E-5. Install Green Roofs in Place of Dark Roofs

GHG Mitigation Potential

Potentially small reduction in GHG emissions from building energy use

Co-Benefits (icon key on pg. 34)

Climate Resilience

Installing green roofs increases resilience by absorbing less heat and keeping buildings cool, increasing the building's adaptive capacity to extreme heat. This also reduces the strain on the overall grid, particularly the risk of power outages during peak loads, and can reduce energy costs. Green roofs have a smaller heat island reduction effect than certified cool roofs but nonetheless are an improvement over conventional roofs.

Health and Equity Considerations

Green roofs provide additional insulation that can keep buildings cooler in the summer and warmer in the winter, reducing energy costs year-round. This can help protect health and increase economic resilience for vulnerable and low-income residents.

Measure Description

This measure will install green roofs in place of dark roofs. Green roofs consist of a layer of vegetation on top of buildings, which provides natural insulation and climate control benefits. This reduces the electricity and natural gas needed to provide cooling and heating, thereby reducing associated GHG emissions.

Subsector

Energy Efficiency Improvements

Scale of Application

Project/Site

Implementation Requirements

See measure description.

Cost Considerations

Green roofs are usually more expensive to install than conventional dark roofs; however, these costs can be quickly offset by reduced energy usage through better insulation, improved stormwater management, and, in some cases, an extended lifespan. Green roof maintenance costs include irrigation, weed control, and fertilizer in order to maintain the vegetation; however, green roofs generally cost substantially less than conventional roofs or cool roofs over a 50-year lifecycle.

Expanded Mitigation Options

Use native plants on the roof for improved ecosystem health, drought-tolerant plants for water conservation, or plant an edible garden for enhanced food security.

GHG Reduction Formula

A = **D** × [(-E × G × I × J) + (-F × H × K × J)]

GHG Calculation Variables

ID	Variable	Value	Unit	Source
Output				
A	Reduction in GHG emissions from building energy	[ ]	MT CO_2e per year	calculated
User Inputs				
B	Building type	[ ]	text	user input
C	Project location (city)	[ ]	text	user input
D	Roof area	[ ]	KSF	user input
Constants, Assumptions, and Available Defaults				
E	Natural gas savings with measure	Table E-5.1	therm per year per KSF	Sailor et al. 2008
F	Electricity savings with measure	Table E-5.1	kWh per year per KSF	Sailor et al. 2008
G	Carbon intensity of natural gas	Table E-4.5	lb CO_2e per MMBtu	U.S. EPA 2020
H	Carbon intensity of local electricity provider	Tables E-4.3 and E-4.4	lb CO_2e per MWh	CA Utilities 2021
I	Conversion from therm to MMBtu	0.1	MMBtu per therm	conversion
J	Conversion from lb to MT	0.000454	MT per lb	conversion
K	Conversion from kWh to MWh	0.001	MWh per kWh	conversion

Further explanation of key variables:

- (B) – The housing and building types are needed to look up the energy savings for residential and office development (E and F). If the user's building type of interest is not presented in Table E-5.1 in Appendix C, they should exercise caution in extrapolating the results from the listed building types.
- (C) – The project location (i.e., city) is used to look up the energy savings for residential and commercial development (E and F). If the user's city of interest is not presented in Table E-5.1, they should use their judgment to select a listed city that has similar climate and precipitation.
- (E and F) – The Green Roof Energy Calculator is a free, web-based tool developed in 2008 by academic researchers on behalf of the U.S. Green Building Council. The purpose of the tool is to enable architects, developers, and others to obtain quick estimates of how green roof design decisions might affect building energy use. To provide the user with a range of energy savings, the tool was run for the two available building types and five California cities using conservative values for the remainder of the tool inputs. These results are summarized in Table E-5.1. If the user can provide

project-specific values for tool inputs (i.e., growing media depth, leaf area index, irrigation, percent of total roof coverage, roof material albedo), then they should run the tool themselves and use the outputted energy savings in place of the values in Table E-5.1 (Sailor et al. 2008). Additionally, the user can consider calculating their energy savings from this measure using U.S. DOE's EnergyPlus, a more complex, robust model that requires more energy expertise and project inputs (U.S. DOE 2020).

- (G) – The carbon intensity of natural gas was calculated in terms of CO_2e by multiplying the U.S. natural gas combustion emission factors for CO_2, CH_4, and N_2O (U.S. EPA 2020) by the corresponding 100-year GWP values from the IPCC's Fourth Assessment Report (IPCC 2007). Table E-4.5 in Appendix C provides natural gas CO_2e emission factors for residential and commercial uses.
- (H) – GHG intensity factors for major California electricity providers are provided in Tables E-4.3 and E-4.4 in Appendix C. If the project study area is not serviced by a listed electricity provider, or the user is able to provide a project-specific value (i.e., for the future year not referenced in Tables E-4.3 and E-4.4), the user should use that specific value in the GHG calculation formula. If the electricity provider is not known, the user may elect to use the statewide grid average carbon intensity.

GHG Calculation Caps or Maximums

It is assumed that the energy demand of the user's project is currently being met by grid electricity that requires *some* amount of fossil fuel–based energy generation and/or onsite natural gas, both of which emit GHGs from fuel combustion. In other words, the local electricity provider has an energy intensity factor (lb of CO_2e per MWh) greater than zero and/or the project consumes natural gas onsite for building energy. For all-electric projects that are served by electricity providers already with a renewable portfolio of 100 percent, this measure could have no reduction in GHG emissions. If the electricity provider is using REC to meet a 100 percent renewable portfolio goal, then some emissions reductions may be achieved. This measure would still result in the co-benefits of reduced electricity use, enhanced energy security, and reduced urban heat island effect.

Mutually Exclusive Measures

If the user selects Measure E-15, *Require All-Electric Development*, they should exercise caution in quantifying the effect of this measure, given that some of the constants and available defaults were developed with the assumption that the building would be supplied with natural gas.

One option for including the quantified emissions reduction from this measure alongside those achieved by Measure E-15 would be to exclude all of the natural gas–related effects from this measure. In other words, (E) should be zeroed out in the above equation. Note that doing this may result in an underestimation of emissions reductions; green roofs provide additional insulation that can keep buildings warmer in the winter, as evidenced by Table E-5.1.

Example GHG Reduction Quantification

The user reduces building energy emissions by providing a green roof in place of a dark roof. In this example, the measure would be implemented in the city of Sacramento (C) for a mid-rise apartment complex (B) that has a roof area of 5 KSF. Therefore, the natural gas savings would be 8.2 therms per year per KSF (E), and the additional electricity savings would be 37.6 kilowatt-hours per year per KSF (F). The project is in Sacramento Municipal Utility District's (SMUD's) service territory and would begin operation by 2022. It would therefore have an electricity carbon intensity of 344 lb CO_2e per MWh (H). The mitigated emissions would be reduced by 0.32 MT CO_2e per year.

$$A = \mathbf{5\ KSF} \times \left[\left(\frac{\text{-8.2 therm}}{\text{yr}\cdot\text{KSF}} \times \frac{117\text{ lb CO}_2\text{e}}{\text{MMBtu}} \times \frac{0.1\text{ MMBtu}}{\text{therm}} \times \frac{0.000454\text{ MT}}{\text{lb}}\right) + \left(\frac{\text{-126.7 kWh}}{\text{yr}\cdot\text{KSF}} \times \frac{344\text{ lb CO}_2\text{e}}{\text{MWh}} \times \frac{0.001\text{ MWh}}{\text{kWh}} \times \frac{0.000454\text{ MT}}{\text{lb}}\right)\right] = -0.32\ \frac{\text{MT CO}_2\text{e}}{\text{yr}}$$

Quantified Co-Benefits

This measure also has direct climate resiliency benefits. Refer to Measure EH-3, Install Heat-Reducing Roof, in Chapter 4, *Assessing Climate Exposures and Measures to Reduce Vulnerabilities*.

Energy and Fuel Savings

The user would decrease the building natural gas consumption (E X D X I) and, depending on the climate zone for the project area, either decrease or increase the electricity use (F X D X K).

Improved Air Quality

The reduction in natural gas fuel consumption from this measure would result in local improvements in air quality because the fuel consumption occurs on site of the project. The reduction in criteria pollutant emissions (L) achieved by the measure can be calculated as follows.

Criteria Pollutant Emission Reduction Formula

$$L = \mathbf{D} \times -E \times M \times I \times N$$

Criteria Pollutant Emission Reduction Calculation Variables

ID	Variable	Value	Unit	Source
Output				
L	Reduction in criteria pollutant emissions from building energy	[ ]	tons per year	calculated
User Inputs				
	None			
Constants, Assumptions, and Available Defaults				
M	Criteria pollutant emission factors of natural gas	Table E-4.5	lb per MMBtu	U.S. EPA 1998
N	Conversion from lb to ton	0.0005	tons per lb	conversion

Further explanation of key variables:

- (M) – Table E-4.5 presents the criteria pollutant emission factors of natural gas for residential and commercial uses (U.S. EPA 1998).
- Please refer to the *GHG Calculation Variables* table above for definitions of variables that have been previously defined.

Sources

- California Utilities. 2021. Excel database of GHG emission factors for delivered electricity, provided to the Sacramento Metropolitan Air Quality Management District and ICF. January through March 2021.
- Intergovernmental Panel on Climate Change (IPCC). 2007. *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 996 pp. Available: https://www.ipcc.ch/report/ar4/wg1/. Accessed: January 2021.
- Sailor, D., B. Brass, and S. Peck. 2008. *Green Roof Energy Calculator.* Available: https://sustainability.asu.edu/urban-climate/green-roof-calculator/. Accessed: January 2021.
- U.S. Department of Energy. 2020. *EnergyPlus™*. September. Available: https://energyplus.net/. Accessed: January 2021.
- U.S. Environmental Protection Agency (U.S. EPA). 1998. *AP 42, Fifth Edition, Volume I. Chapter 1: External Combustion Sources. 1.4, Natural Gas Combustion*. July. Available: https://www3.epa.gov/ttnchie1/ap42/ch01/final/c01s04.pdf. Accessed: January 2021.
- U.S. Environmental Protection Agency (U.S. EPA). 2020. *Emission Factors for Greenhouse Gas Inventories*. March. Available: https://www.epa.gov/sites/production/files/2020-04/documents/ghg-emission-factors-hub.pdf. Accessed: March 2021.