E-4. Install Cool Roofs and/or Cool Walls in Residential Development

GHG Mitigation Potential

Small

Potentially small reduction in GHG from building energy use

Co-Benefits (icon key on pg. 34)

Climate Resilience

Cool roofs and walls absorb less heat and keep buildings cool, increasing the building's adaptive capacity to extreme heat. This also reduces the strain on the electric grid, particularly the risk of power outages during peak loads, and can reduce energy costs. If implemented across a development or throughout a community, cool roofs and walls can reduce the urban heat island effect, building not just individual but also communitywide resilience to extreme heat.

Health and Equity Considerations

Cool roofs and walls can protect the health of vulnerable and low-income residents during heat waves and extreme heat days. In colder climate zones, cool roofs and walls can potentially increase winter heating costs, but the increase may be offset by reduced electricity bills in summer.

Measure Description

This measure will install cool roofs and/or walls in place of dark roofs and/or conventional walls for residential development. Cool roofs have been designed to reflect more sunlight and absorb less heat than a standard roof, keeping buildings cooler in the summertime and thus reducing air-conditioning loads. Complementary to cool roofs, cool walls achieve a similar result through using more reflective paints or materials. This reduces the electricity needed to provide cooling but can potentially increase the energy needed to provide winter heating, thereby reducing associated GHG emissions depending on the project parameters (e.g., climate, level of implementation, carbon intensity of local electricity provider). However, the winter heating penalty may be small with lower levels of winter sunlight due to shorter daylight hours and more overcast skies.

Subsector

Energy Efficiency Improvements

Scale of Application

Project/Site

Implementation Requirements

Cool roofs can be made of tiles, shingles, coatings, membranes, or metal, among other materials, in a wide range of colors (not just white). Similarly, cool wall paints and materials come in a range of colors, though light-colored paints have the greatest cooling effect. To apply the effectiveness reported by the literature, the albedo of the proposed surface must be at least 0.25 for walls and at least 0.4 for roofs.

Cost Considerations

Installing cool roofs and walls leads to substantial cost savings for relatively low additional input costs. Low-effort residential maintenance options, like painting walls with light-colored or more reflective paint, cost about the same as darker paint colors, and yet immediately reduce the cost of cooling the building. Cool roofs can have higher initial costs, depending on the material chosen, but these costs can be offset by lifetime energy savings.

Expanded Mitigation Options

Pair with Measure E-21, *Install Cool Pavement*, to install cool pavements. This measure could also be paired Measure E-15, *Require All-Electric Development*, to eliminate the implementation disbenefit of worsened air quality, further discussed below under *Quantified Co-Benefits*.

GHG Reduction Formula

$$H_T = H_N + H_S + H_E + H_W$$

$$L_T = \sum L_z \times \frac{H_z}{H_T}$$

$$A = \left[\left(\left(I_R \times G_R \times H_R\right) + \left(I_T \times L_T \times H_T\right)\right) \times M \times O \times Q \times R\right]$$

$$-\left[\left(\left(J_R \times G_R \times H_R\right) + \left(J_T \times L_T \times H_T\right)\right) \times N \times P \times Q \times R\right]$$

GHG Calculation Variables

Many of the values for the variables in this equation can be obtained from the Lawrence Berkeley National Laboratory's Cool Surface Savings Explorer (Explorer) (Levinson et al. 2019). The Explorer is an Excel tool that parses a database containing the results of whole-building model simulations that calculate the building energy changes from the use of cool walls and cool roofs under various scenarios for different building types in California.

ID	Variable	Value	Unit	Source
Output				
A	Reduction in GHG emissions from building energy	[ ]	MT CO_2e per year	calculated
L_T	Composite solar availability factor of non-roof building sides to be cooled	[ ]	unitless	calculated
H_T	Total area of non-roof building sides to be cooled (N+S+E+W)	[ ]	KSF	calculated
User Inputs				
B	Building type	[ ]	text	user input
C	Building climate zone	1–16	integer	user input
D	Building orientation	[ ]	text	user input
E	Building side(s) to be cooled (N, S, E, W & roof)	[ ]	text	user input
F	Albedo of cool surface(s)	0.25–0.60	unitless	user input
G_R	Coverage of cool roof material	0–100	%	user input
H_z	Coverage of cool building side z (N, S, E, W, R [roof])	[ ]	KSF	user input
Constants, Assumptions, and Available Defaults				
I_R	Change in natural gas use of building (roof only)	Savings Explorer	therm per year per m^2	Levinson et al. 2019
I_T	Change in natural gas use of non-roof building sides (N+S+E+W)	Savings Explorer	therm per year per m^2	Levinson et al. 2019

ID	Variable	Value	Unit	Source
J_R	Change in electricity use of building (roof only)	Savings Explorer	kWh per year per m^2	Levinson et al. 2019
J_T	Change in electricity use of non-roof building sides (N+S+E+W)	Savings Explorer	kWh per year per m^2	Levinson et al. 2019
K_z	Wall canyon aspect ratio of building side z (N, S, E, W)	Table E-4.1	unitless	Levinson 2019
L_z	Solar availability factor of building side z (N, S, E, W)	Table E-4.2	unitless	Levinson 2019
M	Carbon intensity of residential natural gas	117	lb CO_2e per MMBtu	U.S. EPA 2020
N	Carbon intensity of local electricity provider	Tables E-4.3 and E-4.4	lb CO_2e per MWh	CA Utilities 2021
O	Conversion from therm to MMBtu	0.1	MMBtu per therm	conversion
P	Conversion from kWh to MWh	0.001	MWh per kWh	conversion
Q	Conversion from lb to MT	0.000454	MT per lb	conversion
R	Conversion from KSF to m^2	92.9	m^2 per KSF	conversion

Further explanation of key variables:

- (B) – The building type is needed to run the Explorer, further discussed under (I). The Explorer provides two types of residential buildings and eight types of commercial buildings.
- (C) – Climate zones are specific geographic areas of similar climatic characteristics, including temperature, weather, and other factors that affect building energy use. The CEC has specified numerous EDFZs in California, which are referenced in CEC's Commercial Forecast and RASS. Note that this measure references the 16 building climate zones (BCZs) that were developed for Title 24 Standards and differ from the EDFZs. Users should ensure that they are selecting the appropriate BCZ by referring to Figure E-4.1 in Appendix C (CEC 2020). Alternatively, users can search for the appropriate BCZ by looking up the project address or zip code in the CEC's web-based interactive map (CEC 2018). The BCZ is needed to run the Explorer, further discussed under (I).
- (D) – The building orientation is needed to run the Explorer, further discussed under (I). Building orientation refers to whether the building's longer axis runs east-west or north south.
- (E) – The building side(s) to be cooled is needed to run the Explorer, further discussed under (I). The Explorer provides 16 combinations of sides for the user to choose from. Note that the user cannot select roof at the same time as a wall, so the Explorer will need to be run twice for projects that include both cool walls and cool roofs.
- (F) – The albedo of the cool surface is needed to run the Explorer, further discussed under (I). The energy changes outputted by the Explorer are based on a scenario of a roof with an aged roof albedo of 0.10 and walls with an aged albedo of 0.25. The Explorer provides several options for modified albedo: walls = 0.4, 0.6; roofs = 0.25,

0.4, and 0.6. Users should exercise caution in interpreting their results if the project would have different albedos than provided.

- (G_R) – The coverage of the cool roof material represents the percent of the roof area that is a cool roof.
- (H_Z) – The area of building side to be cooled represents the area of the building side minus any area that would not be covered in cool materials.
- (I_R, I_T, J_R and J_T) –The change in annual building electricity use and natural gas consumption per square meter of building surface modified can be obtained from the Explorer. Increased cool surfaces would result in a heating penalty (i.e., increase in gas consumption to heat the building and, for select commercial buildings, any electricity that provides auxiliary heat) and a cooling savings (i.e., decrease in electricity to cool and fan the building).[22] Users can run the Explorer to output these values using the following instructions.[23]

1. Download the tool and database from the ZIP archive online at http://bit.ly/2Kwvtpu. To install, copy the two files to a local folder.
2. Open the Savings Explorer file. Click the "Launch Simulation Selector" button.
3. The following inputs should be the same for all projects: simulation region = California; building vintage = new,[24] property = site energy; metric = savings intensity.
4. The first query of the Explorer should be done to output energy intensity values for roofs (I_R and J_R). The second query should be done for building sides (I_T and J_T).
   a. The following inputs should be specified based on project-specific information.
      i. Building type (class/category) = (B).
      ii. Building climate zone (location) = (C).
      iii. Building orientation = (D).
      iv. Building side(s) to be cooled = (E). The first query should be roofs only, if applicable. The second should be the applicable building sides.
      v. Albedo of cool surface(s) = (F).
   b. Once all inputs are specified from #3 and #4, the Explorer will update the variables and results in columns A and B of the workbook.
   c. Sum the results from Column B for cooling, electric heating, and fan. This represents the change in electricity use for cool roofs (J_R). Take the gas heating results from Column B, which represents the change in natural gas use for cool roofs (I_R).
5. Repeat #4 for the building sides to output (J_T and I_T).

- (K_z) – Table E-4.1 presents the four canyon aspect ratios used by Levinson (2019) to determine standard solar availability factors (SAF) for each wall direction. The canyon aspect ratio is the ratio of the project wall height to nearest building separation. The

[22] As the effects of climate change become more severe, temperatures and solar radiation during the winter may continually increase. The heating penalty may therefore be lower in future years, making this measure more effective at reducing GHG emissions.

[23] See additional instruction in Appendix P, Section 4 of Levinson et al. (2019).

[24] New as termed in the Explorer refers to buildings compliant with the 2016 Title 24 Standards. The latest Title 24 Standards are from 2019 and are updated every 3 years. Users should exercise caution in interpreting their results for future years subject to more stringent Title 24 Standards.

user should select the canyon aspect ratio that best corresponds to each project's cool wall to appropriately lookup the SAFs (Lz) in Table E-4.2.

- (L_z) – Table E-4.2 presents the average U.S. SAFs by cardinal direction and canyon aspect ratio. The SAFs are presented for two scenarios, one in which the neighboring building has cool walls and one in which it has conventional walls. The solar availability of the walls at the project building can be lowered by shadows cast by neighboring buildings and raised by sunlight reflected from neighboring buildings. The SAFs are used in the GHG reduction formula to adjust the values for energy use change from Levinson et al. (2019), which were based on model simulations with isolated buildings that were not surrounded by any buildings.
- (M) – The carbon intensity of residential 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). See Table E-4.5 in Appendix C for more natural gas emission factors.
- (N) – 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 Appendix C), the user should use that specific value in the GHG calculation formula. If the electricity provider is not known, users may elect to use the statewide grid average carbon intensity.

GHG Calculation Caps or Maximums

It is assumed that the electricity demand of the user's project is currently being met by grid energy that requires *some* amount of fossil fuel-based energy generation, which emits 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. For projects that are served by electricity providers already with a renewable portfolio of 100 percent, this measure could have no reduction on GHG emissions. If the electricity provider is using REC to meet a 100 percent renewable portfolio goal, then some emissions reductions may be achieved. In situations where the electricity from the electricity provider is already carbon free, this measure would increase GHG emissions by requiring additional natural gas consumption for building heating. This measure would still result in the co-benefit 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 it was developed assuming the residence would be supplied with natural gas (e.g., space heating).

Example GHG Reduction Quantification

The user reduces building energy emissions by providing a cool roof and walls in place of dark roofs and walls. In this example, the measure would be implemented in BCZ 7 (C) for a single-family home (B) with a fully covered (i.e., 100%) 1 KSF cool roof (G_R), and all building sides of 1 KSF covered in cool materials (H_z or H_N, H_S, H_E, H_W, and H_R). The project is located on a residential street with conventional surrounding buildings and has a canyon aspect ratio of 0.2 for all walls (K_z). Using this information, the SAFs (L_z) can be looked up in Table E-4.2. The electricity and natural gas use changes for the roof (I_R and J_R) and walls (I_T and J_T) can be looked up using the Explorer. The project is in San Diego Gas and Electric's service territory and would begin operation by 2022. It would, therefore, have an electricity carbon intensity of 542 lb CO_2e per MWh (N). In this example, emissions would be reduced by 0.3 MT CO_2e per year.

$$H_T = \mathbf{1\ KSF} + \mathbf{1\ KSF} + \mathbf{1\ KSF} + \mathbf{1\ KSF} = 4\ \text{KSF}$$

$$L_T = \left(1.02 \times \frac{\mathbf{1\ KSF}}{4\ \text{KSF}}\right) + \left(0.95 \times \frac{\mathbf{1\ KSF}}{4\ \text{KSF}}\right) + \left(0.96 \times \frac{\mathbf{1\ KSF}}{4\ \text{KSF}}\right) + \left(0.95 \times \frac{\mathbf{1\ KSF}}{4\ \text{KSF}}\right) = 0.9$$

$$A = \left[\left(\left(\frac{-0.003\ \text{therm}}{\text{yr}\cdot\text{m}^2} \times \mathbf{100\%} \times \mathbf{1\ KSF}\right) + \left(\frac{-0.005\ \text{therm}}{\text{yr}\cdot\text{m}^2} \times 0.97 \times 4\ \text{KSF}\right)\right) \times \frac{117\ \text{lb}\ CO_2e}{\text{MMBtu}} \times \frac{0.1\ \text{MMBtu}}{\text{therm}} \times \frac{0.000454\ \text{MT}}{\text{lb}} \times \frac{92.9\ \text{m}^2}{\text{KSF}}\right]$$

$$- \left[\left(\left(\frac{2.383\ \text{kWh}}{\text{yr}\cdot\text{m}^2} \times \mathbf{100\%} \times \mathbf{1\ KSF}\right) + \left(\frac{2.242\ \text{kWh}}{\text{yr}\cdot\text{m}^2} \times 0.97 \times \mathbf{4\ KSF}\right)\right) \times \frac{542\ \text{lb}\ CO_2e}{\text{MWh}} \times \frac{0.001\ \text{MWh}}{\text{kWh}} \times \frac{0.000454\ \text{MT}}{\text{lb}} \times \frac{92.9\ \text{m}^2}{\text{KSF}}\right] = \frac{-0.3\ \text{MT}\ CO_2e}{\text{yr}}$$

Quantified Co-Benefits

While the measure will achieve electricity savings, it can increase fuel consumption and potentially worsen ambient air quality. 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*.

Worsened Air Quality

While not quantified in this Handbook, lowered ambient air temperatures as a result of the reduced urban heat island effects (which can be significant if adoption is widespread) can decrease ozone formation, improving air quality.

If natural gas is used for heating, the increase in natural gas fuel consumption from this measure could result in local worsening of air quality. If electric heating is used at the project site, then there would not be an increase in criteria pollutants or worsened air quality. The increase in criteria pollutant emissions (U) resulting from the measure can be calculated as follows.

Energy Savings (Increased Fuel)

The increase in building natural gas consumption (S) and decrease in electricity use (T) achieved by the measure can be calculated as follows.

Natural Gas Increase Formula

$$S = ((I_R \times G_R \times H_R) + (I_T \times L_T \times H_T)) \times R$$

Electricity Reduction Formula

$$T = ((J_R \times G_R \times H_R) + (J_T \times L_T \times H_T)) \times R$$

Criteria Pollutant Emission Increase Formula

$$U = O \times V \times S \times W$$

Criteria Pollutant Emission Increase Calculation Variables

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

Further explanation of key variables:

- (V) – 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

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