$

Where:

HLF	=	Heat load reduction factor (no unit)
$H_{load,post,s}$	=	Heat load post-retrofit for dwelling s (kWh/m^2)
$H_{load,pre,s}$	=	Heat load pre-retrofit for dwelling s (kWh/m^2)

[24] In the United States there are several established energy auditing programs that are credible and accepted as industry best practice. Examples include, but are not limited to RESNET HERS rating, Building Performance Institute Audit, Home Performance with Energy Star, Maine Certified Energy Audit, Energy Plus. The certification process is a substitute for a single industry standard.

S	=	Number of sample dwellings
s	=	Sample dwelling undergoing post retrofit audit

Reductions must be calculated as follows:

$$ER_y = \sum_{i=l}^{I} Elec_{b,i} * EDF * ECF_y * CDDCF_y * Elec_{CO2} + \sum_{i,j=l}^{I,J} F_{b,i,j} * HLF * HDDCF_y * Cal_j * F_{CO2} - L_y \quad (16)$$

Leakage, L_y, must be calculated using Equation (8).

8.2.1 Quality Assurance

When using the pre- and post-audit approach, energy bills based on direct metering of consumption must be collected for one year pre-retrofit and compared with post-retrofit energy bills based on direct metering of consumption in a sample of dwellings. When dealing with non-regulated fuels, an acceptable alternative measure must be compared to that same measure as shown in the post-retrofit audit to ensure the energy savings were achieved. The sample size for quality assurance samples must be established by multiplying the 0.6 by square root of the total number of dwellings, *i*, or appliances, included in the project. The reduction in demand as calculated in Equation (14) and Equation (15), must be compared to the reduction in consumption based on directly metered electricity or natural gas consumption data, or in the case of non-regulated fuels an acceptable alternative measure. The sample group must be tested for a significant discrepancy between the calculated reduction in energy demand as shown in the post-retrofit audit and actual reduction in consumption calculated from directly metered energy bills. When dealing with non-regulated fuels an acceptable alternative measure must be used, as noted above. If the discrepancy between the two mean values is found to be significant, the mean energy consumption from the directly metered value must be used to calculate the HLF or EDF.

When the two data samples come from the same dwelling, significant discrepancy is defined on the basis of a dependent two-sample t-test for equality of two means. If the t-value of the above statistic obtained from a t-value table or calculation is greater than the corresponding value of the t-distribution for a 95% confidence level and degrees of freedom given by $n - 1$, then the null hypothesis of equal means is rejected and the observed discrepancy is concluded to be significant.

A dependent two-sample t-test must be applied to test for the difference of the two means. The two means to be compared must be from the sample group of weatherized dwellings, and must be the mean of the energy demand determined by the post-retrofit audit and the mean of the directly metered energy bill in the case of electricity and natural gas. However, in the case of non-regulated fuels, the two means compared must be based on an acceptable alternative measure, such as blower door test value as shown in the post-retrofit audit, and the blower door test value recorded one year post-retrofit.

The parameters to be monitored in the pre-and post-retrofit audit approach are listed in Section 9.

8.3 Control Group Approach

In this approach a control group and a sample group must be defined. The control group must be comprised of dwellings from the same building stock that are not, and must not be weatherized.[25] The sample group must be comprised of dwellings to be weatherized, or, in the case of mobile homes, replaced. Electricity and fuel bills must be collected for both groups annually throughout the project crediting period. The control group must consist of dwellings that have not been weatherized as part of the project. The project must not prevent or deny weatherization to any homeowner, or individual for the purpose of maintaining the control group. Instead, as the population of weatherized dwellings increases, the control group sample may include different dwellings as long as the control group contains only non-weatherized dwellings.

The difference in the energy consumption between the control group and the sample group each year will constitute the fuel and electricity savings for all dwellings in the project for that year and must serve as the basis for calculating emission reductions.[26]

The sample group must come from dwellings included in the project activity. The control group must be selected from dwellings not included in the project activity and must have the following requirements:

1) Participants must not have the ability to “opt-in” to the control group.
2) Once selected, homeowners must be required to make their fuel and electricity bills available to the project. Where appropriate, the homeowner will be requested to sign a waiver granting the project proponent electronic access to directly metered electricity and gas bills.
3) Dwellings must be in the same building stock.

GHG emission reductions must be calculated as follows:

$$ER_y = \sum_{b=1}^{B}\left\{\left(Elec_{CG,y,b} - Elec_{SG,y,b}\right) * Elec_{CO2}\right\} + \sum_{j=1}^{J}\left\{\left(F_{CG,y,j,b} - F_{SG,y,j,b}\right) * Cal_j * F_{CO2j}\right\} * I_b - L_{y,b} \quad (17)$$

[25] The control group sample size must be large enough to be statistically valid. When approaching complete saturation of weatherized homes, the control group will diminish in size as the number of non-weatherized homes diminishes. This is a risk that must be weighed when choosing the control group approach. One option for addressing the diminishing control group is to use the control group approach for as long as possible and then switch to the adjusted consumption approach. The control group monitoring will be able to be used as the baseline in the adjusted consumption approach.

[26] Since the energy consumed by retrofitted dwellings must be directly compared to the energy consumed by non-retrofitted dwellings within the same building stock and the same year, there is no need to apply the electricity and heating/cooling degree day correction factors.

Where:

$Elec_{SG,y,b}$	=	Mean electricity consumed by sample group dwellings in building stock *b* in year *y*
$Elec_{CG,y,b}$	=	Mean electricity consumed by control group dwellings in building stock *b* in year *y*
$F_{SG,y,j,b}$	=	Mean fuel type *j* consumed by sample group dwellings in building stock *b* in year *y*
$F_{CG,y,j,b}$	=	Mean fuel type *j* consumed by control group dwellings in building stock *b* in year *y*
I_b	=	Number of dwellings in building stock *b*
$L_{y,b}$	=	Leakage in building stock *b* in year *y*

Leakage, $L_{y,b}$, must be calculated for each building stock using Equation (8).

To ensure conservativeness in the emission reduction calculation approach, a 95% confidence interval, with an alpha value equal to 5% (α =0.05) must be applied to the fuel and/or electricity consumption within the control group and the sample group, denoted by $Elec_{SG,y,b}$, $Elec_{CG,y,b}$, $F_{SG,y,j,b}$, and $F_{CG,y,j,b}$ above. The lower bound of the confidence interval of the control group, and the upper bound of the confidence interval of the sample group must be the values compared to determine the emission reductions resulting from project activity.

The 95% confidence interval must be calculated as follows:

$$x - Z_{0.025}(SE) < \mu < x + Z_{0.025}(SE)$$
$$SE = {}^{\sigma}/_{\sqrt{n}} \; and \; \sigma = s * \sqrt{n/(n-1)} \quad (18)$$

Where:

x	=	Mean energy consumption calculated from the sample
$Z_{0.025}$	=	1.960, established standard value
s	=	Standard deviation calculated from the sample
n	=	Sample size
μ	=	Mean of the population; not actually calculated, instead it is contained within the upper and lower bounds of the equation
SE	=	Standard error
σ	=	Standard deviation that approximates the standard deviation of the population, used to calculate the standard error

The parameters to be monitored in the control group approach are listed in Section 9.

8.4 Deemed Savings Approach

Emission reductions for the replacement of appliances must be calculated as follows:

1) The energy demand (rated capacity) of both the appliance to be replaced and of the replacement appliance must be determined from the nameplate, manufacturer's specification sheet, or direct metering;
2) The typical annual hours of operation of the appliance to be replaced in the project area must be recorded or, for HP/HPWHs, modelled (see Section 4 for modelling requirements);
3) The GHG emission reductions from an individual appliance must be calculated by comparing the energy demand of the replacement appliance with that of the replaced appliance, multiplied by annual hours of operation and by the grid emission factor. To account for failed operation of appliances a correction factor must be applied.

GHG emission reductions must be calculated as follows:

$$ER_y = \sum_{k=1\ thru\ K,f} a_k (E_{f,dem.pre,k} * h_{k-pre} - E_{f,demn.post,k} * h_{k-post}) * EF_{f,CO2} * Corr_k - L_y \quad (19)$$

Where:

$E_{f,dem,pre,k}$	=	Energy demand of appliance type *k* using energy source *f* before the replacement takes place (Btu/hour)
$E_{f,dem.post,,k}$	=	Energy demand of appliance type *k* using energy source *f* after the replacement (Btu/hour)
$h_{k\text{-}pre}$	=	Annual working hours of the appliance type *k* before replacement (hours)
$h_{k\text{-}post}$	=	Annual working hours of the appliance type *k* after replacement (hours)
$Corr_k$	=	Correction factor for failed operation of each appliance type *k*
a_k	=	Number of appliances of type *k*
K	=	Number of appliance types
k	=	Appliance type

Leakage, L_y, must be calculated using Equation (8).

Note – $EF_{f,CO2}$ is given in Equation (9b) as emission factor for energy source f (t CO_2e/Btu).

Note – When baseline and project appliances use the same electricity energy source $E_{f,dem,pre,k}$ and $E_{f,dem,post,k}$ can be supplied in kWh, and EF_{CO2} can be substituted by $Elec_{CO2}$, using the grid emission factor per Equation (7).

Modelling results for HP and HPWH will yield comparable Btu (or kWh) results (that is $E_{dem} \times h_k$ both pre and post) for baseline and project (pre/post) appliances (not Btu/hour as *E* is defined in Equation (19)) since the models calculate the equivalent hours that HP/HPWHs need to run to deliver the same level of service as the baseline systems. So the Btu/kWh results from modelling will incorporate both the product of both the *E* and H_k factors.

Monitoring must consist of verifying the operation of a sample of the appliances within the first year of installation and in three year intervals thereafter or, for HP/HPWHs, modelling results .

The parameters to be monitored in the deemed savings approach are listed in Section 9.

8.5 Mobile Homes Approach

GHG emission reductions for the replacement of mobile homes must be calculated as follows:

1) The heat load of both the mobile home to be replaced and of the replacement home must be determined from best practice heat load modelling. In the case of the home to be replaced, the heat load must be calculated by applying a heat load formula that applies a default energy consumption value determined from statistically significant fuel consumption records.[27] In the case of the replacement home, the heat load must be modelled taking into account the building specifications. The building specifications may include but are not limited to; R-value of insulation in the floor, walls and ceiling, U-value and size of the windows, and the R-value of the skirting.
2) Emission reductions must be based on the difference between pre- and post-replacement heat load[28] and pre-and post-replacement size of the mobile home, multiplied by the annual heating/cooling degree days, and both the calorific value and the emission factor of the fuel consumed within the dwelling.[29]
3) If appliances are replaced at the same time the mobile home is replaced, the calculation of emission reductions from appliance replacement must follow the deemed savings approach. Total emission reductions must be the sum of emission reductions from the replacement of the mobile home plus the emission reductions from replacement of the appliances, minus leakage.

GHG emission reductions must be calculated as follows:

$$ER_y = \sum_{i=1\ to\ I,j} (H_{j,loadpre,i} * S_{pre,i} - H_{j,load.post,i} * S_{post,i}) * HDD_y * F_{CO2,j} + ER_{ARy} \quad (20)$$

Where:

$H_{j,load,pre,i}$ = Heat load from fuel type *j* of mobile dwelling *i* to be replaced (GJ/m^2/HDD)

$H_{j,load,post,i}$ = Heat load from fuel type *j* of replacement dwelling *I* (GJ/m^2/HDD)

HDD_y/CDD_y = Heating/cooling degree days

$S_{pre,i}$ = Size of dwelling *i* to be replaced (m^2)

[27] The heat load formula must be based on best practice energy modeling software that takes into account the number of rooms, the metric size of the rooms, the energy load per meter, and the degree days of the region. In the United States, for example, the design heat load calculation that is used to determine fuel award amounts in the national Low Income Home Energy Assistance Program may be used. That equation is: number of rooms multiplied by the square feet per room, multiplied by the Btu consumption per square foot per degree day multiplied by degree days, all divided by 1 000 000 Btus to yield the MBtu needed to heat/cool the space. In metric the equation would be: number of rooms multiplied by the square meters per room, multiplied by the kJ consumption per square meter per degree day multiplied by degree days, all divided by 1 000 000 kJ to determine the GJ needed to heat/cool the space.

[28] The heat load of a dwelling must include cooling load when both heating and cooling are provided by one central system.

[29] When electricity is the central heating/cooling source, the grid electricity factor must replace both the fuel calorific value (Cal_j) and the fuel emission factor ($F_{CO2,j}$). In this case, the heat load must be expressed in kWh per square meter per degree day.

$S_{post,i}$ = Size of replacement dwelling *i* (m^2)

ER_{ARy} = Emission reductions from appliance replacement

i = Number of dwellings

Note – In a region with a predominantly hot climate, the equation may be changed to incorporate cooling load $C_{j,load,pre,j}$ *and cooling degree days* CDD_y*, which would replace* $H_{j.load,pre,j}$ *and heating degree days* HDD_y *respectively.*

GHG emission reductions from appliance replacement, ER_{ARy}, must be calculated using (19).

The parameters to be monitored in the mobile homes approach are listed in Section 9.

9 MONITORING

9.1 Data and Parameters Available at Validation

Monitoring parameters for the performance benchmark for Category A and B				
Parameter	**Unit**	**Parameter description**	**Source**	**Frequency**
a	Percent	Average performance, defined as the annual average percent savings in weather normalized energy consumption in dwellings within the same building stock	Calculated from regional or national statistics for at least the three most recent 12 month periods for which data are available from dwellings within the same building stock. A sample of the dwellings may be used. Percent savings are calculated by comparing year 1 to year 2 and year 2 to year 3.[30]	Once per project crediting period
σ	-	Standard deviation of the annual percent savings	Calculated from regional or national statistics used to calculate the average performance.	Once per project crediting period

[30] Year 1, year 2 and year 3 may be non-consecutive. For example: Year 1 data may cover 2019, year 2 data may cover 2021, and year 3 may cover 2024.

Monitoring parameters for the performance benchmark for Category C				
Parameter	Unit	Parameter Description	Source	Frequency
a	kWh/appliance or Btu/appliance	Average performance, defined as the annual average energy consumption by existing appliances, of the same appliance type	Calculated from regional or national statistics for at least the recent 12 month period for which data are available. A sample of the dwellings may be used.	Once per project crediting period
σ	-	Standard deviation of the annual energy consumption of existing appliances	Calculated from regional or national statistics used to calculate the average performance.	Once per project crediting period

Monitoring parameters for the adjusted consumption approach, pre- and post-retrofit audit approach, control group approach, and mobile homes approach				
Parameter	Unit	Parameter Description	Source	Frequency
$Elec_{CO2}$	t CO_2e/kWh	Grid emission factor for the regional electricity source	Obtained from a recognized authority; or calculated by the project proponent based on raw data obtained from a local, or national electric utility.	This parameter may be available at validation or may change throughout the project crediting period.
Cal_j	GJ/mass or GJ/volume	Calorific value of fuel type *j*	Local, regional or national data. Where unavailable, IPCC default values must be used.	Once per project crediting period
F_{CO2j}	t CO_2e/GJ	CO_2e emission factor for fuel type *j* (baseline fuel)	Local, regional or national data. Where unavailable, IPCC default emission factors must be used.	Once per project crediting period

Parameter	Unit	Parameter Description	Source	Frequency
$Elec_{CO2}$	t CO_2e/kWh	Grid emission factor for the regional electricity source	Obtained from a recognized authority; or calculated by the project based on raw data obtained from a local, or national electric utility.	This parameter could be available at validation or it could change throughout the project crediting period
$EF_{f,\ CO2}$	t CO_2e/Btu	Emission factor for energy source *f*	Obtained from a recognized authority; or calculated by the project based on raw data obtained from a local or national utility/credible source.	Once per project crediting period

9.2 Data and Parameters Monitored

Monitoring parameters for the performance benchmark for Category A and B				
Data/ Parameter	Data unit	Description	Source of data	Frequency of monitoring
$EL_{pre,i}$	Btu/m^2	Pre-retrofit energy load of dwelling *i*	Energy audit	Once
$EL_{post,i}$	Btu/m^2	Post-retrofit energy load of dwelling *i*	Energy audit	Once

Monitoring parameters for the performance benchmark for Category C				
Data/ Parameter	Data unit	Description	Source of data	Frequency of monitoring
$a_{rc,\ k}$	kWh/appliance or Btu/appliance or credible	Annual energy consumption of the	Nameplate, or manufacturer's specification sheet;	Once

Monitoring parameters for the performance benchmark for Category C				
Data/ Parameter	Data unit	Description	Source of data	Frequency of monitoring
	efficiency metric/appliance (e.g., AFEU, SEER, CEER, ERR COP for HP, UEF for HPWH)	replacement appliance, type *k*		

Monitoring parameters for the adjusted consumption approach				
Data/ Parameter	Data unit	Description	Source of data	Frequency of monitoring
$Elec_{b,i}$	kWh/yr	Electricity consumed in the year prior to project implementation in dwelling *i* (baseline consumption)	Electricity bills for 12 months pre-retrofit. Bills for a sample of the dwellings in the same building stock must be monitored, or bills may be collected for all dwellings in the project.	Once
$Elec_{p,y,i}$	kWh/yr	Electricity consumed by the project in year *y* for dwelling *i*	Post-retrofit electricity bills	Collected monthly, recorded annually
$F_{b,i,j}$	Mass or volume per dwelling per year	Fuel type *j* consumed in the year prior to project implementation for dwelling *i* (baseline consumption)	Pre-retrofit fuel bills covering a twelve month period. Bills for a sample of the dwellings in the same building stock must be monitored, or bills may be collected for all dwellings in the project.	Once

Monitoring parameters for the adjusted consumption approach				
Data/ Parameter	Data unit	Description	Source of data	Frequency of monitoring
$F_{p,y,i,j}$	Mass or volume per dwelling per year	Fuel type *j* consumed by the project in year *y* for dwelling *i*	Post- retrofit fuel bills covering a twelve month period[31,32]	Annually
ECF_y	-	Electricity correction factor for year *y* The ECF is only to be applied in the equation if it is negative.	Calculated by the project based on national energy statistics.	Applied annually
CDD_y	Degree days	Cooling degree days for year *y*	Regional statistics	Annually
CDD_b	Degree days	Cooling degree days in the year prior to project implementation	Regional statistics	Once
HDD_y	Degree days	Heating degree days for year *y*	Regional statistics	Annually
HDD_b	Degree days	Heating degree days in the year prior to project implementation	Regional statistics	Once
J	-	Number of fuel types	Project proponent database	Annually
I	-	Number of retrofitted dwellings	Project proponent database	Annually
C	-	Continued operation of the installed measures	This parameter will be monitored in the sample of dwellings selected for quality	Annually

[31] Fuel consumption must be based on fuel purchased as reflected in the billing. Some households may store some fuel, or refill the tank before it is empty. However, the fuel storage level will become inconsequential over time as any fuel purchased to fill the fuel tank above the storage level will be consumed and therefore reflected in the billing upon refueling. Any remaining differences in the filling level, before Project implementation and at the end of the Project lifetime, of individual households will cancel each other out over the entire sample of Dwellings.

[32] In the case where consumed energy for each household cannot be measured separately or in the case of district heating, the temperature in/out and water discharge (flow rate) of the heating system must be monitored. Fuel consumption monitoring must take place using the utility company fuel inventory for that specific district heating system.

Monitoring parameters for the adjusted consumption approach				
Data/ Parameter	**Data unit**	**Description**	**Source of data**	**Frequency of monitoring**
			assurance monitoring. Non-operational measures must be excluded from reduction calculations.	
$a_{np,k,y}$	-	Replaced appliance of type *k* not properly disposed of in year *y*	Disposal documentation and project proponent database	Annually
$E_{dem.pre,k}$	kW	Electricity demand of appliance *k* before replacement	Nameplate, or manufacturer's specification sheet, or direct metering of the appliance	Once pre-replacement
h_k	Hours	Annual working hours of appliance *k*	Sampling, consumer surveys, or common practice based on local, regional, or national data[33]	Once, may be updated
RCC_a	Grams	The refrigerant charge capacity of the cooling appliance not properly disposed of.	Manufacturer's specification sheet on the cooling appliance.	Once
R	-	Type of refrigerant used in the cooling appliance.	Manufacturer's specification sheet on the cooling appliance.	Once
-	Mass or volume per dwelling per year	Quality assurance sample group of fuel consumption within the dwelling	Fuel bills covering a twelve month period. Bills for the sample group sample of dwellings in the same building stock must be monitored.	Annually, for 2 years

[33] For example, in the United States, the US Department of Energy publishes annual operating hours of common household appliances in the Buildings Energy Data Book. This information is publically available at http://buildingsdatabook.eren.doe.gov/TableView.aspx?table=2.1.16

Monitoring parameters for the adjusted consumption approach				
Data/ Parameter	Data unit	Description	Source of data	Frequency of monitoring
-	kWh/yr	Quality assurance sample group of electricity consumption within the dwelling	Electricity bills covering a twelve month period. Bills for the sample group sample of dwellings must be monitored.	Annually, for 2 years
$a_{k,y,OPS}$	-	Number of appliances of each appliance type *k* installed and in operation during project year *y*	Project proponent database	Annual
$RCCinstalled_a$	Grams	Charge capacity of refrigerant gas of installed cooling or heat pump appliance *a*	Manufacturer's specification sheet on the cooling or heat pump appliance	Once
$LR\%y$	%	Annual leakage rate of refrigerant gas *R* used in installed appliance	Common practice rates based on local, regional or national data	Once

Monitoring parameters for pre- and post-retrofit audit approach				
Data/ Parameter	Data unit	Description	Source of data	Frequency of monitoring
$Elec_{b,i}$	kWh/yr	Electricity consumed in the year prior to project implementation in dwelling *i* (baseline consumption)	Electricity bills for 12 months pre-retrofit. Bills for a sample of the dwellings in the same building stock must be monitored, or bills may be collected for all dwellings in the project.	Once

Monitoring parameters for pre- and post-retrofit audit approach				
Data/ Parameter	**Data unit**	**Description**	**Source of data**	**Frequency of monitoring**
$E_{dem,pre,i}$	kW	Electricity demand pre-retrofit for dwelling *i*	Pre-retrofit audit report	Once
$E_{dem,post,i}$	kW	Electricity demand post-retrofit for dwelling *i*	Post-retrofit audit report	Once
$F_{b,i,j}$	Mass or volume per dwelling per year	Fuel type *j* consumed in the year prior to project implementation for dwelling *I* (baseline consumption)	Pre-retrofit fuel bills covering a twelve month period. Bills for a sample of the dwellings in the same building stock must be monitored, or bills may be collected for all dwellings in the project.	Once
$H_{load,pre,i}$	kWh/m²/HDD GJ/m²/HDD	Heat load pre-retrofit for dwelling *i*	Pre-retrofit audit report	Once
$H_{load,post,i}$	kWh/m²/HDD GJ/m²/HDD	Heat load post-retrofit for dwelling *i*	Post-retrofit audit report	Once
ECF_y	-	Electricity correction factor for year *y*	Calculated by the project based on national energy statistics.	Applied annually
CDD_y	Degree days	Cooling degree days for year *y*	Regional statistics. Use localized data when available	Annually
CDD_b	Degree days	Cooling degree days in the year prior to project implementation	Regional statistics. Use localized data when available	Once

Monitoring parameters for pre- and post-retrofit audit approach				
Data/ Parameter	Data unit	Description	Source of data	Frequency of monitoring
HDD_y	Degree days	Heating degree days for year *y*	Regional statistics. Use localized data when available	Annually
HDD_b	Degree days	Heating degree days in the year prior to project implementation	Regional statistics. Use localized data when available	Once
J	-	Number of fuel types	Project proponent database	Annually
I	-	Number of retrofitted dwellings	Project proponent database	Annually
S	-	Number of sample dwellings	Pre- and Post-retrofit audit reports	Once
$a_{np,k,y}$	-	Replaced appliance of type *k* not properly disposed of in year *y*	Disposal documentation and project proponent database	Annually
h_k	Hours	Annual working hours of appliance *k*	Sampling, consumer surveys, or common practice based on local, regional or national data	Once, may be updated
$E_{dem.pre,k}$	kW	Electricity demand of appliance *k* before replacement	Nameplate, or manufacturer's specification sheet, or direct metering of the appliance	Once pre-replacement
RCC_a	Grams	The refrigerant charge capacity of the cooling appliance not properly disposed of.	Manufacturer's specification sheet on the cooling appliance	Once

Monitoring parameters for pre- and post-retrofit audit approach				
Data/ Parameter	Data unit	Description	Source of data	Frequency of monitoring
R	-	Type of refrigerant used in the cooling appliance	Manufacturer's specification sheet on the cooling appliance	Once
$a_{k,y,OPS}$	-	Number of appliances of each appliance type *k* installed and in operation during project year *y*	Project proponent database	Annual
$RCCinstalled_a$	Grams	Charge capacity of refrigerant gas of installed cooling or heat pump appliance *a*	Manufacturer's specification sheet on the cooling or heat pump appliance	Once
$LR\%y$	%	Annual leakage rate of refrigerant gas *R* used in installed appliance	Common practice rates based on local, regional, or national data	Once

Monitoring parameters for control group approach				
Data/ Parameter	Data unit	Description	Source of data	Frequency of monitoring
$Elec_{SG,y,b}$	kWh/yr	Mean electricity consumed by sample group dwellings in building stock *b* in year *y*	Electricity bills	Monitored monthly, calculated annually
$Elec_{CG,y,b}$	kWh/yr	Mean electricity consumed by control group dwellings in building stock *b* in year *y*	Electricity bills	Monitored monthly, calculated annually
$F_{SG,y,j,b}$	Mass or volume per	Mean fuel type *j* consumed by sample	Fuel bills	Monitored monthly or as fuel is

Monitoring parameters for control group approach				
Data/ Parameter	Data unit	Description	Source of data	Frequency of monitoring
	dwelling per year	group dwellings in building stock *b* in year *y*		delivered, totaled annually
$F_{CG,y,j,b}$	Mass or volume per dwelling per year	Mean fuel type *j* consumed by control group dwellings in building stock *b* year *y*	Fuel bills	Monitored monthly or as fuel is delivered, totalled annually
J	-	Number of fuel types	Project proponent database	Annually
I_b	-	Number of dwellings in building stock *b*	Project proponent database	Annually
$a_{np,k,y}$	-	Replaced appliance of type *k* not properly disposed of in year *y*	Disposal documentation and project proponent database	Annually
h_k	hours	Annual working hours of appliance *k*	Sampling, consumer surveys, or common practice based on local, regional, or national data	Once, may be updated
$E_{dem,pre,k}$	kW	Electricity demand of appliance *k* before replacement	Nameplate, manufacturer's specification sheet, or direct metering of the appliance	Once pre-replacement
RCC_a	Grams	The refrigerant charge capacity of the cooling appliance not properly disposed of.	Manufacturer's specification sheet on the cooling appliance	Once
R	-	Type of refrigerant used in the cooling appliance.	Manufacturer's specification sheet on the cooling appliance	Once
$a_{k,y,OPS}$	-	Number of appliances of each appliance type	Project proponent database	Annual

Monitoring parameters for control group approach				
Data/ Parameter	Data unit	Description	Source of data	Frequency of monitoring
		k installed and in operation during project year *y*		
$RCCinstalled_a$	Grams	Charge capacity of refrigerant gas of installed cooling or heat pump appliance *a*	Manufacturer's specification sheet on the cooling or heat pump appliance	Once
$LR\%_y$	%	Annual leakage rate of refrigerant gas *R* used in installed appliance	Common practice rates based on local, regional, or national data	Once

Monitoring parameters for replacement of appliances				
Data/ Parameter	Data unit	Description	Source of data	Frequency of monitoring
$E_{f,dem,pre,k}$	Btu/hour Note: if there is no fossil fuel switching, kW may be used, substituting $E_{dem,pre,k}$ for $E_{f,dem,pre,k}$ and substituting $Elec_{CO2}$ for EF_{CO2} in Equation (19). Substitute parameters are given in tables above	Energy demand of appliance *k* using energy source *f* pre-replacement	Nameplate, manufacturer's specification sheet, or direct metering of the appliance. Note that for HP HPWH modelling, Applicability Condition in Section 4 applies.	Once, pre-replacement
$E_{f,dem,post,k}$	Btu/hour Note: if there is no fossil fuel switching, kW may be used, substituting $E_{dem,post,k}$ for	Energy demand of appliance *k* using energy source *f* post-replacement	Nameplate, manufacturer's specification sheet, or direct metering of the appliance	Once, post-replacement

Monitoring parameters for replacement of appliances				
Data/ Parameter	Data unit	Description	Source of data	Frequency of monitoring
	$E_{f,dem,post,k}$ and substituting $Elec_{CO2}$ for EF_{CO2} in Equation (19) Substitute parameters are given in this and other tables		Note that for HP HPWH modelling, Applicability Condition in Section 4 applies	
$E_{dem,post,k}$	kWh	Electricity demand of appliance *k* post-replacement	Nameplate, manufacturer's specification sheet, or direct metering of the appliance	Once, post-replacement
$h_{kpre,\ hkpost}$	hours	Annual working hours of appliance *k*, pre and post retrofit	Sampling, consumer surveys, or common practice based on local, regional or national data. Note that for HP HPWH modelling, Applicability Condition in Section 4 applies	Once, may be updated
$Corr_k$	-	Correction factor for the failed operation of type of appliance *k*	Surveys conducted by project proponent, other proponent operation data, or common practice rates based on local, regional, or national data	Within the first year of installation and in years 1, 4, and 7 thereafter
$a_{np,k,y}$	-	Replaced appliance of type *k* not properly disposed of in year *y*	Disposal documentation and project proponent database	Annually

Monitoring parameters for replacement of appliances				
Data/ Parameter	Data unit	Description	Source of data	Frequency of monitoring
RCC_a	Grams	Refrigerant charge capacity of the cooling appliance not properly disposed of	Manufacturer's specification sheet on the cooling or heat pump appliance	Once
R	-	Type of refrigerant used in the cooling appliance.	Manufacturer's specification sheet on the cooling or heat pump appliance	Once
K	-	Number of appliance type	Project proponent database	Once
a_k	-	Number of appliances of each appliance type *k*	Project proponent database	Once
$a_{k,y,OPS}$	-	Number of appliances of each appliance type *k* installed and in operation during project year *y*	Project proponent database	Annual
$RCCinstalled_a$	Grams	Charge capacity of refrigerant gas of installed cooling or heat pump appliance *a*	Manufacturer's specification sheet on the cooling or heat pump appliance	Once
$LR\%y$	%	Annual leakage rate of refrigerant gas *R* used in installed appliance	Common practice rates based on local, regional, or national data	Once

Monitoring parameters for mobile homes approach				
Data/ Parameter	Data unit	Description	Source of data	Frequency of monitoring
$H_{j,load,pre,i}$	kWh/m²/HDD GJ/m²/HDD	Heat load of mobile dwelling *i* to be replaced from fuel type *j*	Calculating the heat load by applying a heat load formula with default values derived from reliable regional energy consumption data or best practice heat load modeling based on the specification sheet provided by the manufacturer.	Once
$H_{j,load,post,i}$	kWh/m²/HDD GJ/m²/HDD	Heat load of replacement dwelling *i* from fuel type *j*	Calculated using best practice heat load modeling based on the specification sheet provided by the manufacturer.	Once
HDD_y	Degree days	Heating degree days in year *y*	Regional statistics	Annually
CDD_y	Degree days	Cooling degree days in year *y*	Regional statistics	Annually
$S_{pre,i}$	m²	Size of dwelling *i* to be replaced	Project proponent database	Once for each dwelling
$S_{post,i}$	m²	Size of replacement dwelling *i*	Disposal documentation and project proponent database	Once for each dwelling
$E_{f,dem,pre,k}$	Btu/hour Note: if there is no fossil fuel switching, kW may be used, substituting $E_{dem,pre,k}$ for $E_{f,dem,pre,k}$ and substituting $Elec_{CO2}$ for EF_{CO2} in Equation (19).	Electricity demand of appliance *k* using energy source *f* before replacement	Nameplate, or manufacturer's specification sheet, or direct metering of the appliance Note that for HP HPWH modeling, Applicability	Once pre-replacement

Monitoring parameters for mobile homes approach				
Data/ Parameter	**Data unit**	**Description**	**Source of data**	**Frequency of monitoring**
	Substitute parameters are given in tables above		Condition in Section 4 applies	
$E_{f,dem,post,k}$	Btu/hour Note: if there is no fossil fuel switching, kW may be used, substituting $E_{dem,post,k}$ for $E_{f,dem,post,k}$ and substituting $Elec_{CO2}$ for EF_{CO2} in Equation (19). Substitute parameters are given in tables above.	Energy demand of appliance *k* using energy source *f* post-replacement	Nameplate, or manufacturer's specification sheet, or direct metering of the appliance Note that for HP HPWH modelling, Applicability Condition in Section 4 applies	Once post-replacement
$h_{k\text{-}pre}$ $h_{k\text{-}post}$	Hours	Annual working hours of appliance *k*, pre and post retrofit	Sampling, consumer surveys, or common practice based on local, regional, or national data Note that for HP HPWH modelling, Applicability Condition in Section 4 applies	Once, may be updated
$Corr_k$	-	Correction factor for the failed operation of type of appliance *k*	Surveys conducted by project proponent, other proponent operation data, or common practice rates based on local, regional, or national data	Within the first year of installation and in three-year intervals thereafter
$a_{np,k,y}$	-	Replaced appliance of type *k* not properly disposed of in year *y*	Disposal documentation and project proponent database	Annually

Monitoring parameters for mobile homes approach				
Data/ Parameter	Data unit	Description	Source of data	Frequency of monitoring
RCC_a	Grams	The refrigerant charge capacity of the cooling appliance not properly disposed of	Manufacturer's specification sheet on the cooling or heat pump appliance	Once
R	-	Type of refrigerant used in the cooling appliance.	Manufacturer's specification sheet on the cooling or heat pump appliance	Once
I	-	Number of retrofitted dwellings	Project proponent database	Annually
$a_{k,y,OPS}$	-	Number of appliances of each appliance type *k* installed and in operation during project year *y*	Project proponent database	Annual
$RCCinstalled_a$	Grams	Charge capacity of refrigerant gas of installed cooling or heat pump appliance *a*	Manufacturer's specification sheet on the cooling or heat pump appliance	Once
$LR\%y$	%	Annual leakage rate of refrigerant gas *R* used in installed appliance	Common practice rates based on local, regional, or national data	Once

DOCUMENT HISTORY

Version	Date	Comment
v1.0	7 Dec 2010	Initial version
v1.1	10 Oct 2012	Revised to conform with VCS requirements for standardized methods.
Draft v1.2	12 Dec 2024	• Adoption of most recent VCS methdology template • Inclusion of HP and HPWH as appliances in Category C and fuel switching in Category A/B approach 2, and Category C and D • Inclusion of leakage emissions from HCFC leaks from appliances • Adoption of VCS tools *VT0008 Additionality Assessment* and *VT0011 Electricity System Emission Factors* to replace the CDM tools